Johannis Hevelii Machinae coelestis pars prior; Organographiam, sive Instrumentorum astronomicorum omnium, quibus Auctor hactenus sidera rimatus, ac dimensus est, accuratam delineationem et descriptionem, plurimis iconibus, aeri incisis, illustratam & exornatam, exhibens

[The Celestial Machine, Part One: Organography, or the Description of All the Astronomical Instruments]

(1673)

by Johannes Hevelius (1611–1687)
Translation by Scott Weisman



Ars Astronomica
2026

"Johannis Hevelii Machinae coelestis pars prior; Organographiam, sive Instrumentorum astronomicorum omnium, quibus Auctor hactenus sidera rimatus, ac dimensus est, accuratam delineationem et descriptionem, plurimis iconibus, aeri incisis, illustratam & exornatam, exhibens," published in 1673, is in the public domain. All translations, original additions, including illustrations, commentaries, and summaries, are copyright.

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Translator Version 2

Upright reason dictates that the recipients of the good, of whatever type and level of beneficence it may be, must show gratitude and blessing to the beneficent person in every way possible, commensurate with the value of the beneficence. And one who has benefited all the people of the world — for example, one who invented a new instrument for the good of the world, or a good book — it is fitting for every discerning person, out of the obligation of love of fellow beings, to at least purchase it, so that the man will profit and his heart will be encouraged thereby to invent yet more good instruments in the world. And similarly, all other wise-hearted people will likewise strive and exert themselves to invent good things and instruments needed for the repair of the world and its perfection.

And therefore, whoever says: "What do I need this new instrument for?" — he does not act well towards the world. For if not for the man who invented it, where would you be? And what would your city do? And more than this, if the man did not exert himself, what would the world do?

— R. Pinchas Eliyahu Hurwitz, *Sefer HaBris HaShalem* (1797)

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A note on the work

Johannes Hevelius, a Danzig brewer and city councillor, built on the roofs of three adjoining houses the largest observatory in Europe after Tycho Brahe's Uraniborg. The *Machina coelestis* is his account of it. This first part, the *Organographia* of 1673, describes and illustrates every instrument he used: sextants, quadrants, octants and the great azimuthal quadrant, along with their construction, division and use. He printed it at his own press, with engravings after his own drawings and those of Andreas Stech. Its defence of open, naked-eye sights over telescopic ones led directly to Robert Hooke's *Animadversions* (1674), and so to the dispute that brought Edmond Halley to Danzig in 1679 to compare the two methods in person.

The *Machina coelestis* was issued in two parts. This volume is the *Pars prior* (1673); the *Pars posterior* (1679), with the observations themselves, is translated separately in this series. Only three chapters have previously appeared in English (Forshall, 1882).

A note on the translation process

This translation was produced with the translation-pipeline. See the linked repository for details on the process.

A note on the references. A scriptural or bibliographic reference given in brackets or parentheses is, in most cases, an **editorial identification of an allusion rather than a citation printed in the source**. Books of this kind quote and weave scripture constantly without naming it, and the identification is supplied here as a convenience to the reader. Where the source does print a reference of its own, it is given as printed. **An identified allusion is not evidence that the author cited that passage** — look at the original before resting an argument on one.

This text is the product of a highly refined automated translation process. It has undergone only cursory human review and should not be treated as an authoritative or scholarly rendering. It is offered solely as a reference and reading aid — a way to make an otherwise inaccessible work approachable — and any passage of real consequence should be checked against the original source.

Acknowledgements

The scanned copy used here belongs to the Smithsonian Libraries (Dibner Library of the History of Science and Technology). The Smithsonian digitized it and placed it in the public domain through the Internet Archive.

Translated with the assistance of Claude. The translator thanks the Anthropic team for making this work possible.

Notation and abbreviations

A few conventions have been applied uniformly throughout this translation, so that one quantity is always written one way. They change how a value is *written*, never what it is; where the printed source and this translation differ in notation, the source's own form is recorded in the editorial apparatus.

Numerals are Arabic, even where the source sets Roman ones. Roman numerals are kept only in headings, running headers and signatures, which are transcribed as printed.

Dates are given as year, month, day — *1572 November 11*. Dates are Julian, as the source gives them, and have not been converted to the Gregorian calendar.

Times are written with raised unit letters: $7^{h}\ 36^{m}\ 12^{s}$ for seven hours, thirty-six minutes and twelve seconds. An interval longer than a day carries a raised d — $3^{d}\ 7^{h}$. The degree and minute signs below are never used for time.

Angles are written with the conventional signs — 23° 27′ 30″. Early modern astronomy divides the degree sexagesimally and often runs to places for which modern writing has no common symbol; the orders used in this book are:

sign	order	the source's term
°	degrees	*partes*, *gradus*
′	minutes of arc	*scrupula prima*, *minuta*
″	seconds of arc	*scrupula secunda*
‴	thirds	*scrupula tertia*
⁗	fourths	*scrupula quarta*

Where a table in the source spreads one quantity across separate columns for degrees, minutes and seconds, those columns have been joined into a single column and the value written whole. Where a value runs to thirds and beyond, the columns are kept, since there the columns are the notation.

Diagram. The engraved frontispiece. In the cartouche at its foot: *Johannes Hevelius, The Celestial Machine.*

In the upper half, on clouds, a crowned woman with a star above her head and a crescent moon in her raised hand rides in a chariot strewn with stars; a sun with a face shines beside her. Before the chariot, female figures lead harnessed beasts (a lion and a spotted cat), one of them in a robe covered with numerals, another in a robe marked with triangles; a pair of scales hangs in the air at the left. At the upper left an angel blows a trumpet hung with a banderole; at the upper right a winged, bearded old man holds a long staff and the end of a second banderole stretched across the top of the scene; a small running animal crosses the clouds at the top centre.

In the lower half, before a ruined amphitheatre, an obelisk and a distant city, four men stand or sit around a celestial globe painted with constellation figures. Two are seated at the globe at the left, one of them pointing to it with a pair of compasses; two stand at the right, one bareheaded and holding a book, the other in a plumed hat, fur-trimmed cloak and chain, looking down at the globe. On the tiled floor in front stand an armillary sphere and, at the lower right, a large framed instrument with a divided arc; an open book lies on a stand at the right. Along the left edge rises a pillar hung with five laurel wreaths, each enclosing an emblem and a word, and set on a pedestal carrying an engraved dedication.

- Banderole, angel at upper left: "To the immortality of the divine art."
- Banderole across the top, centre-right: "To God and to posterity."
- Pillar, first wreath (a star): "They are searched out."
- Pillar, second wreath (a heart): "To the most constant."
- Pillar, third wreath (a wheeled emblem): "To the indefatigable."
- Pillar, fourth wreath (an eye): "To the lynx-eyed."
- Pillar, fifth wreath: "To the most acute."
- Beside the foot of the seated figure at the left: "Much discovered."
- Beside the foot of the standing figure at the right: "But a very great deal left to posterity."
- Below the border, left: "A. Boy drew it."
- Below the border, right: "I. [?] engraved it."

Inscription on the pedestal of the pillar:

> To the glory of God, Best and Greatest, and to the increase of the commonwealth of letters, the Fathers leave this monument of sidereal science — founded so solidly many centuries back, and built up so happily with the utmost powers of mind and body and at incredible expense — to their sons and grandsons, to be religiously preserved from now on and further adorned.

JOHANNES HEVELIUS
THE CELESTIAL MACHINE
PART ONE
presenting an ORGANOGRAPHY,

or an ACCURATE DELINEATION AND DESCRIPTION of all the astronomical instruments with which the author has so far searched out and measured the stars, illustrated and adorned with a great many figures engraved in copper;

together with certain other matters, as pleasant as they are worth knowing, pertaining to the mechanical and the optical art;

above all, on the construction of the very largest tubes and the most convenient way of directing them;

and also a new and very easy method of polishing any lenses whatever from conic sections.

With the privilege of their Sacred Imperial and Royal Polish Majesties.

DANZIG,
printed with the author's type and at his expense,
by Simon Reiniger,
in the year 1673.

TO THE MOST POWERFUL, MOST INVINCIBLE
AND
MOST CHRISTIAN
KING OF FRANCE AND NAVARRE,
LOUIS XIV,
HIS LORD, BY FAR THE MOST GRACIOUS.

MOST CHRISTIAN KING,

The most brilliant splendour of Your Most August Majesty, lighting up most gloriously the whole world, as far as it extends, with the admirably flashing rays of heroic virtues; and, on the other side, the slightness of my name and talent, when I measure myself by my own small measure — these could certainly have deterred and repelled from Your most eminent throne a man, a foreigner above all, born under the Bear and lying hidden in his own corner; and perhaps they even ought to have done so, by right and with good reason. But Your incomparable goodness and clemency on so lofty a summit, and also that supreme inclination — as admirable as it is venerable in the highest degree — towards the sciences and the arts, and above all towards our Urania, by which Your Most Sacred Majesty, out of innate royal generosity, never fails to deign to regard that goddess and all her devotees: this has in turn given me courage, so that I do not fear to approach You, Most Invincible King, and — this Celestial Machine of mine, dedicated and consecrated by the best of rights to the most august name of Your Majesty, in order to testify most humbly to the veneration owed by a most grateful and most obedient mind — at Your royal feet prostrate, to offer and lay down with a most submissive and devoted hand. I dare to do this relying on the best of hopes. For You, Most Sacred King, as is more than sufficiently known to the whole learned world, always hold it glorious to contemplate the admirable orbs of heaven — to the glory of God and for the cultivation and benefit of the human mind — and to search out the most beautiful forms of the heavenly bodies and the stars; indeed, You

are accustomed earnestly to give diligent and knowledgeable surveyors of the heavens the task of investigating, cultivating and adorning celestial things more and more. My hope is that Your Most August Majesty will not disdain to admit most graciously this little Celestial Machine, such as it is: built by me, indeed, with no small zeal and labour (to say nothing of costs and expenses), and moreover applied now for so many years to the starry heaven itself, with Urania not so very unwilling. Grant Your assent, therefore, most glorious of kings, and this very slight little work, undertaken by me solely so that the science of the stars might be cultivated more successfully and advanced more easily; but Your incom- parable kindness and supreme munificence brought it out into the public light by an immortal benefaction: look upon it with a most gentle countenance and most serene eyes. And most indulgently allow the author himself as well — who strives for this, as is fitting, with a most humble and devoted mind — to be refreshed from now on, as he has been until now, by the most longed-for rays of YOUR ROYAL MAJESTY AND GRACE. If I obtain this, I shall consider myself not only fortunate on that account, but also to have gained by far the greatest fruit of my labours and of my night watches. My spirit will grow from it, so that with greater eagerness than ever before I may bring forth and push out into public view, for the good, as we trust, of the astronomical arts, the things I am still labouring at and intend, if GOD permits, to share with the learned world — things somewhat worthier and loftier, as some judge, drawn from the very aether with these instruments of ours. For the rest, from my inmost heart I pray to GOD, Best and Greatest, that to YOUR MOST AUGUST ROYAL MAJESTY — very many years of life, the most longed-for health, and perpetual happiness — He may most graciously grant, to the glory of the DIVINE NAME and the greatest benefit of the Christian and the learned world. Given at Danzig, in the year 1673, with the Sun in the middle of Leo.

OF YOUR SACRED AND MOST CHRISTIAN MAJESTY,
the most humble and most submissive
J. HEVELIUS.

Engraved roundel. A circular allegorical engraving, without lettering, set in the upper half of an otherwise blank page. At the top, a winged female figure in flowing drapery flies among clouds, blowing a long trumpet and holding a second; a banner bearing fleurs-de-lis hangs from each trumpet. Below her, a royal crown with a fleur-de-lis finial is flanked by a pair of outspread wings, set against clouds with rays spreading behind. From beneath the crown a stream of small discs, apparently coins or medals, pours down on to a celestial globe in its stand at the centre of the ground line. Around the globe lie books and astronomical and mathematical instruments: divided frames and arcs, long tubes, a pair of compasses and an ornamented tablet at the lower left.

- No engraved letters, labels or credits are visible on the roundel.

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JOHANNIS HEVELII IN MACHINAM COELESTEM PRÆFATIO AD LECTOREM.

Johannes Hevelius's Preface to the Reader on the Celestial Machine.

[Margin: Astronomy is the queen of the other mathematical sciences.] That astronomy raises its head higher than all the other mathematical disciplines, and rightly earns the most exalted seat of honour above the very many other sciences acquired by the natural light, is not in dispute among the learned. [Margin: It is concerned with the most excellent objects.] For it is occupied not only with the noblest and most beautiful subject of all — namely those greatest ethereal bodies, the most wonderful works of GOD, whose size, distance and wonderful, indeed manifold and most abstruse motion it contemplates, investigates and uncovers more and more, and then hands down to a late posterity, to the honour of the Creator of all things and the greatest benefit of the human race. [Margin: It rests on solid foundations and on the firmest reasoning.] But it also uses a way and method of exploring those most widely remote things, and the most hidden of other natural things, and of demonstrating them, that is far more effective and more certain than that of the remaining arts and sciences: a method derived and drawn, namely, from the very springs of geometry and arithmetic, and also from ocular demonstration and from very many observations obtained with the proper instruments over a long series of times.

[Margin: The ethereal bodies are the great works of Jehovah.] Beyond this, if we look somewhat more deeply into this whole Machine of the World, what, I ask, among all other things is more excellent and more magnificent than the Sun, more beautiful than the Moon, more admirable and nobler than the planets and all the stars — all of them created solely to proclaim and celebrate the Glory of GOD? [Margin: It is an altogether sublime thing to apply oneself to the secrets of the heavens.] It must therefore be freely granted that there is

nothing more sublime or more excellent, nor more delightful, praiseworthy and useful, than to contemplate and search out somewhat more deeply — from this little earthly body, in this frail and brief course of our life — those vast and wonderful celestial bodies, for a greater knowledge of the wonderful works of the Supreme Deity. [Margin: By the contemplation of ethereal things human hearts are wonderfully raised to the heavenly things above.] By this our mind, just as it is most powerfully called away from earthly things, is conversely drawn and raised beyond all measure towards those eternal things, so that we may come to know all the more intimately the wonderful Power, the unsearchable Wisdom and the ineffable Goodness of the Founder of the ages.

Since this is so, genuine astronomy, which leads us there, is most deservedly the noblest and most delightful of the mathematical sciences; and what is more, it also lends much light and benefit to many other arts, sciences and studies. [Margin: Astronomy, cultivated [?] with every mark of respect, they have always honoured with due veneration.] Hence it has come about that it has never failed to stand in the highest honour and esteem among all the wiser sort — indeed among kings and princes who hold the sceptres of the world — who held nothing preferable to protecting it most generously in every age, preserving it with great spirit, and even being able to devote their own vigorous effort to it.

[Margin: The pagans as much …] With what ardent love and singular veneration the pagan philosophers, and the wiser among others as well, have honoured this divine science of the stars is expressed partly by Seneca, in Book VII, Chapter I of the *Natural Questions*, in these words: *"No one could have sought anything more magnificent, or learned anything more useful, than the nature of the stars and constellations"*; partly by Plato in the *Epinomis*: *"Do not be ignorant that astronomy is something supremely wise."* So too Pliny, a man of great learning, honoured the students of celestial things with this excellent address: *"Blessings on your genius,"* he says, *"interpreters of the heavens, minds able to grasp the nature of things, discoverers of a reasoning by which you have conquered GODS and men."* Again

Ovid, by no means the least of the poets, proclaims all observers of the heavens fortunate and blessed:

> *Happy the souls whose first care it was to know these things and to climb*
> *to the dwellings above.*

[Margin: … as the Christians.] But no less did those who have given their name to Christ value astronomy very highly, so that they strove by every means to uphold and spread its dignity, as a most useful science and one fully worthy of a Christian. [Margin: Indeed Sacred Scripture itself most greatly rouses and invites all people to the spectacles of celestial things.] Indeed the Prophet himself, led by divine inspiration, earnestly exhorts and urges everyone, as it were, to the contemplation of the ethereal bodies. *"Lift up your eyes on high,"* he cries, *"and see who has created these things. It is the Lord, who brings out their host by number; he calls them all by name: by the abundance and the mighty power not even*

one is lacking" (chap. 40). It is as if he meant to say: these most splendid and vast celestial bodies, endowed with wonderful motion, were kindled and set in place in the highest aether by GOD, the Craftsman of the World, in an order wholly beyond comprehension — not so that we should merely gaze at them as brute animals do, nor so that we should, with the purblind pagans, either fear them, or adore them, or venerate them with divine worship; but so that they might declare His Glory and how great are the works of Jehovah, as the King and Prophet David says. [Margin: To what end?] And so that, through beholding these divine works and contemplating them more intimately, the Creator's Wisdom, Power, Goodness and admirable Direction may shine out and become known to us more and more; and that our hearts too may be raised to a purer worship of the Divine Deity and to due veneration. [Margin: The stars serve the human race above all.] Above all, it is so that we may be roused all the more keenly to give our most humble thanks with our whole heart, because He created those most splendid bodies of the heavens for the greatest benefit of the whole human race, and has kept them entirely in that wonderful and invariable order to this day: so that they may perpetually *divide*, as Sacred Scripture itself says, *the day from the night, and be for signs, and seasons, and days and years*, and so that mortals may order and spend their life all the more conveniently, to the Glory of the Most High and the benefit of their neighbour.

[Margin: The science of the stars delights and refreshes people wonderfully.] These celestial contemplations, just as they lead us most effectively to eternal salvation, so also wonderfully refresh and delight our mind, more than almost all the other sciences. Cicero attests this in Book IV of the *Academic Questions*: *"The consideration and contemplation of nature,"* he says, *"and above all of celestial things, is a kind of natural food for minds and intellects."* And again, in Book V of the *Tusculan Questions*: *"What is sweeter than lettered leisure? I mean those letters by which we come to know the infinity of things and of nature, and, in this very world, the heavens, etc."* Above all, what is more pleasant and more delightful than to contemplate and survey with one's own eyes — especially in our own time, with the help of excellent and very large telescopes — the true faces of so many vast luminaries, and their wonderful varieties and changes, luminaries which display a motion that is indeed perpetually variable, yet most orderly and most constant?

[Margin: Astronomy outstandingly advances and adorns almost all the other sciences.] Moreover, this divine science of ours also has its very wide usefulness throughout the whole of human life, and contributes a great many supremely necessary things to the remaining sciences and arts: not only to geometry, arithmetic, optics, gnomonics, harmonics and mechanics (whose services it in turn uses not infrequently itself), but also to medicine, agriculture, commerce, navigation, hydrography, geography and chronology — so that most of them could not, without the help of astronomy, be properly cultivated or preserved, nor in any way stand on their own.

[Margin: Medicine as much as agriculture and commerce.] What the science of the stars can do in medicine we have more than amply established, even from the warning of Galen himself to the sick: he advises them, if they would take care of themselves, not to entrust themselves to the hands of physicians ignorant of astrology. How greatly, besides, agriculture and commerce need months and days in order to distinguish the seasons correctly — the precise length of which astronomy alone has prescribed and reduced to fixed laws — needs no fuller proof. Hence, long ago, people [?] held this science as a rule for carrying on agriculture and commerce. For the ancients, before they had obtained calendars, from the risings and settings of the fixed stars they distinguished the seasons of the year and marked the right times for their work.

[Margin: As also navigation.] Likewise navigation: could it survive — and indeed be carried on so successfully across the whole ocean and around the circuit of the earth, and that most safely, by day and by night — unless sailors had at least some knowledge of astronomy, so that they could properly investigate the altitudes of the pole, the Sun and the stars, and other things of this kind, with suitable instruments? I leave that for everyone to judge. [Margin: Geography.] In the same way almost the whole of geography depends on the science of the stars. For it not only uses, in drawing its terrestrial globes and in distinguishing places, exactly the same poles and circles that are otherwise employed for the heavens; but also, unless it sought the longitudes and latitudes of places from astronomy itself, could it show us a correct delineation of any region whatever, let alone a description? [Margin: Chronology.] No less with chronology: no one will easily persuade himself that it could be founded, established and demonstrated exactly and solidly without any calculation at all of the eclipses of both luminaries, obtained from the interpreters of the stars. [Margin: Chronography.] Indeed, what would chronologers, chronographers and all the writers of history undertake and accomplish, if astronomers did not supply them with the true length of any year, month and day, derived from observations of the equinoxes and solstices? [Margin: Only by the care and labour of astronomers are the true lengths of years, months and days investigated and preserved.] It is abundantly known how great an error in the reckoning of time — indeed, what confusion — arose while, over the course of certain centuries, astronomy was in part silent, or rather gently dozing: so much so that already in the time of Julius Caesar the harvest festivals no longer fell in summer, nor the vintage festivals in autumn, as Plutarch and Suetonius attest. [Margin: Of old there was great confusion in the reckoning of time.] What happened afterwards, in the course of time, in the same matter concerning the Julian calendar, and what would without doubt befall in future centuries if the diligence of astronomers were to cease, the learned see very well. By the verdict of all, therefore, it is most certain that the true distribution of years and months depends solely on the science of the stars.

[Margin: The calendar is of the greatest necessity.] Hence, if every calendar were done away with (though at present, owing to the abuse of astrology,

almost nothing is held in lower esteem), the order of affairs could in no way be properly maintained, in civil or in ecclesiastical matters, whatever life you lead and whatever station you are in; nor could principalities or kingdoms be rightly administered and governed.

[Margin: What the surveyors of the heavens have accomplished.] But truly: who, I ask, first laid the foundations of this knowledge? Who has preserved it in order up to now, bounded within fixed limits? Who computes and determines, for any time, past as well as future, the eclipses of the Moon and the Sun, the full moons, new moons, quadratures and the other aspects of the stars — things most worth a man's knowing, and indeed sometimes supremely necessary? Who sets out most plainly, and foretells most truly, for any horizon, the unequal length of days and nights and the rising and setting of the stars, the Sun and the Moon, so that the tide of the sea may be known in advance — to pass over very many other things — to the very great benefit of the whole human race? [Margin: The most illustrious names of astronomers.] Was it not Meton, Eutemon [Euctemon], Oenopides, Cliostratus [Cleostratus], Eudoxus and Calippus [Callippus] who arranged the calendars [Fastos] and cycles among the peoples of Greece and Asia? Were these not experts in the stars? Among the Romans, did not Julius Caesar, well versed in this science, accomplish the very same, with the scribe Flavius and with Sosigenes, whom he had summoned from Egypt for that purpose? But this is not the place to list in order all the benefits that astronomy brings so abundantly to almost all the mechanical arts, civil as well as military, to the study of physics and to the whole of philosophy, and in part even to theology itself. [Margin: Almost all people draw no slight benefits from the science of astronomy.] In sum, to put it at least briefly: farmers, soldiers, merchants, sailors, mechanics, chronologers, geographers, hydrographers, cosmographers, philosophers, physicians, jurists, statesmen, theologians, princes and citizens — almost all people — have something to draw from the springs of astronomy.

[Margin: From the beginning of the world there has been no one who did not labour vigorously to] Led, then, by these reasons, not merely for some centuries but from the very beginning of the world, the foremost names among mortals — indeed their very heads, such as princes, kings, [Margin: cultivate and advance the science of the stars.] emperors and monarchs — have left no stone unturned, first to bring this sublime science of the stars out of darkness itself by care and thought, and then also to adorn and enrich it, and earnestly to hand it on to distant posterity, on account of its excellence, delightfulness, usefulness and necessity. So much so that, by everyone endowed with even some small measure of the light of nature, both this divine science of the stars itself and its discoverers and interpreters — especially the more outstanding, who above the rest enriched it with some notable invention — have always been held in the highest honour and esteem.

[Margin: As the Asiatic peoples did of old, so now the European peoples hold those truly skilled in astronomy in the greatest honour.] Of old, among the Asiatic nations, and above all among the Persians, no one was made king unless

he was versed in the disciplines of the Magi, that is, of the astronomers. Likewise the Chinese, who yield to very few peoples in prudence and ingenuity, have a most ancient custom, devoutly preserved down to these times, of admitting men versed in the science of astronomy even to the highest prefectures and dignities. With what intense love and honour the princes of Europe and the Christian kings hold this same science, now as of old, and how very graciously and liberally they continually receive its cultivators — that is, the true astronomers, who excel above the rest — will be evident from what follows. [Margin: Who is a genuine astronomer, in the view of Plato and Crüger.] But who these men are in actual practice is amply clear from the words of the most wise Plato near the end of the *Epinomis*, and from the short commentary on those same words by the distinguished Crüger [Peter Crüger], once my most honoured teacher: *"It is necessary,"* says Plato, *"that the true astronomer be not the one who, following Hesiod, considers all setting and rising of this kind"* (who writes calendars, Crüger adds to this, and other things following the ephemerides of Kepler and others), *"but rather the one"* (Plato continues) *"who considers the eight circuits"* (that is, Crüger adds, of the seven planets and of the primum mobile) *"and how the seven turn beneath the first, and in what order each completes its own circles"* (that is, Crüger adds, rather the one who understands the foundations of the ephemerides).

[Margin: Which of the Christian princes, of old, above the others, the stars' sci-] Men of this kind, I say, have always had very great influence with princes and kings throughout Europe, and have been thought worthy of no ordinary honour; and of these great men not

[Margin: -ence and its cultivators held dear.] a few indeed there have been who both earnestly favoured these studies and themselves cultivated them with the greatest ardour: the emperors Charlemagne, Frederick II and III, Charles V and Rudolf II; the kings Alfonso of the Spaniards, Matthias of Hungary and Frederick of Denmark; William, Prince of Hesse — to say nothing of a great many others. With incomparable favour they fostered the searchers of the stars in cultivating and restoring astronomical studies, spurred them on with the most splendid munificence, and spent very great, indeed incredible, sums on the work itself.

[Margin: In this age of ours too the greatest patrons and promoters of sidereal matters are found.] But it is not worth the effort to list at length here the benefactors, promoters and patrons who flourished in centuries now past. Let it suffice that in this very time of ours there flourish, by the grace of God, men who not only deserve by right to be ranked equal with them but are even to be set far above them; the glory and the splendour of their heroic virtues will never fade from the world as long as the stars exist, above all among those devoted to astronomy. And to touch on only one or two of that order — the greatest and incomparable patron [Maecenas] of astronomical studies in this age: how kind, how munificent Louis XIV, the Most Christian King, shows himself towards this sidereal science! [Margin: Among whom Louis XIV, the

Most Christian King, rightly stands out.] With what clemency and favour he honours the observers of the stars — and not only those subject to his own kingdom, but others here and there as well, though they lie hidden in a corner! What an illustrious college of the most outstanding and most learned men of this century he has founded for the good of astronomy, and how very liberally he has provided for it! What a splendid and magnificent Uraniborg, enriched and adorned with the best instruments of the most varied kinds, he has had built at immense expense!

[Margin: Charles II, King of Great Britain, also the greatest benefactor of celestial studies.] Nor is it right to pass over in complete silence the most praiseworthy King of Great Britain, Charles II, who never fails to judge our most illustrious Society, first gloriously founded by him, worthy of his favour and protection, and omits nothing at all that might serve its honour and advantage, and above all that of astronomical studies.

[Margin: From which it is very clearly evident that God wills to preserve the science of astronomy right up to the destruction of the world.] From all this, then, it becomes quite evidently clear that — since in every age outstanding patrons and the greatest supporters have shown themselves devoted to astronomy with singular inclination and goodwill, and suitable persons have also come forth in the world — God, Best and Greatest, who at the very beginning of the world set out these immense and most wonderful heavenly bodies in the highest aether for man to contemplate, will certainly go on, in his infinite mercy, to provide that this sidereal study of ours cannot fail to be cultivated more and more, to the glory of his most divine name and the greatest benefit of the whole human race, and to be happily preserved to the final end of the world.

[Margin: In every age God has raised up one or other cultivator of astronomical study.] We are also held by a great hope that the Almighty will grant us this wish. For he has never failed to look upon this sidereal science with so very kindly an eye that, from the very beginning, hardly a century has gone by without God's most mercifully willing that, if not more, then at least one or two able men of powerful intellect be born to advance that study, implanting in them the greatest ardour, so that, if they could go no further, they at least strove by the best means to preserve it. Indeed, some have arisen from time to time through whose ingenious studies and tireless labours that divine science has grown and risen not a little. So it is most plainly evident that, although outstanding men of this kind — men who take up and pursue these matters with the greatest effort — by no means meet us in great numbers everywhere, nevertheless at least some arise in every age, now from these nations, now from those, whose whole care and heart's desire it is to look more deeply into these heavenly secrets and to uncover them further. [Margin: Now in these regions, now in those, commerce with the stars is practised.] As the most learned Causinus rightly holds in the preface to his book *On the House of God*:

"Yet God scarcely permits nations to be so remote from heaven that there should be some who have no secret commerce with the stars."

[Margin: Where astronomy was first cultivated, and how to] In the beginning, indeed, the greatest part of these men appeared in the more eastern regions — in Chaldea, Persia, Egypt and Arabia — where the first foundations of astronomy were also laid; but afterwards, in the course of time, [Margin: other peoples, one after another, it migrated.] (just as in this whole world things have their turns and are subject to the greatest changes) a great many were raised up in Greece; from there they migrated to Italy, Germany, France and England; and finally some settled among the more northern peoples as well, namely in Denmark and Prussia. And just as this astronomical science gradually withered among the Asiatics, so it began to flourish again among the Europeans and grew, step by step, to a remarkable degree, as will appear more clearly from what is to be said.

[Margin: To the Asiatic nations, as the first discoverers of sidereal science, the laurel is certainly owed; but to which of them in truth, the case is still before the judge.] We most willingly grant the eastern nations the glory of having been the very first discoverers and expounders of astronomy. But to which of those peoples — since a great many dwelt towards the east — the chief honour is owed, in what place that science truly took its origin, and who was the foremost of its discoverers, is still disputed. It is indeed beyond controversy that the science of astronomical matters took its origin with the first men. [Margin: The author holds that men applied themselves to astronomy from the very first beginning of the world.] For it could scarcely have happened that those splendid bodies of the heavens failed to strike the eyes and minds of men, of whatever nation they were, very greatly indeed, even at first sight — bodies some of which display such evident changes almost from day to day, indeed from hour to hour: the Moon with its waxing and waning, the stars about their rising and setting in respect of both their daily and their annual motion, and likewise the eclipses of the luminaries, extremely diverse now in colour, now in magnitude and duration. They drew men into wonder, and also most powerfully inflamed even the dullest of them to the worship of the Supreme Deity, the director of all these things. [Margin: All men, by a natural inclination, long eagerly for the sciences.] Nor is there any doubt that some of the more sensible, endowed beyond the rest with singular wisdom, were greatly roused by these wonderful phenomena of the heavens — partly struck by the novelty of the thing, partly also by that innate natural inclination by which the human mind leans towards the sciences — to search into them and explore them more and more. For just as God made all men desirous and capable of the sciences, so by nature they are drawn and led to the desire for knowledge.

[Margin: Which of the patriarchs was the first discoverer of the science of the stars.] But whether the sons and grandsons of Seth, with no delay at all, began to cultivate Urania and at once extended her bounds, as Josephus records; and whether Abraham was the first to hand this science on to the Egyptians; or

whether Joseph, Abraham's great-grandson, received it from the Egyptians, or whether he learned it from them — of all this we find not even a trace in Holy Scripture, and so the case is still before the judge. [Margin: It is certain that in the times of Moses and Job the study of astronomy was no longer hidden.] Yet it is abundantly clear from the Prophets themselves that in the time of Moses, about the year 1550 before Christ or even a little earlier — that is, in the times of the Jews and of Job — the science of the stars had already become partly known, and that it was not altogether unknown to the Chaldaeans and Babylonians either. But in what year, or in what place, the divine knowledge of the heavens took its true beginnings, if we want the matter somewhat more exactly, is simply not known.

[Margin: This science was already partly known even before the Flood.] Whatever the case, it seems to me not so very far from the truth that astronomical studies had already been partly discovered not only in the times of Noah but perhaps even somewhat earlier still, namely before the Flood. For the year and the months were well known even to the patriarchs themselves. [Margin: The author is almost persuaded that Adam was the first contemplator of celestial things.] And I am not far from being convinced, with certain others, that Adam himself was the first of all, and that he discussed these mysteries at no small length with his sons and grandsons. For since he was the very first of mortals to behold those great lights of heaven, and was moreover endowed with a far greater light of nature than any of those who came after him, it is surely credible that he was wonderfully kindled by the contemplation of these sublime things; that through so many unbroken centuries as he lived he without any doubt discovered a great many things from the stars; and that he taught them most fully, as the greatest miracles of God, to his descendants in no trifling commentaries — so that they, little by little in the course of time, by searching more and more and keeping to the footsteps of those before them, were able without difficulty to arrive at a deeper knowledge of these things.

[Margin: After the Flood this divine (science) …] From them, then — after the Flood, that is — this venerable science no doubt flowed out to many different peoples,

[Margin: … passed over to various peoples.] who thereafter devoted their labour to it jointly and kept watch over observations. [Margin: Which of the heathen were the first observers of the stars.] Among the heathen nations, however, which were altogether the earlier — the Chaldaeans or the Egyptians — is not so easy to decide, for lack of histories. Yet it seems more consistent with reason, and is also more readily demonstrated from the observations themselves, that this science of the stars, just as it first came out of Asia from the patriarchs, so also flowed first of all to the Chaldaeans, Assyrians and Babylonians. But whether the science first fell wholly to Abraham, or to his father Terah (who, as Philo holds, was already well versed in these matters), or whether it passed at the same time to other Chaldaeans as well, I would not venture to affirm with any great certainty; yet I judge the latter rather to be embraced. This can be

corroborated without difficulty from the observations of the Chaldaeans made about 330 years before the time of Abraham — provided we can safely rely on the histories and the reckonings of the times. Of these, however, more fully presently.

[Margin: The Chaldaeans were indeed earlier than the Egyptians in the science of the stars, but at once turned it into divinatory astrology.] It must therefore certainly be laid down that this glory is to be credited to the Chaldaeans: that they cultivated astronomy earlier than the other nations. But they at once turned it into astrology and the art of divining and foretelling the future. *"For whatever knowledge the Egyptians as well as the Chaldaeans had of the stars, they referred it all to astromancy; and for that reason what flourished among them was not genuine astronomy so much as a spurious one, that is, divinatory astrology"* — as Gassendi rightly says in his preface to the *Life of Tycho*. For the most part they were regarded as casters of nativities [Genethliaci], people who had dealings with the magic arts. From this one may conjecture that they concerned themselves very little indeed with the true science of the stars, which contemplates and searches out the motion, distance and magnitude of the celestial bodies, and other things of this kind.

[Margin: Others leave the first knowledge of astronomical matters to the Egyptians.] There are indeed others who attribute the first discovery of astronomy to the Egyptians, on the grounds that Babylonia was a colony of the Egyptians, as Diodorus Siculus holds. But if this dispute is to be settled from the observations themselves, made by each of the two nations, the palm is surely owed to the Chaldaeans and Babylonians.

[Margin: When the Egyptians began to observe.] For of the Egyptians there are almost no observations from before the time of Alexander the Great (unless perhaps they have perished); whereas the Chaldaeans and Babylonians had observations reaching back 1993 years up to the capture of Babylon by Alexander, as Callisthenes, while he was staying at Babylon, wrote to Aristotle, and as Porphyry reported. [Margin: The Chaldaeans set up observations much earlier.] They would therefore have begun to observe at the beginning of the Assyrian monarchy — indeed immediately after the Flood itself, which falls in about the year 2298 BC — and so the observations themselves would take their beginning in the year 2334 BC, if the matter rested on a solid foundation.

[Margin: When the Chaldaeans began to observe eclipses.] Admittedly, the eclipses of the Chaldaeans recorded by Ptolemy go back no further than the year 718 BC, namely to the second year of Mardocempadus and the times of the prophet Ezekiel. Pliny the Elder too seems to corroborate this when he says that Epigenes found among the Babylonians no observations older than those of 720 years, inscribed on baked bricks.

[Margin: The Chinese are shown to have observed the stars still much earlier than the Chaldaeans.] If, then, we must rely solely on observations and histories — as indeed we rightly should — other Asiatic peoples could call this primacy of the Chaldaeans into question: the Chinese, namely, who are not only

rightly counted among the most ancient peoples, but have also had knowledge of astronomy for a great many years. The authority is Martinius [Martino Martini], in the preface to the *Atlas Sinensis*: *"They say that the mathematical sciences were very ancient among the Chinese, as the very ancient observations of the stars also abundantly show."* But what those observations were like, and at what time they were made, he does not mention there; he says only that the Chinese had letters and history from three thousand years before the birth of Christ, from the time of Enoch — namely from the year 1712 of the Julian Period. [Margin: In the time of the prophet Samuel, Cheucungus, a Chinese astronomer, was already keeping watch over celestial things.] Whether they also had observations from that time onwards cannot be conjectured with much certainty from what has been said. This much, however, is perfectly clear, as Martinius, just cited, plainly indicates on p. 62 of the Chinese *Atlas*: that the great mathematician of the Chinese was already devoting himself to observations in the time of the prophet Samuel, that is, in the year 1120 BC. [Margin: Where, with what instruments, and what kind of things he observed.] *"In that place"* (namely the city of Teng-fang), he says, *"there is still to be seen a huge rule upon a bronze plane set upright, perpendicular to it, and divided into definite parts, as is also a line drawn out on the very surface of the plane, likewise distributed into its parts. With this instrument Cheucungus, that great astrologer and mathematician among the Chinese, and once the supreme prefect of the whole empire, used to observe the meridian shadow, and from it he sought out the elevation of the pole and the other things that can be gathered from it. He lived 1,120 years before the birth of Christ. In the same place one may see the tower in which he used to record the courses and revolutions of the stars; it is called Quonsing tai, that is, the tower for viewing the stars."*

[Margin: Already in 1120 BC the Chinese achieved things of no slight weight in astronomy.] This shows abundantly that already in the year 1120 BC the Chinese not only had a rudimentary knowledge of the science of the stars, but had already penetrated a great many matters of no slight weight, since they applied instruments that were by no means unsuitable to celestial observations — namely, to investigating the meridian altitude of the Sun and the elevation of the pole. Hardly anyone could easily persuade me of this: that these peoples, so long an interval of time before anything on this subject became known to the Chaldaeans and Egyptians (so far as is recorded), had already made such progress in astronomy, and that the very same tower, together with the very instrument Cheucungus used for the stars, has been preserved whole and intact down to our own times — unless all of it were proved by evident arguments, and not by arguments put together and made up out of someone's head. [Margin: The Chinese have histories older than those of all other nations.] For it is established from the histories of the Chinese, which down to this day they possess as the most ancient of all peoples, that they enjoy documents of the most remote antiquity, and can produce observations far older than any of the other nations can. Martinius seems to affirm this solemnly in his *Historia Sinica*,

p. 15: namely that under the third emperor, Hoangtius, in the year 2697 before Christ, at about the time when Enoch died while Methuselah was still alive — that is, in the year 962 of the Julian Period — [Margin: In 2697 BC the Chinese discovered the cycle of the Sun, the pole, the sphere, and a great many other things.] *Tanaus* (the emperor's prefect) *completed the cycle of the Sun* (of sixty years) *which the Chinese use to this very day, in the year 2670 before the common epoch of Christ, in the first cycle, and also in the twenty-eighth year of this emperor. Another* (prefect), *Yumchinius, was the first to observe the pole and the stars proper to it, and with some instrument, whose form the writers do not record, with a sphere, that is, one representing the orb of the heavens, he imitated the figure of the celestial orb; he also learned by experience many things from which changes in the air and in the lower heaven can be detected.* [Margin: Shortly after Adam the Chinese already had a calendar and ephemerides.] Again, of the fifth emperor, Chuenttious, in the year 2513 before Christ and the year 1248 of the Julian Period — nearly the same year in which Adam died, by our reckoning — the same author records on p. 21: *They report that a calendar was published by him* (the emperor, that is) *and received throughout the whole kingdom. He also wrote ephemerides of the five planets, all of which, during his reign, he saw in conjunction in the sky on the day on which the conjunction of the Sun and Moon was observed. And he wished that day to be the first of that year, as the writer on Chinese affairs indicates — in the constellation called XE, which now begins at about the eighteenth degree of Pisces and extends as far as the fourth of Aries.* [Margin: The year in which the Chinese saw all the planets in conjunction in one and the same sign.] He continues: *Perhaps this is that famous conjunction of the planets in one sign which the European chronologers assert took place in the age of Noah. What those who count fewer years back to Noah's Flood will say to this, I do not know,* etc. *I say, however, that this is altogether the first observation of the stars on which authors do agree. What will our Europeans say to this? I solemnly declare that I found the observation in the Chinese history I have spoken of, among the acts of this emperor.* So he writes. [Margin: According to the Chinese, the Flood fell much earlier.]

[Margin: Already in Noah's time, if the Chinese are to be believed, Hius and Hous restored the year and the months.] Of the seventh emperor of the Chinese, Yaus, who lived in the year 2357 before Christ — that is, in the sixtieth year before the Flood, in Noah's time, by our computation — the same Martinius reports on p. 25 of the *Historia Sinica*: *Delighting above all in the contemplation of the stars, he restored the measure of the year, which was subject to a number of errors; he also brought the intercalary and surplus month back to its proper order. To accomplish this he used the services of two men, both eminent in that discipline, one named Hius and the other Hous. He urged them to the constant veneration of the great Heaven and ordered them to make various instruments suited to mathematics; to observe diligently the motions of the Moon and the stars; to draw out from these, for the use of the common people, precepts for the proper practice of agriculture; and finally to record the winter solstice with the greatest accuracy. For it mattered that this turning of the Sun should not be unknown to the king, because on that day he*

was accustomed to distribute all the offices among his ministers, etc. [Margin: At the same time they measured the Moon and the stars with instruments.] *But to return to the solstice* (he continues), *the Chinese writers say that in those times it* [Margin: In what part the winter solstice …] *about the first degree*

[Margin: … of the heaven it was first observed by the Chinese.] *of the constellation HIU was observed, which now takes its beginning at about the eighteenth degree of Aquarius. If this reckoning is to be approved, the solstice must meanwhile have shifted more than 48° from its origin. Certainly one of those who have interpreted the book Xuking does not hesitate to affirm that under the reign of Chincungus, of the Sung family, in the year 1005 after the birth of Christ, the solstice had already changed by 42° from the earlier observation, over 3,342 years. For its first observation was made 2,337 years before Christ.* [Margin: How great a variation of the solstices the Chinese had already detected in the year 1005 after Christ.]

[Margin: In about 2150 BC the Chinese observed a notable eclipse of the Sun.] Finally, the author himself also notes that under Chumkangus, the fourth emperor of the Hia family, in the year 2158 before Christ and about the hundredth year after the Flood, a memorable eclipse occurred *while the Sun occupied the star or constellation called FANG, which at the present time is at about the twenty-eighth degree of Scorpio. Because the royal astrologers, through negligence, had not predicted it, they were punished with death. I do not find the year of this eclipse to be the same in all authors. Some assert that it occurred in the second year of this emperor, 2158 before Christ; others assign it to his sixth year, which would be 2154 before Christ.*

[Margin: The records of the Chinese seem not to be rejected altogether.] Indeed, these are rightly counted among the clearer testimonies, unless someone should declare it all fabrication and reject the whole history of the Chinese outright. Yet in my opinion, accounts that report dates, the names of authors, many particulars, and the observations themselves can hardly be repudiated altogether; above all, what has been recorded about the two observed winter solstices, and about the interval that elapsed between the two solstices, does not seem to be baseless. [Margin: The Chinese bring forward far older observations than the Egyptians and Chaldaeans.] In sum, it is clearly evident from what has just been cited that the Chinese, of all the Asiatic nations, bring forward much more evident documents and far older observations — older even than those of the Egyptians and the Chaldaeans themselves. For already in the year 2513 before Christ, at about the time of Adam's death, they detected a conjunction [synodus] of all the wandering stars [errones], and they also constructed calendars and ephemerides. [Margin: With about four hundred …] Moreover, two or three thousand years before the birth of Christ, they already, with instruments, the solstices, the motion of the planets and the altitudes of the pole — these they observed, and other things of this kind. [Margin: … years earlier the Chinese kept watch on the stars, the first glory is rightly owed to these peoples.] Indeed, even granting that the account of Callisthenes is certain — namely, that the Chaldaeans had observations from 1,993 years before down to the times of

Alexander — the Chinese nevertheless devoted themselves to observations nearly four hundred years earlier, if their histories are to be trusted. So by the best of rights the laurel is owed to the Chinese among all the Gentiles.

[Margin: Even though the Europeans lacked those very ancient observations, they nevertheless now far surpass the Chinese in this astronomical science.] Yet I cannot wonder enough how it came about that, although these Chinese have had for so many thousands of years no slight knowledge of astronomical matters, together with notable observations, and have preserved these properly down to the present, adding very many others drawn steadily from the heavens themselves, they did not make far greater progress in that science than our Europeans. For the Europeans, so far as I know, have so far obtained nothing at all of their very ancient observations, but only a very few observations of the Babylonians and of Hipparchus — apart from those that they have gathered for themselves with tireless study over the last few centuries.

[Margin: From whom the Chinese learned the celestial sciences.] But this is too much about them. Let it be enough to have shown abundantly that the science of the stars took its first origin from the Asiatics, and especially from the Chinese — who nevertheless without doubt did not draw it from themselves, but from Noah or the first patriarchs, since it is clear from the foregoing that the observations of the Chinese seem to fall in the times of the first patriarchs. [Margin: The author leaves the reckoning of the years up to the Flood to theologians and chronologers.] How these things agree with our chronology, which sets even fewer years up to the Flood itself, I leave to theologians and chronologers to settle. On this occasion nothing more falls to me than to show briefly who chiefly among the Gentiles were — in my opinion only — the first discoverers and founders of divine astronomy.

[Margin: Who among the Gentiles first discovered astronomy, and how the science grew step by step.] Proceeding further now, let us inquire specifically into those first authors themselves, so far as the histories will allow: who exactly they were; what one discovered and achieved in this art ahead of another; and then how they the science of the stars more and more from day to day emended, advanced and cultivated. [Margin: Nothing is perfect from the beginning.] For it is easily gathered that astronomy could not at once, from its very beginning, reach the perfection to which it was gradually brought over a longer stretch of time, through much labour and tireless study. For, as Seneca says, *nothing is complete when it begins*; and it is by use and practice that people acquire an art and a science. Besides, whatever exists in the whole world has its beginning and its progress. [Margin: The study of the stars is made more perfect in the course of time.] So too our celestial studies can certainly be made more complete as the ages advance, provided that the diligence of posterity does not cease. For a great many things are first recognized and detected only after many years, indeed centuries, have passed — things that previously lay wholly hidden and seemed impossible to explore.

[Margin: The moderns have always been far more fortunate than the ancients in advancing astronomical science.] Hence it also happens that the most praiseworthy ancient astronomers, though they attempted the matter with equal talent and industry, were never able to advance as far as the moderns, who have at all times been far more fortunate than they in discovering and cultivating celestial matters — as will become clearer from what is to be said. [Margin: The most abstruse things are uncovered only slowly and little by little.] For difficult things, which demand much labour and effort, proceed at the slowest pace, and their knot can be untied only with the greatest difficulty. Indeed, as Cicero aptly says in *On Old Age* (*De Senectute*), *great things are not accomplished by strength or by speed of body*. And nature willed that nothing should become great quickly, but set before every finest work a difficulty to be overcome by labour and practice.

[Margin: Genuine measurers of the stars have at all times been very few.] But to come to the interpreters of the heavens themselves in particular: it must be understood that those who in this field have attempted something outstanding and sublime beyond the rest, and have set the crowning touch on the work, have never, from the very origin down to now, been so numerous a company; rather, they have truly been very rare. Tycho himself supports me on this in his *Epistolae Astronomicae*, p. 257, in these words: *of whom very few are found — which is to be lamented — even among those who in this age wish to be regarded as astronomers.* [Margin: Why experts in astronomy are not found in greater numbers.] There is no reason, kind reader, for you to wonder at this. For although this study is rightly ranked among the most excellent, the most delightful and the most useful, it nevertheless also has its own very great difficulties, and of great labour and effort it is; what is more, it demands no small expense. For these reasons very few appear who take up the care of these matters — above all when one considers that in this age of ours it contributes very little indeed to food and clothing, or, as the distinguished Crügerus [Peter Crüger] used to say, that the chimney of this science gives off little smoke.

[Margin: Casters of nativities are very many everywhere, but rarely is there scarcely one or another who inspects and measures the stars.] Astrologers, to be sure, and casters of nativities [Genethliaci], or the very many others who always have astronomical matters on their lips — who argue and write about them at length, doing their reckoning, of course, by the stove, and leafing through the tables and books of other eminent men — are met everywhere in great numbers. But scarcely a very few come forward, wherever you look for them, who draw something solid from the aether itself, day and night, even at the greatest cost to their health and their means (of which great care must be taken in these times); who assiduously turn over that great volume of the heavens, and with strenuous effort contemplate, observe and search out its starry pages one by one.

[Margin: Very many compose and leaf through tables and ephemerides, and speak of celestial matters, but very few examine the very course of the stars.]

Accordingly the excellent P. Gassendus [Pierre Gassendi], a philosopher and astronomer of no common kind, and once my very great friend, rightly says in his *Epistolica exercitatio* against Fludd [Robert Fludd], p. 277: *But, my Mersenne [Marin Mersenne], it cannot be told how few immortal Urania counts worthy of her. Judicial astrologers you may see everywhere; you may see those who skilfully compose or handle tables of the motions and ephemerides; you may see, finally, those who delight in little spheres, armillaries, astrolabes, little quadrants and other tiny instruments of that kind, as if in treasures. But those who worthily take up those weightier cares* (namely, observations of all the celestial bodies) *are scarcely as many as the gates of Thebes or the mouths of the Nile. And would you wonder if what so few teach about the celestial bodies — few, yet skilled in celestial things through their own eyewitness* [Greek: ἀυτοψία (autopsia, "seeing for oneself")] — *is commonly counted among paradoxes, when the number of those who speak or write of celestial things is countless, and yet all of them devise their opinions not from the heavens themselves but out of their own brains?* etc. *The book of nature itself must be read,* (the same author adds a little later) *if anything certain is to be learned; and those who think that goat's-wool quibbles [caprilineas] and technical disputes are the study of nature are to be held of no account.* So he.

[Margin: Not every talent is suited to celestial studies.] But granted that one or another may be found here and there, it is nevertheless not given to each and every one straightaway to go to Corinth, since rarely does anyone, as regards talent, and mind, proves to be carved out — or made — for handling astronomical matters. [Margin: With what endowments of mind and body the astronomer ought to be equipped.] For these celestial studies demand not only a most acute, most sagacious, and indeed mechanical talent, and a man strong in mind and hand, but also one who enjoys firm health and a compact body; above all, one strong in keenness of sight, so as to discern the smallest things excellently both at a distance and close at hand; one, moreover, who spares no labour and does not shrink from undertaking any task, whether by day or by night, in heat or in frost; who has ample means from which to draw the necessary expenses, or at least has a most munificent patron [Mecœnatem] who supplies suitable and sufficient equipment for anything whatever; and finally, one who is tenacious of purpose and constant of will, so as to continue and advance studies once undertaken right up to death, and as far as his strength permits. [Margin: A searcher of the stars endowed with these virtues can, with God, accomplish something.] Such a man, I say, having attained this rare good fortune, can in the course of time accomplish things worthy of praise, which may one day redound to the honour of the Creator of the stars, to the growth of the divine science, and to its perpetual preservation.

[Margin: In the frontispiece of this *Machina Coelestis* the author wished to sketch both the astronomer and how the said science was cultivated, established and preserved.] These qualities, which Urania altogether requires of her devotees, and the virtues with which they ought to be endowed by nature; further, how these sublime studies may be rightly set up, advanced, and happily

propagated to posterity with great profit; next, who those men were who, before many others, were endowed by God with these excellent gifts of mind and body and stood forth as the chief princes of this — that is, of the starry — kingdom; and finally, by what way, with what labour, industry and ardour, and at what expense that Machine of Astronomy was founded, built and adorned, and also by what means its dignity and glory cannot fail to be preserved [?] for ever and rescued from all destruction: all this it has pleased me to sketch to some extent, in certain figures, as much emblematically as hieroglyphically, in the very frontispiece of this book, and to set it before the eyes of everyone.

[Margin: Explanation of the frontispiece of this book.] First, on the left, an obelisk crowned with laurel and a star presents itself, representing, as it were, astronomical science; or, if you prefer, it is like a monument, with a certain inscription, in honour and perpetual memory of the science, erected by our most praiseworthy predecessors, which they faithfully commend to posterity to be preserved with reverence: so that, namely, they may bend all their strength to ensure that this most splendid machine, built by themselves with so much labour, so much diligence and so much expense, for the glory of God and the benefit of mankind, and raised at last after so many centuries, should not contract a flaw or defect in any way, much less collapse altogether. [Margin: The requisites of astronomical study are revealed through emblems.] And so that the work might succeed the more happily in future, the Fathers saw fit to indicate, by certain emblems inscribed on the obelisk, how those who strive to devote their effort to astronomy ought by all means to be constituted by nature.

[Margin: What things are required in an astronomer.] The first emblem, going upward, shows a human skull with the inscription "With the keenest" [Acutiſſimo]: as if they were saying that the true astronomer should have a very sharp intellect and a loftier mind, so as to grasp abstruser matters promptly and to explore and penetrate them thoroughly. [Margin: Judgement.] The second emblem in order shows an eye, with this word added, "With a lynx's" [Lynceo]: that is, just as this searcher of the stars is to be talented, so he should also be strong in sight, or have lynx eyes, fit for duly distinguishing any of the most minute things, and also highly fit for observations. [Margin: Very keen eyes.] The third emblem bears a plough, with the inscription "With unwearied" [Indefeſſo] — that is, labour. [Margin: Unwearied labour.] For the surveyor of the heavens [Cœli Metator] should shirk no labour; like a ploughman, he should be unwearied in his work. For he must sweat not only with his talent, mind and eyes, but also with his body, above all with his hands, and with all his strength: in devising instruments [rebus organicis], and — if he is granted to go so far — in making them by his own efforts [ſuo Marte], dividing and testing them, and in carrying out observations, writing them up, drawing them and engraving them in copper. [Margin: Constancy.] To the fourth emblem a heart is attached, with this little word, "With the most constant" [Conſtantiſſimo] — that is, mind. For the astronomer must be most persevering,

and, holding his course most constantly in his contemplations, observations and studies, must be in no way weary, by day or by night, of all the things which, with divine aid, are drawn from the heaven itself, are explored with ingenuity and toil, and are also to be brought to actual use and effect. Nor should he allow himself to be broken, either by distaste for the difficulties or by the length of the labours, nor to be torn away or deterred from this business by fear of wearing out his health and of the expenses to be laid out; nor should he let himself be called away from these studies in any way by any allurements, by the enticements of the desires, or by the most agreeable companionship of friends, when very rare phenomena, most worthy of note, which matter greatly to astronomy, occur. Rather, he should press on assiduously, with God, in the praiseworthy work he has once undertaken, with a most steadfast mind and a most persevering will, and never abandon that path once taken, but rather spend his whole life advancing eagerly along it. [Margin: And thus one goes to the stars.] Fifthly: at the point of the pyramid is read "They are searched out" [Inveſtigantur] — namely, the stars; and this is what that star at the summit of the obelisk, girt with laurel, expresses. It is just as if our most honoured predecessors wished to recall to our minds that, just as the sidereal science was founded and cultivated with the keenest intellect, the lynx's eye, unwearied labour and the most constant mind, so too it can be preserved safe and whole by posterity in no different way, and further adorned and enlarged as well: so that, passed thus as it were from hand to hand, it cannot fail to be handed down to posterity at every time richer and more splendid.

[Margin: An excellent exhortation of the ancient astronomers, by which they wished to rouse posterity to cultivate astronomical study more and more.] But so that this may be undertaken with greater ardour and care both by us and by our sons, the praiseworthy ancients wished, as it were, to put spurs to us by an inscription cut into the stylobate of the obelisk, which they left us as a kind of testament out of their most excellent goodwill towards their successors, in these words, namely: *To the glory of God, Best and Greatest, and the increase of the Republic of Letters: this monument of the sidereal science, founded many centuries ago as solidly as it was happily built, with the utmost powers of mind and body and at incredible expense, by sons and grandsons devoutly henceforth to be preserved, and further adorned: so the Fathers leave it.*

[Margin: How astronomy may be advanced with success: the author sets it out hieroglyphically.] Moreover, what we expressed in the emblems inscribed on the pyramid we wished to illustrate likewise, as if in the aether, and indeed hieroglyphically: namely, how the divine Urania ought to be received, handled and advanced, so that a happier success in celestial studies may be conveniently obtained.

[Margin: Very many arts and sciences quite often serve astronomy as its auxiliaries.] And so the chariot that you see, kind reader (it stands, of course, for the study of astronomy), has been depicted, engraved and wrought throughout with art and the utmost elegance by most ingenious Mechanics herself, with

the help of most excellent Optics, most outstanding Painting, and also most worthy Engraving. In this shining chariot, and indeed in its more prominent place, sits Astronomy herself, bearing a star on her head and the Sun and Moon in her hands, clothed in a robe varied and adorned with art with asterisms of many kinds and a great many little stars. By this, it should be plain to everyone at first glance what she chiefly looks to, and with what things she is occupied. [Margin: The study of astronomy can in no way be cultivated by one wholly ignorant of the other sciences and arts.] This chariot, however, made with wonderful art — or the sidereal science seated in it — is moved from its place only with great difficulty, still less is it pushed forward very easily by bare hands. Different animals are therefore required, and indeed ones livelier and stronger than others, so that this work may succeed as one wishes, and readily, at every time without exception. [Margin: The astronomical course is set out on and carried through only with various animals.] For that reason a lynx is first to be yoked to the chariot. That is: if anyone resolves to apply himself to astronomy — not at all in a little hut by the stove, but under the open sky — he must be endowed with bright and sharp eyes. Second, to the lynx is yoked a noble and fearless horse, undaunted by labours and patient of them; for the business demands that the searcher of the stars spare himself no labour and no sweat. Third, a lion is brought up beside these two. That is: he must be vigorous, ardent and steadfast, to complete the course he has taken up. When these, I say, have been happily obtained, the work is carried forward by a team of three, at the swiftest pace and on the straightest course indeed.

[Margin: The sidereal science is to be handled with the highest judgement.] But lest Astronomy, or he who has devoted himself to this science, fall from the chariot, or from the straight path to the winding laby- rinthine turning be led away — since these animals are untamed, fiery and very hard-mouthed, and so unbridled that without some prudent driver they would easily turn off the road and come upon a doubtful way; that is, lest this study, so excellently conceived, should rush on a wandering course over precipices, or fall into errors, or at least be turned aside from the true goal — it is worth the effort that these brute animals, which can neither govern themselves nor keep themselves strictly on the track, should be guided and driven, with bridles fitted on them, most gently by some well-skilled and practised charioteer: that is, by Reason herself, seated in the front part of the three-horse team.

[Margin: Only with Arithmetic and Geometry as companions is it granted to approach Urania.] For however amply provident of things Reason herself may be, however sharp and most circumspect, she by no means carries this business alone, nor is she sufficient to drive these animals on, unless most noble Arithmetic and most ingenious Geometry come to her aid, seize the reins, turn those fierce and disobedient animals at will, and restrain them from every deviation, so that the prudent direction and counsel of Reason is obeyed entirely at her nod. Geometry therefore stands at the right, clothed in a garment adorned with various geometrical figures and bearing a triangle on her head;

at the left, again, Arithmetic, adorned with a most beautiful tunic of numeral characters, holds the steering. [Margin: Celestial studies proceed as one wishes if they are undertaken rightly and duly by one who is skilled and apt.] And so, with this team of three, with a driver and guides, our Urania advances exceedingly far, well secure that she will not easily be led astray or swept over the precipices of error. That is: if anyone enjoys the gifts of mind and body already mentioned several times, and Arithmetic and Geometry assist him, then — with the assent, that is, of divine grace — a most desired outcome of this sublime study is certainly to be expected, so that there can be no doubt [Margin: Astronomy at last turns to the glory of God and the benefit of posterity.] that it will at last also turn out happily to the glory of the Most High, the honour of the science, and the everlasting memory of its authors. This is what flying Time proclaims through the aether in this proclamation: *To God and to Posterity*; and Fame, the companion of Time, in these words: *To the immortality of the divine art.*

[Margin: Who were, of all astro-] Finally, in the same picture, four principal high priests of astronomy, the leaders of all the others — for each and every genuine astronomer, to follow in their footsteps — I have chosen to bring forward: [Margin: -nomers were the most eminent.] both as an eternal memorial, on account of the supreme virtues of these excellent men and of their labours, so splendidly carried through with such great effort, and to show in what honour and esteem I never fail to hold them, and how I revere their studies. For they are, as it were, four columns on which the whole of astronomy rests, like those four globes, or corner-stones, on which the obelisk of the sidereal science has been most happily built; or rather, they are the men who, for so many centuries up to now, have most gloriously borne our whole sidereal machine on their shoulders, with such great praise, and who admirably defend it from every blemish and from destruction.

[Margin: Hipparchus.] The first in order is Hipparchus, who, first of all men, compiled a catalogue of the fixed stars and made a celestial globe, and also left us observations of the equinoxes. [Margin: Ptolemy.] The second is Ptolemy [Ptolomæus], the standard-bearer of the rest, who was the first to bring all things into order and under a definite hypothesis. These two carry a torch before us, as it were, and remind us with what close attention and with how great assiduity we ought — taught by their example — to contemplate and search out the courses of so many shining stars. [Margin: The ancients have not yet thoroughly overcome every difficulty.] And so that we may not persuade ourselves that our forebears have already overcome absolutely all difficulties and brought the science fully to its summit, they declare with one voice: *We have laid foundations — solid ones, indeed; but more solid and greater ones are to be hoped for in their own time.* For a hard work, once begun, is not at once and in one stroke completed in every respect and bound by indubitable laws; the arts are cultivated only by searching, correcting and adding. [Margin: By progress, greater things are still to be hoped for.] For that reason we, too, hope for more

perfect things, with God and with time — as has indeed already happily come to pass. Yet the ancients are not on that account the lesser; rather, they equally deserve the greatest praise, because they stood forth as the leaders of the front rank, breaking through the first difficulties and the ice.

[Margin: What Copernicus and Tycho achieved.] The remaining standing figures are our great Copernicus and the incomparable Tycho Brahe, who, with the greatest genius indeed, and heroic daring, set about astronomy: the former by devising a new and far easier hypothesis — with the Sun, namely, standing at the centre of the world, and the Earth immobile; the latter by so many, many observations of both the fixed stars and the planets, carried out with success beyond all others and left to us like a treasure. All this — to say nothing of their other merits — is entirely open to view. These very great men, I say, like the two before them, conferred together about the studies of the ancients and their splendid endeavours, and at last broke out in these words: *Much indeed has been discovered, but a very great deal has been left to posterity.* [Margin: Every age has its work to do.] That is said no less wisely than rightly. For every age has its work to do. And so there is no reason for us to imagine that nothing more remains that must still be discovered, worked out, corrected and refined. So far, indeed, is that from being reasonable that we have found the very opposite to be clearer than daylight. [Margin: Divine Wisdom is unsearchable.] For no one will ever exhaust the abyss of Divine Wisdom, even in natural things, as will become more fully evident from what follows. This, then, is what we wished to say on the occasion of the title of this work — namely, about the nature, character and office of the investigator of celestial things; and further, how this science ought to be cultivated and spread.

[Margin: Who were the foremost among astronomers.] Next, as we proposed, we must look more deeply into the histories, so that it may be clear who served vigorously under the banner of Urania, and who, above the others, achieved the more distinguished things from the beginning. [Margin: Concerning the progress of astronomy the poets invent a great many things.] For what the poets tell as fables, or invent, about the origin and progress of astronomy — about Caelus [Cœlo], for instance, as though he had been the first of all to contemplate the stars, together with his children, namely Atlas, Saturn, Titan, Hyperion, Iapetus [Japito] and Hesperus, son of Atlas, inhabitants of Africa and Mauretania; and likewise about Hercules, Mercury, Prometheus [Promotheo] and Cepheus, about Endymion, Orpheus and others who laboured at astronomy — we have decided to pass over entirely in silence, since these things seem to be mixed with a great many fables and rest on no certainty. [Margin: Because of the lack of histories, pro-] Let us therefore come down to what has been plainly recorded by trustworthy authors, beginning first with the

Greeks — although they were by no means the very first discoverers of all; others were, namely barbarian and Asiatic peoples, as Plato himself in part freely testifies, and as is in part also evident from our account above. [Margin: …the progress of astronomy the author traces only from the Greeks.]

[Margin: Thales is rightly held to be among the first astronomers of the Greeks.] Onto this astronomical stage, then, let us bring Thales first of all, born in the second year of the 35th Olympiad, that is, in the year 637 before Christ; he is rightly counted among the more ancient astronomers of the Greeks. For he was the first to discover the course of the Sun from turning-point to turning-point [à converſione in converſionem], and he said that the lunar orb, compared with the magnitude of the Sun, is its seventieth-and-twentieth [ſeptuageſimam & viceſimam] part. They also report that he was the first to discover the seasons of the year and their changes, and that he divided the year into three hundred and sixty-five days; and also that he found Cynosura, the Little Bear, and predicted eclipses of the Sun. Yet, according to some, he wrote no more than two little books — namely on the solstices and on the equinoxes — as Laertius testifies. He died in the year 586 before Christ.

[Margin: Anaximander, a hearer of Thales, held the Earth to be like a centre.] His pupil was Anaximander of Miletus, who held that the Earth is like a centre, and spherical. He also demonstrated the solstices and equinoxes of the Sun, and moreover, having constructed a sphere, was the first to teach how to tell the hours from the shadow of a gnomon — although others attribute the discovery of the obliquity to Pythagoras, or to Oenopides of Chios. [Margin: Anaximenes and Anaxagoras said that the Moon is mountainous, and also that it enjoys another's light.] Anaximander's hearer, in turn, was Anaximenes of Miletus, who said that the Moon shines with a borrowed [notho] light, and is therefore deprived of light when the Earth is placed between the Sun and the Moon. Anaxagoras, again a pupil of Anaximenes, said that the Sun is a round mass, and a glowing one; that the Moon has hills, valleys and various dwelling-places; and that the Milky Circle [Lacteum orbem] is a reflection of the Sun's light, the stars not shining in among it.

[Margin: Astronomers owe a very great deal to Pythagoras, especially because he was almost the first to hold the Earth to be mobile.] In the time of Anaximenes, Pythagoras flourished in Italy, about the year 525 before Christ. He learned the sidereal science from the Egyptians and Chaldaeans, and the Greeks and his followers owe him a very great deal for the whole theory of the planets — no less do the moderns, and all of us who now hold the Earth to be mobile. For among other things he was the first to teach that the Sun is the centre of the planets and of the whole world, and that it stands still together with the whole heaven, while the Earth moves around it like a planet. [Margin: He likewise held the Sun to be the centre of the planets and of the whole universe.] Afterwards a great many very weighty men went over to his side: Philolaus of Croton [Cratoniates], Nicetas [Niceta], Seleucus, Cleanthes [Cleantes] of Samos, Leucippus, Ecphantus, Heraclides Ponticus, Nicolaus Copernicus, and very many of the moderns — indeed, nearly all of them now who are not afraid to speak out more freely the opinion they cherish in their hearts. [Margin: A great many astronomers, ancient and modern, have embraced the motion of the Earth.]

[Margin: Democritus and Empedocles: when they lived.] In the 458th year before Christ, Democritus of Abdera, a pupil of Anaxagoras of Clazomenae and of Leucippus [Licippi], flourished; he wrote a number of things about the pole, about the wandering stars, and about the great year. A little later Empedocles of Agrigentum succeeded him. [Margin: Euctemon and Meton observed the solstice.] Then, in the 429th year of the same era, Euctemon and Meton observed the solstice at Athens; Meton also devised the nineteen-year cycle, or golden number, as well as a sundial, along with certain other things. He was followed by Eudoxus of Cnidus [Gnidius], the discoverer of not a few things. Likewise, in the 340th year before Christ, Autolycus of Pitane [Autholycus Pritanæus] lived; two of his books are still extant, one on the sphere, the other on the rising and setting of the fixed stars. [Margin: Callippus introduced a period of his own.] At about that time Callippus [Calippus] came forward, introducing a period of 76 years and beginning it not from the autumnal equinox but from the preceding solstice.

Afterwards Theophrastus of Lesbos [Theophraſtes Lesbius] and Aratus emerged; and under Ptolemy Philadelphus — namely in the 315th year before Christ — Conon was famous. He collected observations of eclipses of the Sun and Moon, and added the Hair of Berenice to the constellations. [Margin: Timochares and Aristyllus devoted their efforts to the declinations of the fixed stars.] At about the same period Timochares and Aristyllus also flourished; through their industry we possess declinations of fixed stars, from Hipparchus as reported in Ptolemy. Among other things, Timochares discovered that Spica Virginis precedes the point of the autumnal equinox by 8°. [Margin: Aristarchus of Samos …] Above all, around the 210th year before Christ, Aristarchus of Samos and Archimedes were of great renown: the former

held, together with Pythagoras and Philolaus, the opinion that the Earth is mobile while the Sun stays unmoved; yet nothing of his has come down to us except on the sizes and distances of the Sun and Moon. [Margin: Aristarchus of Samos spread the opinion of the Earth's motion.] The latter, by contrast, laboured over recording the solstices. He transferred the motions of the Sun, the Moon and the rest of the wandering stars into an artificial sphere with the greatest ingenuity, and he was the author of a great many other inventions. [Margin: Archimedes, a distinguished mathematician.]

These were followed, under Ptolemy Philometor and Epiphanes, by two very distinguished men. One was Eratosthenes of Cyrene, Prefect of the Library of Alexandria, who measured the distance between the tropics and the motions of the heavens; at his urging, armillae [Armillæ] and rulers [Regulæ] for celestial observations were set up at Alexandria by Ptolemy. [Margin: At Eratosthenes' urging armillae and rulers were set up at Alexandria.] The other was the great Hipparchus of Nicaea or of Rhodes, in his own time altogether the prince of astronomers and very well known to every investigator of the stars — namely in the 140th year before the birth of Christ. [Margin: Hipparchus rightly stands out among the foremost, for the very many things he accomplished admirably.]

What he achieved in the study of the stars, and how much astronomy owes him, we all know well: he left us very many equinoxes that he had observed himself with all the diligence he could, and above all a catalogue of very many fixed stars by longitude and latitude, together with very many observations of the most ancient eclipses from the time of Mardocempadus. [Margin: He left us equinoxes and eclipses.] He also applied a more correct form of the Callippic period. And when he had noticed the variable latitude of the Moon, the anticipation of the nodes, and also the eccentricity, and that the Moon's motion is slower around the apogee and faster at the perigee, he constructed hypotheses and tables of the motions, from which he was afterwards able to predict eclipses safely. [Margin: He constructed hypotheses and tables for the Sun and Moon.] Indeed, he would have built tables for the remaining planets too, had he obtained suitable observations from the Chaldaeans, Babylonians, Egyptians and Greeks. So he was very nearly the first to touch the threshold of the door, and he laid firmer foundations for astronomy. For this reason he is rightly held in the highest honour and is most worthy of every praise. [Margin: Hipparchus laid the first foundations of astronomy.]

Next came Geminus and Theodosius of Tripoli; Sosigenes, through whose work Julius Caesar restored the calendar; [Margin: Through Sosigenes' effort Julius Caesar corrected the calendar.]

Andromachus; Agrippa, who observed a conjunction of the Moon with the Pleiades in Bithynia; Menelaus, who in the time of Trajan also devoted himself to the fixed stars; and not long afterwards Theon of Smyrna, who investigated the stars at Alexandria no less. [Margin: Menelaus and Theon also kept watch on the fixed stars.]

Among the others, however, Claudius Ptolemy won himself an immortal name, around the 130th year after Christ; for his doctrine of the stars he is one of the few worthy to be preserved in cedar. For he is quite plainly, as it were, the first founder of astronomical science. He reduced the observations of Hipparchus and of others, with his own added to them, to a systematic form, and devised clear methods; and in this way he embraced the whole doctrine of the Sun, the Moon, and of both the fixed and the wandering stars in his *Almagest* — a doctrine which not only the Alexandrians but all the Arabs and Latins went on retaining through a long succession of ages. [Margin: Claudius Ptolemy was the first to restore the whole of astronomy, and he derived fixed laws for it.] A long interval after Ptolemy, certain outstanding men came forward: namely Pappus and Theon, both of Alexandria, together with his daughter Hypatia, who was highly skilled in astronomical matters; Proclus, and others. [Margin: Hypatia devoted herself to celestial matters.]

Among those devoted to astronomy, moreover, Sulpicius Gallus was also famous; but far more famous was Julius Caesar, who corrected the old year through the work of Sosigenes — and by this labour he deserved well of the whole world. [Margin: Julius Caesar won himself an immortal name by restoring the calendar.] Apart from these, however, there were very few indeed

among the Latins who devoted their efforts to genuine astronomy. [Margin: Among the Romans very few measurers of the heaven are found.] But in the time of Charlemagne not only did the Emperor himself take intense delight in these studies, but so did other great men and princes as well: namely Maimon, King of the Saracens at Babylon; Almeon, King of the Arabs, who recorded the greatest declination of the Sun 50 years before al-Battānī; likewise Albumasar [Abū Maʿshar], and Mahumetes Alfraganus, or Alferganus [al-Farghānī]. [Margin: Great princes and kings, of the Saracens as well as of the Arabs, devoted their efforts to astronomy.] Among the Arabs, however, al-Battānī stands out greatly: a Syrian prince, otherwise called Mahometes Aractensis, who in the 888th year of Christ carried out various observations of great importance, to the very great benefit of astronomy, partly at Aracta [ar-Raqqa] and partly at Antioch. [Margin: Among the foremost, however, al-Battānī must be placed, since he cultivated the sidereal science earnestly and in varied ways.] Above all, he found that the apogee of the Sun had advanced in the order of the signs since the time of Ptolemy; and that the fixed stars,

recede towards the east by 1° within 70 years; that the obliquity of the ecliptic was, roughly, smaller at that time; and many other things concerning the planets as well. In this way he too corrected Ptolemy in many points, built new tables, and at the same time composed a book on the science of the stars.

A century after al-Battānī, Alfarabius [al-Fārābī] the Arab and also Geber, or Gebrus, became famous; among the Latins, in turn, Abbo, Abbot of Fleury, and Hermannus Contractus [Hermann of Reichenau]; and also Arzahel or Arzachel [al-Zarqālī] the Spaniard, who in the 1080th year of Christ had observed the obliquity of the ecliptic to be smaller still, by one minute, than al-Battānī had — although in the 1142nd year Almeon Almansorius, an Arab, noticed the greatest declination of the Sun to be smaller again by one minute, namely 23° 33′. [Margin: Alfarabius, Geber and Arzachel, very distinguished astronomers.] [Margin: Almeon observed the greatest declination of the Sun to be smaller than the others did.] At about the same time there flourished Humenus in Egypt, Abraham Abenezra [Abraham ibn Ezra], Averroes or Aben-Roes, Campanus, and Hali son of Abenragel [ʿAlī ibn Abī l-Rijāl]; and besides them, in the 1132nd year, Johannes de Sacrobusto [Johannes de Sacrobosco] and Jacobus Alkindus [al-Kindī].

Among the very many men of great name and princes, however, there shone in the 1270th year of Christ Alphonsus [Alfonso X], King of Castile and León, who set about building new tables of the celestial motions. He perceived very clearly that the tables both of Ptolemy and of al-Battānī departed from the heavens by an excessive amount. [Margin: King Alphonsus, a great patron of astronomy.] For this reason he summoned all the celebrated men, of the Arabs as well as of the Jews, so that by making more accurate observations they might carry this undertaking through with the greatest zeal; but they did not reach the goal, at least as the excellent King imagined it to himself. For they paid attention to certain mysteries more than to the observations themselves, of

which they in fact made almost none. [Margin: The Alphonsines themselves made scarcely any observations.] The chief of those who directed this work was Rabbi Isaac Hanan, Cantor of the Synagogue of Toledo. [Margin: Rabbi Isaac Hanan, the chief author of the Alphonsine Tables.] Shortly afterwards, around the year 1300, there followed Thebetius the Arab and Prophatius the Jew, who made a number of observations concerning the obliquity of the ecliptic and the motion of the fixed stars, a motion which the Alphonsines had utterly neglected. Yet the matter, not yet brought to that point [Margin: The Alphonsines did not reach the goal at all.]

where the Tables agreed with the heavens in every respect. [Margin: After the Alphonsines, astronomy was silent for a long time.] And in the hundred and fifty years that followed, scarcely anyone emerged after them who gave serious thought to this work — although others appeared here and there who devoted strenuous effort to judicial astrology, that is, to the art of divination. At length two outstanding men came forward in Germany: Georgius Peurbachius [Georg Peuerbach], namely, in the year 1423, and his pupil Johannes Müllerus [Johannes Müller], otherwise called Regiomontanus, in the year 1436 — both worthy of every praise, and rightly to be counted among the most deserving astronomers. [Margin: At length Peuerbach and Regiomontanus came forward, men most expert in astronomy.] These men indeed wished for nothing more than to come to the aid of a tottering astronomy with adequate remedies, and to restore it properly with the observations it required. [Margin: Their one thought was to come to the aid of the restoration of the sidereal science.] To that end, therefore, they built suitable instruments, and also derived from the heavens themselves a great many things most worthy of note; but an early death put a barrier in the way of both, so that they did not bring to a happy completion everything they had in mind.

In these times there were men of illustrious fame: in Italy, Dominicus Maria [Domenico Maria Novara] and Johannes Blanchinus [Giovanni Bianchini], of Bologna; likewise Abraham Zacutus [Abraham Zacuto] in Africa, and Joh. Stöfflerus [Johannes Stöffler] at Tübingen in Germany. But none of these achieved greater things, at the beginning of the century just past, than the great and never sufficiently praised Nicolaus Copernicus, our countryman, of Toruń, a Prussian, canon of Warmia at Frombork. [Margin: Copernicus undertook astronomy with great effort, following the hypotheses of the Pythagoreans.] For, spurred on above all by the example of Peuerbach and Regiomontanus, he began with all his strength to cultivate astronomy according to certain hypotheses of the Pythagoreans, who held that the Earth is mobile in the ecliptic and the Sun immobile at the centre of the universe. He therefore made various observations with such instruments as were then available to him, and constructed new Tables, as precise as could be achieved. Yet not even these satisfied all the phenomena. For concerning the fixed stars [Stellae Inerrantes] he had accomplished nothing whatever beyond what Hipparchus and Ptolemy had done. [Margin: Copernicus founded new Tables, but did not restore the fixed

stars.] Since he had also foreseen this very clearly, he afterwards earnestly urged Joachim Rheticus [Georg Joachim Rheticus] to labour above all so that the fixed stars, if not all of them, at least the principal ones, might be restored around the ecliptic. And yet not even Rheticus, nor anyone else after Copernicus, brought that task to its longed-for end — although not a few distinguished men lived at that time who earned no small praise by their most varied astronomical studies: among others, Petrus Appianus [Peter Apian], in the year of Christ 1525; Johannes Schonerus [Johannes Schöner]; Erasmus Rheinholdus [Erasmus Reinhold]; Petrus Nonius [Pedro Nunes]; Gemma Frisius; Johannes Stadius; Michael Mæstlinus [Michael Mästlin]; and Conradus Dasypodius [Conrad Dasypodius]. [Margin: Who after Copernicus were men of renown in the sidereal science.]

This lasted until that most splendid Danish luminary came forward, the incomparable Tycho Brahe, born in the year 1546. To him, among almost all others — however many (if I may be allowed the word) have ever devoted themselves to Urania — the first place is owed, and he is at all times most worthy of immortal remembrance. [Margin: Tycho Brahe undertook and accomplished things far more illustrious than all his other predecessors.] For he achieved more things, and nobler and more accurate ones, in every part of astronomy than any of his predecessors ever did, devoting himself for very many years, from his very youth until his death, to serious observations — and with larger and more perfect instruments at that — in order to restore the collapsed foundations of our sublime sidereal science. Since those foundations, however, depend solely on the restoration and correction of the fixed stars, and since that noble man had also clearly perceived this very point, he not only undertook with a heroic spirit and tireless labour that arduous task, which no one at all since the time of Hipparchus had dared to attempt, but also, after the course of many years — without meanwhile neglecting all the remaining planets — brought it happily to completion. [Margin: Tycho, after Hipparchus, was the first to restore the fixed stars.] This he did, namely, by founding and working out that new and more accurate catalogue of the fixed stars, and by enriching it besides with about two hundred new fixed stars. With how much labour, how much constancy, and how great an expense — which he laid out on so numerous and magnificent an apparatus of instruments, on buildings, on observatories, on hired labour, and on everything else — it would take too long to recount here. [Margin: Tycho spent great sums on astronomy.] The most splendid monuments which he left to us and to posterity — such as his outstanding writings, and above all the observations made over so many years — those Herculean labours, namely, bear abundant witness to them, and the matter speaks for itself. [Margin: Tycho, overtaken by an early death, could not fully work out each and every thing.] When, however, this incomparable man was carried off by an untimely death in the year 1601, on 24 November, in the fifty-fifth year of his age, he was not able to found the whole theory of astronomy and new Tables as he had wished — as indeed he had proposed

to himself — and he was compelled to leave a great many things for others to work out and refine, as happens to all of us. [Margin: We cannot do everything at once.] For the human mind is not able to search out each and every thing in nature all at one time; rather, these things must be entrusted to one person after another to be unravelled more thoroughly.

At almost the same time — indeed somewhat earlier still than Tycho himself — the most illustrious and most praiseworthy Prince Guilhelmus of Hesse [William IV, Landgrave of Hesse-Kassel], at Kassel, namely from the year 1561 to the year 1597, devoted much effort to observing the stars, especially to restoring the longitudes and latitudes of the fixed stars, partly himself and partly through his men, the most distinguished Christophorus Rothmannus [Christoph Rothmann] and Justus Byrgius [Jost Bürgi]; and he used most excellent quadrants and sextants as well. [Margin: The Prince of Hesse, an outstanding promoter and cultivator of astronomy.] [Margin: The Prince, with his Rothmann, kept watch above all over the fixed stars.] This is shown clearly both by his letters to Tycho and by the catalogue itself — although he corrected the places of only certain fixed stars from his own observations — which has now at last been published, through the work of Father Albertus Curtius [Albert Curtz] and by order of the Emperor, together with the history of the Tychonic observations.

Afterwards there came various other most learned men, who illuminated and advanced our astronomy more and more: namely Jacobus Christmannus [Jacob Christmann]; Christophorus Clavius [Christoph Clavius]; Galilæus de Galilæis [Galileo Galilei]; Bartholomæus Pitiscus [Bartholomäus Pitiscus]; Joh. Antonius Maginus [Giovanni Antonio Magini]; Christophorus Scheinerus [Christoph Scheiner]; Severinus Longomontanus, that outstanding founder of the Danish Tables, who for many years served Tycho as his assistant for observations — indeed, he was in large part in charge of them. [Margin: After the Landgrave and Tycho, a great many most excellent astronomers followed.] [Margin: Longomontanus constructed the Danish Tables.] Likewise Wilhelmus Schickardus [Wilhelm Schickard], Adrianus Metius [Adriaan Metius], and Willebrordus Snellius [Willebrord Snel]. Above all, however, Johannes Keplerus [Johannes Kepler] earned much praise among the offspring of Urania, a man of the most penetrating and most ardent intellect, a most acute and subtle investigator of the hidden things of the heavens. Although he could do very little in the way of observations themselves, because of the weakness of his sight and the lack of instruments, he nevertheless accomplished a very great deal with the happiest success — if anyone ever did — in establishing theory on firm foundations, in searching out the minutest details, in restoring the Tables from the Tychonic observations and in constructing the Rudolphine Tables; and what he could not achieve by observation he very nearly obtained by the sharpness of his intellect. [Margin: Kepler, a man of admirable intellect, cultivated astronomical science wonderfully.]

He also left us various monuments of recondite learning, as is more than abundantly clear not only from the many volumes already printed but also from all his manuscripts, which have not yet seen the light. [Margin: Kepler's very diverse writings have not yet seen the light,] For a great many of Kepler's works have not yet been made public. I can witness this myself, since all of his manuscripts are now in my hands — together with all his letters, written in his own hand to the most distinguished men of this age, and their replies — obtained from his heirs, happily, now at last, after many years. [Margin: All Kepler's manuscripts are in the author's hands.] Among the rest, not the least in my view is the one named *Hipparchus*. This book contains a very great deal of labour and sharpness of intellect; but it is to be regretted that it was never fully put in order by the author himself. Nevertheless Kepler himself cites it quite often in his volumes, from which one may gather that the author set no small value on his *Hipparchus*. [Margin: Kepler put much work into his *Hipparchus*.]

For the rest: just as this age has been most fertile in lofty minds in every branch of learning, and the sciences and arts have grown greatly up to now, so too a great many most excellent and by far most learned men have come forward throughout all Europe [?], by a singular guidance of the Divine Power, cultivating our astronomy in every way — some of them already dead in recent years, some still living. [Margin: Our age has been most fruitful of lofty minds.] To list their names here in order, and to recount all their merits, would truly be far too long-winded, indeed superfluous. Since their excellent labours, ingenious inventions and lasting monuments lie before the eyes and in the hands of all the learned — what of the fact [Margin: What each of them accomplished in the sidereal science is plain to see.]

that they themselves still blaze with flashing rays throughout the whole learned world, so that almost no one is unaware of what outstanding work each of them has undertaken, carried through and brought to light?[1]

Truly, however: over many past centuries down to this very day so many great luminaries have, with divine help, already overcome the greatest difficulties in this sidereal science, have discovered a great many of its most abstruse matters, and have, besides, left almost nothing untried by which whatever still remains to be searched out in astronomy might be successfully tracked down. [Margin: Although everyone has laboured strenuously from the beginning until now, astronomy has nevertheless not yet been brought to the highest step of perfection.] And yet it must be freely admitted, even by the makers of the astronomical tables themselves, that all tables without exception — whether the Danish, the Lansbergian [those of Philips van Lansbergen], the Philolaic [those of the *Astronomia Philolaica*], Riccioli's [Giovanni Battista Riccioli] Bolognese tables, the British, or even the Rudolphine — depart from the heaven itself in a great many places, not only in eclipses but also in almost all the planets, quite evidently and sometimes even enormously, and so stand in need of serious

[1] the print reads *nemo ferè non neſciat*, literally "almost no one is not ignorant"; the sense of the passage requires "almost no one is ignorant".

correction. We demonstrated this most clearly with a great many examples in our *Mercury* [*Mercurius in Sole visus*], and the most recent observations of all observers abundantly confirm it. [Margin: All tables without exception are still deficient in certain respects.]

Hence there is not one of the devotees of astronomy who does not long for and seek, above all things, that this sublime and most abstruse study be given help, and that, with God, it be cultivated and advanced more and more each day. But this depends solely on certain and indubitable observations of all the planets and fixed stars; [Margin: All astronomy depends on sound observations.] and these in turn have been almost exceedingly rare — from the very beginnings of astronomy up to Tycho, and likewise from Tycho himself down to our own times. And such as have been obtained so far were for the most part made with instruments that were barely adequate, both in size and in material. It is therefore worth the effort for us to labour wholly at this, in preference to all other contemplations and all celestial studies, so that a good many observations, continued over many years — not only of eclipses and occultations, but above all of the Sun's meridian altitudes, the solstices, the equinoxes, the places of the planets in any part of the heavens, [Margin: The fewer observations, apart from Tycho's, that have been obtained so far, the more effort must be spent on obtaining more of them now, in the course of time.]

and especially for restoring the catalogue of the fixed stars [Inerrantium Stellarum], which in other respects needs much correction — may be obtained by us from the heaven itself with suitable, very large and more perfect instruments made of solid metal, and that we may record them for the good of the learned world and bring them to light. [Margin: The catalogue of the fixed stars still needs correction.]

But not everyone is granted this, and these contemplations carry a very great deal of difficulty. Above all, they demand a lofty and likewise most profound intellect, and a mind that is industrious, assiduous and constant, and also entirely free from cares of every kind. Add that, being an altogether royal study, they also require royal expense and the greatest leisure; and where these are lacking, every effort truly comes to nothing. [Margin: Not everyone is granted to cultivate Urania.] So I never at all imagined, knowing my own slender means very well, that I could undertake anything at all worthy of praise in this field, still less carry it through. Nevertheless, since the sweetness of understanding all things overcomes all difficulties and labours, I took this undertaking in hand, relying on divine help, and not with one hand only, as will be clear from what follows. [Margin: The author never persuaded himself that he could attempt anything at all in so sublime a science.] I did so above all because, as I myself always felt, and as others too perceived in me from my tender years, there were in me no common natural impulses and a singular inclination of mind toward this celestial study.

It came about, then, by God's will, that my parents — whom I must always remember with the fondest recollection — agreed, at the persuasion and urging

besides of friends who wished me well, that I should apply my mind, which was eager enough already, to the study of mathematics. [Margin: From his youth the author was inclined toward the study [?] of astronomy.] This permission was obtained all the more easily because a mathematician of singular learning did not have to be sought far afield. [Margin: With his parents' consent the author took up mathematical studies.] For at that time Danzig maintained at its Gymnasium, as public professor, the distinguished Petrus Crügerus [Peter Crüger], a man endowed not only with a lofty intellect but also with a rare gift for teaching and the most agreeable kindness. To his most desirable instruction I submitted myself in my spare hours, without neglecting the other humane letters in the meantime — namely in the year 1627, in the sixteenth year of my age. [Margin: The author was once a pupil of Crüger, a man most learned in the sidereal science.] [Margin: In the year 1611, January 28.] But how faithful and devoted an effort this excellent teacher of mine always gave me, I should be ungrateful indeed if I did not acknowledge it here too with a most grateful heart and honour his memory as it deserves. [Margin: … New Style, at 8^{h} 30^{m} in the morning, the author was born at Danzig.] For by his very easy and exceptionally clear method of teaching he not only passed on to me the first rudiments of arithmetic, geometry, gnomonics, trigonometry, spherics, chronology and astrology, but also instilled astronomy itself into me — and that within the space of only one or two years (since my circumstances did not allow it to go on longer, which I regretted) — to such a degree that, be it said without boasting, I was able to compute readily from the tables both the places of all the planets and eclipses, whether lunar or solar. [Margin: The author honours the memory of his teacher with the highest regard, for the faithful effort he devoted to him.]

So that the mathematics I had begun might advance the more happily, Crüger urged me to devote effort at the same time to the art of drawing and also to certain mechanical matters, since these things, he used to say, would in due time bring a student of the mathematical sciences much light, relief and usefulness. [Margin: At Crüger's urging the author applied his mind to certain mechanical arts.] I readily seized on this advice, then, and whenever I had leisure I applied my hands assiduously to those things, and to engraving as well, so that from the start I would not be unable to draw small geometrical instruments and proportional compasses and to mark them properly with divisions and numbers (although I had not foreseen that this might some day turn out to be of use to me), and so that anything which perhaps could not be had for money might thereafter be made by my own hands. I felt my mind somewhat inclined towards this mechanical study, and by God's help those labours were also turning out moderately well for me; so I eagerly undertook at the same time to learn from a certain skilled craftsman the art of the automaton-makers — of working any instruments whatever, and likewise of turning and filing any other things, whether of wood, brass or ivory — so that in this way, as the matter required, I might turn the lathe, the hammer, the file and the graver

to my own convenience as I wished. [Margin: To which he was also much inclined, above all to engraving and the craft of automata.] And although this labour was troublesome, heavy and thankless, I nevertheless held firmly to my resolve, and by diligent and frequent practice I at last overcame every difficulty, encouraged in it above all by that far from common saying: that nothing is sweeter than to know all things, and that the study of all the good arts has, at some time, its own outstanding usefulness. [Margin: Desire for knowledge conquers all the trouble of labour.]

Above all, however, Crüger, of honoured memory, seriously advised and persuaded me — seeing that by natural inclination I leaned especially towards mathematics and mechanics — not to give myself to astronomical calculation alone, but much more to look into the heavens themselves at every opportunity offered, and to devote myself to observations as diligently as could be done. [Margin: Crüger urges that the celestial observations themselves be undertaken.] For on this foundation, he used to say, the whole of astronomy rests, and so these are the foremost and most worthy things that can be undertaken and carried through in this sidereal study — especially if we approach the business with an attentive mind, due industry and the most convenient instruments. [Margin: The business of observation is the principal thing in the whole of astronomy.] For this reason he often set Tycho before my eyes, adding that if every student of celestial things were to model himself in every respect on Tycho's most praiseworthy example, astronomy would without any doubt make far happier progress than it has in some past centuries. [Margin: Cultivators of astronomy ought to imitate Tycho in every respect.]

Crüger himself also took wonderful delight in celestial observations (although weakness of sight in making out distant things as he wished, and a lack of instruments, held him back), and so, to spur me on all the more, he called me in on every occasion, above all to watch eclipses, and employed me in that work. [Margin: The author was frequently present at Crüger's observations.] Grown accustomed to these things in this way, in the following years, for as long as it fell to me to remain here at Danzig, I never let any eclipse [Deliquium] or any other phenomenon whatever slip by — unless the sky was entirely against it — without noting it down in the way that was then possible. [Margin: The author never left eclipses unobserved.] From the year, however, in which I was sent abroad to continue my studies, and through all the time I spent in the Netherlands [Bataviâ], England, France and Germany, I was scarcely able to attempt even slight things in mathematics — except that I sometimes observed the eclipses that came my way, when clear weather allowed, and cultivated more and more those studies, the theoretical as well as the practical mechanical ones, in which I was already moderately grounded: namely by learning the arts of architecture, of shading [Sciagraphicam] and of perspective [Scenographicam], and also whatever seemed to bear on the doctrine of optics and catoptrics, or whatever I had judged might some day turn to my profit. [Margin: His celestial studies were partly interrupted by his travels.]

After some years had passed, I returned safely to my native country once more, and saw clearly that anyone who strives to lead an honourable and comfortable life with his family must turn his mind to something other than bare mathematics. [Margin: Astronomy for the most part supports its cultivators very sparingly.] For although, as was shown above, scarcely anything in the world is nobler, more honourable, more pleasant or more useful than the contemplation of the celestial vault, yet — especially in this age — it provides its pupil with the means of sustaining life most sparingly. For this reason, on the advice of friends and especially of my honoured parents (who were eager to keep me, their only son among their other children, here at Danzig), I suspended that Uranian commerce to some extent for a certain interval of time. I devoted myself wholly to applying my mind, here in Danzig, to the affairs — civic affairs, in fact — that seemed advisable to my excellent parents, by which I could lead a life both honourable and sound, and by which my affairs might prosper and by no means decline; so that in this way, God willing, with my household affairs thus partly provided for, I might later also come to the aid of astronomy in some respects, and some day carry out its labours the more readily. [Margin: The civic way of life is very convenient for the sidereal study.] It is better too, I thought, to play the mathematician as a good citizen with some property than as one who is naked and needy and hangs on the nod of others.

Yet while I was doing this, I did not in the meantime entirely abandon the worship owed to Urania, at least as far as my cares, private as well as public, allowed. Rather, as far as I could, I exercised myself diligently in mechanical matters — in sketching and constructing things — and in optical and catoptrical ones, above all in working and polishing lenses and in bringing hyperbolic glasses to completion. [Margin: The author at no time entirely abandoned mathematical matters, although he was greatly taken up with other business.] I did so especially because the distinguished Crüger was spurring me on to that kind of study more and more every day; but I felt myself fired most of all by the address he made to me in the year 1639, in the month of May, a few days before he exchanged life itself for death, in these very words: "Since I am well aware," he said, "that a solar eclipse visible on this horizon of ours is shortly at hand, certainly no concern would be more pressing for me, [Margin: By his address Crüger spurred the author on in no ordinary measure to pursue celestial studies.]

than to be able to observe it properly, for the good of the whole of astronomy, which has the greatest stake in it. But I see very well, and I sense the Divine Will beforehand, that I shall never again perform this very task as I have done until now. Therefore, at my departure from this life, I earnestly urge you again and again, and I ask you, out of that most ready affection with which I have always embraced you and astronomical studies, that from now on you undertake to cultivate astronomical studies — on which, and on the other matters belonging to them, you have spent no small amount of time — somewhat more eagerly still, and with greater care, than you have so far; not doubting in the least that

you will never regret it. For this business, just as it is honourable, so too can it one day turn to the benefit of astronomy and to the honour of your fatherland." [Margin: The study of astronomy is both honourable and a source of honour.]

So he spoke. A few days later, to my great sorrow, this man, an astronomer of profound inquiry, died. He did leave a great many writings, composed with great talent and diligence; but through the carelessness of his own people and the injury of the times the greatest part of them has perished, so that scarcely a very few still survive.

From that time on it can scarcely be told with what love and ardour I pursued astronomical studies — far more eagerly, indeed, than ever before. [Margin: After Crüger's death the author took up celestial matters with greater ardour.] Accordingly, when the eclipse occurred a little later, namely in the year 1639, on June 1, I caught it, drew it and recorded it with the utmost diligence, as far as my abilities then allowed. Then, at about the same time, I began to strive with every effort to be able to bring the divine Urania my services and studies, such as they were, with some fruit. For I knew well that astronomy could not really be helped by setting out mere calculations under a roof — since there has never at any time been a shortage of such men — but that observations of the ethereal bodies must be sought from the sky itself, with suitable instruments, as large as possible, made of solid metal. [Margin: Casters of nativities are never lacking in the world.] "For you know," as Gassendi rightly writes to Caesius (page 51 of the *Letters*), "that observations are the foundations on which astronomy rests; and that although very many men are always arising who can compose or correct tables and ephemerides, yet only in rare ages are men born who themselves observe with diligence. Hence it is no wonder if, after so long a series of centuries has run its course, [Margin: Makers of ephemerides and tables are found quite often, everywhere; but very rarely, scarcely …]

this celestial study could not yet be perfectly restored, since from the whole of antiquity the aids left by observers are exceedingly scarce. One man, Tycho Brahe, most worthy of the memory of every age, devoted himself to this task above all." [Margin: … scarcely anywhere any accomplished surveyor of the stars.]

Accordingly, there was nothing I wished for more at that time — since I judged that I could not employ my effort to better purpose in that matter — than to procure for myself suitable instruments of this kind, with whose help some fruit of usefulness might be brought to astronomy. But when I considered again how immense, arduous and lofty a work I was thinking of undertaking — how much knowledge of things, what talent, what strength this very study requires; how many labours and sweats it calls for to be endured (where sleep must never be allowed near one's eyes); and, most of all, how great an expense this sidereal study demands, to which the means of any private man are almost unequal if this business is to be carried through successfully; and that it needs, above all, the favour and munificence of princes, and also a tranquil life and the most ample leisure — turning all this over in my mind, I lost heart, and

almost all my desire for that enterprise vanished entirely. [Margin: The author, perceiving so very many difficulties in carrying out the celestial business, almost lost heart.] For I knew full well that I was endowed with slender talent and exceedingly little learning; that my bodily strength was not very robust; and that I was a private man, who had chosen the civic way of life, had taken a companion for life, and had a very weighty household business to manage at the greatest cost of time. And so, with very many other affairs, private as well as public, arising one after another, scarcely enough time would be left for me to give myself properly to those studies. [Margin: The author measures himself by his own yardstick.] I say nothing of the fact that no hope whatever then shone on me, nor could I by any reasoning persuade myself that I might ever earn the munificence and favour of some very great Maecenas by any work at all worthy of it.

Nevertheless I held firm in my resolve, and chose this one thing for myself in which to spend my life, trusting in God, Best and Greatest, that He who had most mercifully inspired in me the ardour to attempt these things would also most kindly provide that in His own time neither the strength, nor the means, nor the leisure, nor the other things required for this would [Margin: Although conscious of his own slenderness, the author nevertheless persisted in his purpose, committing everything to God.]

be lacking to me in any way, so that my best intention might meet with the happiest success, to the glory and honour of the Divine Name. [Margin: God most kindly assented to the author's wish and purpose.]

It also fell out auspiciously that this matter turned out better than I had ever hoped. For since I was relieved, as I had wished, above all of domestic occupations, through the singular solicitude and due care of my dearest wife, I was given the opportunity of watching over celestial matters somewhat more freely. Accordingly, straight from the year 1639, I had quadrants and sextants made, more accurate than before: not of plain wood, indeed, but of solid brass [aes], with a radius of three or four feet. In my opinion at that time these instruments seemed amply capable of observations, and indeed in the following years — namely in the fortieth, forty-first, second and third years of the present century — they were often applied to the stars, to eclipses and to other phenomena. [Margin: The year in which the author procured more solid instruments.] Having procured these, and also telescopes of very different lengths, worked and built with my own hand for properly viewing the lunar spots, the solar spots, and the faces of Jupiter and the other planets, I had an observatory built on a higher part of my house — namely in the forty-first year — although I was not a little hindered by a most burdensome public office laid on me at that time. [Margin: The author sets up an astronomical observatory.] Observing from it, a little later, the eclipse of the Moon on October 18 of that same year, I immediately found that the phases of eclipses can scarcely be determined and judged so accurately without any knowledge — or rather delineation — of the lunar spots, even by the most practised observer of all,

however excellent the telescopes and however much effort we apply to it; above all because the magnitude of eclipses rests on conjecture alone, according to each person's judgement or imagination, in which one man excels another. [Margin: On the occasion of the eclipse the author proposes to draw the lunar spots.]

At the time of that same eclipse, therefore, I judged that it would be a labour neither fruitless nor unwelcome if some delineation of all the spots existing on the Moon and appearing in a better telescope — as regards both their position relative to one another and their magnitude, [Margin: The author did not doubt that some representation of the lunar spots would be welcome to posterity.]

varied shape, light, shadow and colour — were undertaken and carried through with every care. Yet I knew that no one up to that time, so far as I was aware, had brought to light such a face of the Moon and of its spots (except Galileo, and he with a rather crude figure attached to his *Sidereus Nuncius*, though of no use). So shortly after the eclipse had ended I burned with the desire to attempt something in this field myself: to see whether, with telescopes [Tubis] made by my own hand, I could produce anything that would be of service, above all to celestial observations. [Margin: At the outset the author had all but abandoned hope of drawing all the spots on the Moon.] I certainly did not lack the desire to attempt it, nor the art of drawing, which is supremely necessary for this matter, nor keenness of sight, for which I give undying thanks to the Most High. Nevertheless, as I began, the labour seemed almost too great, and scarcely ever to be brought to completion, because of the multitude of things and their very great variety. Yet I persevered, and by no means despaired of a happier outcome, since all beginnings are hard but grow lighter as one advances.

So every day, provided it was shining, I took down the Moon with telescope, stylus and brush, with strenuous effort — but only with the intention of sketching a single full moon accurately, and that not to be set out for public use, which at the time had never entered my mind, but solely for my own benefit, so that I might in future obtain observations of eclipses more exactly. [Margin: At first the author had resolved to sketch only a single full moon, and solely for his own benefit.] Having advanced somewhat further in that business, however, I saw very clearly that I would never obtain an absolute full moon, nor any accurate symmetry of all the spots, unless the phases of all the days — that is, of the whole month, or of the Moon's periodic motion — were sketched at the same time, the waxing as well as the waning. [Margin: But as he advanced, he depicted all the phases.] Accordingly, noticing that the business was gradually going more happily, and at last indeed as I wished, I did not fear to undertake this labour. From it, however, I was very nearly deterred, namely when I had read through what Pierre Gassendi had published in the *Life* of Peiresc [Nicolas-Claude Fabri de Peiresc] in that same year, the forty-first: namely, that Gassendi himself, at the instigation of the excellent Peiresc, had already undertaken to have the lunar spots painted by the work

of a certain most outstanding painter and engraver [Margin: The author very nearly came to be called away again from this selenographic work.]

— as can be seen in Book 5, page 229. For this reason, in 1644 January 14, I wrote to the celebrated Gassendi to ask whether he had completed a specimen of his own *Selenography*, or not; and whether it seemed advisable to him that I should carry the *Selenography* I had begun further, right through to the end — some figures of which, for the most part already drawn and in part also engraved in copper, I had also sent him. [Margin: The author writes to Gassendi on this matter.] What he replied in April of that same year is clear from the following:

"Moreover, I also owe you immense thanks for so excellent a figure of the Sun, in which you have painted in several spots and faculae; and I rejoice that you both possess so excellent a telescope and use a method which seems far easier than Scheiner's [Christoph Scheiner], and that you excel not only in sight — so that you might truly be taken for a Lynceus — but also in a hand so elegant that nothing could be drawn more accurately. This certainly makes me not only consent but, as far as I may, even urge that you yourself complete the Selenography that I aimed at; for since I, ignorant of painting, had to use the hands of others, you can, with rare good fortune, use your own, both in painting and — what matters most — in engraving in copper." [Margin: Gassendi urges the author, and spurs him on more and more, to complete the *Selenography*.]

Likewise in another letter, dated the Ides of October [Idibus Octobris] — that is, October 15 — of the same year: *"With wonderful joy, on another account, I kissed the figures of the phases of the luminaries which you sent with it; for I could not help admiring so greatly both the sharpness of your eye in observing and the industry of your hand with the brush and in handling the graver. For since, besides, you have the zeal to carry it through, there are in you alone those gifts which are scarcely ever found in anyone else, and unless they come together, the completion of a most difficult work would be awaited in vain."* [Margin: Gassendi again advises that the selenographic labour should be continued.]

And so, having learned that this most excellent man had altogether abandoned this work, with no further wish to take it up again at any other time; and, moreover, that my phases did not so very much displease him, nor certain other men of great name, but rather that they, besides, vigorously urged me again and again to pursue them — my Urania was exceedingly roused, and the desire to go further still grew in my mind, so much so that I wished for nothing more than that the very things I had meditated and contemplated day and night, acquired with the utmost vigils and the greatest labour, and not without the loss of a good part of my health and my means, should be brought to light as quickly as possible. [Margin: At the persuasion of distinguished men, the author eagerly set about the *Selenography*.] Accordingly,

I wiped the sleep from my eyes, sparing no clear night when the Moon was shining. Those nights I spent wholly in contemplating the face of the Moon more deeply and in sketching it; the days, in turn, in drawing those faces more neatly and more fully with pen and stylus, in refining them, and indeed even in

engraving them with the graver itself — as the *Selenography* itself bears witness. [Margin: The author sketched the lunar phases by night, and engraved them by day.] And so at last I understood how very fortunate it was that in my youth I had deliberately learned to guide and handle the stylus, the brush and the graver at will. Otherwise — had this skill been denied me — believe me, I could never have so much as dreamed of this selenographic labour, laborious and costly enough as it was, let alone undertaken it and published it illustrated with so very many observations and figures of this kind. [Margin: Unexpected things very often turn out to the greatest advantage.] How much work it was for one man alone to carry all this through, and at what expense it was at last brought to the press, those experienced in such matters readily know; so it would be no wonder even if I had spent on that one work a span somewhat longer than a single lustrum [unius luſtri], that is, five years. [Margin: The *Selenography* was born only of the greatest labour.] Meanwhile, however, we pursued the remaining observations — of the planets, eclipses and occultations, and also of the spots on the Sun and on Jupiter — by no means less zealously, and indeed with those instruments built a little before, as we said; the observations themselves will show this at greater length in Books 2, 3 and 4 of this *Celestial Machine*. [Margin: In delineating the lunar spots, the author at the same time took account of the other heavenly bodies.]

And so, that work having been brought to completion — namely in the year forty-seven — and having learned, both from private letters and from published writings, that my labours, such as they are, undertaken for the public good, had by no means been distasteful to learned men, even to the greatest benefactors of the Muses, but had moreover spurred me on to pursue astronomical studies further, I wished to comply as quickly as possible with the wishes of my friends and of all those men. [Margin: The author, seeing that his small labours did not so very much displease the learned, girds himself for observations of the planets.] For I was thoroughly persuaded that I could not spend my life better for the public than if I now also applied myself strenuously to observations of all the planets. But I saw very clearly that I could not, in turn, draw these out successfully unless the fixed stars themselves were observed with untiring zeal, all together and each one individually, [Margin: Without a restoration of the fixed stars, one labours in vain at the motion of the planets.]

and their places were duly restored. Above all, a great many experts in the stars spurred and urged me to this zeal at that time, [Margin: A distinguished astronomer fires the author to restore the fixed stars.] as one may read, in part, in the letter sent to me on 1648 February 28 by the distinguished de Leonibus [Elias von Löwen], husband of the most celebrated Maria Cunitia [Maria Cunitz], the mother of the *Urania Propitia*:

"Do not take it amiss if I go on adding a spur to you, though you are spurred on enough by your own genius, and urge you above all to examine thoroughly the places of the fixed stars themselves. For although Tycho may rightly seem to have spent every effort of human industry on this business, some errors [sphalmata] *nonetheless remain,*

partly gross, partly slight, to be corrected by the industry of those who come after. [Margin: A great deal concerning the fixed stars still remains to be corrected.] *So that you need not take this on my word, I shall produce two of my observations, made on two fixed stars: namely the bright star in the right shoulder, and the star in the right arm of Heniochus, or Auriga. The latter I observed repeatedly in the year 1634, in the months of February, March and April, by various methods, with various instruments and in various positions with respect to the prime motion, in 25° 26′ Gemini, with northern latitude 13° 45′, whereas the Rudolphine Catalogue allowed it only 24° 56′, and Longomontanus and the* Progymnasmata *24° 26′.* [Margin: How far the arm of Auriga departs from the heavens.] *Having obtained this longitude for it, I examined the other star as well, to which the catalogues of Longomontanus and the Rudolphine assigned 26° 20′ Gemini, and I found it at only about 25° 56′ Gemini, with latitude 21° 29′. It will be for you, gentlemen most fully equipped and furnished with an exquisite stock of instruments, who perhaps have more leisure and convenience than I, to consult the heavens on these matters and to judge freely which of us has come closer to the truth — I, or the Catalogue of the Fixed Stars. For the corrected motion of the planets has already often and clearly confirmed that these positions were duly assigned by me to the stars in question. And do not think that these two alone call for correction: there are others too, which I noticed long ago.* [Margin: Very many fixed stars need correction.] *Of these there is no point in writing at present."*

I would indeed have tackled these long ago of my own accord, had I not been more than sufficiently occupied with observations of the Moon and the other planets (to say nothing of the rest) — as I replied at the time to the aforementioned de Leonibus.

But I had thoroughly established that these observations could not be undertaken with any profit using the instruments of three or four feet that I had acquired earlier; larger and more ample ones were needed. [Margin: The very largest instruments are needed for observations of the fixed stars.] Accordingly, since an azimuthal quadrant of solid metal — at the instigation, some time before, of the distinguished Crüger, through the work of a certain most skilled craftsman, out of the singular [Margin: On our largest azimuthal quadrant.]

inclination of our most noble and most ample Senate of Danzig toward the sidereal science and all letters, with no slight funds supplied for that same quadrant — had been begun, indeed, but by no means completed, and was standing idle in a certain place here in Danzig, and that among the instruments of war, with which by rights it should have had nothing to do, I properly requested it for the benefit of astronomy and the honour of my dearest fatherland. I obtained it, too, without any effort, around the year forty-five, from our most noble Senate, by virtue of the love and favour with which it has never failed to attend me and my studies.

Once this was granted, I immediately had all the parts of that most splendid quadrant that had not yet been brought to completion worked up as carefully as possible, and had a rule with pinnules added as well, which it still lacked. Then, for its sake, since I had no suitable place to put it, I built a special

observatory, or tower, standing far higher even than my earlier observatory, at no trifling expense, so that observations might thereafter be carried out all the more conveniently. [Margin: The author built a special tower for the azimuthal quadrant.] But before I could duly set that great and excellent azimuthal quadrant on the meridian line in this observatory, examine it properly in every respect, and be thoroughly certain that it fulfilled its function in every way, I lost a great deal of time and labour. [Margin: It is no trifling matter to fit out instruments properly and to set them up for observations.] For it is no trifling matter to have thoroughly tested the powers of the instruments with which the most important things must be investigated — such as the Sun's meridian altitudes, the equinoxes and the solstices, and from these in turn the tropical year, the eccentricity, the apogee and the whole motion of the Sun, to pass over the rest.

When this outstanding azimuthal quadrant, [?] of brass and ample enough, had at last been duly fitted and brought into use, I immediately noticed that there would also be need of other instruments larger than those I had built before — namely sextants, horizontal quadrants and octants. [Margin: Observations are carried out not with the azimuthal quadrant alone, but with other instruments of various kinds besides.] Therefore, since at that time I could conceive of nothing better, after the pattern of Tycho's instruments, as regards their quality [Margin: The author at first, after the Ty-] as much as their size, I had various instruments made: namely of solid, seasoned wood, overlaid with brass plates and fitted with rules and brass pinnules (six feet in radius, that is, such as Tycho described in his *Mechanica*) — both a hanging quadrant [Quadrans Pensilis] and a sextant, and also an octant larger even than Tycho's by two feet. [Margin: Tychonic manner, built instruments.] These larger instruments too were urgently needed: for it is easily understood what can be achieved with the azimuthal quadrant alone, unless we can at the same time measure the distances of the fixed stars and the planets from one another.

But in making, dividing and testing these instruments, and in working up and procuring everything else that bears on them, several years went by before everything was so arranged in the observatories that they could readily be used for observations, especially of the fixed stars. [Margin: The construction of the instruments took up much of the author's time, and the polishing of hyperbolic lenses no less.] Then, too, a great deal of time passed before it was possible to take up the business itself in earnest — namely in the study of optics, in polishing glasses, in building telescopes, and above all in at last bringing hyperbolic lenses to the hoped-for end. This too, by the favour of divine grace, I happily achieved in the year 1649 — in my own opinion, at least — after I had attempted it in different ways and by various routes, including the Cartesian, but in vain, at no small cost of time; as will be told more fully in its place. Besides this, after the *Selenographia* had already been published, we spent no small stretch of time investigating the libratory motion of the Moon and duly establishing its limits; all of which was first explored in the year 1648.

But what diverted me most of all from my purpose was a very acute illness, with which I struggled most gravely, indeed mortally, for some months in the following year; [Margin: In the year 1649 the author fell gravely ill.] and also no few most troublesome cares. All of these drew me away far too much from the labours and observations I had undertaken, and prevented me from attempting very much in that business in those same years, as I had intended. Meanwhile, nonetheless, we duly noted down, as well as they allowed, whatever phenomena presented themselves during that same time, and deline- ated them, and indeed engraved them in copper, as our observations themselves will show further on.

For these reasons, I say, it happened that I could not arrive at those serious and very important observations — the ones, that is, to be carried out with the larger and more recent instruments which I had conceived in my mind for restoring the motions of the fixed stars as well as of the planets — any sooner than, at last, in the year 1652. [Margin: When the author first had the opportunity to observe with larger bronze instruments.] From that time until now I have never had a greater concern than, first, to observe with deliberate care, with that brass azimuthal quadrant [Quadrans Azimuthalis Orichalcicus], the meridian altitudes of the Sun and of the fixed stars on every clear day and night, and also, as occasion offered, every equinox, and the solstices, winter as well as summer; and then to measure the distances of the stars with the other instruments as well. [Margin: The author observed the Sun's meridian altitudes, the equinoxes and the solstices very frequently.]

I confess that I was strongly spurred on to pursue this business steadily by the comet with the very large head that supervened at that time, in the year 1652 — though without neglecting the observations of this hairy star itself. [Margin: The comet of the year 1652 fired the author's enthusiasm for celestial matters most of all.] What was detected and recorded about its course, and what labours had to be swallowed in investigating its path thoroughly and in explaining every one of its phenomena, the *Cometographia* itself shows. On that occasion it also came about, while the comet was being taken now from this fixed star and now from that, that I became more and more convinced of the erroneous positions of a great many fixed stars, and then learned by experience that what Kepler, the most sagacious of astronomers, had once written to Wilhelm Schickard in a letter of 1618 March 11 is entirely true: [Margin: The appearance of the comet contributed much to correcting the fixed stars.] *"Next, I would have you know this: it is not altogether safe to trust the Tychonic catalogue of the fixed stars, because the places of the fixed stars were computed from the observations by various students, and small errors are found here and there,"* etc. [Margin: Kepler thinks the Tychonic catalogue of the fixed stars must be corrected.] Indeed, errors were beyond doubt sometimes made not only on that account — in the calculation — but in the observations themselves as well, as the same Kepler, in a letter to Michael Mästlin dated 1620, suspects, and not wrongly, when he writes: *"I ask most earnestly — and this for the public good and for the honour of our profession, which consist in this — helping it along, that you look into what you think should*

be done in correcting the motion of the fixed stars. For I think I can extract similar results from some observations of Venus as well, such that the daytime observations of Venus do not agree very well with the nearest Tychonic night-time ones, when Venus's hourly motion is interposed between them."

For that reason the desire grew all the more in my mind to come to the aid of the principal stars with some correction, as far as I could. [Margin: At first the author had resolved to correct only the principal fixed stars.] Yet I had never resolved to observe and examine each and every fixed star; nor could I in any way imagine that I, even had I wished it with all my heart, could ever do all of them, for which some thousands of observations would have had to be made. For I considered that the great Tycho, though supported by the work of ten and sometimes even twelve assistants, had barely managed in the space of twenty years to bring that immense work to its end, even with so magnificent an apparatus of instruments and at such enormous expense; whereas I, utterly lacking at the outset, above all, such means and the most necessary requisites, could neither promise myself a life as long as that, let alone in any way endure so many sleepless nights to be spent — supported, moreover, by the help of no more than one or two men. [Margin: The author never imagined that he could in any way examine each and every fixed star.] Hence, as I imagined, the earth would sooner climb up into the aether than I would ever be able to scrutinize so numerous a cohort of fixed stars in every respect. Yet a divine light shone forth, so that this immense work — which after Hipparchus no one but Tycho undertook, with great daring, and at the same time also brought to completion — has, in the course of time, turned out more happily for us, beyond all my hope. [Margin: Yet the business succeeded better than hoped.]

When, therefore, I had attacked this business with all my strength, and that very notable comet shone out, I wanted to devote a little effort to it as well, since at that time I lacked nothing that seemed to bear on the matter. And from then on it came about, at the urging of friends, that I kept watch over this unusual phenomenon more than I would ever have persuaded myself I would, and even wrote the *Cometographia* itself. [Margin: The author put much effort into his cometographic labours.] Yet that most troublesome labour I would surely never have undertaken, nor a great many other things, had this comet not blazed forth. However, just as for a good many observers of the stars so it befell me too, a cultivator of the stars such as I am, that I was more and more fired by that new star which had recently risen to carry my astronomical studies further, according to the small measure granted by God, with still greater effort than before. [Margin: Comets for the most part rouse astronomical minds to attempt something more.] For that reason I deliberately went looking for a man who was both diligent and of strong eyesight, who would carry out observations with me assiduously with the sextants and octants, and give me vigorous help in all those things for which I alone would not suffice. For, as the experts are well aware, no one can manage the business alone with sextants and octants, as can indeed be done with quadrants: with these I always take altitudes

alone, and at every time also record them. [Margin: More than one person is required for the observations.] For I acknowledge that I have always laboured under this disposition — whether good or bad it will be yours to judge, kind reader — that I do not readily put my trust in anyone else, whoever he may ever be, in observing the stars, when I can accomplish the business myself with my own eyes and hands, as much in directing the instruments and counting the degrees and their minutes as in recording each single observation. [Margin: In his own observations the author hardly puts his trust in another.]

Around the year 1653, however, I was again interrupted to the utmost by various cares, and also by the cometographic labours I had undertaken, which grew from day to day: by the most tedious calculation, which I alone had to carry out, and by the very many figures [iconismi] that had to be drawn and engraved. Above all, the *Almagest* of the Reverend Father Riccioli [Giovanni Battista Riccioli] supervened, into which its author had inserted some things that seemed in part to concern the *Selenography*, and also because he had cast away almost all hope of properly finding and penetrating the genuine libratory motion of the Moon. Moved by these things, in the year 1654, having then received his *Almagest* for the first time, I wrote a rather long letter to Father Riccioli on the said libratory motion of the Moon and published it in print. In it was shown that the very thing he had almost despaired of had now, with the assent of the Divine Majesty, been attained with happy success and reduced to fixed laws. Then also, for the sake of relaxing my mind, I published various other small works: namely, a letter on the eclipse of both luminaries, to the most illustrious Nucerius [Pierre des Noyers]. [Margin: The author published letters to Riccioli on the libratory motion of the Moon, and to Nucerius on the eclipses of the luminaries.] Likewise, in the year 1656, a dissertation on the true appearance of Saturn, at the prompting of the Most Serene Gaston, Duke of Orléans. [Margin: A dissertation on Saturn, to the Most Serene Duke of Orléans.] Nevertheless, notwithstanding all those hindrances, we pressed on eagerly with that business of observation.

These observations were therefore continued over an interval of some years, and it was thoroughly established that our azimuthal quadrant did indeed perform its function with the greatest constancy; but that the remaining instruments — namely the smaller brass ones of three or four feet, and also some made of wood after Tycho's pattern and merely overlaid with brass plates — deviated somewhat from the right path in the course of time, so that we could by no means rely on them safely. The smaller ones did so, even though they were made of pure metal, for this reason: that they are not of the proper size for showing the parts of seconds accurately, and also because their sights [dioptrae] stand at a smaller distance from each other. The larger Tychonic instruments did so because, although they display the most exact divisions, fine enough to determine roughly the twelfth part of each minute, with time and after some years had passed they showed the same distances between the stars now one way, now another, in the minutes themselves — not to say in the seconds —

from what they had shown at first. And so I had found by sure signs that such instruments are, through long use, extremely subject to change, as will be explained at greater length in its proper place. [Margin: The author at last discovered that the Tychonic instruments are subject to change in the course of time.]

So I then learned from the fact itself that what Tycho himself once admitted in Book II of the *Progymnasmata*, p. 256, is perfectly true: namely, that *instruments* (made of wood, that is) *degenerate through use and age from their first perfection*. Likewise, *instruments* [Organa], he says, *unless they are skilfully worked from solid metal, are subject to change; and even granting that they are made of metallic material, unless they are huge they do not show the finest divisions of the degrees sufficiently. When they do achieve this, they so weigh themselves down by their size and weight that they easily deviate from the proper plane, or from the proper figure, while they are turned about, and also become unmanageable through their bulk. Therefore a greater art, joined with equal judgement, is required in constructing astronomical instruments free of every defect than has so far been noticed by very many people — which practice itself, and long experience acquired with no little labour and at no moderate expense, have taught us.* [Margin: Tycho himself admits that very little is to be attributed to wooden instruments.] [Margin: It is a hard thing to construct suitable instruments.] Besides this, the said author adds on p. 358 of the same

Book II of the *Progymnasmata*: *How much subtlety and diligence are required in carrying out celestial observations mechanically, no one knows for certain except one who has made the knowledge of these things familiar to himself through the experience of many years and through various instruments, with no little labour or expense.* [Margin: Carrying out celestial observations is a most subtle business.]

And so I had likewise ascertained abundantly, and had also learned by experience, that it is altogether necessary, if anyone is anxious to serve celestial observations, astronomy and posterity with some profit, that he should have instruments not only of the greatest size, divided most accurately into parts of seconds, but also made of solid metal — and indeed instruments of such a kind as could be turned and directed at will to all quarters of the sky and to every inclination of distances, and yet would not by their weight be the least hindrance to the observations. [Margin: The stars require instruments that are very large, at the same time of solid metal, and also revolvable at will.] But since this very thing had seemed difficult even to Tycho himself, the prince of astronomers, by far the most practised in this arena, how could it not be far easier for me to conceive than to devise and bring to completion — and that for a man who led hardly more than a private life, who had his means to spend on other things, and who enjoyed no one's help nor the liberality of any prince? [Margin: But it takes art to build such things.] Nevertheless I persevered in my purpose, always heartened above all by this consolation: GOD will provide.

And so I pondered day and night how I could build quadrants, sextants and octants — not merely very large ones, of six, seven, eight and nine feet, made of pure, unalloyed metal with all wood entirely excluded, but ones which,

just as they would be divided most finely into the smallest parts, would also turn very readily and be extremely light to direct in any direction, though otherwise very heavy. [Margin: The author left no stone unturned to obtain for himself very large and very well-fitted bronze instruments.] With God's help, and the work of a very skilled instrument-maker [Automathurgus], I actually undertook this task in the year 1655. But since it cost a great deal of labour to make such vast and heavy instruments out of solid metal, a year or two went by before they were completely finished; indeed, the chief craftsman himself died before he had put the last hand to them. [Margin: Years went by before they were obtained.] So I took into my house, to be maintained there, another instrument-maker [Automapoeus], who would bring the instruments to the long-desired perfection, and would build other necessary things besides.

But once these instruments had been obtained as I wished, a convenient observatory, and a place open on every side for carrying out observations, was again lacking. For neither the tower built for the azimuthal quadrant nor that earlier observatory was roomy enough; much less did the earlier observatory allow a view on every side sufficient for observations to be made conveniently, as observations absolutely required. [Margin: The author fits out a larger and higher observatory for housing the remaining instruments.] I therefore had to spend fresh money once again, to build another astronomical observatory, much better suited, higher and larger, on the roof of the rest of my house, entirely free of every obstruction, under the open sky. Into it I at last moved those very large and solid instruments, arranged in such a way that none was a hindrance to another, even though they were used together for observations.

So, having abandoned the Tychonic instruments — those earlier ones, that is, made of wood — I have used these instruments made of bronze constantly at all times, since they excelled all the rest enormously in every respect; in which respects, however, will be learned later. [Margin: The author rejected Tycho's wooden instruments altogether.] My assistant at that time was a most excellent young man of very sharp and subtle mind, Master Michael Kretzmerus of Danzig, whom I had summoned from Rostock for that purpose, and who was never anything but glad to spend even whole nights without sleep with me. [Margin: Kretzmerus, an excellent cultivator of astronomy, was the author's assistant in the business of observation.] He certainly deserved to live as long a life as possible; but GOD saw otherwise, for death, after he had devoted scarcely three years to observations with me, snatched him away, to my great grief. Forced, therefore, I went in search of another companion; in the meantime, however, I took no holiday from these studies, but used the help of others who were then my assistants, until I had found another. Students of this kind, it is true, who labour to undertake something solid in this field, are not met with everywhere, but are rare birds, since astronomy is costly and usually brings little profit to those who cultivate it. [Margin: Students of mathematics are very few.] For this reason too I could not so readily come upon another man of that kind;

so that it became absolutely necessary to use the services of my instrument-maker — whom, as I said a moment ago, I was then keeping in my house to build various other instruments and clocks — so that he might serve me every night as an assistant in taking distances. [Margin: In taking distances the author quite often used his instrument-maker as well.] In this business he became so practised that he would not readily yield to anyone, even the most learned. But he too did not live long: in the very next year after the death of my former companion, he likewise exchanged life for death in my house. [Margin: When the instrument-maker died, another companion was indeed put in his place for the observations, but he too was carried off by sudden death.] I therefore took on another from Frankfurt, namely Master Christianus Pelargus, a young man warmly recommended to me for his learning and the uprightness of his life; but he too had scarcely entered my house, and before he had completed even a single observation with me, he was seized by a most acute illness and died a few days later.

As a result my circles were thrown into extraordinary disorder, in that I could enjoy the help of no co-observer for any great length of time. For such changes, when one person after another is so often put in the place of the last, are extremely unfavourable to the principal director of the observations — indeed tiresome and harmful: one is forever, that is, losing one's means and one's leisure on new recruits. [Margin: To change the assistants in observation often is as troublesome to the director as it is damaging to the observations themselves.] For much time slips away before any assistant can be properly trained, with sufficient practice, to be fully equal to observations of every kind. Nevertheless I by no means lost heart, nor was I overcome by weariness and disgust because these matters turned out otherwise than I wished. Instead, in the meantime I called in other members of my household, and my wife herself as well, for the observations, and with them I carried out the work just as accurately as with those others — until Master Andreas Marquardus came to me from Wittenberg, a young man otherwise learned and well versed in mathematics, who served me as assistant in the observations for more than two years. [Margin: Marquardus, a young man well versed in mathematics, was the author's assistant in the observations for several years.] But since the circumstances of us both no longer allowed it, he went elsewhere. In his place I had afterwards chosen another, a Master of Philosophy at Leipzig; but obstacles intervened that prevented him from reaching Danzig.

Since, therefore, it was extremely tiresome for me to be looking so often for one companion in observation after another, I judged it would be better if I procured for myself assistants who would persevere, men who would serve me as helpers permanently: matters would then without doubt go forward much more readily, with less waste of time and, conversely, with greater certainty. [Margin: It was most tiresome to the author to substitute co-observers so often, one after another.] And so I called in to this business those whom I kept permanently in my house — among others, namely, my printer, a Dutchman,

together with the dearest partner of my marriage bed, who was well suited to this pursuit by natural inclination. Within a short space of time both she and he were carrying out all the observations with me as finely as any of the earlier assistants ever had; so that up to now, for ten years and more, I have been using their help in observing the stars, and with satisfaction enough. Nor shall I ever look for other co-observers, so long as I am permitted to enjoy these — which I wish with all my heart. [Margin: At last, with happy success, the author called in his wife and his printer for the observations.]

But let us come to our observations themselves, and to the instruments made for that purpose. At first, when I was using a Tychonic sextant and octant on the heavens, Brahe's observations always served me as a rule, or level, against which I tested and corrected both our instruments and our observations — as has always been the practice of very many others, even of Tycho's own household. [Margin: At first the author conformed himself to the standard of the Tychonic observations.] That is, whenever they were about to take certain intervals between stars, they first tested the instrument itself on some definite distance between stars, to see whether it showed exactly the same distance that Tycho had found. If it did not, they adjusted the instrument to that value, by changing and resetting either the divisions or the sights, until exactly the same distance came out as had once come out for Tycho. [Margin: How the Tychonians and others tested observations and instruments.] I too used to do this, believing this method preferable to all others — although experience afterwards showed that the matter stands far [?] otherwise.

So I first tested both the sextant and the octant — those wooden ones — against the distance between the bright star of Aries and Palilicium [Aldebaran]. But I found that my instruments, whatever companion I made the trial with, revealed an altogether different distance, and never agreed with the Tychonic instruments down to the seconds themselves, however much care I applied. [Margin: At first the author's instruments did not wholly agree with Tycho's.] Since

Tycho observed this very same interval as 35° 32′ 10″, whereas I, with my instruments, always found it to be 35° 32′ 45″, that is, greater by 35″; and I found other distances besides that differed by a whole minute, indeed sometimes by two whole minutes — and with a variation that was by no means constant. For my observations erred now in excess, now in defect, relative to the Tychonic ones. [Margin: In some they disagreed by as much as two whole minutes.] Seeing this, I constrained my instruments by force — even though I had found no fault in them in any respect — to show the same distance between the bright star of Aries and Palilicium, being wholly persuaded, after the example of others, that Tycho's eyes were to be trusted more than my own. But my expectation deceived me thoroughly, as you will shortly learn. [Margin: The author tried to bring his own instruments entirely into line with the Tychonic ones, but without success.]

For after I had kept watch over the observations for a year and more with those Tychonic instruments of mine, corrected as I thought, a doubt crept into my mind: had it been rightly done at all, that I had compelled my instruments, without any evident fault in them, to show the distances against their own will, according to Tycho's standard? [Margin: At last a doubt was raised in the author's mind, because he had compelled his instruments by a kind of force, at another's pleasure, without any evident necessity.] This was all the more so since I saw that even my more recent and very large instruments, built of solid metal with the greatest care, gave the same distance as greater by 35″ than the Tychonic ones did — namely the one already mentioned, between the bright star of Aries and Palilicium — once again exactly 35° 32′ 45″, just as my wooden ones had shown at the beginning. This, indeed, greatly confused my mind and made almost everything uncertain: I noticed, while wholly ignorant of the cause, that my instruments, even those new ones made of bronze, departed altogether from the Tychonic ones.

In this doubtful matter, however — whether I should rely on my own instruments or on the Tychonic ones — I could see no other way of extricating myself from this labyrinth than to trust none of them and bind myself to no observations, but to bring my own instruments once more to the exact rule, setting aside every preconceived opinion: that is, first to examine thoroughly the divisions, the rulers, the sights and the whole construction, to see whether even some small fault lay hidden in them. [Margin: The author decided to examine his instruments afresh.] If I found nothing whatever, I would rely entirely on my own instruments, and those things that would result, I would hold as entirely true, notwithstanding that others might think otherwise.

To make myself all the more secure about my results, I did not shrink from undertaking a very heavy labour, one scarcely to be completed in a whole year. I followed the example of the great Tycho, who wished each and every thing that he had to carry out to be as accurate as possible, as he himself writes on p. 73 of his *Epistolae Astronomicae*: *For I want the things that proceed from me to be either nothing, or by far the most exact.* [Margin: Rather nothing than to accomplish doubtful things.] For it is better to leave these things untouched than to handle them carelessly and with too crude a skill. This has always been my purpose too: to undertake things either accurately or not at all, and above all in these very observations.

For that reason I chose the safest way, the same as Tycho's. That is, I resolved first to observe with the utmost care all those distances — and indeed the very same distances — of the stars lying near the ecliptic and the equator, around the whole course of the circle; and then to investigate from them the ascensional differences [differentiae ascensionales], in the same way as the excellent Tycho had undertaken on p. 200 of Book 1 of the *Progymnasmata*. [Margin: By what route the author set up a most rigorous examination.] If these differences, taken together, showed exactly an entire circle, or 360°, it would be a sure sign both that my instruments were most correct and that I too had observed everything

properly. But if otherwise — that is, if the ascensional differences gave a circle somewhat larger or somewhat smaller — there would be no doubt that no faith at all was to be placed in mine, but on the contrary that Tycho's footsteps were to be followed in everything. [Margin: By the ascensional differences instruments are tested and corrected best of all.]

But, you will perhaps say, if you are well versed in this science, with what hope have you deluded yourself? Or what have you imagined? Do you think you can achieve more correct results than Tycho himself? Your distances, and your declinations as well, depart from Tycho's not only in the seconds of arc but sometimes by as much as two whole minutes (as you yourself freely confess). How then can it ever happen that the ascensional differences produce an entire circle, when Tycho's distances and declinations, which differ from yours in very many cases, make up an entirely complete circle, except for only a very few seconds? [Margin: Where things differ in the givens, it is consonant with reason that they should disagree in the product as well.] And so you are measuring sand, and you will never draw an entire circle out of yours; and consequently your instruments too, of necessity, suffer from some fault.

So it is, I gladly confess. At the beginning I was thoroughly anxious, holding the wolf by the ears, as it were — above all because I saw clearly the difference between our distances and declinations. [Margin: At first a fault seemed to lie hidden in the author's instruments and observations.] Yet I could not give up this more rigorous examination, even though I saw that I had already been brought, as it were, to a standstill; I was forced to try the last resort, and the die was already cast. Led by I know not what hope, I committed everything to the examination, resolved to accept the outcome willingly however it might fall out; and if I saw that my results needed some correction, I would not on that account pursue the task any less earnestly.

Still, a great hope held me of a better outcome to the matter. For I knew that my instruments — let it not be taken as boasting — were of the proper size, made with great dexterity, finely divided by my own hands, and with their pinnules duly fixed to them. [Margin: The author nevertheless hoped for better things.] I knew too that all the observations had been made with my very experienced companion Kretzmerus, without any preconceived opinion, and had been properly checked not once but many times, and indeed by very different assistants.

So I submitted my distances and declinations to calculation — bare, just as they were, in no way painted or dressed up, as sometimes happens, but exactly as they had been observed many times and entered in my journal, as befits every honest man. For everything must be done candidly, and such painted-up results are to be utterly shunned. When the calculation was done, the matter certainly turned out far better than anyone had ever supposed: the ascensional differences found made up an entirely complete circle, so that not even a slight difference of some seconds was detected. [Margin: When the examination was done, everything was found to be in order.]

And so, just as at the beginning I had been thoroughly perturbed in mind, so now I felt fresh courage given to me in turn, once I was made more certain about the construction of our instruments, their division [?], and also the care taken in carrying out the observations. For if there had been even the least error in a single distance, there is no way that 360° would have come out without any seconds attached. This is the most perfect standard of all for examining instruments — whether they need no correction or some — as those more skilled in astronomy know very well.

But you may ask besides, kind reader, how it could ever have happened that the same results sought were drawn from different givens — namely yours and Tycho's — which is surely contrary to arithmetic and geometry, and indeed to reason itself? I gladly grant that this is entirely so. Nevertheless I affirm that my distances and declinations are, and have been, wholly the same as when they were observed at that time — and anyone can still test them in the sky with suitable and very perfect instruments — and also that I produced an entirely complete circle from the ascensional differences, as will be explained at length in its place, perhaps in our *Prodromus Astronomiae*. [Margin: A remarkable thing! From different distances and declinations both Tycho and the author alike drew out an entire circle.] But how it came about that an entire circle also came out, to within 22″, from Tycho's differing distances and declinations would take too long to show here. I therefore gladly put it off to the next occasion, where it will be demonstrated to the eye, God granting, that all these things really are so. [Margin: How that came about will be shown elsewhere.]

I would not, however, have you seize on this as though it were said to the prejudice of the Tychonic observations — far from it! I have always held Tycho's observations in as great esteem as anyone ever has, and I want nothing whatever taken away from them. Whatever has been reported here has been said and undertaken only for the sake of truth and of advancing celestial studies. For in this business too the saying must always stick in everyone's mind: Plato is a friend, Aristotle is a friend, but truth is a greater friend. God willing, I shall appeal to the very vault of heaven; to the observations of the Most Illustrious Prince of Hesse, made with the celebrated Rothmann and Justus Byrgius; and to the keenest examinations of others who are equipped with very large, bronze and most accurate instruments. To their judgement I commit each and every one of our observations, not doubting that time will teach which of them are to be relied on in future. [Margin: For the good of truth (with Tycho's reputation preserved) the author appeals to the very vault of heaven and to the fairest judges of these matters.]

In this way, therefore, I examined our instruments rigorously and with all diligence, and became certain that nothing was lacking in them, but that they were to be trusted entirely. [Margin: The author, at last made more certain that nothing at all was lacking in his observations and instruments.] And so neither to the instruments nor to the observations of others did I wish to conform myself in this respect at all; rather, whatever our own instruments showed,

used with due diligence, I recorded faithfully. And so, with divine help, I set about that great undertaking — the observations, namely, of the planets as much as of the fixed stars — with an eager mind, especially since I was so often pressed by my friends. [Margin: With the most trustworthy instruments the author undertakes the business of observation.] And so that I might be the more secure about the labours I had carried out earlier with those wooden Tychonic instruments, concerning the very many distances already obtained, I by no means found it irksome to bring each and every one of those earlier intervals back to the anvil once more with our new instruments made of solid metal, which by a particular method and arrangement show five seconds — testing, that is, whether the older instruments too had contracted some flaw. This, however, was not the labour of a single year, as can be seen from our observations themselves.

In the year 1657, then, we first began in earnest to search out the places of the fixed stars with those larger bronze instruments, namely the sextants and octants. [Margin: When the observations of the fixed stars were begun in earnest with the larger instruments.] From this labour I have never since allowed myself to be torn away, although various most grievous misfortunes intervened which could easily have held it up, had I not been happily rescued from all of them by divine aid. So I was able not only to continue the labours I had undertaken, but also to publish my Mercury in the year 1662 — and that from our own press, which I had then for the first time had brought from the Low Countries at no small expense, so that from then on I could bring to light the works I had in hand more promptly and more accurately, being present myself and correcting everything. [Margin: The author's Mercury was the first work printed with his own type.] But so that I should not be disturbed in this business by anyone, as certain people were already daring to do, and so that I should be free to keep printers in my house at any time, the Most Serene Casimir, King of Poland, most graciously provided for me with an excellent and most honourable privilege, out of His most favourable disposition towards me and my Uranian studies — a disposition I also experienced quite often when he was staying here in Danzig. [Margin: King Casimir granted the author's press an excellent privilege.] For not only to submit my astronomical equipment, such as it is, to his own eyes several times, but even, deep into the night, to contemplate the stars with telescopes from my observatory, and most kindly to encourage me to apply myself vigorously to them from then on — this he did not disdain. [Margin: By the clearest signs the author came to know King Casimir's favour towards Uranian studies.] From this, indeed, my desire to pursue what I had undertaken grew; especially since at about the same time the incomparable favour and munificence of the Most Christian King, flowing from his innate and supreme clemency towards the sidereal science and those who cultivate it, was most graciously revealed to me, though by no merit of mine, through the clearest and most highly honourable testimonies. Above all I perceived that His Sacred Royal Majesty nodded with a kindly countenance

on our astronomical endeavours and judged them worthy of His indulgence. [Margin: The Most Christian King ordered his royal clemency to be shown to the author.] And as my being most graciously adopted into a company of men most celebrated for their fame and learning happened not only beyond my hope and expectation, so I was fired more and more, and thereafter pressed on more boldly with what I had until then undertaken with moderate labour and industry, and also at some expense — roused above all by that royal judgement of my slender abilities. [Margin: By the Most Christian King's judgement the author was greatly inflamed to pursue his celestial studies.]

There was added to this the Royal Society, sanctioned and established about this time through the singular inclination of the Most Serene King of Great Britain to promote the sciences and arts: that most illustrious Society testified at length, in most courteous letters, its most abundant goodwill towards me, so that I should eagerly continue the astronomical studies I had once undertaken; and at the same time it kindly disclosed to me on which part I should chiefly labour. [Margin: The illustrious British Society encourages the author at length to the same purpose with most courteous letters.] This can be understood from the letter written to me in its name and by its order by the Secretary of the most illustrious Royal Society, Oldenburg [Henry Oldenburg], in the year 1664, on May 11. "Moreover," he writes, "they rejoice to see that you stand unmoved in the sincere worship of Urania, and hold nothing more important than, by constant vigilance over observations of the fixed stars, to free their catalogue from the errors with which it teems, and so to equip your Celestial Machine, which you are constructing, for the increase of learning. [Margin: Letter of the Royal Society to the author.] They acknowledge with you that unless this care for the restoration of the fixed stars is seriously undertaken, it will be in vain to observe the planets and to seek to reduce their motion to its proper rule, or even to work out anything worthwhile in any part of astronomy. Since, then, the hinge of the matter turns on this business, what remains, most celebrated Sir, but [Margin: Oldenburg exhorts the author to press on vigorously in the restoration of the fixed stars, as …]

that you and those like you devote yourselves wholly to this, so that, leaving no aid unsought, they may accomplish this distinguished and most useful work with unwearied zeal. You show yourself here a leader most worthy of praise, since, amid the press of business that falls to you both as consul and as judge, you not only make leisure for yourself to devote to this contemplation of the heavens, but also summon from every quarter whatever aids you can." [Margin: … as being in the principal part of astronomy.]

From this so singular and lengthy address of the most illustrious Royal Society, the ardour to attempt at least something, however scanty my equipment might be, and to bring it to light, grew once more in my breast beyond all measure, so that I might hasten as quickly as my strength allowed to complete those observations, undertaken with God's good help. [Margin: By this address the

author was moved more and more to advance further in the observations he had undertaken.]

But it is a work of immense labour to measure correctly with instruments all the fixed stars — those known until now as much as those remaining neglected up to this time — as many as come into view above our horizon, and to compile a new catalogue of the fixed stars, and also never to leave any of the planets unobserved. So this could be done only with time and the labour of many years, with effort assiduously applied, even though I did not readily let a single clear night slip by on purpose. [Margin: To observe the stars assiduously and to compile a new catalogue of the fixed stars is a very arduous thing.] And so it was drawn out over a number of years — especially since the Cometographia also took a great deal of time from me. Yet it did not seem advisable to abandon it altogether after so many calculations and labours already endured; indeed, I thought it would be a disgrace to me to throw away entirely what had been begun with so great an effort, reflecting that it is no less a virtue to carry praiseworthy things through to their end with the most constant spirit than to begin them. [Margin: The end crowns the work.]

To this cometographic work I was strongly drawn not only by that remarkable comet which arose in the year 1661, in the month of February, but above all by those most splendid and very rare comets that followed in the years 1664 and 1665. For I saw that heaven itself, as it were, by kindling so many most brilliant temporary lights in the aether, was admonishing and compelling me to contemplate these divine miracles and these wonderful bodies and phenomena of the heavens more and more, to the glory of the Creator, to explore them, and to set them forth in the light. [Margin: Several comets as it were compelled the author to complete the Cometographia.] It happened, then, just as I had wished, that those three outstanding comets, while the Cometographia was still in hand, appeared. To that work they certainly contributed no small measure of elucidation and of material for discussion; indeed, they supplied examples observed by me myself, which were illustrated and adorned with a great many engraved figures [Iconiſmis].

How much trouble the comets already mentioned gave me before I had obtained all those observations, examined them by calculation, engraved them in copper and written them up, let others judge. [Margin: The comets gave the author a great deal of trouble.] A great deal of labour also went into the *Prodromus Cometicus*, published in 1665 at the urging of friends, and likewise into the *Mantissa Prodromi*, with the description of the later comet. I would certainly have refrained from composing that in 1666, especially at a time when the gravest afflictions had befallen me, had it not been wrung from me by certain people. [Margin: The author first published the *Prodromus Cometicus*, and also the *Mantissa Prodromi*.] So a great deal of time slipped away in dispatching not only these matters but others as well — my learned correspondence, to say nothing of the rest — before all this could be overcome and the *Cometographia* itself could appear.

When at last, by God's kindness, those most troublesome and most burdensome cometographic labours had been carried through, in 1668, I cared for nothing more than to be able, with divine help, to bring my *Machina coelestis* happily before the public as quickly as possible. [Margin: What the author undertook and accomplished once the *Cometographia* was published.] For that reason I left no stone unturned to bring out and record, as quickly as possible, all the remaining observations bearing on the catalogue of the fixed stars — without in the least neglecting, meanwhile, the other observations, namely those of eclipses, of occultations and of all the planets, for correcting the tables of the motions, so that in due course the astronomical tables themselves, which waver not a little in many places, might be restored all the more readily. With the assent of divine grace I have so far gathered a great heap of these observations, written up in five volumes; and I hope, if God prolongs my life, to continue these labours right to the end of my life. [Margin: The author's observations are contained in five manuscript volumes.] For I do not in the least doubt that they will not be useless to posterity — indeed, that perhaps they may one day turn to my own advantage. For I have resolved, if it so please God, once both the catalogue of the fixed stars and the *Prodromus Astronomiae* — the latter already for the most part finished — have been worked out and published, to attempt something also towards the investigation and restoration of the tables, so far as it lies within my power. [Margin: Once the catalogue of the fixed stars has been worked out, the author has resolved to publish the *Prodromus Astronomiae*.] The will to attempt it is certainly not lacking, provided that the Founder of the universal machine — to the glory of whose name and the celebration of whose wonderful works I have undertaken these things — most mercifully grants me life and strength of mind and body, so that I may complete all of it as the learned world expects, as my friends desire, and as I myself wish.

I have indeed begun this very large work, and solid foundations have already been laid — glory be to God — on which our whole *Machina coelestis* is to be built. Indeed, the matters that are nearly the most difficult of all, and that are also necessarily required for the restoration of the tables, have now, by God's kindness, been explored: namely, a precise knowledge of the elevation of the pole at Danzig, of the obliquity of the ecliptic, of the solar apogee, of the eccentricity, of the parallax and of the refraction; likewise of the greatest equation of the Sun and of the magnitude of the true tropical year — not only from our own observations but also from those of Hipparchus, Ptolemy, al-Battānī, Walther [Bernhard Walther], the Landgrave[2], Tycho, and also certain other more recent observers. As a result I have not only duly derived the solar epochs but have also now constructed new solar tables. [Margin: Firmer foundations have now been laid for constructing new tables.] Believe me, I have spent a very great deal of time on them in recent years, with the

[2]identified as William IV, Landgrave of Hesse-Kassel; the page prints only Landgravii

greatest labour — indeed greater than you perhaps imagine — before all of it had been investigated in the way I wanted. Yet I do not regret this work, since the undertaking, praise be to the Most High, has succeeded to the point that I consider it — unless my own things please me too much — not to have been in vain. [Margin: The matters pertaining to astronomy that are nearly the weightiest of all have now been overcome, though with the greatest labour.] How far these solar tables of ours differ from the tables of the other authors, in what respects they disagree or agree, or how they answer to the observations of the older as much as of the more recent observers, is not for this place to set out at length here; these matters will have to be deferred to our *Prodromus Astronomiae*, which, if God favours our purpose, I shall shortly set before your eyes, kind reader, and before your most acute judgement. Would that I were granted both leisure and the help of some companion for the calculations (since this is not the labour of one man), so that I might pass on to the other planets as well, as I burn with desire to do. [Margin: If it so pleases God and help is not lacking, the author has resolved to come to the aid of the other planets too, as far as his modest means allow.] But, as you know very well, no one will ever duly restore the remaining six planets — however much he may strain every sinew of his intellect towards that study (if I may be pardoned the expression) — unless the fixed stars are first corrected and restored. The most noble Tycho earnestly insists on this in many places, especially in Book I, chapter II, page 137 of *De nova stella*: "After the precise investigation of the course of the Sun," he says, "the next and principal place in restoring and establishing astronomy is deserved by the fixed stars. For just as without this neither they nor the wandering stars either can be brought into their due order and harmony, so too, without exact knowledge of the fixed stars, it is not granted to measure the places of the planets accurately. For these are certain visible and bright bodies of the heaven, set out here and there, by which, as by fixed turning-posts, the various passages of the wandering stars through the whole zodiac, in longitude as much as in latitude, are conveniently discerned. So much so that anyone who, without first restoring the places of the fixed stars, tries to prescribe some rule for the course of the planets and to imitate that course with numbers, accomplishes nothing, whatever he does." [Margin: Without the restoration of the fixed stars, anything attempted in the business of the planets is attempted in vain.]

Since all the interpreters of celestial things are by no means unaware of this, they have long since earnestly wished that this work be taken in hand. They have quite often pressed me not only to hasten it on as quickly as possible, but also, without further delay, to make public the observations themselves, which they knew I had already carried out, with God's help, in some number over the space of so many years. [Margin: A great many learned men urge the author to complete at last the business of the fixed stars.] So, among others, the illustrious and most learned Cassinus [Giovanni Domenico Cassini] declared in a letter sent to me on 1669 July 23: "You have certainly roused in us a great desire

for your *Machina coelestis* and for all your observations, which you lead us to hope for; and I ask you again and again to satisfy it as soon as it can be done. For we do not doubt that, given their very great precision and reliability, they are as well suited as anything could be for establishing the hypotheses of the motions of the planets more accurately." [Margin: Cassini likewise admonished the author on this matter.] Likewise the most celebrated Bullialdus [Ismaël Boulliau], in 1670, on August 26: "I long for your *Machina coelestis* so eagerly that never to stop urging you to complete a work of such importance [Margin: As did Boulliau too, with earnest persuasion;]

I could. You give legitimate reasons, to be sure, for the delay in publication; but I want you to be persuaded that, of all your works, which deserve every praise and applause, this one is the most important." Just so, in almost all the letters he wrote to me, he earnestly urged me — above all when he called to mind the changeability of human affairs: that our life is short, and that after our death everything that had been gathered with such care from the very aether, through so many night watches, sweats and chills, over the space of so many years, might easily perish or fall into the hands of others, from whom it could afterwards be wrested back only with very great difficulty — that I should therefore spend every effort, setting all my other studies aside, to bring all of it to the end so much desired, and at the same time to bring it out in public as quickly as possible.

Since, then, very many learned men had urged me so earnestly, time and again, to complete the *Machina coelestis* and to publish our observations, and since the greatest princes too had roused me to the same purpose by their incomparable grace and clemency, I certainly had no more pressing concern — my other labours having been partly dispatched — than now at last to press on in earnest with this work of mine. I meant to set before the learned world all our observations — of eclipses, of occultations, of the planets and of the fixed stars, both of all those that stand on the globe and of more than five hundred other fixed stars not yet entered on the globe — observations made from the year 1630 up to now and obtained, by the favour of divine grace, as I had wished; and at once to publish a new catalogue of the fixed stars, and a globe as well. [Margin: The author had at last no more pressing concern than to oblige the learned world.]

But since it is a very extensive work, contained in several volumes of manuscript, it requires no small interval of time before all these observations can be set in type. It therefore seemed advisable, at the persuasion of friends, that in the meantime, while the said observations are busy in the press, the first part — that is, the Prior Book — of this *Machina coelestis* should be issued to the public. [Margin: While the observations themselves are busy in the press, the author thinks it expedient to publish in the meantime the Prior Part of the *Machina coelestis*.] This Prior Part, however, is purely mechanical: namely, all our instruments, whatever [Margin: The Prior Part of the *Machina coe-*] I have used up to now for observing the heavens — these it sets out. [Margin:

-*lestis* sets out the Organography.] Indeed, I also thought it reasonable that whatever comes first in order should also be brought out first. Moreover, it is also necessarily required that the instruments with which the observations were made should first be submitted to everyone's eyes and judgement, and set out for them, so that it may be clear whether these instruments of ours are equal to those of my predecessors, and of such value that they are fully sufficient for so many diverse observations of the very greatest moment? — lest, if they were withheld, the observations should perhaps be called into question by someone; or, if they do not find favour, so that they can still, in the course of time, as will certainly be possible, be made more accurate and more complete. [Margin: Why the author published the Organography first.]

Moreover, so that this Prior Part of the *Machina coelestis*, or Organography, might see the light all the more promptly, and all the plates be engraved on copper all the more quickly, I purposely summoned an engraver from Holland to Danzig, not without some expense, and took him into my house. [Margin: The author called an engraver to his aid.] For although in all our works hitherto I have made all the drawings, and more than four hundred figures, with my own hand and engraved them on copper, I could not by myself keep up with this rather arduous labour. I considered that I have by no means enough leisure from my other labours — the daily observations, and the writing up of drawings and everything else, seeing it to the press and correcting it — to carry this out; above all because quite enough work still remains for me myself in engraving the plates for the Posterior Part of the *Machina*. [Margin: The author alone was not equal to engraving the plates on copper.] Besides, who would have advised me to do myself, spending a year or two on it and doing nothing else, what could conveniently be done by someone else? [Margin: It was not advisable for the author to engrave each and every plate on copper by himself.] For my life has almost run its course: I am now, glory be to God, in my sixty-third year, at which scarcely a very few seem to remain, and these must therefore be put to the best possible use. Nothing is more precious than time, which surely never returns and cannot be made good. Hence I thought it better to leave aside what is less necessary, and to do, solely and with all my strength, what necessarily falls to me alone and cannot be done by another. [Margin: It is better to do the more important things, especially at an advanced age.] Since, moreover, a great many of my other works, far more difficult ones, still remain to be completed, as I was saying just now; and I certainly wish, with the most willing heart and with God's favour, to bring them to the end so much desired.

In this way, then, it has been possible to complete this Prior Part of the *Machina coelestis* sooner than I had hoped; and I now, under God's auspices, set it before the eyes of all patrons and devotees of the stars. [Margin: The author never took up astronomical matters without great zeal and seriousness.] So that they may not be unaware with what spirit and ardour (be it said without boasting) I took up astronomical studies, never sparing any labours, or expenses drawn from my own purse — even though this happened not without some

loss to my health and my means — I was nevertheless always inclined to all of it, provided only that I saw I could obtain through them, and bring to effect, something that might at least in some way serve the good either of our divine science or of posterity. But whether this little work is to everyone's taste, or can greatly please all who are devoted to celestial things, or entirely satisfy their desire and expectation, I truly do not know; and so, kind reader, I commit all of it to your most equitable judgement. [Margin: Even if this effort of ours has not pleased everyone equally, you will nevertheless see that I have at least attempted and intended something.] I rely on this most certain hope, and on your fairness, that you will readily acknowledge that, even if in this part I have by no means reached the goal itself (as it is never possible for me, or for anyone else, to do), I have at least shown by no obscure signs that I undertook everything with the best intention, and wished for some things with the most ardent spirit, according to the rather slender powers of my talent and my modest means. Let him who is endowed by God with a loftier and happier talent, and who has ampler means, see to it that he brings forth something of this kind that is more splendid and more perfect: as indeed it is much easier for him to do, since he is already treading a paved road, and the ice has already been partly broken for the discovery of a great many loftier inventions. Nor have I any doubt that you, or anyone else among posterity, provided only that you take up the matter just as wholeheartedly and leave nothing untried, will, with God and time, discover far more, and far more excellent, things than these discoveries of mine, such as they are. [Margin: Without doubt more and greater things will be discovered with time.] For one climbs to higher things only step by step. No one was ever so fortunate that he, at one stroke and at the same time explored, penetrated and uncovered everything. For the poet rightly sings: we learn and we die; life is our school right up to death itself.

[Margin: The author entreats God that He may further favour his endeavours.] For the rest, I thank God, best and greatest, with my whole heart, that amid so great a mass of business and troubles He has most mercifully granted me life, health and leisure for carrying these celestial studies, for a good many years now, as far as they have come, to the glory of His most divine Name. May He further stand by us in His divine kindness, so that I may not be unable, happily and as quickly as possible, to bring to light, for some benefit of astronomy, the remaining works as well — those still in hand and those I carry in my mind, which still need some labour. [Margin: Which works are still in the author's hands.] Above all, my *Prodromus Astronomiae*, with the complete catalogue of the fixed stars and the reformed celestial globes; and also the Posterior Part of the *Machina coelestis*, presenting Books II, III and IV, which has already been very busily at press for two years.

[Margin: The subject of the Second Book of the *Machina coelestis*.] The Second Book will present all our celestial observations — of eclipses, of occultations, of the planets as well as of all the fixed stars — in the order in which they have been drawn from the sky, from the year 1630 up to now. [Margin:

The subject of the Third Book.] The Third Book will report the meridian altitudes of the Sun, the equinoxes and the solstices, from the year 1632 up to now; and also the particular observations of each planet, with the times added, corrected from the altitudes. [Margin: The subject of the Fourth Book of the *Machina coelestis* [printed Cœleſtls, recte: Cœleſtis].] The Fourth Book will comprise a catalogue and index of all the distances — of which there are several thousand, and those taken with the larger brass sextants and octants — together with the distances of other authors, as many as it has been possible to find: namely those recorded by Wilhelm, Prince of Hesse, by Tycho, by Gassendi and by Riccioli. [Margin: Since the observations of others are added to ours, it will be easy to recognise the discrepancy.] In this way it may be evident at once, at a single glance, which of them agree and which, on the other hand, disagree with one another; so that any curious cultivator of the stars, once he knows the discrepancy, may, if he wishes, look at the sky himself and examine and investigate those very distances anew — that is, to determine which ought to be trusted and adhered to more than the rest. [Margin: In astronomical matters there is no need of faith.] For I am entirely of the opinion that in this sidereal business there is no need of any blind faith, nor is it right to attribute too much to the authority of anyone at all, where the matter is open and the same observations can be repeated on any day. [Margin: Whoever claims to pass judgement on the works of others must not come to it with unwashed hands.] On the contrary, whoever sets out to examine and test the observations of others must be thoroughly versed and practised in these matters, and amply equipped with suitable instruments, larger ones, made of solid metal; otherwise it would surely be foolishness to pass judgement on what others, who are well practised, have observed. And since this Fourth Book of the *Machina coelestis* is like a kind of index, [Margin: In what order the distances of the stars have been arranged by the author.] all the distances are arranged in alphabetical order and by the sequence of the stars, to the point that you will be able, with no labour and as quickly as possible, to find the distance of any stars whatever from any star, as recorded both by us and by other most distinguished observers. To our distances the year, month and day have also been added, as well as how often, and with which instruments, they were observed by us; but you will learn more about these when these three books of the Posterior Part of this *Machina* have seen the light.

[Margin: The Prior Part of the *Machina coelestis* presents nothing but the author's astronomical instruments.] But let us return to this Prior Part, which, as we said just now, presents to you, kind reader, nothing but our astronomical instruments, those we have used from the beginning of our observations and still use to this day. It does not, indeed, present our entire astronomical equipment, which I have acquired for myself over so many years, together with a mechanical apparatus of various kinds that is not to be despised; but only the larger instruments, those at least two or three feet in size, as measured by the

radius. All the other, smaller ones are passed over, although I have them in some quantity, acquired at no very low price.

[Margin: What order of the instruments is followed in this work.] The order of the instruments that follow, however, was neither anxiously sought by me nor observed. Rather, it pleased me first of all to treat of instruments in general, both of the ancients and of the more recent writers, and then of what seemed especially worth noting about them. Next, I turned specifically to our own instruments, and indeed to the smaller and lighter ones. Third, I presented the wooden ones, partly overlaid with brass plates, such as were in use by the most noble Tycho Brahe. [Margin: The structure and use of the instru-] In the fourth place there are seen the very largest instruments, those made of solid metal — namely quadrants, sextants and octants — with the whole of their necessary apparatus, and with a sufficient description of their construction, of the divisions, of the sights and of other things, both those that were formerly in use and those that have only recently been invented. [Margin: -ments the author has set out fairly fully.] In sum, everything whatever that I judged to bear either on their structure or on their use is discussed there, each and every point, in sufficient detail.

Fifth and last: [Margin: Telescopes are now held in great esteem among princes and the learned.] I have ascertained well enough that in this age of ours very many people are found, among the learned as well as among magnates and princes, who take a wonderful delight in telescopes and optical tubes for contemplating those wonderful ethereal bodies — not only the smaller and common ones of three, six or twelve feet, but also those of twenty, thirty, indeed sixty feet in length. [Margin: Through telescopes the sciences have grown not a little.] Moreover, no one can be unaware[3] how great an increase the sidereal studies began to take from the first invention of these telescopes; and just as the telescopes have been made more perfect with the passage of time, so too these sciences have grown not a little. Indeed, if they were perfected more and more, and longer ones were built (as I think can also be done), very many things that still lie hidden in obscurity would without doubt be drawn out into the light, to the greatest good of astronomy. [Margin: The author decided to make mention of his own [?] optical tubes as well.] For these reasons I did not wish to pass over the opportunity, now that it is given, to make mention of my telescopes as well (since they too claim some place for themselves among the astronomical instruments) — and indeed of those that were made partly by me myself, and partly by other distinguished craftsmen and eminent cultivators of optics. Not, however, of all that I possess, but only of the chief and longest, which are at least twelve feet long and grow to one hundred and forty feet: tubes so very long, as far as I know, have nowhere yet been built, nor applied to celestial things.

[3]the page prints *nemo non neſciat*, which taken word for word says the opposite, "there is no one who is not unaware"; rendered by the sense the sentence requires

[Margin: The author has not undertaken, on this occasion, to hand down the art of polishing the lenses themselves.] These optical tubes, I say, I shall place before the eyes of every more curious investigator of the stars — not, indeed, the method by which the lenses are to be worked and polished on every side: by no means. For that would demand an entire volume to itself, which is not my purpose on this occasion; but only how their tubes are constructed and with which lenses, and then by what varied means they are to be applied to the heavens, so that even the longest of them all can be directed at will, most conveniently, to any of the very smallest objects, with hardly more than one hand and as lightly as can be, however great their weight. [Margin: The author puts forward a new invention for directing even the very largest optical tubes with wonderful ease.] And this, indeed, with one singular advantage: you can catch the smallest things in the tube in the twinkling of an eye, and keep them continuously in the telescope for as long as you wish, until you have had your fill, so that not once can the object pass out of it against your will, even though it is carried along by the swiftest motion, whether the common motion or its own. This directing of telescopes to any objects whatever, above all of the longest ones, has until now otherwise given observers a great deal of labour, to the point of nausea, sometimes at the very greatest loss of time. And although now and then, by some lucky chance, a star has suddenly been caught in the tube, it has slipped away from the eyes again just as easily as it was found. For no one, whoever it may be, can ever hold a telescope of thirty or fifty feet — not to say seventy, or one hundred and forty — so firmly on any object with bare hands that the object is not at once lost again, or does not pass out of the tube: as every one of those who has any dealings with telescopes [Tubo∫picillis] will freely admit.

[Margin: In this way very many troubles are avoided, while, on the other hand, not a few advantages are introduced.] By this method and invention of ours, however (be it said without tempting fate), you will be able to avoid that most troublesome and most tedious labour entirely, and to carry out those contemplations with the very greatest pleasure, almost as if playing with optical machines of such enormous size. So much so that you may always be sure that you can not only find any object, however minute, on the instant — indeed, before you look into the tube (which will perhaps seem a wonder to some) — but also hold it firmly for as long as you please. You will also be free, on leaving the telescope, to give up your place to someone else, with the telescope directed with the greatest accuracy to any object desired,

[Margin: The author hopes it will not be unwelcome to the cultivators of the stars to know this machine properly.] Since this is a thing entirely new and never yet attempted, and likewise of great advantage, and since it makes all observations to be carried out with those longer telescopes, I say, far more pleasant and easier than they have been until now, I thought it would be work not without use — and not unwelcome to those who search into the

deeper matters of the heavens[4] — if I added this invention of ours, with some description and drawing, to my other instruments. You will see that the thing itself answers to the words, and with what very little trouble even the largest tube-machines, though of one hundred and fifty feet or more, can be built of bare wood without any iron at all, indeed without a single iron nail driven into them; so that they are not incapable of being assembled from a few parts — three, or four at most — and steered; and of being taken apart again, and also kept in their own place, safe from all the harshness of the weather. [Margin: The longest tubes are of nothing but wood.]

[Margin: The author leaves the working of lenses to others.] On this occasion we could, as was desired, have discussed and treated at somewhat greater length the working and polishing of the lenses themselves for any tube, both in general and in particular, and everything that bears on this art, as very many friends have also long and most earnestly requested. But since this demands a volume of its own, as I was saying just now, the business is to be entrusted to others, who have perhaps laboured over it still more, and who have more leisure. I do not doubt that, just as we have done with the construction and direction of tubes, they too will gladly, for the benefit of posterity, communicate with the most complete candour this art of polishing any lenses whatever (known rightly until now to only a few), together with what they have recently discovered, laying open every one of their aids.

[Margin: In place of an appendix the author communicates a particular invention, on the polishing of conic lenses.] And so that I myself may not seem to go against this excellent admonition, I shall add a few things at the very end of this Prior Part of the *Machina coelestis*, namely on making and polishing hyperbolic lenses: that is, by what method they can be perfected not altogether ineptly, and also how some of them were worked by me long ago with the happiest success; these are still kept in my possession. [Margin: The author long ago worked certain lenses from a conic section.] Since, therefore, the greatest things depend on these, especially if in future they are perfected more and more — as I by no means despair, even though some years ago most of the learned and of the mechanics contradicted me, and very many all but despaired of that business;

the matter certainly deserves to be set before the learned world and subjected to a more exact examination. [Margin: The author submits the invention of working conic lenses to the judgement of others.] I rely on the most certain hope that others will come forward in time (if they follow in these footsteps) — people wholly devoted to optical studies and thoroughly versed in them, and with more leisure — who will not only continually advance these hyperbolic lenses for longer telescopes but at last also bring them to the most longed-for outcome, and who will not be unable to polish, with very little trouble, not only convex lenses of that kind but also concave ones (in my opinion, at least).

[4]the page prints *nec non … adeò ingratam*, which taken word for word would make the work "so unwelcome"; rendered by the sense the sentence requires

[Margin: Had the author not been occupied with weightier studies, he would perhaps already have achieved something more in this business.] Had my very weighty occupations and my ethereal contemplations not stood in the way until now, I myself would perhaps have advanced somewhat further in this area too. But because the labours of mine just mentioned seem to me far nobler, and because it is also more to the advantage of astronomy that they at last be brought to completion, as others wish, I was of necessity compelled to give up that study, and indeed I willingly chose to forgo it. I was not unaware that no one can accomplish everything, and that very many people are to be found who are more practised and better suited to this matter, who have leisure in abundance and cling continually to this one study, leaving all others aside. [Margin: Those who are continually intent on a single thing certainly achieve more than the rest.] These, I say, will discover and accomplish a great many things with happier success than one who is intent on a great many things and constantly has now this, now that to carry out. For anyone who cannot give whole, unbroken days to these tasks will achieve very little indeed.

I ask you therefore, kind reader, to take in good part this little invention, such as it is, which I set before you in all candour. [Margin: The author urges students of optics to perfect that matter further.] If you think that this slight invention can be made more complete — and that is my opinion too — please do not spare your effort, and be of good heart. For, as Seneca says in Book 6, Chapter 5 of the *Natural Questions*, *he who hoped that it could be found contributed very much towards finding it*. And when you have brought the business to its summit, share the matter with us in turn: without any doubt you, who have perfected the hyperbolic lenses, will win greater glory than he who handed down the method of polishing them.

[Margin: Which instruments in this Orga-] These, then, as we have said, are our larger and principal astronomical instruments. Of those smaller ones, such as radii, astrolabes, astronomical rings, or certain others — however much they may belong to observation — I considered it by no means worth the trouble to mention here. [Margin: …nography were set out.] Indeed it would be too long-winded, and very tedious to the reader as well, to waste time on these trifling things, which I myself never used for serious observations, regarding them as toys. I confess, however, that among the mechanical apparatus some new inventions are to be found which in various ways are of excellent use, above all for carrying out the business of division more exquisitely, and which also cannot be unwelcome to some students of mechanics. But I judged that time had to be spared. You, therefore, who may perhaps need these things in your own time, can devote the same labour to them; and without doubt, by the felicity of your own talent, you will discover both similar things and more excellent ones.

[Margin: What drove the author to bring out the *Celestial Machine*.] Let it suffice, then, to have the things that I have chosen to present in this First Part of the *Celestial Machine*, out of a good — indeed the very best — will

towards these sublime celestial contemplations, and moved partly also by the persuasion of certain most distinguished friends, partly by the vicissitudes of human affairs. For we know abundantly well that death sometimes, in a very short time, swallows up again and utterly destroys the many things that one man has devised, built and anxiously acquired over the space of many years, with the greatest labour, trouble and expense — especially when the carelessness of heirs and the injury of time are added — so that scarcely any trace, or any memory at all, of all those things survives to posterity. [Margin: Tycho's *Mechanica* rescued his instruments from all destruction.] The example of Tycho is at hand. Had he not left us his *Mechanica*, even the idea of so great an apparatus of most excellent instruments would have perished altogether; for not a single one of them, if you except the globe, survives any longer that has not been broken, or diverted and transferred elsewhere to entirely alien purposes. And therefore, lest these instruments of mine, such as they are, likewise meet the same adverse fortune, perhaps through the negligence of my heirs, I wished — with the same mind and affection with which I have always embraced this sublime sidereal study — all of them pro- perly drawn and engraved in copper, as far as could be done, to be left to posterity together with a sufficient description. [Margin: If anything has been achieved in this business, thanks are owed to God alone.] If perhaps some things are found that seem in part to contribute to the growth of astronomy, and in some measure please you, my student of the stars [Astrosophe], then give immortal thanks with me to God, the Founder of the whole Machine of the World, for having most mercifully provided me until now with life, health and the necessary means to devise, construct and bring to light these things, such as they are — not without some labour, care and expense. You, for your part, can understand them very clearly from a very few pages, without any trouble or loss of time, and readily turn them to your own profit.

[Margin: Friendly reader, beseech God with us besides, that he may further favour our endeavours still to be carried through.] Lastly, kind reader, if you likewise judge that the things which still remain with me, and which I have resolved to bring forth with divine help, are worthy to come before your eyes and those of others, then revere the Supreme Godhead, and pray to Him with me besides from the depths of your heart, that He may most graciously grant further that our labours and endeavours be brought at last to a happy end — to the greater glory of His Name, to the contemplation of His mighty works, and also to a somewhat fuller knowledge of our divine science. Farewell, my lover of the stars [Astrophile], and continue to favour our studies.

JOHANNIS HEVELII MACHINÆ COELESTIS PARS PRIOR, SIVE LIB. I. ORGANOGRAPHIAM EXHIBENS.

The Celestial Machine of Johannes Hevelius, Part One, or Book 1, Setting Out the Organography.

CAPUT I.

Chapter 1.

De Inſtrumentis Aſtronomicis, tam Veterum, quàm Recentiorum in genere.

On the Astronomical Instruments of Both the Ancients and the Moderns, in General.

[Margin: Each of the arts needs its own particular apparatus of instruments.] Just as all the mechanical arts, taken together and one by one, and every craft, necessarily demand particular and well-suited equipment or implements [armamenta, sive organa] according to the nature of whatever work is to be done, so too each of the mathematical arts and sciences calls urgently for its own singular instruments, most especially proper to it — an apparatus of implements — according as these seem more and more suited to getting their business done. Geometry has its compasses, rulers, set squares and the most diverse things of this kind, with which it draws and delineates circles and figures. Optics possesses its telescopes — to say nothing of the rest — with which it, as it were, reaches for the heavens — the ethereal bodies' native faces, their figures, and whatever bears on them, it contemplates and searches out. In the same way astronomy, too, has the greatest need of its own particular and most convenient instruments [Organa], with which it probes, scrutinizes, explores and uncovers the motion, magnitude and distance of the ethereal bodies, and other related features of this kind. [Margin: Without instruments astronomy is by no means cultivated, nor does it subsist.] Our most praiseworthy predecessors, devoted to the sidereal science, doubtless saw this clearly even from the very beginning: that no one would ever explore these sublime matters — namely the motion of these loftiest ethereal bodies — more deeply with the naked eyes or by the contemplation of the mind alone, however surpassingly keen the intellect with which he might be endowed, much less bring this science to its summit, unless suitable and most apt instruments were first devised and skilfully constructed, such as might grasp and uncover the marvellous and most intricate motion of those bodies. [Margin: By reason alone, and with the naked eyes and hands, nothing whatever is accomplished in sidereal matters.]

[Margin: Astronomical instruments were without doubt very plain at first; but of what kind is not known.] We can easily conjecture, moreover, that just as the beginnings of all things were hard, and nothing has grown and been made more perfect except with time (as is quite clear from the equipment of all the mechanical arts and crafts, and from their whole apparatus), so in the same way the first and most newly devised astronomical instruments of every kind, whoever first invented them, that were used for probing the stars were without any doubt very slight and very simple, and departed exceedingly far from those found later in the course of progress. But what they were really like, and in exactly what manner they were built, we cannot here reveal in full or offer a sufficient sketch of, since the histories make no mention of them. Yet when the sidereal science had passed down to the Chinese, the Assyrians,

the Babylonians and the Egyptians, astrolabes, torqueta, radii, parallactic rulers [Regulae Parallacticae], and perhaps other things of this kind that have not come to our knowledge, were in use. [Margin: What instruments the Eastern peoples used.] Then, when Timochares, Hipparchus, Ptolemy and al-Battānī followed, they employed zodiacal armillae [Armillae Zodiacales], as is clear from Ptolemy's *Almagest* and from other writers. [Margin: When armillae were constructed.] But however supremely splendid and costly the said armillae may have been, they nevertheless by no means displayed everything with complete exactness, as they ought to have done. The same is true of the equatorial armillae [Armillae Aequatoreae], although they had been fashioned of solid metal, inasmuch as they distinguished no more than a sixth part of a single whole degree; from which it is plain that they were not of sufficient size, as the observations of Hipparchus and Ptolemy attest. [Margin: The armillae by no means fulfilled their function.] Add to this that the use of these armillae, even of all the larger ones, is laborious, troublesome, and at the same time very treacherous. For since they are composed of different parts or circles, it certainly cannot come about that each and every one of them always agrees most accurately at a point; and in such a construction and arrangement they sometimes even deviate enormously from the plane during observation. [Margin: What the cause of this was.] In particular: if they are very large, they are less mobile because of their bulk and weight; again, if they are of smaller size, they admit a subdivision into minutes, let alone into the parts of these; so that a conspicuous error is readily committed with these armillae even by a most highly practised observer — as also happened quite often to those of older times.

As for the rest, the torqueta and Ptolemy's parallactic rulers likewise consisted of the most diverse parts, and very heavy ones at that, so nothing accurate can be achieved with them either, however much they display the proper size. This is chiefly because, on account of their excessive weight, they can be brought correctly into balance, and turned in every direction, only with great difficulty. [Margin: Torqueta and parallactic rulers likewise do not suffice for celestial matters.] Conversely, if they are lighter, they are at the same time also smaller, and then, as with the armillae, the divisions fall short. Moreover, there is no need for any fuller demonstration of what the radii achieve with the smaller and larger intervals between the stars [Stellarum Intercapidines] — whether they are made of wood or of brass [aes], of whatever length, and however finely divided into the most minute particles and skilfully worked — since those more expert in these matters have amply ascertained this very point. [Margin: The use of radii is also very treacherous.] So it is more certain than certain that no instruments whatever — whether astrolabes, radii, torqueta, parallactic rulers, or even the armillae — that the ancients used on the stars fulfilled their function, if you look for accurate and proper precision in every respect; just as Tycho himself in [Margin: We cannot rely firmly on all the instruments of the ancients.]

his excellent writings, above all on p. 146 of the letter to Rothmann [Epiſt. ad Rothmannum], rightly warns: "For even if it (the torquetum, that is) were of the proper size, it is nevertheless intricately composed of too many and diverse parts, and many things are required for arranging the individual parts which are hard to manage all at once during observation, so that while one thing is guarded against, another is easily neglected; and any one of them by itself can introduce some sensible error. [Margin: Tycho's judgement on the torquetum.] I say nothing of the fact that the instrument itself also weighs itself down too much by its own bulk, since its arrangements are not adapted to its turning in accordance with equilibrium. So there is none among all the astronomical instruments devised by the ancients that gives the observer less ready and settled certainty, however ingenious its structure may well be — the structure by which the Arabs, its first inventors (as I believe), tried to reduce the armillae used by Hipparchus and Ptolemy, more compactly and at less expense, to a kind of flat framework of circles, etc."

[Margin: Tycho's predecessors did want to make good the deficiency of the instruments; but they attempted it in vain.] And so the more recent men of the preceding century tried to remedy the defects of these instruments, namely by constructing quadrants and rings [Annuli] and by improving astronomical radii. But not even they hit the mark as they longed to, inasmuch as these were for the most part made only of wood and were of small size. When, however, the most illustrious Prince of Hesse and the most noble Tycho Brahe came forward, and with the intention of devoting serious effort to astronomy, the instruments became immensely more accurate in every respect — not only as regards division, construction, sights and the whole apparatus, but above all because they built instruments that were, on the whole, far larger and yet not at all unwieldy in observation. [Margin: But the Prince of Hesse and Tycho continually advanced this business.] Prince William of Hesse took his instruments, which before had shown only whole 2′ at a time, so far that afterwards they showed each single 1′ exactly — indeed half of it, and sometimes even a quarter; some of these were of solid metal, 3 feet in radius. [Margin: What instruments the Prince of Hesse possessed.] But the incomparable Tycho, advancing still further with the magnificent apparatus of his instruments, possessed not only some likewise of brass, or metal, 1½ and 2 and also 2½ feet in size, but also various others, though for the most part wooden, for [Margin: Tycho surpassed even the Prince with his magnificent apparatus of instruments.]

a readier use and an easier and more convenient pointing towards any objects whatever (as the author himself then supposed), of six feet; and he had a single Mural Quadrant made, six and a half feet in size. These instruments indicated, by a method by no means unsuitable, not only each single 1′ but even a sixth part of any 1′. [Margin: Why Tycho's instruments were for the most part wooden.]

Moreover, he was not content with parallactic rules [Regulae Parallacticae] and with zodiacal armillae of pure, unalloyed metal on the Hipparchan or Ptolemaic pattern — and these indeed with fewer circles — for obtaining the longitudes and latitudes of the fixed stars directly. He also acquired three equatorial armillae, of which a single one, of five feet, was built of only one and a half circles. By means of this one he measured the declinations and right ascensions of the stars at once, with no great labour and without any calculation at all. [Margin: How many instruments, and of what kind, Tycho had.] Above all, he was the first to devise a certain most noble instrument and bring it into practice — namely the sextant, and also the octant — for which all posterity owes him a very great deal. For the sextant is found to be the most convenient of all the other instruments that can ever be applied to measuring the stars, as experience testifies. [Margin: Tycho was the first inventor of the sextant, the most convenient of all instruments.] Of these sextants he possessed two, of six feet in radius: one for taking the altitudes of stars, the other for measuring distances alone. That second one, in my judgement at least, I rightly prefer to all the rest, however many there were. For in place of the first sextant, the one meant for altitudes, we use quadrants far more readily and conveniently, if they are of equal size. [Margin: For altitudes, quadrants are more convenient than sextants.] Tycho too, as is clear from his *Mechanica*, had six such quadrants, among which four were azimuthal. Those first three, however, though made of solid brass [ex puro ære], were not large enough for anything exquisite and solid to be achieved with them, as Tycho himself admits. The first of all the principal ones was the Mural Quadrant, otherwise called the Tychonic, which nevertheless consisted of nothing more than a single brass arc fixed to a wall. [Margin: Which were Tycho's principal instruments.] The second was indeed of no less proper size, namely 6 feet, so that it indicated any quarter of a single 1′; but was built almost entirely of wood, except that it was faced with brass plates and had brass sights [Pinnacidia] and a rule. The third quadrant was entirely of steel, enclosed in a steel square as well, and at the same time azimuthal. Tycho was very fond of it, as indeed it deserved, since among the largest instruments it was the only one made of solid metal. [Margin: Tycho's sextants were built of wood.] It would have been desirable, however, for the sextants too, on which equally lofty matters depended, to have been cast of pure brass. Then he would surely never have complained so much that instruments built of bare wood eventually fell short of their proper perfection through use and time. For timber, however very solid, very dry and very old it may be, nevertheless decays in the course of time and gives way to the air and to bad weather, as will be explained more fully later, in its place.

You may ask, however, why Tycho did not make these sextants of brass as well. Did he do so to spare expense? Certainly not. [Margin: Why Tycho did not build all his instruments of solid metal.] For Tycho was very rich and did not spare expense: as is well known, he spent more than 300,000 florins on astronomical equipment without reluctance, to say nothing of what the King

of Denmark, with the greatest liberality, never failed to bestow to that end. [Margin: Tycho spent a very great deal on astronomy.] And so he could have produced such brass sextants far more readily, and at less loss to his own estate, than any private person who has to draw everything from his own purse. The genuine reason why Tycho did not do so is this: he was firmly of the opinion that sextants and octants made of metal at so great a size could in no way be handled by two observers, as they properly ought to be, much less turned in any direction at will, so that for this reason the bulk and weight of the instruments would entirely obstruct the much-desired result. [Margin: Tycho thought that instruments made of brass could not be moved at will.] Yet he saw very well that metal instruments would be far more excellent and more secure for celestial observations, provided they could be handled with quite slight effort and directed nimbly. For he complains in many places that even the wooden sextants gave the observers a great deal of trouble, so that more than [Margin: Wooden instruments too used to give the observers a great deal of trouble.]

two assistants were needed for a single sextant, to raise, tilt and hold it conveniently, especially on unfavourable surfaces and in awkward positions. Moved by this, he built the octant too, or bipartite arc [Arcus Bipartitus], and also the azimuthal semicircle, whose radius was four and a half feet, for the most part of wood, so as to avoid the labour and trouble all the more.

It is therefore most plainly evident with what care and concern Tycho cultivated astronomy, how far he came to the aid of the instruments, by what path he corrected them, and with what outstanding inventions — sparing neither labour nor expense — he enriched and adorned them, as none of his predecessors ever did. For although there were kings and monarchs among them who built and erected wonderful structures, most costly and splendid pyramids and gnomons, and other magnificent instruments of this kind, some of which are still to be seen in China and elsewhere, nevertheless with none whatever of their instruments did they ever accomplish as much in astronomy as Tycho himself, who can never be praised enough — as the facts themselves declare and so very many observations show. [Margin: Nor did any of the kings of old possess more excellent instruments than Tycho himself.] For had Tycho not achieved this, neither would the *Rudolphine Tables* have seen the light, nor would Urania herself have been advanced so far in very many respects. And so immortal gratitude is owed to him, both by all of us and by the whole of posterity; indeed, may his most dear memory flourish for ever in the minds of astronomers, because he paved the way for us his successors and showed the method by which, with God and in the course of time, step by step, by applying the necessary expense, due diligence and unwearied labour, we may not be unable to reach higher things. [Margin: The laurel is owed to Tycho, because he advanced astronomy so far and carried the torch before us all.]

After Tycho, indeed, there were very many most distinguished men in various places who did excellent work in compiling tables and refining other astronomical matters. But very few indeed stood out — and this I should wish

to be said with the leave of all — who brought help to Urania through the observations themselves, taken from the heavens; much less any who in any way corrected the instruments of the ancients, and of Tycho himself as well, made them lighter and more convenient for any tasks whatever, for more accurate [Margin: After Tycho, astronomical instruments were made scarcely any more perfect.]

results — so that some of these might be gained little by little and made known to posterity.

[Margin: What instruments Lansbergen had.] Philippus Landspergius [Philips van Lansbergen], for his part, thought that with his wooden quadrant he would come much closer to the truth. "Each of its radii," he says (*Progymnasmata* Book I, p. 15), "was about four feet long; and we repeated the same work after making a larger bronze quadrant." But he does not add how large it was. Without doubt it was not larger than the first, since he does not state its true capacity and construction.

[Margin: Whether with these he could achieve anything more than Tycho.] What, then, could the author just mentioned accomplish in this arduous celestial business with a bare quadrant of four feet — perhaps even somewhat smaller still — without any sextant or any other instrument whatever, even had he been the most ingenious and most perceptive of all? And could he carry the matter further than Tycho with his most splendid and magnificent array of instruments? Let others judge — although his own observations show abundantly how very far from the goal of truth he aimed.

[Margin: The author doubts whether Father Riccioli's instruments were better suited than Tycho's.] The Reverend Father Riccioli, moreover, the distinguished writer of the *Almagest* and author of the *Astronomia Reformata*, also made a good many observations together with his colleague Father Grimaldo [Francesco Maria Grimaldi], using quadrants and sextants of three, four and six feet, and one of twelve feet — but chiefly, I judge, wooden ones, since he has not added that all of them were made of metal. The exception is that in Book IV, chapter 15 of the *Astronomia Reformata* he reports: "We more often used two iron quadrants, one Tychonic, or movable, the other Grimaldian and fixed, set very firmly in the plane of the meridian." Then they also used parallactic rulers [Regulae Parallacticae], first of six feet and afterwards of eight, and a fixed gnomon of fifteen feet. But whether these instruments came near to Tycho's or surpassed them I would not dare affirm with much certainty, since he nowhere gives a fuller description of them.

[Margin: Whether the moderns of our day now have quite distinctive instruments, the author has not ascertained.] But what instruments great and highly skilled men of these times have had, or still have, both here in Europe and elsewhere, of what construction and kind, and what outstanding and singular things they have accomplished with them for the good of astronomy, is entirely hidden from me, since nothing has yet appeared, so far as I know. Meanwhile, however, I by no means

Diagram. A full-page engraved plate in a ruled frame, labelled *Fig. A* at the foot. It shows a quadrant set on a stand: two straight limbs meet at a right angle at the top, the centre, and are joined by cross-braces, with foliate ornament between the limbs below the apex. A graduated arc closes the frame at the bottom, with a sight block at its left-hand end. A central pillar and a turned column carry the instrument, a plumb-bob hangs at the centre beneath the arc, and the whole stands on a tall three-legged wooden support, its feet fitted with screws, set on a plank floor before a balustrade. Loose parts are drawn on the floor in the foreground: at the left, a round plate with an upright pin and a screw; below it, a wedge-shaped wooden clamp with holes, an upright pin and a screw; in the centre, a box-like piece with a long arm; and at the right, two small square plates, each with two screws beneath it.

- Arc (bottom of the quadrant), numbering read left to right: 80, 70, 60, 50, 40, 30, 20, 10
- Foot of the plate, centre: *Fig. A*

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doubt that each and every one of those who devote their efforts to Urania, or will yet devote them, has done his duty or will still do it — namely by aiding and supplying her with excellent and entirely new inventions, so that our Urania may henceforth raise her head higher with her most splendid equipment of instruments [supellectili Organicâ]. For it is fitting that we should always be tireless in action, and most eager to know and penetrate sublime things more deeply — above all since this tends to the glory of the Most High and accrues more and more to the good and profit of the republic of letters. [Margin: It is our part that we all labour so that instruments may be made more perfect from day to day.]

Tycho, moreover, as a man by far the most practised of all his predecessors in this arena, earnestly impresses on the minds of lovers of the stars what he has to say about the construction and division of instruments, and about which kinds should be chosen for observing the stars (*Progymnasmata*, Book I, chapter IV, page 335). "In the instruments themselves," he says, "a particular choice must be made (for not all of them hold in reserve what they promise at first sight), and solid diligence is required in making and handling them, joined with equal circumspection — greater, perhaps, than most people have so far reckoned. Unless they also have a size sufficient for distinguishing the individual minutes of the degrees, and are made of a material not liable to change from the air, the oil and the labour are wasted. This, therefore, must be secured above all: that they be as simple as possible, not made up of many less necessary parts and fittings, and moreover rendered thoroughly handy and ready for handling and use." All who are skilled and practised in these arts will readily acknowledge with me that all this is truly so. [Margin: What astronomical instruments should be like, in Tycho's view.]

It certainly cannot be denied that the most noble Tycho, as we have learned, spent no small sums and applied every care and diligence to procure for himself

the instruments best fitted to him and most suitable. Yet from the passages just cited, and also from those taken from Tycho's *Progymnasmata*, Book II, page 256, which we inserted in our Proem, it is abundantly clear that among his very many instruments — twenty of which are shown drawn and described in his *Mechanica* — he possessed scarcely five or six that could safely or rightly be chosen and brought to celestial observations. This, however, [Margin: Among his very many instruments Tycho had scarcely a very few on which he could properly rely.]

is no cause for you to wonder. For since he was, as it were, the first of all to take up this art in that praiseworthy way, he could not reach the very summit straight away at the outset, discovering every aid in its better form; rather, it was through long experience, step by step, that he first learned what had to be changed, corrected, kept, or even rejected altogether. [Margin: No one was ever so fortunate at the outset as to reach the summit at once.] Nor ought any observer to find it irksome to remove, now and then, a great deal from what he has devised, however laboriously, if it does not answer to his wishes; otherwise you will very rarely bring forth any singular and perfect invention. For not all speculations and ideas of the mind are brought to effect and carried over into use, as one indeed persuades oneself at the beginning; most of them perish and vanish in practice. [Margin: Very often, too, the subtlest inventions are not carried into practice.]

But to return once more to Tycho's instruments: it is certain that he had a great many made after the fashion of an older age, such as parallactic rulers [Regulae Parallacticae] and zodiacal armillae — which, however, as we showed above, even in Tycho's own opinion always promised more than they actually delivered. [Margin: Tycho possessed a great many instruments made after the fashion of the ancients.] And although Tycho afterwards made himself equatorial armillae, fairly large ones and with fewer circles, he could in no way obtain with them either longitudes and latitudes or right ascensions and declinations as exquisitely as ought rightly to have been done, or even as with sextants and quadrants; and there is no astronomer who will not readily agree with me. [Margin: Nor do the equatorial armillae accomplish the matter so accurately.] With the armillae, indeed, we settle the matter itself very easily, without any calculation; with sextants and quadrants, on the other hand, we learn it only from distances and altitudes, after a calculation has first been carried out, and not without some labour — yet far more accurately and safely, and this above all must be carefully heeded in celestial matters. [Margin: The safer road is always to be taken.]

Hence in our age most astronomers, taught by experience, all agree on this: that all armillae, both zodiacal and equatorial, and also parallactic rulers, torqueta and other instruments of this kind, can with the best right be removed from the heavens entirely — above all from those [Margin: Instruments we can very well do without.]

observations of any importance, by which we strive to restore the motion of the celestial bodies. For playful purposes, indeed — for show, on behalf of great lords who sometimes treat the subject not seriously but to relax the mind, and who avoid all calculation and labour as far as they possibly can — instruments of this kind serve not badly. But for serious matters of the greatest moment, where sextants and quadrants of bronze of proper size are to hand, I grant them nothing at all, believe me. [Margin: Armillae are not to be employed for serious matters.]

Of these armillae and parallactic rulers, Tycho had six in number. The three remaining, smaller quadrants, although they were skilfully worked from metal and were one or two and a half feet in size, were likewise by no means suitable for particular observations (except that they sufficed for correcting the times) — such as restoring the motion of the Sun, finding the elevation of the pole, or determining declinations, to pass over the rest — as Tycho himself clearly testifies in his *Mechanica*, under letter A 3, in describing these instruments. [Margin: Tycho himself rejected certain instruments when he investigated higher things.] Besides these, two other wooden instruments of lighter construction are found in the same place, which Tycho used for the New Star in the year 1572, before he had procured better ones for himself; and Tycho himself also set little store by them, as he admits in the *Mechanica* just mentioned, under letter E: "The skilful investigator must, however, beware of those instruments (namely the ones just mentioned) and of their arrangement, since they easily wobble or are in some way liable to develop a defect." [Margin: Tycho urges that we beware of certain instruments.]

With the steel sextant for measuring distances by a single observer, Tycho likewise, as is evident, achieved very little, since better instruments were at hand. For it was only four feet in size and had no sight at all at the centre, that is, at the observer's eye; and then a single person was forced to take the distances alone, whereas it is certainly far more reliable for two to carry out the work together. Moreover, with that azimuthal semicircle, as also with the Great Quadrant built of wooden beams, which because of its excessive weight could be turned round only by twenty men — since he had far more suitable quadrants, which could be trusted more safely than semicircles, [Margin: Some instruments were of no use.]

he could certainly also have done perfectly well without them, just as, so far as I know, he also achieved scarcely anything worth noting with them.

There were therefore fourteen of these instruments in number that gave Tycho scarcely any notable and distinguished service, so that only six remain — namely three quadrants, a single octant and two sextants — which could suitably be applied to this arduous work. Tycho himself also rightly preferred these to all the others. Above all, however, he held in the highest esteem one particular sextant among those just mentioned, which he used very frequently and on which he relied for most things, and for the chief ones; and in his *Mechanica*, under letter D 2, he also praises it highly: "Of this instrument," he

says, "I can testify that it gives the intervals of the stars with such certainty and precision, and so quickly and easily, that nothing could be found wanting in it." [Margin: Six instruments Tycho held in esteem above the others.] [Margin: Tycho credited the sextant most of all.]

To some Momus wholly ignorant of these matters these six instruments will perhaps seem very few. But it must be understood that number counts for little in this business, and it makes no difference how many of them there are; what matters is how skilfully the ones that are necessarily required are made, with how much diligence they are divided, and how true and correct they are in every part. [Margin: Astronomy depends not on many instruments but on correct and exquisite ones.] If astronomical instruments are not meant to be like toys, or to be hung up in a treasure-room for show, but to be applied to lofty and serious matters, then it matters very little how great their number is; what matters is the quality of their construction and their power. I am of the opinion — and very many experts in astronomy will also agree with me — that at the present time we can do perfectly well without parallactic rulers, armillae, and also those fourteen instruments mentioned above. To restore the whole of astronomy it is enough to have at hand about three quadrants, one of which must necessarily be azimuthal; likewise two or three sextants, with a single octant; in addition, several highly accurate clocks, with some very excellent and very long telescopes, and the rest of the smaller apparatus of various kinds that is most needed. Once these have been procured, each and every task concerning celestial observations can be carried out best of all. [Margin: How many instruments are needed for observations of celestial things.]

This holds, however, on the express condition that the instruments are skilfully made of bronze, divided most finely and exquisitely into the smallest parts of minutes, fitted with suitable sights, properly examined in every part, and accurate in every respect; that they turn at a nod, and in any situation, or at any inclination, obey the observer most readily in every way, without any resistance. I would have you make an exception if you are anxious to place instruments in several places and observatories, and also to have some portable ones that can readily be set up in one place after another, which the very large and very heavy instruments do not allow. And so I assert again and again that this celestial business depends neither on very many instruments nor on numerous observers.

For, as far as I have learned in the nearly thirty or forty years in which I have devoted myself assiduously to observations, I have found by solid experience that it is indeed not possible to explore every deeper matter with one single instrument or a second; but also that it is far safer not to use three hundred, changing very frequently now to this one, now to that. [Margin: To change instruments too often is not altogether safe.] If you possess a single azimuthal quadrant, or two at most, perfect in every part, then it is certainly far better and safer to investigate the meridian altitudes and the solar declinations, and their annual variations; and let the same be said also of sextants and octants.

For such very frequent variations and changes sometimes introduce some small discrepancy into the observations, which in due time can cause you or someone else no little trouble; of these perhaps more fully elsewhere. For this reason it is also better that a single observer, in one and the same place, should carry out each and every task diligently, if he is wholly equal to them on his own, than that he should have it done by very many companions and with the help of the most diverse people. [Margin: One or two practised observers are worth more for advancing astronomy than three hundred less skilled ones.] For those younger students who are assigned to observations, and who for the most part undertake those labours under compulsion, forced, for the sake of their keep or of a reward, will never handle the matter with as much diligence, as much circumspection and as much spirit — nor indeed can they in any way, being less experienced and practised — as [Margin: Those who are led by love of knowledge alone handle the matter with greater skill indeed than those who handle it for gain, as if under compulsion.]

those who, solely for the sake of advancing truth and knowledge, and hired by no one for money, put their necks to the burden. If the labour had not been too much for Tycho, with his own rather difficult method of observing, to carry out the whole business by himself with quadrants, and with sextants together with a single, constant assistant — and if he had by no means entrusted the work so very often to so many different students, very many of whom he always maintained — he would without any doubt not have been led astray so often in various ways. [Margin: Tycho would certainly have erred more rarely if he had not entrusted his observations to so many.] For the fact that some errors crept in here and there is to be ascribed only to his students, who were not equally practised, and by no means to Tycho himself. Indeed it is a hard thing before we can trust anyone else absolutely and entirely in searching out the stars. Add, too, that companions, who sometimes stay only for a very short space of time and devote their efforts to observations, can never carry out the work as correctly and exquisitely as the principal director of the observations, who himself built, divided, fitted out and tested the instruments. [Margin: No one can carry out observations more exquisitely than one who is engaged in constant practice.] For such a companion has explored less thoroughly the particular character of each instrument — how now this one must be governed and directed in that way, and now that one in this way, and what in each must be avoided and, on the other hand, strictly observed — than one who sits at the instruments constantly, day after day, and assiduously exercises himself with them.

Therefore, when God, Best and Greatest, so willed that I too, from a certain inclination of my own towards astronomy, had begun to take up these celestial studies, I had no greater concern than to undertake this celestial business according to that excellent advice given in Book I, chapter IV, page 335, and likewise in Book II of the *Progymnasmata*, page 256 — the latter cited by us in the Proem, page 53, the former in this very first chapter — and to choose and

build for making observations such instruments as would be more in keeping with Tycho's advice and more convenient in use. [Margin: From the outset the author laboured with all his might to procure suitable and highly accurate instruments for himself.] Accordingly, I at once turned my mind entirely away from parallactic rulers, torqueta, radii, rings, astrolabes, and also from armillae, both zodiacal and equatorial, so that I would attempt anything of consequence with them; nor did I burn with much desire to make small [Margin: What kind he built first.]

quadrants and sextants. The quadrants and sextants I built first, however, with a radius of three feet and made entirely of brass, indicated single minutes, and their fourth part, well. After that, following Tycho's example, I had still larger instruments made, with a radius of six feet but for the most part of wood, for the same reason that once seemed good to Tycho: so that they would be lighter and turn more easily.

Soon afterwards, however, I recognised and fully established that those wooden Tychonic instruments (as we have already said in the Proem) could in no way perform their function so exquisitely, nor so persistently. It then happily occurred to me that it would be of the utmost necessity to procure instruments made entirely of solid metal, of the same size — indeed of a size somewhat larger still — if anything worth noting was to be accomplished and left to posterity. [Margin: The author rejected the wooden Tychonic instruments outright, and put larger and more solid ones in their place.] Such things, as you readily understand, usually cost a great deal of labour if they have to be devised first of all and brought into practice. So to me too this seemed a hard task at the start. Nonetheless, as has already been related above, while I persevered in my purpose, attempting the thing in earnest and sparing no expense, it succeeded, and the work turned out, more happily than I had ever imagined at the outset.

The singular new method by which those very large quadrants, sextants and octants were built, fitted out, and divided so as to show each five seconds distinctly; then how they may be governed most conveniently and readily, and directed and inclined to any position and every inclination as fast as possible, as if with one hand, and held firmly there and kept in place; and further, how the rulers and the pinnules may be moved most delicately and lightly in a moment of time and, once they have taken their due place, never be moved from it — these and particulars of this kind anyone will see fully from the special Description and Delineation of our instruments that follows. [Margin: The singular artifice by which the author's instruments were built will be explained in its place.]

I have no doubt that, if not all, then at least most of those well versed in this science, who understand its inner parts, will, from what is to be [Margin: Most will without doubt acknowledge that the author has attempted astronomy not with one hand alone.]

said below, freely confess how seriously and earnestly it has been my heart's concern to want to achieve something within my small measure, and that I

have never spared any expense whatever drawn from my own private purse. These expenses indeed run to no few thousands, especially if you consider the outlays — to say nothing of the rest — that I have never been anything but most glad to make on buildings, structures and observatories, on so many very costly instruments of the most diverse kinds, astronomical as well as optical, on printing, paper, printers, engravers, copperplate engravers and assistants, and on enriching my library, so that I might at least devise and obtain something more correct and more refined. [Margin: The author spent no modest sums on the study of the stars.] But whether the work has succeeded as I wished, and how far, and whether this art has in some part been enriched and adorned by some entirely new invention, is not for me but for you, judicious reader, to judge.

I have no doubt that no one will ever come forward to claim for himself that he devised, earlier than I, such very large and very heavy instruments of solid metal, moving and directing them in a movable observatory with such ease and agility (if I may say so without boasting) and by an entirely new method, and applied them to the heavens. Nor will anyone claim to have directed quadrants to the plane and the perpendicular by means of a single screw, nor all the rulers of the quadrants and octants, and likewise the pinnules of the octants, so very readily at will and wish — to say nothing of the other recent methods: of building azimuthal quadrants in a peculiar way and governing them, and of directing and supporting very long tubes of a hundred, indeed a hundred and forty feet, and that by the aid of only some quite light little machine, as this First Part of the *Celestial Machine* will show fully and at greater length. [Margin: The author added very many new inventions to the instruments.]

Above all it will be plain, and not obscurely, that just as our most praiseworthy predecessors in the centuries just past — the most celebrated Tycho above all — strove with every effort to make astronomical instruments better and more perfect, so too in this age of ours they have been enriched and adorned, to the greatest benefit and growth of astronomy, with inventions no less outstanding and with most ingenious aids: [Margin: In this age of ours things far from common have been discovered.]

as the matter itself declares, even late posterity will, without doubt, acknowledge of its own accord and at greater length — and above all that we too, in these times, did not live wholly in vain, and that we laboured towards it vigorously and with all our strength, as far as God granted.

But you have no reason to think, my fellow lover of the stars, that the crags and peaks of every difficulty have already been surmounted, that everything has been brought to perfection of every kind, and that the whole science has been exhausted to its foundations by these means. By no means, indeed! Rather, just as we human beings, placed in this worldly body, can in no way reach the highest summit of perfection in the sciences, and here know the sciences and arts only in part, so too it must be freely granted, in these astronomical matters of ours as well, as we warned in the Proem, that *many things have indeed been*

discovered, but very many are still left to posterity. [Margin: Very many things still remain to be discovered.]

Hence, although the sidereal science has so far been cultivated, corrected and continually advanced not a little, and its instruments, with a wonderfully and abundantly enriched apparatus, have been made far more perfect and remarkably adorned, nonetheless they can without any doubt be brought to a wonderful degree more refined and more complete still — if only our successors, with every care, labour and diligence, and with expense not spared (without which, indeed, nothing is accomplished), set the same undertaking in motion and carry it forward, after the example of some of our predecessors. [Margin: And the study of astronomy will, beyond all doubt, grow day by day.] *For certainly all the arts and sciences* (as the most distinguished Mästlin rightly writes to Kepler in a letter of the year 1599) *have climbed to their higher and highest summits not at all through the first, but through those after them, who added to the discoveries their own gifts, granted from heaven.* [Margin: In very many things posterity is more fortunate than its predecessors.] And so there is no doubt that the whole of astronomy will, in the course of time, be made loftier and more splendid than can be estimated. That this may come about — even if all our labours, such as they are, and all our little inventions should be overshadowed by those yet to be discovered and set entirely aside, provided only that the sciences and the good arts grow to the honour of the most divine Godhead and become more and more widely known — we pray with all our heart! [Margin: The author's prayer.]

CAPUT II.

Chapter II.

De Quadrante Orichalcico.

On the Brass Quadrant.

I wanted to put this quadrant before the reader first, not because it is the most important of all the instruments of ours that follow, nor because it was the most familiar to me on every occasion, but rather because it was very nearly the least of all our other astronomical instruments (if you except the small ones of one or two feet, such as radii, astrolabes, little quadrants and a great variety of things of that kind, which are of no account here), and because, although I had nonetheless used it, more or less, for serious work, I at last withdrew it entirely from observation as well. [Margin: Although this instrument comes first in order, it is not for that reason the most important.] Not that it suffered from any defect in its construction or in its division — not at all — but because in the course of time I acquired better, larger and more perfect ones.

This quadrant had a radius of three feet and was made entirely of brass. It was of such thickness, and so well joined with braces of the same material, that it was fully adequate to any task intended for it, and yet its bulk did not burden

the observer. [Margin: The size of the quadrant.] It could therefore be carried elsewhere conveniently, set on its pedestal, and pointed in any direction very readily. It was built, however, without a ruler, with only a plumb line hung from its centre, as quadrants were mostly made in former times. This was done deliberately, because their use is easier and safer in this way; and in particular, those less practised in this field, even when they attend to every detail, do not go wrong so readily with quadrants of this kind as they would if the quadrants had rulers or had first to be set to the level of the horizon. [Margin: Quadrants furnished with a plumb line are easier for the unpractised to observe with.]

As in all the other instruments I have ever used, so in this quadrant too I made the divisions with my own hand. [Margin: The author divided the quadrant himself.] For I hold firmly to the opinion that no astronomical instrument whatever, especially one intended for the loftier ethereal matters, can, even at the hands of some other craftsman, however expert in this art, with as much care and dili- gence be divided, likewise fitted with pinnules, and tested on every side, as by the observer himself who has resolved to use it. [Margin: Hardly any craftsman can fit out and examine instruments as accurately as the measurer of the stars himself — provided, that is, that he is above all versed in the mechanical arts.] For I believe that no one will ever attend to this business as seriously — especially one who is drawn to it for the sake of gain — as one who takes the matter up of his own accord, solely out of love of truth and only for the sake of a deeper knowledge of the ethereal bodies. Such a man, so as to earn the greater gratitude from posterity, will certainly carry everything out with greater care and industry than someone hired for money. But he must be thoroughly skilled in that same art and well accustomed to mechanical work from his youth; otherwise every effort is in vain. For how readily some quite slight error can be committed in these most delicate matters — an error the maker deliberately conceals from the observer himself, and which afterwards, in time, brings into the observations themselves a great many errors, far greater ones! No one, not even the most perceptive of all, a Lynceus, could foresee them at the very outset; he would notice them only after a long interval of time, perhaps at great loss to himself and of his time, and could make good that damage of very many years only by correcting this instrument or by putting another, more correct one in its place.

I therefore urge you — having learned this by experience — not to trust anyone else in this respect, if you are yourself sufficiently equal to carrying everything out. [Margin: What you can accomplish yourself in building instruments, do not entrust to another.] In this way you will yourself recognise any defects and faults that cling to the instruments (as can easily happen) far more readily than any other mere maker or craftsman of instruments, and correct them in turn, and you will remedy every inconvenience of the instruments with the greatest ease.

These divisions were engraved on the arc by us in such a way that I could detect not only single minutes but nearly [?] their quarters. [Margin: How

the divisions were made.] First, each degree was divided into three parts, that is into 20′, and each third part into two equal parts, that is 10′. Then ten parallel circles at equal distances were drawn on a sufficiently ample arc and divided by transversal lines, so that single minutes could be noted exactly and their intermediate parts properly judged — just as anyone even moderately experienced in these matters easily understands; the rest, however, will also understand it very well from the drawing to be added below.

The pinnules are made in the Tychonic manner. [Margin: What pinnules the quadrant has.] Why I have used this kind and no other, and still use it, will be explained at greater length in connection with the larger instruments, where sights will be treated expressly, in general and in particular. In the middle of the front pinnule — the one standing at the centre of the quadrant — a very small hole can be seen, for solar altitudes, through which the Sun can cast its rays onto the rear pinnule. In the middle of that pinnule, in turn, a point, or else a little circle the size of the solar disc, has been described, so that when the Sun shines the whole disc is fully lit, and the centre of the Sun then coincides exactly with the centre of the little circle. Since the quadrant is only three feet, this little circle hardly equals even a fifth or a sixth part of a single digit [digitus]. [Margin: The hole of the front pinnule must not be too wide.] The same little circle could indeed be made somewhat larger if the hole of the front pinnule were also a little wider; but the Sun's rays then come out somewhat blunter, so that you cannot make out the Sun's periphery so distinctly. Care must therefore be taken that the hole of the front sight has the proper proportion to the size of each instrument.

So that the disc, or the light of the Sun, may appear all the more clearly and distinctly in the little circle of the lower pinnule, I always use a four-sided tube, whose lower part, which is to be fitted to the pinnule nearest the eye, is much wider, and indeed entirely open towards the observer, as can be seen from the preceding figure. [Margin: A channel is needed for solar altitudes.] This tube is attached to the arm of the quadrant, between the two pinnules, with little hooks or clasps. The Sun's rays, passing through the hole of the front pinnule, then present themselves much more clearly at the little circle of the lower one, so that you can take altitudes all the more exquisitely, and indeed far more accurately than by means of the shadow of the front sight. [Margin: Without a channel, the Sun's rays in quadrants are far blunter.] For all superfluous and surrounding sunlight is kept away entirely from the pinnule and its little circle, as in a darkened chamber. Through the tu- bum, however, my reader, I do not mean a telescope furnished with lenses, but a plain little tube made of nothing but paper.

[Margin: Construction of the pedestal.] As for the pedestal, or support, of this quadrant, it is made of solid oak and has four feet standing on a crossed base, as you see from the figure. All the parts of this support can be joined very conveniently and fixed with particular screws, and in the same way taken apart and separated again just as easily, so that it can be moved elsewhere all

the more readily when needed. A steel screw is fitted into each foot, by which you can direct and set up the quadrant by the level or plumb line, so that the plumb line itself neither clings too closely to the arc nor moves away from it and swings. [Margin: In quadrants the setting of the plumb line must be most accurate.] For unless this plumb line, hung to show the altitude, hangs as close as possible to the arc, with almost no space between, yet perfectly freely, so that it touches nowhere, you will certainly never achieve anything accurate, however much care you take, as the more experienced know very well. Reason therefore demands above all that every observer attend to this matter with the greatest care right at the start of the observation.

But since this is a matter of considerable labour, and a great deal of time is spent before the quadrant is set quite correctly by means of these four directing screws, I have devised an entirely different way of directing quadrants to the plumb line and of inclining them, precisely and as quickly as possible, so that nothing could be readier or more accurate: by means of a single screw, in any direction, however far the support may decline from the vertical circle or tilt towards the horizon. [Margin: The author has found an entirely new device for directing the plumb line.] This device for setting up quadrants, just as it was wholly unknown until now, was first devised by us. To some carping critic, once he has seen it, it will perhaps seem very trivial; but those who look more deeply into celestial matters, and those devoted to mechanical things, will learn from practice, and will then perceive from what follows, that it is a wonderful aid, and also has greater use in very many matters than it promises at first sight.

[Margin: The director of the quadrant, for obtaining the plane: how it is constructed.] It is constructed in the following way. The upper, square wooden part of the support — the part that is inserted into its pedestal as into a stopcock or small axle, to which that round iron is otherwise fixed, and on which in turn the quadrant, fitted to it by its channel, is directed to any altitude — is made of two parts joined by a hinge. The part into which that round iron for attaching the quadrant (the quadrant's prop) is inserted is movable, and by means of an iron screw attached to a movable nut it can, as each need and inclination requires, be separated and opened out more and more, or brought together and closed up again, with a very slight movement. And so the quadrant, hung by its channel on the upper, movable part, is directed at will and without any trouble to the exact plane of the vertical, or to the plumb line, most precisely and very gently, with one finger as it were, towards any region of the sky. Indeed it is directed so firmly that it never slips out of that corrected position, however much the horizon, or floor, may rise here and there and abound in unevenness, and the support itself lean over, as anyone will be able to find out by experience. [Margin: This method of directing suits all quadrants.] Accordingly, since this very aid is, in my judgement at least, most suited to observations, I have applied it to all our quadrants as well; and when we come to the remaining instruments, we shall give it drawn and described more fully and more accurately, as it deserves.

[Margin: The author did not use this quadrant for the more exalted observations.] Although this same quadrant properly shows single minutes, and their parts besides, I nevertheless did not use it at all for the more exalted observations, such as the altitudes of the pole, the meridian altitudes of the Sun, the obliquity of the ecliptic, the declinations of the fixed stars, parallaxes, refractions and things of this kind, but only for altitudes of the stars, to correct clocks. Instruments of this kind, which show single minutes, are amply sufficient for this task, so that there is no need for larger ones; but for the other, finer matters there is no reason to trust them too much. [Margin: The larger instruments are, the more excellent they are.] For the larger instruments are, and the smaller the parts they are subdivided into, and further the more they are made entirely of metal, the safer and surer their use: provided that, to any parts of the sky, without much trouble, they can be steered and turned round very gently by any observer, and do not burden anyone with their bulk and excessive weight.

[Margin: It takes greater skill to steer the largest instruments with two fingers than to build them with every effort.] For it takes great ingenuity and labour not only to devise and build huge, very large and extremely heavy instruments of solid bronze, but also to steer such instruments, for all their enormous bulk, very lightly with a touch of the fingers, and to direct them very swiftly to any part, at any elevation and in any position. Such instruments, too, with the help of God, I have at last not only conceived in thought and drawn, but also successfully assembled in a particular way and brought to completion; as will be shown more fully below, that is entirely how the matter stands. [Margin: Things once counted among the impossible are now in our hands.] It will also become very clear that a great many things which to the ancients, and indeed even to Tycho himself, seemed wholly not to fall within the nature of things, in the matter of directing instruments of solid metal — the largest ones, that is — are now very much in our power. For day teaches day, and Nature does not hand over her sacred things all at once. [Margin: In the sciences and arts we always advance further.] It seems quite plain to me that posterity, having seen these instruments of ours, such as they are, will without any doubt find and discover still greater and more sublime short cuts and aids. "For the time will come" (as Seneca aptly says) "when daylight and the diligence of a longer age will draw into the light those things which now lie hidden." [Margin: The author is confirmed by the various things he has discovered that, as one advances, more excellent things can be discovered.] This too can easily happen, since it is easy to add something to what has been invented. So I too, as I must freely admit, have from day to day learned and discovered more convenient and more accurate things, which suit now this work, now that, far more aptly, as will be abundantly evident from some of our little inventions, which are not altogether inept. [Margin: The author never spared expense.] These, however, I did not seek from others, nor did I take them secretly from anyone, but I achieved them by my own efforts, with very great labour and at no ordinary

expense. What they cost me, alone, to make is beside the point; yet from what follows some will be able, if not to know it fully, at least to guess it in part.

[Margin: It is no trifling matter to direct quadrants most precisely to any altitudes.] For the rest, this quadrant can indeed be moved gently on its stopcock, and it can also be fixed by means of a screw inserted into a channel at the back of the quadrant, so that it holds the altitude taken without any change; but it must be carefully atten- ded to that, while you draw in and tighten the screw, the instrument does not move away from the set altitude, as can easily happen. But if you do not tighten the quadrant with that screw at all, it is again readily shifted from its proper place in various ways, so that you can almost never be sure enough of the altitude taken before. [Margin: Another new and notable invention for directing quadrants.] For this reason I devised another, entirely new method, most convenient for this business and also for a great many other purposes. It is indeed a very small instrument, consisting of a single screw, and of little cost; but it certainly accomplishes greater things than you perhaps imagine, even with the largest and heaviest instruments. It does so to the extent that you can not only direct any quadrants whatever to any desired altitude most promptly and to a hair, and set them most exactly, but also clamp them most firmly; so that the plumb line is in no way at all moved from its true place, and an altitude once found remains always the same and unchanged — as will be shown at length in connection with the quadrants that follow.

CAPUT III.

Chapter III

De Sextante Orichalcico.

On the Brass Sextant

[Margin: The joining of the parts of sextants must be very firm.] This sextant is no less entirely of bronze than the quadrant just described. It is also made of as great a thickness as the size of the instrument necessarily requires, so that its plane cannot in any way be damaged, bent or spoiled in steering, moving and tilting it. For unless sextants are built and joined together with thoroughly firm braces and stays, they are by no means fit for obtaining observations and distances. The radius of this instrument is 3 feet long. [Margin: Why larger instruments were not built at the start.] I did not dare to build a larger one at that time — at the beginning, that is, of my observations — lest too great a weight burden the observer and hinder the observations, by keeping the instrument from being carried readily and with no effort from one place to another together with its support. This support, for the same purpose, likewise, like the preceding one (that of the quadrant, that is), of sturdy wood

Diagram. Full-page engraved plate, captioned *Fig. B.* below its ground line. A sextant stands on a tall turned wooden pillar carried by a three-legged trestle with a flat disc at its foot, on a plank floor before a balustrade. The sextant

frame is a triangle of two radii and a graduated arc, braced by crossing bars, mounted at its centre on a ball joint at the head of the pillar; a short cylindrical post stands at the apex, and a sight is fixed at the upper end of the arc with a second sight on the arc below it. Lying on the floor in the foreground are loose parts: a jointed piece with a ball-and-socket housing and threaded ends at left, and at right a small sight on two pins and a small cylinder on a pin. No lettered key is engraved on the plate.

- Arc numerals, from the lower left end towards the upper end: 60; [?] (30 or 50); 40; 30; 20; [?] (near the upper end, set at an angle)
- Caption (below the ground line): Fig. B.

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— oak — about six feet high, and is built so that it can very easily be joined and united by one or two screws, and equally be taken apart or separated again. This pedestal differs from the previous one, however, in that it has only three feet and only three directing, or adjusting, screws, by which sextants are supported more firmly and more conveniently. [Margin: The support always keeps the same height.] Moreover, this support always keeps the same height; although, if the matter required it, it could be extended a whole foot further, by means, namely, of the upper part — the column inserted into that round wood — to which that movable brass ball is fitted. But I have no need at all of that arrangement, even though Tycho's supports were built in such a way that they always carried out their observations standing on their feet, without bending the body. For we measure all distances most comfortably sitting down, at any inclination and direction of the sextant, with the help of a special chair that can be extended and drawn in at will, as you will see and understand when we come to our larger instruments.

[Margin: Construction of the ruler.] The ruler of the instrument itself, like the whole body, is of brass, and is indeed so solid and well consolidated that it cannot easily be bent or acquire any defect; especially since it rests on the arc on every side so very exactly, and clings to its edge, that it can in no way be dislodged, and yet it can be moved very gently to any distance. Towards the end of the ruler, namely below the pinnule, a screw is inserted, by which, once the interval has been found, the ruler is fixed so that it does not leave its proper place, as has mostly been the custom until now. You may say, however, that the ruler should be clamped to the arc uniformly, to the point that it cannot easily be driven from its proper place. [Margin: The ruler must be able to turn.] That is indeed easily done, either with a nail tightened further at the centre, or with a small steel spring [plumula] acting as a brake; but I would have you know that this very thing contributes least of all to obtaining exact observations. For in that way the ruler cannot be guided and moved with a finger this way and that so very lightly and readily as the matter requires. Then, if the ruler sits on the instrument more firmly than it should, it mostly jumps or springs back, so that you can almost never obtain, so precisely, the very distance you would wish. [Margin: Rulers that are fastened to the limb only by

a clamping screw never determine the matter accurately.] Hence, whether you use this firmer ruler or else the screw mentioned above, by which the ruler is to be clamped to the arc, then however very practised you are in this business, you will nevertheless by no means — not even once, except by some chance — determine the distances of the stars quite as accurately as the matter demands, as you too know very well, because of either the resistance of the ruler or the fault of the screw, which, when tightened, produces a discrepancy. And so, with instruments of this kind, which both Tycho and others, as far as I know, have used until now, very many intervals do not attain their due precision; they would indeed attain it if the rulers could be drawn very gently in every direction by a practised observer, as he wished, and would adapt themselves to the nod of his mind and hands. From this one may conclude with certainty that with such instruments, in times past, nobody at all could have measured distances as safely and correctly as ought indeed to have been done. It surely happened by chance if ever the same distance, repeated again several times with the same precision, came out as it should in the very minutes, not to say the seconds.

Moved by this, therefore, I devised an entirely different method of directing the rulers with their pinnules, which I afterwards also applied constantly, with the happiest success, to our larger bronze instruments. [Margin: Formerly the loose rulers of sextants were always directed with bare hands.] For since in that old method the rulers have to be moved and directed with bare, uncovered hands, it can in no way be done so accurately that you do not go somewhat wrong, now in excess, now in defect. This is especially so in winter, in the most intense cold, when the better observations must mostly be carried out because of the clearness of the sky — when, that is, the cold slips in through the nails, and the fingers grow so stiff from constantly feeling and handling the ice-cold metal that you cannot even control them, let alone sense in which direction the ruler is being drawn. Sometimes, indeed, one must abstain from observing altogether, because the excessive cold cannot be endured. For in that method, as I was just saying, the rulers have to be moved with bared fingers; otherwise you will produce nothing accurate whatever. [Margin: The author has devised a new method, by means of a single …] Conversely, by this recent method of ours, the rulers and sights, to a nicety, with the help once again of a single screw only, are governed; and indeed all observations are always carried out not with bare hands but with hands protected by gloves. [Margin: … directing screw, of directing the ruler, and that with covered hands.] This will be explained more fully in the description of our larger quadrants, sextants and octants, to which I have at all times applied this invention.

[Margin: On the pinnules and the cylinder of the sextant.] Furthermore, in place of a sight at the centre of the sextant, a brass cylinder is set up, 1½ digits in diameter and 2 inches high. Towards the observer's eye, at the end of the ruler, the other pinnule, with two small slits that stand apart from each other by the thickness of the cylinder, is firmly fixed with separate screws, so that, if

it has not been fitted to the instrument quite correctly the first time, it can be opened up again, moved a little from its place, and so corrected completely — that is, when the sight does not answer to a stricter test. How this test ought to be made we have partly touched on already in the Proem, and partly it will have to be told somewhat more clearly in its place. [Margin: The divisions of this sextant agree with the divisions of the instrument above.] Moreover, the divisions of this sextant correspond exactly to those found in the preceding quadrant, both as to the parts of the minutes and as to the transversal lines (since both instruments are of equal size), as will be drawn for the eye when the various divisions of the instruments are dealt with expressly.

[Margin: Sextants must turn as freely as possible at will.] Sextants of this kind are mostly used for the distances of the stars, but rarely for altitudes if quadrants are at hand, even though they can in some measure also take the quadrants' place. Reason therefore demands of necessity that they turn as freely as possible and obey every direction, so that they can now be raised, now lowered, now inclined with respect to the horizon, or to the plumb line, to any plane of the stars or position of the phenomena; yet in such a way that at any inclination, even an irregular one and one very close to the vertical plane, it always holds firmly in the same place and never leaves it even in the least for as long as you wish. Otherwise, indeed, all the labour would be in vain if the instrument resisted its proper plane, or if it, most exactly and most constan- tly, refused to hold it for any distances of the stars whatever — as those more experienced in these matters understand perfectly well, even without my saying so. [Margin: What is moved gently is rarely moved quickly.] And yet these two things are entirely different, indeed contradictory: to be able to be moved most gently and most quickly, and at the same time, in the same moment, without any screw at all, to stand most firmly in the same plane of its own accord, so that it cannot be shifted from it unless some force is applied. But be that as it may, exquisite observations absolutely demand it; whether the thing is entirely possible, however, will become clear from what is to be said.

[Margin: How Tycho controlled his sextants.] The most noble Tycho, the first inventor of the sextant for obtaining the intervals of the stars, applied to his wooden sextant of six feet, as is clear from his *Mechanica*, a wooden globe covered all over with brass, two feet in diameter, and carefully furnished, with much labour, with a great many different iron springs [plumis ferreis]. [Margin: The author attempted the matter quite differently.] I, however, have at last learned by experience that there is no need for so very large and so anxiously elaborated a globe, since I can manage the same thing with a far smaller little globe, and indeed far more accurately, at any inclination whatever and without any trembling. For sextants of this kind, the smaller ones of three feet, I at first used no little globe, but only that small instrument which is familiar to geometers for directing astrolabes, and which has a double hinge [cardo] — a transverse, or crossed, one — such as you see depicted in the preceding figure. [Margin: A prop turning on a double hinge was applied to the sextants.] With

its help, I say, I carried out observations not so very badly — but, so that you understand the matter rightly, with the smaller and lighter sextants, in which the weight did not prevail. [Margin: Larger sextants must be directed by another method.] A similar instrument made with a crossed hinge could indeed be applied to larger sextants as well, in proportion to their weight, constricted so tightly that it would hold the sextant properly; but with this very great inconvenience, that it could scarcely be moved from its position even by great force, and not without damage to the whole instrument; and conversely, if it were not of such strength, it would not stay put at any inclination, namely once the centre of gravity was already moving out, unless it were held up by other supports — which, however, would be very troublesome to the observer.

[Margin: To construct a turning globe for moving and directing sextants.] For this reason I removed this prop, which turned in two ways, from my instruments altogether, and placed beneath them instead a brass globe — for this sextant of three feet not so very large, only five or about six inches in diameter, but turned and polished as round and as evenly as possible, so that its spherical surface is entirely free of all cracks, unevenness, projections and flaws. Into this bronze globe a round iron rod, like a pillar, is inserted — or rather, so that it should be all the more solid for supporting the sextant, it is cast into it. Next, this globe is set into a hollowed hemisphere, cast from bronze of considerable thickness and well polished on both its outer and its inner side. After that a thick and sturdy ring, about one digit wide, is placed over the same globe; it should be turned and hollowed out as evenly as possible to the diameter of the globe so often mentioned, yet in such a way that the width of this ring is somewhat less than the great circle of that globe, or sphere. Further, several steel screws, 8 or 10, are set through the edge of that ring, by means of which that brass globe is clamped together with the hemisphere through the said ring — and indeed as tightly as the matter requires, by means of a turning handle. [Margin: Sextants of moderate size are directed at will [?] by means of a turning globe.] And so, with the help of this turning bronze sphere, the sextant is guided and directed at will and pleasure, and also obeys and holds fast in every plane. But great care must be taken that the sextant which is to be set on this movable globe is well bound and consolidated all round with bronze crossbars and ties, and also fastened and propped on either side with beams of steel or iron, so that it can duly resist all the force applied in moving and inclining it (since the globe is moved from its place only with great difficulty; otherwise it would not hold this rather heavy instrument in whatever plane one chose). Otherwise, certainly, it would easily depart from the perfection of its construction and contract a defect, so that it could scarcely be of any use.

[Margin: But the largest sextants are not moved as one wishes even by this turning globe alone; but] However, not even this turning brass globe, though it can perform its function in smaller instruments, proved satisfactory in every respect when applied in this way to larger instruments. Therefore I strove with all my strength so that I might, with the assent of the Divine

Will, devise another, singular method, both safer and much more convenient [Margin: they still need another invention.] — and indeed one such that with its help all sextants could be brought far more easily, lightly and readily into any plane whatever, in which they would stand firmly of their own accord, with any screws, springs or retaining devices removed. I later also applied this new invention, though in a particular way, to smaller sextants of about four feet, as will be explained in its place, to the no small benefit of the observations.

For supporting this sextant of three feet I found that turning globe strong enough, and so I also used it for instruments of this kind and size, especially at the beginning of my observations, some twenty or thirty years ago. Since I did not yet have the larger instruments at hand, I used this sextant very frequently for the distances of the stars, and indeed quite successfully (as the second part of the *Machina coelestis* will amply show), with the help of a certain assistant of mine in observing. [Margin: Ordinary sextants must be directed by two observers.] For with sextants of this kind no one can measure the intervals of the stars alone, as one indeed may with quadrants; two observers must always attend the instrument if anything accurate is to be determined — unless you have at hand another sextant, constructed in an entirely different way, by whose help even one single observer is equal to determining any distances whatever. I also obtained such a one for myself some time ago, and we shall give it, drawn and described, in the following chapter.

CAPUT IV.

Chapter IV

De Sextante Chalybeo.

On the Steel Sextant

[Margin: A single observer can direct this sextant.] The sextant we now present likewise consists of solid metal; for the most part, however, it is of steel, except for the arc and the pinnules, which are made of brass. This instrument, moreover, is constructed in an entirely different way from the preceding ones, so that one single ob-

Diagram. Engraved plate, *Fig. C.*: the steel sextant mounted for use. The sextant sits on a ball-joint head carried by a tall post, which is braced by a tripod of struts on a cross-shaped base; it stands on a plank floor before a balustrade. The arc is divided and numbered along its outer rim. Loose parts of the mounting lie on the floor in front: a curved arc-piece with two clamp-sleeves, an upright socket tube, a cylindrical sleeve with a projecting screw, a disc with a small knob, a second cylindrical piece with a threaded rod, and an open ring-collar with hinged straps; a rod with a key-handled screw lies at the left. The plate carries no letter key.

- Lower left: *Fig. C.*

- Arc numerals, from the upper end of the arc to the right end: 60 [?], 50, 40, 30, 20, 10 server can, with its help, measure the distances of stars or of comets whenever the matter requires it. [Margin: In what respects this instrument differs from Tycho's.] The most noble Tycho Brahe possessed one of nearly this kind, and of the same size as well — namely, four feet in radius. In its construction, however, and in its support and also its sights, this sextant of ours is entirely different from Tycho's. For Tycho's support wobbles easily when it is moved even slightly, and the instrument itself carries a great many superfluous things and screws, all of which we can very well do without, and still direct ours most conveniently at will.

Accordingly I use a prop in the form of a tripod, like the one I employ for the sextant described above. [Margin: This sextant can easily be taken apart.] This steel sextant itself can also be taken apart into pieces when there is need, or when one has to travel abroad. It seems to me that, since the construction of our turning brass sphere was not yet known to Tycho at that time, he necessarily needed that larger arc R S fixed to the support, as appears from his *Mechanica*; otherwise the instrument could certainly neither have been directed to a given plane nor in any way held in it, because of its weight. But there is no reason for me to concern myself with any of this. For if you have at hand a turning brass globe of the kind we have already partly described on the preceding page, and shall also partly describe more fully below, an instrument of this kind is moved as you wish and stands firm in any position whatever, even if the stars appear under the same vertical. But exactly how this steel sextant is constructed — how that sturdy steel arc, fixed to the immovable leg, passes over to the other, movable leg and supports it; how, in turn, another, smaller holder attached to this arc is to keep the other arc, the brass one marked with the divisions, always in its proper position and plane, especially when the movable leg is brought closer to the immovable one, that is, for smaller distances — all this, I say, together with everything else that belongs to the construction, even a beginner in these mechanical matters will understand best of all from the accompanying drawing, so that a fuller description is hardly needed. [Margin: The construction itself is plain from the accompanying drawing.] Anyone who however, is entirely unskilled in these matters, it makes little difference, I think, whether he understands each of these things quite correctly or not.

It should be understood, moreover, that when this instrument is to be applied to the intervals between stars [Intercapedines Siderum], the divided arc must be turned away from the observer, while the centre of the sextant, with its cylinder, is brought up to the eye — as you understand without my saying so. Next, so that the movable arc may move the more easily and accurately, I have firmly attached to each leg a small iron bar passing through movable nuts [matrices mobiles], so that it should not resist the motion. To this iron bar, in turn, a steel screw [cochlea chalybea] is joined at the movable leg, and by means of it the angle of the instrument is made now larger, now smaller, for any distance whatever. For since this instrument has no separate ruler of its own, as

the other sextants indeed have, but the movable leg — the one that marks the degrees and minutes — takes its place, the matter absolutely requires that this movable leg can be drawn in at will now, and opened out now, by means of this screw. [Margin: This sextant has no ruler; instead it has the movable leg.]

So we have no need at all of that larger and longer screw, passing from one leg to the other, which Tycho used in his steel sextant; indeed, that screw is more a hindrance than a help in carrying out observations. [Margin: It is governed by a screw of its own.] For example, let the movable leg of the sextant be set at 50°, and then immediately, without any delay, some distance of about 10° must be observed. How much time, I ask, is needed before you bring the movable leg there — through 40°, that is — by turning that screw so many times? Will you not quite often lose some excellent opportunity of observing that will never return, as with comets, the Moon and Mercury, whose observations call for haste if you are anxious to obtain anything accurate? With this screw of ours, by contrast, although it is much shorter, you can bring the movable leg in a moment, as it were, and very swiftly — from 60° even down to the first degree, if need demands — without any turning or winding of the screw at all. [Margin: The screw that directs this instrument is shorter, and far more convenient than Tycho's longer one.] For the iron bar to which this screw of ours is fixed, by means of some smaller screw, is now released from the immovable leg and now drawn tight to it again, so that you can bring the movable leg suddenly, at a single stroke, wherever you wish, to obtain the distance proposed. Then, once the movable leg is made fast with that smaller screw, you will be able — with the larger screw, that is — to determine any distances whatever to a nicety [ad unguem], and with such certainty, indeed, that once set in its proper place it can never leave it, even though you shake the whole instrument hard. So that everything may be clearer, moreover, I have chosen to set before your eyes once again, at the foot of the instrument and on a somewhat larger scale, that arc which carries the whole sextant, and also the small bar, with all its nuts and pulleys.

Our pedestal, like Tycho's, cannot indeed be extended any longer, nor drawn in any shorter; for even if it could, that would be entirely superfluous. [Margin: The support is neither lengthened nor shortened.] For provided the support is built from the outset to the height of a man, or nearly 6 feet, so that observations can be carried out standing at middling directions, we have no need of a longer or shorter support. For at the higher or lower inclinations of the sextants we always use stools of various heights [ſcabella diverſorum graduum], or chairs that can be raised and lowered as necessary; so that by means of these stools and chairs we can always carry out our observations most comfortably sitting, and never standing, or with the body bent, stooped and turned away — unless perhaps one decides otherwise. [Margin: By means of movable chairs and stools we carry out any observations whatever sitting.] This convenience is certainly no slight one in carrying out observations. Indeed, believe me, no one with his body bent, or down on his knees, will ever accomplish this as

accurately as if he were sitting in the most suitable posture — especially with those instruments whose rulers must be moved and directed with bare hands, without any screw, as happens with Tycho's. [Margin: With the body stooped and in a less convenient posture, observations are by no means carried out so exactly.] We therefore have no need at all for the supports of sextants, of whatever weight or size they may be, to be now raised and now lowered, as most people indeed have believed until now.

On an instrument of this kind Tycho had no more than two pinnules — one at the tip of each leg, that is, by the arc divided into degrees — and these, moreover, in the form of a small square plate. At the centre of the instrument, however, he placed none; instead, with the eye brought roughly to the centre of the sextant, he determined the distances on his own by means of those two pinnules alone. [Margin: In a sextant of this kind Tycho had only two pinnules; the author, by contrast, three cylinders.] In this way, certainly, he could never once obtain distances quite precisely, except by some lucky chance, however lynx-eyed one might be and whatever diligence one applied. For unless the eye always rests uniformly at a certain, most exactly determined place — or rather at an infallible pinnule — how, I ask, will you hit the mark exactly in so very delicate a business? [Margin: This instrument of Tycho's always produced parallax.] That too is why Tycho complains, and rightly, that this instrument always produced some parallax, which he first had to remove from the observations.

Seeing this, I was therefore at once concerned to find how I might remedy this inconvenience. For in observations of distances neither this sextant, for one observer, nor all the other sextants, for two observers, ought to introduce even the least parallax; rather, they must at every time and place give the distances of the stars — of the fixed stars, that is — entirely correct and in no way corrupted. [Margin: No sextant whatever ought to introduce any parallax.] Accordingly, at the centre of the instrument, as we have been accustomed to do in other sextants, I placed a cylinder of its own in place of a pinnule; but one fitted out in a singular way, such as hardly anyone, beyond all doubt, has ever seen until now. [Margin: The cylinder is built with special movable wings that serve both legs at once.] On each leg of the instrument, at the arc that carries the divisions, we likewise fixed a cylinder, about 1½ inches in diameter and nearly 2 inches high, so that this sextant has three cylinders and no plates at all, such as Tycho indeed had. The cylinder that stands at the centre and is brought to the eye has wings, as you see on the pinnules of quadrants and other sextants; with this difference, however, that on this cylinder the wings are movable, by means of a certain small brass tube to which they are firmly fixed, and with which they can be turned round the cylinder. Between the movable wings and this cylinder, moreover, two small slits have been left, wide enough that the stars can conveniently be made out through them while one observes.

[Margin: How an observation is made.]

So when the distance between two stars is to be determined with this sextant, the fixed leg is first directed accurately at one fixed star, by means of that movable cylinder at the centre and the other cylinder at the limb. Once this is done, the whole instrument is at once clamped firmly to the ball on which it stands, by a screw intended for the purpose, so that it cannot move out of position. Then the movable cylinder is immediately to be turned through a right angle toward the other leg, the movable one, and its cylinder, so that, by means of that screw fixed to the small iron beam, the leg can be directed precisely at the other star. With the legs thus turned most exactly toward those two stars, you have the distance of the stars you are looking for. But you must repeat these observations several times and with every care; otherwise you will certainly go astray very easily with this instrument.

[Margin: The wings of the cylinder are always set at a right angle to each leg of the sextant.]

So that the wings of the cylinder at the centre of the instrument always stand at a right angle, of their own accord and precisely, with respect to each leg and to that leg's more distant cylinder, a small pin is fixed in each leg near the wings; so that, even in actual darkness, the wings can always be set at a right angle, and never otherwise. For better understanding we have also shown this movable cylinder, both whole and taken apart into its parts, in a somewhat larger drawing in the preceding figure.

[Margin: The divisions on this sextant are slightly different.]

I likewise completed the divisions on this instrument with my own hand, as carefully as I possibly could — again, that is, by transversal lines, but in a slightly different way from the two preceding instruments. For since this sextant has a radius of 4 feet, the circle could be subdivided into somewhat smaller parts, and with fewer circles, in this way: each degree is first divided into three equal parts, and then a third part of it into four parts, so that with the help of only five circles you can correctly distinguish half, and indeed a quarter, of any minute.

[Margin: Instruments of this kind, for a single observer, never do the work as accurately as the others do with two observers.]

Lastly, my lover of the stars, I would not have you unaware that I have used this sextant for the more delicate work only very rarely indeed — however skilfully it is made of solid metal for its size, however exquisitely it is divided and well furnished with exact pinnules, and although it obeys every direction as one could wish. For although instruments of this kind are more finished than any others, a single observer on his own by no means searches out the intervals between the stars as accurately as two observers do with a sextant equipped with a movable ruler, both of whose legs are fixed and all of whose parts are firmly braced with crossbars and timber framework.

[Margin: The author used this sextant only very rarely.]

And so from the very beginning I took care to obtain several of this kind, and indeed ones still larger in radius, with which, in the course of time, I carried out all my observations as well — as many as Books II, III and IV of the *Machina*

Coelestis contain — together with a well-trained companion whom I always kept in my house for that purpose. If, however, I sometimes obtained some distances with that steel sextant on my own, I by no means accepted them as beyond doubt until I had examined and confirmed those very intervals several times with other sextants and octants, and indeed larger and more solid ones.

CAPUT V.

Chapter V

De Quadrante Horizontali ligneo.

On the Wooden Horizontal Quadrant

The instruments described above, such as the quadrants and sextants, are built so that they can conveniently be carried elsewhere and set up in the open air, anywhere one pleases.

[Margin: This quadrant must be kept in some fixed place.]

This quadrant, however, because of its size and weight, is not so readily moved to any place, and particularly not into the open air; rather, it serves the observations best that some suitable place under a roof be assigned to it for carrying them out. For although it consists for the most part only of rather solid oak wood — if you except the brass arc, the pinnules, a few crossbars, clamps, props, and the bronze ball on which it stands — it is nevertheless

Diagram. Full-page engraved plate, *Fig. D.*: a large quadrant in use indoors. The quadrant is a wooden frame of braced timbers, with its arc at the bottom, divided and numbered; its two radii meet at the upper end, from which a plumb line hangs to the arc. The instrument is carried on a cylindrical pillar, banded with a metal strap, that stands on a tiled floor, and the arc rests on a fitting at the top of the pillar. A small sight stands at the upper end of the frame, and a cylindrical sight at the right-hand end of the arc. An observer, wearing a cap and a long coat, sits in a chair at the right, looking up toward the instrument and holding a weighted cord in his raised hand. On the wall behind, two weight-driven clocks hang at the right, with their weights and pendulums; a third clock, with a bell on top, stands on a shelf at the left. Above, a bracket fixed to an upright timber carries a small plank with a pin and a disc. In the foreground lie loose parts: a disc seen face-on, showing an internal cut-out and a screw; and an open box-shaped sight fixed to the end of a long rod. The plate carries no letter key.

- Lower left, beside the disc: *Fig. D.*
- Foot, left of centre: *A. Steck Delin.* [drew it]
- Foot, right of centre: *J. Saal Sculpsit.* [engraved it]
- Arc numerals, from the lower left end of the arc toward the observer: 10, 20, 30, 40, 50, 60, 70, 80 difficult to move from its place and carry elsewhere except with the help of two men.

[Margin: The author's former observatory, and what its construction was.]

At first my astronomical observatory was not open to the sky on every side; it was roofed over at the top. It did, however, have windows facing the four cardinal points of the world, tall and wide open, and these, just as they could conveniently be opened and closed again, were all equally well suited to quadrants. For beside each window stood a movable wooden column, as you see from the accompanying drawing, on which a quadrant was hung. By means of this column the instrument could not only be turned round readily but also, as will be explained more clearly a little later, be set exactly to the rule of the plumb line, that is, to the vertical line — and with no effort at all.

[Margin: The size of the quadrant.]

The quadrant itself measures four cubits, or six feet, from the centre to the circumference. It is amply strengthened with crossbeams and timber framework, so that it can stand up well to any movement and can by no means depart from its accuracy or easily contract any fault. It was built almost entirely on the pattern of Tycho's revolving quadrant [Quadrans volubilis], which is nearly the foremost of all the others, since at that time I did not yet know a better method of constructing quadrants.

[Margin: This quadrant was very like Tycho's revolving one.]

[Margin: How it is hung and governed.]

This quadrant hangs on a round wooden column six or seven inches [digiti] thick. That column in turn stands on another, sturdier column, which is very firmly fixed to the window by hooks and stays; at its upper end it turns, by means of a round iron pin, in a hole — also of iron — in the upper part of the window. So that the upper part of the column, together with the quadrant, can be turned round lightly, a wooden disc is inserted by its axle into a bored block fixed to the lower part of the window and set upon it, as we have sketched in the figure. On the face of this disc a special iron fitting is fixed with small screws; its middle part, which is sturdier, is moved to and fro by means of a longer screw. Into this movable middle iron, in turn, a square hole has been let, so that the longer, upper column can be set on the lower one by its axle, which is likewise square and of iron — and in such a way, indeed, that the directing screw, on the far

[Margin: How, by one single screw, the whole instrument is governed toward every quarter of the sky and to the plumb line.]

side, stands at right angles to the plane of the quadrant. For in this way, in whichever direction you turn the quadrant, the screw just mentioned always makes right angles with it. And so, by the help of this screw alone, in whatever position and at whatever altitude the instrument leans toward or away from the vertical line, however far it may lean, you can at once, with no trouble, correct it and set it to a nicety, so that the plumb line, which shows the degrees and minutes, neither stands too far off the limb of the quadrant nor clings to it too closely.

[Margin: Great importance lies in the setting of the plumb line.]

This the matter absolutely requires in these instruments: for unless the plumb line touches and shows the limb and its divisions properly and exactly, you will certainly stray from the truth continually — indeed, sometimes even in the degrees. I therefore urge every observer who takes sights [Collineator] to take good care over this, so as not to be deceived. He can best avoid it by means of that directing screw, by which the whole column to which the quadrant is fixed is set most exactly to the plumb line in any position. Everyone will understand this more fully who weighs somewhat more deeply the drawing of the preceding quadrant, and the thing itself as well.

[Margin: Although this invention may seem of scarcely any importance, the author nevertheless ranks it among the most important — that is, for directing the largest instruments.]

I am of the opinion that, however slight this invention may seem to some, it is nevertheless of the greatest importance for directing these and similar instruments, whatever their size and weight, and for setting them most conveniently to the level. Believe me, this method is much more convenient and better suited than Tycho's, although he had a quadrant of this kind hung on a round iron rod like a column. For he needed his iron column to be shifted from its place with the greatest force, by applying very heavy hammers — which could sometimes be done only with the greatest inconvenience to the observer and with loss of time. Indeed, more often, though you put every effort into it, you will nevertheless, because of that extremely violent motion — driving the quadrant, as it were, with wedges now this way, now that — by no means bring the instrument to its due precision by that method; you will err now by excess, now by defect, as anyone will learn amply by experience. But with this, our

[Margin: This method of ours for directing quadrants is truly far more convenient than the one Tycho used.]

own directing screw, the whole column, together with the quadrant itself, is moved and directed so gently in any direction — and indeed always to the plane of the vertical — that you do not feel it in the least, nor does the whole instrument wobble. With wedges and hammers, by contrast, this is attempted entirely in vain, however careful you may be and however skilled in these matters.

[Margin: By what means the quadrant is directed to any altitude with the help of a special movable arm.]

The quadrant, then, is hung on a round, oblong iron rod fixed to the column (which serves as a prop), with its channel set at the centre of gravity of this quadrant, and it is fastened firmly to that same prop by a screw. In this way you can conveniently examine any observations and altitudes while seated — by means, that is, of a plumb line hung, as you see, from the centre of the instrument to the upper pinnule. So that this can be done all the more exactly, I fixed to the column an iron arm, movable together with the quadrant in parallel motion, so that it is kept always in the same position and at the same distance

with respect to the instrument. To the end of that arm, on the side toward the observer, a brass pulley has been added. By its help, and that of a cord led over it and tied to little hooks set in the opposite part of the quadrant, the instrument itself is moved and directed to any elevation as lightly and as gently as possible with one hand — indeed, as you will readily understand, with a single finger.

[Margin: How the quadrant stands most firmly in every position, and of its own accord, by the help of a counterpoise.]

Next, so that this quadrant may also never fail to stand motionless in any position and at any altitude, a weight is hung on the cord that the observer leads by hand. This weight duly answers to and fully satisfies the counterpoise of the whole instrument, so that the quadrant is held accurately at whatever altitude and does not easily leave its position. In certain higher positions, however, if the quadrant does not yet obey this single weight, a second [?] weight is fixed opposite, to the other leg. While this drives the quadrant toward the horizon, it preserves the equilibrium all the better in every part, and precisely at any altitude, so that because of the balance of weights it can by no means leave its place of its own accord. And so with the least force you are well able to raise and lower even instruments of however great a bulk — and indeed most conveniently, either standing, if the

[Margin: Sometimes the greatest things are accomplished by the least.]

altitude does not exceed 45°, or seated at the remaining elevations — with the help, as we touched on above, of our stools and chairs, which can be lengthened or shortened at will. So you see that this method of turning quadrants about, raising them, and examining the plumb line and setting it exactly is not altogether to be despised. Nevertheless, in the course of time I devised a still far more suitable and convenient way of achieving all these things, as will be shown in its place.

[Margin: Although it is plain that this method of directing is convenient enough, the author nevertheless found a far more convenient one afterwards.]

The pinnules, or sights [Dioptræ], are built in exactly the same way in which we usually make them on most of our larger instruments, as will be described more fully in what follows. The pinnule nearer the eye has four slits, or little chinks, for examining the stars; by a special device of small wheels these can be widened or narrowed, as the light and size of each star requires. The other pinnule, however, at the centre and opposite this one, is merely quadrilateral and has no chinks at all, so that by means of its edges you are not unable to mark the stars to be observed. Those chinks of the first pinnule that are parallel to the horizon are used for altitudes; the vertical ones, together, for determining azimuths, finding the meridian line and examining its altitudes — but of these too we shall have to speak more fully below.

[Margin: Of what kind the pinnules of this instrument are.]

If, however, you want altitudes of the Sun by day, we use, in place of the chinks, a very small hole made in the centre of the first sight, through which the Sun casts its rays onto the centre of the other, lower pinnule. From this

centre, moreover, a small circle has been described — on the inner surface of the pinnule, that is — and of just such a size as the Sun's disc requires for its circle at the given distance between the sights. For determining the Sun's disc it must be neither larger nor smaller, so that it takes in nothing but the whole face of the Sun, and nothing more. In these solar observations, moreover, it helps to use a square paper tube, otherwise empty of lenses and somewhat wider around the lower sight, such as we drew in the preceding figure; and between

[Margin: By what means solar observations are carried out.]

[Margin: A tube is absolutely needed.]

the two pinnules it should be either hung on little hooks or tied with some cords, so that the light of the Sun and its rays (as usually happens in a darkened chamber) cannot fail to be led all the more vigorously and brightly through the tiny hole of the first pinnule to the small circle of the lower one, and so that the altitudes and azimuths are determined all the more precisely. Otherwise — without this plain tube, that is — you will certainly attempt the thing in vain, and, believe me, however much you leave no stone unturned, you will achieve nothing perfect and accurate, as experience, the mistress of things, will teach anyone.

As for the divisions, we likewise expressed them on this quadrant by means of transversal lines and five circles, in such a way that each whole degree is first divided into three parts, that is, 20′ each, and then each third part is divided again into four parts. So, if you examine the matter with an eye that does not wander and use a very fine thread or plumb line, you can without difficulty distinguish clearly not only the single minutes but also their fourth part — indeed their sixth.

[Margin: The method of the divisions.]

Since, then, this quadrant was built most carefully in the manner Tycho used, and divided into its parts most finely by me myself, and furnished as well with more accurate pinnules, and since it also obeys every motion and direction exactly with the help of that directing screw, I used this instrument very frequently at the beginning of my observations — above all for obtaining the meridian altitudes of the Sun and of the fixed stars, and their declinations. At first, indeed, it did its duty well for the space of some years. In the course of time, however, the same thing happened to me as to Tycho, as [?] I have learned amply enough by experience: namely, that all wooden astronomical instruments, in whatever way they are built of rather solid wood, whatever crossbeams, timber frameworks and iron clamps join their parts together — indeed, even if the whole instrument is well coated with oil or with paints, or even artfully encased on every side with brass plates and protected — nevertheless change and deteriorate with time, according to

[Margin: At first the author used this quadrant rather often.]

[Margin: In the course of time wooden instruments fall short of their original perfection.]

the nature, that is, of the woods, which are highly liable to change and to decay from the air — as Tycho likewise rightly observed, Book II, page 256. For either the pinnules are partly shifted out of their proper place by this alteration, or sometimes the whole instrument as well is bent and departs from its straightness, that is, from its perfectly flat surface, so that the divisions — although at the outset they were more accurate than any — can no longer satisfy the observations. For when the arc, or the instrument, is bent, all the distances appear really otherwise than they are; and this error runs not only to a few seconds but quite often even to whole minutes. Such a fault is certainly not so easily corrected in these instruments; indeed it is noticed only with difficulty by anyone at all, even if he looks after his affairs with the greatest care. Hence it happens not seldom that several years go by, and a great many observations are made with the instrument in that faulty state, before it can be detected and properly restored. How much disturbance and confusion this then brings upon posterity and upon the future makers of tables — when the observations do not correspond exactly with one another at all times, and the distances of the stars are not always entirely the same, as has quite often happened to certain distinguished observers with those wooden quadrants and sextants — those skilled in astronomical matters understand without difficulty.

[Margin: The faults that instruments contract are not so easily corrected.]

[Margin: If instruments unexpectedly contract a fault, that is very damaging to observations.]

Since, then, I had clearly detected these things, I at once set to work to free the quadrant completely from those faults it had contracted through long use, and to bring it back to its former perfection — although it is no trifling matter to restore a distorted and damaged instrument completely once again. But it occurred to me, and indeed [?], that no observer whatever, however perfect the instruments he possessed at the start, could ever in the course of time be entirely sure — even if he had corrected and examined them several times — that over a space of many years, that is, they would not contract faults or be altered in any way, or that they would be passed on wholly unharmed and unchanged to his successors and to posterity. For nothing is more certain than that

[Margin: Even if we restore wooden instruments once, we are never secure about their constancy.]

the wood in no way departs from its corruptible nature — above all since instruments are quite often used in the open air and are frequently exposed to snow, rain, mist, dew, hoarfrost, heat and cold. As a result they are all the more readily liable to alteration and easily contract some fault, even though they have been coated with pitch in many ways, covered all over with oiled linen cloths, and their parts firmly glued to one another.

[Margin: Wood is very liable to decay.]

Every diligent observer, therefore, has reason always to fear for himself whenever, that is, he uses wooden instruments, lest he undertake and carry

through an immense labour which he will afterwards regret most of all. And so at last I resolved, seeing that it would be much safer and better if I built the quadrants, sextants and octants of solid metal, with all wood removed. For in that way the instruments would certainly never fall away from their original perfection, once they had been made perfect in every respect at the very outset, examined most rigorously by various methods, as is fitting, and approved by long use; rather, they would always preserve their complete integrity with the greatest constancy and contract no harm from the air — provided only that due care is taken that they do not fall, or are not damaged through carelessness, or violently struck. And so, I thought, there would be no reason to fear that the observations would be either wavering or discrepant (as we now indeed find even in the observations of certain most distinguished men); rather, provided they were always taken with equal care, they would necessarily be equal in every respect and agree with one another to a hair. This, too, is what is most of all sought in this business: that the observations be constant and consistent with one another — those, namely, that ought always to coincide. Otherwise you will continually create inextricable troubles, both for yourself and for posterity.

[Margin: Observers should beware lest they be badly deceived by wooden instruments.]

[Margin: The author finally saw very clearly that bronze instruments would be altogether more constant.]

[Margin: Observations ought to agree with one another at all times.]

On this occasion it also occurred to me to construct such instruments of bronze — which would be extremely costly and would equally demand art and labour — and to make them of such a kind that their weight and heaviness would not hinder their use and movement. For all astronomical instruments must of the utmost necessity be in every way able to turn, and easy to handle, if anything solid is to be achieved. These were also the reasons that moved Tycho himself to build his larger quadrant, sextant and octant at that time not of pure and solid metal but for the most part of wood: as he imagined, they would be too heavy and cumbersome to manage, and this method of managing such instruments conveniently had not yet been explored and discovered at that time; otherwise he would certainly not have had instruments of that kind made. For surely you need not think that the excessive expense to be laid out on them drew him away from his purpose? Not at all: he himself was not only very rich, but also had at his disposal the royal purse, which never failed him in founding instruments. He could therefore have acquired such very costly things much more easily than many a private person, who has to draw all the expenses from his own purse alone.

[Margin: At first it seemed to the author an arduous task to build very large instruments of bronze that would turn.]

[Margin: Why Tycho chose wooden instruments.]

[Margin: Tycho could far more readily have founded instruments of solid metal than any other private person.]

Nevertheless I did not let myself be deterred or turned away from that purpose. Rather, just as I found in my mind, from my very youth, an immense ardour to advance these studies, so I strove with all my strength not only to devise bronze instruments so fitted together and united on every side with iron beams and bands that they would resist no motion — that is, no directing and inclining — and could in no way at all be bent or contract even the least fault, but also, what is more, that they would not burden the observers with their weight or cause them disgust, however many hundred pounds any one of them might weigh. This was certainly not so easy to do as someone perhaps will imagine on looking at these instruments of ours, such as they are; on the contrary, it truly cost me sweat — indeed, I spent a great many sleepless nights before I had devised all the requisites and aids and had brought each and every one of them to convenient use and the desired end. For I did not draw these inventions from elsewhere (be it said without boasting), nor did I secretly take them from anyone else, as once happened to Tycho at the hands of Wittich [Paul Wittich]. Certainly not; indeed, to tell the truth, never even an instrument of that kind, either on my travels or wherever

[Margin: The author spared no effort to obtain suitable bronze instruments.]

[Margin: Not without great sweat did the author procure for himself a sufficient apparatus of instruments.]

[Margin: The author himself first had to invent a great many things.]

else I have been, has come my way — of such a size, I mean, not even a wooden one, let alone one wrought from solid metal — from which I might have drawn some design, or which might have given me occasion for some new inventions, however slight. Nevertheless, by the kindness of God, on whom I have always relied, I at length happily acquired in the course of time the things I had always wished for from my heart, for the honour of the Most High and the benefit of astronomy. How all of them are built, and how successfully they are managed, will be treated most fully in its proper place — once I have first set before your eyes, kind reader, the remaining instruments, made partly of wood and partly fitted with brass plates.

[Margin: What they were, you will learn in their place.]

CAPUT VI.

Chapter VI.

De Sextante magno ligneo.

On the large wooden sextant.

Since we are now engaged in describing, in order, our wooden instruments made in the Tychonic manner, I think it worthwhile to give a drawing and description of this sextant, which in former times we often used for taking the distances of the stars, before I had acquired more solid bronze ones. It is built exactly like the preceding quadrant, on the plan of Tycho's better sextant,

and of the same size — namely four cubits or six feet, indeed somewhat larger. Moreover, it is made of rather dry and solid oak, very well braced with cross-beams and timber framework; and, like Tycho's, it is skilfully fitted with a brass arc and provided with a sturdy ruler and brass pinnules. For at that time I could not be persuaded that I would ever be able to fit out and build a better sextant than one on the plan of that sextant of Tycho's which the most noble Tycho himself constantly used for his chief and weightier observations to the very end of his life, and also always held to be the best of all. The eminent Tycho just mentioned himself, in his *Mechanica*, in the description

[Margin: This sextant too was built after the pattern of Tycho's more excellent sextant.]

[Margin: The author had never persuaded himself that instruments better than those made in Tycho's manner could ever be fitted out.]

of this sextant, testifies that "it gives the intervals of the stars with such certainty and precision, and so quickly and easily, that nothing could be wanting in it." So it is quite certain, and no one disputes it, that this very instrument was the chief and the most perfect of all the other instruments he then had at his disposal and that were then known — even though he possessed others far more splendid and costly in appearance. Hence I rightly place far greater trust in the observations made with this sextant by Tycho himself than in all the others, made with other instruments of whatever kind by his companions and students; as the *Historia Coelestis* of Tycho's observations abundantly proves.

[Margin: Tycho preferred a sextant of this kind to all his other instruments.]

[Margin: He possessed more costly ones, indeed, but not more perfect ones.]

[Margin: More is to be attributed to the Tychonic observations made with this instrument than to the others.]

Why Tycho built this sextant not of pure metal he relates himself in his *Mechanica*: "For if," he says, "all its parts were covered with metal plates" (how much more, then, if it were entirely of bronze, as all our instruments now are) "the instrument would be made unmanageable by its excessive weight. Indeed, by its own heaviness it would work against itself in being held in its proper plane." At first, then, I was of the same opinion — or rather, following Tycho's opinion, I had imagined it so — and so I had this sextant made on the Tychonic plan as carefully as could ever be done. I myself transferred the divisions to it with the greatest diligence, in the same way as on the quadrant above, so that it was capable of showing single minutes, and every 15″, indeed every 10″. Then I also provided it with good sights, set very accurately in their proper place, and tested it to the point that it did its proper duty for me in observing. Even so, this sextant did not show, in every one of the intervals of the fixed stars, the very same separation of the stars that Tycho had noted; but where this small discrepancy came from — whether from my carelessness, or from Tycho's, or from that of his assistants — will have to be learned in its place.

[Margin: Why Tycho did not have his sextants made of bronze.]

[Margin: At first Tycho's reasons moved the author to build wooden instruments as well.]

[Margin: The author praises the construction of this sextant.]

At the very beginning, however, I at once found abundantly from practice itself that observations — not with such speed, ease and preci-

[Margin: The author learned by experience, not with such success, …]

Diagram. Full-page engraved plate, Fig. E: the large wooden sextant described in Chapter VI. The sextant's frame of timbers, braced by many cross-pieces, stands in a vertical plane on a turned column carried on a heavy wooden tripod with splayed feet and a round foot-plate. A ball joint sits behind the frame where it meets the column. The graduated arc at the lower left is numbered every ten degrees, with a sliding clamp on the arc where the movable ruler (the long diagonal timber pivoting at the apex) meets it, and a second block at the lower end of the arc. The scene is set on a boarded platform with a balustrade behind; at the left stands a small adjustable stand (a post pierced with holes, carrying a flat top on scrolled brackets, on a three-armed foot), and on the floor at right lie loose parts: a block with a projecting screw, a stack of discs, and a further block with a cranked handle.

- a (top right, at the apex beside a cylindrical stub): label only
- b (upper left corner, end of the arc): label only
- [?] (mid-length of the upper edge, between b and a): one letter, not resolved
- e (on the right-hand leg): label only
- f (on the arc, with a leader stroke): label only
- c (lower corner, where the right-hand leg meets the arc): label only
- 10, 20, 30, 40, 50 (degree numerals along the arc, running from c towards b)
- Fig. E. (caption, lower left) sion as I had earlier imagined were carried out with this sextant. And although, being made of wood, it was in itself far lighter than if it had been built of solid bronze, it nevertheless gave us a great deal of trouble in bringing it into its proper plane and in fitting its ruler to complete precision, as the matter demands.

[Margin (continued): as he had imagined, that observations could be carried out with this sextant.]

For the ball, fitted in Tycho's manner, on which the sextant was set, never and nowhere stayed in place of its own accord, nor could it hold the sextant firmly in any plane whatever unless it was carefully propped with two longer staves, as can be seen in Tycho; one of the observers guided these by hand to obtain the instrument's proper inclination. This was truly very troublesome and laborious for the observers: to keep raising and lowering by hand an instrument of such size — one which, though made for the most part of wood, was nevertheless not without a weight of its own — and to hold it firm and entirely motionless in the open air, especially when the wind was blowing,

without any tottering or wavering, while at the same time giving their attention to scrutinising [the sky].

[Margin: Various obstacles presented themselves at the outset of observing.]

I therefore at once set another support under it, of almost the same kind as you see on the smaller brass sextant, except that it was somewhat larger, stronger and taller. Straightaway, too, in place of that Tychonic ball I built another holder, furnished with a double hinge — indeed a transverse or crossed one — but made of wood, so that its weight should not hinder its use: such a holder as we have sketched in the accompanying figure. But even this did not satisfy my wish. For although it seemed to me better suited than that Tychonic ball, the sextant still could by no means be kept precisely in any plane and position whatever with the help of this revolving holder, unless you brought up those two staves to support the holder and keep it in its place.

[Margin: The author substituted certain other aids to make observations easier.]

Not yet content with this device, therefore, I fitted out another ball, cast of solid metal and about twelve digits in diameter, with its cup, into which the ball was to be set; and I also made a bronze ring to be tightened by various screws — as has already been partly said above, and partly also below, in Chapter IX, in the

[Margin: The author fits a new revolving ball, for convenient direction of the sextant.]

description of the bronze sextant, will have to be explained more fully. However tightly this ball is clamped by its casing and its ring, it nonetheless turns round wonderfully smoothly and evenly, so that by means of this revolving ball the sextant can be directed to any position whatever, and can also be kept in any plane whatever without any props or holders, by its own strength and its screws alone. In certain positions and planes, however — above all those inclined to the horizon — we could not hold the sextant, deprived entirely of any other external aid, so tightly and so firmly that it would not move from its place in the least. For even if you had tightened this ball more closely to the cup by its ring and the screws, you could not have moved the sextant from its place by so much as a nail's breadth, let alone directed it in any direction you pleased. This seemed to me very tiresome: that the ball and the sextant utterly refused to obey my bidding, and so it was in no one's power, whether with this ball or with that Tychonic one, to carry out observations entirely correctly and accurately in every respect.

[Margin: The revolving ball alone is not equal to holding and directing the sextant; it must be helped by weights.]

And yet I did at last partly remedy this inconvenience with certain weights, to preserve the balance. We do not wish, however, to go on at length about these on this occasion; let us put them off until we come to those larger bronze instruments.

The pinnules of this sextant are just like those seen on the preceding quadrant: there are two of them, namely one fixed to the leg of the instrument and the other standing on the movable ruler. There is, however, this difference between the sights of this sextant and those of that quadrant: on this instrument the pinnules have only two small slits parallel to the plumb line, whereas on the other they have four slits, as we pointed out in its place. Those slits on all the larger instruments, moreover, can be widened very gently and narrowed again by a special device — namely, certain toothed drums concealed inside, at the centre of the pinnule; all of which will be fully described in their place. At the centre of the sextant, however, where the legs meet and the ruler turns, in place of that pinnule

[Margin: The pinnules of the sextant and of the quadrant: in what they differ.]

[Margin: The slits of the pinnules can be widened and narrowed by an internal device.]

in the form of a small square plate, such as is usually fixed to quadrants, I set up a cylinder. In its breadth it measures almost two inches, and so equals the distance between the two slits in those opposite pinnules; in its length it measures almost three inches, and so equals most exactly the height of the other pinnules.

Consequently, in this sextant as in all the other sextants, three pinnules are required, since the observations must necessarily be carried out by two observers, whereas with a quadrant a single observer handles the whole business by himself. One of the observers has to stand at the pinnule fixed to one of the legs; the other, the principal observer, who has the direction of the work, sits at the ruler so as to steer it as the matter demands.

[Margin: In sextants three sights and two observers are needed.]

The points that must be properly attended to in this business of observation, however, are not grasped as easily as someone inexperienced in these matters may perhaps persuade himself, nor can they be set out so briefly. Indeed — I would have you believe me — you will scarcely learn this business of scrutinising the stars from any description whatever, unless you acquire that knowledge for yourself by frequent practice and long use, and make it familiar to you. This will be discussed somewhat more fully below, for the sake of beginners; the more practised need no admonitions.

[Margin: The business of observation is to be learned not from books but by frequent practice.]

Although I suppose that some are to be found who persuade themselves that they understand this business better and more thoroughly than could ever be revealed to them by anyone else, I would nevertheless venture to affirm that if these smatterers had finer observations to carry out with very large bronze instruments, they would without doubt stray exceedingly far from the mark, and would not grasp the matter as promptly and accurately as they imagine.

[Margin: To some, scrutinising the stars is a rather trivial matter.]

Some of them have also been with me, and at first they fearlessly boasted that they could take the matter just as precisely, and in the same space of time, as any other observer however practised. But how anxiously they afterwards handled this business once they took up observing, how wonderfully they tormented themselves, and at what a loss of time before they dared to settle anything solid at all — those who were present at the time will testify. Indeed, when the same observation had to be repeated, almost never

[Margin: But in the work itself we find the contrary.]

did they find the same distance. So it is as certain as anything can be that these tasks call for long experience and practice — if, that is, you wish to determine every particular exactly and very promptly, and in a very short space of time, and on different occasions always to obtain the same distance equal to itself.

[Margin: Since the Tychonic sextants readily wobble, the author applied a remedy to them.]

For the rest, since this sextant is mostly brought to bear on the stars in the open air, it is very difficult for the one observer, who sits at the fixed pinnule, to hold the instrument with free arms and bare hands so firmly that it does not wobble or tremble a great deal — above all when the other observer moves the ruler, which otherwise clings tightly to the limb, this way and that. Nevertheless, if you are anxious to obtain anything accurate, it is above all necessary that the sextant should stand as if entirely motionless and fixed; otherwise you will lose the whole thing, and it will be in vain even to attempt anything refined. Since this can in no way be achieved with the Tychonic sextants, I brought a remedy to the matter: namely, by constructing a certain support, or prop [Sustentaculum], which can be lengthened and shortened as the position and the occasion demand, to hold up the observers' arms. In this way the sextant is the better governed and directed, and held more firmly in place, so that it does not nod even in the least, and the whole business is carried out far more exquisitely — as experience itself will abundantly testify.

[Margin: A special support to hold up the observers' arms.]

As regards, moreover, the use of this sextant: it is mostly employed to determine the larger distances, which nevertheless do not exceed 60° and are not smaller than 10°. Otherwise they cannot conveniently be taken with this instrument fitted out in the manner described, because its whole limb comprises only 60°. Nevertheless it can be constructed in a certain way — namely with the sights arranged differently — so that it shows, without inconvenience, intervals running out to 150°, and likewise even the very smallest of all, of only a few minutes. For smaller distances a further cylinder is set at *e*, towards the centre of the instrument; and on the limb of the sextant, which is marked with its divisions, at *f*, a sight with two slits is in addition fixed with screws, so that both

[Margin: The use of the sextant.]

[Margin: With the sextant, distances both larger and smaller than 60° can be taken in a certain way.]

pinnules run on a course parallel to the line that passes through the centre to the thirtieth degree, or that divides the sextant into two equal parts. Through these pinnules, therefore, if one of the observers scrutinises a star while the other stands at the ruler and uses that cylinder at the centre, measurements of any smaller distances whatever can be undertaken.

Again, if you wish to measure a distance greater than 60°, another pinnule, constructed with slits, is set at *c*, and a cylinder at *h* — namely in the middle of the leg, with respect to the divisions and to the centre of the sextant. In this way, with one observer sighting along the line through *c* and *h*, and the other through *b* and *a*, an angle of 90° is determined. Then, the further the ruler with its pinnule is moved towards *c*, the more it departs from that right angle (of 90°, that is), or the smaller that angle becomes — as Longomontanus explains more fully in Book II, Chapter VII of the *Astronomia Danica*.

[Margin: How intervals greater than 60° are handled with the sextant.]

But when pinnule *c*, with its slits in reversed order, is moved to *h*, and the cylinder to *c*, then — with one observer sighting along the line through *h* and *c*, and the other scrutinising the stars through the pinnule of the ruler — the more the ruler is moved from *b* towards *c*, the more the angle *a b c* widens. Hence, with the ruler set not at *c*, we found two stars at an angle of 150°, the angle *b a c* being 60° smaller; again, with the ruler set not at *c* but at 35°, the angle is greater than 90° by just that many degrees — namely by as many degrees as the ruler stands away from *b*. Indeed, if you transfer the cylinders to *b* and *c*, you will be able, should necessity demand it, to determine even an angle of up to 180°. The same Longomontanus likewise discusses these matters more fully in the same place.

[Margin: The way to determine distances of 150° and 180° with the same instrument.]

And yet, although all these things rest on a solid geometrical foundation, and these distances can certainly be determined in this way, I would nevertheless not advise anyone to remove the sights from their place too often and transfer them elsewhere. For in this way they easily take some harm, so that afterwards the result — somewhat otherwise than it should, if not in the minutes themselves then at least in the seconds (something that must nevertheless be avoided by every means) — altogether

[Margin: The author advises against undertaking observations in this way.]

is shown.

And so I am very reluctant — unless driven by the utmost necessity — to unfasten my pinnules once they have been fitted and fixed to the instruments with the greatest accuracy and rigorously tested, let alone to transfer them elsewhere. For although you may apply every care to bring them back and set them up again most exactly, it can still scarcely ever happen that some small discrepancy does not arise from it, since the matter turns on the very smallest quantities, and no one can ever be too exacting in this respect.

[Margin: Pinnules, once properly fitted to the instruments, are never to be moved.]

In addition, there is another reason why those larger distances of 150° and 180° cannot be observed as correctly as those that fall under 60°, however much you strain every nerve of your eyes to it: namely, that on the sextant the pinnules must then be set much closer to one another than otherwise, when an angle within 60° is being measured. And the smaller the distance between the two pinnules, the less — believe me — the observations rightly deserve trust. For that reason, too, more compact instruments are not equal to larger ones: in the smaller ones, that is, the sights cannot be set as far apart from each other as in the larger — as anyone experienced in these matters will readily agree with me.

[Margin: Why we cannot measure greater and smaller distances so accurately with sextants.]

It is therefore more advisable — if you ever happen to need such very great intervals, which will nevertheless seldom occur (because, if you have the smaller ones, angles so large, exceeding 60°, are scarcely ever made the basis of calculation in this age of ours) — to apply to those distances a semicircle, such as Tycho had, rather than a sextant. But these semicircles are in turn a very great burden to observers; so I have rejected these too. For nothing ever occurs in the heavens that I cannot dispatch successfully and with the greatest certainty by means of a sextant showing 60°, and also work out by calculation. Hence it has come about that I have not once transferred a quadrant to the measuring of distances, although Tycho many times measured such very wide distances, running up to 90°, with those quadrants.

[Margin: Quite different instruments are required for greater and for smaller intervals.]

[Margin: We can certainly do without distances greater than 60°.]

But the case is quite otherwise in determining smaller distances with any sextant: with the cylinder, namely, moved to *e*, and

[Margin: Smaller distances can indeed be taken with a sextant, but better with an octant.]

the other pinnule moved to *f*. In this way the thing works out not too badly, if you do not have an octant to hand for those narrower distances — as I myself have tried now and then, though rarely. For I consider it better that we set aside a special instrument for these smaller distances, one that serves distances of 45° as well as of a single minute, and indeed of a second. Led by this, at the very beginning of my observations I also had an octant of this kind made, which is to be described in the next chapter.

With the help of this sextant of ours, therefore — since it had been built excellently and skilfully in the Tychonic manner, finely divided into the subdivisions of degrees, and carefully fitted with most accurate sights — I made use of it many times, too, for several years in succession, at first for distances both of the fixed stars and of the planets. But I greatly feared, and it weighed

constantly on my mind, that in the course of time the same thing might also happen to my sextant as once happened to the wooden quadrant described in the preceding chapter: namely, that without my knowing it, it might contract some small fault from the air, or perhaps from the nature of the wood, to my great loss from then on and waste of time. Therefore, since instruments must endure all kinds of weather, I left no stone unturned, all the more, so that I might at last obtain for myself astronomical instruments of every kind made of pure, unmixed and solid metal. In this way I would free my mind from that worry and constant anxiety, and at the same time remove all the wooden ones — however much they had cost me — altogether from the observations and from the sky. And indeed, a little later this was happily brought to effect, with the help of the Divine Power.

[Margin: The author feared that this wooden sextant, however very accurate it was, might eventually also depart from its perfection.]

[Margin: He therefore strove by every means to obtain bronze instruments.]

Before we consider and draw those, however, we wish first to place before your eyes another very large instrument, likewise of wood. In this way you may see at the same time what it was like, and how it too, in its own way, fulfilled its function admirably — and how any other observer, who neither has bronze instruments nor is given the means of building such, may direct similar ones to the stars. For it is better, and more

[Margin: It befits an astronomer to have wooden instruments rather than none.]

honourable for a cultivator of astronomy to have some wooden instruments, overlaid here and there with brass plates, than none at all, and merely to set down circles and calculations in a hut.

CAPUT VII.

Chapter VII.

De Octante Magno Ligneo.

On the Large Wooden Octant.

The most celebrated Tycho Brahe, among his other astronomical instruments, also possessed a special instrument (it was called the Bipartite Arc [Arcus Bipartitus]), intended solely for taking the smaller distances of the stars; its radius equalled 4 cubits, or six feet. It was, however, for the most part of wood, except that the limb showing the divisions, the pinnules, the crossbars and the holders were made of metal. Very much after the likeness of this, I too had an instrument made for taking the smaller intervals between the stars. Its limb spans only the eighth part of a circle (hence the name octant was given to it), but it is still two feet larger than that Tychonic Bipartite Arc, its radius amounting to 6 cubits, or 8 feet. In respect of material it too is chiefly of wood, if you except the arc, the pinnules, and the prop — that is, the ball on which it

rests. It was built, however, of solid and very dry wood, and with very firm timber framework, so that it could not very easily be warped, much less broken.

[Margin: The author built this octant after the likeness of Tycho's Bipartite Arc.]

[Margin: Size of the octant.]

With this octant, indeed, you are not able to determine any distances larger than 45°; but on the other hand you are certainly free to determine all the smallest ones whatsoever, even if they amount to only a few minutes or seconds. The reason is that this instrument has two cylinders, or centres, not one alone as the sextant has. Moreover, these two cylinders are about twelve digits apart from each other — though set at a right angle with respect to the line passing through the middle of the instrument, and at an equal distance from it — and represent, as it were, two different centres. And so from these two points two different arcs too — one from the right-hand centre towards the right, the other from the left-hand centre towards the left, with respect to that middle line — de-

[Margin: With the octant we can measure the smallest distances of all.]

[Margin: The structure of the octant, and what sights it has.]

Diagram. Full-page engraved plate, captioned *Fig. F.* in the lower left, showing the large wooden octant mounted for use on the balustraded observing platform. The octant's frame — a long radius beam running from the head at upper right, where two upright cylinders stand on a cross-piece, down to the graduated limb at the left, braced by cross-bars and diagonal struts — rests on a ball-and-socket support at the top of a turned column. The column is held in a tripod of three long timber legs on a three-armed base set on the floor, with a round disc between the arms. Two small rectangular objects lie on the floor at left and right. Behind the stand runs a balustrade of turned balusters, turning a corner at the right. The limb is engraved with degree divisions and numbered along its lower part.

- Caption (lower left): *Fig. F.*
- Limb numerals (lower part of the arc, reading downward): 5, 10, 15
- Upper end of the limb, beside the clamp at the left edge: the numeral 15
- Below it on the upper limb: the numeral 5 scribed, so that this instrument carries two separate arcs, though entirely equal in the size of their radius, namely eight feet. The arcs, however, do not take their beginning from that middle line — the middle of the instrument — at all, but only at a distance of 6 digits from it. For the two centres on which the cylinders stand are, all told, twelve digits apart from each other; hence the beginnings of the arcs must necessarily be set off by just as great a space as the cylinders are set apart from each other, or from that middle line.

[Margin: The divisions have two beginnings for their numbering.]

Now, therefore, when each pinnule, fitted with its slits, stands at the beginning of the divisions, both observers sight on one and the same star, and so find

no distance — on this condition, however, that the whole instrument has been built with the greatest accuracy and divided with the utmost exactness in the required parts. If it shows otherwise, that is the surest sign that it suffers from some fault, and no slight one. That each cylinder and sight stands so far from the other was done so that the two observers — who are always required for the octant, just as for the sextant — should not knock their heads together, or be wholly in each other's way while observing, when some very small distance between stars has to be determined. For then one or other of the pinnules is clamped firmly with screws at the very beginning of the divisions, which, as we said, lies 6 digits from the middle of the instrument. With the help of this pinnule and of the cylinder on the same side, the other observer brings the pinnule, and the cylinder opposite it, onto the other star, until he has touched the desired star with the greatest accuracy and has also caught it with the utmost exactness through both slits of the pinnule, equally on either side of the cylinder. And so any distance is obtained as desired from the numbers lying between the two sights, correctly counted. But if the distance to be investigated is greater than 20°, the observer sitting at the clamped pinnule must, right at the outset, move it on beyond the first limit of the divisions, towards the end of the octant's limb, as the distance, greater or smaller, requires. Afterwards, with each star's distance properly marked off by each observer, the sum of the degrees of the two arcs, as we said, gives the true interval. Or, if you prefer, set a pinnule to some definite degree on one or other of the arcs; then simply add this definite distance to the arc found on the other side, and you will have the very interval you are looking for.

[Margin: The use of this instrument.]

[Margin: Why the cylinders are set so far apart from each other.]

[Margin: Octants have no rulers.]

Octants of this kind need no rulers at all, as the sextants indeed do; nor, however much you might wish it, can rulers be fitted to them properly without considerable inconvenience to the observers. In my judgement, however, it would be of no small advantage if these octants carried rulers, provided the form of this instrument allowed it. For rulers serve above all to make the pinnule — which is otherwise fixed to the ruler — stand on the arc all the more accurately and readily, always crosswise, at a right angle with respect to the line of sight and to the limb of the instrument, and never deviate even slightly from that path. But on the larger instruments of this kind, rulers, if they had to be fitted to them, would be exceedingly heavy and cumbersome, and would also need multiple supports around the middle of the instrument if they were not to warp and readily lose their straightness. It is therefore better that octants should have no rulers at all.

[Margin: The octants have movable sights.]

For the task can be carried out with equal certainty by those new, recently invented bare sights that are movable on their own. These can be moved in any direction with the gentlest motion, and likewise stand at any point without

the slightest wobble, and they cannot be shifted from it except by the greatest force.

[Margin: The construction of the pinnules.]

As for the rest, the pinnules themselves are fitted out in almost the same way as those on the preceding sextant, namely so that they allow the slits to be widened and narrowed together at will — except that they sit on oblong brass plates, which, in place of a ruler, mark off the divisions, as will be more fully understood in Chapter XV. The base of these pinnules, moreover, is curved with the greatest care to the curvature of the limb, and is well provided with small steel springs, so that it never fails to move back and forth along the arc, or limb, of the instrument — very smoothly indeed, yet snugly at the same time — and also at once cling to it quite firmly.

[Margin: We must guard the sights with the utmost care.]

But so that there need be no fear that these movable pinnules might pick up some fault once the observations are finished, they are taken off the limb and put away, so that they may be kept separately, unharmed and intact. For the greatest care must always be taken of these astronomical pinnules above all, as of the pupil of the eye, if you are intent on more exact observations; a single blow can damage them so badly that afterwards they are of almost no value or use, or at least can be repaired only with great difficulty.

Finally, the pedestal on which this octant rests is not unlike the earlier one. Just as it allows the instrument to be carried about, so it can also be taken apart without much labour whenever you like, and joined together again with certain screws. Moreover, I formerly used an almost identical wooden holder with a double crossed hinge, such as we drew in the preceding Figure E. But noticing that on this instrument, which is otherwise quite heavy, that holder too did not do its job, I fitted the octant as well with a similar bronze globe, which we shall give drawn in Figure N of Chapter XI and which has already been mentioned above. Because this globe is clamped by its ring to the shell [cortex] with very firm screws, it can hold the instrument up reasonably well — except in certain cases, already touched on, such that I was forced to remedy those drawbacks by another method.

[Margin: A rotating globe was also fitted to the octant.]

[Margin: Making observations seated is most convenient for observers.]

Finally, while you are making observations with this octant, you and your assistant may also use the prop for holding up the arms described in the previous chapter, and also the adjustable stools and chairs shown here and there, so that you are not prevented from carrying everything out properly and more comfortably while seated, in every position and inclination of the instrument. For it can hardly be said how tiresome and troublesome it is to carry out observations standing, or with the body leaning back and bent, in some awkward position — as Tycho himself, together with those who were his astronomical assistants, and indeed all investigators of celestial things, have so far amply experienced.

[Margin: The divisions show the sixth part of any minute.]

Lastly, since this octant is two feet larger than the Tychonic one, it admits divisions somewhat finer than the preceding sextant, again by means of transversal lines, so that one can correctly and distinctly read on it not only the fourth part of any degree but also the sixth. How this is done will be shown below in a chapter of its own.

CAPUT VIII.

Chapter VIII.

De Quadrantibus Orichalcicis Minoribus.

On the Smaller Brass Quadrants.

[Margin: The author sets out to describe more excellent instruments.]

Up to this point we have chosen to sketch and describe only those of our astronomical instruments that were built almost on the Tychonic plan and have been in use until now — instruments either of bronze, though not very large, or for the most part of wood — together with certain small new inventions and aids added to them; these I also used for some years at the beginning of my observations. Now, however, let us consider in order the remaining instruments, which are far worthier and more excellent.

[Margin: Instruments: the larger, the more suitable.]

For I have at length learned thoroughly from long experience that it is much safer to have instruments made entirely of solid metal, and also that the larger and more ample they are, the more accurate and perfect they are. Moreover, the earlier instruments, built in the Tychonic manner, lack a great many things with which they ought rightly to be furnished — let this be said, however, with all respect to that great and incomparable man, who deserved so supremely well of the whole of astronomy. For the same reasons it is altogether necessary that they be corrected and improved in part, as regards their material, their structure, the easing of their movement and their divisions, as well as various other aids and helps, so that in this way they could be set to the stars more aptly, more exactly and more readily, with less labour and loss of time, and observations be carried out.

[Margin: Tycho's instruments need to be remedied.]

[Margin: The author has attempted this too, as far as could be done.]

I have therefore applied all my care and effort, according to the slender measure of my talent and of my means granted by GOD — leaving the rest to loftier minds and to men of greater fortune, or to our posterity — so that I might withdraw entirely from the stars the smaller instruments and also all the wooden ones, and in their place provide myself with instruments of pure, solid metal; and indeed of such a kind as

Diagram. Full-page engraved plate, *Fig. G.*: a group of small metal instruments in an observing space with a balustrade. Three instruments stand mounted above the balustrade rail, each on a cylindrical post clamped to the

rail by a two-piece collar fastened with pins. At the left is a quadrant with an openwork scrolled frame and a divided arc, with a clamp and a key-headed screw at the lower end of the arc. In the centre is a smaller, sextant-like instrument on a turned column with an openwork leafy frame and a divided arc, a small box-shaped sight at the right end of the arc, and a pin at the apex. At the right is a quadrant with an openwork frame mounted on its post through a socket at its side, with a curved bar fitted along its arc. Below, at the left, a small vane-shaped instrument with a plumb line stands on a turned base on a table draped with a cloth. On the floor lie loose parts: a fitting with two ring-shaped collars on a threaded rod; a further small instrument of the same openwork kind lying on its side, with its divided arc; a clamp with a ring-handled key and a box-shaped fitting; a pair of small screws; a curved arm with a clamp and a sight fitted on a rectangular block; and a heavy block with a round hole and a wedge-shaped piece. The plate carries no letter key.

- Foot, left: *A Steck delin.* [drew it]
- Foot, left of centre: *Fig. G.*
- Foot, right: *J. Saal Sculpsit.* [engraved it]

Blank page (the verso of the plate, with the engraving showing through).

would be conspicuous for their outstanding size, and would enjoy at once ease of handling and still somewhat more accurate divisions, for obtaining rather finer observations.

[Margin: Tycho's instruments are by all means to be retained as regards their form.]

Not, indeed, that I laboured to devise instruments entirely different in form or figure, bearing no likeness at all to quadrants, sextants and octants. By no means. For I readily grant that I do not yet understand (what GOD may perhaps reserve for future ages I leave aside for now) why the appearance and form of the instruments just named should be utterly rejected or abolished altogether, and new ones of an entirely different kind substituted; or even by what method this should yet be attempted by so easy a route — however much a certain person thinks, or rather dreams, that the peaks of mountains and towers can be put in place of instruments.

[Margin: But which of them in preference to the others.]

And so I entirely agree with Tycho that we do not yet, even in this age of ours, possess, or are able to discover, anything better or more perfect in form for exploring the stars than quadrants, sextants and octants; and further, that instruments of this kind are far to be preferred to all the others, of whatever figure and kind they may be — whether radii, astrolabes, armillae both zodiacal and equatorial, torqueta, or parallactic instruments (as we discussed at greater length in the Proem and in Chapter 1).

[Margin: The author has laboured only to make instruments more suitable for exploring the stars.]

I have therefore striven solely to this end, and with all my zeal: to make quadrants, sextants and octants, as far as possible, somewhat more perfect and

better suited to scrutinising the stars. How far GOD, the Creator of the stars, has by His grace favoured us in this respect, by what means I have come to the aid of this or that instrument, and in what part a remedy has been brought to them, I shall now report briefly and concisely in connection with each instrument to be drawn, as the occasion arises, and show it clearly and graphically.

[Margin: Whether the author has achieved this, let the judgement rest with others.]

But whether these deserve some place among the other astronomical inventions, it is not for me to declare at length; I leave it to be judged freely by those skilled in astronomy who understand this matter more deeply, adding this request: that they should not be loath … these little inventions, such as they are, with a fair mind to accept them, until either they themselves or others devise loftier and more accurate inventions for the good of our divine Urania, and put them suitably to use.

[Margin: Construction of these quadrants.]

First, let us present to lovers of the stars one or two of the smallest quadrants. The first of them has a radius of about one and a half feet, the second of two feet; although I also possess a third, of only one foot, which does its job — namely, taking the altitudes of the stars for correcting the time — just as accurately. As to their construction, these three quadrants are wholly of brass, and are built with skilful and highly ornate framework, expertly worked, partly for the sake of ornament, partly so that they would be the firmer for it and the plane of the instrument would be kept permanently in its due perfection.

[Margin: Why these quadrants contain 110°.]

They appear, however, as is clear from the preceding drawing, to be larger than 90°, just as in fact the limb does exceed a quadrant of the circle. But be that as it may, you will not be able to determine with them any altitude exceeding 90°, even though the division of the degrees is continued towards both tips of the limb — both beyond the first degree, or rather the very start of the numbering, and also where the 90° end. For since hanging quadrants [Quadrantes Pensiles] of this kind have no rulers, nor thread plumb lines with weights hung on them in the usual manner, but are furnished instead with a broad brass plumb line, whose outer part, or limb, shows by its divisions the degrees, and on the smallest quadrant of all the minutes themselves, but on the others parts of minutes of 15 or 10 — that is, seconds — it is certainly necessary that the limb of these instruments should show more than 90°, as you will learn by experience. Otherwise you could by no means make out the parts of minutes around the first and last degrees.

[Margin: These smallest quadrants nevertheless show single minutes on the limb.]

Moreover, although the limb of the smaller quadrant — the one of one foot — shows only whole degrees and half-degrees, it nevertheless shows each single minute distinctly. This most convenient method was first devised not so very long ago; but whose invention it really is — that is, doing without all transversal

lines, with the sole aid of a larger bronze plumb line divided into small parts towards its end — I would not dare to affirm with certainty.

[Margin: Whether Hedraeus is the first discoverer of divisions without transversal lines.]

Benedictus Hedræus [Bengt Hedraeus], indeed, in his little work on the new and accurate construction of the geometrical astrolabe, published in 1643, shows a method by which astrolabes and quadrants are to be divided into minutes and seconds without transverse lines; but from that little work of his I have not noticed that he himself is also the first discoverer of this, nor that he claims this invention for himself. From this I gather how that great quadrant which he shows on page 52, and whose construction he discusses at some length, was by no means born of his own brain; rather, the whole instrument, with all its appurtenances, its little turret or vault, is owed entirely to the said Tycho, as is plain from Tycho's *Mechanica* — although he presents that quadrant there virtually under his own name alone, with that of Tycho, its first inventor, entirely suppressed, whom he nevertheless ought by right to have mentioned. A doubt, then, quite rightly enters my mind: is that new method too, of distinguishing and discerning minutes and seconds, his invention alone, or someone else's? Perhaps, as I judge, Petrus Nonius [Pedro Nunes] laid the first foundations of this invention.

[Margin: This new method of subdividing the degrees is a most splendid invention.]

Whoever was the first finder of this, however, certainly exercised lofty thoughts in bringing it to a fitting result; and it is most deservedly counted among the most excellent inventions that even smaller instruments may, with all transversal lines removed, be subdivided into single minutes and their smallest parts. Nor can it be denied, as Hedraeus demonstrates, that transversal lines indicating minutes and seconds rest on no geometrical demonstration whatever; and that, especially in smaller instruments, which need very many circles and whose radius is only a few digits, the error is quite evident.

[Margin: In larger instruments there is indeed no discrepancy, whether the division is carried out with transversal lines or with altogether plain lines.]

On the other hand, however, it is also perfectly true from practice itself that in larger instruments of 6, 8 or 10 feet, on which very few circles are drawn close together, even though the divisions have been made by transversal lines, it makes almost no difference whether transversal lines or plain straight lines are what the instruments carry. For on very large circular lines of this kind, drawn with a radius of 6, 7 or 8 feet — and that within the space of a single digit — can any curvature be detected? Will not a small part of that circular segment coincide entirely with a straight line? Is it possible in practice for that tiny difference (even though some does exist) to be detected by the eyes in any way?

[Margin: Theory and practice do not always agree in every case.]

These are therefore only the most splendid speculations and ideas of the mind — whatever is put forward about the differences of transversal lines in larger instruments, that is (so that you take my meaning correctly: in the larger ones, I say) — even when that demonstration is granted. For in practice itself they detract nothing whatever from the certainty of observations, as can be amply demonstrated on our larger instruments, on which the divisions of minutes and seconds are seen both by transversal lines and by that new method, namely by plain straight lines. From these, I say, it will be clear to anyone (provided everything has been done properly and accurately, and the smallest details are well noted) that both modes of division always agree exactly — unless perhaps some small fault lies hidden somewhere in the divisions — as you will be able to test all this for yourself without difficulty. Meanwhile, however, it remains beyond doubt that transversal lines, even if they show correctly, can in no way show single minutes on smaller instruments, nor be brought to that fineness; even though, by contrast, with that recent invention by small straight lines you can do the job excellently. And so it would be safer and more fitting to divide the limbs in this new way not only on smaller instruments but on larger ones as well.

[Margin: The author applied both methods of division in his instruments, adding on top another, new one for single seconds, first invented by himself, for the sake of greater certainty.]

For this reason I too decided to inscribe both divisions together on all my larger instruments — indeed, to add on top a third method of ours, first invented by me, by means of a directing screw [cochlea directoria], which also reveals the seconds, as will be explained more fully in its place — so that I might obtain the divisions all the more precisely, detect at once wherever any error lay hidden, and avoid it by every means.

These more compact quadrants, for their part, I have fitted out in such a way that I divided their limbs only into whole degrees and half-degrees. Although this division may seem quite crude to some, it is nonetheless amply sufficient for showing single minutes, provided that the end of the plumb line hung from the centre, where it grazes the limb, is subdivided into certain small parts.

[Margin: On the divisions and construction of the plumb lines.]

Indeed — and this some will surely wonder at even more — this cruder subdivision of the limb is sufficient not only for showing single minutes, but also for tens, fives, and even single seconds on the larger instruments, if, that is, you use our directing mechanism [Machinamentum directorium]. By what device it shows such extremely fine subdivisions, both on the larger instruments and on smaller ones of this kind, of one foot, we shall explain later and represent in drawings — above all in Chap. XV, where the divisions will be treated expressly — since it could not be done in this place.

[Margin: A remarkable method of distinguishing single minutes and seconds clearly on all instruments, the larger as well as the smaller.]

But, to return to the plumb line: its lower part must be filed and smoothed with the greatest care and very gently, so that it touches the whole limb very evenly, yet nowhere adheres too closely; then it must hang quite freely in any position, and the observer must be able to make out properly the divisions both of the quadrant and of the plumb line.

This plumb line is divided in the following way. You mark off with the greatest accuracy, on the limb of the plumb line, a space of 31 half-degrees, and divide it first into three equal parts, and then each third into ten; in this way you will obtain little spaces only very slightly larger than the little spaces of one half-degree. This is because an interval of 31 parts converted into 30 necessarily becomes somewhat larger. Nevertheless, if the divisions of the plumb line approach the limb of the quadrant near the ends of the plumb line, that slight discrepancy of the divisions from one another is barely, if at all, recognisable; near the middle of the plumb line, however, it is evident enough — as anyone can find out more clearly by trying it for themselves than I could set out here in many words.

In the middle of the limb of the plumb line and of its divisions a very small index is placed — namely between the 15th and 16th little space — for distinguishing the whole degrees and half-degrees, which accurately

[Margin: On the index of the plumb line, and how the minutes are to be distinguished and counted.]

the said index shows when the whole space of the plumb line, divided into 30 parts, subtends exactly a space of 31 parts on the limb of the quadrant itself — on the express condition, however, that the whole instrument has been constructed perfectly in every part. But when this index stands a very little further on than some whole degree or half-degree, that is a most certain sign that certain minutes belong to the observation, to be added either to the whole degree or to the half-degree, according as the index is nearer to the one or the other.

[Margin: Distinguishing the minutes.]

The number of minutes, moreover, is recognised from the point at which some small line among the divisions on the plumb line coincides exactly, in one and the same straight line, with some one line on the limb of the quadrant. For, if everything has been done precisely, never does more than a single small line on the plumb line coincide entirely with another on the quadrant. At this meeting of the two small lines, then — where, that is, one and the same line is formed — lies the end of the minutes themselves that belong either to the whole degree or to the half-degree. The minutes are counted from right to left — in these quadrants, that is, if the first degree on the arc begins from the left — as can be understood far more clearly from the instrument itself and from actual practice than from this description, such as it is.

When the plumb line of this quadrant has been constructed in this way, and very precisely balanced, so that neither side of the plumb line outweighs the other, and the index shows nothing other than what the rule of a most

rigorously conducted test requires (which cannot fail to be known to experts), and the divisions have been inscribed on the quadrant quite precisely, so that they admit no fault whatever, then this quadrant can certainly separate single minutes distinctly. Yet I use this smaller quadrant for no other observations than the altitudes of the Sun and of the fixed stars, solely for correcting the time; and since for that business it amply satisfies the work, we certainly have no need of a larger one.

[Margin: The plumb lines of these quadrants have their own counterpoise.]

But if a quadrant of this kind were built two feet in size, like the one you see drawn at the right in Figure G above, it could very conveniently show tens of seconds excellently, and so likewise be used for more advanced observations, such as the meridian altitudes of the Sun and of the fixed stars, if one were not permitted to have larger ones.

Formerly, quadrants as a rule — both the smaller ones, which stood on a table or a window-sill, and all the larger ones, which were hung from some support (as is evident from our earlier quadrant, p. 99) — were usually directed and restored continually by certain directing screws, with reference to the plumb line and the horizon. But this way of moving, directing, raising and lowering quadrants seemed to me very laborious and less suited to observations — above all when the floor was uneven and full of bumps and hollows here and there, so that the quadrants were brought into the plane of the vertical circle only with great labour. Moved by these considerations, I at first applied to these smaller quadrants a particular invention, not yet seen by anyone so far.

[Margin: The supports for these quadrants were formerly not convenient enough.]

To some, perhaps, this may at first sight seem of rather little value; yet in my judgement, unless I am mistaken, it is not so very trifling — above all since it later provided the occasion and the material for discovering far more advanced things, which have turned out no less most happily; indeed, I hope that from that foundation still higher things may perhaps be discovered. Certainly, if I lacked this method I have devised, I do not see how I could direct either the smallest or the largest quadrants so exactly; and, in my opinion at least, all those more skilled in mechanical matters, once they have examined it properly and put it to use, will agree with me of their own accord.

[Margin: The author strongly commends this new method of moving quadrants to observers.]

For the ancients, as also for Tycho, and for the moderns too, the custom until now has been to move quadrants with their bare hands alone, and afterwards either to let them settle freely as they would, or, if they refused to come quietly to rest, they were clamped by a screw set in a groove of the small iron column from which they hung. And so it easily happened that, if they yielded to the gentlest pull, the altitude would very readily (that is, while the screw is being tightened) deflect somewhat from the proper direction that had been obtained;

[Margin: It was easy to go astray with that old method of directing quadrants.]

again, if the quadrants moved under a tighter action [ductu strictiori], they could be set in motion only with very great difficulty. Indeed, even if they sometimes stayed of their own accord at an altitude once set, they were nevertheless easily knocked out of their correct position by a single blow; so that anyone, even by far the most practised searcher of the stars, could, with that older method of simply directing quadrants at the stars, not infrequently and very easily go astray by a great deal.

For this reason I was, as it were, compelled to forestall and remedy these inconveniences and these dangers of going astray, which can almost never be avoided by anyone at all. That each quadrant should always stand fixed, as if immovable, and in no way be moved from its place, and yet nonetheless be turnable at will and at a nod towards any object whatever, and also be brought most accurately and as quickly as possible to any plane by means of the plumb line [ratione perpendiculi] — all this I accomplished successfully with the help of a single screw, glory be to God.

[Margin: The author brought a remedy for this.]

It was done in this way. I made the upper part of the wooden support [Fulcimentum], from which the quadrant is otherwise hung, of two parts. The front part, in which the small iron column for holding up the quadrant is always fixed, could be moved this way and that, most freely and gently, on a kind of axle; and by means of that upper screw, inserted into the immovable part of the support, the other part, the movable one, could be very slightly opened now one way, now drawn together — as is clear enough to everyone from the illustration itself. By a second, larger screw, which passes through a nut [matrix] threaded spirally on its inner side, the quadrant itself is at the same time fastened to the movable part of this support, so that it does not easily leave its position. And so, with this support set upon the lower part of the pedestal as on its stopcock [epistomium], as it were, and with the quadrant well fixed to that part, the plumb line is brought without any labour, as gently and easily as possible, most exactly to the vertical plane, however far the quadrant may lean forward or back. This is certainly a matter of great importance: unless you obtain it most precisely, it is pointless to strive after altitudes.

[Margin: In what way this was done.]

Further, once the quadrant has been adjusted and set most correctly in this way by the line of the plumb line and by the level, it is necessary in addition that the pinnules of the quadrant, for the elevation of a given star,

[Margin: A singular little instrument, or direct-] be directed. Yet this cannot be done with the bare fingers (as has generally been the practice until now) as properly and precisely as that most delicate matter indeed demands.

So I devised another particular instrument — very small indeed, but most convenient. With its help not only is the quadrant brought exactly [ad amussim] to any altitude, while it always remains as though immovable and fixed in its

place, so that it can in no way leave that place nor easily be moved out of it, even if it were unexpectedly pushed by arms or hands or struck by some other thing; but also — best of all — by a particular and new contrivance the divisions of the minutes, and also of the seconds if you wish, can be recognized.

[Margin: -ory of the quadrant, devised by the author for obtaining any altitudes whatever.]

How this aid — or rather this director of the quadrant [directorium Quadrantis], if I may call it so — is constructed can be grasped more clearly from the drawing of the preceding plate G itself, and especially from figure S, which is to be added at Chapter XIV, than from a bare account.

To put it briefly, however: it consists of a single screw, three or four inches long, whose thickness does not yet equal an eighth part of an inch. It runs through two small holes in holders [tenacula], likewise threaded spirally; these holders, or little arms, are fixed into a small square channel [canalicula]. At the end of the screw, in turn, another, different small channel, open on three sides, is hung so that it follows every turn of the screw. By this latter, revolving channel the said longer screw is fastened to the quadrant; by the other, upper channel it is fastened with its two screws to the movable upper part of the support mentioned above.

[Margin: Description of that singular little machine for directing quadrants in taking altitudes.]

So that this could not fail to be done most aptly, I attached to the movable upper part of the support just mentioned a steel arc, not very thick, yet having sufficient breadth, as appears from the diagram. In form it imitates not a section of a circle but a certain conic section, as the matter requires. This too could be described here, but to save time I gladly forgo it, since anyone versed in mechanics and practised in geometry will easily find it for himself; indeed, practice itself will teach him what sort of segment that arc ought to display. But if you depart from the proper figure, do not believe for a moment that this screw of ours will satisfy your wish; nor will it be able to satisfy it in any way.

Next, I attached another brass arc, quite long, though smaller in thickness and breadth than the first, to the limb of the quadrant — indeed to its companion side, opposite the one on which the divisions are inscribed — in such a way that it stands off from the limb itself by at least about a quarter of an inch, or a little more. It begins at the 30th degree and ends at about the 85th degree.

The little instrument itself, then, is applied by one of its channels and fitted to that steel arc of conic form which adheres to the movable part of the upper support. Then the quadrant is first brought roughly to the star to be observed by hand alone [liberâ manu]. Next, by means of the other channel, at the end of the principal directing screw, it is fastened with another, smaller screw to the second arc, the brass one attached to the limb of the quadrant. And then, no less, the first, upper channel, to which the directing screw adheres, is at the same time fixed firmly to the steel arc — following the movement of the

quadrant, or as the given elevation demands — by means of that smaller screw, fitted to this channel for the purpose.

[Margin: The use of this little instrument.]

With these things settled, everything now stands ready for obtaining the altitude most precisely. That is: take hold of the directing screw with your right hand while putting your eye to the pinnules at the same time; and as the screw is turned this way or that, the quadrant is raised or lowered at a nod — and so gently that the movement can scarcely be perceived. In this way you will be able, even in winter and in the most intense cold, to ascertain the matter just as accurately with your hands covered in gloves as with them bare; and this will certainly never fail to be most welcome to observers.

[Margin: We are now never forced to take altitudes with bared hands.]

So once the desired altitude has been obtained with this directing screw — both on the limb from the plumb line and, on a particular small disc attached to the screw, the single minutes from its index, and indeed tens and fives of seconds (of which, as we have just said, more later) — at the same time, with the same effort, the whole quadrant so tightly to the support itself

[Margin: With this director the quadrants are directed very lightly, and are fastened very tightly so that they are not moved from their place.]

you have bound, so that it cannot by any means be shifted even in the least from its place or position — provided only that the pedestal does not wobble or the floor sway.

And to free myself from this concern as well, I generally fix these quadrants to the enclosure [ſepimentum] of my observatory — which is built of the sturdiest beams, with a great many iron holders, so solidly that no force can shake it — in a particular way, namely with two wedges, as the drawing shows. And since the stars often come up for observation now in this quarter of the sky, now in that, I have prepared fixed places on every side of the enclosure that surrounds my observatory for mounting these quadrants, and in a similar way have properly provided hooks and retaining fastenings, so that the quadrants can be set out at any part of the enclosure and towards any quarter whatever, and secured with wedges, and can also be taken away from that part again and moved elsewhere. Believe me, this is far more convenient than if the instrument always had to be set on a support, or that support had to be carried elsewhere frequently and unfastened each time; nor, however it may be managed, does the instrument ever hold to a support as securely and firmly as when the quadrants are fixed to the beams of the enclosure — sturdy wooden posts — with iron hooks clamped on over them. Still, if the situation demands it, you can also set these quadrants on some support, provided you take care that it does not wobble or sway at the slightest disturbance.

[Margin: Quadrants can conveniently be set out for observations without a special support.]

How all these things are to be carried out and put into practice, however, you will learn almost more readily from the drawing itself, placed at page 137,

than from the description. For that purpose I have also shown one quadrant from one face and the other from the other face. In this way you can see not only that bronze ruler marked with divisions, but also those arcs to which the instrument carrying that directing screw is attached, and also the support made of two parts, which holds and directs the quadrant with its own particular upper screw. And to make the matter plainer to you, I have also laid out all the parts piece by piece, scattered across the floor of the observatory, as clearly as I could — not doubting that any lover of the stars who takes an interest in this matter will, having properly considered everything, now grasp the whole of it, and emulate it, more easily than

[Margin: From the scheme itself the whole matter becomes clearer.]

I myself, at first lacking any such instruction and any sketch at all, worked out that very thing.

For the rest, we can also use this quadrant conveniently, especially when we are away from home — indoors, in heated rooms [hypocauſtis] — by setting it on a table or a window, provided you have ready a particular support intended for the purpose, such as you see drawn in the same figure; one, moreover, that must necessarily be fitted with directing screws, by means of which the vertical plane can be restored at once if, that is, the instrument strays somewhat from the plumb line. In this way, however, the quadrant readily leaves its proper position and drifts from the determined altitude, since the quadrant is in no way fastened to the support, and the support itself does not hold so tightly to the table, as is easily understood. Nonetheless, when someone does not have another, more accurate instrument to hand, he has to be content with this one. But there is no reason for anyone to persuade himself that all observations can be carried out as precisely with this little support as with some other — above all that one of ours, recently invented? By no means, indeed, as you will find for yourself.

[Margin: A portable support for the use of these quadrants.]

Finally [Proſtremò] [recte: Poſtremò], these quadrants too can, when circumstances demand it, be fitted out so that they can likewise be used, and not at all badly, for taking the distances of the stars — especially on journeys, when there is no opportunity to make use of some other, larger and finer sextant. That is, if you remove from the quadrant the brass plumb line mentioned above and the upper sight, and in its place substitute a cylinder with a ruler for showing single minutes, with a small plate furnished with divisions attached to it; and then set it on a support and a holder turning on crossed axes, or on a certain revolving globe, which has already been mentioned several times: this sextant you will be able to employ when necessity demands, when no larger one is available.

[Margin: With these quadrants we can also determine the distances of the stars — that is, with a few parts changed.]

Lastly, the pinnules of these quadrants do not differ from those I use constantly, not even in the arrangement by which the Sun is observed. For a very

small hole is made through the upper sight, and in the lower a little circle, with a diameter corresponding to the hole, is likewise drawn; and between the two pinnules a little paper tube is also attached to the quadrant, for receiving the sunlight all the more clearly, as we already mentioned above.

[Margin: The pinnules in these quadrants do not differ at all from the earlier ones.]

And let this be enough said about these smaller quadrants and about their aids for moving and directing them. Let us now set about explaining our larger instruments, which are of considerably greater weight and value.

CAPUT IX.

Chapter IX.

De Quadrante Magno Azimuthali.

On the Great Azimuthal Quadrant.

You have already learned above that azimuthal quadrants are better and more convenient than all other quadrants and semicircles for obtaining the meridian altitudes of the Sun, of the planets and of the fixed stars alike. But how very great a work of skill and labour it is to build a very large instrument of this kind — finished in every part from solid metal and turning in every direction at a nod; one whose ruler is raised and lowered most readily and most gently, while at the same time holding most firmly in any position whatever, and that indeed without any clamping screw or steel spring; one, further, whose horizontal circle, together with the quadrant set upon it, can be directed with the greatest speed and exactness both to the plane of the horizon and of the vertical circle and to the meridian line, if the matter requires it — this, believe me, is scarcely so easily made known, whether by us or by anyone else. Those who are skilled in these matters, and have had one or two quadrants of this kind made, will readily acknowledge that the work is both ingenious and laborious; but the rest, who have scarcely greeted Urania from the threshold, will never persuade themselves of these things at all, much less understand them.

[Margin: It is indeed a great feat of craftsmanship to build a very large azimuthal quadrant, perfect in every part.]

Accordingly, right from the beginning of my observations, around the year 1640, when I had seriously resolved, with divine help, to investigate certain deeper matters concerning the motion of the Sun and of the other stars — and especially concerning the reform of the catalogue of the fixed stars and of the globes — I strove with every care that a sound

[Margin: From the beginning the author took pains to procure such an instrument for himself, as one supremely necessary.]

and perfect azimuthal quadrant might be procured for me — one of altogether more exquisite workmanship, which would show everything with the greatest exactness and satisfy me completely, and which at the same time would consist

in every part of pure metal. But I saw very well that to give out such an instrument to be built for the first time would be a matter of rather long duration; add to this that at that very time no craftsman as ingenious as the business required — one who would dare even to attempt so very large, so elaborate and purely brass an instrument — was to be found anywhere here in Danzig.

[Margin: Craftsmen of this kind, who know how to work out such things, are rarely found.]

Accordingly I was well aware that, many years before — around the year 1618 — the liberality of our native city, out of a singular affection and inclination towards astronomical studies and at the instigation of the distinguished Peter Crüger, formerly professor of mathematics at our Danzig Gymnasium and once my teacher, most worthy of every praise, had already had an azimuthal quadrant of the kind I wanted made for the most part, at great expense indeed, and that by a most skilled and most ingenious mechanic whose name has slipped from memory. But the said craftsman was overtaken by an untimely death (after he had spent many years on this work), and he by no means finished this quadrant at all, nor, for want of various materials, made the ruler, the pinnules and very many other supremely necessary parts; so this instrument was never brought into use. Instead, being unfinished, it was cast aside into a corner of a certain public building of our city (since no one pressed for it or promoted it any longer, Crüger of course being dead). There it stood idle for very many years, merely for the sake of ornament, in the arsenal among the instruments of Mars — where this remarkable instrument, sacred to Pallas, ought least of all to have been laid up or left to rest, still less to lose its worth. Therefore, around the year 1644, I was moved to act, so that this most excellent instrument, brought into being with the best intention by our most noble Senate and destined for higher things, should not lie hidden any longer in obscurity: that it might be exposed as quickly as possible to the Sun and to the whole sky, and then be brought to the point where, to our divine Astronomy, it could at some time be of some

[Margin: At Crüger's instigation the people of Danzig undertake to build an azimuthal quadrant.]

[Margin: But the craftsman died before he had finished it completely, and so it remained in obscurity.]

[Margin: At length this azimuthal quadrant happily came into the author's hands.]

Diagram. Full-page engraved plate of the great azimuthal quadrant. A large quadrant with an elaborately pierced, scrolled frame stands upright on a horizontal graduated circle, which rests on a carved pedestal with winged supports and a turned central column, with winged cherub heads beneath the circle, on four slender legs ending in claw feet, braced by raking struts, set on a stepped base on a chequered floor, with three fleur-de-lis-shaped knobs (probably levelling screws) at the corners of the platform. The upper right

panel of the frame carries the arms of Danzig (a crowned shield with two crosses, supported by two lions). A winged figure stands on a finial at the top of the arc, holding up a ring in one hand and a rod in the other. Two draped female figures stand on pedestals at the lower left of the frame, one holding up a round-topped tablet ruled in a grid, the other raising an open pair of compasses, with a long staff in the other hand resting on its pedestal. A long ruler with pinnules is pivoted at the lower right and runs diagonally across the frame to the graduated arc, and runs on past its pivot as an ornamented arm ending in a pierced eye-sight; plumb lines hang beside it. At the right a man in a fur cap and long coat, seated and leaning far back in a chair, puts his eye to that eye-sight; one raised hand, finger extended, is at a plumb line, the other holds a second, slanting line.

- Lower left, inside the border: ". H." [?] — a plate letter; the scan is cut at the left edge just before it, so anything preceding the dot is lost.
- Lower left, on the ground line: "A. Stech delin" — drawn by A. Stech.
- Lower right, on the ground line: "J. Saal Sculps" — engraved by J. Saal.
- Quadrant arc: degree numerals 90, 80, 70, 60, 50, 40, 30, 20, 10, read from the top downward.
- Horizontal circle: degree numerals 10 to 90 and back down to 10 across its visible front edge, numbered by quadrants.
- No lettered key (A, B, C …) is engraved on the plate. Below the bracket at the lower left of the frame is a foliate scroll ornament, with no lettering.

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use, and at the same time that it might in due course redound to some honour for my most beloved native city, or at least to some memory of it among posterity. And so I firmly resolved to make a proper request to our most honourable Magistracy — since the said azimuthal quadrant, being as it were only half-finished, was of use to no one, and no one burned with any desire for it, nor was anyone at that time devoted to these Uranian matters — that it be graciously granted to me for celestial contemplations, so that it could at last be brought to that point and laudably put to the celestial work for which it had been wholly founded and ordained by our most praiseworthy predecessors. As soon as I laid this wish of mine before our most noble City Fathers, I at once obtained it from them, out of their singular affection and love for me and my sidereal studies.

So, once the said instrument [Organo] had been moved to my house, I had every single thing that was lacking made, at no small expense: the ruler and the pinnules, as well as a great many holders, supports with a sufficient timber framework [contignatione], various directing screws, clamping springs [plumis adſtrictoriis], and various other supremely necessary things. Above all, however, I was anxious to choose a suitable place, the most convenient both for observations and for instruments, where I might set this quadrant, and to fit it out in my house. Accordingly, on top of the rear buildings of my house, I

took the greatest care to have a fairly spacious tower built — an octagonal one — solely in order to house this azimuthal quadrant fittingly; how that tower was fitted out and adapted to this instrument we shall explain below.

[Margin: The author perfected it in every respect and brought it into use.]

[Margin: For its sake he had a special and quite conspicuous tower built.]

Tycho Brahe likewise, noticing that azimuthal quadrants are needed for celestial observations for very many and very weighty reasons, strove with great effort to make himself instruments of this kind too, no less of solid metal, as is abundantly clear from the first pages of his *Mechanica*. Yet the earlier quadrant was no more than two feet in radius, and the azimuthal circle only three feet; the later quadrant, the chief of them all,

[Margin: Tycho too had procured various azimuthal quadrants of bronze.]

[Margin: But they were not as large as they ought to have been.]

measured, as stated in the same place, two and a half feet, and its azimuthal circle [Azimutahlis] [recte: Azimuthalis] only two feet. They were therefore very small instruments, scarcely suited at all to celestial work. For they neither had the proper size for showing the small parts of minutes and seconds, nor was their structure itself — to speak frankly — really convenient, as regards the rulers, in its manner of moving and directing them, so that somewhat finer and weightier observations could have been carried out. Tycho himself freely admits as much in his description of these instruments, for he says: *"It should be known that these two quadrants are not to be trusted too much where the most exact observation is required, to some fraction of a minute — such as the observations that serve to restore the course of the Sun, where the matter turns on the smallest quantities and requires a precision of a sixth, or at the least a third, of one minute; and instruments as small as these, which take in one cubit or one and a half, cannot deliver that."*

[Margin: Hence they could not be applied to more refined observations.]

Yet I have not so far been able to learn that Tycho possessed azimuthal quadrants of that kind — resting on azimuthal circles, and having limbs turned away from the eye, fitted with rulers and pinnules (as these smaller ones were, which in my opinion are superior even to other quadrants, if they have been properly constructed) — and indeed far larger ones, and moreover of pure bronze. He did indeed have larger ones at hand, for the most part wooden and hanging; but by no means revolving on horizontal circles — merely suspended from a support, and indicating the azimuths with an index on a circle fixed to a wall. Among their number was also that iron square [Quadratum], which Tycho gave in a drawing in his *Mechanica* under the letter B, page 12. But quadrants of this sort are not, in my judgement at least, to be put on a par with the azimuthal ones described above, for various reasons that may perhaps be set out elsewhere.

[Margin: What azimuthal quadrants Tycho had besides.]

And so I too chose, from among the rest, a quadrant of this kind, seated on an azimuthal circle. It is four cubits in size, or rather five feet, while the azimuthal circle measures four feet. But its entire structure, with all

[Margin: The size of our azimuthal quadrant.]

the things belonging to it, is such that, just as it can hardly be described by me with any ease, so too it can be drawn only with difficulty in every respect, as regards each and every part. Nevertheless, for the sake of those who take a somewhat deeper interest in celestial matters, we shall describe some of its features, as far as they can be described, and draw them graphically. For this most excellent instrument deserves not to perish wholly in obscurity: since (if I may say so, as the matter truly stands) neither Tycho nor anyone else up to now, so far as I have read and know, has possessed an instrument of this kind at all, and of such a size, made of solid and pure brass. Add that it can be moved and directed so easily on its turning, and with such steadiness; and further, that in the space of nearly thirty years it has contracted no fault whatever, and has always given observations consistent with one another — the same and most exact in the last years as in the first. Our own observations of the meridian altitudes of the Sun and of the fixed stars, of the equinoxes and solstices, and also of the declinations of the stars, will show this abundantly.

[Margin: On account of its excellence this quadrant deserves to be described in full.]

[Margin: So far as the author knows, no similar instrument has been built up to now.]

[Margin: Praise of this quadrant.]

But to come to the matter itself: the pedestal of this instrument equals six feet in height, or the stature of a man; and with all its ornaments, holders and framework it is made of pure, unmixed brass, except for a single wooden support [Fulcro] in the middle and the three iron supports [Fulcimentis] by which the whole instrument is strengthened and made firm. The three winged dragons, so skilfully wrought and standing on griffins' feet, were placed there to sustain the azimuthal circle all the more firmly; they too are made of solid metal. No less so are the three upright supports [Fulcra], which take the place of buttresses [anteridum], likewise holding up the said circle; so that each and every part is built and consolidated of pure bronze. Moreover, into the tripod on which the support [Fulcrum] of the instrument itself stands, three threaded brass screws are inserted with their nuts [matricibus], as is clear from the said figure, so that you can, as it were, bring the whole pedestal with its azimuthal circle exactly to the plane of the horizon, if ever it deviates to some extent. The circle itself, however,

[Margin: The structure of the pedestal, very elegantly and neatly wrought.]

the azimuthal one, is fixed altogether very firmly to the pedestal, so that the pedestal must move together with the azimuthal circle itself, and vice versa. The breadth of its face is as great as the distribution of degrees and minutes by transversal lines requires; its thickness, too, equals a quarter of an inch and more,

so that it may be all the sturdier and steadier for sustaining the whole quadrant placed on top of it, which has a weight of its own. Beneath this azimuthal circle, moreover, a scotia [Scotia, a hollow moulding] has been attached, which carries at its base another circle, projecting somewhat and a little wider than the first. In it certain small wheels [orbiculi] turn, facing the quadrant, and by their help the quadrant placed on top is guided and carried round all the more lightly and smoothly. Of these, however, more later, when the other part of this instrument, or its remaining opposite side, is discussed at greater length; for at present we are considering this quadrant from its principal side, to which the ruler is attached and where the divisions are seen.

[Margin: Description of the azimuthal circle and of the things belonging to it.]

For the rest, the azimuthal circle carries arms of the most varied kinds, or brass holders, issuing from a small ring [orbiculo] of its own which as it were surrounds the centre itself. By these the azimuthal arc itself is braced and secured, so that it does not fall away from the perfection of its circle, but can instead adhere all the more fittingly and firmly to the pedestal. In addition, it is fitted with multiple cross-beams [transtris], props [sustentaculis] and buttresses [anteridibus], duly fixed to the support [Fulcro], so that it always keeps the required plane of the horizon most exactly. But since all these things can hardly be described so clearly, I urge you to turn the matter over somewhat more deeply in your mind, if any concern to understand them seriously touches you. In the upper part of the pedestal, namely beneath the small ring, or crown, of the azimuthal circle, two other separate rings [orbes] of good breadth are set, through which eight threaded screws pass. With their help, by means of a turning handle, the whole of the said azimuthal circle — or rather its middle part, or crown — can be gradually raised and lowered again, or slackened and drawn in again: if, that is, the quadrant itself, standing on the azimuthal circle,

[Margin: The individual parts can hardly be described so accurately that everyone would grasp them all at once, at first sight.]

moves too tightly or too loosely: that is, if the quadrant is not carried round with the gentlest motion, and that most evenly everywhere, or does not grip the circle beneath it evenly on every side. For in quadrants of this kind this above all is the one thing required: that one may clearly make out the divisions at any place whatever on the azimuthal circle, and also turn the quadrant round the whole circle very lightly, as it were with one finger, while it nevertheless clings closely to that circle and sits upon it — yet without any resistance at all. How arduous this is, however, and how much labour it costs to fit out such a vast bronze instrument and bring it to that point, is hardly understood so easily by everyone, except by those who handle and work such things with their own hands. This is above all the case if the quadrant, from the front and from the rear part of the horizontal leg, must show exactly as many degrees and minutes on the azimuthal circle, as the matter absolutely demands — and not only on the meridian line itself, but also at any point of the azimuthal circle wherever it

touches it. This, however, will truly never be possible unless the little column, or small axle [axiculus], fixed to the middle of the lower radius, stands most exactly on the centre of the azimuthal circle, so that it does not stray from it by a hair; and unless, besides, the plane of the quadrant is altogether true and perfect, so that it in no way deflects from a straight line or bends: which is likewise easier said than done, as will be shown at length below.

[Margin: What is above all desired in bronze azimuthal quadrants.]

[Margin: It takes the greatest labour and skill to perfect such an utterly finished instrument in every part.]

Let this much, then, be said briefly, as far as was permitted, about the support [Fulcrum] of this instrument and its azimuthal circle. The rest the lover of the stars who is eager to build a similar instrument will without doubt gain, both from the figure itself [Iconismo] and from serious study of it; and only then will he recognise that very many and varied things are required, and required uniquely, to assemble it properly, which we have not yet touched on even lightly, nor perhaps have they ever yet come into your mind. Moreover, on the subject of that pedestal I think it still worth pointing out that, since it is of such bulk that it can be moved from its place, or carried elsewhere, only with great difficulty — especially through doors, staircases or spiral stairs [cochleas] — the craftsman has nevertheless provided, very well and ingeniously, that this support

[Margin: Very many things in this quadrant have not even been touched on.]

[Margin: The support can be ingeniously taken apart into pieces.]

can, when the situation requires it, be taken apart very conveniently into a great many different parts, and also joined together again by means of spirally threaded screws — and so very finely that you would say all the brass parts, each and every one, had been cast together in a single pour, and yet could be taken apart in this way.

Lastly, I likewise think it worthwhile to mention in this place that it is better, once such a very large and very costly instrument has been set up in some convenient place and properly tested and approved, not to move it from its place often or lightly — still less to loosen it into pieces or tighten it up again. For it can hardly ever happen that, in tightening so many screw-bolts [clavibus cochleatis], it is not partly altered, at least in some respects; and if that were to happen, it would certainly cause the observers the greatest trouble before it could be fully restored, at no slight cost of time.

[Margin: Once an instrument of this kind has been properly set up, it is not advisable to move it from its place.]

And so I too have not moved this quadrant from its place even once, much less taken it apart, since the time — namely the year 1645, or nearly — when I had transferred it to my observatory; but I have kept it there constantly up to now, intact and, as it were, sacred. Nor is access yet open to anyone at all in my absence, either to look at it or, still less, to handle it: so that neither the

ruler nor the pinnules, which I preserve and protect most anxiously, like the pupils of my eyes, can be knocked or damaged in any way.

[Margin: This quadrant has been kept sacredly by the author up to now.]

Moreover, it stands most precisely on the meridian line, which was found there with great care, both from the altitude of the Sun by means of this quadrant and with a special small device (of which more fully in its place); and I also investigated it by means of the circumpolar stars, from their greatest and least meridian altitudes. If over a longer stretch of time it should deviate somewhat from this line, it can be brought back to the same meridian line again with no great labour, by means of a very long ruler [Regula], or iron rule [Norma], of about 13 feet — of which likewise more fully hereafter, when we come to the structure of the tower, or of our observatory.

[Margin: The quadrant is set most exactly on the meridian line.]

The quadrant itself is also entirely of brass, as we said at the beginning, and its inner part is done in openwork lattice [opere reticulato], with small, finely wrought beams [trabeculis everganeis] skilfully elaborated, and with various ornaments, so that thereby

[Margin: Description of the quadrant itself upon the azimuthal circle.]

it would be lighter and handier to move: that is how it is constructed. For if it consisted of a solid, entire, thick plate, it could neither be controlled, because of its excessive weight, nor be moved easily.

Its size, moreover, is five feet and more in radius, while the azimuthal circle is only four feet, as we have already touched on; so the ends of the quadrant project beyond the azimuthal circle on either side by up to a foot.

[Margin: Size.]

And since, on the one hand, the ruler [Regula] projects still further towards the eye, that is, towards the observer, for the sake of greater certainty, as will be said below, and since, on the other, a statue cast in solid bronze, representing Astronomy, stands on a stylobate at the apex of the quadrant, the rear part of the quadrant, which faces the observer, necessarily becomes heavier than the front part around the limb. Hence it was absolutely necessary to extend the radius, or lower leg, of the quadrant on this side, and at the same time to place stylobates on a very heavy bronze base; on these two other statues, likewise of solid metal, are set, so that the balance of the quadrant would be exactly restored again and maintained. Thus these statues were added there not only for ornament but chiefly out of necessity.

[Margin: The quadrant is adorned with bronze statues.]

The upper figure, standing at the apex of the quadrant, is Astronomy, and she is indeed given wings — that is, because in her contemplation she always seeks higher things. In one hand she holds an armillary sphere, in the other an astronomical radius [Radium Astronomicum]. These signify that the contemplation of the heavens must be carried out by means of astronomical instruments, and that with the help of Arithmetic and Geometry; otherwise the labour is in vain. Accordingly, their figures too have been set on the lower and front part of the

quadrant: Arithmetic, namely, carrying a tablet in one hand and in the other a stylus, writing numbers; and Geometry, holding a pair of compasses in her right hand and in her left a triangle, or sextant. That is to say, astronomy is not cultivated without trigonometrical calculation and observations. All three figures, like the whole instrument, are skilfully and most elegantly worked in bronze [ex ære], as we said.

[Margin: What the statues signify.]

[Margin: How astronomy ought to be cultivated.]

Moreover, among the other members of the framework [contignationes] of this quadrant, a square [Quadratum] can also be seen, which boasts its own

[Margin: Among its parts the quadrant includes a divided square.]

very fine divisions. By means of it, just as by the limb of the quadrant, any altitudes whatever are found, so that the ruler determines exactly not only the degrees and minutes on the arc, but at the same time, on this square, in terms of the whole sine [juxta sinum totum] — as cannot fail to be known to students of geometry.

Although for my part, whether squares are small or large, I make very little of them for observations, provided that the limb of the quadrant is properly and exquisitely divided into its small parts. For squares certainly never approach the precision of quadrants. Indeed, since they are inscribed in quadrants, they are always smaller than these; and so their divisions must also be much closer together, and consequently they are also drawn and distinguished on the square with greater difficulty; and for that reason they are not as reliable for observations as the divisions of quadrants. Besides, the divisions on those squares are not equal everywhere, nor can they ever be, since they take their origin from the quadrant — that is, from a segment of a circle — and have to be divided from its divisions. It is therefore perfectly true that the archetype is always far better than any copy, especially one made from it on a far smaller scale. Therefore the quadrant too is rightly preferred to the square. Add to this that I can apply special shortcuts [compendia] to the distribution of the degrees — namely, for distinctly discerning individual seconds out of whole minutes — which certainly cannot be applied to squares. Nevertheless, very many distinguished men, such as Tycho, Gassendi and others, have applied squares of this kind to celestial matters. The reason is that they are made much more readily, and also at less expense, than quadrants themselves — azimuthal quadrants, at that.

[Margin: The author's judgement of squares, which are used by some in place of quadrants.]

[Margin: The quadrant is rightly preferred to the square inscribed in the quadrant.]

[Margin: Squares are easier to construct than quadrants.]

The arc, or the limb itself, of our quadrant has ample breadth and thickness. On the other side, the one opposite the divisions, the whole arc is supported along its length by a crosspiece [transversario] of good thickness and about one

digit broad, set with its breadth at a right angle to the plane of the limb; and it is braced with screws [cochleis] at many points, so firmly that it cannot fall short in the least of its straightness or perfection in any

[Margin: On the limb of the quadrant.]

way. The divisions, moreover, are likewise engraved on the arc by means of transversal lines, so that I can recognise not only whole minutes but also, quite precisely, the sixth part of any minute, that is, ten seconds at a time. With this division I have so far been content — in this instrument, that is — although it would not be hard for me to distinguish even every five seconds on it: namely, if I added to the ruler some special explorer for the seconds [exploratorem pro Secundis], as I have done in the instruments that follow; above all, if I used our directing machine [Machinamentum directorium], about which more will be learned in its place.

[Margin: The limb shows tens of seconds, although it could easily be reduced to finer parts.]

The ruler itself, as in all our other instruments, is made solid of pure brass [ex puro orichalco], and is reinforced on the front side with a small twisted or screw-threaded bronze beam [torquatâ vel cochleatâ trabeculâ æneâ]. For, since it consists of sheet metal that is not very thick, it would easily bend and would not keep its straightness unless it were supported in this way. For this reason too it is wider, especially near the centre of the quadrant, where it is fastened with a headed pin [clavo capitato]. The said ruler, moreover, exceeds the radius of the quadrant by nearly a quarter of it, as I was saying just now; so its total length runs to almost eight feet, and it runs out to two feet from the centre of the quadrant. Furthermore, this projecting part of the ruler is of considerable breadth and thickness: not only so that it should not easily bend when raised and lowered, but above all so that it adds a counterweight to the whole ruler, from the centre to the circumference of the quadrant; and so the ruler itself cannot fail to be moved and raised all the more lightly and readily, without any force.

[Margin: Description of the ruler.]

Tycho's rulers were constructed on almost the same principle, and their projecting part necessarily needed such great thickness, for they were raised and directed to any altitude whatever by that heavier end. But since they refused to stay put of their own accord at the altitude reached, he had added at the other end of the ruler, near the limb, a gripping little spring [plumulam tenacem], like a brake [instar sufflaminis], so that even so the ruler could rest of its own accord in any position; or, if that little spring were still not enough, they might be clamped by a companion with a particular clamping screw [cochleâ adstrictoriâ],

[Margin: How Tycho's rulers were directed.]

so that they would stay in place and not shift from it in the least.

From the very start, however, this way of handling, moving and arresting the rulers seemed to me, for various reasons, neither suitable nor certain enough

— indeed, very harmful to the instruments themselves. It is harmful to the instruments in this way: since the ruler is fairly thin, so as not to hinder the direction by its weight, it would easily be damaged if it had constantly to be raised and lowered by a hand applied to its end (which projects above the azimuthal circle). For a ruler seven or eight feet long is not raised and moved so lightly without some force, however exact its centre of gravity may be. Such a ruler in quadrants changes its balance as it is continually raised or lowered: its condition is one thing around the first degrees, another around the intermediate ones, and yet another around the eightieth and ninetieth, as mechanics know very well. So a ruler has equilibrium only at one particular point of the quadrant, and by no means in the other parts. Hence it cannot stand of itself unless a stop or a brake [offendice vel sufflamine] is added.

[Margin: Why Tycho's method of directing the rulers did not please the author.]

[Margin: Rulers do not stay in equilibrium at every altitude.]

Again, if the ruler is clamped to the limb by the brake somewhat too tightly, you will scarcely move it as you wish; if, on the other hand, you loosen it again, the ruler stays firmly nowhere, but at once leaves its true position. Indeed, even if the ruler is clamped tightly with some threaded screw, it still cannot be that the altitude found does not stray a little from it in the clamping. For this reason that Tychonic method of directing and arresting the rulers is very unreliable indeed. In fact, except by some chance, there is no way at all for anyone to make observations to a nicety and to set the rulers most exactly, so that at least they do not move the whole instrument to some extent — not to mention how long an interval of time would be needed to obtain accurate observations before you got even a single precise altitude, especially if the azimuth has to be observed at the same time. To determine these correctly together and at once, at a single glance as it were, as one must, is truly a matter of skill; and unless you are well practised in these matters, you will labour in vain. Besides this, it is also necessary that you have at hand

[Margin: Tycho's method of directing the rulers is very uncertain.]

an instrument that obeys you at a nod: not only so that you can direct the ruler with one hand as lightly and promptly as possible, but also so that you can move the whole quadrant this way and that above the azimuthal circle, quite lightly, with one finger. Otherwise you will waste both oil and effort, and obtain nothing whatever that is certain and perfect.

For this reason, seeing very clearly the drawbacks of the Tychonic ruler, and also that altitudes could never by any means be obtained in that way, I set my whole mind on how I might move, direct, raise and lower the ruler of the quadrant at a nod — and indeed most exactly, in an instant — without applying a hand to the ruler. This too, by the favour of the Divine Will, at last succeeded for me most happily, by two different methods newly found by me, in each and every quadrant, and in azimuthal ones too, of whatever size and weight they may be.

[Margin: The author devised other methods of directing the rulers as he wished and most exactly.]

The first is this. The arc of the quadrant has at its back another brass arc, fairly broad, fixed crosswise at its middle so that these two arcs make a right angle, for the sake of greater strength and firmness, as appears from the drawing that follows. Over this transverse arc, therefore, on the far side, I led one cord, attached to the ruler at the gripping little spring and the small clamping screw [cochleolam adstrictoriam], towards the upper part of the quadrant — that is, towards the statue of Astronomy and her feet — through a small pulley [trochleam parvulam] fixed there. From there I let this cord down towards the observer, along a course parallel to the upright leg of the quadrant, with some weight hung from it like a plumb line. The other cord, likewise attached to the ruler at the same place, I led through another pulley, fixed to the other leg of the quadrant — the one resting on the azimuthal circle — namely at the feet of the figures of Geometry and Arithmetic; and I led it along that same leg, parallel to the azimuthal circle, over several small wheels [orbiculos], so that it hangs down at the centre of the quadrant, between the headed pin and the azimuthal circle, towards the horizon. At the same time I added some weight to it as well, and indeed as great a weight as the other cord

[Margin: First, by means of cords and their small weights.]

requires for equilibrium — or as the proportion requires for keeping and arresting the ruler at every position. You should know, moreover, that the weight hung on the latter cord, which draws the ruler towards the horizon, is far less than the other, whose cord runs over the upper part of the quadrant and raises the ruler. These two weights are so adjusted with respect to the ruler that, when they are left to themselves, you can keep and hold the ruler steadily, securely and motionless in any part of the quadrant, whether the lower, the middle, or even the upper.

[Margin: By means of the weights the ruler is always kept in equilibrium.]

With these two cords thus arranged and correctly set up, and each weight hung from the ruler, you will be able to search out altitudes most exactly with the greatest ease. That is, by taking hold of one cord with the left hand and of the other with the right, the ruler is guided at a nod and to a hair [ad amussim], raised and lowered — and indeed so gently and promptly that nothing could surpass it. But if you want the azimuth at the same time, take hold of the upper cord with one hand and bring the ruler down to the required altitude; with the other, take the quadrant, directing it, namely at the limb of the azimuthal circle, until you obtain the true azimuth you had to find. (I pass over for now the other way of obtaining the azimuth, namely by means of that longer screw fitted with two small rolling balls, as will be learned in its place.) It is necessary, however, that you be thoroughly practised in these matters, so that you can, almost at the same moment, split the star most exquisitely and evenly on every side, through the four slits of the pinnule nearer the eye and at the four sides of the other, more distant sight [Dioptrae]. The altitude of the Sun, however, is

obtained far more easily, even if the azimuth has to be determined at the same time. But of these things later, after I have first explained the proper face of the quadrant, which shows the ruler, the divisions and the pinnules, and have also described all the other things that belong to it.

[Margin: How altitudes are observed together with azimuths.]

You will scarcely ever persuade yourself, kind reader, what an excellent invention this is in the business of observation, however much it may seem to some to be of hardly any weight — very simple, and indeed quite crude. Nevertheless I would have you know that, whatever its worth, no one as yet

[Margin: An excellent invention: moving the ruler by means of cords.]

so far as I know, has obtained this invention, much less applied it to observations. For until now people have constantly used the old method — that is, the aid of a brake [sufflamen] or of a tightening screw [cochlea adstrictoria] — not without the greatest trouble to the observer, loss of time, and also uncertainty in the matter itself. With this method of ours, however — drawing the ruler in any direction by tightening or slackening the two cords — there is no need for you to touch the ruler with your hand even once, or to apply any force to move it, or to tighten it with any screw; indeed, it at once stays fixed, motionless as it were, in every position, without any brake at all, as we said above. So I obtained, as I had hoped, what I had at first anxiously sought.

[Margin: The ruler can be directed even though you never lay a hand on it.]

In the course of time, however, I devised yet another method (and, as it will perhaps seem to some, a somewhat more convenient and superior one), namely by means of an endless screw [cochlea perpetua]. While it gradually draws in one of the cords described above, it lets out the other again — that is, with the help of two windlasses [succulae], certain notched little wheels, and one grooved small axle. By this means, I say, the ruler is directed to a nicety, as will be explained more fully later in the account of the obverse side of the quadrant.

[Margin: Another method, almost more convenient still, by means of an endless screw.]

The third plumb line, the shorter one — which you see in the preceding figure hung from the upper part at the back of the quadrant, against its upright leg [crus erectum], holding as it were the middle place between the other two — serves entirely for setting the whole quadrant and its vertical plane. With it you can test and set most exactly the quadrant, as if by a level, with respect to the vertical circle, and also, by its guidance, the whole azimuthal circle so that it is exactly parallel to the horizon, before you begin to search out the stars: for if this is neglected, you are ploughing the seashore [littus arabis]. To bring the quadrant back into position, moreover, I generally use three aids: first, the plumb line just mentioned; second, the three grooved screws inserted into the tripod of the pedestal; and third, a singular and remarkable little screw fixed to the obverse part of the quadrant, which is deservedly called the "prince" [princeps]. With its help, with such ease, such promptness and

[Margin: On the plumb line that tests the plane of the quadrant.]

[Margin: What aids are needed to set up the azimuthal quadrant properly.]

[Margin: The "prince" screw.]

speed I true the vertical plane of the quadrant most exactly, so that nothing could ever be more precise; but more fully about these things shortly. And these are the points we had to note briefly about the first side of the quadrant.

Now let us show lovers of the stars, in a separate drawing, the remaining side of this quadrant, opposite the first, and also the tower itself on which it stands; and we will describe all these things too, as far as can be done. First, as regards the support: this other side of it differs in nothing at all from the former one, and its appearance is the same on every side — except that in this picture I wanted to sketch how, in the tripod of the pedestal, the three directing screws are enclosed in certain small cases, to keep out dust, and also so that they are not struck by feet and the quadrant thereby moved from its true position.

[Margin: The rear side of the quadrant.]

Next, I must note about the quadrant itself that it has a little column, or small brass axle, fairly long and strong, on which it otherwise stands and on which it turns, as it were; and also, at the centre of the azimuthal circle, a small channel like a socket [chilonia], into whose bottom a very smooth and highly polished jasper has been set. On this the axle — indeed the whole quadrant — stands, and on it it revolves; the purpose is that the instrument should be all the more apt and light for turning round and directing.

[Margin: The instrument's small axle turns on a jasper.]

Since, however, this quadrant is so large that it could by no means rest on that axle thus bare and free, without any buttress [anteris] or stay at all — much less be turned round so freely in every direction in that azimuthal circle without any wobbling or deviation from the vertical plane — a certain prop or stay has therefore been applied to the quadrant on this reverse side, to hold it up and keep it firmly in its position. This is done as follows. First, a solid and strong small beam of brass is fixed with strong screws to the lower leg of the quadrant, which lies on the plane of the azimuthal circle; it runs at a right angle as far as the limb of the azimuthal circle. To it, cross-bars of the most varied kinds have been very firmly fitted, together with the lower leg of the quadrant, as you see, and thus among themselves

[Margin: How the quadrant is propped and strengthened on the azimuthal circle by a particular prop.]

[Margin: Unless the quadrant were made firm with cross-bars and stays, it would easily fall away from its perfection.]

Diagram. A full-page engraved plate, with no letterpress on the leaf. It shows the great azimuthal quadrant standing inside the roofed tower of the observatory, whose timber roof beams frame the upper part of the plate. The quadrant's frame is filled with ornamental scrollwork, with a coat of arms (two crosses beneath a crown, held by two lions; no name is engraved, and the identification as the arms of Danzig is editorial) in the upper panel; a winged figure holding a bar stands on top of the frame, and two small standing figures

are set at the end of the lower leg on the right. Cords run from the frame to rings and brackets on the posts of the tower. The quadrant turns on a graduated azimuthal circle carried on an ornamented pedestal with a tripod base, clawed feet and winged scroll brackets. At the left an observer in a fur cap sights along the arm at the left end of the lower leg and holds a plumb line; three plumb bobs in all hang from his hand. A notched upright and a round seat stand at the lower left, a cord with a weight runs across the floor to a wheel and roll at the lower centre, and detached parts are drawn on the floor at the lower right. The limb of the azimuthal circle carries graduation figures by tens.

- [?] (lower left corner, cut by the edge of the scan): "…g. I."
- A. Stech Delin. (lower left, artist's signature): "A. Stech drew it"
- J. Saal Sculp. (lower right, engraver's signature): "J. Saal engraved it" — the initial may be I or J
- a, b, c (lower right): a small cylinder with two pins
- d (lower centre): a roll or barrel on the cord
- e (lower centre): a wheel at the end of the roll
- g (lower centre-left): a weight on the cord lying on the floor
- h, h (lower right): two balls at the ends of a rod
- i, i (lower right): two small parts beneath a toothed rack
- k, k (lower right): the upper and lower ends of the rack-and-axle piece
- [?] (lower left): a small mark above the weight hanging at the observer's foot, possibly a letter

Blank page (the verso of the preceding plate, which shows through in mirror image).

joined into a single body, so that when the intermediate beam is moved, the whole quadrant must necessarily move with it at the same time. Indeed, even if you turn the quadrant round by one end, it cannot bend in the slightest, or deviate from its straightness. This would by no means be the case if those stays [retinacula], variously combined with one another, were missing altogether. For all metal, however very solid it is, nevertheless bends easily sideways if it extends to some length, especially if it is not very thick.

[Margin: On the directing handle of the quadrant, by which the quadrant is turned round at will.]

Moreover, so that the quadrant need not be steered by hand at its end either, I have fixed a wooden handle to the small beam at the middle of the quadrant's lower leg, or hung it at the end of the principal cross-bar, namely at the limb of the azimuthal circle. In this way the observer, even while he is searching the stars, may with the help of this handle move the quadrant with his other hand this way and that at will, as lightly as possible, so that there is no need even to touch the quadrant with a finger; and so the quadrant is moved and steered much more readily and easily. For in this way the power of moving the quadrant is far greater at the middle than at the ends of the quadrant — namely because of that framework [contignationes] and the most varied cross-bars which run out from the lower leg of the instrument as far as the limb of

the azimuthal circle, and because of the longer lever, as it were, which they represent. Add that those cross-bars, fixed to the quadrant's lower leg, urge both ends to motion at the same time, both by pushing and by pulling, as you will recognize more clearly from the figure.

[Margin: By means of certain small wheels the quadrant turns round more readily.]

There is the further point that beneath that intermediate small beam of the prop, which rests on the azimuthal circle, the small wheels [orbiculi] mentioned at the beginning of this chapter (p. 154) have been fixed in the scotia, above a certain projecting circle — and indeed to a curved stay made of brass. These small wheels contribute not a little to letting the quadrant be moved and turned round on the azimuthal circle all the more lightly and readily. For while you move the quadrant, these two small wheels beneath the limb of the azimuthal circle turn round most freely, like little rollers [rotulae]; moreover, they prevent the whole prop of the quadrant, resting on the azimuthal circle, from being able either to grip the said azimuthal circle in the least, or, by pressing on it too heavily with its weight, to cause the observer trouble while he is moving it, or to wear away the azimuthal circle itself by clinging to it too tightly and closely, and so to scrape off the very divisions or disfigure them with scratches and cracks.

[Margin: Construction of the quadrant's principal prop.]

Next, on that stouter intermediate beam of the framework, which is attached by screws to the base of the quadrant and to which the handle mentioned is tied, a round brass column of sufficient thickness has been erected perpendicularly, reaching up to the limb of the quadrant. To this column, near its upper part, by means of a pierced little tube about one digit long, three arms have been fitted, issuing as if from a single root — or special curved stays — which are fixed with firm screws to the upper crosspiece [transversarium] of the quadrant. The purpose is that this column with its arms should serve as a prop, so that the quadrant, which otherwise stands freely on the azimuthal circle, should not deviate even in the least from its vertical plane, nor, when it is turned round, fall off the azimuthal circle altogether. For that round column already mentioned, which acts like a pivot or axis, cannot hold the quadrant up by itself alone, notwithstanding those stays and buttresses [anterides] added at the base of the quadrant.

And so that this whole upright prop may be all the firmer and sturdier for holding up and maintaining the whole quadrant and its plane, I have applied yet another buttress — a round column, somewhat both slenderer and shorter — at a certain inclination to the other, longer column, which stands perpendicular. Its lower end is set into the intermediate small beam of the lower framework, which sits on the plane of the azimuthal circle — and indeed at the very end of that small beam. The other point of this shorter supporting column, however, runs at a slant towards that longer upright column; and at that end it likewise also has a rather short little pipe [canalicula], by which it surrounds the upright

column, so that it can move freely up and down, and to every motion and inclinatio- n yield.

Note, however, that the quadrant itself was deliberately set on the azimuthal circle from the very start in such a way that it always, of its own accord, leans not a little towards this rear side and towards the handle hung on the quadrant, and in no way rises by itself alone to stand fully upright or level. Rather, if it is to be set up to the perpendicular, it has to be pushed and directed there, so that it can be brought back to the level all the more readily, easily and exactly, and kept steadily in its true position. [Margin: The quadrant leans by nature and of its own accord.]

I achieved this successfully with one single little screw, by whose help I can restore the quadrant precisely and very quickly, whenever it is needed, however it may lean towards or away from the vertical plane. It is done in this way. Roughly in the middle of the longer round column, or principal upright support, at the point where the other, shorter and slenderer buttress or column touches it — that is, where the latter, rising at an inclination from the circumference of the azimuthal circle, touches the other, upright, longer one — or immediately above the little pipe [canalicula] of the shorter column, already mentioned above, I fitted to the longer column a second plain little pipe, armed with only two separate small threaded screws. Like the lower one, this can be raised and lowered slightly together with its buttress. [Margin: How the quadrant is set up exactly to the perpendicular.]

This upper little pipe, I say (which, for better understanding, you see drawn somewhat more distinctly on the tessellated pavement at *a*), I fastened firmly to the column at that spot with a smaller transverse screw *b*, so that it cannot be moved from its place. The other screw, however, upright and somewhat longer, *c*, which passes through a threaded hole, has its point reaching right to the top of the inclined buttress — that is, to the buttress's little pipe, which goes round the longer column so that it cannot move away from it. When I tighten or close this screw — clockwise, that is — the quadrant is pushed by its turning towards the vertical circle (for the quadrant of its own accord leans somewhat towards the horizon and, as it were, resists that motion). [Margin: Namely by means of a certain screw, rightly called the "Prince" (Princeps).] If by this working you overshoot the mark and press the quadrant too far, so that it even passes beyond the vertical circle — which the attached plumb line [funependulum] at once makes plain — it is necessary to open the screw *c* just mentioned — this longer one, that is — again, or slacken it as far as needed, until the plumb line touches, with the greatest exactness, the vertical point itself, which was described and marked there with the utmost exactness after a rather rigorous preliminary examination (of which perhaps more clearly elsewhere).

This plumb line is the very one that hangs beneath the feet of Astronomia and descends, on a course parallel to the upright side [crus] of the quadrant, as far as the centre of the instrument, to the headed pin that fastens the ruler. At that spot is set the square [norma] that shows a mark like a small slit, onto which

the plumb line [funependulum] must drop and be checked. For when the plumb line touches the slit of the square fully, or falls into it quite gently, but by no means presses against it too tightly (which must be noted with the greatest care if anything accurate is to be done, so that you err neither by falling short nor by excess), then it is the surest sign that the quadrant is directed and set up, with the utmost exactness, wholly in accordance with the vertical plane and the perpendicular. [Margin: A sure sign of when the quadrant stands precisely beneath the vertical circle itself.]

Indeed, you will observe this still more rightly if you turn the whole quadrant round on the azimuthal circle and, in every place and position, check it against the plumb line and its square and slit — not only over the meridian line, but also at any part of the azimuthal circle — to see whether the plumb line, as it tests, falls and comes to rest equally precisely on the square and the slit. [Margin: Another way of checking the quadrant's plane.] If this happens equally everywhere, it is entirely beyond doubt that the quadrant is erected and placed most accurately not only in the meridian line but in any azimuth, both along the course of the vertical circle and according to the perpendicular that runs from the zenith to the horizon — that is, that the azimuthal circle is entirely parallel to the horizon.

All this you will detect very quickly in this very easy way, especially if from the very start the azimuthal circle and its pedestal have been set very exactly level, or most evenly along the line of the horizon, by means of its three lower directing screws inserted in the tripod. Otherwise, certainly, the plumb line of the quadrant will by no means fall equally, with the utmost exactness, onto the square or checker [explorator] towards all quarters of the sky. [Margin: You must first set the azimuthal circle correctly.]

Therefore, in making these observations, it is of the utmost importance that you take care first to set correctly the azimuthal circle, and then also the plumb line itself, by means — as we said above — of that longer principal directing screw *c*, fixed to the principal column of the prop. You will find, however, since every single thing that ought properly to be observed cannot be set out here by us so plainly and fully, that bringing the quadrant back to the square so accurately is entirely a matter of skill, and of some difficulty, until you have acquired some familiarity with it. [Margin: It is somewhat difficult to set up the azimuthal quadrant exactly.] For the rest, unless you rectify the quadrant on every side in the way just described, the observer certainly finds it most troublesome to have to correct the quadrant now one way, now another, as to its plane and perpendicular, at each different azimuthal degree.

With this azimuthal quadrant of ours, there is no reason for me to be anxious on this score. For once the plumb line has been set right, with the circle and the azimuthal quadrant placed in the meridian line, that is, facing south, I am entirely sure that the quadrant is set no less exactly towards all quarters of the sky — namely north, east and west. Indeed, once it has been corrected duly and with every care, even just once, there is scarcely any need to check it or bring it back for a space of several months, although I observe the meridian

altitudes of the Sun and the stars every day the sky is clear. So firmly does this instrument sit on the tessellated pavement, and with such care — almost as though it were the pupils of my eyes — do I guard it and keep it inviolate. [Margin: This azimuthal quadrant fully does its job.]

Accordingly, too, no one alone has access to this quadrant unless I myself am present, so that it should not be damaged or disturbed, nor its pinnules and ruler in some way unexpectedly contract some small defect. [Margin: No one has access to this quadrant except in the author's presence.] Hence this quadrant always remains the same as it was at the beginning of my observations, when I began the meridian altitudes of the Sun — as our observations themselves will show more clearly in due course.

These, then, are the things that, concerning those three plumb lines — namely the two directing ones of the ruler, and the third, the checker — we had to say. Now let us disclose to the curious investigator of celestial things another invention, newly found by me for the first time. It is indeed a very small instrument, if you consider its construction; but if you consider its use, a very great one. [Margin: A singular little machine for directing the rulers.] For with this little machine, by means of one single endless screw *h*, you will be able to direct the ruler to a nicety, and at the same time to keep it, once directed, safely immobile for as long as you wish. I have shown a picture of this invention, as far as was possible, on the floor of the preceding Figure I; but far more distinctly still, on a larger scale and for the sake of better understanding, in the following Figure S of Chapter XIV, number eight, than it is sketched beside the quadrant itself. There I shall at the same time show — since that could not be done here — how, with the help of this little machine, the divisions of the quadrant themselves, both of minutes and, if you wish, of single seconds, can also be marked and distinguished as accurately as possible.

The instrument itself does not exceed 3½ inches in length, and two in breadth. It consists of only three small brass plates, one inch wide, joined to one another. The middle, longer plate joins the other two, the shorter ones, crosswise to itself at a right angle. [Margin: Construction of this device.] Through these shorter end plates, on either side of the longer middle plate, passes a slender round windlass (or bar), *m* and *l*, scarcely ⅛ of a digit thick and about six inches long. At the front of one of the shorter plates, a notched small axle, *n* and *o*, is fitted to each windlass. Each of them is turned round together, at an equal pace and most uniformly, by means of an intermediate toothed little wheel *p*, a little larger than the small axles themselves, and of the endless screw *h*, their teeth biting into one another. Through each windlass a hole of its own, *r* and *q*, is bored; and to each of these windlasses, at the front of the first shorter plate, at the grooved small axles, a handle *i* is fixed. With these handles the said windlasses can nevertheless be turned this way and that — while the endless screw *h* stays unmoved, and so does the intermediate notched little wheel *p*

with its two grooved small axles *n* and *o* — though with a very tight and very close motion. To what end, you will soon see.[5]

When, therefore, we wish to use this device, it is fitted to the lower limb of the quadrant, the one that rests on the azimuthal circle — namely near the centre and the headed pin that binds the ruler — by those two steel clasps *k* fixed to the little instrument, and by means of those two very small screws inserted into these clasps from above, at the top. It is fitted, moreover, between the azimuthal circle and the centre of the quadrant itself, as I said, on the side towards the observer, as you see from the drawing. In this way the observer himself, while he is busy directing the ruler of the quadrant, can conveniently take hold with one hand either of one or the other of the windlasses' handles *i*, or of the endless screw *h* itself. [Margin: An excellent use of this little machine.]

First, however, reason demands — if this little instrument is to be employed in observations — that those two cords attached to the ruler for moving it, raising it and lowering it, to which the little weights are tied (and of which we spoke at length above, on page 161), should first be passed through the holes of the windlasses, *r* and *q*, inserted for that purpose — one cord, that is, through each of the windlasses — and that afterwards the little weights should be attached again. And then you have the power of governing the ruler, and of moving it at will, in two different ways. [Margin: With this device the rulers are moved in two different ways.] First, with those cords alone, as you have already learned in its place; and then also with the help of the endless screw *h* fixed to this instrument, in the following way. To begin with, bring the ruler with those cords alone to the altitude of the star you wish to investigate, but only roughly. That done, take hold with one hand of the handle *i* of one of the windlasses — the left, for example — and wind the cord passed through it, or turn it round several times, on to the said windlass towards the left, until you feel that cord gripping or seizing the ruler tightly. [Margin: By means of the endless screw.] Next, taking hold with the right hand of the handle *i* of the other windlass, wind the other cord round on that windlass, towards the right — that is, with a contrary motion — likewise until you find that this cord too grips the ruler closely. And then the ruler stands as though immobile, and from its place, unless great force is applied or the cords are broken, in no way can it be moved. Afterwards, with everything thus arranged, take hold of the endless screw *h* by its handle, with whichever hand you like, and turn it very slowly in whichever direction you like: you will at once find the ruler either raised or lowered, according, that is, to the direction in which you work the screw. For even though both windlasses, round which the cords are wound several times, are turned round, the ruler is nevertheless brought both up and down. Since the windlasses were at the start wound with a contrary motion, it cannot happen otherwise than that one windlass slackens its cord by as much as the other windlass tightens the other cord. For the said windlasses are of the same

[5]the page prints "mox mox", the word twice.

thickness and are carried by the same motion: they are turned round, that is, both by an equal grooved small axle and also by one intermediate toothed little wheel. And so the ruler is directed to the stars most exactly and most gently, so that you scarcely feel it, now by raising it, now by lowering it, while you turn the endless screw this way or that. [Margin: By this new invention the rulers of quadrants are directed most exactly.]

If this method should perhaps please you more than the earlier one, by drawing in and slackening the two bare cords, you can use it — above all since this device can also be so arranged that, while you govern the ruler by means of that endless screw *h*, you can at the same time also distinguish the divisions of the quadrant, both of minutes and of single seconds, extremely finely, on a special small circle attached to it. And yet you can also be amply content with the earlier method, since it does its job abundantly and always holds firmly enough in its place — except that you can judge the subdivisions only on the limb.

For the rest, if that earlier method does not yet seem to you certain enough, I shall communicate yet another aid: how, by those two cords and the little weights, the ruler can stand on the limb of the quadrant much more firmly than by means of the windlasses and that endless screw — however little that is needed, as I have tested more than enough through long experience on this quadrant. [Margin: A new method besides, for directing the ruler, namely with three little weights.] With this aid the ruler always clings still far more tightly to the limb at any place whatever, even though it turns very freely, and most gently obeys every direction. That is: from a third cord let a small hooked pulley *e* be hung, built with a revolving little wheel; and from the hook of that small pulley let another weight *d* be hung, and indeed as heavy as the case itself requires. Then each end of this new cord (whose length must be determined from the length of the two earlier cords, or plumb lines) is tied to the earlier cords already mentioned, or to their weights *f*, *g* — and so the thing is entirely done. For even if you raise or lower either weight of the earlier cords, this larger weight will nevertheless always keep the same distance from the floor, although this third cord appears now shorter, now longer, now on this side, now on that. [Margin: The larger weight always stays at the same height.] You will understand and grasp our meaning all the more clearly and distinctly from something much the same in clocks built with a pendulum and a single hung weight — namely from Figure D, inserted at page 141.

With this third cord and weight, therefore (since it pulls each of the other weights — or rather the other two cords — equally strongly), it cannot be otherwise than that the ruler holds most firmly of itself in whatever place you like, by this one somewhat heavier weight *d* alone, even when those two earlier little weights are removed altogether — a point that deserves to be well noted. How this third weight *d* has been applied to the quadrant, even with the other two, *f* and *g*, removed, I have indeed not shown in the preceding Delineation, since anyone who weighs the matter a little more deeply will easily understand

it. I have nevertheless placed those three cords with their weights, together with their hooked pulley *e* on the third cord (which is constantly in motion), at the floor of the quadrant, so that beginners too, to whom this experiment matters, may not be wholly ignorant of it; but it is understood more clearly from Figure D, as I was just saying, where such a weight is hung with a pulley on a clock.

Finally, to come to the sights of this quadrant: they are nearly the same as those earlier ones fitted to the preceding wooden quadrant. [Margin: What sights this quadrant has.] The first sight, namely, at the lim- b is nothing but a square plate, in the middle of which a very tiny hole is made to receive the rays of the Sun. The rear pinnule, by contrast, fitted at the end of the ruler towards the observer, is constructed with four little slits, which can be widened and narrowed by means of a special set of little wheels placed inside it. And since the ruler is longer than the radius of the quadrant itself by nearly two feet, the two pinnules stand that much farther apart from each other; and the farther apart they are, the more certain they are and the better suited to observations. [Margin: The ruler is longer than the radius of the quadrant itself by two feet.] So this quadrant, provided with such a longer ruler, is equivalent to an ordinary quadrant of ten or eleven cubits, or nearly seven feet, carrying its other pinnule at the centre. The actual construction of these pinnules we shall set before your eyes and describe below, in a separate Diagram R and in Chapter XIV.

While this quadrant is being directed to the stars — at night, that is — it is a great convenience that the observer, in taking altitudes, can manage the work either standing or sitting most comfortably (for the azimuthal circle is raised as much as six feet above the floor), by means of that revolving or sliding seat, which can be pulled out or pushed in, as the case requires and as quickly as you like, with one hand, as you see it depicted in the preceding Diagram. [Margin: Observations are carried out most comfortably sitting down.] So no altitude ever presents itself to anyone that is not taken with the greatest convenience to the observer; nor will it ever happen that you carry out observations most uncomfortably — at some slant, with the body most awkwardly tilted back or bent forward, or with bent knees, or lying on the ground — as until now has happened to everyone quite often.

If you wish to examine the meridian altitudes of the Sun, and its azimuths, then here too, as we already said in Chapter V about the wooden quadrant, you must fit a paper tube between the two pinnules. [Margin: For solar observations this quadrant too calls for a plain sighting tube.] Its lower part, at the pinnule, should be somewhat wider, or vaulted, and also entirely open on the side facing it, so that the pinnule already mentioned, attached to the extended end of the ruler, may lie freely open to the observer (which pinnule, in that vaulted tube, as if shut in lies hidden), and so that he may see and make out in it all the more distinctly the limb of the Sun, or its rays, on the small circle drawn there. This way of observing the Sun is much more secure and more exact than the one Tycho used — namely, by the shadow of the front cylinder received on

the lower pinnule. [Margin: Tycho's method of observing the Sun was not altogether secure.] There, because of the Sun's incoming light flowing all round, the shadow is certainly never as distinctly bounded as the brilliant solar rays themselves, passed through a very tiny hole, are always received in the dark pinnule enclosed by the vaulted tube. More will perhaps have to be said about this elsewhere.

While observing, you will also always be able to stand most comfortably — if not on the floor itself, then at least on one or another step, or on the step of a footstool; I always have various ones of these ready to hand. [Margin: For observations, various seats and footstools are required.] For sometimes we need higher steps, sometimes lower ones, now two, now three.

Moreover, if the Sun's meridian altitude itself is to be taken, it is certainly done much more quickly than with certain other quadrants, horizontal or vertical, hanging from some support. [Margin: With this quadrant, meridian altitudes are taken most expeditiously.] For since the azimuthal quadrant stands most exactly over the meridian line, it is clear at once, without any trouble, when the Sun or the quadrant reaches that line; so it is not at all necessary, as with the other quadrants, to search out altitudes both before and after noon. But you may ask how, at night, in the matter of the meridian altitudes of the stars, in a very dark observatory — when you are unwilling to light a candle so often or bring a lamp close, lest your eyes be disturbed or hurt by the light — it can be noticed whether a star is already about to reach the meridian line, whether it is already on it, or whether it has already passed it. This is in fact recognised very promptly and conveniently, even on the darkest night. For on the very diagonal [?] line of the azimuthal circle, which faces due south and represents the meridian line itself, towards the observer and the north — at the centre of the quadrant, that is — I have sawn a little slit, which can be found with a finger even in the dark; so that I am never [Margin: A sure sign that the quadrant stands right under the meridian.]

unaware how far the quadrant stands at any moment from the meridian line itself, and also when the Sun or the stars are exactly culminating, or when the moment is at hand and the meridian altitude has to be taken off. As a result it is a very pleasant thing to attend to the stars with an instrument of this kind even at night, with no great loss of time.

As for the case when, the work being done, the degrees and minutes have to be noted down, and because of the excessive height this cannot be done from the benches or footstools; and also how the instrument can be tested at any time — whether it still keeps exactly to the meridian line, and by what method it is to be restored if it has perhaps moved off it — this will be shown below. [Margin: How one climbs up to the limb of the quadrant.] First, however, we have thought it worthwhile to point out a few things about the tower, or observatory [Specula], in which this quadrant is housed.

This tower — about half of which you see depicted in the preceding picture, and in which this most excellent azimuthal instrument is kept — I had built

deliberately, and solely for the sake of this instrument, on the top of the rear part of my house, not without some expense, as you will readily understand. It is made partly of oak, joined together with various frameworks, very sturdy beams, ties [tenaculis], braces [capreolis] and crossbars, and partly of brickwork. [Margin: A special tower was built for the sake of this quadrant.] Its shape is a regular octagon; its width along the diagonals is twelve feet. The height of the crossbars, or transverse beams, which form the parapet [lorica] where the windows begin and rise upward, reaches six feet above the tessellated floor — exactly the same height, in fact, as the pedestal and the azimuthal circle. So, with your eye put to that circle, you can view the horizon itself most precisely all round, along that circle and the upper part of the observatory's enclosure, that is, the parapet. [Margin: Its size and shape.] And just as this was built in this way with every care right from the beginning, so it also has an excellent use of its own, as you will understand more fully a little later.

Besides this, the whole tower all round — whether its wooden lattice-work or the spaces between the uprights, of baked brick — from the floor up to the transverse beams, or rather the parapet, [Margin: The structure of this whole tower.]

where the windows open, is solidly made [constat], and all of it is done in mortared work, with every small chink carefully stopped. The other, upper part has no wall at all, but only eight supports — or rather beams — worked to the angle of the octagon and set upright, about eight or nine feet high. To these, windows or shutters [valvae] are fixed with hinges, and they are closed with bolts. [Margin: All round, this observatory has windows that open.] These windows are of wood, so that they are lighter to open out and to close. The ends of the upright beams, around the upper part of the windows, are bound to one another with strong hooked iron ties in such a way that the tower can by no means gape apart or be burst open in any way.

On these eight upright beams, or wooden columns, rest stout and fairly broad small beams [tigillae], or rafters of the roof-ridge [cantherii culminis]. [Margin: The roof of the tower.] The roof covering itself is covered with thin bronze plates for half its extent from the apex. The remaining, larger part — namely those eight upper windows — is covered over and closed with shutters made in a special way from lighter boards, so that they let in no rain at all. And they can be opened again at any time, and these shutters turned back, with the help of a fairly long lever. So when occasion demands, the whole tower — that is, all its doors and also the upper shutters — can be opened without great labour, so that the view lies open on every side, both towards the horizon and towards the heavens, as is clear from Delineation I. And even though the tower thus lies open on every side at the top, the rain still cannot by any means come down into the observatory onto the quadrant, as you may perhaps suppose. Instead it must necessarily fall onto the ridge of the larger house, running in the small beams themselves, which are partly hollowed out, as in a gutter along the sides of the upright columns — for all round, the upper part of the covering

has been very well provided for with smaller parapets, or deflecting barriers [repagulis declinatoriis].

From each of the hooked ties by which the tower is bound together at the top, an iron ring hangs down, as you see; and from each upright column, in turn, a small cord is hung. The purpose is this: when the altitude to be observed [Margin: How a taller ladder may be set against the quadrant from any side.]

rises too high for the degrees and minutes on the limb to be seen either from the floor or from the footstools — at least those built with a few steps — so that you can then set taller ladders against it without any support, and without inconvenience or hindrance to the quadrant. The ladder, however, must be applied in such a way that it does not touch the instrument anywhere, even lightly; but a ladder on its own, without props, cannot stand by itself, and there is no room for a double ladder or for one carrying props. For the tower is built so that it holds nothing but the quadrant alone. Indeed, if it were larger than twelve feet, it would certainly be much less convenient for observers. [Margin: Why this tower was not built larger.] For in a larger tower the degrees and divisions, both on the quadrant and on the azimuthal circle, could by no means be made out from benches fixed all round, nor would we be allowed to walk round the instrument itself so very conveniently.

There are as many of these benches as the tower has sides, namely eight. They are raised two feet above the tessellated floor, and are so made that they can be opened out and raised, or else laid down and lowered again, by means of certain hinges and movable supports, so that the floor space of the observatory might be all the roomier. Standing on these benches, you can not only go round the instrument and make out any degrees you like on the azimuthal circle, but also contemplate the whole horizon and the heavens from the windows. [Margin: From this observatory a completely unobstructed view is given.] For from the floor there is no view at all through the parapet, since the walls of the tower, or its enclosure, rise from the floor to more than a man's height and are exactly level with the pedestal of the quadrant.

When, therefore, the degrees cannot be distinguished either from the benches or from any other footstool, then, I say, a ladder is set against the right side of the quadrant, from which the ruler [Regula] advances — and in this way. First the ladder, by a kind of double rope tied to each of its legs, is fastened at the top, with a hook or catch, to the iron ring attached to those iron ties of the upright beams; and indeed towards the quarter that coincides exactly with the vertical plane of the quadrant. For example: with the quadrant set up on the very line of the meri- [Margin: By means of three cords the ladder is hung, so that you can safely reach the top of the quadrant.]

dian, the ladder must be tied to the eastern window. Then, by two cords hanging on opposite sides — one, namely, from the northern column, the other from the column facing the Euronotus — each leg of the ladder is drawn tight, so far that it cannot move from its place or wobble in the least. At the same time the ladder cannot touch the quadrant even lightly, but stands by itself by means

of the three cords mentioned, as can to some extent be seen from the Figure. And although the quadrant may face any other quarter of the sky whatever, the ladder is nonetheless brought up to the quadrant just as conveniently and in the same way, since every column has its own cord and every window its own ring for fitting the ladder's bar [repagulum]. This is certainly most convenient for observers: by day, that is, and by night, although the tower is open on every side, they can climb right to the top of the quadrant, at so great a height above the ground, so safely that there is no reason for you to dread danger or fear any hazard — which would certainly be something to fear at such a height if the ladder stood free.

Moreover, this tower is so laid out that with its eight sides it faces exactly the eight principal quarters of the world: the first, namely, the south, and opposite it the north; the third the east, opposite it the west; the fifth the south-east, opposite it the north-west; the seventh the south-west, opposite it the north-east. [Margin: The tower faces all the quarters of the sky with its sides.] Beneath the more westerly window — or rather towards the north-west [Corum] — the door is set, in what is clearly a more convenient place. The doors, however, or the shutters of the windows, could not be drawn in the preceding Figure, lest they should hide the instrument from view; yet anyone can easily imagine how they hang from their hinges, fixed to the upright beams. When they are all open, not one of them will be visible to you as you stand at the centre of the observatory. For each lies hidden beneath its own column, along the line of the octagon's radius, where it is fastened with retaining hooks so that they are entirely safe from every storm. In these larger windows, or doors, other smaller square windows have been set all round, which can be taken out and fitted back, or opened again; and this indeed for the reason [Margin: This tower has both larger and smaller windows.]

that at the outset one or other of them can be opened, and the observer can look out in every direction, or view the sky — to see, that is, which stars he wants to observe and which windows have to be opened — so that none of the larger ones, which take some effort, is opened to no purpose. [Margin: Not all the windows have to be opened at once.] If you are concerned only with taking meridian altitudes, only the southern window should be opened — and indeed the larger, lower one — if the altitude does not exceed 45°. But if a greater altitude is to be taken, only the upper shutter of the roof [teguminis] is folded back, and then, even though the quadrant occupies the centre of the observatory, you will nonetheless reach the sixtieth, indeed the seventieth degree of the sky; more than that, however, this tower does not allow with the quadrant in that position. [Margin: How great the altitudes are that may be measured with this quadrant.] If, on the other hand, you want to move the quadrant from the centre and bring it nearer the window, you will certainly be able to catch even the eightieth degree. This, however, I allow only very reluctantly. For since the quadrant has been set on the meridian line with such great diligence and such care, it is better to keep it there permanently and not

to move it from its place unless the utmost necessity demands it. A great deal of time is used up, believe me, before you can set such a quadrant true to the level and the square on every side.

And yet I always have in this tower a special aid at hand for restoring the quadrant — or rather its azimuthal circle — or for bringing it back to the meridian line if it should ever stray from it in part. [Margin: How the azimuthal circle is brought back precisely to the meridian line.] It is this. As soon as this instrument had been set up at the very beginning, as exactly as possible, on the meridian line itself — found at that time with due care — I laid on the azimuthal circle a ruler of steel, made for that purpose alone and about fourteen feet long, running exactly parallel with respect to the meridian line and the diagonal of the circle, so that with both its points it rested at once on the parapet of the southern and of the northern window. Then, at the places there carefully marked, I firmly fixed with nails [clavibus], on the parapet of each window, little channels, or iron boxes open at the top, of the same width as that steel ruler, so that the said ruler, whenever anyone saw fit, into the little channels or boxes could be let down from above, and in this way be laid at once on both parapets alike and on the azimuthal circle (since the parapet all round corresponds exactly, from the floor up, to the height of the pedestal, or of the azimuthal circle, as we said on page 176). So with no great labour you can examine the quadrant as often as you please and, if it is deviating, restore it accurately and put it right again if need be.

But let us return to those smaller windows. They were also made for this purpose: that you can fix in any window a ball that turns in every direction, with a tube inserted in its bore (as we usually do in a darkened room), for observing the spots, and also solar eclipses. [Margin: For what purpose the smaller windows were made.] For this tower is so built that, when it is closed on every side and the door is shut, it does not admit the least stray light — like some very dark room, in which the images of objects outside are usually received, and the spots and eclipses also observed. In just this way, in the year 1645, it fell to us to record and draw an eclipse of the Sun in this same tower, as we had wished.

Although this tower is no larger than twelve feet, nevertheless, before I built my other, more spacious, open-air observatory on the front and higher part of my house, I also used in it, together with this azimuthal quadrant, that three-foot brass sextant on the stars. [Margin: This tower is also very convenient for a sextant of moderate size.] For a support [Fulcrum] can be firmly fixed with a kind of retaining clamp to the parapet of any window, or to its crossbar, to hold that sextant with its turning ball; so that I obtained distances very conveniently from every quarter of the sky. This in fact turned out successfully for me many times, namely from the year 1652 up to the year 1656, above all when the comet was shining in that same year 1652, as will be clearly seen from Book II of this *Machina Coelestis*. No less was it possible in this tower to direct telescopes no

longer than twelve feet readily at the heavens; so that it is still most suitable for observations of any kind.

And these are the things which, about this most excellent azimuthal quadrant and its tower, or observatory, to say and [Margin: This azimuthal quadrant]

to point out, I thought worth the effort. [Margin: … the author places among his principal instruments.] I rightly count this quadrant among my other principal and most necessary astronomical instruments. Not only was it of the most exquisite workmanship some 30 years ago, but it still performs its office as accurately and precisely as before; and so that it may go on doing so, I keep it with scrupulous care. Yet, to tell the truth, it also cost one or two years of no small labour before I had brought that quadrant to such perfection, and set it on the meridian line, that it now shows the very same things, most exactly, as it did then. This, indeed, is not so easy to do as to say: to examine and approve each and every part — the divisions, the ruler, the sights, and whatever belongs to them — as experienced students of the stars [Astrosophi] will readily acknowledge.

[Margin: What the author has accomplished with this quadrant.] With this azimuthal quadrant, at the beginning of my observations, I measured the elevation of the pole at Danzig; and also, from that time to this very day, I have measured with the greatest diligence the declinations and meridian altitudes of the fixed stars, whenever the sky was at all favourable. Indeed, just as from the year 1652 I explored the meridian altitudes of the Sun on every clear day, so I still pursue this now with unwearied application, whenever my very heavy occupations allow; nor do I willingly let any equinox, solstice, or other things of this kind worth noting slip by, provided that opportunity and the sky do not prevent it. So it is that a huge number of these observations is kept in my possession to this day. [Margin: Our observations will contribute at least something to restoring the course of the stars.] These, as I am convinced, will in due time contribute abundantly and to excellent effect to restoring the motion of the Sun, as I have indeed already found, more than enough, by actual experience in constructing and correcting our Solar Tables. May God, Director of the heavens and the stars, grant that, as in this motion of the Sun, so also in the course of the remaining planets, our undertaking may succeed — to the glory of His divine name, the benefit of posterity and the advancement of astronomy — as our friends and we ourselves wish!

CAPUT X.

Chapter X.

De Quadrante Magno Horizontali Æneo Volubili.

On the Great Horizontal Quadrant, of Bronze and Revolving.

Now that we have come to our larger instruments, the order of treatment requires that, for the benefit of students of the stars, we now give a description

and a drawing of our great horizontal quadrant, fitted with a special ruler — as it certainly deserves. For I hardly think that anyone has yet built one of this kind, if you look properly at its whole construction and its very ample apparatus. [Margin: It is doubted whether such an instrument has ever been built at all until now.] Such quadrants are mostly made without any ruler at all, with only a plumb line, since they are both far easier and less costly to build, and do not need such exquisite care in the actual setting. [Margin: Quadrants fitted with a ruler are superior.] But the simpler they are, the less accurate they certainly are; and never, especially in the open air when even a slight wind is blowing, are observations carried out with such perfection, down to the very seconds, as they are with this horizontal quadrant of ours.

[Margin: The front face of the quadrant.] Let us first show this quadrant of ours from the front, and indeed in the way in which it is kept in its observatory, built specially for it, so that from this side everything can first be grasped in detail: namely, how it is governed and directed in that observatory, or little cabin [Tabernula], set on a column in the centre of the observatory [Observatorium]. [Margin: The size of this quadrant.] Its true size, then, as regards the radius, runs to four cubits and more, or to six and a half feet; so that it even partly exceeds our earlier wooden quadrant built on Tycho's pattern. None of all the quadrants and squares [Quadrati] that Tycho used reached the size of this one, except two: namely, that wooden one at Augsburg, which, because of its excessive weight and a structure ill suited to observations, could scarcely, in my opinion, be applied to the stars; for which reason Tycho too, as far as I know, [Margin: On Tycho's quadrants.]

found nothing worth noting with this Augsburg quadrant. The second is that mural quadrant — if we ought to call this instrument a quadrant at all, since it was nothing but a bare arc fixed to a wall, lacking both its legs, with all the stays and framework removed with which it ought properly to have been assembled and braced. For with all these stripped away, scarcely even a very little is to be credited to any instrument of this kind. Tycho, however, calls this arc the Greatest Mural Quadrant [Quadrans Maximus Muralis]; yet it was only five cubits, while this horizontal quadrant of ours is almost 4½ cubits, scarcely half a cubit smaller. [Margin: Whether Tycho's greatest quadrant was much larger than this one of ours.] Moreover, ours does not consist of a bare arc: just as on the front it is built up from a great many very sturdy brass holders [tenacula], props [sustentacula] and framework [contignationes], variously and solidly joined together, so on the opposite side it is also very well provided with a great many cross-beams, so that it may be all the firmer and better suited for being directed to any quarter and for keeping its proper plane. [Margin: How the quadrant is joined together.] For unless so very vast and very solid an instrument were built in this way, it would by no means keep its straightness and perfection at all times, as will be explained more fully in its place.

[Margin: A great many aids had to be devised for the use of this quadrant.] For the more convenient use of this quadrant, so very many aids were recently

devised and fitted to this instrument that I do not know where I should begin. Indeed, however much I might wish it, I shall in no way be able to draw or describe each and every one so clearly that everyone — especially those who have not seen anything similar with their own eyes — will understand every point rightly and plainly. What is more, believe me, some people, however much more attentive than others and well versed in this matter, will surely see this instrument several times before they duly notice, and most fully grasp, even half of it. [Margin: Because of the multitude of things, hardly everything can be described so accurately.] For, to tell the truth, not even I myself — although each single part came forth and was produced from my brain alone — could set it so distinctly before your eyes, were this instrument not constantly before my own.

Diagram. Full-page engraved plate (Fig. K): the great bronze horizontal quadrant seen from the front, set in its small observatory cabin under a pitched roof with scrolled cresting. The quadrant's frame is braced by diagonal struts ornamented with carved foliate rosettes, with a toothed horizontal bar across the frame; its graduated arc runs from the upper right down to the lower left. A sighting arm (alidade) carrying sights crosses the frame from the upper left to the arc, where the observer — a man in a fur cap and a long buttoned coat — stands on the right and holds the arm's fittings at the arc with both hands. The quadrant turns on a stout vertical column set in the floor; a plumb line hangs beside the arc over a weight, a long horizontal bar runs out to the right at floor level, and a cross-footed stand and further framing stand below. Small loose parts (fittings, pins and a key-like piece) are drawn on the floor at the foot of the plate. Balustrades are visible in the background at left and right.

- a (on the drum of the column below the quadrant's centre): a
- 10, 30, 40, 50, 60, 70, 80, 90 (along the arc, from upper right to lower left): degree numerals of the arc's division
- Fig. K. (foot, centre): "Figure K"
- Stech [?] del. (foot, left): "Stech [?] drew it" — draughtsman's signature, its opening letters cut by the edge of the scan
- J. Saal Sculps. (foot, right): "J. Saal engraved it" — the initial may be I or J; no word stands between initial and surname

Blank verso of the plate (the plate shows through in mirror image).

Nevertheless, I shall take pains to set everything out as clearly as can be done; the rest I shall leave to experienced surveyors of the heavens [Cœli Metatores] to search out further and investigate thoroughly.

[Margin: Why the quadrant is called horizontal.] This quadrant is called horizontal because its upper leg is set exactly parallel to the line of the horizon, while its other leg lies along the vertical line, or plumb line [funependulum]. From the centre of the instrument a fairly heavy plumb line is also hung against this second leg, and by means of it the true position of the quadrant can be checked at any time. This is what is required above all — indeed it is the one thing required — in all observations, if you are intent on making accurate ones.

[Margin: Quadrants must above all be directed most exactly to the vertical plane.] But how exactly this ought to be done, and also how it can conveniently be done, we have undertaken to show below in its place, particularly when we come to consider the other, opposite face of the instrument, on which all those screws are fitted for that purpose and lie concealed.

[Margin: The quadrant has a cabin of its own.] For the rest, this quadrant stays permanently in its cabin [Tabernaculum], set on a sturdy column standing firmly in the centre. It is not moved from that place without some compelling reason, nor can it easily be shifted from there or carried elsewhere, because of its very great weight. [Margin: How heavy it is.] For, unless I am mistaken, this quadrant weighs eight hundred pounds; nevertheless, set in its place, it is so light that it can be moved very easily even with a single finger, or swung in any direction by some quite gentle wind. [Margin: It obeys direction at a touch.] The observatory [Specula] itself, in which it is kept, has been given enough height and breadth for this instrument to be very conveniently exposed for any observations whatever, and also to be fully covered again inside it and kept safe from all the inclemency of the weather. Moreover, the observatory has three sides, made of fairly light boards, and is covered over at the top as well. [Margin: The observatory is most convenient.] When the quadrant is set out for altitudes, it stands one third of its diameter outside the observatory, so that the upper sight [Dioptra], together with the whole vertical leg, is always under the open sky; in this way the observer, always under the roof of the observatory, remains, standing or sitting, and carries out the observations to be made from the first degree to the ninetieth.

[Margin: Construction of the observatory.] This observatory [Specula Observatoria] is fitted out so as to have two floors [contignatio]. The upper one is where the little cabin [Tabernula; printed *Tabernacula*, recte: *Tabernulâ*, per the book's errata], and the observer himself as well, now stand in the preceding picture, and it has been given a suitable height. The other lies a little lower [paullò decliviori]; the column is set into it, and on it stand a revolving seat and a footstool. The purpose is that the greater altitudes can be determined from that floor, or pavement, either standing or sitting. [Margin: It has several floors.] For if the altitudes are greater than the observer can catch with his body upright, suitable stools are set on top of the upper floor, so that you can make out even the smallest altitude of all. Indeed, if this still does not seem convenient enough to you, you can readily fit out a third floor by laying two small planks on the lower beams of the observatory; from it one may then take any altitudes whatever, and do so most comfortably, sitting. I think this is always very convenient and welcome to the observer: as occasion requires, he can stand or sit in whatever way suits best, thanks to those movable seats [sellae ductiles]. The quadrant could indeed have been set on the upper floor, on one and the same pavement, and all the observations made there as well; but our observatory was deliberately sunk [excavata], so that its height would not obstruct our view from the upper observatory, our principal one.

[Margin: The observatory turns, and is readily swung round.] Since this quadrant is not deployed solely for meridian altitudes, but equally for any region of the sky, I chose to fit out the observatory so that it could be swung round easily and readily, as if on a circle, by means of two iron handles fixed at its back and four rather thick wheels shod with iron plates. [Margin: The observatory turns on wheels.] The axles of these wheels are fixed to the lower beams of the observatory in such a way (and I would have you note this well) that they coincide exactly with radii issuing from the centre of the observatory. Otherwise, indeed, the wheels would not turn round, nor could the observatory itself be swung round to any region of the sky

Although the body of this little cabin [Tabernula] is built of rather thick oak beams and also of fairly sturdy fir planks, and so is not without weight of its own, it is nevertheless turned round at will by the work of a single assistant, even one not especially strong in body.

[Margin: How the observatory always faces a fixed centre and never leaves its circle.] So that the observatory should not be shifted from its place by that frequent back-and-forth motion, and so either obstruct the quadrant or harm it in any other way, I have firmly bound two round iron bars, fixed to the front wheels, to a ring which is likewise movable about the column standing at the centre of the observatory, using wedges, also of iron. By means of these bars and of this ring — the column being protected with an iron plate at that point — as if by a movable centre, this observatory of ours can be swung round this way and that, and can be moved only round in a circle, always remaining within the limits once set for it. The reason is that the axles, as I said, point straight towards the centre in their run, and do not allow it to be moved any other way, that is, crosswise, however hard you strain.

[Margin: How the quadrant is protected from all harm from the air.] Under the roof itself an iron crossbar [transversarium] is fixed from one side of the observatory, or of this gallery [Pergula], to the other, and from it a curtain [velamen] is hung by means of rings. In this way, when the instrument is drawn back inside the observatory or turned round once the observations are over, the curtain can be unfolded and spread out so that the instrument is protected from all weather and the whole little cabin closed on every side. Indeed, so that the instrument may be all the freer from all the inclemency of the air, the quadrant is clothed in a further mat [teges] hanging from another crossbar. The limb as well, divided into its small parts, is covered all round together with the pinnules and bound tight with an oblong linen cloth made for that purpose. This is so that the divisions, and that most finely polished limb over which that very large ruler moves, fitting it very closely, should not take any stain or damage from dust, and so that the sights should not be harmed in the least.

[Margin: On the front rings of the observatory.] Many rings are fixed on both sides of the front supports of the little cabin, and some also on the inner side of the observatory, though these could not be drawn in the figure [Schema];

by means of these, with four pulleys [trochleae], the quadrant itself can be moved very gently along the direction of the azimuth, wherever you may be standing, or as you sit at the instrument. But precisely how this is done I am unable to show here, describing it in so few words from the drawing itself, without creating too great a confusion of lines and things. Anyone who has an interest in knowing these matters somewhat more thoroughly will be able to explore further, by his own ingenuity, what we have touched on — just as it fell to me to do when I first built all of this.

[Margin: A singular advantage: directing the quadrant along the azimuth by means of a screw.] I did, however, later devise a far more convenient aid: a longer steel screw that passes through holes, cut with spiral threads, in two small brass balls that turn in a special way, and that is bound both to a prop, or wooden arm, movable about the column on which the quadrant stands, and also to the arc, or the transverse beam of the quadrant's limb. In this way it can scarcely be said how very readily, and at the same time how very gently, the quadrant is directed at will and to a hair's breadth [ad unguem] to any azimuth, or to the meridian line itself: one turns the screw with the left hand, while with the right one seeks out the altitudes, likewise by means of another screw fixed to the ruler — as can in part be seen from the earlier drawing, K. So you have no need to lay so much as a finger on the quadrant itself, but only to direct it by the two screws just mentioned to any vertical you please and to whatever altitude you require — as will be explained more fully later, when we come to the opposite side of the instrument.

For the rest, scarcely anything else of particular note remains to be pointed out about this observatory, except that at the bottom, at the back of this little cabin, a lantern [laterna] is fixed which can conveniently be closed and opened again. By it, at night and in the dark, one may make out the divisions of the instrument by a lit candle and note down what has been observed. So that this can be done conveniently, we have fitted a small table in a corner of the observatory, so that everything that seemed to bear on this business would be to hand. [Margin: All light must be kept away from the observations.] And so, once everything has been noted, the door of the lantern is closed again, lest the light of the candle should get in the observers' eyes. For the darker it is, the more perfectly the stars are made out; and on darker nights even the smallest phenomena of the heavens meet the eye more precisely.

[Margin: On the crypt of the observatory.] Then there is the lower and deeper part of the observatory, the round crypt, at whose base the column itself, or pedestal of the quadrant, is fixed, and where you now see the revolving chair with its footstool. It is generally covered with a semicircular lid made of planks, in such a way, however, that it can be turned round without difficulty when the observatory is moved to follow the quadrant. This covering is never removed entirely, unless altitudes of 80° or 90° happen to need measuring.

[Margin: How it is established that the quadrant stands in the meridian line.] But to return to the instrument itself and to its principal side, the one seen from

the front, I think it still worth pointing out that, in observations of meridian altitudes — whether of the Sun by day or of the other stars by night — there is no need to be anxious about the meridian line itself, as to when the quadrant either reaches it or passes it. Nor do we need anyone else's help to warn us when a star's culmination is imminent, so that the moment of its passage across the meridian is not lost and an opportunity that must be observed very precisely does not slip away. Nor do you have to note altitudes continuously before and after the meridian line in order to be sure of the highest altitude. Instead, you can at any time be sure of the true position of the quadrant in the meridian line itself, even though you give the matter only the slightest attention — exactly as if you had deliberately and precisely set the instrument itself to the meridian line on the azimuth circle. This is done with the help of a small steel spring [plumula chalybea], fastened by a particular screw to a catch [retinaculum] on the quadrant, near the upper part of the pedestal at *a*, as can partly be seen from the preceding picture.

[Margin: How it is constructed.] On that part of the pedestal, moreover, a brass plate made with two slits, or notches, is likewise attached by screws — and at the very place on the column where the plane of the quadrant stands quite precisely in the meridian line itself (something that first had to be established with the greatest care, in the proper way).

This is obtained easily and quickly too, since the plate can be moved this way and that as much as you like, until you have it exactly right. So once this notched plate — or plate furnished with buttresses — has been fixed in place, and the steel spring already mentioned has been properly fitted to it, so that it drops gently into the notches of the plate, or comes up against the buttresses, touching and striking them, then you are indeed safe and secure.

[Margin: When the quadrant stands in the meridian line, it gives a sound.] For when the quadrant is about to reach the meridian line, the spring drops into the nearer notch and gives a sharp sound. It is then time to bring the ruler to the desired altitude and to apply yourself carefully to the observation. For very soon afterwards, after only a short delay, the spring drops into the other, outer notch, again giving a sound, warning you and informing you that the quadrant now stands in the meridian itself, and that it is time to determine the true meridian altitude as exactly as possible. And so the observer does not need to waste much time watching for culminations; instead everything can be dispatched as promptly as possible, and at any time one can know how far this star or that is from the meridian itself — something that cannot be unwelcome to any searcher of the stars whatever.

[Margin: The striking spring.] I wanted to sketch this little invention, such as it is, in a better way in the preceding figure, in its place at *a*. But because the thing to be drawn was so complex, and because of its small size, I could not set it before your eyes as clearly as I certainly wished. I therefore decided to lay out that plate, together with the striking spring [plumula pulsatrix], separately at the bottom of the crypt, or observatory, by the support of the instrument, so

that you can understand without difficulty how everything has been made and fitted out.

[Margin: The division of this quadrant shows single minutes and every five seconds.] Next, it must also be pointed out that the divisions themselves show, distinctly and most precisely, not only the degrees and single minutes but also every five seconds. And they do this not only by means of transversal lines, as usually happens in all the other instruments, but also with the aid of a segment of a circle, divided into its particular small parts, applied to the ruler and fixed with screws, also most accurately that every five seconds are made out on the limb of the quadrant.

[Margin: How the seconds are shown, by the explorer arc.] For since each degree is divided into twelve parts — that is, into five-minute intervals — and the single minutes are thus indicated by means of five special circles, I decided to transfer 61 twelfth parts, namely of one degree, to a special arc fastened to the ruler. This arc — 61/12 parts of one degree, that is, or 1/12 of a degree — I had divided in turn into 60 equal small parts, and I fitted it to the ruler in such a way that, when the ruler itself stands exactly on any one twelfth part of any degree, the arc, divided into its 60 parts, takes in exactly 61 parts on the limb of the quadrant, and nothing more.

[Margin: By means of a subdivided segment of a circle, the seconds are known precisely.] If this is not observed with the greatest accuracy, and that arc — the explorer of the seconds [explorator Secundorum] — is not fixed to the ruler most correctly at the very outset, then, believe me, the instrument will never show correctly even the minutes, much less the single seconds. If, on the other hand, everything has been properly attended to and all the graduations correctly made, the minutes and seconds are shown with remarkable precision — far better, indeed, and more distinctly than by bare transversal lines alone, since these will never achieve this with as much fineness as that explorer arc, divided into unequal parts [partes impares]. For in this segment of a circle the interval of one whole minute nearly equals the interval of one whole degree on the limb of the quadrant itself, and five seconds on that arc are of nearly the same extent as five whole minutes on the main limb of the instrument. So, if each and every part of this very large quadrant has been divided and made most correctly, you will quite plainly detect not only every five seconds but any two or three seconds as well.

[Margin: The author himself divided the quadrant into its parts.] Since, however, this division of the degrees demanded singular care, I chose to carry it out myself, with my own hand and with the utmost attention. How much labour, anxiety and expense of time it all cost is not for me to recount but for those who have seen this instrument with their own eyes.

[Margin: To subdivide so very large an instrument is a task of the greatest labour.] It was certainly a most troublesome business: something of this kind, so very vast and so very heavy, which neither I alone nor anyone else could manage: it always had to be moved during the dividing, by the labour of some

very strong men, in order to get the benefit of the light; indeed it sometimes had to be carried here or there, and also arranged now one way, now another.

There is indeed a great difference between so vast an instrument and one of a foot or two. The small one can be managed, turned round and set in place at will with no trouble at all; the large one only with no slight labour and the greatest vexation. I say nothing of the apparatus that the business of division demands in these larger instruments: what very large steel rulers, what compasses of the most varied kinds, and the various devices thought out at that time for the purpose and built at no ordinary expense. From all this you will gather to some extent, kind reader, both how laborious it was to make such an instrument and at what cost it was procured.

[Margin: It was a matter of much labour and great expense to build this quadrant.]

An excellent craftsman and mechanician [Automapæus], helped by two companions, worked for almost three years on this quadrant, and also on the sextant and octant that follow, before he had completely finished them — although the chief craftsman died before he had put the final touch to them.

[Margin: Some years passed before the instruments were completely finished.]

This, then, is what we wished to say, briefly, about the division and its ruler as well — except that it still remains to describe and draw in its proper place, namely in Chapter XV, where divisions by composition [ex compoſito] will be treated, the method by which the single seconds too are indicated on a special small circle by its index, by means of the directing screw, and that much more accurately even than on the limb of the instruments itself, even if you use that explorer arc fixed to the ruler.

[Margin: A remarkable way of distinguishing single seconds.]

Next come the sights. Two of them are fixed to the ruler — which is otherwise fairly thick and broad — and indeed at a right angle. At the centre of the quadrant, that is, there is a square plate (as on the wooden quadrant above), in whose centre a very small hole is bored through, namely for solar observations. At the limb, on the other hand, towards the observer's eye, a pinnule is fitted, with four little notches or slits, which can be opened wider and wider as occasion requires, and closed again. But the way in which these pinnules, I say,

[Margin: On the two sights of the ruler.]

were made, I shall describe more fully in a special chapter, where the construction of sights, and certain other matters relating to them and to other instruments, will be treated separately.

At night, then, this quadrant is set up for observations of the stars as it is shown in the preceding Figure K. By day, on the other hand, for the Sun, a widened and enlarged paper tube or pipe is fitted around the lower pinnule (as we have already partly said above) and is bound to the ruler between the two sights, or else hung by little hooks from small rings fixed to the ruler. This is

done, however, in such a way that the lower pinnule is entirely surrounded and darkened by the wider part of the pipe, so that the Sun's rays passing through the hole of the upper sight are made out all the more distinctly or clearly on the small circle of the lower one, and all extraneous light is completely shut out.

[Margin: A sighting tube is to be attached to the ruler for solar observations.]

This ruler, moreover, is not simply moved up or down by hand, as has been the custom of Tycho and others until now, nor by two cords and their weights, as we showed on the azimuthal quadrant above. Instead, for this quadrant I devised a singular aid, certainly never used anywhere until now, nor yet discovered or described by anyone. And so, I freely confess, it cost me sweat before I had brought that method of moving the ruler correctly into practice conveniently and as I wished.

[Margin: The ruler of this quadrant is guided in a singular manner.]

To some carper [Obſtrigilatori], perhaps, once he has noticed and examined this device, it will seem commonplace and very easy, and it will be no hard matter for him to achieve it and make something similar — as it once seemed to Columbus's rival. But he ought to have produced this very thing, or something similar, and put it to use, before he had seen and clearly understood ours. I would doubtless have spared myself the labour, and would have thanked him for it.

[Margin: Momus usually carps at others' work, and persuades himself that he can do far better.]

The invention itself consists in this: that the ruler can be raised and lowered in either direction, to roughly any degree, as readily as possible; and then that, by means of a single screw only, one can bind the ruler firmly to the limb and nonetheless, with the greatest exactness, for any altitude,

[Margin: What this new invention of direction achieves in making observations.]

bring it back and forth and direct it — and indeed so gently, quickly and precisely that nothing could ever be more exact. As a result, observations made in this way can very well be carried out far more accurately (be it said without offence) than they formerly could with bare hands, even by the most practised of all.

[Margin: By this device for directing the rulers, observations are now carried out much more accurately.]

For the rulers of such very large quadrants have to be very heavy and very strong, and they in turn must necessarily be bound so tightly to the limb that they do not move from their place even in the least. It follows of necessity that for this reason they can scarcely be moved from their place, and only with great difficulty, even if you put both hands to them. In so very large a quadrant, then, if the ruler adheres so closely to the limb, let anyone come forward who is confident that he can bring the ruler by free hand to the most exact altitude — where not even the seconds may be neglected — and keep it safely there at that same altitude. This is especially so in winter, in severe frost, when one

can scarcely touch lightly the extremely cold metal of which the ruler is made, much less handle the ruler with bare fingers for so long, moving it this way and that. At that season, I say — nor indeed at any other — is there truly anyone equal to handling and directing as he wishes so very heavy a ruler, bound tightly to the quadrant (as it absolutely must be).

[Margin: With a free hand no one can direct the ruler with the greatest exactness.]

With this directing screw of ours, on the other hand, it is a pleasure and a delight to turn the ruler and bring it to its place, even though it be extremely heavy, and the instrument itself much larger than ours.

[Margin: The very great power of our directing screw.]

Moreover — and this is more — while you move the ruler this way and that by our method, the quadrant itself never feels the ruler's motion in the least, but always remains entirely unmoved; nor is the plumb line itself moved from its place in the slightest, since the screw turns within itself and the rest of the instrument is left undisturbed. And, what matters most, you will be able at any time to make observations at will with a gloved hand, while the ruler stays completely immobile throughout. But when the ruler has to be raised and lowered by free hand, then, truly, the quadrant and its plumb line, far too much, from their true vertical position

[Margin: By means of the screw the ruler can be moved very freely over the whole limb, and yet stays most firmly in any position.]

is displaced — so much so that in this way scarcely anyone could manage to complete even a single observation correctly and exactly, with much labour and over no small interval of time. The reason is that the plumb line can never be held precisely in its proper place, however firmly the quadrant may be fixed and braced on every side; and experience itself will teach this to anyone who is not yet able either to grasp it or to imagine it.

[Margin: In the larger quadrants the rulers do not keep the same centre of gravity at every place on the limb.]

I readily grant, indeed, as is also beyond doubt, that in very large instruments of this kind, which carry such extremely heavy rulers, the plumb line swings one way when the ruler stands in the upper part of the limb, around the first degrees of the quadrant, and another way around the middle of the limb, near 45°; and differently again when the ruler rests at 70° and 80°, that is, at the bottom of the limb. For as the ruler is moved this way or that, the quadrant acquires one centre of gravity after another. I urge the careful observer of the heavens [Rei Sidereæ Obſervator], again and again, to be most attentive to this, so that he always corrects the plumb line if it happens to be disturbed and brings it back as it should be. In this quadrant of ours, however, this is done with the greatest ease and so exactly that nothing could surpass it, with the help of certain screws fixed for this purpose to the other side — that is, the side facing away — and also of a particular weight hung from the serrated crossbeam [transverſariam trabem ſerratam]; of these, more fully below.

[Margin: With certain screws the plumb line is very easily restored.]

In short, I am entirely confident that there is no one who, once he has rightly and fully understood this method of ours and has himself used this screw of ours, will not freely grant and acknowledge that this invention is not so very trivial, nor the least of the others; for by it, in my judgement at least, our astronomical instruments have grown in no small measure up to now, and have been made more perfect. Without any doubt everyone will acknowledge — as did the excellent Boulliau formerly, when he was staying here in Danzig, and other most distinguished men who were frequently present at our observations — that more is due to any observations whatever made by this new method of ours than to those obtained hitherto (let there be no vain boasting, however)

[Margin: And by this method the instruments have been made more perfect.]

in the older way, and moreover that they are carried out far more easily and quickly. With God's help, and also with the assistance of an experienced collaborator, I am confident (let there be no boasting) that by this method I shall obtain two observations, indeed more, much more quickly — with the quadrant, the sextant and the octant alike — than anyone else could obtain even a single one by the old method; and in the same way anyone well practised in these matters, accompanied by an equally capable companion, will without doubt accomplish no fewer.

[Margin: By this invention of ours the Sun stays as if motionless in the little circle of the pinnule.]

By the same method, too, with the help of these screws you will be able to keep the Sun in the little circle of the lower pinnule not only for some minutes of time but even for a whole hour, so firmly that it does not stray from it by a finger's breadth. "What, pray," you will perhaps say, "can you bind the Sun fast? Does it stand still, is it without any motion?" Not at all. But so that you understand rightly: although the Sun — or the Earth, in our view — is carried by the diurnal motion, it is nonetheless in my power to bring about precisely what I have just said. This is done not only with the screw attached to the ruler, which I turn with my right hand, but at the same time with that other, somewhat longer screw I mentioned above, which is fastened both to the quadrant and to a curved wooden arm (or prop) near the upper part of the movable column, and which governs and turns the quadrant along the line of the azimuth, just as the first screw governs the ruler in the vertical circle.

[Margin: How the Sun seems to be completely at rest in the pinnules.]

So, by working these two directing screws with both hands while the Sun stands within the little circle of the pinnule, one is able to follow the Sun both lengthwise [ſecundùm Longitudinem] and along the line of the azimuth at the same time, so precisely that the Sun is not allowed to leave that little circle at all. Is it not possible, then, I ask, to make accurate observations in this way? For we see the Sun as though motionless in the pinnule, and the very swift motion of the Sun, or of the Earth, does not hurry us at all, nor prevent us from following it with such readiness in each of its two very different motions. This

is especially so when you learn from what is still to be said that, with the help of these screws, the divisions of the minutes too, more exactly still than hitherto, and indeed in the very

[Margin: With all motion of the Sun removed, observations are made far more exactly.]

seconds themselves, can be distinguished. Do you yourself now agree with me? In the older way, without these two directing screws, the stars can by no means be investigated so accurately, even by the more practised among all observers of the heavens, and consequently observations equally certain (I wish this to be said without offence to anyone's reputation) are not to be had at all. Not wrongly, then, did we assert above that I hope that in time still more solid and loftier things will be discovered in astronomy — above all if you, my student of the stars [Aſtroſophe], together with the other energetic followers of the stars, add something to these inventions of ours. For it is easy to add something to what has already been invented. Nor is it at all absurd that, over a longer span of time, far more excellent things still may be found, which do not occur to us at all at present and, besides, seem almost impossible. Meanwhile, so long as we do not yet enjoy better aids, let us for the present be content with these of ours.

[Margin: Astronomy will certainly gain greater increase with each day.]

Now something must also be said about that very long glass tube [canalis vitreus], with a small head [capitellum] at each end, which is seen in Delineations K and L on the upper arm of the quadrant, parallel to the line of the horizon. This glass tube, I say, is fastened by a great many small brass hooks, worked with much care (as you will see from Figure L, which follows), since they can be opened and closed, and also lengthened and shortened, by the turning of a screw. So much quicksilver [hydragyrum] is poured into this pipe that each small head is filled at least to half. In the upper part of the small heads little holes are bored, so that the air may have free exit and entry. This pipe is set on the quadrant — and indeed, as I said just now, parallel to the line of the horizon as accurately as possible under the most rigorous test — for this purpose: that if at any time you are not yet willing to rest content with the bare plumb line hanging from the upright arm of the quadrant, you may at any time rectify the quadrant by this pipe filled with quicksilver, almost more exactly still than by the plumb line. Moreover, if everything has been properly attended to, the plumb line and the quicksilver must coincide completely; namely, by this

[Margin: The pipe filled with quicksilver, and what use it serves.]

[Margin: How you may recognise from this pipe the true position of the quadrant.]

method: on the small heads of the glass pipe a line or mark is made in some readily noticeable colour — red, black, blue or green, it makes no difference — at the level to which the quicksilver [argentum vivum] rises in each small head when, that is, the quadrant has been set up as exquisitely as possible and exactly true, and its vertical plane has likewise been corrected as precisely as

can be. For since quicksilver is extremely fluid and at the same time extremely heavy, it responds most readily to any motion, however slight. It therefore cannot happen otherwise than that, at any inclination of the quadrant, even one scarcely detectable by anyone, the quicksilver rises higher in one small head or the other and passes the mark — and indeed by as much as, in the other small head, it falls short of the true mark, or stands below it. Add that, since the pipe is almost six feet long, even the smallest difference is noticed from the motion and position of the quicksilver — far more distinctly, certainly, than from the plumb line alone, which is always exposed to the open air, especially when a rather strong wind is blowing. So it is easily seen from this by how much the instrument must be restored, so that it is brought back again to its original uprightness.

[Margin: By means of the quicksilver the quadrant is rectified almost more exactly than by the plumb line.]

These, then, are more or less the points we had to note about this front side of this quadrant, except that it remains for me to add here the inscription that I placed on the front face [frontiſpicium] of the quadrant and engraved with my own hand, in kind memory both of the Author, who had this instrument fitted out and built, and of the Craftsman, who worked it with singular skill. I do so in order that after our death, should this most excellent instrument perhaps fall into the hands of some eminent searcher of the stars, or of some great patron of celestial studies, it may not be wholly unknown where it came from and where it was going, and also for what purpose it was made. For this instrument — fitted out and built with such care, such diligence and such expense, scrupulously preserved up to now, and used for so very many observations — deserves to be kept whole and undamaged for many years to come, for the good of astronomy, if not by my heirs then at least by someone else, and its dignity and distinction upheld.

[Margin: This excellent instrument, produced with such labour and expense, deserves to be preserved for a very long time.]

Building such a very large bronze instrument is certainly no trifling matter — and not only building it, but also being able to assert of it that it is correct and exact in every respect. It would therefore be greatly to be regretted if, after my death, this excellent instrument and others of ours of this kind were no longer looked after with the utmost solicitude, and had to suffer the same ill fortune as the instruments of the most noble Tycho, of which, so far as I know, scarcely a single one survives any longer — or at any rate in its original vigour and strength. But such is the changeability of human affairs: one man, with the greatest care and industry, with immense labour and no small expense, accomplishes certain things and guards them carefully; another, without any labour at all, out of sloth and dullness of mind, unworthily neglects them and lets them be ruined — so that things which once cost a thousand are afterwards worth scarcely even a trifle.

[Margin: It is to be lamented if any misfortune befalls outstanding instruments.]

[Margin: One man builds with the greatest effort; another destroys.]

However that may be, and even though these instruments of ours too should meet with hostile fortune in the course of time, after our death, I am nevertheless lifted by this hope: that my instruments have not been idle, unemployed showpieces or marvels in a treasure-cabinet [Cimeliarchium] of astronomy, but have already discharged their office abundantly and amply; that over a span of many years (for which I heartily revere God, the Best and Greatest) I have now happily carried out and obtained with them so very many thousands of observations, especially those which, with the assent of divine grace, I had ardently longed for from the beginning; and that thus — to God be the glory — this astronomical equipment of ours has not been vain and empty, nor the expense laid out on it entirely wasted, either then or now. The rest I commit and commend to God and to posterity. The inscription of this quadrant itself is as follows:

[Margin: The author's instruments have already done their duty.]

From a most eager desire to cultivate and advance the study of astronomy, THIS QUADRANT, of an entirely new workmanship, was caused to be made by JOHANNES HEVELIUS, Consul of the Old Town of DANZIG, *in the Year of Christ* 1659, through Wolfgang Günter.

[Margin: Inscription of the quadrant.]

Having thus examined and explained the first side, from the front, I also think it worth the effort to show all cultivators of the sublime arts the other side as well, the one turned opposite to it [illi obverſum], carefully drawn in a special diagram, and to set it before their eyes duly described, as far as will be possible. Here, in the first place, kind reader, a great many very diverse things are to be seen which are highly necessary and deserve to be explained and unravelled somewhat more accurately. A great many things, however, were omitted — both so that they should not get in one another's way and cause excessive confusion, and because space was lacking — which by rights ought not to have been omitted, since they give the quadrant an outstanding usefulness.

[Margin: The rear side of the quadrant is explained.]

In order to set out each part all the more clearly and distinctly to view, I chose deliberately, in this Figure L, to show the quadrant as if outside the observatory, in the open air for once — in fact it is kept permanently inside the observatory, and has never been used on the sky outside it — and to display here nothing but the quadrant itself standing on its support, with only the base of the little cabin and its crypt [crypta], in whose centre the pedestal is fixed.

[Margin: In the accompanying picture the quadrant is shown as if outside the little cabin.]

The quadrant now sits in this pedestal; or rather, into it is inserted that longer, round little column [columella teres] of that very strong iron prop or retainer

[Sustentaculum sive Retinaculum], from which the whole quadrant is suspended, and without which it would be wholly impossible to turn the instrument to the stars. But so that this enormous and extremely heavy instrument may nod or shift all the less, this column (that is, the pedestal) is, as you see, bored through and hollowed out beyond its middle. In this way the little column of the prop is let down to the very bottom, and indeed into a little steel pipe, in the bottom of which a rather thick small steel plate is set, with its convex face very highly polished. This little column of the retainer is likewise excellently polished and smoothed around its end, so that it — or rather the whole quadrant with all its apparatus — can be moved and turned round the more readily and lightly in the said steel tube, upon that convex plate. And although this instrument weighs as much as several hundred pounds, since it is made of entirely solid metal (except for that single arm, or wooden retainer, to which that longer

[Margin: On the pedestal, and on the special prop of the quadrant.]

[Margin: However heavy this instrument may be, it nevertheless turns very easily.]

Diagram. Full-page engraved plate, Fig. L: a great quadrant standing on its pedestal in the open, with no observatory building around it — only the floor of the little cabin and the circular crypt beneath, into whose centre the tall cylindrical pedestal is let down. The quadrant frame is braced by diagonal struts and decorated with foliate scrollwork; a long horizontal toothed bar crosses the frame at mid-height, with a bell-shaped counterweight hung from its right end, and a horizontal rod with clips and ball ends runs across the top. At left an observer in a long buttoned coat stands on a step, his eye at the sight, his raised hand on a screw-handle at the arc. A long rod and two stays reach from the frame down to clamps on the pedestal. On the floor of the crypt, at lower left, lie separate small parts of the apparatus — plates with screws, a twisted rod ending in a ring, a toothed bar on a base plate, a hexagonal nut, and small pins. No key letters are engraved on the plate.

- Foot left: *A. Stech Delin.* (drawn by A. Stech)
- Foot centre: *Fig. L.*
- Foot right: *J. Saal Scul* (engraved by J. Saal)

Blank page: the verso of the plate, with Fig. L showing through in mirror image.

directing screw is fastened), it is nevertheless moved gently and easily with one finger; indeed, it yields at once to a rather light breath of air.

Now, so that we may begin this description in order and clearly, let us first review a few general points about the rear face of the quadrant. Just as everything on the front face, each and every part, consists of pure brass, so on this face every part is made of steel and iron. Indeed, even if I had wished above all to have these parts made of brass, it would by no means have been advisable, because brass is too soft; and then this quadrant would never have acquired the strength to keep its proper plane so constantly up to now, wherever you may take hold of it.

[Margin: The whole instrument consists of solid metal.]

To make the quadrant all the stronger and more solid, however, and to bind its parts all the more firmly to one another, I devised an entirely singular method of building instruments (by which all our instruments [Organa] were afterwards constructed), so that we have no need at all to build them with such great weight and thickness, or from cast and solid square bars of pure metal. The thicker such bars are, the more they bend under their own weight, and the less they strengthen the instruments — as I could show more clearly, if I did not fear that it would be tiresome to detain you with long digressions.

[Margin: A singular method of building, joining and consolidating instruments.]

Our method of joining and strengthening instruments, then, is this. All those flat brass plates of which both legs, the arc itself and all the framework [contignationes] are made, I have so consolidated and reinforced on the other, opposite side with a great many transverse bars of parallelepiped shape — whose faces [hædræ] are a little more than about two fingers wide, while the thinner ones are only about a quarter of a finger thick — set at right angles to the said brass parts and fastened with a great many ties and screws: binding, that is, those said brass plates to these quite broad and thick steel bars, and so the whole instrument, that not even by a nail's breadth to bend this way or that, or on this side or that from its straightness and perfection can it depart; yet only so far that, whenever occasion demanded, all the parts and the screws could again be tightened and loosened without difficulty, and so that instrument could, if need be, be carried elsewhere. I have certainly laboured to set this method of building and consolidating any instruments before the eyes of every student of mathematics as clearly as possible. But since it could by no means be drawn so distinctly on so very narrow a page, anyone who has an interest in the matter must turn it over in his mind all the more carefully until he grasps it all and puts it into practice. Yet a man skilled in mechanical matters will understand what has been said without difficulty, and will also find from the thing itself that this undertaking succeeds as one would wish.

[Margin: In what the skill consists.]

[Margin: The whole instrument can conveniently be taken apart and put together again.]

Before we go further, however, it will not be out of place to learn what is well known to mechanics: that all oblong and extended solid bodies — whether they are of wood or cast from any metal, and whether they are cylindrical, square, hexagonal or octagonal in shape, it makes no difference — all such bodies, I say (square beams, for example), when they are of great length relative to their thickness, certainly bend more, however strong they may seem, than a parallelepiped body made up of unequal faces [hædris], two of them especially broad relative to the rest: planks, for instance, even if only one or two fingers thick — but, to be understood correctly, with their broader faces set upright. In the same way a square bar or iron pole with equal sides bends more easily

than an iron pole of equal length that is made up of unequal faces, two of them higher, even though the other two are quite thin: as experience itself testifies. Hence it is quite certain that if two poles of parallelepiped form, with two broader sides, are joined at a right angle — one thinner side, that is, set upright against the broader or flattened (or higher) face of the other pole — and are firmly fastened and tightened to each other with headed pins or screws, they will certainly resist all bending far better, and keep the straightness once given them, than solid square poles,

[Margin: Which oblong bodies bend more.]

[Margin: Flattened bodies, set in a certain way, bend less than square oblong ones.]

even though these are much heavier than the two fastened to each other. For when two parallelepiped iron poles of equal length, a quarter of a finger wide or thick and two fingers high, weigh, for example, only 8 pounds, a square pole or small beam of the same metal, with equal sides likewise of two fingers, will on the other hand come to not 8 but 64 pounds; that is, this one will be eight times heavier than that, and nonetheless this heavier, regular one will bend more easily, if it is to rest only on its two ends, than those two joined and clamped to each other crosswise at a right angle with respect to their broader sides. For when one oblong body, flattened in this way, is combined and joined with the other at a right angle in the manner we have described, it yields to bending only with very great difficulty, although either of them separately can be bent aside from its flattened side very easily, even by quite a slight force. But when those small parallelepiped beams hold together in a crosswise position, each resists the other by its height, so that they cannot in any way be bent this way or that, or twisted out of straightness, unless some immense force is applied.

[Margin: Not every heavier body is harder to bend.]

[Margin: Flattened bodies, joined to each other in a certain way, resist bending most of all.]

Therefore you may be fully convinced that all bronze instruments (as also various other things) are made by this method of ours far more easily, at less cost, and also with much less weight; and moreover that they are immensely stronger in themselves and firmer against every force than if the legs, arcs, braces [retinacula], props [sustentacula] and all the framework had been composed and built of solid metal, equally thick on every side.

[Margin: By this method of building of ours, instruments are far sturdier and nonetheless lighter.]

And all that has been said here is not bare ideas of the mind, but has its place in actual practice, as I myself have abundantly found it to be so and no otherwise. For this reason I also deliberately had all my instruments made in this way. Had they been put together and cast from square cast bronze beams, they would certainly be eight times heavier than they now are. Hence this quadrant of ours, built by our technique, which now, if I remember rightly, with all its

[Margin: If the author's instruments [Organa] had been built from square beams, much heavier] apparatus comes to 800 lb., would by the other method have weighed several thousand pounds. What expense, I ask, would such an instrument demand? And would it, because of that excessive weight, be fit for observations at all, or manageable in any way even by quite a strong man? Above all, what would happen with sextants and octants (if the metal were of such thickness), which stand on their centre alone and whose whole weight comes down solely on that centre? You see, then, that by our invention larger instruments [Organa], and lighter ones, can be built at less expense; moreover, the lighter they are, the more suitable they certainly are for observations, and they surpass the others: which was to be shown.

[Margin: would have been, but by no means suitable for directing.]

[Margin: The author's instruments are made by his method at less expense.]

For that reason I was led to set flattened steel beams, two inches high and about a quarter of one finger wide, here and there beneath this quadrant, and to fasten them very firmly, standing upright as you see, to its brass plates with a great many headed screws — not only to the arc, but to all the other transverse parts, seven in number. Around the centre of gravity, moreover, which was located with the greatest care and on which all the strength depends, I added certain further braces [retinacula] and transverse steel ties, so that the instrument might be kept all the more securely in its strength. All these, each and every one, could not be shaded in Delineation L as I would have wished; nonetheless, I think, you will understand them all well — especially from the specimen of the same construction added in Figure L at the lower part of the column, namely of the beams fixed upright to the flattened parts of the instrument — so that there is no need [?] to explain them at greater length.

[Margin: The quadrant's centre of gravity must be thoroughly ascertained.]

The oblique steel beam that supports the limb, or arc, of the quadrant is worked with particular skill: it is given an equal height and width throughout and filed, and then bent with the greatest care to the proper sweep of the circle. It serves not only to strengthen the limb sufficiently, but also so that, in any part of this flattened beam set upright at a right angle, it can, by a small channel [canalicula] which

[Margin: The crosspiece [transversarium] of the limb, and the purpose for which it is fixed.]

adheres to the directing screw fixed beneath the ruler, be clamped [adstringi]. In this way you cannot fail, by means of this screw, to move the ruler this way and that with the utmost precision, and at the same time, by a particular method likewise first invented by us, to read off every single minute and second on a small attached disc [orbiculus] almost more distinctly still than on the limb itself, whether from the transversal lines or from that attached explorer arc — as will be explained more fully later, in Chap. XV.

If this crosspiece of the limb were not of one and the same thickness throughout, and did not match the circle most exactly in its curvature [obliquatio], it

would certainly not be possible for that small channel already mentioned to be applied and fixed equally smoothly anywhere — if, that is, the crosspiece showed even the slightest inequality. Everyone will find this in actual practice: namely, how much labour it takes to equip so very large an instrument in this way, though in smaller ones the task is far less. For when such huge arcs are made, it cannot turn out otherwise, even if you apply every diligence from the start, than that often, while so many headed pins and threaded screws are being fixed to the limb, they produce inequalities here and there. These, moreover, can by no means be corrected unless, every time it happens, you unfasten all those countless screws, take away the beam beneath, smooth off every roughness, and straighten out every bend. The same thing likewise happens to you, and not rarely, with the other steel crosspieces fixed, or still to be fixed, to the quadrant: you are forced to remove them again perhaps as many as ten times, and to waste time loosening those many screws and tightening them again — even though those crossbars were at the outset brought as accurately as possible to a steel square [norma] and trued with a file. Hence almost more time is spent correcting larger instruments of this kind and bringing them to the proper plane than making and finishing them, as experience has amply taught me.

[Margin: Instruments are indeed built by the author's method with the greatest trouble.]

On the other hand, you enjoy this singular benefit: when you have skilfully worked such an instrument out of solid metal and made it absolute and perfect in every respect, it is a work of longer life, and most stable;

[Margin: But again, to the greatest convenience of observers.]

so that you can be entirely certain that it can at no time contract any fault or blemish, unless it is damaged by heavier force and the utmost violence. This you will certainly never achieve with wooden instruments, even if you spare no labour in equipping them; for in the course of time they nonetheless alter and decay.

Now let us come to the small steel column [columella] from which this quadrant hangs. Where and how it is fixed, and in what way this small column must be directed so that the quadrant always keeps exactly to the horizontal and the vertical plane and stands most correctly in every quarter of the sky — this very thing, I confess, gave me a great deal of trouble, and was not a matter of such light inquiry. For this quadrant nowhere rests on, or adheres to, anything either at its upper part or at its lower; it does not lie and rest on an azimuthal circle, nor on a wall, nor on a sturdier beam stretched over the observatory or a turret, as Tycho's indeed does; it stands only by itself, supports itself alone, and also directs and moves itself. To bring this about conveniently therefore took real skill, as is plain from the Delineation itself.

[Margin: How the quadrant is fixed to the small column, and how it is directed in every direction.]

I set about it, however, in almost the same way in which I had undertaken to direct the earlier, smaller brass quadrant in Chap. II. First, I had a large,

sturdy and sufficiently long iron made, namely 5 ft long, about 3 inches wide over half its length and about 1 inch thick — that is, the part towards the top; the remaining lower part was made entirely round, its diameter coming close to 2, indeed almost to 2½ digits. By this round part the iron — or rather the quadrant's prop [Sustentaculum] or stay [Retinaculum] — has been let into a hollowed wooden support [Fulcrum], as far as the iron knot where the round part ends, through a fitted iron hole fixed with screws to the top of the column, so that the prop can turn round all the more smoothly and firmly. Second, in the pierced column itself, at the bottom, a steel socket [matrix], or small channel [canalicula], has been set (into which, as we said above, a fairly thick plate [lamella], convex on one side and well polished, has been inserted); into this socket, I say, or plate [tabula], the round point of the said stay, likewise well smoothed, is let in, so that the whole instrument can all the more readily,

[Margin: A singular and most convenient prop, built by the author for supporting and directing the quadrant.]

lightly, and indeed entirely without any resistance, be turned round and, without fail, directed in every direction.

It is supremely necessary, however, that this iron, or prop, be set up exactly plumb [ad perpendiculum], and so fixed in the column itself. Yet it cannot be that the whole pedestal is erected so precisely, or that the very floor of the observatory on which it stands is laid perfectly level [ad libellam], or even that the stay's small column is fitted into the support so exactly right at the outset, that it agrees in every respect, on every side, with the plumb line.

[Margin: The prop must be set up precisely level.]

I therefore inserted into the support four steel screws, set opposite one another through threaded holes, and in such a position that they touch, crosswise as it were, the very socket or small channel into which the point of the stay — or rather of its small column — is set. My chief purpose was this: if that iron prop, from which the whole quadrant hangs, should deviate not a little from the perpendicular and lean this way or that, it could at once be corrected for the most part, and restored, by means of those screws. For when one of them is loosened a little, and the one opposite it tightened by as much, the prop's small column is necessarily pushed towards the loosened screw, so that the whole quadrant leans the opposite way, towards the screw I had just tightened. In this way, therefore, as you will perceive without any obscurity, both the stay and the whole instrument can without fail be directed and trued to a nicety [ad unguem].

[Margin: When it leans, how it must be restored.]

And so that you may have easier access to the socket and to the lower part of the small column (for the matter sometimes requires either that the point of the small column be smeared with oil, or that the screws be adjusted), I fitted a little window [fenestella] at that place in the support, which can be closed, and opened again, with the greatest ease.

Further: at the upper part of this flattened iron, namely at its knot, where the round part ends, I set a hinge [cardo], so that another, similar iron of as great a thickness, width and length could be applied there, to the extent that it can without fail be opened, after a fashion, above the movable whorl [verticillum], and closed again — relative, that is, to the former flattened iron, the part of the prop inserted with its small column into the support — in a manner not unlike that in which that wooden stay in Chap. II

[Margin: Construction of the prop.]

of that brass quadrant was constructed.

On this movable leg, moreover, is fixed a sturdy iron axle [axiculus], from which the quadrant is suspended — at the lower part of the movable leg, that is, close to the hinge itself. For it is at that place that both the said movable leg of the stay and the axle exert their greatest force, and also that the quadrant itself is moved most easily and readily of all. Now when these two legs are set fully upright in parallel alignment, they do not touch each other with their inner faces, but stand three or four inches apart because of the hinge on which the movable leg turns. So that this movable leg may nod or wobble the less when it is partly opened or closed, a projection ending in a point, fixed to the top of this leg, is fitted into a groove [striga] in the part of the immovable leg that is bent at a right angle, in such a way that the movable leg can indeed move gently in that groove, but can in no way stray to the sides or wobble.

Next, another iron, squared [quadrarium] like an arm and nearly four feet long, is firmly fixed crosswise to the top of the movable leg and joined into one piece with it, as is clear from Figure L, and especially from the Figure S that follows it, in which this stay is sketched on a somewhat larger scale for better understanding. At the hinge, however — that is, at the lower part of this movable leg — two other arms, very strong ones as it were, or supports [Fulcimenta], wrought from a single solid iron, are fastened very firmly with very strong fly-screws [cochleis muscariis]. For what purpose this lower support and that upper one were applied to the movable leg of the prop will be explained at length shortly.

[Margin: The construction of the prop is seen more clearly from Figure S, inserted in Chap. XIV.]

Further, through a spirally threaded hole in the immovable leg is inserted a strong and fairly long screw, fitted with a handle, which in turn is fastened right to the movable leg, yet so that we can turn it freely in its well-smoothed hole. The purpose is this: that when it is tightened by means of this screw (which from now on we shall call the royal screw [Regia], because of its outstanding and royal service), the movable leg together with the quadrant can be opened, or [moved] further from the immovable part towards the

[Margin: By means of the royal screw the quadrant is directed most exactly to the vertical plane.]

opposite side, be pushed forward and drawn off. In this way, when that screw is tightened, the quadrant and its plane must of necessity incline somewhat

towards the horizon, and the plumb line itself must depart from the vertical line.

But if you wish to bring the plumb line back towards the quadrant, so that it touches or strikes the limb more closely — or, what comes to the same thing, to raise the plane of the quadrant more and more upright — you need only turn that royal screw already mentioned, or undo it [recludere], with the right hand, that is, towards the left. And so, with no effort at all, by means of one single screw, the plane of the quadrant is restored most exactly from every quarter of the sky — so exactly that nothing could ever be more precise — and is corrected, namely by the guidance of the plumb line [funependulum], with respect to the vertical plane.

Nevertheless, since the whole quadrant, with everything attached to it, is of very great weight and hangs from a single axle set in the movable leg of the stay, so that it is entirely free on every side, above as well as below, it is for that reason quite impossible that this quadrant, however carefully you have levelled it [ad libellam], should stay in its most exact position for any length of time; rather, it necessarily departs continually, quicker than words can say, from the plane and from its true position.

[Margin: For greater firmness I added still other supports to the prop.]

Therefore, to forestall this inconvenience, I devised those four arms or supports [Fulcimenta] and fixed them to the movable leg of the prop, so that the quadrant could be firmly fastened to the said prop and in this way be strengthened and secured on its own, so that once the quadrant had been exactly restored and corrected, it would thereafter keep its position constantly and entirely flat, to whatever side it was turned. More than that: even if the quadrant should stray somewhat from its genuine, most exact position, there would at the same time be the means — that is, by four separate screws — of amending it most exactly and correcting it again, to whatever quarter it might be facing, by the plumb line, or by the tube filled with mercury [fistula hydragyro repleta] spoken of above, and by the vertical point, that is, the position parallel to the horizon (on which still greater things depend, almost, than on the plane of the instrument). This is done as follows.

First, as you can see from the picture, I fixed two four-sided iron bars [vectes] to the steel crossbeam of the quadrant's upper leg, and made them long enough not only to reach the lower arms of the prop but even to pass beyond them on that side. The tips of these bars, as is evident, are threaded spirally like screws and fitted with four nuts [matrices], or whorls [verticilli] threaded in the same way. So by tightening or loosening the lower or the upper ones — this nut or that [pericochlea] — you can properly restore the quadrant to the plane of the horizon, that is, or to the plumb line. But I would have you note here that if you tighten either of the lower nuts, you must without fail loosen one of the upper ones again by the same amount. Thus, by means of these two bars and four whorls, anyone has full power to rectify the quadrant to the plumb line — or vertical line — or to the direction of the horizon, with respect to the

upper leg, and to restore it with the utmost precision. And in this way, once all four of these whorls have been properly tightened against one another and closed, this quadrant — as those more experienced in these matters will readily acknowledge — cannot be moved from its place in the least, much less depart of its own accord from its true alignment.

[Margin: How the quadrant is brought accurately to the position parallel to the horizon.]

Yet I thought the instrument would be stronger and better fitted still, on every side, if, besides these threaded bars and their four whorls, I furnished two further screws, applied them to the upper arms or supports of the quadrant's stay, and at the same time fixed them with a special iron to the steel crossbeams of the instrument, at a place where they could conveniently go. In this way they would support and strengthen the quadrant more and more and come to the aid of the earlier screws; and so, likewise, with their help the whole instrument would not only be rectified the more perfectly and exactly, but also be kept as firmly and for as long as possible. Use afterwards taught me abundantly that the matter did indeed turn out as I had wished. It is wonderful to tell, therefore, how readily, gently, promptly and soundly this enormous and exceedingly heavy instrument is moved, steered and restored, and how

[Margin: By means of the threaded whorls, and of other things attached besides, the quadrant is directed with wonderful ease and kept sound.]

steadily its soundness can be maintained — namely by means of these four threaded whorls, and also of the remaining two upper ones applied to the arms and their screws: in accordance, that is, with the plumb line and the vertical line. This is almost the chief thing that must be attended to above all in instruments of this kind — those that carry rulers but rest on no azimuthal circle — and in observations of that sort.

Then, too, how very easy it is, by means of that larger royal screw, to direct the movable leg of the whole directing prop — according to the vertical plane, that is — and its plumb line. Yet one and the same plumb line suffices for both tasks, provided it is hung correctly and properly from the vertical leg of the quadrant, so that it touches the completed ninetieth degree precisely and lightly, as it should.

But if the plumb line strays only very slightly to one side or the other, so that it is not worth undoing all the threaded whorls, I devised yet another aid. I fixed an oblong flattened iron, or toothed crosspiece [transversarium denticulatum], across the middle of the quadrant from the upright leg right to the limb, parallel to the other, horizontal leg, as is clear from the preceding Figure L. By this means I could hang a considerable weight of several pounds by its hook from that toothed crosspiece — and in the very place that the case required.

[Margin: When the quadrant deviates only very slightly from the true position, how it is restored with a very light movement.]

For you should know that, however much this instrument has been provided with frameworks, cross-beams, stays, props, screws and threaded nuts, the

plumb line is nonetheless moved somewhat from its proper place when the centre of gravity changes, so that the quadrant inclines a little this way or that with respect to the vertical line. The centre of gravity of the whole quadrant changes when the ruler — which is in any case made of solid metal, fairly broad and thick, is fitted moreover with very strong pinnules, and has no ordinary weight — is moved from one place to another. For the centre of gravity stands in a quite different relation when the ruler is set at about the fifth, tenth or fifteenth [degree] (as in the preceding Figure) than when it is set at about the fiftieth or sixtieth

[Margin: When the ruler is moved, the centre of gravity of the quadrant changes at once.]

degree of the limb; and again it is entirely different when the ruler has been brought down to the eightieth or ninetieth, that is, to the lower part of the quadrant, towards the upright leg. For in this latter position of the ruler, since a greater weight comes over to the upright leg, it is absolutely necessary that the plumb line hung from that leg should move outwards away from its line. When the ruler is set, on the contrary, at about the second or third degree, the plumb line itself must then turn inwards from the said vertical line. So it is beyond dispute, as those skilled in mechanical matters know very well, that any quadrant of this kind, provided — as it necessarily must be — with a very heavy ruler, is moved somewhat from its true position by reason of this widely varying position and of the weight added, even though at the start the instrument was directed and corrected precisely by means of all the screws.

[Margin: This deviation is remedied by a weight, so that the quadrant always keeps its equilibrium.]

This drawback, however, is readily met at any time, wherever the ruler may stand: namely, if you set that hooked weight against the ruler and hang it from the toothed beam on the side opposite to it. That is, when the ruler stays near the upper part of the quadrant — at the first degrees, namely, as is clear from the preceding picture L — the weight is hung towards the upright leg — and that by moving it this way or that until the plumb line has been brought back exactly to the vertical line and the centre of gravity of the instrument has been restored. Conversely, when the ruler is placed near the upright leg at the later degrees — that is, at those greater altitudes where the quadrant is forced of its own accord, or rather as if by a greater weight added, to make the plumb line deviate outwards — that hooked weight is moved to the opposite side, namely towards the limb of the quadrant, and as far as suffices for equilibrium and as the plumb line and the mercury [hydragyrum] enclosed in the upper tube set on the quadrant entirely require.

You may ask, however, whether it is not enough to bring this quadrant to the level [ad libellam] with the screws intended for that purpose. Certainly, my reader, that is the better course, I admit, right at the start, when you begin to observe; but

[Margin: Why is the quadrant not brought back to the plumb line by the screws?]

when the ruler has been moved on only a little way, it is far easier for anyone to bring the plumb line back with that weight than to re-correct the quadrant by loosening and then tightening again so many screws. For in that way, unless you are very practised in this business, you go wrong, now by excess, now by defect. When, however, the quadrant deviates considerably, then I myself advise you first to rectify its position with the screws and those spirally threaded whorls; and if some slight remainder is still left afterwards, or some lesser fault creeps in, you can remove it with that weight.

So it will be open to you, in any position of the ruler — even if you are as yet less practised in this arena [pulvis] — to re-correct the instrument most exactly. Indeed, if you sit by the plumb line, any servant, even the most unskilled, can do it under your direction, by shifting and placing that weight now here, now there, until the plumb line corresponds most exactly to the vertical line. It is most necessary that this, like the vertical plane too, always be observed most exactly in every observation. Otherwise you will certainly stray from the truth — persistently, at times — as has no doubt quite often happened to more than one person. This is certainly clear enough, and more than enough, from the fact that very many observations which ought by all means to agree do not fully agree with one another or correspond to each other.

[Margin: In all observations the position of the quadrant must be examined.]

Besides this, I fixed a long, round handle [manubrium], armed at its end with very strong iron, to the immovable leg of the quadrant's prop with two flattened plugs [obthuramenta], or wedges. The purpose is that you should have no need at all to take hold of the quadrant itself, or its limb, with your hand, or to move it towards any azimuth whatever, but should direct the whole quadrant in any direction, quite lightly, with this handle alone. For although this quadrant is so strengthened and bound together by so many iron crossbars, jointed beams, stays, bolts [repagula] and screws that it yields only in the least degree to bending or to any moderate force, it is nevertheless better to move and turn the quadrant about with that handle.

[Margin: Directing the quadrant with a directing handle in accordance with its motion in azimuth.]

Moreover, by means of this handle too, in a certain new and special way,

[Margin: How by means of pulleys and ropes …]

namely with certain pulleys [trochleae] fixed both to the side of the observatory and to this handle, and also with two silk cords led through the pulleys just mentioned, you may guide and direct this instrument towards any azimuth as gently as possible, with nothing to surpass it. So you need touch neither the handle nor the quadrant itself with your hand, wherever the observer may sit, whether the ruler is raised or lowered moderately or to the utmost.

[Margin: … the quadrant can likewise be moved.]

I would indeed gladly have sketched this device, with these two cords and the little weights hung on them, in both Delineations of this quadrant. But because of the very many and various things attached to this instrument, I was not able to set it before the eyes of Urania's devotees so clearly and distinctly. Those, therefore, who take a somewhat deeper interest in these matters will be able to turn them over further in their minds. I have no doubt at all that they will now grasp everything more easily than I did at the start — to whom these very things did not at first occur even in a dream — and will also put them into practice. For this purpose you see certain pulleys hung on the quadrant's pedestal, by means of which the hauling cords [funiculi ductarii] can be conveniently led so that they hang at all times right at the support itself and are worked there. But enough for the expert.

[Margin: This could not be sketched so distinctly.]

This way of directing the quadrant in azimuth is therefore not so very inconvenient. But, as we have already touched on above, I later devised yet another, quite different method by which the quadrant can be guided — in azimuth, that is — far more exquisitely, by means of a single longer screw alone; and in such a way that the instrument always stays most firmly fixed in its place and is never moved from it, even if you strain against it with all your might, or knock against it, or push it. So that this may be more convenient in use and be brought into practice, I thought it worthwhile to construct beforehand a kind of arm, or special wooden prop, as you see best of all in Delineation L. For better understanding I also chose to draw this in a separate Figure S, in which some other aids for the instruments are seen on a larger scale. This

[Margin: The best method of all for moving and directing quadrants in azimuth.]

arm, however, since at one end it consists of two segments of a circle, is fitted between two wooden dovetails [securiculae, sive subscudes], and fastened with two screws — yet in such a way that, when either screw is slightly loosened, it can be turned round without any resistance. And so that it would move more smoothly, I surrounded the support at that place with very thin, well-polished plates, and also covered the two inner circular parts of the arm with leather. In this way the arm is moved about the support very readily and very lightly in any direction, and at the place where you want it to rest you need only tighten the screws.

[Margin: A wooden arm for attaching the directing screw.]

Next I had a screw made 16 or 18 inches long. It is inserted into two brass balls of two inches, exactly turned and polished, so that it passes through the hole of one ball, which is threaded spirally, and through the plain hole of the other, secured on the other side by a collar [verticillus]; so it can turn very readily both in this plain, polished hole and in the threaded one. The brass balls themselves are clamped by four smaller screws between perforated plates whose holes are slightly smaller than the great circle of the balls. In this way, although they adhere quite firmly and tightly to the plates, they nevertheless

revolve in every direction and remain turnable together with the longer screw set in them, as is clear from the preceding Figure L. This is almost the same principle as that of the revolving ball on which sextants are elsewhere set to the stars and moved, which we have already mentioned in part in Chapter VI and of which we shall have to speak more fully in the next chapter.

[Margin: A special screw fitted with two revolving balls.]

[Margin: Construction of the balls.]

Moreover, a little steel pipe [canalicula], open on one side, is fixed to each of the larger plates; indeed, to the plate nearest the handle [ansa] of that screw I attached two such pipes. In this way one end of the screw, with its ball clamped between those two plates, can very well be fastened by a smaller screw intended for this to that wooden arm which moves about the quadrant's pedestal, while the other ball, with its plates, can very well be attached to the limb of the quadrant, or rather to the arched steel beam set transversely beneath it. As for the latter ball just mentioned, with two, or rather in fact three, little pipes set crosswise

[Margin: This turnable screw, both for the quadrant and …]

we chose to fit it, this was done so that the said screw with its balls could also conveniently be used on our great brass sextant, to be described in the following chapter, and also on the azimuthal quadrant shown in Chapter IX. For one pipe [canalis] suits only this quadrant, another the sextant, and the third only the azimuthal quadrant just mentioned, as will be explained at length in its place.

[Margin: … and for the sextant, is very convenient.]

When an observation is to be made, therefore, the quadrant is first directed roughly in azimuth, so that you have the star to be determined close by. Then the ruler too, once released, is brought by free hand almost exactly onto the star and clamped there by its channel. When this is done — if the vertical and horizontal plane still then corresponds quite precisely to the plumb line, so that you have nothing at all to re-correct (if not, you must first rectify the quadrant) — I loosen the screws of that wooden arm, which moves about the instrument's support, and bring it towards the quadrant by about a palm's breadth, or one span. To it I fasten the ball by its outermost plate, or rather by its little pipe, with a screw, and indeed at whatever part of the arm the observer's convenience and arrangement require, given the altitude to be observed; for this arm, or prop, is so arranged that the screw with its balls can be fastened now at a higher, now at a lower place.

[Margin: Use of this screw fitted with balls.]

[Margin: The screw is clamped at one end to the arm, at the other to the quadrant.]

Next the other ball, the one nearer the handle, is attached to the quadrant — or rather its little pipe is — with its screw: at its rear side, that is, to that steel beam fixed to the quadrant's limb, as was said above, at a place exactly opposite the first ball. In this way this directing screw (if I may call it so) adheres to

the quadrant crosswise with respect to the quadrant and its limb, that is, in a direction parallel to the horizon, as is plain from the earlier Delineation L.

So the quadrant is now joined to that revolving wooden arm, and in turn this arm to the quadrant, so closely that when either is moved the other must of absolute necessity move as well. And so, by means of this arm, the quadrant, wherever you wish, most readily and most lightly — namely to the star

[Margin: When the directing screw is attached, the arm too is turned round together with the quadrant.]

to be determined — is brought.

Once all these things have first been arranged and set out in this way, if the observation itself is now to be undertaken seriously and carefully, that arm (together with the quadrant attached to it) must first of all be made fast to the support by its screws, which were mentioned above, so that neither the arm nor the quadrant can be moved from its place in any way or to any degree at all. For that longer directing screw, fitted with balls, little plates and little pipes, entirely resists all motion and wavering, just as if the quadrant had been fixed to the pedestal, as it were, in every way, and on purpose.

[Margin: How the observation itself is to be conducted.]

Nevertheless it turns very freely, and obeys every direction most promptly at a touch, into whatever quarter you strive to bring it. For, taking the handle of the directing screw in the left hand, and with the other — the right hand, that is — that screw which lies beneath the ruler (of which more fully later), and turning these two screws in this way, you can determine with the left hand the azimuth of the star or the Sun, and with the right hand the altitude itself, more exactly than words can say or than you could ever imagine. Since those two screws govern and direct the quadrant and its ruler to a nicety, as you turn them and twist them this way or that, the ruler is now raised, now lowered, and the quadrant itself is also brought this way and that most gently and most lightly, even though the whole instrument, as you have learned, is of the greatest weight.

[Margin: The screw turns very freely, whichever way you twist it.]

[Margin: How the altitude and the azimuth are obtained together.]

Accordingly I may affirm with every assurance, as we have already indicated in its place, that with this new invention, discovered by me (for no one, as I know very well, has ever yet published a similar invention, much less applied one to the stars), I can keep and hold the Sun by day, as if motionless, in the little circle of the lower pinnule, and the stars by night, as though wholly exempt from all diurnal motion, most exquisitely and for a long time — as long as you wish — remaining most steadily in the pinnules and not in the least leaving them.

[Margin: With this new invention I can imitate the whole motion of the heaven, as if the celestial bodies stood entirely motionless.]

Likewise, with this directing screw fitted with screws, you will no less be able (as we already partly touched on the preceding page) the azimuthal quadrant

shown in Chapter IX, to direct to a nicety, once it has been brought parallel to the horizon.

[Margin: With this directing screw we can also direct the azimuthal quadrant most conveniently.]

For since a third little pipe, set opposite the sextant's little pipe, has also been added to the revolving ball nearest the handle, you need only attach the outer ball, by means of that little pipe, with its clamping screw, to the horizontal leg of the quadrant that lies on the azimuth circle — towards the observer, below the ruler, at the headed pin (where that directing contrivance for directing the cords is usually fixed). Then clamp the other ball likewise, by the appropriate little pipe already mentioned, to the azimuth arc. When this is done, taking the handle of this directing screw in the left hand, that is, and grasping the cords with the other, the right, you will be able in the same way, with that azimuthal quadrant just as with this horizontal one, to determine azimuths and altitudes together and at once, most exactly and most promptly. I thought it worth recalling this here, since in Chapter IX no mention has yet been made of this directing screw.

How much this new method of directing the quadrant now contributes to celestial observations, especially the more subtle ones, I leave to fair-minded cultivators of astronomy to judge. By its benefit above all you can produce observations not only very quickly and very promptly, with almost no trouble, but also thoroughly and most exquisitely, even though you need not touch either the ruler or the instrument itself with any hand. The instrument, besides, is of itself so firmly fixed and bound on every side that it cannot be moved in any way at all, even when the strongest wind is blowing. For everything is moved in itself and by itself, so that the instrument itself in fact feels no motion, not even the least, nor any slight twisting at all — as indeed happens in the other quadrants, in which the ruler has to be directed, raised or lowered, now upwards, now downwards, with bare hands or with no slight force.

[Margin: This is the most desirable method of all for conducting observations.]

Therefore I have no doubt at all that genuine surveyors of the heaven, more painstaking than others, who are moved by some [?] concern for advancing and adorning the astronomical science, will one day give me signal thanks, both for that royal screw for bringing the vertical plane of the quadrant

[Margin: For these three aids to observation the cultivators of the stars will without doubt give thanks to the author.]

back into true, and for those two others: the one, that is, the directing screw fitted with balls, for determining the azimuths of the stars, and also the other, for directing the ruler so as to take any altitude properly. At the same time they will also at last acknowledge that undertaking observations by this method is a most excellent thing (be it said without offence) and supremely necessary. Without it, assuredly, no observations of any importance at all will ever be

properly carried out by anyone, whatever anyone may claim for himself in this business by the older method.

[Margin: By the older method scarcely anything accurate is ever achieved.]

Besides, I am thoroughly persuaded that these screws will furnish more than one person with still loftier ideas for governing and directing very many and most diverse things easily, promptly and exquisitely — just as they have so far given me, too, occasion for various excellent inventions: for instance, how microscopes can be directed to a nicety onto any object, far more conveniently indeed than hitherto by means of that larger and ampler screw fitted to the objective lens; and then, how, no less, with the help of these screws we can recognise on any instrument the minutes themselves, indeed individual seconds, and that almost more accurately than by any other method, in the very limb of the divisions, and distinguish them most finely. But perhaps there will be an opportunity elsewhere to discuss these inventions and describe them more fully.

[Margin: These screws will pave the way to matters of higher inquiry.]

Finally, it would be worthwhile for me to explain somewhat more clearly that screw attached to and set beneath the ruler. But it could not be sketched so accurately in the figure, and so described here, both because of the innumerable things that bear on the quadrant and because of the narrow space of the page. Whatever could not be done concerning this quadrant, however, we shall accomplish on the occasion of the sextant that follows, and we shall also set it before your eyes in its place in a special figure S, together with certain other lesser things. Notwithstanding all this, I shall dispatch it in three words: beneath the ruler I set two steel buttresses, about two inches long, and fixed them there very firmly. They have holes near the end, threaded in a spiral, through which a screw is passed, which in turn at its end a square little pipe, open on one side, with a special

[Margin: On the screw attached to the ruler.]

[Margin: How the ruler is fitted with a directing screw.]

smaller little screw — a pipe, moreover, that revolves, so that it can be turned round on the larger screw very smoothly, yet without any wobble at all. This little pipe is of such a width, and stands at such a distance from the limb (that is, from the steel crossbeam set beneath it), as the two buttresses already mentioned stand from that same beam. In this way the longer screw, by means of the little pipe, can be clamped neatly to the beam beneath it at any place whatever, with the help of that smaller screw.

But the whole crossbeam set beneath the limb must be filed most evenly along the course of the circle, smoothed, and of the same thickness throughout; and the little pipe must also be fitted to it very closely, so that it can be applied and adjusted to the beam not just at one single place on the limb but at any place whatever, and, once that smaller screw is slackened, can be moved elsewhere again as promptly as possible. For unless the little pipe is adjusted to the beam in every respect, so that it can be clamped anywhere very smoothly and

released again in turn, whatever you undertake in this matter is in vain, and this invention turns out to be more of a burden to you than a help, as you will find for yourself in practice.

[Margin: Everything must be neatly finished.]

Admittedly, as we have already mentioned above, it takes skill and labour to complete all of this with such care; yet it certainly can be done, provided you are not afraid of sweat. There is surely no doubt that you will obtain the result you wish just as I have in this very quadrant, in which each and every part has been made and worked so exquisitely that perhaps even you, if you had the chance to see it, would be satisfied.

[Margin: To construct all this in this way is difficult indeed, but it is not altogether impossible to do.]

Finally, when the altitudes of the stars themselves are now to be taken, the ruler, with its directing screw beneath it, is first raised by the free hand, or lowered as the case requires, and so brought round to find the desired altitude. Then, taking the little pipe of the smaller screw in the left hand, one applies it to the beam (that is, the steel arc of the limb) and at the same time clamps it there by means of that smaller screw set in the little pipe. Once this is done, the ruler can no longer be moved from its place in any way, nor be turned askew this way or that in the least — just as if it had been cast onto the quadrant or fastened to it with screw-bolts. But if you nevertheless wish to move it and direct it towards a star, nothing but the handle of that screw

[Margin: How the altitudes are to be obtained.]

do you need to grasp, turning it whichever way you wish. In this way you will bring the ruler, with wonderful exactness and at the same time very smoothly and very quickly, to take any desired altitude of a star, without any jolt, shaking or push.

Add to this that, once the altitude itself has been fixed in this way, we can at the same time, by means of this same directing screw — namely from the little disc attached to it and its indices, which are moved along the course of the screw by a singular contrivance of notched little wheels — distinguish most conveniently and most exquisitely not only single minutes and seconds in fives, but even single ones. But since this could neither be described sufficiently on this occasion nor sketched clearly enough in the pictures above, I have chosen to reserve this remarkable and entirely new invention for its proper place, Chapters XIV and XV, where the sights, and above all the divisions, will be treated expressly.

[Margin: A little disc is fixed to the directing screw, for showing from its indices the first minutes and single seconds.]

Believe me, I set some value on this aid; what you and others think of it, once you have examined everything thoroughly, you are free to judge. Meanwhile, however, I would have you know that I am not afraid, with this new invention and by means of those screws, to draw from the sky itself at any time one or two thoroughly exquisite observations that agree well with each other, more

readily than anyone else — be it said without boasting — could draw even a single one by the older method, moving the ruler with the free hand.

[Margin: This method of observing seems to the author of some importance.]

Lastly, it would likewise be my task to explain briefly what kind of little steel springs [plumulae] the ruler of the quadrant and the directing screw beneath it have. But that cannot be done here, since they cannot be sketched at the same time; it must therefore be put off until we treat expressly of the pinnules and their parts, as we have said.

[Margin: On the little springs fixed to the ruler.]

And so nothing more now remains than to relate in a few words how the observer can carry out observations with this quadrant at every altitude, always with the greatest convenience. If, that is, the ruler has to be raised considerably, as at the lower heights of the stars, I lay planks on the lower beams of the observatory, to which the wheels are fixed crosswise; and in this way a kind of raised storey is formed, from which, either sitting in that

[Margin: Observations are always undertaken without any trouble.]

revolving chair, or standing, or even, if it cannot be done otherwise, from stools, you will carry out the observations. But if some lower altitude is to be determined, I stand on the floor itself in which the wheels run their track, or sit on it; or if the altitude verges almost on the zenith, I withdraw into the crypt, and there likewise, standing or sitting as the occasion requires, I carry everything out. So I am never forced to make any observation in an awkward posture of the body, or by applying force, in some unsuitable position of the stars or of the ruler.

And these, finally, are the things I wished to set out about this bronze quadrant of ours, which is by no means an ordinary one. I admit, indeed, that it matters very little to the great many who handle the divine Urania with a light arm, and merely for form's sake, that I have treated these matters at somewhat greater length. Nevertheless I hope that some will come forward, even if very few (since our contemplations bring slight wealth — indeed almost none), who will take up a candle and look at these things of ours, such as they are, with steady eyes, and turn them over in their minds. For their sake, then, and above all for the good of astronomy, we have gladly not declined to undertake this labour too.

[Margin: I think that those devoted [?] to the deeper astronomy will at last acknowledge the author's effort in this part.]

CAPUT XI.

Chapter XI.

De Sextante Magno Orichalcico.

On the Great Brass Sextant.

I have always counted this sextant among our principal instruments [Organa]. This is not only because it too is made of solid metal, built front and back with steel crossbeams, dovetails [subscudes], buttresses and crossbars, and well joined together on every side; but also because it is of no ordinary size — namely four cubits, or six feet, and indeed somewhat more, as regards the radius; and besides, because it is made in an entirely singular way and is governed with altogether wonderful ease and promptness. For this reason I have used it to measure a great many of the loftier and finer distances both of the planets and of the fixed stars, so that it fully deserves to be depicted somewhat more accurately and more fully than the rest of our instruments,

[Margin: This instrument is not the least of the others.]

[Margin: Its size.]

[Margin: The author has made a great many observations with this instrument.]

Diagram. Full-page engraved plate, Figure M: the great brass sextant in use. The sextant, limb downward — a tall triangular body of two radii and a central upright, filled with symmetrical scrollwork — is carried on a vertical pillar rising from the floor; ropes and chains run from pulleys on a timber beam overhead to rings on the instrument and on the posts of the observatory. Two observers sight along it: on the left a man seated in a high-backed chair works the sight on the carriage at the left end of the limb; on the right a woman in a fur-trimmed robe stands at the sight fixed near the other end, one hand raised open toward the arc, the other held under a rod-and-disc fitting hung from a bracket beneath the arc. Also shown: a cloth valance along the overhead beam, weights hanging at the left post, a long rod lying on the floor from the foot of the pillar, an upright pierced with square holes at the right edge, and a wheeled box behind the man (its purpose not shown); the fixed sight at the right end of the limb is a cylinder with a ball on top. A balustrade runs behind them; a round stool stands on the boarded floor at the right. The limb carries engraved degree figures, and small statuettes: a man holding a telescope to his eye at its left tip, and two small figures flanking the pierced sight plate of the movable carriage. The plate shows no lettered key.

- Lower left, below the floor line: *Fig. M.*
- Lower left margin of the plate: Stech [?] Delin. (Stech drew it)
- Lower right margin of the plate: J. Saal Sculps. (J. Saal engraved it)
- Figures on the limb, left to right: 60, [?]0 (partly hidden behind the carriage), 40, 50[6], 20, 10 and described — above all on account of its observatory or little cabin, in which it is kept and under whose roof all the observations are also carried out continually. For it certainly cost me a great deal of trouble, and racked my wits not a little, before I had devised, and fittingly brought into effect, each and every thing that seemed in any way to bear both on this movable observatory and on a convenient

[6]so engraved; the series would give 30

> method of directing this instrument. It will therefore not be wasted labour, in my judgement at least, my lover of the stars, to detain you with this description a little longer than is due. For I am fully convinced — as a great many people who have either seen various, and by no means trifling, inventions of this kind with their own eyes, or will later also handle them with their own hands, will freely admit in their own time — that this method, namely of raising, moving, governing and directing sextants to the stars, is certainly to be counted among the very foremost and most distinguished inventions that have ever yet been discovered by anyone and handed down to memory in mechanical astronomy, that is, in determining the distances of the stars (without, however, any empty boasting).

[Margin: Before the author had arranged everything conveniently, he lost a great deal of labour.]

[Margin: This method of directing sextants is certainly of some importance.]

We shall show this sextant first from its principal and front face. The ruler itself and the pinnules are fixed to this side, and from it the observations themselves are also carried out by the directors [Directoribus], two of whom are always required in the observatory to direct the instrument, since one person alone can never accomplish anything with a sextant of this kind. Since, however, for very many years now I have often lacked, in conducting observations, the help of some well-practised student of mathematics who could assist me at the sextant, I persuaded my dearest wife, and drew her into searching out the stars, so that she too, being always at hand, might bring me help in this respect, in directing the sextant. And as she at once took this burden upon herself with the greatest willingness, so by frequent practice and continual use I brought her, with God's assent, in a short time to the point that she can … any intervals of the stars whatever, however exceedingly difficult (although I still have other assistants at my side as well)

[Margin: The front face of the instrument.]

[Margin: The author employed his wife as an assistant in the observations.]

[Margin: In this exercise she even now acquits herself so well that she does not easily yield to anyone, even someone more learned.]

whenever she pleases, measure them with me, to complete satisfaction in every respect and with the greatest exactness — indeed almost more readily than any of all the others, however much more learned he may be. For women are just as suited to observations as men, since this business depends not on the highest learning and a sharp intellect but on tireless practice and a lynx-like eye; above all, however, on the proper and circumspect direction of the principal observer, who sits at the ruler as at a helm and bears the whole burden. But to act as director in measuring the distances of the stars is — believe me — a matter of considerably greater importance than anyone would ever persuade himself who is either wholly unpractised in handling instruments, or who rarely or

never pursues the stars under the open sky and contents himself merely with leafing through the pages of ephemerides or the little works of others.

[Margin: To direct observations is a matter of some importance.]

In this position of the sextant you see only the front part of the observatory, and, hanging by their hooks from the upper crossbeam, four pulleys through which the draw-ropes [funes ductarii] are led. To one of the two ends of these ropes quite strong hooks are attached, which open when a small steel spring is pressed and close again when it is released; to the opposite ends of the ropes, in turn, two weights are hung, as heavy as the instrument itself requires — in this one, about 60 pounds. Furthermore, a great many brass rings are fixed, ascending in order, as can be seen, to the front uprights [Statumina] of the observatory — that is, the upright beams that support the roof — so that on either side you can attach a pulley by its yielding clasp [fibula cessili], and also similar ones at each end of the sextant, namely from the steel crossbeam, from which several rings likewise hang. Through these pulleys, likewise, finer cords are now threaded double, with small weights of one or two pounds hung at the end of the cords, so that the sextant itself may be supported and steadied all the more firmly in every quarter and in whatever inclination it meets (as can be seen from the drawing).

[Margin: The front part of the instrument.]

[Margin: What purpose the rings hanging from the uprights serve.]

Formerly, in Tycho's time, and right up to the present, wooden sextants of moderate size scarcely … without much labour and

[Margin: Until now wooden instruments scarcely … with-] sweat could they manage to govern and direct them, even in the most convenient position; and with certain little rods and levers they were scarcely able to prop them up and keep them so firm that they were entirely free from all wobbling. By this new method of ours, however, you can move even the largest and heaviest instruments of all — in any position, however unfavourable, or on an inconvenient plane — both quite lightly and very promptly, and then at once hold them there entirely motionless, so that they do not wobble or sway in the least; and that, moreover, with no trouble, by a tap of a few fingers, and with the greatest speed. However far the plane rises, even up to the vertical line, sextants of any weight whatever nevertheless obey you at a nod, and stay in their place of their own accord and firmly, as if fixed there with beam-nails.

[Margin: Until now wooden instruments could scarcely be governed without great labour; now, however, even the heaviest are governed with almost no trouble.]

So that this could be done all the more aptly, I attached several quite thick bronze rings to the lower steel crosspiece of the sextant, so that one should not be prevented from fixing the thicker ropes elsewhere, for greater convenience and firmness — if they should perhaps be in the observer's way, or if the vertical plane of the instrument or its centre of gravity required it — as well as from hanging the finer cords with their pulleys now inside, now outside the

observatory, now on higher, now on lower rings; so that the sextant would rest on them all the more and consequently also stand much more firmly. What kind of convenience this is, and how great — and also with what care and how much labour we achieved it — only those skilled in the mechanical arts will readily recognise. Yet all will confess with one voice, once instruments have been fitted out and arranged in this way, that it is as splendid and most excellent an aid to searching out the stars as could ever be given or found of this kind, be it said without boasting. Certainly, had I not happily hit upon this singular invention, it would have been entirely in vain — or at least very hard, troublesome and exceedingly laborious — to set such immensely large bronze instruments to the stars and direct them.

[Margin: Sextants are governed by several ropes led through pulleys.]

[Margin: To direct sextants in this way is a most excellent aid.]

Furthermore, the sextant itself is set on a pedestal which stands very firmly, like a column, outside the observatory.

Into the upper part of this support, which is bored out to about half its depth, the little column of that turning globe which carries the sextant has been inserted. Of this revolving globe something has already been said above, and more will be said more fully presently below. Next, where the little pipe [canalicula] in which the little column, or small axle, of the instrument turns sits on the rear side of the sextant, there lies the centre of gravity; and it is certainly of the greatest importance that this be accurately sought out and properly determined. For if you go astray in this respect to any degree, you will only with great difficulty bring the sextant to its proper plane, even with the weights and all the other aids applied, nor will it ever stay in its place of its own accord; rather, it will swing now to this side, now to that. Usually, however — even when the centre has been properly marked — in the more sloping distances of the stars, of two or three degrees, especially when both stars are entirely equally distant from the horizon: in that position, I say, the end of the sextant where the cylinder, or front pinnule, stands tilts very steeply towards the horizon and cannot hold itself there. The reason is that in that position, exactly parallel to the horizon, the larger weights on their ropes move the instrument out of its centre of gravity.

[Margin: The sextant's pedestal.]

To remedy this inconvenience in turn, and to restore the sextant's balance properly — above all, so that the observers do not give way under excessive burden and labour (for this sextant, as you will readily understand, weighs several hundred pounds) — I hung a very short cord by its little hook, carrying a ring at its end, on the front crossbeam of the sextant, and indeed at the very place (for you see several rings fixed there) where the principle of equilibrium requires it for the given inclination of the instrument. There, I say, a further weight of ten or twenty pounds — as heavy, that is, as is altogether needed — is attached. By this means not only is the sextant's equilibrium restored, but it is also brought about that the instrument can stand both very quietly and firmly

in any horizontal positions whatever, or in the most unfavourable inclinations, and that of its own accord, so that you have no need to help it with a finger, much less with props [Tibicinibus] or any substructure.

[Margin: In what position the instrument's centre of gravity must be assisted.]

[Margin: The actual method of observing.]

So, once the sextant has in this way been set to the particular distance between the stars that is wanted, and to the inclination of its plane — how this is always to be obtained as accurately as possible you will learn, to save going over ground already covered, not so easily from anyone's lips as from practice and exercise itself — the task falls to the other, secondary observer, who stands or sits at the sight fixed to the other arm, as on the right in that figure M (although this sight can also be put on the left, if you arranged the ruler and the divisions that way from the very start). He must first bring the sextant to the star and direct it by means of both pinnules, and then set up the collimation properly and complete it with the utmost exactness, as this method certainly allows — either with free and bare hands or (what is better, and far more suitable) by means of that longer directing screw, armed with two revolving little globes and first invented by us, which we described towards the end of the preceding chapter.

[Margin: On the extensible support, for clamping the revolving screw.]

When this is done, this same observer takes hold of the arm — that wooden prop [Sustentaculum], attached by two hinges to a round piece of timber (which is in turn fixed to the front right support of the observatory) — and with its screws clamps that arm at a convenient place, now higher, now lower (for it can be raised and lowered again at will), according to the direction and position of the instrument, as is clear from both figures, M and N; but you will see its construction best of all in its own place, in a separate drawing. This arm is of the greatest service not only to the said observer, who acts as assistant to the primary one, by letting him lean his right arm — indeed almost his whole body — on that extensible support and rest on it (which, believe me, is a singular aid and a most excellent convenience for holding instruments always at the same point quite firmly); it also allows the longer directing screw to be clamped by its end and its little pipe [canalicula] to the ring of the front part of the support — at the very place, that is, which suits the observer and which the direction of the instrument requires — the said screw lying almost parallel to the run of the limb.

[Margin: By means of the two screws, with the utmost accuracy of all, obser-]

When this too has been done, the other little pipe, belonging to the other revolving globe, likewise by its own screw, to the steel beam that lies beneath the divided arc is fixed, as is quite clear both from the preceding figure M and from the following one, N.

[Margin: (continued) … observations are carried out.]

Then the observer, holding the handle [manubrium] of the directing screw in his left hand, and with his other hand taken away altogether, can direct the sextant at will as promptly and exactly as possible, without any wobbling (for it is fixed firmly to the observatory); and, what is more, so very gently that the other, primary observer, who controls the ruler, feels no movement at all — except that he notices the instrument moving towards the star until it reaches it exactly in both slits of the pinnule, at the place where it then stands. How very conveniently, exactly, and at the same time quickly all this can be accomplished by a well-practised searcher of the stars you would hardly believe, unless you take the business in hand yourself; and then you will admit without any doubt that this is by no means the last among the other inventions. By means of it, namely, the instrument can be clamped most firmly — indeed immovably — to the observatory, or little cabin [Tabernula], in which it stands, so that it cannot leave its place in the least, but can be shifted and turned round only together with the observatory itself (which is likewise movable, on four wheels, with everything belonging to it), its plane being preserved and kept always intact — unless you either loosen the said directing screw or take it off the sextant altogether — as you will understand more fully hereafter.

[Margin: The construction of the extensible chairs.]

In observations of this kind, however the instrument may be inclined with respect to its plane, each observer is given the means of standing comfortably or, with the help of our extensible chairs, of sitting at will. These chairs, by means of a transverse support, or stop [offendix], set beneath them, are very readily raised and lowered with one hand on their upright support — which stands on a crossed base and is cut through with a great many square holes — so that you can sit by the sextant now higher, now lower, as the nature of the stars to be observed demands; and at the same time, in every more raised position, so securely that you need have no fear at all of falling. For while you sit on this chair, it is made fast and clamped to its support more and more firmly by the weight of your body, so that the lower stop by no means can jump out of its hole, unless you first stand up and loosen the stop.

[Margin: We have the greatest need of extensible chairs.]

Hence seats of this kind are not only most useful but also most necessary; had I not procured them for myself, I hardly see how I could have carried out so very many observations. For even granted this aid, keeping watch assiduously over the celestial observations by day and by night is, believe me, no ordinary labour. Among the other chairs of this kind I have also fitted some with a very long support, so that, when one end [cuspis] of the sextant is lowered, I can sit comfortably at the other, well raised, with a stool of two or three steps set under my feet — as can be seen from the preceding drawing M, and above all from N.

[Margin: Unless the primary observer is well practised, observations are undertaken in vain.]

To come now to the principal and primary observer, who generally sits at the ruler and very often needs the taller chairs: on him falls the whole burden both of directing the ruler and of bringing the sextant to its proper plane. He must therefore be thoroughly practised in this arena, so that he can at once detect and correct any errors whatever — above all those sometimes committed by the other, secondary observer as well — and can meet every inconvenience; so that he is not easily deceived by the other man, his assistant, but on the contrary is at once aware when the assistant is handling the matter well or badly, that is, aligning on the star. For unless the principal controller of the instruments has so much experience and practice that he can properly recognise and judge the work of his companion from his own pinnule alone, at which he sits — however well versed he may otherwise be in astronomical matters, and however much he credits himself with — he will surely labour in vain, whatever he may ever attempt in taking the finer distances, and he will rather often, and continually, stray from the truth.

[Margin: Presiding over observations is not inborn in everyone.]

From what signs, however, and by what method you can instantly detect your co-worker's deviations is not so easy to disclose or to understand. Whoever proposes to devote himself to these matters, and strives to win something solid and exact from the heavens, will have reason to train himself with deliberate effort until, in the course of time, he too reaches the goal. For right at the outset, when he is beginning, he will in no way at all bring matters to the point where all and every one of his observations agree with one another completely, or show the proper perfection at all times — however much he may possess instruments of the right size and of the most exquisite workmanship.

[Margin: How instruments were examined in the past.]

It was the custom of the Tychonians, of Kepler, of Gassendi and of others, when they came to their observations, to test and examine their instruments against the standard of some distance between stars that Tycho had once observed: namely, whether the instruments gave the very same interval or a different one. If a different one — as generally happened to them — they then either took the whole difference, exactly as many minutes as lay between their newly observed distance and Tycho's, away from all their more recent distances, if Tycho's separation of the stars was the smaller; or, conversely, they added the difference, if Tycho's was the greater.

[Margin: A method which seems to the author unsuitable.]

This, however, seems to me very unsuitable and does not please me at all: namely, that instruments should be examined first of all by this method, as if by this means we could be entirely sure of the work and diligence of both observers. As though the observers themselves — above all if they have sweated very little in this arena and are by no means strong of sight — did not sometimes stray from the truth! Indeed, even the most practised of all sometimes goes astray, whether in searching out, or in counting, or through some other unforeseen

accident that supervenes; so that at times more departure from the truth lies hidden in the directors than in the instruments themselves.

[Margin: Even the observers themselves are sometimes deceived.]

Grant that your instrument errs by excess. But how, I ask, can you be wholly certain of your companion's operation? Indeed, even if you trust yourself abundantly, do you suppose that your companion could not sometimes slip into error, now by excess, now by defect — as was very easy in that older manner of observing? Will you then be able, in every single observation, to add or subtract the difference in the same way from the remaining intervals, according to the standard of the earlier distance you had found?

[Margin: That older method of examining instruments is very slippery.]

Would not observations very often be disturbed by this trifling method, and thrown into the utmost confusion? Truly, with that experiment or test you are holding an eel by the tail. For my part, to speak candidly, I would not give a rotten nut for observations of this kind when it comes to investigating more abstruse and subtle matters, however much someone else may perhaps think otherwise. For I am entirely of the opinion that instruments of any kind whatever ought to be built, tested and approved so very exactly in every part that I can always be sure of their certainty and constancy.

[Margin: Instruments must first be examined most rigorously of all, before observations are undertaken.]

The examinations, however, ought to be made entirely by means of the ascensional differences of certain fixed stars lying about the ecliptic and the equator, carefully computed around the whole circle of the heavens from their duly observed distances. If the said ascensional differences show that circle to be completely perfect in all its parts and their subdivisions — that is, in 360° — then that instrument is fully finished in all its numbers and parts, so that nothing more can be desired in it, as we have already said at length in its proper place.

If anyone, however, has not yet tested his instruments by such a stricter examination and come to know their capabilities, I urge him to carry out this work first, before he dares to approach the observations themselves; failing that, let him give up altogether a matter so delicate and so lofty. For he will deceive not only himself but others too, and badly, and will lead them into the greatest errors, to the great harm of astronomy.

[Margin: It is necessary that we always have instruments such that nothing whatever is lacking in them.]

But if instruments may now be tested precisely by the most exquisite method just described, it is not worth the trouble to examine, by work so unsteady — and indeed for the most part the work of untrained companions who very seldom look at the sky — things that must of themselves necessarily be as correct as possible at all times. And so it is more fitting to examine the dexterity and diligence of the observers from instruments that are perfect in every respect.

[Margin: Let no one trust himself too much, even the most practised.]

For my own part, although I too have acquired some knowledge of the business of observing over a span of thirty, indeed forty, years, I nevertheless never trust myself so far as to suppose that I could not sometimes go astray, even together with the man who is my assistant. Hence it is my custom to repeat observations and distances rather often; if I see that they disagree a little, not at once to the instruments, but rather to the observers themselves, and above all to my companion, that I assign the blame. For we are human, and not seldom very prone to go astray.

[Margin: From differing observations it is easy to understand what is to be attributed to the instruments.]

As for the instruments, however — our larger bronze ones — you may be fully convinced that they have been built and fitted out with such care and diligence that it is possible, though only for practised observers, to measure the same observations at any time, even after the lapse of many years, as exactly equal in magnitude.

[Margin: The office of the principal observer.]

But, as we have said, it matters a very great deal that you have the most perfect instruments, and that the primary director of the observations is also well suited to this task by nature; and then indeed everything will turn out as you wish, so that you need not in the least fear that any notable mistakes could easily occur. The office of the principal observer, moreover, is to sit at the ruler and govern it; next, to bring it roughly onto his star with bare hands — the sextant having of course first been directed as accurately as possible onto the other star by the other assistant [Coadjutor].

[Margin: How the ruler is directed to a nicety by the directing screw.]

Only then does he clamp that directing screw (which has already been mentioned rather often), which lies hidden under the ruler, by means of its little pipe [canalicula] attached to the ruler's end, to the curved transverse beam lying beneath the limb, with a little screw intended for the purpose. Once this is done, the ruler obeys every direction most promptly, and is guided so gently and exquisitely this way and that, wherever you turn and rotate the directing screw — and with one hand alone, the other entirely withdrawn, without any resistance and with no force at all applied — that it is in your power to determine any distances whatever more closely and more exquisitely than has ever hitherto been possible with the free hand, if I may put it so.

[Margin: What the division of the sextant is like.]

The division of this sextant was carried out in exactly the same way as in the preceding horizontal quadrant: each degree is distributed into twelve parts and, by means of a number of circles and transversal lines, into single minutes. Then, further, by means of a certain segment of a circle, likewise divided into its small parts as in the quadrant, which shows the seconds five at a time as accurately as possible; and also by means of a special little wheel attached to the ruler's directing screw. From this little wheel and its indices, namely, both

the minutes and the individual seconds are read off most exactly — as we have partly said already, and as will partly be stated more clearly in its proper place.

[Margin: The slits of the pinnules can likewise be widened and narrowed again.]

The pinnules, too, are built in entirely the same way as in the preceding quadrant, except that each pinnule has only two slits at the limb. These, however, can likewise be now widened, now narrowed, as in the earlier instruments; by what internal contrivance this is done will be shown and described in a separate drawing [Delineatio].

[Margin: For what purpose the statues have been set beside the pinnules.]

On either side of the pinnule fixed to the ruler a statue cast in bronze, holding a laurel wreath, has been placed in the role of a caryatid or buttress [Anteris] — the one bearing the form of Arithmetic, the other that of Geometry, each with her own arms, namely a tablet filled with numbers and a triangle. This was done not so much for ornament as so that the sight itself, which must always be kept sacred and intact like the pupil of the eye, should be wholly immune from every external injury and jolt.

[Margin: On the little steel springs that hold the ruler tight.]

Moreover, as for the little steel springs [plumulae chalybeae] with which the ruler of this sextant is furnished, so that it presses rather firmly against every part of the limb continuously and yet at the same time adheres to it very gently: since this is not so readily demonstrated, I leave it to mechanicians to investigate further.

Furthermore, to the right of the other, fixed pinnule, so that it likewise should not easily be damaged, I set on its outermost part an Atlas, also skilfully cast of pure metal, bearing the heavens on his shoulders. No less, at the other, opposite end of the sextant (since a sight is sometimes moved there too, to measure distances greater than sixty degrees), I fixed with a pin a Hercules, likewise made entirely and neatly of bronze — so that they might serve as telamons defending each outer pinnule.

[Margin: What the statues signify.]

This was not without a particular meaning in my mind: namely, that nothing whatever in astronomical matters can ever be undertaken, let alone carried through, without arithmetic and geometry. For necessity absolutely demands that these two bring help to every cultivator of the stars and at length, with their own hands, set the astronomical crown upon him. Atlas and Hercules, for their part, signify and designate that the astronomer has the greatest need of eagerness, labour and constancy in scrutinizing celestial things. Add that, since Atlas and

Hercules, according to the ancients, devoted no small effort to the sidereal science and cultivated it unceasingly, I wished to adorn this sextant of ours with their images as a perpetual memorial. At the same time I wished, in these little verses engraved on the bronze at the limb, to set out briefly my affection, such as it is, for the whole of astronomy; also to commend the sextant itself and its

structure, in the best ways I could, to those who cultivate celestial studies; and likewise to add an inscription, so that after our death people should not be left ignorant by whose care and labour, and at what time, this notable instrument (which deserves to be preserved for a very long time) was founded and built.

[Margin: In some little verses the author wished to set out his most devoted feeling towards the study of the stars.]

Here the strength of Hercules, the shoulders of Atlas are required, if you would look deep into the halls of heaven. Here let it not be grievous to bear wakeful nights, or heat, or frost, together with cares of every kind. But gentle Urania, who alone shines — the welcome rewards of eternal praise lighten the toil.

The various ethereal motions the stars undergo in the vault, or the positions they all usually hold, the SEXTANT alone unfolds more readily than the other instruments that skilful care can fashion. Do not fear its excessive bulk and troublesome weight, which, with the help of art, a single hand lifts.

[Margin: Inscription of the sextant.]

THIS SEXTANT, for the good of astronomy, of solid metal, *by an entirely new and singular method, had made* JOHANNES HEVELIUS, Consul, and for the present Judge, of the Old Town, AT DANZIG, *in the year of the Christian era* 1658, by Wolfgang Günter, instrument-maker.

But to return to the pinnules of this sextant of ours:

the third, shaped like a cylinder, is fixed at its centre in such a way that it also binds the ruler fast. How high and wide it is has already been stated in connection with the earlier sextants. And so let this be about enough to have said concerning the front face of the instrument, and also how it is to be directed to the stars at night.

[Margin: How the sextant should be set to the stars when the Moon is shining.]

It will, however, not be out of place to add here how observations are to be carried out when the Moon is shining and endowed with greater light, so that you may obtain the other planets, the fixed stars and also comets most accurately in spite of the Moon's brightness. Until now, indeed, neither Tycho himself nor anyone else, so far as I know, has used one method of observing the stars when the Moon is dark and a different one when it lights up the horizon.

[Margin: The Moon's brightness easily leads observers astray.]

Through frequent observations, however, I have learnt that the light of the Moon — especially when the cylinder is lit more on one side than on the other — can lead into error not only a beginner, only moderately used to this business, but sometimes even the most practised observer; and that it therefore takes greater skill to search out the stars when the sky is lit all round than on a moonless night.

[Margin: By what means, with the help of little cases, the Moon's light is kept off the cylinder.]

For this reason I fashioned two different little cases out of rather thick paper glued together: one for when we have to measure some distance between two

fixed stars while the Moon is not far off, and the other for when we have to measure the Moon itself against some fixed star. The first is about one and a half feet long, and in width it is twice the cylinder of the sextant. It is covered above and below, and also on each of its narrower sides, so that it is open only on its two longer sides, which face each other. In the lower covering of the larger sides, exactly in the middle, a hole is cut wide enough for this case to be set on the cylinder of the quadrant, that is, of the sight. So now, when two small stars are to be observed without hindrance from the Moon's light, set this case on the cylinder and turn one or other of its covered sides towards the Moon, so that the whole cylinder is completely shielded from the Moon's light, while at the same time the observers have a perfectly free view through each open side for observing the two stars together. This too works conveniently even when the interval is sixty degrees, so that in any positions whatever of the stars and the Moon you keep the Moon's light entirely off the pinnule, and then carry out your observations just as accurately as if the Moon were dark, or not present at all. You will see a case of this kind sketched below in a separate drawing, R, under number 14.

[Margin: Construction of the smaller case, for distances of the Moon and the fixed stars.]

The second case, made for distances between the Moon and the stars, has the same shape, but it is much smaller and lower: it is barely half the height of the cylinder, while in length it equals eight digits and in breadth six digits. In both the lower and the upper covering of this case a hole is likewise cut to the width of the cylinder, so that it too can be fitted onto it, namely when the Moon and a star are to be measured apart at the same time. The observer who takes the Moon needs no covering or screen. The other, who searches out the star, covers half of the cylinder or of the pinnule with this case, so that his companion keeps the other part of the cylinder, upper or lower (it makes no difference), free and uncovered. The one who uses the covering turns the closed side of the case towards the Moon, so as to keep its light completely off that half of the cylinder, while the view through the open sides of the case stays free for picking out the star. Then the Moon is no obstacle to you, and the cylinder remains dark on every side, so that you can make out the star on either side just as distinctly as at the time of new moon [tempore Interlunii]. What an aid this is in this sidereal business, however very simple it may be, our imitators will no doubt acknowledge of their own accord.

[Margin: To observe the Moon exactly is almost the greatest art.]

But how the Moon is to be searched out and determined very precisely at all times is not something anyone can readily understand from a bare description; it has to be acquired by use and practice. For although the Moon appears much larger than the other stars, and is also so very bright that anyone can make it out far more distinctly than any star of the sixth magnitude, you must nonetheless know that to measure the Moon quite exactly is the chief and almost the greatest task among the other observati- ons, almost all of them,

both because of its excessive borrowed light and because of its very swift proper motion; and above all because the distances have to be determined not from the centre of the Moon but from one or other side of its illuminated limb. For this reason you always find it very hard to hit the mark.

[Margin: How daytime observations of the Sun and Venus are to be carried out.]

It remains for us now to say something also about daytime observations of the heavenly bodies, namely about taking the distances between the Sun and Venus exactly. This business is of the greatest importance, and so it must be undertaken with the utmost attention and circumspection, and also with special aids. Tycho, indeed, was not, as it seems to me, so very concerned about the matter: he merely caught the shadow of the Sun, cast by the cylinder of the front pinnule, on the plane of the rear sight, as best he could. But, if I may say so with all respect to so great a man, I have always been convinced that, however hard I tried, I could not measure these distances by that method as precisely as so very delicate a matter otherwise absolutely demands.

[Margin: How Tycho went about these.]

Therefore, to take the matter in hand somewhat more strictly, I took up special little inventions of my own, and different ones according as the Sun or Venus presented itself to one observer or the other. The one to whom Venus falls to be searched out cannot accomplish it otherwise than through the bare slits of the pinnule, with the cylinder between, in exactly the same way as must be done at night with the other stars, even when the Sun is standing on the meridian itself; and we too have done this not infrequently. But these daytime observations truly demand lynx eyes: to make out Venus most accurately with the naked eye, by day, in the clearest air and with the Sun shining, through the slits of both pinnules.

[Margin: It is very difficult to observe Venus by day.]

Moreover, anyone can find out for himself how much hurt and harm to the eyes this causes, and how hard it is for observers to detect and examine Venus near the Sun in the first place. I have no doubt that he will afterwards agree with me that to carry out such observations properly is a most arduous task, and calls for no ordinary skill. At night, for those with more practice, keeping watch on the stars is almost child's play; but by day the distances of the Sun and Venus exactly to ascertain completely, I say, torments even the most practised of observers beyond measure.

[Margin: How Venus is observed from the Sun.]

But to the matter itself. Suppose that Venus first presents herself to the companion sitting at the fixed pinnule: he then searches her out only through the bare slits of the pinnule, as we have just said. Yet it will be most fitting, and best suited to the work, if he sets the smaller case described above right down on the cylinder and turns it so far as to keep the Sun's light entirely off the cylinder; believe me, this is a remarkably convenient help in these observations. "But," you will say, "how, I ask, will you, sitting at the ruler, be able to look at

the Sun, let alone observe it?" I would have you know, however, that my eyes are far too precious to me for me to gaze at the Sun's most brilliant radiance with sharp and straining eyes; and also that it is no hindrance at all to me that my collaborator has covered the cylinder completely with the case to turn away the Sun's rays. For I, standing at the ruler, have to attempt the thing by an entirely different route if anything solid and accurate is to be obtained, namely in this way.

[Margin: On certain small plates to be placed on the pinnules.]

I had a small brass plate made, two inches high and as wide as the diameter of the cylinder, set upright perpendicular above a ring, with two feet or supports added, equal in height to the cylinder and made of rather thick bronze wire. In the centre of this plate a very small hole is bored to receive the Sun's disc. I set the plate on the upper part of the cylinder and turn it towards my line of sight along the direction of the ruler, until the plane of the plate stands exactly crosswise to the ruler.

[Margin: The plate placed on the cylinder moves together with the ruler.]

Then, once both feet of that ring, or plate, have been fastened to the ruler with some screws, this plate can be moved very conveniently on the cylinder at will, together with the ruler itself, and turned in any direction, while the face of the plate always stays turned squarely towards the lower pinnule fixed to the ruler, at which I then sit. But this is not yet enough. For since the hole in the plate set on the cylinder now stands much higher than the centre of the little circle drawn on the lower pinnule, the Sun's rays passing through that hole in the plate will certainly not fall into the said small circle parallel to the direction of the sextant at all, but, with respect to the plane of the distance between the Sun and Venus, entirely obliquely. So the plane of the sextant, where the interval is to be observed, will be quite faulty and badly inclined; and in consequence the observations too, if they are carried out in that way, will be altogether erroneous and of no value whatever.

[Margin: On each pinnule a plate is placed.]

I therefore made another plate of exactly the same size and placed it opposite, on the other pinnule, the one nearest the observer's eye, setting it exactly true to the level, and fastened it firmly there with two small screws; so that when the ruler is moved, this plate and the other one opposite it above the cylinder move together, their faces always turned towards each other. And since on the lower plate, the one placed on the pinnule at the eye, I fixed, again with the greatest accuracy, in the middle, the centre of a small circle drawn to match the distance between the pinnules, to receive the Sun's disc, the plane of the sextant cannot be tilted in the slightest from the inclination of the distance between the Sun and Venus. Rather, provided that the other pinnule is properly directed at Venus and the plates are exposed to the Sun so that the Sun's disc fills the small circle completely, it must necessarily always be most accurate. To let you make out the small circle and its centre more distinctly, I covered the face of the lower plate that is exposed to the Sun with very white paper, and on it I

drew the centre and the small circle in ink, so that the Sun's rays would show on it much more clearly and vividly.

[Margin: A square channel to be fitted to the ruler.]

But even these measures do not yet carry the whole business. Therefore, to complete the arrangement, I set on the ruler a square channel of thick paper, though fairly light, long enough for its ends to reach both plates: in this way the Sun's light flowing round about could be kept out more effectively, while the Sun's disc, falling through the hole of the first plate onto the small circle of the second, could be detected and marked more clearly and sharply. Something that helps very greatly here is that I have surrounded the whole lower pinnule of the ruler, together with its plate, with a fairly roomy paper case, open on one side only, so that the place there should be quite dark, like a darkened chamber, as we usually do with quadrants and as we also explained in Chapter V, in the description of the wooden horizontal quadrant, where we likewise sketched a covering of this kind; although on sextants I use a somewhat different covering and channel, to suit the instrument and the observer's convenience. A tube of this kind we have drawn below in a separate picture, R, at number 13.

[Margin: By the author's method daytime observations, which otherwise involve the greatest trouble, are carried out as a game.]

Once all these things have been properly fitted and arranged in this way, then, wonderful to say, believe me, it is easier and quicker for us to carry out observations of this kind than it once was for Tycho's people and his followers. In this way, indeed, the labour is most agreeable and is done almost as if in play, provided only that the assistant who searches out Venus directs both his pinnules precisely. He can certainly do this most deftly if he applies to the sextant that longer directing screw fitted with rolling balls, and so with its help follows and accompanies the star continuously, just as the director of the ruler does, who is intent on nothing more eagerly than to receive the Sun's disc with the utmost precision in its small circle, drawn on the plate above the pinnule, and to hold it in that small circle as firmly as is needed.

[Margin: The Sun is held on the pinnule as though motionless.]

With the help of that screw fixed under the ruler, he can do this readily, so that it seems as though the Sun stood quite motionless in the sky and there were no daily motion at all in nature. Is this method of observing the Sun by day, then, far safer than the one hitherto customary with nearly everyone, namely by the shadow of the cylinder received bare on the opposite pinnule? Let the judgement rest with you and the other investigators of the stars, once you have put the matter to the test.

[Margin: The author is convinced that this method is safer than the Tychonic one.]

I am thoroughly convinced that this way of separating the Sun from Venus is the safest of all so far. Whether anyone else will yet be able, by his own reflections, to arrive at and devise a better one (as may certainly happen, for

one day teaches the next), I leave open. And let that be enough said now about daytime observations as well.

However, since we are still engaged in considering the right-hand, or principal, side of the instrument, we see two chains of iron hanging from the front crossbeam of the observatory. From these, once the observations are finished, the sextant is always suspended by its very strong hooks, fixed at the back, that is, on the left side, to the legs of the instrument.

[Margin: The sextant does not rest or remain permanently on its support.]

For I never let this sextant, which I always hold dear, rest on the turning ball on which it is mounted when it is no longer in use for observations, in case it should be damaged or jarred, or its most accurate plane should over a long time suffer some harm from its own weight, which is in any case considerable. Much labour, indeed, and much time goes into setting the instrument on its support and fitting out and preparing everything else; and again it is no less work to take the instrument down from its seat, bring it to rest, cover it with wrappings, shut it in, and protect it thoroughly from all harm from the weather. But be that as it may, anyone fired with love for the things of the heavens must not weary of this business in the least, even if this labour has to be repeated several times in a single night when the air is uncertain or changeable.

[Margin: Two observers alone set the sextant on its support.]

This happens rather often on these more northerly shores of ours, where we are very frequently subject to sudden changes in the weather. Still, it is a comfort that each and every part is so arranged and fitted that I can by myself, with the help of only one companion, set this instrument on its pedestal and its ball without very great trouble, and take it off again: thanks, namely, to those weights and other aids, which cannot each be described so precisely; but above all thanks to the placing of the support, the chains and the rolling ball, so that you need only a lighter force to raise, direct and remove the instrument, although two or three very strong men would carry this sextant, with all its necessary equipment, elsewhere only with great difficulty because of its very great weight.

[Margin: How the instrument is covered after the observations are finished, and stored in the observatory.]

So, when all the observations are finished, that is, once the instrument has been hung from the chains and covered with a cloth, and the limb has moreover been wrapped in a special covering so that it is entirely protected from all dust settling on it (otherwise, indeed, that limb

, most finely polished and divided, and also the ruler itself, would easily pick up scratches and stains) — then, I say, the curtain [peristroma] is let down. It hangs by three small cords from the front and upper crosspiece of the observatory, by which it is otherwise raised and drawn up. At once, even as it falls, it is drawn tight by those other various cords arranged on each side, so that, almost quicker than it can be said, the whole observatory is covered and

completely shut, and there is no way in except through the door built in one or other side of the little cabin.

[Margin: The back face of the instrument.]

Now, having drawn and explained the front side of the sextant, let us pass from here to the back side opposite it. This too I have gladly chosen to set before your eyes, kind reader, in a separate figure N, with the greatest care so far as could be done: so that you may survey the individual parts of the instrument the more clearly, that I may be given the better opportunity of setting everything out, and also that the things we touched on just above may be grasped more plainly by everyone.

[Margin: How the observers sit at the sextant.]

The instrument is seen as if we were outside the doorway, as it stands set up in its little cabin and directed by the observers at the stars. One of them, the assistant [Coadjutor], sits at the sextant on a stool in a lower place by the fixed pinnule, leaning with his right arm on the rotating support. The other, the principal observer, sits in a somewhat higher place on that taller swivelling chair, with a footstool under his feet, as this oblique and steeply inclined transverse setting of the instrument now requires, so that he can view each and every thing the better.

[Margin: The construction of the observatory.]

In this view you also see the observatory itself, with its whole equipment, from the inside, fairly distinctly: that is, what shape it has, and what size in height, breadth and depth. It is made, to be sure, of rather light fir boards, as though put together by a rustic hand; but this little cabin truly gave me a great deal of trouble before I had conceived it in my mind and drawn it in its proper proportions. For unless you construct it correctly in every part — in breadth, that is, in height and in depth — you will certainly labour in vain afterwards, whatever else you may try, whether with ropes, weights,

Diagram. Full-page engraved plate, figure N: the back face of the great brass sextant as set up in its little cabin, seen from outside the doorway. The open-work scrolled frame of the sextant stands on a pillar, mounted by a squared head and ball; chains hang from the crossbeam of the cabin's timber framework, one hooked to the sextant's upper arm, with pulleys on the beam and a rolled covering lashed along it. At lower left the assistant sits on a stool at the lower end of the arc, his arm raised to the instrument; at centre right the principal observer sits on a tall chair with a footstool beneath his feet, his eye at a sight on the limb. Ropes, counterweights and rings run down the right-hand wall beside the door, and a telescope projects from a mounting on the back wall. Loose parts lie on the floor in the foreground: tubes, a squared block with pins, ball-and-socket pieces, rings and a pinnule-like fitting. No reference letters are engraved in the picture.

- Lower left, inside the border: "[?]ig. N." — figure N (first letter cut off at the gutter)

- Lower left, below: "[?]ch Delin." — "… drew it" (the delineator's name is cut off at the gutter)
- Lower right: "J. Saal Sculpſit." — "J. Saal engraved it"

Blank page (verso of plate N, with the plate showing through in mirror image).

props and directing screws. For it is necessary not only that this observatory be sturdy enough to bear the instrument, but also that it be fit to stand firm, and no less fit to be turned round. It must, moreover, be strong enough not to give way easily to any push; and on the other hand it must not be too heavy either, so that it can be steered and turned round at will by the moderate strength of a single man. Otherwise this observatory will certainly be more of a hindrance to you than a help.

[Margin: The observatory must be built to suit the instruments.]

What size this observatory of ours actually is, I do not think it worth while to recount at length, since every instrument, according to its size, demands a construction of its own. I therefore leave this matter to whoever intends to direct a sextant in this way. He will certainly find that, even though he has each and every part drawn so accurately before his eyes, the thing by no means succeeds straight away as he wishes, as he perhaps imagined it would.

But to proceed. Like the earlier observatory of the quadrant (although in its dimensions it is quite different, being both broader and taller), this observatory is carried on four wheels protected on the outside with rather thick iron plates; the bearings [matrices] of the wheels, in which the iron axles turn, are cast of solid bronze. [Margin: The sextant's little cabin also turns on wheels.] The axles just mentioned are fixed to the lower beam in exactly the same way as we described for the earlier observatory of the quadrant, so that they point straight at the centre of the observatory, or of the pedestal. Otherwise, as has been said, one man could certainly not turn the little cabin round so lightly by one or other of the iron handles conveniently fixed to the back of the little cabin. And so that the whole observatory should not leave its centre, or be pushed out of its proper place, I fixed two iron bars [phalangae] at one end with nails to the tip of the lower beam, and at the other end bound them firmly with iron wedges to a movable ring around the support of the instrument, which is reinforced there with small plates. At the same time I covered this ring with a leather covering, so that it might be free (since the pedestal of this instrument is set not inside the observatory, as we saw in the earlier observatory of the quadrant, but outside it in the open air; as, from the accompanying picture, each detail is clearly evident). Moreover, the door of this little cabin was built in its side, so that the way in should lie open when the covering has been drawn over it.

[Margin: In the sextant's observatory solar eclipses are observed with the telescope more conveniently than in some other darkened chamber.]

So when this observatory has been closed on every side and blocked up all round, it then appears quite dark inside, like a darkened chamber, so that both sunspots and eclipses can conveniently be observed in it at any time whatever

— just as, for a long time now, I have also been noting all eclipses there. For the space inside is not only roomy enough, but it also turns out very conveniently that this observatory is movable, can be steered in any direction, and can always be set directly facing the Sun, so that one may continually observe the Sun by direct rays and by no means by oblique ones. That is certainly not granted in other rooms and darkened chambers, whatever quarter of the sky they face; instead one must rather often change one's place and windows because of the Sun's more oblique position and its continual motion. This led me to build a small window in the upper part of each side of the observatory, so that at will, when occasion offers, I can insert there that swivelling globe with its telescope, belonging to the helioscopic machine [Machina Helioscopica] — drawn in part long ago in our *Selenography*, pp. 40 and 98, and in part to be described still more clearly below, in Chapter XVIII — namely for recording sunspots and eclipses. Our movable observatory is thus most suitable not only for the sextant but also for various other observations.

[Margin: From this back side of the instrument each and every part is more clearly evident.]

You have no doubt already understood above, my lover of the stars, that this sextant can be steered, supported and held firmly very easily and most promptly by means of screws and ropes. All of this, however, now becomes far more clearly evident to you from the preceding figure N: namely, in what way the instrument hangs from iron hooks, and how the main ropes carrying the sextant, from which those two larger weights hang, have been passed and led through those four screws and over their small wheels — and indeed toward the side where they are not the least hindrance to the observers, but rather where, in any directions of the instrument they come to their aid in the greatest measure.

[Margin: The sextant is steered and directed very skilfully by weights.]

You will find, kind reader, what an outstanding aid to carrying out observations these two weights are, hung thus on the ropes. But these alone would not yet suffice had I not at the same time added two other small cords, led through certain small screws [cochleolae], with two small weights hung on both sides. For by means of these the sextant is kept most constantly in its proper plane, especially in awkward positions — indeed in every position, whether in steeply inclined or in upright directions. For example, suppose the instrument is inclined so obliquely that one of its legs is lowered toward the support and the horizon, the aspect in which we drew the sextant in the preceding figure. In that position, certainly, those larger weights, even if they were twice as heavy, would by no means hold it firmly in its place unless the smaller weights came to their help. [Margin: What the small cords achieve in this direction.] For the instrument rests so strongly on one of the small cords — attached to the fixed pinnule, at which the companion sits, and hung from the upper rings — and is so supported by it, that it can no longer incline or tilt in the least toward the horizon and the support. By the other small cord, in turn,

which carries a small weight and is fastened by its screws to the other end of the sextant, it is held back, so that it cannot leave its balance [æquipondio], or slip from its position, nor be overcome by that larger weight. And so, in any directions and inclinations, one small cord comes to the help of the other, so that the larger weights never prevail, but the instrument, wonderful to say, is always kept in its equilibrium.

[Margin: The observer should not be unaware of how the weights and small cords must be properly managed at every inclination.]

But it is necessary that, at any different inclination, you should certainly not be unaware of how those thinner cords are to be attached — now to higher rings, now to lower, now to inner ones, now to outer (since very many such rings are fixed here and there in the observatory) — so that at all times each of the ropes performs its function most conveniently. Especially if you are busy acting as director, it is absolutely required that you be so steeped in experience that in any case whatever — when this or some other hindrance arises, so that the instrument either refuses to be steered or cannot stay in place — at once to bring a remedy to the matter, or your assistant what is to be done, [Margin: But this is obtained only through long use.]

what must be changed, and how the work should be attempted so that everything is brought back again, the parts answer to one another, and all goes as you wish as promptly as possible: in all this you must be able to instruct him duly. But believe me, these things are easier said than done, as you yourself will one day learn more than enough from practice itself.

[Margin: The sextant's weights are attached now in one place, now in another.]

Next, in the figure above you see not only very many rings scattered here and there, especially those hanging from the front prop of the observatory, but also a great variety of them attached to the steel crosspiece at the limb of the sextant — partly, as we said, for hanging the thinner small cords, and partly also for fastening the thicker ones — so that they can conveniently be shifted now to one place, now to another, as the matter requires. For in each different position of the sextant they demand a different place for themselves, partly so that they are no obstacle to the observations, partly so that the instrument's equilibrium is restored and kept, as use and practice will teach you abundantly.

[Margin: The sextant is properly consolidated with very many crosspieces, crossbars and stays.]

How, moreover, this instrument is provided all round with flattened steel crosspieces set up on their edge, and how the said crosspieces are skilfully fixed to the brass body itself with very many screws, you can see abundantly and more clearly from this rear side of the preceding picture. It cannot therefore be denied that this sextant is strong and firm enough to keep its straightness and perfection at all times. Above all, at the centre of gravity — where the little pipe is fitted for inserting the small column of the turning globe — it is built

and consolidated with sturdier crossbars and stays, so that it can amply resist the force of the directing.

[Margin: The construction of the turning globe is accurately described and drawn.]

As for how the brass turning globe [globus versatilis] itself is constructed (which we have already described fully enough in Chap. III, p. 107, and Chapter VI, p. 125), and of what parts it is composed, I wanted to set this out somewhat more clearly still in the figure above, at N, so that, if not from the description alone in those places, you may at least learn fully the structure of each of its parts from this accurate sketch. First, I drew the whole bronze globe with its wooden prop; second, the prop with the cup alone, from solid metal cast, into which the brass globe itself is to be inserted. To this cup I have added the small plate [patella] that is applied to the bottom of the cup over certain small steel springs [plumulae], so that the globe itself can be turned all the more lightly and readily, and be governed in every direction most evenly, most gently, and nonetheless most tightly. Third, you see there the globe itself with its rounded iron, like a column or a stopcock. Fourth, the ring with its screws, by which the globe is clamped most firmly to the cup — though not so very tightly when the sextant is needed armed with its weights. But if the turning globe alone has to support the instrument, then even if it were clamped as firmly as possible by those headed screws, it would by no means be wholly equal to bearing so large and so very heavy an instrument, built of solid metal, and to keeping it exactly in place at any inclination whatever.

[Margin: On the prop for supporting the arms, and on fitting the screw provided with small globes.]

For the rest, in that later figure N the curved prop, fitted out to support the arm of the second observer, is also shown more plainly: namely, how it is fixed to the observatory by two hinges jointed in the middle, and is raised and lowered on a round timber. Likewise, if that longer directing screw, armed with its two small turning globes, has to be used, the figure shows how it is fastened to the prop — or rather, joined at the end to the prop's disc — and likewise to the instrument, so that it is ready for operation; and also how the observer guides and moves it with his left hand.

[Margin: How the chief observer girds himself for the work.]

No less plainly shown there is how, and in what posture, the chief observer girds himself for the work: with his left hand, that is, he attaches the little pipe of the directing screw fixed under the ruler to the steel beam lying beneath the limb, while with his right he turns and steers the directing screw itself. It also shows how, when the matter requires, he can sit at the sextant in a higher place on a swivel chair, his feet resting comfortably on a footstool, and can also finally climb up by degrees to make out the measurements, so that none of the observers, as we have often touched on, with bent knees by this method of ours of searching the stars ever has any need to carry out observations.

[Margin: On the screw provided with two rolling small globes.]

Lastly, for better understanding, we wanted to show that longer screw, armed with two rolling small globes, drawn once more in the preceding figure N, so that its structure may be all the clearer to everyone.

[Margin: Why the screw is furnished with the said small globes.]

You may ask, however, what these two small globes contribute to the work, and whether a bare screw could not produce the same effect. Certainly not: the said screw, stripped of its small globes, would by no means perform the operation it rightly ought to. For the motion to which the sextant is then subject follows the path of a circle, whereas this directing screw is entirely straight and proceeds only in a straight line, without any curving. Hence, if the said screw passed not through small globes but merely through bare small plates [lamellae], it would resist that circular motion, even a very slight one, and the sextant could then no longer be governed in any way. Therefore, to forestall this inconvenience, and so that the directing screw would always adapt itself to the curved motion of the instrument, I fitted out the screw — or rather its nuts, in which it turns and revolves — both where it is plain and where it is spirally threaded, so that, as far as the matter then required, it can turn itself about and closely follow that circular motion of the sextant. As a result, the said directing screw, thus armed with rolling small globes, adapts itself most freely and gently, without any resistance, or even a slight one, not only to this circular motion but also to any other, whether the instrument is raised or lowered, according to the direction of the inclination. So when the sextant is inclined or directed a little differently, there is no need at once either to change the prop for the arm, or to loosen the screw from its disc and remove it, or to move it elsewhere.

In a corner of the observatory I fitted up a small table and also a lantern: the table for recording the observations, and the lantern so that I can look over what is needed by the light of a lit candle and, once that is done, close the lantern again — namely by releasing a small wooden shutter [valvula], which drops by means of a small cord and the small weight hung from it. For observations of the finer sort do not tolerate any light flowing round about them, because at night, in the dark, such light obstructs the eyes. Paying no attention to this, the Reverend Father Riccioli insists on a candle to light the front pinnule of the instrument on a moonless night, if it is to be marked even in part. But why this method of Riccioli's for illuminating the pinnules in no way assists observations will be shown in its place below, where the sights of instruments are treated expressly. For my part, I can quite truly never search out the stars more accurately than with all light removed, in deep night, when the air is less lit. For the darker the night, the better my observations succeed: our sights must necessarily be so constructed that even on the very darkest night they can be seen perfectly and the readings noted.

[Margin: In darkness observations are carried out more accurately.]

When we come to observe, the chains hanging from the upper and front crosspiece of the observatory (already mentioned), from which the instrument is at other times suspended, must be drawn aside with a small cord to a place

where they are in nobody's way; again, when the sextant is taken off its support and is to stand idle, the chains are slackened. Once the instrument has been put away, then, the support [Fulcimentum] must also be taken out of the pedestal together with the turning globe, and once this is stored well out of all the inclemency of the weather, the cavity of the support [Fulcrum] is covered with a headed lid, so that no rain or damp of any kind gets in, and so that the head of the prop, in which the turning globe is fixed, is not hindered in its motion when it is turned round. When the observatory is closed and drawn over with its covering, the support of the instrument remains outside that observatory, protected by its lid or cap [epystilium]. Moreover, so that a storm should not at some time shake the observatory together with the instrument stored in it, batter it, or even overturn it altogether, it is firmly braced on the inside by a fairly sturdy holder fixed to the foot of the support, and on the outside it is bound with ropes to the parapet of the fence by which the whole observatory [Observatorium] is otherwise enclosed. And such great care is needed if so outstanding an instrument, brought into being with no ordinary care, labour and expense, is to be preserved for very many years

[Margin: When the observations are finished, the sextant is taken off its support and the observatory is closed.]

and then handed on to successors entirely unharmed and intact, as it eminently deserves.

With the help of this sextant I have measured nearly all the intervals of the fixed stars and planets — of which I already possess not a few thousand — except for those smaller distances that were obtained with our very large octant, the next instrument. Take into account above all that this instrument has not only been built skilfully and very solidly by the craftsman, and divided by me myself most accurately into its finest parts, but has also been equipped with a most exquisite ruler and pinnules, and furnished as well with sufficient apparatus and everything belonging to it: in sum, that it is as correct as we could possibly make it.

[Margin: The author set very great store by this instrument, and so examined the stars with it most frequently.]

That it really is entirely such, there is no reason for you to take my word for it, nor do I report this on my bare opinion. Before I put this sextant to use, I first subjected it with the greatest care to a most rigorous examination, and explored its powers — whether, that is, it also met every requirement, as it should. My aim was that it should not be necessary to test and examine it only then, when the instrument was already to be put seriously to the stars, from certain distances observed formerly by others, such as Tycho's and others', as has very often been the practice until now.

[Margin: Before the author applied this sextant to the stars, he examined it most rigorously in every respect.]

But, you will say, by what route, pray, did you attempt this very thing, so that it might escape no one that the matter was undertaken and carried

out correctly and properly? Know, then, that I spent almost a whole year investigating and searching out each point before I became entirely sure of everything. For at the beginning I was very doubtful and anxious about the whole construction of my instruments, since these instruments of mine showed me certain principal distances of some fixed stars — however often I took and repeated them, even with any companions whatever — somewhat differently in certain small particulars from what had once come to the most eminent Tycho from his instruments. This left me so uncertain that I simply did not know which way to turn or what path to take. For although, having properly examined everything — pinnules, divisions, ruler, the whole construction — I found no fault at all, I nevertheless gave much more weight to Tycho's distances

[Margin: By what route he undertook this.]

[Margin: At first our sextants did not agree with Tycho's in certain respects.]

[Margin: By this the author was greatly troubled; and therefore more scrupulo-] than to my own; whether I did well or badly in this will very soon become clear from what is to be said. Notwithstanding all this, however, I took heart and firmly resolved — although the most noble Tycho had cleared his instruments of all suspicion by an undoubted examination with certain distances (as may be seen in Book I of the *Progymnasmata*, on the new star of 1572; of which perhaps more fully in Book II of the *Machina coelestis* or, God granting, in our *Prodromus Astronomiae*, where we shall speak of the observations themselves) — to inquire thoroughly into these instruments of ours, and above all this sextant, by some more solid and more exquisite examination, to find whether any error lay hidden in it; and so to make myself entirely certain whether it was wholly correct or faulty, and whether or not I ought to follow in Tycho's footsteps. This I undertook at once, in a long series, sparing no labour, and at length also completed successfully.

[Margin: -usly investigated everything.]

But to bring out just one or two examples of the distances in which this instrument of ours disagreed quite evidently with Tycho's, let me begin with the bright star of Aries [Lucida Arietis] and its distance from the Palilicium, which Tycho once observed as 35° 32′ 0″, as may be seen in the letters to the Prince of Hesse, p. 50. Later, however, after his *Historia Coelestis* had been published, I found that Tycho had not at all times found and determined this very interval to be of exactly the same magnitude, in some of its seconds: he set it down now as 35° 32′ 10″, as on p. 200 of the *Progymnasmata*; now as 35° 32′ 20″ and 35° 32′ 15″, as on p. 58 of the *Epistolae*; sometimes as 35° 33′ 0″, and indeed as 35° 33′ 15″. What is more, if that same distance is again duly computed from the longitude and latitude of those stars, the distance between the bright star of Aries and the Palilicium comes out as 35° 31′ 40″. This confused me more and more. For I believed that the most practised observers, equipped with instruments perfect in every part, neither could nor should waver so much, or deviate by so much in one and the same distance. Above all, since I myself, over several successive years, with our sextant, the same distance again

[Margin: How far Tycho's distances of the fixed stars depart from ours.]

[Margin: Measurers of the stars practised with more perfect instruments must always observe the same thing when the trials are repeated.]

and again, very many times indeed, and with various assistants who were by no means so very unpractised but quite skilled, have drawn from the sky as 35° 32′ 45″. But, you will say, what, pray, do these few minutes and seconds mean? Will they add anything of note to observations, or take anything away? A great deal, I say, my friend. But I do not wish to pour out many words on this subject here and now; what must necessarily be said will have to be reserved for its proper place, the one this matter belongs to — perhaps our *Prodromus Astronomiae*. For the present let it suffice to have said, in three words, that this slight discrepancy gave me altogether more and more occasion to investigate the matter somewhat more deeply and more closely.

[Margin: In subtler matters the smallest things sometimes bring on the greatest.]

Besides this, there is the distance of the Palilicium from Pollux in Gemini. Tycho had given it in his *Epistolae* as 45° 5′ 0″, but in his observations variously, namely as 45° 7′ 20″, 45° 7′ 0″, 45° 4′ 15″ and 45° 3′ 40″; and from Tycho's longitude and latitude it comes out as 45° 5′ 30″. I, with my instrument, measured it many times with the greatest care as 45° 3′ 45″. This discrepancy is certainly quite evident. But which of us, I ask, has reached the goal in this searching? I am afraid to declare it at present, nor is it my part now; rather, I leave this controversy to be settled by the most skilled investigators of the sublimer celestial things, from their own observations and by this most rigorous inquiry of ours, which each of them may try for himself with the greatest diligence.

[Margin: A quite evident slight discrepancy between Tycho's distances and ours.]

And so, right at the beginning of my observations, I had no concern whatever more pressing than this. There are the following intervals between fixed stars, eight in number: namely, the bright star of Aries and the Palilicium; the Palilicium and Pollux; Pollux and Regulus; Regulus and Spica; Spica and the star in the hand of Serpentarius; the star in the hand of Serpentarius and Aquila; Aquila, in turn, from Marcab; and finally Marcab from the bright star of Aries. After I had found these, measured again and again, always exactly the same with our sextant — although they departed not a little from Tycho's distances — my concern was to subject them to a stricter calculation and to inquire into their ascensional differences. When these were then added together, I clearly found that all these ascensional differences produce an entire circle exactly, namely 360°, and indeed

[Margin: Through the ascensional differences the author investigated the whole matter scrupulously, as is fitting.]

very precisely — at which I myself then marvelled again and again — so that they did not err by even one or two seconds, either in excess or in defect. For

me at that time this was as good as an infallible experiment and a demonstration beyond all exception: namely, that my instrument was not only perfect in every part, but that each of the observations, too, had been carried out by us with the utmost exactness. And so, altogether won over — indeed, compelled — I was obliged to place my full trust in these observations of ours, to rest content with them, and by no means to embrace the observations of any others whatever as a standard, but to leave them at their own value. That I have done this faithfully and vigorously ever since I certainly do not yet regret. I have no doubt whatever that each and every one who examines these results of ours properly and duly will find the matter exactly the same, both in the sky and in the calculation.

[Margin: The matter having been well explored, the author rejects all authority. Rightly? Heaven itself will prove it.]

But what the cause is, that Tycho's distances — those very ones, although they disagree with ours — likewise produced, through the ascensional differences, almost an entire circle, if you except a very few seconds, I cannot now set out at greater length, still less show fully, as so sublime a matter, on which the most important points of astronomy depend, rightly demands. Yet I hope, if God, Best and Greatest, grants me life and health, to fulfil my duty abundantly in our *Prodromus Astronomiae*, as I was just saying. For this time, to conclude, let it suffice that this sextant of mine has been duly constructed, properly divided and accurately examined, so that we can certainly rely on it with confidence — as our observations themselves, in Books II, III and IV of this *Machina coelestis*, will amply declare and demonstrate in actual fact.

[Margin: Why Tycho and the author derived the same entire circle from different observations will be shown in the *Prodromus Astronomiae*.]

CAPUT XII.

Chapter XII.

De Octante Maximo Orichalcico.

On the Very Large Brass Octant.

Just as this octant is not the least of all my other instruments, so too I rightly place it among those I have ever held close to my heart and in my hands. For its construction, first of all, no labour,

[Margin: This octant is to be counted among the better instruments.]

and no expense did I spare; but above all I applied every care to the divisions and the sights, which are made with an altogether singular and new skill. Sights of this kind, unless I am mistaken, have never yet been in use anywhere, nor do I know whether anyone has yet fashioned pinnules similar to these of ours. The octant itself, like the sextant above, is made of solid metal: the front side, being the principal one, of pure brass, while the rear, secondary side is built of frameworks, crosspieces and crossbars that are solid and of steel and are joined

together very firmly — as its structure plainly shows from the drawing placed here. First of all, beneath the limb I placed a very strong crosspiece of flattened iron, set upright to the height of the flattened side, just as in the instruments above, and fastened it properly with headed screws. Beneath that very tall and quite broad intermediate brass holder, to which the limb with its legs is otherwise fixed, I also placed a still much stronger iron beam as a support. This was so that this noble instrument, resting on its centre of gravity, should not, because of its size and weight, depart from its perfection when it is moved, directed, or set on and taken off the turning globe; nor contract any bending through very frequent use; nor have its cylindrical pinnules distorted with respect to the plane of the octant.

[Margin: It has entirely new sights.]

[Margin: It is made of solid metal.]

[Margin: It is built with very strong crosspieces.]

For this instrument equals six cubits in its radius, or nearly nine feet, and its limb is of such extent that it holds 45 whole degrees, just as the name of octant also requires exactly so many. And it was given so great a size for this purpose: that I might make the divisions of degrees and minutes all the more distinctly and exquisitely, and also afterwards measure the intervals between the stars all the more accurately. Distances exceeding 40°, however, cannot be determined with this octant, although its arc is divided into 45°, indeed 46°; the reason on which this depends will have to be stated below, when the pinnules are discussed. All the remaining star intervals, however, even the smallest of all, although

[Margin: Size of the octant.]

[Margin: The smallest distances of all, but not the largest, can be decided with the octant.]

Diagram. Full-page engraved plate, *Fig. O.* A large octant hangs, limb downward, from a heavy timber gallows-frame: its triangular body is filled with openwork foliate scrollwork, and a tall upright post runs through its centre and on above the apex, where it carries a pair of curled hooks, to a crossbar with two pegs standing free below the frame's top beam. Two ropes run from pulleys on the upper beam to the ends of the instrument, two chains with rings hang from the beam beside them, and further ropes run from the frame's uprights to the sides, with counterweights hanging on the right and a small bell-shaped weight on the left upright; a cloth valance hangs along the upper beam. The upright stands on a column with a cross-handle below the limb. Two observers stand on a boarded floor before a balustrade: on the left a man in a long coat, leaning back against a tall inclined board, one foot on a two-step stool, grips the sight at the left end of the limb from below with one hand, his eye to it, and holds the other open, palm up, beneath the limb; on the right a woman holds an eye-ring to her eye at the sight at the right end, her other hand on her hip. Between them a separate jointed sight-fitting with a ring is drawn floating free. The limb carries engraved degree numerals, set symmetrically

about the centre: 15, 10, 5 on the left half and 5, 10, 15 on the right. Small statuettes flank the sights at both ends of the limb; the two at the right end each hold up a round disc on a staff. No lettered keys (A, B, C …) are engraved on the plate. Along the foot of the border: *A Stech Delin.* (drawn by A. Stech) at left, *Fig. O.* at centre, and *J. Saal Sculps.* (engraved by J. Saal) at right.

- Limb, left half: 15, 10, 5
- Limb, right half: 5, 10, 15
- Foot of plate: "A Stech Delin." · "Fig. O." · "J. Saal Sculps."

they amount to only a few minutes, or indeed seconds, can certainly be determined to a hair; just as I also measured all the intervals of the Pleiades with this very large instrument, as I had wished. Whether that very thing has yet been attempted or accomplished by anyone, I doubt very much indeed. For this reason, too, I have appointed this octant chiefly for the narrower distances. Not, indeed, for the reason you may perhaps imagine — that it is too vast, too heavy, and less manageable to direct? By no means, certainly. On the contrary: although by its weight — since it consists of pure, unmixed metal — it very nearly exceeds the strength of two very powerful men if it has to be carried bare to another place, I can nevertheless direct, raise and lower this octant, and shift it from one side to the other, much more lightly and readily than the preceding sextant, smaller though that is by two feet — and with one hand only — while it always keeps its inclination and direction as firmly as possible, even in the exactly vertical position, as when you wish to determine the distance of two stars standing on one and the same vertical. We have done this very often, and a great many learned men have watched this very thing with attentive eyes.

[Margin: Even though it is extremely heavy, it can nevertheless be directed quite lightly.]

That it obeys every direction so easily and readily, however, must be credited entirely, and equally, to the movable observatory described at some length in the preceding chapter (in which the sextant is otherwise kept), and also to the ropes, weights and directing screws, and all the rest of the apparatus. Accordingly, when we wish to use this octant, I remove the sextant from that observatory, or else draw it off to the rear part of the little cabin, where it is in nobody's way, and hang it up there, as can also be done conveniently. Only then do I bring the octant into the observatory and fit its little pipe, which is fixed at the back, onto the small column, or little axle, of that turning globe set on the support, as we have already said clearly above. Next, those two thicker ropes with their weights are attached by means of their yielding clasps to the steel cross-beam, wherever seems convenient to you, since you will find a great many rings there; and no less, on either side, the smaller cords with their

[Margin: That it turns so easily, and always holds very firmly in any direction, is to be credited to the observatory and its apparatus.]

[Margin: Observation is made with the sextant and the octant from one and the same observatory.]

little weights, as the diagram makes clear. Once these are fitted, it is easy to steer and direct the octant at will, with the greatest pleasure.

During observing you will be free to stay continually under the roof of the observatory, and, since the observatory can be drawn along, to avoid all winds entirely, unless pressing observations demand otherwise at the time. Moreover — and this is certainly a great convenience — each observer is allowed either to stand at the instrument or to sit by it, as suits him; and at all times a prop is at hand for the assistant to support his arm, so that he can hold the octant in its proper place all the more firmly and exactly — namely, when you have no wish at all to use that longer directing screw fitted with little balls, or perhaps do not have it to hand.

[Margin: The observers always remain under a roof.]

Besides, this octant enjoys one singular convenience over all our other instruments: namely, that the companion who assists the director, and who stands on the right in the preceding Figure O, can be put to use in three ways for searching out the stars. First, however, I would have you know that each pinnule of this octant can be moved in any direction at will, so that for a given distance it can be shifted back as gently as possible and at the same time as tightly as possible, and clamped at any point of the limb wherever you like, so that it cannot be dislodged from its position by any means. For example, let the interval of the stars to be observed be 20, 30 or more degrees. In that case the companion's pinnule is brought almost to the end of the limb — to the fifteenth, eighteenth or twentieth, as you see in the sketch already mentioned — and there it is fixed to the limb, or rather to the limb's steel beam, by the screw intended for it, once its little pipe has been applied. When this is done, the principal director himself likewise first moves his own pinnule with a free hand according to the distance of the stars, not far from the true value, and then fastens it to the limb in the same way, as was shown for the sextant. Next he orders the companion to sight on the star, now in earnest and with attentive eyes, so that half of its light is seen with the utmost precision on each side of the cylinder — as we have already touched on in its place, and as will also be said more fully below.

[Margin: In what this octant excels the other instruments.]

[Margin: On the directing of the sights.]

The companion, who serves the principal observer as his aide, can direct this instrument to the stars in three ways, as I was just saying. The first, namely, is by bringing it to the star with a free hand and holding it firmly there until the principal observer has caught the star set before him with perfect accuracy by means of the directing screw fixed under his pinnule.

[Margin: The assistant can make observations with this octant in three ways.]

When this has been achieved, the director first counts the degrees and their parts on his own part of the limb, and to the distance so found — say 18 degrees — he adds the 20 whole degrees of the other side, at which place the companion's

pinnule had been set right at the start; and so the whole true distance comes out as 38 degrees. For since the octant possesses two different centres, presented also by two cylinders, so likewise this octant has two different arcs, each described from its own centre. Hence no divisions are given in the middle of the limb; they first begin at the same distance from the diagonal line that divides the octant into two equal parts as either cylinder stands from that very line.

[Margin: Sometimes the divisions are to be counted on both arcs of the octant.]

The reason for this we have already partly explained in Chapter VII, page 133: namely, so that in determining narrower distances, of only a few minutes, the observers (since instruments of this kind always require two of them altogether) do not knock their heads against each other and get in each other's way, when each pinnule is set at the beginning of the numbers, or divisions, not far from the diagonal line already mentioned, and the one is moved away from the other only very slightly — indeed no further than the two cylinders on the face of the octant stand from each other.

[Margin: Why the octant has no divisions in the middle.]

The second way of directing the pinnule, which the companion will be able to use, is much more accurate and more convenient than the first. If, that is, someone brings the other pinnule to the desired star with its own directing screw — such as lies beneath each pinnule — just as the principal observer does, and turns it precisely, then there is no need to hold the instrument as firmly as possible with every effort until the director has finished the business; rather, in any position of the instrument whatever, with it entirely free, only

[Margin: Each pinnule on this octant is movable.]

with one hand, the right, turning the screw backwards, the matter is settled exactly. For since each pinnule is built with the same contrivance — that is, by means of a directing screw — the companion can likewise first bring his own pinnule with a free hand to roughly the right place, and there, once its little pipe has been clamped, determine the distance with the utmost exactness by the working of the directing screw, just as the other observer does. This much difference there is, however: the chief observer has to count the degrees and minutes not only on his own semi-arc but also on the other one, at which the companion stands, and to put them together into one and the same sum — if, that is, he wishes to know the true interval between the two stars.

The third way is, as a rule, much more convenient still for both observers. First, namely, the companion's pinnule, on the right side of the octant, is brought to some definite whole degree — for example, to 15 degrees; the octant itself is then directed to suit the inclination of the distance, and the observatory is also moved forward until you see the star. The arm-prop is then at once raised almost to the limb and fastened there with its screws to that round wooden bar. Next, that longer directing screw fitted with rolling little balls — which we have already mentioned quite often and have also fully described in its place — is attached by one of its little pipes to the ring fixed to the end of the prop,

and at the same time by the other, in turn, to the limb, or rather to the steel beam set beneath that limb, just as we showed for the sextant above. When everything has been arranged in this way, the assistant here will be able, by means of this directing screw, to measure the star as exactly as possible, either by tightening it or by slackening it, just as the principal observer also accomplishes the matter with his own directing screw. You then need to count the degrees and subdivisions on one side only, namely the director's, and add to them that side's interval of 15 degrees; and so you will obtain the whole desired distance.

[Margin: Which way is the most suitable of all for directing the octant.]

The divisions of this instrument have been made in almost the same way as on the preceding sextant: namely,

[Margin: On the division of this octant.]

each degree has been divided into twelve parts — that is, into parts of five minutes — and these again into five, or rather two, seconds, but by a peculiar and entirely new contrivance that has not yet been applied to any of the other instruments. It is not done by means of some segment of a circle distributed into its small parts, such as the ruler of the sextant and quadrant above was fitted with; the matter has been successfully settled in an entirely different way. For if it had had to be done with a simple segment of a circle, I would scarcely have obtained five or two seconds even with an arc nine digits long (since the space of a single degree on this octant equals about two digits). Yet to attach an arc of such length to the pinnules did not seem suitable for the work, nor advisable: such arcs would easily be ruined, or be bent out of true by some quite slight bump or knock — to say nothing at all of other drawbacks — as we shall explain more fully and completely in its place, when the structure of the pinnules is to be treated expressly. For it could in no way be done here: in the preceding delineation, as you see, it was not possible to draw the sights so large that I could set this method of ours, which we were the first to devise, plainly enough before the eyes and make it entirely clear.

[Margin: The octant here shows the seconds by an entirely different method.]

As for the rest, the pinnules just mentioned are of almost the same structure as the pinnules of our other instruments: their little slits are now widened, now narrowed, from either side, by means of a small toothed wheel inside. The only difference is this: the sights of this octant show the minutes not in one place only but in four different places together at once, and always display any distance exactly the same, neither greater nor smaller even in the least amount. This can certainly also be achieved, provided the divisions everywhere, on the limb as well as on the pinnules, are extremely accurate; otherwise you will surely never bring the instrument to that perfection. Hence, if you see these pinnules — the measurement of some distance not altogether equally accurately in four different parts of the limb, and likewise also in a fifth (since the intermediate divisions of the sights, both the minutes and the

[Margin: The pinnules of the octant show degrees, minutes and seconds together in different places.]

[Margin: From which it may be known that the divisions have been made correctly and exactly.]

two-second intervals) — it is a most certain sign that there has been error in some of the divisions; especially if you notice that all those divisions do not altogether agree with those marked on the small wheel attached to the directing screw of the ruler, in the first minutes as well as in the individual seconds themselves. For on this octant — and this should be noted — you are free to determine the size of a distance with the utmost exactness in six different places. This, indeed, as it is the most excellent and equally the safest method of dividing instruments, so it deserves to be described most fully hereafter.

But to proceed: on each side of the pinnules a statue cast in bronze has been placed, chiefly so that they are not easily damaged or crushed. For sights of this kind, when they are perfect in every respect, are truly most precious, and therefore also deserve to be preserved carefully and scrupulously. I wished, moreover, to place in that position the images of the foremost leaders in astronomy who have ever lived — namely Hipparchus, Ptolemy, Copernicus and Tycho — not only for their everlasting memory but also to show how highly they stand in my eyes. Indeed, as far as was possible, I had their faces and figures rendered from life, and furnished each with the particular instrument he chiefly used and the hypothesis he favoured in his time. For example, the incomparable Hipparchus holds in one hand an astronomical radius [Radius Astronomicus] and in the other a sphere of the fixed stars; the most praiseworthy Ptolemy shows in one hand an astrolabe and in the other an armillary sphere displaying the Earth at the centre. On the other pinnule you see the most ingenious Copernicus with his parallactic instrument, and also an armillary sphere showing the Sun at the centre of the world and the Earth in the great orb; and finally the most noble Tycho, with his sextant and an armillary sphere, presenting the Earth at the centre of the world and the Sun at the centre of the planetary system.

[Margin: Statues have been placed at the sides of the pinnules.]

[Margin: The foremost high priests of astronomy have been set up on these pinnules.]

[Margin: Who these were.]

To the outstanding honour and the most glorious everlasting fame of these supreme men, and also for the sake of grateful remembrance, this monument, such as it is, on this far from ordinary instrument of ours (since anything larger, more splendid

[Margin: A monument in honour of Hipparchus and Ptolemy.]

and more accurate, made of solid metal by this very method, has yet been built anywhere else, I would scarcely believe) — this monument we gladly and deservedly wished to set up, and also to adorn with some little verses engraved

in the middle of the limb among the divisions: namely with these that follow, on the side where Hipparchus and Ptolemy are seen.

The hosts that are seen wondrously scattered over the lofty fields, distinguished by the number of the stars and by their position, the skill of Hipparchus first handed down to the world. Next Ptolemy bound the wandering stars by laws, so that, though not even by sight, the courses that each one ever undergoes, and how variously, one might come to know.

On the other side of the limb, where Copernicus and Tycho stand by the pinnule, these little verses are read:

But mighty Copernicus moves the earthly weights, and at the same time leads the stars along shorter crossways. Famed for his Daedalian structures, Tycho climbed the splendid heights of heaven with fortunate endeavour. So every diligent age had something to seek, and how much remains to be sought by new studies.

[Margin: A monument to Copernicus and Tycho [?].]

Thus I was not unwilling to attend these incomparable high priests of heaven with this honour and veneration — by a means however slight, yet with the greatest affection and stirring of mind; and I hope hardly anyone will take this amiss of me. For it is entirely just that we should never forget those who, with the highest praise and by the vote of all the learned, have set the crown upon the work, but should remember them with the best of memories whenever occasion is given. And so that even after our death — if this most excellent octant of ours should perhaps be preserved intact for very many years, as it well deserves — our successors too may not be unaware to whose glory, for what purpose, at what time and by what maker it was made, it was decided to cut this inscription with the graver into the bronze at a suitable place on the instrument.

[Margin: It is right to honour with the best of memories those who have achieved something outstanding.]

[Margin: Inscription of the octant.]

In honour of the SUPREME ARCHITECT, for the advancement of astronomy by nightly contemplations of the stars — may it be happy and auspicious! — THIS BRONZE OCTANT was dedicated by JOHANNES HEVELIUS, Cons. V. C., AT DANZIG, in the year 1659. Wolfgang Günter, instrument-maker, made it.

Apart from this, almost nothing whatever remains to be said about this front face of the instrument, except that the whole assembly, with its flowery scrolls skilfully worked, is constructed and adorned with pure and most brightly polished brass; and so the appearance of its face looks all the more splendid and magnificent. On the rear side of the instrument, all the beams — the transverse ones as well as the thicker one running straight on to the cylinders — are indeed of iron, but nevertheless, like all the rest of our instruments, properly gilded, so that they should not easily contract any rust or become stained; for instruments are quite often exposed to rain, dew, hoarfrost, hail and snow. By what means the crosspieces, crossbars and holders of this opposite side are joined together

and fastened with headed screws, so as to give the octant sufficient firmness, you can grasp partly from the preceding figure O and partly also with your own ingenious mind. For it is not in our power to draw and describe each and every thing so clearly.

[Margin: The front face of the octant is entirely of brass.]

[Margin: The back, however, is of steel, and gilded throughout.]

Those sturdier hooks fixed to the straighter middle holder serve so that, once observations are finished, the instrument can be hung from chains and the observatory itself closed up on every side. Before the little cabin itself is closed, however, it is absolutely necessary that the instrument itself be covered with a special covering, and the limb too, together with both pinnules and its two-sided explorer of seconds [anceps Secundorum explorator], as was said for the sextant and the quadrant above, so that, together with its extremely fine sights and divisions, it may be kept entirely safe from every harm from the air. Some will no doubt find this far too laborious: to open everything up on each occasion, unfasten it, uncover it, bring it out, fit the instrument to its support and set up the whole apparatus. But, as we have already touched on above, whoever is wholeheartedly devoted to this study does not count that trouble of any weight; rather, by his zeal for the attempt and his desire to investigate sublime things, he overcomes all labour.

[Margin: Erecting the instruments is indeed a matter of much labour; but no less so is taking down the whole apparatus again and keeping it in its place.]

For it is certainly labour, believe me, to devote oneself to the stars on every clear night, as anyone who strives to investigate something solid in astronomy must. Not only is it a matter of much effort to spend so many sleepless nights and to be unable to enjoy one's ordinary and accustomed rest freely; one must also spend whole nights in almost continuous movement of the entire body. Truly, unless someone is so formed by nature that, led solely by love of the sidereal science, he undertakes this very heavy labour for the furthering of the glory of God and the good of posterity, and pursues it with a steadfast mind, no one would ever undergo the harshness of this business by night and by day, in kindly and adverse weather alike — now in fiercer heat, now in more intense frost, especially in these more northerly and extremely cold regions — at the greatest cost to his health and his means, even if he were hired for no slight sum of money or wage.

[Margin: To keep watch over the stars every night is a matter of great effort.]

Finally, as to what still seems to concern the directing of this octant: since it has already been fully discussed above in the description of the sextant, I do not wish to repeat it here at greater length — except that I would like to add that not long ago I devised yet another, different method of directing such octants and sextants, whether they are of the same or of a smaller size. By its means they can be set to the stars, governed and directed just as easily, readily and very conveniently, even without any movable observatory and without such

costly apparatus — and indeed in the open air, even in some rather confined place that would otherwise not admit a movable observatory at all. But how

[Margin: Sextants and octants can also be conveniently directed without an observatory.]

this very business should be undertaken, and how it may also succeed, will be shown abundantly in the next chapter and also set out graphically before everyone's eyes.

CAPUT XIII.

Chapter XIII.

De Sextante Portatili.

On the Portable Sextant.

These last four astronomical instruments — namely the azimuthal quadrant, the horizontal one, and the sextant together with the octant — each and every one necessarily requires its own tower, or little cabin, or some movable observatory, and at the same time also some very large area or a good-sized observatory [Observatorium], if, that is, they are to be brought conveniently into use and set to the stars with some profit. Yet however well suited this apparatus may be to observations of every kind, and however much it may serve astronomy, it nevertheless does not suit every cultivator of astronomy equally. For in the first place, not everyone is granted an observatory of such extent that he can conveniently set up in it, under an open view, so large a movable observatory with such furnishings, and turn it round in a circle. Very many, too, lack the means that must necessarily be spent on so very large an undertaking and so very costly an apparatus — as you have learned in order from the foregoing — so that, however much they may wish it, they are wholly unable to acquire such things for themselves. Indeed, almost all the rest, even though they lack neither a suitable place, nor aids, nor strength, are nevertheless quite unwilling to bear such great expense from their own purse to provide all these things: they would sooner abandon that sublime science entirely, however utterly it might perish. For in this age of ours there is far more care for gold than for all the sciences and arts.

[Margin: It is not granted to everyone to furnish an astronomical observatory.]

And, to confess the truth, this celestial study of ours certainly also requires immense expense, which befits kings and princes more than any private man. I for my part — how much, in proportion to my slender means, on that whole very large apparatus and on the instruments themselves partly

[Margin: As the science of astronomy is a royal study, so it also demands royal expenses.]

Diagram. Full-page engraved plate, Fig. P: the portable sextant in use. The sextant, its frame filled with open floral scrollwork and stiffened by two

diagonal bars, hangs from a gallows-like wooden stand — two upright posts with diagonal braces and pulleys at the top — by cords that run over the pulleys to hanging counterweights. The instrument is carried on a turned column with a carved capital, set into a three-legged base of braced timbers standing on a planked terrace in front of a balustrade. On the right an observer in a long coat and fur cap holds one of the cords with his left hand and lays his right hand on the graduated arc. Engraved numerals along the arc, from its right-hand end: 10, 20, 30, 40, and 60 at the left-hand end; no numeral is visible between 40 and 60. The plate carries no letter key. Signed at the foot: "A. Stech Delin." (drawn by A. Stech) and "J. Saal Sculps." (engraved by J. Saal).

already shown and partly still to be shown, I have laid out in expenditure for so many years now, from my own private purse alone — so that they might be built, repeatedly enriched with new inventions, adorned and preserved — and especially on buildings, observatories [Observatoria], observatories [Speculas], and various most costly machines, astronomical and optical as well as mechanical of an altogether different kind: this I cannot express so very easily. Yet anyone at all, even if he has only a superficial knowledge of these matters, will guess amply enough that each and every one of the things brought forth in this little work alone cost us not merely hundreds but thousands — to say nothing of the countless other things, which I have chosen to pass over entirely in silence.

[Margin: The author has spent no small sums on astronomy.]

Accordingly I devised an altogether different method of handling sextants as well as octants — whether of two, three, four or five feet, or indeed somewhat larger, unless they are of excessive weight — and of directing them in every direction, without any movable observatory, in any place whatever: whether under the open sky, under a roof, or in some room, provided only that the window openings and little doors are open wide enough. And this indeed is done just as conveniently, lightly, gently, accurately and quickly as can ever be done with the help of any movable observatory. Moreover, the device is such that it is built at lighter expense and is easily carried elsewhere: when needed, and when it must be transported even to the most remote places, it is quickly taken apart into its pieces and put back together again in a very short moment — which our turning observatory [Specula versatilis], described above, by no means permits. For such little cabins must necessarily always remain in the same place once they have been set up, and they are taken apart only with great trouble. This new invention of ours nevertheless suffers from one inconvenience, namely when it is set up under the open sky: it is then absolutely necessary, once the observations are finished, always to remove the instruments from that three-footed and turning support [Fulcimentum tripedestale et versatile], to be described shortly, to carry them elsewhere and keep them in their place under some roof; and then also, every time one has to return to observing, to bring them out of doors again with the whole two-footed prop [sustentaculum bipedestale] and all its fittings, to place them on the support [Fulcrum],

[Margin: Another new method of directing sextants and octants under the open sky, with any observatory set aside.]

[Margin: It is nevertheless more convenient to bring the instruments to bear on the stars in an observatory than under the open sky.]

and first to fit everything out. With those very large and very heavy instruments of ours described above, such as our bronze sextant and octant, this would be done only with great trouble and labour: they are carried elsewhere only with the help of several people. Add to this that if some adverse storm in the air comes up, or some sudden and violent wind, that two-footed revolving prop with its instrument mounted on it can hardly be covered and wrapped up in any way at all. Indeed, before it is taken down and everything is saved, the parts are spoiled by moisture — by rain, that is, and snow. Moreover, the observers themselves then have nowhere to retreat to and ward off the storm; nor, when the air is whipped up by the wind, can you bring a lighted candle to instruments set up under the open sky as promptly as under some covered movable observatory.

[Margin: This new invention is better suited to smaller instruments than to larger ones.]

It cannot be denied, then, that this new invention of ours for handling and directing instruments is indeed most convenient, most apt and most useful — but only for those whose size, as measured by the radius, does not exceed five feet. Those very large instruments built of solid metal, on the other hand — of six, eight or nine feet, that is — are better exposed to the stars in their own particular turning observatory and kept there permanently with their whole apparatus. Otherwise, surely, instruments of such great weight and value would readily be damaged by some careless collision or some unexpected accident, and would take on a defect.

[Margin: It is better always to keep the largest instruments in a fixed place.]

Hence the less and the more rarely instruments of that kind are moved from their place and carried elsewhere, the more and the more safely their soundness is preserved. For, I grant, let them even be fitted together most firmly on every side out of the thickest metal: still, if not the body itself, then at least their ruler, cylinder and sights easily suffer damage, so that they are pushed somewhat out of their proper place and bent. And then the matter itself would certainly give you a very great deal of trouble before you had examined each and every part and rectified it with the utmost exactness. I myself, believe me, would far rather build, divide and fit with pinnules an entirely new instrument than

[Margin: It is easier to build a new instrument than to correct and restore a damaged one.]

accurately repair some other one that has been damaged or bruised in some part, free it of all its defects, and also subject it once again to that stricter test. For the labour spent on such a thing is usually in vain, and very rarely is an instrument once damaged in this way restored to its former perfection. And for that reason I take every care that our instruments should not acquire any

blemish or defect in any way whatever. And so that this may happen even less, no one other than myself has access to the instruments and the observatories, and in my absence I do not permit any others whatever to see them, still less to expose them to the stars.

But to come to the invention itself and describe it, I wished first to set before the eyes of all curious cultivators of astronomical matters an exact delineation of this invention: namely, in what way I first conceived that portable machine in my mind, and then also successfully brought it to bear on the sky.

[Margin: This machine is for a sextant of four feet.]

The machine in question was built for a sextant of four feet in radius. On its principal and front side this sextant is made, like the one described above, of solid brass, and is bound together with its limb and its legs by most ornate braces running obliquely between one another, and by flowers skilfully worked from the same metal — and indeed in a still more elegant manner than that larger one above. On the back side, in exactly the same way as already stated, this sextant of ours is supported and fitted out with a great variety of crosspieces, crossbars and supports of gilded steel, so that it in no way yields to bending.

[Margin: The construction of the sextant.]

Moreover, the ruler, the pinnules and the divisions are also made on the same principle, in proportion to its size, as in our other, larger instruments — except that on the arc of the divisions they do not show individual 5 seconds, let alone 2, but only 10 seconds. Nor could it have been done otherwise, since this sextant is two feet smaller in radius than the other one above. Nevertheless, on the small wheel which is likewise attached to the directing screw, as with the preceding larger instruments, it shows both 5 seconds and, indeed, single seconds equally distinctly.

[Margin: By a special method it gives seconds.]

However, from the delineation that I have just set before your eyes, friendly reader — almost from it alone — anyone skilled in astronomical matters recognizes clearly enough how this machine, that is, the turning prop of the sextant, should be built and handled, and indeed without any further explanation or description: a word to the wise is enough.

[Margin: To a carper everything seems trivial.]

Nevertheless, for the sake of those initiated into these sciences who may perhaps wish to use this aid, I shall set the matter out somewhat more clearly — even though to some sharp-nosed little critic, who usually carps at and mocks everything that has been accomplished and always lays claim to far better things, the matter may seem rather slight and of hardly any importance. But, I grant, let the matter be as easy as that and readily done: why then did you not put that commonplace method into use before me, or, if you had already found it out for yourself, why did you not disclose it to others? For it is perfectly true, as you will yourself freely admit, that although this little machine is not of any very great construction, nevertheless each and every instrument can in this way be moved very lightly and very readily — and indeed with one hand, without

any trouble — the instrument staying put at once at every inclination, even in the vertical direction itself, as though immovable; and again, in a moment, it is moved and directed this way and that, exactly like that larger sextant and octant in the turning observatory, as we showed above.

[Margin: With this turning prop any instruments of moderate size are directed just as well as in an observatory.]

The reason is that this turning prop is fully supplied with all the things and aids it needs, just as the movable observatory otherwise is — except for that support for holding up the arms and for clamping that directing screw fitted with little balls. And yet this support too can very aptly be applied to this turning prop, not only from one side but from both, so that it can serve the convenience of both observers most suitably.

You can set this little machine either on the three-footed support, described in its place, or on a bare round support fixed to the fence of the observatory, as is evident from the following delineation. In the first sketch, on a pedestal of this kind, the sextant — on the same kind as that on which that smaller brass sextant (page 102) and that other, larger wooden one (page 124) were represented — you see displayed; provided only that the pedestal is so put together, and so firm, that it stands solidly in any place and does not wobble in the least. Next, on this support I set a turning ball of brass, of exactly the same kind as the one I had fitted to that smaller sextant (page 102), and which I have also drawn clearly in the following delineation Q; and it makes no difference even if the ball is of no notable size. For this ball does not at all hold the instrument up at every inclination; it only keeps it, as it were, at its centre. For that reason, too, there is no need for it to be clamped so very firmly with screws: with a freer motion, provided it does not sway, it does the whole job as gently and as readily as possible, since the weights hold up and govern the sextant.

[Margin: Description of the turning prop.]

[Margin: The turning prop also needs a revolving ball.]

But before the turning ball already mentioned is set, with its post, on the support, this ball must first be joined to that wooden turning prop — namely by passing the ball, as can conveniently be done, through the lower crossbeam, which is pierced for it. For the hole in the prop is of exactly the size that the support of the turning ball, to which it is attached, altogether requires. And so that the prop cannot be turned round and directed without the ball, nor in turn the ball without the prop, the two are clamped firmly to each other by a large iron spike driven through them.

The construction of the prop itself is, I think, more than sufficiently clear from the preceding figure; and if anything perhaps still remains unclear, you will understand it fully from the following one — above all from that bare prop, set on the floor for the sake of better understanding. From these it is evident that the prop consists of only three small wooden beams — namely one crosspiece and two uprights — joined and fastened together at a right angle, but that it is well strengthened with sufficient braces, holders and iron buttresses,

so that it cannot in any way either bend or give way (for this little machine alone supports the whole sextant together with its weights)

[Margin: The delineations show the structure of this machine more clearly still.]

— and thoroughly secured. It is likewise clear enough how those transverse small beams are fixed to the bent upper part of the upright beams, with struts, or dovetails, set beneath them; and then how at the four tips of the upper transverse beams, which project beyond the uprights, four pulleys are also attached; and also four others, on the curved small beams set on the uprights and dovetails. Through these pulleys, as you see, are passed those thicker ropes from which the weights hang, and which are tied at their other end to the sextant by yielding hooks — as is plainly evident from figure P.

[Margin: The turning prop has all the apparatus with which the observatory is otherwise equipped.]

On both sides of the uprights I fixed a great many rings, so that, just as in the movable observatory, they would serve for hanging the cords with their weights, and so that the cords already mentioned could be tied now to the upper rings, now to the lower, as the plane — or the inclination and direction of the sextant — then required. Once the instrument has been set up in this way together with its pedestal prop, all the cords are hung on with their weights. But please note that in a four-foot sextant of this kind there is no need of such heavy weights as in the larger instruments described above. For right from the start — that is, when the sextant is being built — you can so arrange it with respect to its centre of gravity that small weights of four, five, or at most six pounds suffice. With these, just as well as with those larger ones, you can move and direct this sextant as lightly and as readily as possible; and also, at once, at its centre of gravity, in any place and at any inclination, you can stop its motion as firmly as possible, and so hold it fast as though it were restrained on every side by brakes and buttresses — and this with one hand, indeed with two fingers, so very easily and so precisely that you would scarcely believe me unless you had tried the thing yourself. For while you move the turning ball, or the crosspiece of the prop, the whole instrument at once, with all its apparatus, its ball and its weights, keeping its inclination and elevation most con-

[Margin: By means of this prop instruments can be directed with fairly light little weights.]

Diagram. Full-page engraved plate, Figure Q: the portable sextant mounted on the turning prop at the observatory fence. At the top, two wooden uprights carry short crossbeams projecting on either side, each fitted with pulleys; ropes run from these down to the sextant, whose frame is filled with foliate scrollwork and has a suspension ring at its apex. Four bell-shaped weights hang on cords at either side. The sextant sits, by a ball joint, on the head of a round post which passes through the lower crossbeam of the prop; the post is clamped to the top rail of a balustraded fence by a collar fitted with two winged screws. Below the balustrade, standing on the floor, is the bare prop: two uprights joined at a

right angle to a lower crosspiece with a slotted block at its centre, the joints held by iron braces. In the lower left lies a loose ball with its socket and stem. Across the foreground lies a partly unrolled sheet or board carrying long rods, with an ornamented arc-segment where it curls up at the right.

- Lower left, above the floor line: "Fig. Q."
- Lower left corner: "Stech Delin." (drawn by Stech)
- Lower right corner: "J. Saal Sculps." (engraved by J. Saal) stantly — and indeed so very gently and so very lightly that nothing more suitable could truly be devised. Hence this method of directing is truly far superior to, and more convenient than, that older Tychonic one — if I may say so. With that method you have constantly to raise and lower the instruments with the utmost force, to prop them up with the help of several people, and to hold them steadily with great force so that they do not shift from their place, in order to avoid any deviation. Indeed, even if they omitted nothing at all at the time that seemed to bear on this, they were nevertheless scarcely ever able in that way even to establish the proper plane fully exactly, as it ought to have been, let alone to keep it constantly. There is without doubt no one who has himself handled the Tychonic instruments with his own hands, and also directed them at the stars, who will not freely admit this.

[Margin: This way of directing instruments is far more suitable than that older one.]

And so, with the sextant correctly set up according to this new method of ours, you may take any distances you like, provided that they are not too small — of 2°, 3° or 5° — and also that they do not exceed 60°. For no sextant is capable of the intervals mentioned unless different pinnules, for the larger as well as for the smaller distances, are brought in to help, as we have already touched on in its place in the description of the larger sextants. Likewise this sextant of ours, although it is governed by a new device, requires two observers to undertake the task: in the same way as before, one stands at the fixed pinnule, the other at the ruler that is to be directed. And so that minutes and their fractions may be distinguished properly in this sextant no less than in those larger ones, and everything determined most exquisitely, provision has been made on the ruler for distinguishing minutes and seconds, both by a directing screw and by an arc serving as an explorer, and also by a small wheel, with its indices, fixed to the said screw.

[Margin: This sextant agrees in almost everything with our larger sextant.]

But so that you may grasp everything the more clearly, judicious reader, I have decided to give you this sextant drawn once more, from its rear face, in this picture Q. There you will see at the same time how the thicker cords are led and passed through those remaining pulleys, which are fixed crosswise to small beams, to the uprights; and that in this way the matter, every bit as successfully,

[Margin: The rear face of this sextant and of its prop.]

succeeds as with the former arrangement — indeed almost better still, and more safely — especially the heavier the instruments are. For at the place where the pulleys now hang, the power of that upper part of the prop is far greater (since they come closer to the uprights, where the force of support increases) than at the place where the pulleys were first hung, as anyone skilled in mechanics can easily see from the power of the lever. You can therefore make use of whichever pulleys better suit your observing and directing.

[Margin: The same thing can be done with different pulleys.]

From this rear view it also becomes clear how this sextant — or octant, it makes no difference — can be set on the bare support, fixed to the fence of the observatory by a semicircular holder and wedges, and turned towards the stars. There is, however, this difference: you can then direct the instrument only to one particular region of the sky, with only a slight change of position; but when it is set back on the pedestal, which is free on every side and can be walked around, you may direct the sextant in any direction without any hindrance and use it as you wish, and you then have no need to move the sextant, with its whole prop, somewhere else.

[Margin: The sextant is set on a support; sometimes it is also clamped to the fence.]

It cannot be denied, therefore, that although this prop is not of laborious construction — indeed it is very plain — it is nonetheless furnished with all the requisites and aids that the turning observatory itself has, with a single exception, of which more presently; and so it also performs everything just as well in actual operation. But this holds on one condition: for directing instruments that are not so very large, of only three or four feet, which are easy to carry and to move. What this prop lacks, however, is the arm support [Fulcimentum brachii], which you have seen elsewhere fixed to the upright on the other side of the observatory; by means of it one of the observers can prop up his arms or, to hold the instrument the more firmly, lean on it with his whole body. But this inconvenience too is remedied with the greatest ease, as we were just saying, namely if you use that support which can be lengthened and shortened to suit anyone's convenience, for holding up the observers' arms;

[Margin: This prop of ours is nothing other than an observatory, open on every side and portable.]

[Margin: How the support for holding up the arms can be fixed to this prop.]

which we discussed in Chap. VI, p. 128 — or indeed, far more conveniently still, by building a similar support for holding up the arms, which, like the one in the observatory, can likewise be raised at one moment and lowered at another. Moreover, if need be, it can be fitted for each observer on either side of the pedestal, provided that it consists of a round post, or of wood of some other shape, running from the floor right up to the turning ball, without feet. This is the way to do it. Make two separate round uprights [Statumina], about 1½ or 2 inches in diameter, like the one in the observatory. Fix these, I say, to

the pedestal, or support, on which the instrument stands, but in such a way that some gap remains between the support itself and these round uprights. Then take care to build similar supports, or arms, as large as the instrument's general directing support requires — in exactly the same way as you saw in Drawings M, N and O, and as you will see still more clearly from Figure S, which is to be added: namely with two hinges that break in the middle, each with its own clamping screw, so that these supports, just like that one inside the observatory, can very easily be raised and lowered.

[Margin: Construction of the support.]

[Margin: You will understand the author's meaning more clearly from the drawing to be added.]

Once these are fitted, each observer may use these supports for holding up the arms, as he pleases and most conveniently, at any elevation, position and direction of the sextant, however steeply oblique and however awkward — just as I wished to express the idea of this invention by a kind of sketch on the very floor of the preceding Figure Q. Indeed I could have added these arms directly to the instrument itself in that same figure, had I not forgotten, or had the bronze plate not already been engraved. Add to this that these turning supports are very helpful not only for holding up the arms but also for tightening that directing screw fitted with the little balls. We therefore have no need at all to direct this sextant too, furnished with such a prop, with bare hands and hold it firm; we need only govern the sextant with that directing screw, as we have amply explained several times in its place. Finally, you will also be able, in any instrument's position, to sit beside it, provided you always have ready the things that belong to this — such as swivel chairs, stools, and benches of various heights; these too we have already described fully.

[Margin: The screw fitted with little balls can also conveniently be applied to those sextants that are governed by that prop.]

Let this much, too, suffice on this new method of directing instruments. Let us now turn to the pinnules themselves, which we have undertaken to describe more fully in a chapter of their own.

CAPUT XIV.

Chapter XIV.

De Inſtrumentorum Pinnacidiis, ſive Dioptris.

On the Pinnules, or Sights, of Instruments.

Mathematicians have until now used entirely different kinds of pinnules on their instruments. For they have employed some for the stars and the celestial bodies far removed from us, and others again for terrestrial and nearer things — that is, on geometrical instruments, such as smaller quadrants, semicircles, circles, astrolabes and the like. But since we have nothing to do with these geometrical matters at present, let us leave all of them to the geometers and

geographers themselves, or to others whom the care of such things concerns. On this occasion let us pursue and examine only the instruments for searching out the stars, and our own astronomical concerns: namely, in what way the pinnules, or these sights, must be constructed if we mean to draw anything accurate from the heavens themselves.

[Margin: Pinnules of different kinds are in use.]

But just as all the sciences and arts without exception have grown over the succeeding centuries and been cultivated more and more, so, no less, has the apparatus of instruments, together with the pinnules themselves — above all since it was noticed that the sights of the ancients had not yet reached perfection in every respect. Hipparchus, whom Ptolemy followed, introduced sights (as Kepler mentions in his *Paralipomena* on Witelo [Paralipom. in Vitell.], prop. 28, p. 216), "so that, with a very narrow hole applied to the eye, the alignment [collineatio] might be more certain. But today," he continues, "in place of a sight they make a very fine slit, by setting up two pinnules almost touching each other. But not even this slit, especially at shorter distances,

[Margin: The sights, too, have been made more perfect in the course of time.]

[Margin: What kind of sights the ancients had.]

did the authors think could be trusted. Moreover, in sights directed at the stars Tycho noted this drawback: if the holes are narrow, they hide the stars; if they are wide, they do not keep the required precision of minutes [ſcrupulorum]. For this reason some place, instead of the farther sight, a very small ball held by little loops in the middle of a perforated plate, and they align on the stars not by looking at them but by covering them. Others, in a rather wide little window in the plate, set two strings crosswise to cover it, so that the crossing of the threads serves instead of a sight or a ball. But both balls and crosses vanish in the dark, and when a candle is brought near, vision is impeded."

Accordingly Tycho, an outstanding and most expert practitioner in these matters, finding that those sights were not yet fully adequate for more exact observations, devised entirely different ones, which the Illustrious Prince William of Hesse afterwards also used with great profit. He set a cylinder at the centre of the sextant — that is, at the place on the instrument farther from the eye — and, near the eye, a pinnule with not just a single small slit, or cleft, but two slits parallel to each other, the gap between which exactly equalled the thickness, or diameter, of the cylinder. In quadrants, however, instead of the cylinder they used only a nearly square plate, whose height is exactly equal to the height of that pinnule and whose width likewise equals its gap between the two slits — that is, so that the plate matches the pinnule in size on every side — with a very small hole bored through the centre of this plate, for determining solar altitudes. The lower pinnule, at the eye, Tycho (already mentioned) furnished with four slits, of the kind we have partly described above already, and shall partly present shortly, drawn and explained still more clearly.

[Margin: Tycho fitted more accurate pinnules to sextants.]

[Margin: What kind he applied to quadrants.]

But the most distinguished Riccioli, in his *Astronomia Reformata*, Book IV, Chapter 15, says: "We, however, using different kinds of sights, have found by experience that the quickest and most certain of all is the one in which the eye, through a tiny hole smaller than a coriander seed, aligns on a needle set up perpendicular from the centre of the instrument, and so slender that, given the distance between it and the eye, it does not hide the stars — except perhaps those of the fourth or fifth magnitude — but optically bisects the rest.

[Margin: Riccioli thinks his sights are far more convenient.]

It is necessary, however, that the eye should not be brought right up against the hole, but, kept back a digit or two, should see clearly that it is aiming through the very centre of the hole at the needle and at the centre of the star — which is the case when the eye sees the needle already mentioned, like a diameter, optically cutting the hole in two and at the same time cutting the disc of the star. Moreover, on moonless nights, or outside twilight, or when the Moon stands far off, the needle already mentioned must be lit — not by a flame left in the open, lest it either shine into the observer's eye or disturb his vision by the movement of the air and its flickering brightness. Rather, the lamp's flame is to be enclosed in a lantern that is opaque towards the eye, screened towards the needle with a thin sheet of crystal or of talc, and brought close to the needle, below it, at a distance of about one palm, or span. If this is done, it will at once be evident with what clarity one aims at the centre of the star. We have convinced several people of this by actual experiment and by a comparison made with Tycho's sights. And although it is not necessary, we nevertheless also use this aid for holding the eye in position, and at a suitable distance from the hole: we insert the eye into a hemispherical box, or little bowl, perforated at the bottom; this little bowl should be soldered to the plate of the hole, so that its hole matches the hole of the plate, or tablet, equally on every side. Finally, the fiducial line [linea fiduciae], in the part that is to mark on the periphery of the instrument the desired point for the minutes and seconds, must be perfectly straight and must run into the centre of the hole and into the middle, or axis, of the needle erected from the centre of the instrument; this straightness is tested by stretching a very fine silk thread." So he writes.

[Margin: Riccioli brought a candle up to his pinnules.]

But truly — if I may say so with the leave of that most distinguished man — I think quite otherwise. From observations of the celestial bodies, made assiduously over a span of thirty, indeed nearly forty, years, I have also learned by experience, amply enough, that these kinds of sights are not among those that can be trusted entirely, and that can be kept always whole and undamaged; nor can they be used conveniently on those larger instruments of six, eight or ten feet. Far rather, they disturb the observations and cause us a great deal of trouble on moonless nights, in stormy air and in adverse weather.

[Margin: The author dissents entirely from Riccioli on the method of sights.]

For first, those especially who have some familiar acquaintance with celestial matters are not unaware how much it matters to observations that we have pinnules of such firmness and strength that, once they have been set and fixed on the instruments with the greatest accuracy, so that permanently

[Margin: It is of the greatest benefit to have very firm pinnules.]

they remain unaltered, and so that they are by no means damaged or bent in any way by a lighter knock or by some collision, even a considerable one, much less moved or pushed out of their true place once it has been fixed.

"But," says the most learned Riccioli, "the needle erected at right angles from the centre of the instrument must be so slender that it cannot hide even a star of the third magnitude." But I, for my part, even though I set cylinders two inches in diameter at the centre of the instruments, by means of four little columns, and also clamp them firmly with various screws, am nevertheless at all times very anxious that they should not be damaged or handled carelessly. What, then, I ask, would happen to that more slender needle erected at right angles from the centre? Is it possible for it to be kept always unharmed and intact on any night, however dark, and at times in the very darkness, while we set the instrument on its support and take it off again? Indeed, even if it were at some moment as true as could be, it could nevertheless very easily bend this way or that from straightness without our knowing; and then the instrument would sometimes stray from the truth not only by seconds but by whole minutes. So much so that, in using such needles, however much anyone may be the most perceptive, most skilled and most careful of all, he can still never be entirely sure that instruments fitted with such frail and flimsy pinnules will always show the same thing quite exactly on one occasion as on another. And that is what must above all be avoided in our very large instruments. And so, in my opinion at least, pinnules can certainly never be too strong and sturdy, provided they are not unsuited to observations. Besides, I remove them from the instruments only very reluctantly, unless the utmost necessity presses me. And for this reason I may rightly congratulate myself that, in 15, 20, indeed 30 years, I have not once had, up to now, to remove, renew or restore any of the pinnules set on our principal metal instruments; rather, they still hold as firmly in their original place, where they were once set, as if they had first been newly made and fitted there. By contrast, if such finer needles

[Margin: A slender needle is easily moved out of its place.]

[Margin: Sights cannot be too sturdy.]

[Margin: The author's pinnules have never yet had to be restored.]

had to be used, oh, how much trouble we should very often be put to in restoring and correcting the pinnules!

Beyond this, what security would that pinnule of Riccioli's, like an upright needle, afford in observations, and with stars of the fourth, fifth and sixth magnitude, since it always hides them entirely? Could I determine them to seconds, much less resolve the same distances as always equal to the very seconds — even granting that the needle already mentioned could be seen most distinctly

(which, however, I strongly doubt): that is, that the needle could be seen in any directions whatever, even if you use a lamp or a candle? For you will certainly never bring the candle so aptly up to the needle that the half of the needle facing our eye is always lit; rather, now this side of it, now that, will be lit more and more by its light. Consequently, if not both observers, then at least one of the two would be deceived, so that he could not in any way cut, or divide, the star in two — not to mention with how much labour and how much loss of time this would be done before you set the lamp or candle in its proper place for discerning the needle properly, attach it, and remove it again. That light would dazzle the eyes now of this observer, now of that, and would harm the observations more than it would help them. Besides this, I consider it utterly impossible that a lamp could be fixed near the pinnule itself, at a distance of about one palm, or span, so firmly that it stays there without any hindrance: if it does not get in the way of this observer at the larger intervals, it will certainly get in the way of that one at the smaller. Even granting that a candle can indeed be properly placed and fixed in some convenient orientation of the sextant, not much inclined — yet how, I ask, will a candle or lamp stay in place in those positions of the instrument where both stars fall almost under the same vertical? Will not the candle already mentioned drop out of its little pipe and put itself out? What a great deal of time would be consumed in snuffing, in substituting one candle after another, or in moving it backwards, and in these other trifling matters.

[Margin: With Riccioli's pinnules the smallest stars are scarcely ever observed accurately.]

[Margin: It would be a very great inconvenience always to apply a lamp to the pinnules properly.]

[Margin: Indeed, it seems impossible in every position of the instruments.]

Far be it from me to indulge in vain boasting. With the help of the Divine Power, I have measured each and every one of the fixed stars hitherto inscribed on the globe — not once, but most of them fifty times, a hundred times, indeed more often — together with five hundred, indeed almost six hundred entirely new ones, hitherto wholly unknown, over twenty, thirty and more years; so that it might seem to some that I have acquired at least some knowledge in this business of observation. Yet I am by no means so bold as to trust that I can measure stars of the fifth or sixth magnitude really accurately while the Moon is shining, in twilight, or even with some light shining from a distance — not to say one set close by, at a span's distance — since at such times I can barely, if at all, make them out properly with the naked eye.

[Margin: Although the author has acquired some experience, he does not trust himself that the smallest fixed stars can be observed with the utmost precision while a light is present.]

Moreover, how much strain on the eyes and disturbance of vision result when the divisions on the limb are counted and noted by a lit candle! Indeed, eyes that were by then accustomed to the darkness are so dimmed, darkened

and overwhelmed that one must rest for some while, and abstain entirely from observations, before one can again properly distinguish even the smaller stars through the pinnules. For, as optics teaches, every pupil contracts more and more with excessive light, and conversely dilates more and more in darkness. Hence in a darker place, with the pupil of the eye more dilated, we see the stars more clearly and distinctly than in a better-lit place, with the eye more contracted — on this express condition, however, that we also have sights of a kind that can be made out very well in a dark place.

[Margin: In darkness the pupil dilates.]

Many experiments and long use have therefore assured me that those pinnules of Riccioli's are by no means to be trusted, and consequently that they are not at all to be used in the more exacting observations. For that reason I have chosen, before all others, Tycho's sights, or pinnules, with two or four slits or little chinks, together with a cylinder placed at the centre of the sextant or octant, and in the quadrants, in place of the cylinder, a small plate, as we have said. For I have not yet been able to devise entirely different ones that are better and more accurate — although that method of observing in

[Margin: The author far prefers Tycho's pinnules to Riccioli's.]

certain respects (as we have also in part already done) can certainly be made more refined and more perfect.

Riccioli, indeed, claims that Tycho's pinnules are very troublesome and tiresome in the dark: namely, that with their help the stars cannot be distinguished so very accurately, and now this star, now that one, is caught without discrimination. He adds that while you bring the sextant into its proper plane and at the same time direct it at the star, and search for the star by turns now through this little slit, now through that, much time slips by, especially because of the continual diurnal motion; and that the observer's attention is greatly disturbed by this constant shifting of the eyes. But you should know that this can indeed happen to some unpractised observer who does not know how to govern and direct instruments, especially with an instrument that resists and refuses every movement it is given; but I by no means concede that it can happen to well-practised observers. Indeed, it can hardly be told with what readiness and with how much speed these men — those, I say, who are skilled in these matters — carry out their observations, even with by far the largest instruments, provided they turn freely and obey: scarcely have you taken the instrument in your hands when at once you have found the proper plane as well, and have the distance nearly determined; so that it is a pleasure to be present at such observations.

[Margin: Riccioli thinks Tycho's sights are troublesome in the dark; but he is mistaken.]

[Margin: To the unpractised, nearly everything usually seems difficult.]

I am confident that with the help of my pinnules I shall obtain two or more distances with the utmost precision more quickly than anyone else — though let this be said without prejudice to the honour of all — will obtain even a single

one with a finer needle, that is, and a very tiny hole. Sometimes in a single night, aided by Divine help, I have measured more than seventy intervals of fixed stars and planets in the space of nine hours. "But," you will say, "it matters very little how many there were, but how accurate." I myself, indeed, do not wish to be the judge of my own work; rather, our observations in Book II of the *Machina Coelestis* — those, that is, made in 1661 on February 2 and October 26, to pass over the rest — will speak for themselves; and then everyone will be free to examine what they achieve, and afterwards to set out his judgement of them. So that I am thoroughly persuaded that with these pinnules of ours I

[Margin: The author affirms that with Tycho's pinnules he will carry out far more observations than anyone else with Riccioli's.]

[Margin: How many observations the author carried out in one night.]

shall manage the whole business much more quickly, more conveniently and more precisely, as regards both the plane and the distances, even with the smallest little stars of the sixth or seventh magnitude, however very closely they are set together — as in the Pleiades, for instance (all of whose distances from one another I have by now also successfully measured). This might perhaps prove laborious for some by Riccioli's method, especially if a candle lighting up the whole observatory at once has to be brought up to the pinnules. But you may ask how those smallest little stars are caught, exactly bisected, through each slit of the sight and also on each side of the cylinder. It can certainly be done excellently — but in a clear sky, on a moonless night, and by someone who has keen sight and is well practised in this exercise. Otherwise, indeed, the effort will be ill spent, and however great the exertion and zeal with which it is pursued, nothing accurate will ever be achieved.

[Margin: Practice is needed for carrying out observations.]

As for the construction of Tycho's pinnules, it is clear enough and more than enough from his *Mechanica*, especially from the supplement, where at the end the author dealt with the division and the sights. In the pinnules of the quadrants he did indeed show, on the side towards the observer's eye, four slits, or little chinks, three of which could be now widened, now narrowed, like doors, by means of clasps or ties. But that method using hinges did not seem to me altogether suitable — above all because in the dark, done in that way, the little slits, or little leaves, are hardly ever all opened and closed again equally. For this reason I tackled the matter with another device, namely a grooved little axle, or toothed little wheel, by means of which not only two, but three or four slits can be opened to whatever width you like and closed again very tightly — and indeed always together and uniformly, with all light removed, even in the very deepest darkness.

[Margin: Of what construction Tycho's pinnules were.]

[Margin: The author loosens and tightens the slits of the pinnule by a new method.]

We have drawn the true appearance of this pinnule, both front and back, as it really is, in the following picture R, under Nos. 1 and 2. On the front side, at No. 1, you see a small wheel, which in turn a circle, in its small parts distri-

[Margin: With a certain outer small wheel] buted, surrounds. The purpose is that, by means of the little axle — or rather of that small wheel which carries the index — you can open or close two, or all three, of those leaves more and more, as the condition of the stars and of their light then requires; and at the same time recognise on that divided rim how far the leaves, or slits, are open, or are to be opened at this time or that. So it is evident at once from the divisions and from the index of the small wheel whether they are narrower now, or whether they were narrower at some other time.

[Margin: …being turned round, the thing is accomplished.]

For they must be widened in one way on a moonless night and in a darker place, and in another way, conversely, when dawn is approaching, when the Moon is shining, well grown and gleaming with its whole disc, or even in the daytime. Every practised observer ought not to be ignorant of this difference, for it matters a great deal to know how to direct everything correctly in this business.

[Margin: The slits of pinnules cannot always keep the same width.]

But how these pinnules of ours are actually constructed on the inner side you also see clearly from the drawing under No. 2. By means of a grooved little axle, namely, and of toothed holders (which are fixed to the leaves) engaging one another, not merely two slits but four together can be widened and narrowed again — by turning, that is, the outer small wheel. Tycho, indeed, could open and close only three slits; but a fourth is likewise suitably made — namely, if you first make the lower fissure of the pinnule good and wide, and then in the same way cover this wide slit on the inner side with a smoothed little plate, which also has its own grooved holder, so that all four leaves together can be drawn back and controlled by means of those holders and of the grooved little axle. This you readily understand, although I have not set out such a pinnule with four slits, widened and compressed, here. For sextants and octants, indeed, no sights are needed other than those that have two leaves which can be drawn; but for quadrants we absolutely need such as are provided with four leaves, so that we may measure the azimuth together with the altitude.

[Margin: The inner construction of our pinnules.]

[Margin: The pinnules of quadrants are to be made with four fissures, but those of sextants with only two.]

The other pinnule, which is otherwise set at the centre of the quadrant, is nothing but a good thick little plate, as at No. 3

[Margin: What kind of pinnule at the cen[tre] …]

Diagram. Engraved plate, captioned *Fig. R.* at the foot, inside a ruled frame filling the upper three-quarters of an otherwise blank leaf. It shows twenty-two numbered pieces of pinnule and sight apparatus. No. 1 is a pinnule seen from the front: a plate with a rounded hood at the top, two rounded side leaves, a

footed base, and on its face a ring divided and numbered round a central square opening. No. 2 is the same seen from the inside, with two H-shaped holders whose toothed ends meet at the centre and two screwed rods below; above it stands a domed piece with a toothed shank. No. 3 is a plain thick plate on a footed base; No. 4 a small bar with square ends; No. 5 a cylinder with two clamps on its top and a line across it; No. 6 a pinnule with hinged side leaves and a scalloped hood. Nos. 7 and 8 are complete pinnule assemblies on their bases, each attended by two small figures holding up armillary spheres — in No. 8 a standing figure at each side, the base carrying two divided scales and a screw with a crank handle; in No. 7 a figure with a staff and another holding a small wheel, with a key-headed screw below. No. 9 is a decorated frame with a key-headed screw and a crank. No. 10 is a ring with a tilted plate and a bent strap; No. 11 a square frame with a circle at its centre; No. 12 a hatched screen in a round ring; Nos. 14 and 15 open boxes with a round opening in the top; No. 16 a plain cylinder; No. 13 a long ruler carrying a hatched box at one end; Nos. 17 and 18 small angled pieces; No. 19 a frame with an upright and an inclined ruler, and No. 20 a small rounded plate. Nos. 21 and 22 are mechanisms: No. 21 a divided wheel with four spokes driven by a long screw with a ring handle, and No. 22 a pair of toothed wheels driven by a similar screw.

- 1–22 (beside the pieces): piece numbers
- dial of No. 1 (round the ring): 90, 100 (at the top, split by a tick), 20, 30, 40, 40 (lower right, set upside down), 50, 60, 70, 80
- No. 8: a, b, c, d; on the scales 1, 2 (upper) and 3, 4, 5 (lower)
- No. 9: e
- No. 21: l [?], g, g, k, i, i
- No. 22: h, h, m, l, k, o, p [?], n [?]

Blank page (the verso of the plate, with Fig. R showing through in mirror image).

[Margin (continued): … at the centre of the quadrant is to be set up.]

can be seen; it is of the same size, in height as well as in breadth, as the lower pinnule. It has, however, at its lower part, where it stands on the instrument, a fairly wide slit or little window, made oval on one lower side, which corresponds exactly to the slit of the lower pinnule, so that you can, as we said, determine the azimuths at once and at the same time.

[Margin: The window of the front pinnule of the quadrant is to be covered with a plate in solar observations.]

If, however, you are taking the Sun's altitudes in the daytime, you must cover the slit already mentioned in this plate, or upper sight, with the little box made for that purpose, at No. 4. Otherwise the Sun, with its rays passed through this slit and the paper tube, would light up the lower pinnule; it should instead throw its light onto the little circle only through the hole bored in the middle of the plate.

[Margin: In sextants a cylinder is set up in place of the sight.]

Further, in sextants and octants a cylinder is substituted in place of this plate, or upper sight. It is, as we have already stressed several times, exactly as large as the lower pinnule built with its slits; except that in octants two cylinders are set up, which correspond to the two pinnules, as you have already gathered above.

[Margin: The lower pinnules of octants are movable.]

Since in octants the lower pinnules are required to be movable, they must necessarily have their own fixed bases to stand on, so fitted that they can be moved or drawn back and forth along the limb conveniently and very smoothly, like the ruler of the sextants. We have now given a drawing, at No. 6, of a pinnule of this kind that can be drawn along [Pinnacidium ductile]: the one used, that is, on our wooden octant. And although its base, made with two notches, is in itself exquisitely fitted to the limb, I inserted various special little steel springs [plumulae] in the notches so that it should nod or wobble all the less. With their help it travels, or is moved, along any part of the limb very firmly and at the same time very smoothly.

[Margin: The author constructed the very large pinnules of the octant on a singular new plan.]

But our great bronze octant of nearly nine feet, drawn and described in Chapter XII, we have fitted with quite singular and hitherto new pinnules, such as, without doubt, no one has ever yet seen anywhere except here at my house. Not only are they much more convenient, but they travel far more firmly when, back and forth, they are moved over the surface of the limb. For they are set on a fairly sturdy, oblong, four-sided brass plate, cut away or edged, and fitted with a great many little steel springs, in such a way that these pinnules not only can be moved firmly and at the same time smoothly, but can also be controlled and guided to a nicety by a special directing screw (such as otherwise lies under the ruler of the sextants).

[Margin: The pinnules of the octant show every two seconds.]

Moreover, just as they show the degrees and minutes accurately, so too they show every five, indeed every two seconds — and that not at a single place on the limb, namely at the middle of the pinnule, as is usual elsewhere on the rulers of sextants and quadrants, but at five different parts of the edged plate that lies under the pinnule. Some, perhaps, will wonder at this before they see it for themselves and put it to the test.

[Margin: These pinnules cost the author sweat.]

Such a pinnule, built on a flattened, edged support, will indeed seem to you of rather light construction. But believe me, it cost me the greatest labour and exercised my mind well before I had worked it out as fittingly and as exquisitely as the thing itself demanded, and brought it into practice — so that it has pleased in every respect not only me but also others who have at times had the chance to see it. Accordingly, since the undertaking has succeeded happily for me in this respect too — glory be to God — I also have no doubt at all that this movable pinnule, with its edged base, will in future fully satisfy each and every one of those with a keener interest in these matters.

[Margin: Nor will anyone else imitate them so easily.]

But I would like you equally to believe this: although I have set these pinnules before your eyes abundantly clearly, they will nonetheless give more than one craftsman or instrument-maker [Automatarius] — and not so very unskilled a one — a good deal of trouble before he has completed each and every part rightly and consistently: the construction, the divisions, the little steel springs, the stops or brakes, as well as the directing screw. He will sooner spoil one or another sight of this kind than make a single one perfect. And without doubt that would have happened to me too, had I not myself taken the file, the square and the graving tool in hand and finished the principal parts — above all, which is of the greatest importance, set the pinnules in their proper place.

[Margin: It is better for the observer himself to make the finer things.]

It is therefore of the greatest benefit to have been used to mechanical matters from a tender age, and to know how to put one's own hand to astronomical instruments. I would not advise anyone to entrust the whole construction of the instruments — especially of the pinnules, the divisions and other finer things — to craftsmen alone, however well skilled they may otherwise be in their art. And so I have almost never allowed instrument-makers to make and finish my pinnules unless, at the very least, both my eyes and my hands were present.

[Margin: In these matters trust should not easily be placed in anyone.]

For I confess that in this respect my temperament labours under this defect: I do not readily put my trust in any instruments, pinnules, divisions or observations unless, if I have not finished them myself, I have at least examined and investigated them properly. In this business, after all, one is very easily deceived.

[Margin: Those who believe easily are easily deceived.]

I am thoroughly convinced that it has not rarely happened to very many eminent men in this sidereal science that they were thoroughly tricked — men, that is, who sometimes relied on craftsmen, companions and others gaping only after their pay. Therefore I earnestly urge observers of celestial things, again and again, by my example such as it is, not to rely at once on the instruments of craftsmen without first testing the matter, even though the craftsmen proclaim them most perfect in every respect.

[Margin: What difference there is between the pinnules of the wooden and of the brass octant.]

But let us return to the movable pinnules lately invented by us, which we use on our largest bronze octant. They are indeed of the same construction as those earlier ones that belong to the wooden octant, and also of the same size and shape, being made, that is, with two slits and an inner grooved little axle, and also with toothed holders for the leaves. They differ only in this: this new one of ours rests on a four-sided plate that is much longer, and moreover cut away and edged, whereas the other rests on a smaller, almost square, solid plate which covers the limb completely. We have shown this in three different drawings in the preceding Figure R, so that it may be seen all the more clearly

from every side — front and back as well as underneath, where it travels on the limb. But since the page did not allow me to set them before everyone's eyes in a larger drawing, scarcely all and each and every one of the smallest details could be grasped, and grasped distinctly; therefore, if you perhaps still find anything lacking, I do not doubt that you will obtain it fully by a keener investigation.

[Margin: The front face of the pinnule.]

At No. 7 you see the pinnule just mentioned from its front face, the one that faces towards the observer: how, that is, it is fixed with screws on its flattened support, and also where that longer directing screw is attached by which the whole pinnule is moved and controlled.

[Margin: The size of the pinnules.]

The support on which Hipparchus and Ptolemy stand is made of a brass plate seven or eight digits long and three wide — wider still, indeed, if you consider the whole space. The inner part, however, which is cut away and edged, is about four or five inches long and one wide. This is done so that the divisions of degrees and minutes made on the limb may be seen through it, and these may be clearly compared with the graduations on the margin of the little plate, or support — as you will grasp everything more clearly in the next chapter, where we shall deal with the divisions in particular. For in these smaller drawings I have not been able to convey everything so accurately. Let us therefore keep for now only to its construction.

[Margin: Why the pinnules are cut away and edged.]

For this occasion let it be enough that you are aware that the cut-away and edged part of the support, or its little window, was made for this purpose: that on the margin of each side 61 twelfth-parts of one degree are engraved, divided into 60 equal parts, so that by their help even the seconds themselves could be determined excellently.

[Margin: At different places the numbers of the divisions on the pinnules always coincide uniformly.]

The whole degrees, moreover, and the single minutes are shown on that lower plate not only at *a*, on one side, as the rulers of quadrants and sextants usually show them, but at four parts of the little plate at once — namely, as at *a*, so also at *b*, *c* and *d* — simultaneously, and so very exquisitely and evenly that in any part of a minute they always agree exactly to a nicety. This holds, however, on the express condition that this pinnule of ours (and also the whole instrument) has been correctly constructed, properly divided in its small parts, and scrupulously set on its support, or little plate. Then indeed the numbers coincide most accurately on every side, at five different places, that is. In the same way this very thing, like some most rigorous examination, and standard, shows that the whole instrument, together with its pinnules, has been constructed with the utmost exactness and the utmost care. For if even a single small particle of the divisions on the limb of the instrument, or on the margin of the support, is even slightly off, the fault, arising from some discrepant marking

of the minutes and seconds, is at once betrayed most plainly, and so is the part in which it lies hidden. So much so that it scarcely ever happens that anyone skilled in these matters easily goes astray in distinguishing minutes and seconds when determining distances; on the contrary, with such an instrument in use we can be well assured of our observations.

[Margin: The pinnules of the octant are controlled by the directing screw.]

Next, it is also by far the most convenient arrangement that at the same time, by means of the directing screw so often mentioned, we can control and direct the whole pinnule precisely. This screw, as you see from Drawings 7 and 8, passes through two holders, or steel legs, firmly fixed under the little plate, whose holes, as you readily understand, are grooved. To the end of the screw, moreover, another curved holder is attached, which can turn, and from it in turn a little pipe hangs by a special little clamping screw.

[Margin: How the screw is fitted to the pinnules.]

This little pipe, together with its holder, can indeed be turned round, but with such firmness that it nowhere wobbles even slightly. The little pipe is hung there for this purpose, as I have already touched on several times in the proper place: so that it can be fixed to the steel crosspiece set beneath the limb wherever you wish, and in this way, by the directing screw, be clamped firmly to the instrument at the same time, so that the pinnule can be moved very gently when needed. How we usually do this we have already shown abundantly in Chapters X and XI, in the description of the quadrant and of the sextant.

[Margin: By what device the pinnules wobble as little as possible on the limb.]

Under the support, or plate, where the two holders that hold the directing screw are seen — and especially inside the brass dovetails [securiculae], of which at least five are found under each pinnule — we have fitted very many and very different little steel springs [plumulae]. This is so that the whole pinnule may travel along every part of the limb, and evenly at that, all the more smoothly and firmly, and be clamped there. Indeed, if they are removed, you will by no means achieve this. But how they are made, what they are like, and in what way they are fixed, since almost all

[Margin: Not everything could be set out so clearly that no further investigation is needed.]

lie hidden inside the dovetails themselves — if you except the two larger bent ones at *e* and *f* in Diagram 9 — I cannot show and explain each and every one of them as clearly as I should indeed like. Had that been required, a great many particular drawings, of a good size, would necessarily have had to be presented, together with a fuller description; but that seemed to us too long-winded and laborious. For a skilled mechanic it will, I think, be more than enough. If I, in my slender measure — I to whom nothing whatever on this subject was known before, let alone ever seen — have devised all this from my own brain alone, why should not someone else, endowed with a happier talent, once he

has examined and understood these things in part, dig them out, bore them through and work them out?

So for this occasion, now that these three different drawings of this pinnule, Nos. 7, 8 and 9, have been set before everyone's eyes, I have nothing more to add than this:

[Margin: These pinnules of the octant are wonderfully skilfully made.]

that both these pinnules, as regards their whole construction, have been made with exceeding skill and exquisiteness — more perfectly, indeed, than anyone might perhaps ever persuade himself. Not only, as we said above, do they indicate every five, and every two, seconds at five different places together and at once, with the utmost equality; they also cling to the limb on every side, entirely accurately and firmly, so that they do not wobble or nod in the least. And nevertheless they are moved and brought along very gently, very lightly and very quickly, with the utmost evenness, by that single directing screw already mentioned, at will, wherever you wish. Moreover, the screw's little pipe is attached to the crosspiece at any place on the limb.

But how much industry and what kind of skill are needed before you bring the whole arc of the instrument, with the curved transverse beam set beneath it, to such perfection and evenness, and the pinnule itself too with all its parts, you will hardly understand any sooner than when you have tried the thing yourself.

[Margin: It is advantageous for the astronomer to be skilled in mechanical matters.]

Indeed, unless the observer himself, the director of the observations, is somewhat versed in the instrument-maker's art [Ars Automataria] and knows how to handle a file, and the whole business has instead to be entrusted to the craftsman alone, who is wholly ignorant of astronomy, then it is beyond measure how much, for you, at the greatest loss of time, before indeed each and every thing in that way you obtain from him, will be a burden to you.

[Margin: The pinnules are protected by the statues.]

For the rest, those statues of the principal astronomers — namely of Hipparchus, Ptolemy, Copernicus and Tycho — were set up there, as we said in the preceding chapter, not so much for the sake of ornament as so that the pinnules should not easily be damaged. For I am constantly and greatly concerned that all our pinnules be kept perpetually intact, a matter of the utmost importance. And this is what we wished to set out at present about the sights of our octant; the divisions, however, both of the instrument itself and of the pinnules, we have proposed to treat in the next chapter, to which I refer the reader.

[Margin: How the pinnules are to be protected in solar observations.]

It remains for me to explain somewhat more clearly still, to those investigators of celestial things who search out higher matters beyond the rest — above all the restorers of the solar motions — and indeed to set before their eyes in a drawing, how the pinnules both of the sextant and of the octant (about which we already said something above, in Chap. XI on the sextant, p. 238) are to be fitted out and protected when, namely, the daily distances of Venus from the

Sun are to be measured. First, we said there that in determining the distances of Venus and the Sun with the sextant, one of the observers — the one sitting at the fixed pinnule and searching for Venus — needs a kind of little box (which we shall very soon give in a drawing as well), with which he can cover the cylinder set at the centre of the instrument and turn the Sun's rays entirely away from it. Indeed, it would without doubt be advantageous (although I have not yet tried it myself) for a square paper channel to run from the cylinder itself, or from that little box, along the leg of the instrument as far as the lower pinnule, so as to shade the observer's head just as it shades the cylinder. For in this way the Sun's rays would not cast a haze over the eyes of the said observer, and Venus would be found and observed much more easily and readily in a very clear sky, as anyone understands for himself even without my saying so.

[Margin: A plate is to be placed on the cylinder.]

But on the other observer, the one sitting at the ruler and searching for the Sun (as we said on the same page), it is incumbent that a ringed plate, carrying at its centre a very small hole for the Sun's rays to pass through, on the cylinder itself he should place. To this plate, or rather to the ring set beneath it, two legs or props are attached, one almost straight, the other bent in part (so as not to obstruct the observers' view), so that the said ringed plate can be fastened to the sextant's ruler with its screws, and so be moved together and at once with the ruler on the cylinder, or rather above and around it. We sketched such a ringed plate under No. 10 of the preceding picture R.

[Margin: Likewise on the lower pinnule.]

Likewise, a plate of the same size is placed on the lower pinnule, as you see at No. 11, and fastened with little screws. On its face, which is turned towards the Sun, a small circle has been drawn, onto which the Sun's rays, passed through the hole of the upper plate and right through the square paper tube, are received as in a darkened chamber, by means of that wider square tube.

[Margin: How the author carries out solar observations.]

But if it falls to the other companion to observe the Sun, he then places on the cylinder only that ringed plate at No. 12, without legs, and fastens it to the cylinder with screws; at the same time he fits that bare plate at No. 11 to the lower pinnule, so that both pinnules are brought to the same height. And so, with that square paper channel set between the pinnules (drawn at No. 13 with its wooden supports, as it lies evenly on the sextant in every part), the observations are carried out as one wishes. This is the way I too have always been accustomed to perform them, although Tycho dispatched that business with far less labour — namely by the shadow of the cylinder, as we have already touched on in its proper place. Whose method of observing Venus from the Sun is the more exact and the safer, I indeed leave to your judgement and that of others.

[Margin: On a peculiar and new invention for showing finer distinctions.]

Before we proceed further, it remains for us, on the occasion of our pinnules described in this chapter, to touch lightly also on that new and peculiar invention

of ours, or contrivance, which is attached to the rulers and pinnules of the instruments by means of the directing screw g and h, and also to sketch it in part, as far as the preceding page R allows. For since that invention, at Nos. 7 & 8, together with the revolving pinnules, cut away and edged, lest all the rest be thrown into confusion, could not be set before the eyes, I thought it would be worthwhile if we showed that whole little machine clearly to everyone, with its directing screw, in exactly the way it is attached to the rulers of the instruments or beneath the sights of our larger octant, in a special drawing at No. 21 and No. 22 — but only on a smaller scale, since space is lacking — although on this occasion there is no need for a larger one either. For the said mechanism will be explained and described more fully and amply (as it deserves) in the next chapter, in various figures.

[Margin: This will be duly and accurately disclosed in the following chapter.]

Therefore at this place I shall set out the matter only in general terms, so that the kind reader, and the lover of the stars who is more curious about these things, may first grasp and conceive in his mind, only in part, how the said little machine is put together and attached to the directing screw — above all so that the whole matter, which is to be set out more fully hereafter, may be understood and penetrated the more deeply and readily.

[Margin: The director of minutes and seconds is shown from the front.]

First, at No. 21 I have set out this mechanism from its front side, where the whole small wheel with its pointers lies open to view from the front, as if it had already been applied to the ruler of the sextant or quadrant, or to the pinnule of the octant at No. 7.

[Margin: What parts it is composed of.]

The small wheel i, on whose limb both the minutes and the individual seconds are contained most distinctly, is fixed to the directing screw g, together with a little pipe open on one side, or dovetail k, by means of a certain curved support l and a joining plate (which, however, does not meet the eye in this diagram).

[Margin: By means of this director the individual seconds are recognised far more exactly than on the limbs of the instruments themselves, from those customary divisions.]

This is so that the pointers of the said small wheel can very well be directed and moved, as the directing screw is drawn and turned, by means of a certain crown wheel m fitted to the point g of the said directing screw, and also of certain grooved little axles, and of one index wheel and another, subsidiary one; and so that, from that very swift motion (since the pointers are carried round with a very rapid motion), the individual minutes as well as the seconds, and indeed their small parts, can very well be marked most exactly — and that on the individual instruments much more distinctly and accurately than on the limbs of the instruments themselves, although these are larger, are moreover furnished with an explorer, and also have divisions in every respect most perfect.

These matters, however, will be discussed more fully, and shown graphically, in the following Chapter XV, where the divisions are to be treated expressly.

[Margin: Here the mechanism of the divisions is set out only in general terms; below it will be explained fully and in detail.]

For the present, my Reader, you will be content to understand, at least in a rougher way, what device and aid we have fixed to our directing screw — on whose motion alone everything depends — and roughly how its parts hold together; and then also how it is attached to the instruments by means of the dovetail *k*. But by what method we went about the divisions of the small wheel, how those various pointers divide those markings, with what speed and with what different motions they are carried, and also how those most minute particles are recognised most perfectly beneath the larger spaces — all this is reserved, as we have said, for the next chapter, in which the whole matter will be explained in detail and as clearly as possible.

[Margin: The inner face of this little machine.]

Secondly, at No. 22 I show you the little machine from its rear, or rather its inner, side, as if it were fixed to the pinnule of the octant at No. 8 of the preceding Figure R, at the end of the directing screw *h*. In this view the index small wheel, being turned completely away from us, is not seen from the front. On the contrary, however, the whole inner mechanism of little wheels and little axles — so far, that is, as we were able to show it on this occasion at this smaller size — lies open to anyone.

[Margin: The directing screw governs the whole mechanism through its crown wheel.]

Above all, one sees how the crown wheel *m* is fitted to the point of the directing screw *h*; how with its teeth it bites into the larger grooved little axle *n*, the windlass [succula], and the principal directing pointer; likewise how the other, smaller grooved little axle *o*, by means of the subsidiary little wheel *q* and a certain tube, governs and moves the other index wheel *p*; and then how all the parts fit neatly together and are fixed to the little pipe, or dovetail, *k*.

[Margin: On the motion of the screw depends every movement of the ruler and the variety of the divisions.]

Besides this, it is plain to see how the whole little machine, with its little pipe duly attached to the limb of the instrument, stands ready to move and direct both the ruler, or sight, of that instrument and those various pointers on the small wheel that displays the divisions; and that at any motion of the directing screw, even the very slightest, or at the least twist, the pointers of the small wheel too must advance at its bidding — and indeed in the direction toward which you turn the screw, now toward the preceding signs, now in the order of the signs, now going forward, now going back. The result is that on the small wheel you perceive and recognise the motion of the ruler and pinnule, in any of the most minute particles of the degrees, much more quickly, readily and also distinctly than could ever be done by anyone, by any means, on the limb of any instrument.

[Margin: All the loftier measurers of the stars will without doubt acknowledge this invention to be a most excellent aid for directing instruments and marking divisions.]

But how outstanding and how convenient this invention is for directing any instruments whatever, and for discerning the markings on any of them, it is not for me to proclaim at length, lest I seem an empty boaster of my own achievements. For it will become amply known hereafter; above all, once you yourself have fitted a similar little machine and directing screw to your instruments and have tested it in practice, you will without doubt testify that this aid — however light its construction may perhaps seem to some — is nevertheless of greater value, and far more convenient and exact for any instruments whatever, than you yourself would ever have hoped at first sight.

[Margin: Why the author does not yet fit those new telescopic sights to his instruments.]

And so let this suffice to have said about the sights, or pinnules, which we have used up to now and still use on our quadrants, sextants and octants. But very many devotees of these matters will wonder why I do not employ those new telescopic pinnules, discovered not so long ago, which certain most distinguished men already apply to their observations. They are even held by some to be the best and most accurate sights of all — so much so that some have come to the opinion that these telescopic sights are ten, twenty, thirty and forty times more exact than the common pinnules; and further, that some small instrument furnished with a radius of a single span can be made to work much more exactly than the very best one having common sights, even if it were made with a radius of sixty feet.

[Margin: Some think that even the smallest instruments of all, fitted with telescopic sights, are forty times more certain than larger ones with only the customary pinnules.]

Indeed, if these things could be brought into effect so readily, and would succeed so easily in the work itself, as they are promised and asserted, it would truly be a matter of great moment, and one not to be bought for any money. But a great many things seem most certain in theory which, in actual practice, sometimes depart quite far from the truth.

[Margin: A great many things do not always produce the effect they promise at first sight.]

Before we go on, however, let us set out the matter itself somewhat more clearly, chiefly for the sake of those to whom it is not yet fully known: namely, by what method this new device is to be taken in hand — and indeed according to the view of a certain most distinguished man. In place of the common pinnules, that is, a telescope furnished with two convex lenses is to be fitted to quadrants as well as to sextants.

[Margin: How telescopic pinnules are fitted out.]

Let the telescope, he says, be fitted out for this purpose as follows. First, with a four-sided wooden tube of very good quality, and also with a draw-tube at

that end of it which faces the eye, in which the eyepiece lens (convex) and the reticle [rete], or point of direction, are to be fixed. Once the lenses have been set at their proper distance, this draw-tube is to be secured by means of a small screw fitted to the side of the larger tube. Let the reticle, or point of direction, be either the point of a very sharp needle, or two very fine hairs, or two very thin threads from a ball of silk, crossing each other at right angles near the middle of the lens. This will strike the eye sufficiently if the Sun, the Moon, any daytime object, or one of the brighter planets is being viewed.

[Margin: At night a candle is to be brought up to these telescopic sights.]

But if you wish to observe the smaller fixed stars, or other fainter objects, at night, you will then need a little lamp or small candle (as Kepler and Riccioli once thought) fixed to the side of the tube. Through a small hole bored through the side of the tube it will be able to light up the said threads, crossing one another at right angles, so that they are made visible; yet it must be screened from the eye so that it does not trouble it in any way. And in this way telescopic pinnules are now to be constructed.

[Margin: The author has always held telescopes in great esteem, and still does.]

For my part, I readily grant, of my own accord, that optical tubes can continually lend aid to our astronomy in various ways, and have actually done so. Moreover, if there are any who have ever held telescopes [Tubospicilla] in some esteem and hold them so now, and have spent money on acquiring and constructing them, and also with them certain things in obser- vations, then I too (be it said without arrogance) may rightly be counted, at the least, among the last of them.

[Margin: In these observations telescopes [Tubofpicilla] are of very great value.]

Equally, I admit that some things can be achieved with the help of telescopes that certainly cannot be achieved with other astronomical instruments, even the largest. Examples are: resolving the closer distances of stars, which run to only a few minutes or seconds; the sizes of the diameters of the luminaries and the planets; eclipses, and solar and lunar spots; and also the distances of the Jovian satellites [Jovialium], and other phenomena of this kind. This holds above all if that device built with the two threads is inserted into the optical tube at the intersection of the rays between the two lenses — the device which both the French and the English, the former on 1667 May 16, the latter on November 11, described quite fully in their ephemerides and also drew in a figure.

[Margin: The customary pinnules are by no means to be rejected.]

But that the customary Tychonic pinnules, which we have also in part improved, should be removed altogether from all instruments — that is, from quadrants, sextants and octants — and telescopes substituted in their place in the manner just described, does not yet seem to me either advisable or safe enough.

Our pinnules, at any rate, can be fitted to the instruments very precisely by a well-skilled craftsman. Moreover, once they have been fitted to them properly

and duly and thoroughly tested, they can be fixed so firmly and tightened with screws that they in no way readily shift from their place, or are moved out of it by some slighter knock.

[Margin: Telescopic pinnules can be disturbed, and moved from their place, far more readily than ours.]

But truly, you will not fit optical tubes to instruments so readily, so exactly and so firmly, even if they are four-sided. Indeed, granted that at length, after a great many trials, with the greatest labour and loss of time, some telescope can be correctly adapted to an instrument, yet the tube itself, or the upright needle, or those crossing threads, can very easily and with a slight push be moved out of their proper place again — and that without your knowing it. And then you will certainly go wrong not only by seconds but by a great many whole minutes, and that in every single observation.

[Margin: To apply telescopic sights [Dioptras Teleſcopicas] to sextants and octants is a very slippery business indeed.]

Among the other instruments, telescopes could indeed be fixed most easily of all on quadrants. But on sextants, and above all on octants, which have no rulers, I certainly do not see how they are to be fitted there and made to indicate the divisions with the greatest exactness — and that so constantly that we can always be sure they will not in the end be impaired but kept in their original perfection, especially if observations are to be undertaken and continued every night. I cannot in any way imagine that those tubes can be fitted to instruments as exactly and firmly as our pinnules can, or keep their proper position so steadfastly. Add to this how easily so slender a needle (as we already indicated above, on page 277) or such very fine threads are damaged, worn away, and finally torn. And then, how much trouble you would have in restoring each of them in turn, and in testing the instrument afresh with so much labour and vexation before you brought it back to its original soundness!

[Margin: Various accidents can introduce a very great discrepancy into telescopic sights.]

Besides, how readily those glasses are broken, since time and again — especially in severe cold, when any breath clouds them with a mist or film so that you cannot even see through them — they have to be taken out and wiped. There is also this: if at any time the observer does not always sight through the centres of the lenses equally directly and precisely — as, believe me, would happen quite often — some parallax could easily be introduced into the observations, which would in time continually mislead the investigators of the heavens. Moreover, since the needle or threads stand so close to the eyepiece lens, at a distance of scarcely a few digits from the observer's eye, I doubt whether this sight, so near the eye, can detect any of the smallest stars much more accurately than our pinnules, which are set six or nine feet apart. For even if you see the object more distinctly, yet because your sight sits closer to the eye, you may stray further from the truth than we do with our pinnules, which are set so great a distance apart. To say nothing of the fact that the intersection of the

threads hides the smallest stars from you, whereas to us, in a clear sky, a view is given on both sides of the cylinder even of the very smallest little stars, which is much safer, in my opinion.

[Margin: A great many difficulties arise in the use of telescopic pinnules.]

So a great many difficulties present themselves, and from them I am almost persuaded that in those serious observations which are to be undertaken to restore astronomy — for instance in correcting the fixed stars and the motions of the planets, and likewise in solar observations — one cannot rely so safely on those telescopic sights.

[Margin: Tubes likewise show the fixed stars as hairy.]

At first sight these sights do indeed seem more accurate than all the others, by as much as telescopes discern the smallest things more distinctly than the naked eye. But a great many things intervene that hinder the effect they promise — above all on moonless nights, when the needle or threads cannot be made out so accurately, especially around the smallest stars. A tube of four or six feet, and much less a tube of one span, shows these hardly otherwise than as hairy and with adventitious rays, just as they otherwise appear to us when we look with the naked eye.

But suppose you say that a candle or lamp should be brought up to the tube near the needle or threads (as Kepler and Riccioli once thought). To that I have already answered fully on page 278 of this chapter, explaining why it does not succeed in actual practice. Or suppose you add that the hair of the stars is to be removed by placing a very small hole over the objective lens (as we taught on page 36 of the *Selenography*), or by smoking that very lens, as the distinguished Hugenius [Huygens] would have it. That certainly will not succeed, since in this way you will not detect the stars themselves even with much labour, nor distinguish them properly with your tube.

[Margin: Experience will teach whether the said sights prevail in all observations.]

But what is the point of saying more on this matter? The practice of observation itself, and experience itself, will prove abundantly and amply whether those who undertake all their observations in this way, with instruments of any kind fitted with those pinnules, have (as some indeed imagine) reached the very goal.

[Margin: From no more exalted observations has the author yet been able to infer that telescopic sights]

For my part, up to now I have seen nothing whatever from serious observations of any importance — that is, what has been observed with those telescopic sights concerning the equinoxes, the solstices, and meridian altitudes continued over several years — nor what distances they have obtained in restoring the fixed stars and the planets. I cannot therefore yet grant that, compared with ours, those telescopic sights are forty times more

[Margin: are forty times more exact than ours.]

accurate, and consequently that the observations made with them are correspondingly more precise as well.

What has been observed with our pinnules up to now is partly already open to view in the comets and in our other observations, of the luminaries as well as of the planets, and will partly become clear before long from the second part of our *Machina Coelestis*. But whether those observations made with telescopic sights are forty times more exact than ours, I very much doubt indeed (if I may say so with their leave).

[Margin: If telescopic sights are to answer to the opinion of some, they must determine distances in thirds.]

For my part — be it said without boasting — I am confident that I can determine the distances even of the smallest little stars not only to single minutes but, with a well-practised companion, to 10″, indeed usually to 5″, and can repeat them as often as I please. It follows that with their telescopic sights, since these are so much more accurate, they must without fail always measure those very distances not only in seconds but at the very least in thirds themselves, and likewise repeat them as often as they wish — even with a little instrument only a single span in size, as some would have it. Whether this can really be achieved I leave to others, highly practised in this arena, to investigate and judge.

[Margin: The author has not yet learned whether the recent comet was observed far more accurately with telescopic sights.]

Recently, in 1672 March, we had a rather faint and slender comet. How it was examined day after day through our pinnules, and with what diligence, is open to everyone; but it has not yet been my lot to see whether they themselves, through telescopic sights, were able to see and measure that comet forty times — in their own opinion — more exactly and distinctly, as they rightly should have.

[Margin: How it might be accurately established which sights are superior.]

For the sake of truth, so that we may at last settle something certain in this matter, I should like some vigorous and highly practised surveyor of the heavens [Cœli Metator] to be willing to determine, with a sextant fitted with telescopic pinnules, certain distances of fixed stars lying near the ecliptic and the equator, and to communicate them to us — and indeed those very distances that Tycho once observed: namely, the distance of the bright star of Aries from Palilicium [Aldebaran], then of Palilicium from Pollux, of Pollux from Regulus, of Regulus from Spica, of Spica from the upper star in the left hand of Serpentarius [Ophiuchus], of this one again from the bright star of Aquila, of Aquila from

Markab, and finally of Markab from the bright star of Aries. Then, if we were at the same time to set out my own measurements of those very distances, determined with our pinnules, anyone could readily judge whether, and by how much, those observations surpassed ours; and also which pinnules should be trusted more in future, and which ought to be preferred in this business.

[Margin: It should not be taken amiss that the author has not yet entirely rejected the Tychonic pinnules.]

Since, however, it has not yet been my lot to investigate this, and nothing has come into my hands from which I could conclude it with certainty, I should not be blamed for keeping my own pinnules longer. Over a span of thirty years I have tested them, more than enough, in so very many observations, and I am wholly certain of them: they do not vary with time, but have performed the same from the beginning until now, and likewise reveal the same quantity even to 10″, and usually to 5″. As a result I am in a position, with God's help, to measure again in exactly the same way those very distances observed ten, indeed fifteen, years ago, even with any of our larger instruments.

[Margin: The author is content to have brought the matter down to 5″.]

With these results I am indeed fully content, and I give thanks to God, who has most graciously granted that we could successfully bring these matters so far. If anyone is able to bring the same business down to thirds themselves, it will not only be most welcome to all students of the stars [Astrosophi], but the whole of astronomy will be continually advanced. May God, best and greatest, grant that it come about!

[Margin: The author leaves telescopic sights the value they are capable of.]

Meanwhile, judicious reader, there is no reason for you to persuade yourself that I reject optical tubes and these telescopic sights altogether — certainly not! On the contrary, as I have already said above, I am entirely of the opinion that they can indeed accomplish no small things in a great many observations, already set out in their place. But they can by no means do so in every kind of observation: above all at night, on moonless nights, around any of the smallest little stars, when a candle has to be brought up (as we have explained in its place); nor in solar observations of altitudes and distances, as experience will teach.

[Margin: But he by no means grants that a little instrument of a single span can be preferred to our larger ones.]

Much less can I ever imagine that so tiny an instrument, a single span in size, however very finely it may be divided into minutes and seconds by any method whatever, could ever, except by some lucky chance, produce any celestial observations more accurate than all our instruments, 6, 8 and 9 feet in size, fitted with our pinnules.

[Margin: The author hopes that telescopic sights can in time be made more suitable.]

Yet I do not doubt at all that these telescopic pinnules too can, in the course of time, be made more perfect and better suited to observations — especially if it could be arranged that our customary pinnules stayed firmly in their place, with some suitable telescope added on top of them in a certain way. Then, as it seems to me, observations would be carried out far more safely than if we removed all the pinnules and entrusted the whole business to telescopes alone, in the manner described above.

Finally, since the occasion offers, and the space on the earlier picture R allows it, we shall here set before your eyes, together, the two cases for observing the Moon that were mentioned in Chapter XI, in the description of the sextant.

[Margin: On the cases for keeping the Moon's light off the sights.]

At No. 14, then, you have the larger case, for observing the distance of two stars, which is to be fitted by its hole onto the cylinder so that the Moon does not light up the cylinder. It is large enough that each observer has a completely free view to either side of the cylinder, even when the distance to be determined is 60°. The smaller case, drawn at No. 15, is, as you see, far more sloping than the former, since it has to shade only half of the cylinder, either the upper or the lower part, and serves only one observer, the one measuring the star; for it is altogether necessary that the other should have half the cylinder free and bare, as we showed more fully above on page 236.

Lastly, having presented and explained certain things that are supremely necessary for astronomical instruments, I think it worthwhile also to set out here, somewhat more fully and clearly, as we promised, several further things that could not be drawn and described so accurately and lucidly in the pictures and in some of the earlier chapters; to bring them before your eyes in the accompanying Figure S; and also, above all, to show how our directing screw not

[Margin: The directing screw]

Diagram. Engraved plate, captioned *Fig. S.* at the foot, inside a ruled frame filling the upper three-quarters of the leaf, signed at the lower left *And. Stech delin.* and at the lower right *J. Saal scul[?]* It shows eight numbered pieces of screw and sight apparatus, with some unnumbered parts. No. [?] (top centre) is a stand: an upright post on a socket with a side handle, carrying a bent crossbar above and a second, deeper bent crossbar below, the two joined at their ends by stays fitted with small winged nuts; a long tapered pin hangs below the socket. A small cup-shaped piece stands to the left of the post. No. 2 (left) is a curved arc braced by struts, ending below in an open clamp, with a ring carrying a side clamp beneath it. No. 4 (top right) is a long arm ending in a cross-hatched pad at one end and a shaped plate with two upright hooked brackets at the other. No. 5 is a directing screw with a ring handle, running through a bracket on a shaped plate with heart-shaped cut-outs, ending in a crank and a block surmounted by a heart-shaped finial. No. 7 is a screw carrying two balls, with a bored block, a clamp and a key at one end and a key-headed finial at the other. No. 8 is a screw with a ring handle running through two blocks on a footed base, with a bracket at its far end from which a small pendant hangs. No. 6 (right) is a tall cylinder on a round base, decorated with figures, with an upright column beside it bearing a sliding piece, a screw and a key, a rod with a ball, and a stud on the base. No. 3 (foot) is a long screw with a ring handle passing between two blocks: the left block carries a box with a ball and an inclined case; the right block has a small drawer and a pointed finial below.

- [?], 2, 3, 4, 5, 6, 7, 8 (beside the pieces): piece numbers

- No. [?] (top centre): d, d (crossbar), e (ring handle), c, a (post), b (side handle), f (tapered pin)
- cup-shaped piece: g
- No. 7: h, d, c, b, g, p, a, p
- ring beneath No. 2: [?] (outside, lower left; e, l or q), [?] (inside; l, i or long s)
- No. 6: e, f, p, b, g, e, p, l, k, [?] (right of the disc; l, e or q), h, c, d, m, o
- No. 3: i, h, a, g, b

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only in astronomical matters but also in various other things — microscopes and burning mirrors, for instance, to say nothing of the rest — is of the very greatest service.

[Margin: is very conveniently applied to other things as well.]

First, in Chapter X we mentioned a prop [Sustentaculum], or catch [Retinaculum], inserted into the hollowed wooden support through an iron hole made to fit it — the prop, that is, of the great revolving horizontal quadrant — and there we also explained it at sufficient length and drew it in a figure as well. But since, because of the multitude of things and the very great diversity of that quadrant's parts, it could not be sketched so distinctly on those narrow little pages, I have now chosen to depict that same prop just mentioned somewhat more fully and clearly in the accompanying picture S, at No. 1; without it this very large quadrant could by no means stand. From this drawing it is now plain that *a* is the movable leg; *b* the little axle from which the instrument hangs; *c* the immovable leg; *d* the squared arm [brachium quadrarium]; *e* the royal screw [cochlea regia], by means of which the quadrant is directed with remarkable precision to the vertical plane; and *f* that sturdy little iron column which is inserted into the support through the hole *g*. The rest you will find described abundantly and at length in Chapter X already mentioned, page 206, and there — to which I refer you — you will learn the use of this prop most fully.

[Margin: The prop of the great quadrant shown more clearly.]

Second, in the same Chapter X, page 214, we also spoke of the wooden arm, that other, turning prop, which is movable about the upper part of the quadrant's support so that the longer screw armed with two revolving little balls can be attached to it. We have likewise chosen to give this more clearly sketched in this Figure S at No. 2, so that it may be evident how it is made up of two semicircular parts, and how it is fastened to the pedestal by two screws and their nuts [pericochleis]. Besides this, for better understanding, we have chosen to draw that same screw fitted with little balls once more, on a larger scale, at No. 3, so that everyone may know all its parts the more accurately. The rest are shown in their own place.

[Margin: On the wooden arm of the same quadrant.]

Under No. 4 you have that other arm, or wooden prop, for the sextants and octants, about

[Margin: The prop of the great sextant.]

which we treated in Chapter XI, page 227. Not only is that often-mentioned screw, armed with yielding little balls, fastened to this arm; the observer's arms are also very conveniently supported by it.

At No. 5, moreover, I have set out the ruler of a quadrant or sextant with its directing screw, and set it out in such a way that you can view it from the back, the side from which that screw is otherwise most fully visible. We have likewise described it fully enough in Chapter X, pages 194 and 232, and also elsewhere. Nonetheless, so that lovers of the stars may grasp all the better a thing so useful and necessary — indeed, not the least of my other inventions, such as they are — namely, how it is made up of its buttresses and other parts, I thought it necessary to append a separate drawing of it here, since this could not be done so distinctly in Figures K, L, M and N; above all so that it may be explained the more clearly in the following chapter, where the divisions will be treated. For it deserves to be held in some esteem: unless my opinion deceives me, I am fully confident that far greater things still, which are now entirely hidden from us, will be discovered in the course of time by means of a screw of this very kind.

[Margin: The ruler with its directing screw.]

And to show that I am, without doubt, prophesying truly: see what I myself achieved not long ago with microscopes by means of a directing screw of this kind, so that they can now be directed to any object much more readily and accurately than before. This instrument, it is true, does not belong at all to astronomical matters, which alone we have proposed to treat on this occasion, and so there is no reason for us to concern ourselves with it in the least, as a thing foreign to our subject. Nevertheless, since I came upon it by chance, I think it right to show briefly how this directing screw of ours can be applied, to the very great benefit of the sciences and the arts, both to microscopes of every kind and even to burning mirrors, and also to very many other things that must be moved and directed promptly, precisely and quickly.

[Margin: The directing screw is very useful for directing microscopes.]

The better microscopes, however, of all those ever built up to now, whether in England (I also own some very excellent ones of that kind) or elsewhere,

[Margin: How microscopes have been fitted out until now.]

have at the lower end, at the little case *m* in No. 5, in which a smaller and more convex lens is set, a screw *k* almost two inches thick; with its help, and that of its spirally grooved nut *l*, the instrument just mentioned has been directed up to now. For, as is evident, a microscope, however perfect it may be, must nevertheless be set most exactly to suit each object, according as the object is larger or smaller, finer or coarser, and brought to the proper distance; otherwise you will certainly labour in vain and accomplish nothing solid.

[Margin: Microscopes, of whatever kind they may be, must be directed according to the nature of their objects.]

To this nut, moreover, is fixed a little pipe *d*, with a little steel spring, or stop [offendix], and its clamping screw *h*, so that by means of this little pipe *d* it can be fitted to an upright iron column standing in the support *e*. In this way you can raise and lower the whole microscope, with its thicker screw *k*, on that column *e* as far as you wish, and so set the lenses at the distance each object requires. For, as we were saying just now, according as this lens or that has been worked from a larger or a smaller segment of a sphere, so the distance of the lenses from the object must be greater or smaller. When the lenses have thus been roughly set, and the microscope has likewise been fastened in that place by the ordinary screw *h*, you must obtain whatever is still lacking for the true position, or the accurate direction, by turning that larger screw *k* this way or that.

But I saw at once that in this way, with that larger screw, the microscope cannot be brought to as exact a direction as this most delicate business rightly ought to have. For if that screw *k* turns freely, it usually wobbles and nods in its nut *l*, and consequently distorts the objects; if, on the other hand, it is tighter and runs closely in its grooves, you cannot turn it round with your hands in any way; and if you do apply some force, the whole microscope is moved out of its true place, so that you never hold the object precisely under the lenses, whatever effort you make. For now you err in this way by excess, now by defect, so that by this method you can almost never obtain the proper, most exact direction except with great labour,

[Margin: In the customary way microscopes cannot be directed so readily and perfectly.]

just as everyone acquainted with these matters will certainly agree with me.

For this reason I called our directing screw to my aid. With its help, if it were properly applied, I did not hesitate — although it is a very slender little screw and of rather small value — to direct the microscope at a nod and to a hair's breadth, as the matter required: not by one line or another, but by 2, 3, indeed 4 whole inches, and moreover so readily and gently, with one finger or two, always keeping to the line of direction, that no one, however unskilled, could ever easily go astray. To achieve this, I fitted to the microscope a screw much like the one I fixed to the rulers of the instruments, likewise passing through holes in two buttresses, the hole of the one, *a*, grooved, and that of the other buttress smooth. To the first buttress *a* I attached the little pipe *b* with its little clamping screw; the second buttress *c*, in which the directing screw *p* sits in a merely smooth hole, as I said, I had fixed to the ordinary little pipe *d*. The length of the main screw *p* itself is about four inches, and its thickness roughly 1/5 or 1/6 of a digit.

[Margin: With the directing screw microscopes are directed most exactly.]

When these parts have been assembled and connected, the whole microscope itself must first be inserted into the nut *q*; then both little pipes *d* and *b* are to be fitted to the column *e* and lowered until the lower lens *m* has nearly reached its proper remoteness from the object *o*, as the distance requires. Then the little

pipe *b* (note this well) must at once be clamped firmly to the column *e* by its little clamping screw *g*, while the other little pipe *d* is loosened — or rather its little clamping screw *h*, which otherwise, up to now, had to be fully tightened if the microscope was to be governed by that thicker screw *k*. Once this is done, you have the whole thing complete, and there is no further need in any way of that larger screw *k*, so that with this new method of directing we can do without it entirely; for the microscope has only to be soldered to the catch *l*, so that it cannot move at all. And so, when some object *o* has been placed under the microscope, if on looking in you notice that the said microscope in the proper direction is not yet quite settled, at once take hold of the handle *f* of the screw *p* with your right hand and turn that screw until you have the true distance of the microscope from the object *o*. In this way you will obtain it gently, remarkably easily and promptly, and also as precisely as could ever be done, while the microscope stays perpetually in one and the same line of direction and never draws back from the object itself.

[Margin: How the said screw is attached to the microscope, and how the microscope is governed by it.]

How the individual parts are attached to the microscope is clear enough from the preceding Fig. S, at Nos. 6 and 7 — that is, from the complete microscope sketched there. You see, then, that this directing screw of ours contributes not a little to microscopes as well, and that it is not absurd that it can conveniently be applied to other things too in the course of time — especially to burning mirrors and to the helioscopic machine for observing sunspots and solar eclipses. How it is applied to mirrors I pass over here, to save time; of the helioscopic machine, however, enough will be said in Chapter XVIII. Let it suffice, then, on this occasion to have touched on these things only lightly, and to have kindled in those who cultivate the heavens an ardour to hold this directing screw of ours in the highest regard, so that they may refine it more and more, for obtaining things far greater still and more excellent than these of ours.

[Margin: The directing screw has, besides, very many other excellent uses.]

Finally, lover of the stars, I trust that you too will welcome it if I sketch here somewhat more clearly still that singular little directing machine [Machinula Directoria] of our smaller quadrants, which was described clearly enough elsewhere, in Chapter VIII, page 145. For since it is no common invention, and could not be drawn so lucidly there, in Figure G, I wished now, as we promised, to set it before your eyes a little more distinctly, in all its parts, in the preceding picture S, No. 8. If you compare this drawing of the little machine with the quite full explanation in Chapter VIII, page 145, and also with the one to be added in the following chapter, I have no doubt at all that my intention and its whole structure, and also how, in a special small wheel attached to it, by

[Margin: The director of the azimuthal quadrant.]

various toothed little wheels it can mark most distinctly, likewise on our smaller quadrants, every single minute as well as every ten seconds, you will fully grasp; so there is no need to say more on this matter.

CAPUT XV.

Chapter XV.

De Inſtrumentorum Diviſionibus.

On the Divisions of Instruments.

Although astronomical instruments, with their rulers, pinnules and all their apparatus, may be constructed skilfully and very handsomely with singular artifice, and also worked out as exquisitely as possible, yet unless they are at the same time divided into their parts as correctly as possible, they are, as it were, bodies without a breast, and things wholly without use, which can in no way be applied to the stars. Hence it is altogether most certain that the business of division is the chief of almost everything that must be observed and attended to most of all in building astronomical instruments, if you are striving to undertake and accomplish anything accurate and solid, and creditable, in measuring the stars. The whole fabric of the instruments can certainly be entrusted to some experienced craftsman; but as for the divisions of degrees, minutes and seconds, my advice is that the investigator of the stars himself, who has resolved to apply the instruments to the heavens, should carry them out — on the express condition, however, that he is thoroughly versed in these mechanical matters and trusts himself to perform all of it properly. Otherwise, believe me, as we have already set out more fully in Chapter II, page 97, he will splendidly waste his labour and lose it entirely.

[Margin: In astronomical instruments the greatest attention must be paid above all to the divisions.]

[Margin: The divisions themselves are hardly to be entrusted to any craftsman, as the construction indeed may be.]

For this reason I laboured with strenuous effort so that I might also be able to divide every one of our instruments duly into its parts with my own hand; and so I entrusted this matter, so momentous, on which the whole hinge of the business turns, to absolutely no one, so that I should not in any way be secretly and covertly deceived and led into an error from which I could not afterwards extricate myself so promptly. But how our smaller instruments — that quadrant and sextant, namely, shown in Chapters II and III — by means of transversal lines not only into single minutes but also, of any minute, nearly a quar-

[Margin: The author divided the instruments with his own hand.]

[Margin: The smaller instruments, by transversal lines, only whole minutes,]

ter part of any minute, are divided we have partly already said in its place. For the rest, since the matter is well known to those who cultivate the heavens, I do not wish to dwell on it any longer, nor to mark that very thing specifically in the following diagram [Schema] T, since it can be clearly understood from the divisions of our larger quadrants and sextants, which I have chosen to add here: namely, what method and proportion I chose, both for the degrees and

for the minutes, and observed in all the other instruments as well, whether the smaller bronze ones or the larger wooden ones built after Tycho's method.

[Margin: and their fourth part, they divide.]

But in the larger ones, made of solid bronze — namely, above all, in the revolving horizontal quadrant shown in Chapter X, the great brass sextant in Chapter XI and that very large octant in Chapter XII — I used entirely different divisions, as we have already touched on here and there. That is, I accomplished the business not only by transversal lines but at the same time also by straight ones, so that I could distinguish on the limb not only single minutes and their quarter parts, but could also recognise, entirely precisely, every five seconds. How this very thing was undertaken has likewise already been shown in its place, and also that this method — of marking the divisions, that is, on the limb itself — is the safest of all, whoever may have been the very first to discover it. Therefore let what was set out in Chapter VIII, page 276, suffice on this occasion; and nothing more now remains than to give, drawn in the next diagram, how this arc, fixed to the ruler, was made both in our revolving horizontal quadrant and in the sextant, and also how it was distributed into its small parts.

[Margin: The author's larger instruments show distinctly even every five seconds.]

[Margin: By what method, has already been shown in its place.]

First, each degree on the limb of these instruments is divided into three equal parts — that is, into 20 minutes — as is evident from diagram 1 of Drawing T, which follows shortly; then each third part again into four equal parts, so that each degree is divided into twelve small parts, and into parallel straight lines, on the lower as well as the upper side of the limb. Next, between these little straight lines, or the nearly square twelfth parts of the degrees, five minutes each

[Margin: How the arc of the instruments is divided.]

each showing five minutes: five equidistant circles were drawn, in keeping with the breadth and proportion of the limb, and these were subdivided, as you see, by transversal lines.

Once these have been carefully finished in every respect, it is possible without difficulty to distinguish, precisely enough, both the single minutes and their small parts down to a quarter — indeed almost to a sixth — by means, that is, of the ruler at *a*, which points out or intersects the divisions. But I was not yet content with this method of subdivision alone. I had a certain segment of a circle, such as you see at *b b b*, made from a brass plate, and fixed it firmly to the ruler with screws, with the purpose that it too could in its own way be divided into certain small parts, for distinguishing not only single minutes but also every five seconds. This I achieved readily and accurately by the following method. I transferred to the edge of the segment just mentioned a space of 61/12 parts of one degree — or, what comes to the same thing, the space of five whole degrees and one twelfth part of a degree. I then divided it first into five

equal parts, and next each part again into twelve; that is, I divided the whole interval of 61/12 of the arc of the divisions in this segment into 60 equal small parts, as is clear from the first and upper figure. Hence each fifth part shows a whole minute, while the intermediate twelfth parts show every five seconds.

[Margin: How the author, by a certain segment of a circle fixed to the ruler, obtained even every five seconds.]

[Margin: The method of laying out the explorer.]

These divisions are recognised by means of this segment *b b b*, or explorer, on the arc of the instruments itself, as follows. First, from the setting of the ruler at *a*, you note both the single degrees and the minutes; then, likewise, between which transversal lines the ruler itself stands — the first, or else the second, third, fourth or fifth. For example, if the sighting line of the ruler falls or ends between the first and second circle, it is entirely certain that the seconds belonging to it lie between the first and second minute marked on the segment of the arc, or explorer, and are to be sought there; that is, that nowhere except in that space can some little line of the explorer coincide with some other line of the limb than there, in that

[Margin: In what way the subdivisions of the seconds on the limb are recognised.]

[Margin: If the method of the subdivisions rightly]

Diagram. A full-page engraved plate, captioned at the foot *Fig. T**, showing eight numbered figures of a geared counting mechanism driven by a screw, with its read-out dials. Figure 1 (top left): a screw with a ring handle passing through a bracket and driving a toothed wheel set against a disc, with a rack and bar above and a pinion train. Figure 2 (right): the same kind of assembly in perspective, with a vertical screw carrying clamps above it. Figure 3 (left): a large dial with concentric graduated rings, a cross-shaped pointer, and the engraved inscriptions *Singula Minuta* ("single minutes") and *Secunda* ("seconds"), each twice. Figure 4: a smaller dial of the same kind, inscribed *Minuta et Secun* [?] ("minutes and seconds"), with its screw and handle beside it. Figure 5 (lower right): a geared disc with a key-handled screw. Figure 6: a frame carrying a train of small gears, with a dark disc beside it. Figure 7 (bottom): a long screw with a ring handle running from a bracket to a block fixed on an arc. Figure 8 (right): the gearing within a disc, seen from the front.

- Fig. 1: a, b, b [?], c, f, g (rack), g (ring), i, i, r, n, d, m, k; one letter by the small pinion not read [?]
- Fig. 2: a, b, c (on the vertical screw), h, g, r, i, i, n, m, l, e, e, k, g (knob); one letter on the lower rack not read [?]
- Fig. 3: i, i, i, u; e; a sign below the centre not read [?]; dial inscriptions *Singula Minuta* / *Secunda*; ring numerals (read in part) 100, 10000, 1000, 9000, 2000, 8000, 7000, 3000, 6000, 4000, 5000, and 5 to 90
- Fig. 4: a, b, c, z, i, i, i, u; e (right of the hub); a sign below left of the hub, x or z [?]; dial inscriptions *Minuta et Secun* [?] (upper) and *Min. et S* [?] *cunda* (lower, inverted)

- Fig. 5: a, b, c, d, g, r, i, i, b, k [?], g, m, x; one letter on the lower rack not read [?]
- Fig. 6: k, k, m, r, l, i, i; letters on the gears and the dark disc not read [?]
- Fig. 7: a, b, c, d, e, f, b [?], g, k, l, m, m, n, n, i, i, i, i
- Fig. 8: l, n, n, f, o, u, t, t, S, r, g, p [?]

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Diagram. A full-page engraved plate, captioned at the foot *Fig. T.*, signed in the centre *J. Hevelius inv. et sculps.* ("J. Hevelius designed and engraved it"). At the head, in a cartouche over the first figure, an engraved couplet:

What would elsewhere escape even Argus, ingenious Art here teaches the one-eyed to see with no effort.

Figure 1 (top): a long divided strip of a limb, shown flat. Its upper border carries the numerals 6, 1, 2, 6, 3, 4, 6, 5, with a row of minute numerals 10 20 30 40 50 under each division; below them a deep band of five parallel lines crossed by slanting transversals; beneath, a row reading 40, 20 in each division, and at the foot the degree numerals 51, 50, 49, 48, 47, increasing from right to left. At its right end stands a vertical piece lettered *a*, set against a short divided segment carrying 4, 20, 20, 4; the numeral *1.* stands beside it, and at the extreme top right the script words *Ne molem / Artis* ("*Ne* … the mass / of Art"), cut off at the right by the edge of the leaf. Below this, a second divided strip in an ornamented frame fixed with screw-heads: upper numerals 1, 2, minute rows 10 20 30 40 50, the transversal band, and a lower row 0 40 50 / 10 20 30 40 50 / 10 20 30 40 50 over the numerals 3, 4, 5; it is lettered *c* at its left end and *b* at its right. To its right, a frame with a short divided segment (9, 20, 20, 9) lettered *a*, and the script legend *Locus Dioptræ* ("place of the sight").

Below the engraver's signature, the numeral *2.* and a large screw-driven mechanism: a ring-handled screw running through two bearings on a pierced base plate and engaging a toothed wheel, which drives a pinion and a train of gears set on a disc. Smaller detached parts are numbered 3 (a screw on two pointed feet), 4 (a toothed ring, with a small square block), 5 (a bracket), 6 (a scroll-shaped piece on a foot), 7 (a pinion on a spindle) and 8 (a pair of meshing gears on a plate). At the lower right, under a second numeral *2.*, a large dial with concentric graduated rings and a cross-shaped pointer, inscribed *Singula Minut* [?] ("single minutes") and *Secunda* ("seconds"), each twice.

- Fig. 1 (first strip): *a*; numerals as above
- Fig. 1 (second strip): *c*, *b*; *a* on the right-hand frame; one letter at the extreme left edge not read [?]
- a second numeral *1.* below the carved boss at the foot of the right-hand post, at the head of the *Locus Dioptræ* box
- Fig. 2 (screw-and-gear assembly): *a*, *b*, *c*, *h*, *m*, *l*, *g*, *e*, *k*, *e*, *d*; on the disc *i*, *r*, *r*, *g*, *o*, *n*, *e* [?]; one letter by the upper gear not read [?]; *f* on the base plate at the lower left
- Fig. 3: *b*, *c*, *h*; one letter cut at the left edge [?]

- Fig. 4: *m*, *t*
- Fig. 5: *e*, *e*; *k* on the separate spool-and-key piece above it
- Fig. 6: *d*
- Fig. 7: *o*, *n*
- Fig. 8: *r*, *y*, *g* [?], *s*, *p*, *r*
- Dial: *i*, *i*, *i*, *t*, *u*; *e* (right of the hub) and a sign below left of the hub, x or z [?]; ring numerals (read in part) 100, 10000, 9000, 1000, 8000, 2000, 7000, 3000, 6000, 4000, 5000, and 5 to 90

Blank page: the verso of the plate leaf, with the plate showing through in mirror image.

said space between the first and second minute; and that, where these two meet, the seconds themselves are to be marked.

[Margin: has been set up, only a single line on the explorer can agree exactly with some other line on the limb of the instrument.]

Now since the ruler in our figure marks 45° and 36 whole minutes, and the two little lines meet only at the number 20, the angle is necessarily 45° 36′ 20″. For nowhere except at this place, at the number 20 between the first and second minute of the explorer, does any little line coincide with another on the limb; nor can it coincide except in one single place, as is plain from the drawing — provided, that is, that all the divisions, both on the arc itself and on the explorer, are laid out with the utmost exactness, as we have already advised many times, above all under the quadrant and the sextant, and as the more learned know very well. So much so that in this way not only every single whole minute but also every 5″ can be marked with the utmost exactness and distinctly perceived, both in our quadrants and in the larger brass sextants shown in Chapters X and XI.

[Margin: In our quadrants and larger sextants every 5″ is discerned quite distinctly.]

In our octant, however, since it exceeds even the instruments just mentioned in size, it is easy to determine accurately and distinctly even half of those 5″, that is, 2½″, as will shortly be seen more fully.

[Margin: The larger octant comes close to 2″.]

But by this method — that is, with the help of the explorer — I was not able to divide the arc of this octant into finer subdivisions. Whether anyone else has carried this business further by the method described, so as to recognise even single seconds precisely and quite distinctly in any part of the limb of instruments (for I am not unaware that this can certainly be done close to the truth), I have truly not yet been able to learn; nor can I be persuaded that it has been fully accomplished by anyone at all, and so far brought into effect.

[Margin: The author has not ascertained whether anyone has brought instruments of this kind to finer divisions.]

Nevertheless, although these subdivisions of ours, in my judgement such as it is, amply satisfy observations — since one may divide them down to every 5″, indeed every 2″, and we can therefore certainly rest content with them — I

was still seized by the desire to carry the matter a little further. To that end I devised another, entirely new aid, which is truly a device, unless

[Margin: The author devised a singular device, so that any instruments, even single seconds down to 15‴, distin-] my judgement deceives me, it is no common one. For with its help, even though the arcs of any instruments whatever — whether they are of only two, three, four or six feet — are divided only roughly, that is, merely into whole 5′ intervals, or indeed even if they are divided only into half-degrees, we are nevertheless entirely free to separate single minutes and single seconds alike, and very distinctly at that; and moreover, in the larger instruments of six and eight feet, even fractions of a second, with a fairly noticeable little space set, if need be, between any one fraction of a second and the next, so that you can carry out so fine a task without any strain on the eyes and with almost no trouble.

[Margin: distinctly show.]

Moreover, even given some very small instrument — namely one of one foot in radius — it is not difficult to carry it down in the same way to every 5″; at which some will perhaps be surprised.

[Margin: By the method described, even a little instrument of one foot shows every 5″.]

It should be well understood, however, that these finer subdivisions are marked and counted off not on the arcs of the instruments themselves, as is otherwise the usual practice, but in another convenient place — mostly beneath the arcs, where, however, they are in no one's way. These must be dealt with more fully shortly [mox mox], and then, for the sake of greater clarity, this recent invention of ours, such as it is, must at the same time be set before the eyes of those who cultivate celestial matters, graphically, in various figures. For until now no occasion has offered, nor could it conveniently be done in the description of the instruments above, because of the many other things that had to be explained and drawn. But first, in discharge of my duty, I consider it worth the effort to deal with the ordinary divisions of our larger octant.

We have indeed already dealt with all of these on p. 259. But since I am persuaded that a further and plainer explanation is still needed for everything to be rightly understood, and also because the matter is entirely new and, as far as I know, has never yet been attempted by anyone in this same way, we have not found it burdensome to sketch a specimen of it in the preceding Figure T and at the same time, as far as was possible, to lay it out. You will have understood, moreover, from the cited

[Margin: On the ordinary divisions of the larger octant] place, kind reader, that octants have no rulers, but only two revolving pinnules, which are moved back and forth in place of rulers. Since, therefore, there is no ruler on these instruments, we could not attach to them any explorer for minutes and seconds either, as we did on our quadrants and sextants. Above all, because of the excessive length of this octant's radius, that arc would have turned out far too large if it had had to be constructed on the same method as above; and it could

not then have been supported by the pinnules so as to be kept permanently undamaged together with its sights, as we have already partly touched on in its place.

[Margin: On octants no ruler is provided.]

For this reason I transferred those very divisions, which I am otherwise accustomed to set down on the explorers of the quadrants and sextants, to the base of the octant's pinnules, namely to the plate on which the sights are placed and set up. How these sights were constructed is abundantly clear from the preceding Chap. XIV, p. 284 and following, so that we have no need of a fuller description here. I would only remind you once more that the bases or plates of the sights, on which the sights stand, are cut away and edged along the course of the arc, and indeed so far that the space cut out is enough for showing the seconds, and also so that all the divisions of the transversal lines there, with their small portions of squares and their straight lines, meet the eye conveniently on both sides of the limb.

[Margin: On the octant the explorer for seconds has been transferred to the bases of the sights.]

The basis of these subdivisions is indeed entirely the same as that of the divisions shown on the quadrant and sextant: namely, that on the octant likewise 61/12 of one degree, that is, five whole degrees with one twelfth part, are divided into sixty equal parts. There is only this difference: these divisions do not run continuously along one and the same line; instead, half of these sixtieth subdivisions is engraved on the upper edge of the cut-away plates that lie beneath the sights, and the other part (namely 30 parts) on the lower edge. Hence that explorer could be shortened to half its length, yet with an equal, indeed almost more convenient, effect than that longer explorer on the quadrants and sextants.

[Margin: The divisions of this octant rest on exactly the same basis as that which our quadrants and sextants otherwise enjoy.]

[Margin: But they are inscribed in an entirely different arrangement.]

So that you may come to know this invention more fully and distinctly, discerning reader (and you will doubtless likewise hold it in some esteem), I wished on this occasion to set out those subdivisions somewhat more distinctly and clearly still in delineation T above, although I already showed them to you in Chap. XIV, in Figure R, in a somewhat smaller form; and in fact, on our octant itself, they are a little larger still.

[Margin: For better understanding, this method is set out somewhat more clearly in Fig. T.]

The limb of the octant, moreover, is divided on almost the same plan as is drawn in Figure T above at No. 2, and indeed quite similarly as regards the subdivisions of the degrees, the circles and the transversal lines that we adopted on the quadrant and sextant at No. 1. Namely, I divided each degree first into three equal parts, and again each third part into four small parts, that is, each degree into twelfths, so that each twelfth [doduecima] part represents 5″ [quina

referat Secunda], marked off by straight, parallel little lines from both the upper and the lower side; while the space between them, as on our other instruments, is marked by five equidistant circles and divided by transversal lines, as appears at No. 2.

[Margin: How the limb of the octant is divided.]

Moreover, so that I might also distinguish every 5″, indeed every 2″, distinctly, I cut away the plates lying beneath the pinnules, at the place where they cover the divisions of the limb, over a space of almost four degrees of the arc lengthwise, and across its breadth to such a width that you can see perfectly all the transversal lines together with those straight little lines that indicate every 5′.

[Margin: By what means every 5″, indeed every 2″, may also be recognised.]

But it is absolutely necessary that the bases of the pinnules, namely those plates on which the sights sit and which are cut away, be worked exquisitely and precisely, so that on every side they fit the limb, marked out with its divisions, most evenly and closely; yet in such a way that nowhere do they gnaw or scrape it even slightly, but are moved back and forth along the whole arc most gently and lightly, both by free hand, that is, with the loosened

[Margin: The pinnules must be skilfully constructed in every part.]

directing screw, and with that screw tightened, by turning the said screw, which is attached to the pinnules, as we have already pointed out fully in many places.

The margins of the pinnules, then, are divided only along the length of the octant's limb, as we were just saying: namely, 61/12 of one degree is divided into sixty equal parts, of which thirty are carried onto the upper margin and the remaining thirty onto the lower. But it matters very greatly that you should know at which point of both the upper and the lower margin you must begin, or where the first little line is to be marked; for unless you begin this duly and correctly on every side, you will labour in vain and obtain nothing at all that is perfect. This most delicate business, in which we cannot be too careful, must therefore be undertaken with the greatest attention and diligence — if, that is, all the subdivisions, each and every one, are to agree with one another most exquisitely in any part of the arc, as they entirely should and also can, as this octant of ours attests, and at the same time are to divide degrees, minutes and seconds quite uniformly in six different parts of the arc.

[Margin: The margins of the pinnules are divided into certain small parts.]

[Margin: But this work must be undertaken with the greatest attention, if more accurate results are to be achieved.]

The safest remedy, however, seems to be this. At the outset, the pinnule to be divided, with its sighting line running through the centre of the octant, a, is brought up to some line marking a whole degree, so that the pinnule, by its principal margin a, which otherwise divides the divisions, fixes the said line between some two degrees most accurately, and indeed in the middle of the line. The space on the base of the pinnule between a and b is exactly equal to

one whole degree of the divisions on the limb, although necessity does not demand this; it may instead be, at will, now wider, now narrower. It matters only to this extent: when the said principal sighting line a marks a whole degree for the sight, then line b necessarily also marks the next whole degree adjoining it; otherwise, if the one sighting line a shows somewhat less or more in minutes and seconds, the other, b, indicates exactly as much. In much the same way the other two sighting lines, c and d, opposite, have been laid out and worked, so that equally on every side, in

[Margin: The method of transferring the divisions onto the pinnules.]

[Margin: The size of an angle not only from one; but] the very minutes and seconds they always coincide. So much so that these four different sighting lines of the pinnule, in four different parts of the limb, must invariably mark and divide the same size of the angle, or the desired distance, down to the very smallest particles — provided only, as we have said, that all the subdivisions, both those on the limb and those required around the sighting lines a b c and d, have been marked most exactly.

[Margin: but is shown at the same time from different parts of the limb.]

When, therefore, the pinnule with its base now cuts some whole degree, or some little line marking 5′ — for example, as in figure 2 of the preceding picture T, exactly 11° 40′, so that all the sighting lines of the pinnule, a b c d, show exactly the same number of minutes — then, with the pinnule (that is, its principal sighting line) set to the right, you must inscribe on the left, namely opposite, beginning from c at the thirteenth degree, those sixtieth-part divisions mentioned above, thirty of them, on the upper margin of the pinnules towards the cut-away plate b a. Do it, however, in this way: when twelve small parts have been marked out, draw a longer line at that point, as was done at No. 1, so as to recognise the first minute in order; then mark out twelve small parts again and draw a similar longer little line, as the second whole minute in order; then to these 24 small parts now add six more small parts, on this upper margin, that is, and so you will have there two and a half whole minutes, with every 5″ marked between them.

[Margin: Where the subdivisions of the pinnules begin.]

[Margin: In what order the divisions are marked on the margins of the sights.]

Where the last little line on the upper margin of the pinnule ends, however, it will fall squarely in the seventh square, and indeed precisely in its middle, of the divided arc of the octant, counting, that is, from the eleventh degree: that is, at the thirty-second minute and the thirtieth second. When these have been marked, you have the upper margin of the cut-away plate, which serves as a checker, correctly finished and divided. Next proceed to dividing the lower margin, and begin likewise near c, opposite the sight b a; but by no means, as at the outset, at the thirteenth whole degree with respect to the divided arc, but

[Margin: Where the subdivisions on the upper margin end.]

[Margin: How the upper margin of the sights is divided,] somewhat further, towards the left, by half of one sixtieth particle — that is, to speak accurately, at the fourteenth degree and the 58½th minute, namely in the very middle of that square particle. But, as you should note well, mark this point as exactly as possible, and then likewise transfer those sixtieth particles, continuing towards the right; but when the first six have been set out, draw a longer line again, to distinguish, that is, the following third minute; then, when twelve more have been marked out in turn, let the fourth minute be marked with a longer line, and so on, until on this lower margin too you have marked thirty sixtieth particles, that is, 2½ minutes, with their 5″ divisions between them. Here, however, you should note that the last particle on this lower margin, if you have carried everything out properly and diligently, ends most exactly at the eleventh degree and the thirtieth minute of the arc; so that these sixty particles on the upper and lower margins of the pinnule, or of the plate lying beneath it, necessarily take in 61/12 particles on the arc of the octant.

[Margin: Where the subdivisions on the lower margin end.]

Moreover, if each step has been carried out duly, not only in the one place of the arc where at the outset you began the scheme of these divisions, but everywhere, wherever you set the pinnule or to whatever point you bring it — so much so that when those four sighting lines together mark whole minutes, the intermediate divisions of the cut-away plate must also show as many whole minutes; but if the sighting lines a b c d stand between the circular and the transversal lines, that is, at a place where seconds are also attached to the minutes — for example, if the principal sighting line a is set at 9° 21′ and somewhat further on still, towards the second circular line from the side of the upper limb, that is, if the intersection falls between the first and the second circle of the transversal lines — then it is also absolutely necessary that the intermediate subdivisions of the checker show as many minutes, and in addition just so small a space, that is, also as many seconds by the reckoning of the subdivisions, and indeed that they actually and visibly end at the very place where some straight little line of the intermediate divisions

[Margin: From which it may be evident that everything has been carried out duly and accurately.]

[Margin: How the minutes and seconds are distinguished.]

of the pinnule and some likewise straight line of the twelfth parts of one degree, dividing off 5″ each, on the arc of the octant beneath, fall exactly into one and the same straight line (it makes no difference whether this happens in the upper or the lower margin of the subdivisions on the checker) — there, I say, is the true end of the measure of the desired distance. For example, just as in our figure above at No. 2: the eighth twelfth part, completed from the earlier first minute toward the following first minute, the second in order [printed *in Scrupulo primo priori ſubſequens*, recte: *à Scrupulo primo priori versùs ſubſequens*, per the book's errata], together with the fourth twelfth part, counting from the eleventh degree, run entirely into the same straight line with this twentieth

minute; therefore the distance so determined comprises 9° 21′ 40″. The four bare sighting lines a b c d also reveal that same distance, though not so precisely nor so distinctly, namely as 9° 21′ and 2/3 of one minute.

[Margin: Where the end of the measure of the desired distance falls.]

[Margin: Points to note.]

Here I should like you to note further that when, as in this figure of ours above, the principal sighting line a falls between the first and the second circle, you need look on the checker only for the seconds between the first and the second minute. Again, if that sighting line stands on some transversal line between the second and the third circle, then the seconds between the second and the third minute are to be sought, and so on. This, kind reader, you will learn more clearly and readily from practice itself than from any description. Moreover, while we dwell on these matters, I remind you again and again that this noble invention is a most excellent aid for separating and recognizing, most exquisitely and quite distinctly, down to 5″, indeed 2″ (if the two little lines, namely that of the checker and that of the arc of the instrument, do not coincide exactly but stand in the middle place). This holds, however, on the condition we have often impressed on you: that the instrument itself has been skilfully and carefully constructed and divided, and that the pinnules likewise have been made and subdivided correctly and with the greatest diligence. Otherwise you will surely waste your oil and your labour, and never, uniformly and everywhere, will the angle in the seconds themselves

[Margin: If you have entered rightly into the method of the divisions, you will carry out wonderfully exquisite observations.]

be shown. But if you have paid the utmost attention to these matters in every respect, as by God's favour has happily been our lot with this octant, you may also hope for the same reward: that you will be able to determine the matter at every place on the arc with equal precision, down to the very smallest particles, and indeed more accurately than you would ever have hoped. With this you will rest content for the present, for I think that enough has been said, in part, about these matters for the expert. But if some scruple perhaps still troubles anyone, let him not be reluctant — as it also fell to me at the outset — to weigh the matter somewhat more deeply, and then he too will without doubt grasp and explore the whole matter thoroughly.

[Margin: On a new device for recognizing single seconds, indeed almost thirds.]

Lastly, let us now pursue that second method, by which one may advance not only to the recognition of seconds in fives but also of single seconds, indeed of their parts, namely to thirds, if need be — a method so accurate and so exquisite in every way that scarcely anyone could wish for anything more in that respect. We have indeed already given brief notice here and there of this device, recently discovered by us for the first time, but we have put off a fuller description and delineation of it until now. In Chapter X, p. 195, I did not shrink from declaring, of our directing screws attached to the rulers, by which

these are moved and directed, that their invention is by no means the least of all the others by whose help our sidereal science has so far gained no small increase. Elsewhere too we have spoken here and there to that effect, both of the directing screws just mentioned and of the longer one fitted with turning balls, and of that little instrument, the director of the azimuthal quadrant; above all in Chapter X, p. 218: namely, that I did not doubt that the true devotees of the stars, who have a greater and more anxious concern to look somewhat more deeply into the heavens, would one day render me signal thanks for all those screws, which I have applied to astronomical instruments with the happiest success (glory be to God). We said that we hope no less that, in the course of time, the screws already mentioned, however flimsy a construction they may seem to some Momus, will

[Margin: Through the benefit of the directing screws the Author was persuaded from the start that far greater things could yet one day be devised,] give the measurers of the stars a handle and an occasion for accomplishing and devising still greater and loftier things, just as they have also gradually furnished me with a number of other things not yet disclosed until now.

[Margin: The Author was not disappointed in his hope.]

There is no reason, however, my reader, for you to think that these are frivolous and empty thoughts and mere fictions of my brain. See for yourself, in actual fact, that this business of the directing screws stands entirely as I say, if only you try it. To that end I shall now explain to you somewhat more clearly, as far as I may, how, with the help of these directing screws — both those fixed to the rulers of quadrants, sextants and octants and that longer one fitted with balls, and also that directing apparatus of the azimuthal quadrant, by which the instruments are otherwise governed most finely and most lightly — one may, by a method equally new and quite singular, which has not yet entered anyone's mind even in a dream, still less been applied so far to astronomical instruments by anyone else, namely through these directing screws of ours, distinguish at once all the minutes of the instruments, and at once the single seconds and their parts. And this is done beneath the limb, on a special small wheel, much more exactly and distinctly than can ever be done on the arcs themselves, of any instruments whatever, whether larger or smaller, and however crudely their arcs are divided, only into whole degrees or at most half-degrees; nonetheless the distinctions of the minutes and of the single seconds appear most distinctly — but, as we have just said, with the aid of the directing screws.

[Margin: For by means of the directing screws he has brought the subdivisions of instruments down to distinguishing single seconds, indeed their parts.]

To these screws a special aid is attached, which serves all quadrants, sextants and octants alike, though each in its own particular way, and which can be fitted at the most convenient place on each instrument in such a way that it can be no hindrance either to the observer or to the instruments themselves, and can readily be removed from them again without any trouble at all.

[Margin: To the said screws a special aid is attached, constructed by a singular device of little wheels.]

But to come to the matter itself: I have resolved not only to describe the whole business in detail at this place, but also to sketch it graphically and accurately in picture T above, and clearly before the eyes of the devotees of Urania

[Margin: This whole invention is clearly set out and graphically delineated in Fig. T.]

to set it. Since, without any delineation, it would be open neither to me to disclose the matter fully nor to you, kind reader — believe me — to grasp it sufficiently, even though you are otherwise abundantly practised in astronomical study. At the outset, however, I do not consider it necessary to speak at length about the construction of the directing screws themselves, which lie hidden beneath the rulers: that is, in what way — to begin with these — in the quadrant (Chapter X) and from the sextant (Chapter XI) they are to be fixed and directed to the crosspiece of the instruments' limb by means of a little pipe [canalicula]. For we have already discussed all these matters abundantly enough in their proper place, to which I refer the reader, so that he may picture them well to himself beforehand and have each of them thoroughly examined. Otherwise, surely, what is about to be set out will scarcely be understood by anyone at all, and all the labour will be almost in vain. And so we shall treat the following business as though the earlier matters were known to you perfectly [ad unguem], as indeed they rightly ought to be.

Several times in the description of the earlier instruments — namely of that larger quadrant, the sextant and the octant — we have already pointed out that we could not carry their subdivisions beyond five seconds, and at most two. With these we may certainly rest content, since nothing finer, so far as I know, has yet been achieved by anyone. Nonetheless, some years ago I burned with the desire to bring these subdivisions of the instruments down further, to single seconds at the least. You will perhaps urge, however, that this very thing could have been accomplished no less by means of some checker applied to the arc. But in instruments of that kind, with a radius of six, eight or nine feet, this is by no means granted, because of the closer divisions, of course, which run into one another, so that nothing at all accurate becomes known as regards the single seconds, I say. Therefore, leaving these aside, I approached the matter by an entirely different route, and indeed, as we have touched on, by means of the screw of the directing ruler. For since the said screw governs the ruler in every respect by its turning, and at every gentlest motion and softest touch distinguishes the subdivisions on the arc of the instruments now in one way, now in another, it certainly also lies within the power of that screw, by itself, not

[Margin: Since the author could not distinguish single seconds on the limb of the instruments by means of any checker, he approached the matter by an entirely different route.]

[Margin: The screw that governs the ruler also shows the divisions.]

attending to the arc of the instruments, to show finer divisions. And so I imagined that if I attached to those directing screws a special small wheel [orbiculus] with its various pointers [Indices], it could not but happen that in this way — by a singular route, however — not only the minutes but also the single seconds, indeed down to the thirds if need be, would be marked distinctly and most exquisitely; and indeed much more clearly and finely than by means of some checker arc of the ruler, applied on the very limb of the instruments. Nor, certainly, did this belief deceive me: for the work, just as I had first conceived it in my mind, afterwards turned out no less excellently, and as I had wished. For the pointers on the said small wheel are carried round with such speed, by means of certain notched little wheels and grooved little axles, that although the screw itself proceeds somewhat more sluggishly by itself (which is nonetheless very convenient for the business of directing), and in one revolution completes and marks out roughly three whole minutes on the arc of the divisions, the pointers of the small wheels are nevertheless so very swift that in one turn of the screw they fly round the whole small wheel three times, and in one circuit they complete scarcely a single minute. Hence almost the entire periphery of the small wheel lies open for distinguishing the seconds and their parts, which are surely evident enough in themselves and set well apart from one another. So when you take hold of the screw, even though you notice the ruler being moved forward in no way at all, the pointers on the small wheel nevertheless advance at once, very swiftly and quicker than thought, and most clearly mark off the divisions down to a quarter of one second, that is, fifteen thirds.

[Margin: The pointers on the small wheel are very swift, so that they fly round the disc three times before the screw is driven once round its circuit.]

The little machine itself, however, is not constructed in all instruments with an entirely similar arrangement of little wheels, nor could it have been. Rather, to suit the convenience of each instrument — so that it should neither obstruct the observations nor be a hindrance to them — it is put together and fitted out in one way or another, and is attached to the directing screw at the very place where, of course, it is before everyone's eyes; and it can be fixed without any trouble, at any place on the limb, to the crosspiece lying beneath the arc by the little pipe of the directing screw. Therefore, kind reader,

[Margin: The little machine for showing the finer subdivisions is not always constructed with the same arrangement of little wheels, but takes one form or another to suit the convenience of each instrument.]

we have set before your eyes in picture T above, under a special designation, this directing contrivance [Machinamentum directorium] for showing the minutes and seconds of any instrument of ours, both whole and taken apart into its components; and we shall also explain it briefly and clearly as we proceed, so that there is no one touched by any deeper concern for these matters who will not penetrate each point more thoroughly, and who cannot thereby, if he

wishes, more easily and readily apply a similar and most suitable aid to his own instruments.

First, however, let us present that little machine which serves our large horizontal brass quadrant (Chapter X): namely, with what arrangement of little wheels, windlasses, sockets [cheloniae] and little axles it is constructed, how it is attached to the instrument, in what way the divisions on the small wheel are marked, by how many and by which pointers they are distinguished, and how wonderful a use this aid offers in observations of every kind.

[Margin: Director of minutes and seconds for the horizontal quadrant.]

First, then, in the preceding picture T, towards the lower part, at No. 1, I have set before your eyes, friend reader, this new director of minutes and seconds, as clearly as I was able, from the inner side: that is, the parts, little wheels, little axles and screws of which it consists and is composed, so that the pointers of the small wheel can be governed and turned round by a quite slight impulse. The principal directing screw *a h*, on which the whole business depends, runs, as is evident from the said figure, through steel buttresses *b c* fixed into a certain thicker plate *f*. This base [pedamentum], together with the said screw and its little machine, which is to be attached to the quadrant, is then fixed beneath the ruler by very strong tightening screws. Moreover, to that directing screw *a h* — since formerly it was applied only to the directing of the ruler, and at that time had been fitted out solely for that purpose — nothing was fitted but a curved arm *l*, and to this in turn a square little pipe, open, that is, on one side, or dovetail [securicula] *k*; so that, with the said little pipe clamped to the limb of the quadrant, by the movement of the directing screw at the same time

[Margin: The director of the divisions for the horizontal quadrant is disclosed and described at length.]

[Margin: The directing screw had at first been made only for the directing of the ruler.]

the ruler itself could be governed and directed to any altitude, at will and as desired, most exactly and most promptly.

[Margin: A special little machine is attached to the directing screw, for distinguishing the single minutes and seconds.]

Now, since the directing screw just mentioned is at the same time destined for a higher task — the showing, likewise, of finer distinctions, namely the single minutes and seconds and their parts, on a special small index wheel [Orbiculus index] — I therefore not only passed the end *h* of the directing screw through the hole in the curved arm, but also fitted a crown wheel *m* to that end of the screw, as can be seen in the said figure at No. 1, and joined it to it very firmly with a clamping nut [pericochlea adstrictoria].

[Margin: The whole construction of the director of the divisions.]

Next I clamped a certain connecting plate *e* to that curved arm *l* and to the little pipe with several clamping screws, and bent the plate so that the quadrant itself, and the place where the small index wheel *i* was to be set, absolutely

required that very bend; the connecting plate itself, together with the attached little pipe *k*, can be seen in a separate drawing at No. 5. To this plate *e*, further, I likewise fixed the small index wheel *i* firmly with screws, and also the socket [chelonia] *d*, which is set obliquely, just as the centre of the small index wheel *i* demanded, so that the windlass, or bar, *n o* of the pointer, drawn separately at No. 7, would pass at right angles through the said small wheel.

[Margin: Of how many teeth and grooves the little wheels and little axles consist.]

Two grooved little axles, the larger *n* and the smaller *o*, are set on this windlass. The larger serves this purpose: that the crown wheel *m*, with its 45 teeth, can seize the larger little axle with its 15 grooves, and so move and turn the windlass, together with the smaller grooved little axle *o* attached to it. Further, at the nose of this windlass, near the smaller little axle *o*, I fitted a little index wheel [rotula index] of 60 teeth, together with the small index wheel *i* itself and its two pointers, or tongues, *u x* and *vv*, of which more fully below.

[Margin: How the crown wheel governs two different pointers at the same time.]

Thus this crown wheel *m*, by means of the larger grooved little axle *n*, governs the longer and faster tongue *u x*; and likewise, by means of the smaller grooved little axle *o*, that other, subordinate little wheel *q*, which is also made with 60 notches. The little index wheel *p*, however, although the windlass or spindle *n o* no less through passes through the very centre of this little wheel, is nevertheless in no way moved along with it by that windlass. The reason is that a special pipe *s* is soldered to the centre of this little index wheel *p*, as is clear at No. 8; through this pipe the oft-mentioned windlass runs and turns freely, the little index wheel *p* being in no way moved by it or driven along with it. The purpose is that the lower, slower tongue *vv*, fitted to this pipe *s*, should have its own particular motion by means of the crown wheel *m*.

[Margin: How the little index wheel depends on the subordinate little wheel.]

For the motion of the little index wheel *p* depends solely on the subordinate little wheel *q*, which also has the same size and the same number of teeth as the other little wheel *p*, but has its own centre and windlass, with another, different subordinate grooved little axle *y*, likewise of six notches, as is clearly shown at No. 8. And so that this shorter windlass, with its subordinate grooved little axle *y*, can be carried conveniently on its own centre, a special transverse plate *r* has also been attached there in place of a socket, as you see; in the middle of it a very small hole has been made for the subordinate grooved little axle *y*, which carries and directs the subordinate wheel. In this way this subordinate little wheel *q*, together with its grooved little axle *y*, can be moved by the smaller index little axle *o*; and in turn the little index wheel *p*, by means of the subordinate little axle *y*, can be moved together with its pipe *s*, which runs very firmly in the centre of the small index wheel *i* and to which that lower and slower tongue *vv* is fitted.

[Margin: Use of this little directing machine.]

And so you have the whole construction of this contrivance, or our director, for showing the minutes and the single seconds. How the small index wheel *i* itself is divided into its parts will very soon be disclosed and shown. I do not doubt that all who are even slightly versed in the mechanical art will now easily grasp and understand how this little machine can be brought into use and applied to instruments, to the very great benefit of astronomy. For with the support, or base, *f* (in which those two buttresses *b* and *c* are otherwise set) fixed to the ruler of the quadrant by its several clamping screws, and with the ruler to the desired altitude of some star, near the true directed by the naked hand, nothing more remains than for you to apply the little pipe *k*, which is attached to the directing screw *h* by means of the curved arm *l* (for the arm, together with the whole little machine, can turn about the nose of that screw), to the upright crosspiece lying beneath the limb of the quadrant, and to fix it firmly with the little clamping screw *g* intended for that purpose.

[Margin: By this invention of ours not only is the ruler directed exquisitely, but finer distinctions are also discerned most exactly.]

Then the whole device stands ready for carrying out the business of observation, so that you can not only govern and direct the ruler readily, most exactly and as desired, as we have already noted many times, but also, with the help of the little wheels, windlasses, little axles and tongues of this device, discern most distinctly any of the finest subdivisions in minutes and seconds, and indeed certain parts of them.

[Margin: The origin of the distinctions.]

But before we go further, it is first pertinent to know how the distinctions are described and discerned. The foundation of this whole invention lies solely in that directing screw of ours, *a h*, as we have already touched on here and there. For as the screw is driven this way and that, and turned round, the crown wheel *m* attached to it is at the same time driven in the same way, and consequently all the remaining little wheels, with those two tongues, are carried along — yet not all equally, nor with the same speed or slowness as the directing screw *a h*; for although that could have been done with the slightest effort, it would not have been advisable.

[Margin: The little wheels and pointers are not carried at equal speed.]

For the business of discerning the finest subdivisions, which is now my sole aim, it is much more useful if the tongues that mark the divisions are not a little faster than the directing screw *a h* itself. For the faster the pointers are than the screw just mentioned, the more evident the finer distinctions become, set out over larger spaces. Their motion and the ratio of their speed lay in my power and choice.

[Margin: The faster the tongues are than the directing screw, the more evident the distinctions become.]

[Margin: The ratio of the speed of the pointer to the directing screw.]

Hence I judged that in our quadrant, as in almost all the other instruments, it would amply suffice for showing the single minutes, the seconds, and indeed a quarter of these, if I built this director of ours in such a way that the principal and faster tongue *u x* three times the small wheel's whole periphe- ry would traverse and complete, while the directing screw, that is, turned itself precisely once only; in other words, with one revolution of the screw the pointer *u* would complete three periods of its orbit. In this way the said pointer would advance fast enough to distinguish the small parts of the seconds, although the motion of the screw would proceed so slowly that it could scarcely be detected.

[Margin: How many teeth the crown wheel has, and how many grooves the primary little axle has.]

To bring this about and put it into effect, I had a crown wheel made of conspicuous size and with 45 teeth, and fitted it to the directing screw. And since the grooved little axle *n* consists of only 15 notches, the windlass *n o* necessarily turns three times before the directing screw *a h*, together with the crown wheel *m*, is turned round once, since the said little axle has only a third part of the teeth relative to the crown wheel.

[Margin: The more teeth the crown wheel has, and again the fewer grooves the little axle has, the faster the pointer is.]

For the more teeth the crown wheel has, and the fewer grooves the grooved little axle *n* shows, the more quickly and rapidly the pointer *u* is moved, and then the small parts of the divisions become larger and more evident. For example, if the crown wheel consisted of 48 teeth and the larger little axle *n* of only 12 grooves, the pointer *u* would go round the small wheel *i* four times, or complete four periods of revolution, before the directing screw *a h* was carried round once.

[Margin: By what means the tongues are made quicker.]

Again, if the said little wheel *m* had 60 teeth, and the notched little axle showed only 6 notches, that tongue *u x* would be ten times faster than the directing screw itself; that is, with one revolution of the said screw it would complete the whole circle ten times. How great this speed would be is easy to understand.

[Margin: It is not difficult for us to determine even the single thirds with this director of ours.]

Indeed, if we chose to adopt this proportion of teeth and grooves, and it served the work, we would be free to discern clearly from that small index wheel not only the seconds but also the single thirds. But our business of observation has no need of such great subtlety; it is enough that we can arrive, quite distinctly, at the seconds themselves, keeping that proportion of the crown wheel to the larger little axle *n*, namely as 3 to 1.

[Margin: Whoever carries his observations down to the seconds certainly proves himself a man.]

Whoever carries out all his observations accurately to that point, in his duty surely abun- dantly acquits himself, so that nothing whatever more ought to

be expected of him, as all the more profound investigators of celestial things will readily admit along with me.

[Margin: The author chose not to have faster pointers.]

For this reason too I deliberately chose not to build faster pointers into these directors of ours, since, as you will very soon understand, they amply suffice for the work of showing the single seconds on our small wheel *i*, as we were saying just now. The small wheel *i* at No. 2, however, I chose to show there deliberately at the same size as it actually has in the director of our quadrant, so that I could set the subdivisions of the small wheel, at perfectly equal intervals, before anyone's eyes.

[Margin: The small index wheel can be divided in various ways.]

As for the divisions themselves, I could indeed have marked them out in various ways. First, namely, so that the longer pointer *u* would distinguish the single seconds, the lower and slower one *vv* whole minutes, and a third whole degrees; so that when the upper pointer completed the small wheel once it would register 60 seconds, while the other, *vv*, would indicate only one minute, and when this one had completed the whole circle, namely 60 minutes, the third pointer would show the first degree in order.

[Margin: The method of dividing the small wheel into degrees, minutes and seconds did not seem to the author suitable for the work.]

Just as this method of dividing is very plain and clear, so it will certainly seem to everyone, without doubt, very well suited to observations; but I judged it not advisable to carry the matter out in that way. For this would not only demand a quite different contrivance of little wheels and little axles, of greater labour; but also to bring the director, for any instruments whatever, to the point where it would afterwards settle the matter most exquisitely in every number would be, believe me, a business of much and immense work. I add that if, at the outset, you committed even a very slight error in investigating the motion (as you will perceive more clearly a little later), you could easily depart not a little from the truth in any observations whatever.

[Margin: The author's method of dividing the small wheel is very easy and suited to observations.]

For this reason I devised a special method, likewise very plain and very evident, by which the whole periphery of the circle, both for the upper and faster pointer *u* and for the slower *vv*, is divided only into 100 equal small parts. With these distinctions, although very plain and general, the whole business of subdivision nevertheless far more exquisitely, and far more safely, without any danger of error, can be carried out than if I had at once distributed the small wheel into degrees, minutes and seconds.

[Margin: How the same director can serve different instruments.]

And, most important of all, if the director is divided in this way into at least hundredths, the same director can be applied equally accurately and successfully not only to one single instrument but to very many at once, even though they are of different sizes (at which you will no doubt be surprised). If, on the other

hand, you lay out the divisions in that other way, namely by degrees, minutes and seconds, you need to build a special director for each instrument.

[Margin: In what way the divisions are inscribed on the small wheel, and with what numbers they are marked.]

But for better understanding I show you the small index wheel *i* itself, divided only so far, as I said, into hundredths, for the two principal tongues *u* and *vv*, at No. 2 in Figure T above. I have written the numbers on the divisions in two ways, running both to the right and to the left, so that I could count off the small parts of the distinctions forwards and backwards. Between the numbers of the two circles, the upper and the intermediate, there is no other difference except that in place of the 10 and 20 laid out on the upper circle, 1000 and 2000, and so on in sequence, are marked on the intermediate circle for the slower tongue *vv*; and they run in the former up to 100, but in this intermediate circle up to 10,000. Thus when the longer pointer *u* completes a whole revolution of its 100 parts, the lower pointer shows only a single part in its circle, so that at no moment should it fail to be exactly clear to me how many revolutions and how many small parts the directing screw, or the pointers of the small wheel, had completed.

With these two circles now divided, I added a third division, but only for this quadrant of ours, since this way of distinguishing (however much that of the two upper circles is universal) is only special, for one particular instrument, for discerning the seconds themselves promptly at first glance by means of the third, shorter pointer *x*, set directly opposite the upper one. But more will be learned of these distinctions a little further below.

[Margin: How the minutes and seconds are derived from the hundredth parts.]

Now I think it necessary first to show how, from these hundredth parts and those two longer tongues *u* and *vv*, the minutes and seconds themselves as accurately as possible can be recognised — and indeed, I affirm it again and again, much more precisely than on the arcs of the instruments themselves, whatever their size and however very fine the small parts into which they are divided, even if you apply a more accurate checker with the utmost attention.

First, you should know that this small index wheel of ours requires no fixed size: you are free to set its diameter as you please, provided that the instrument itself, or the structure of the director, or the place where it is to be fitted, does not prevent a larger one being attached. It is therefore better to use a larger one if nothing stands in the way, since the divisions then come out larger, as is easily inferred.

[Margin: The larger the small wheels are, the clearer the divisions become.]

For this quadrant of ours, however, the size shown in the figure above at No. 2 seems to me both sufficient and quite convenient, since those hundredth parts on the small wheel just mentioned are quite large and distinct, and so are the seconds themselves: for in this quadrant two hundredth parts designate just one single second. I therefore deliberately chose not to make this small wheel

larger, so that the little machine would not become more unwieldy and would not trouble the observer anywhere.

But let us come at last to the point where I may show by what method the divisions are marked off correctly and finely. You should know that I took the following route. Once that little machine had been completely constructed, duly fitted to the directing screw, and also fixed to the little pipe by means of the combining plate, all the little wheels and axles, with their teeth and grooves, were then duly examined: whether the teeth, and likewise all the notches, engage one another correctly, lightly and smoothly, yet nonetheless closely enough, without any empty or superfluous small gap (as the makers of automata say), and whether the work runs backward without any staggering or wobbling.

[Margin: The divisions rest on a solid foundation.]

[Margin: The workmanship of the little wheels in this mechanism must be most exquisite, without any wobble.]

For this device demands above all that the directing screw, together with all the little wheels, be moved very closely indeed, but nonetheless very smoothly and with little force, so that anyone can guide it lightly with two fingers. Otherwise the labour will certainly be futile and most troublesome, and you will obtain nothing at all accurate from that invention;

but in the meantime I would not have you think that it is very difficult to do in this way, much less impossible. Not at all, provided you have at hand a skilled craftsman who works everything out dexterously. That this succeeds as one could wish, the little machines on every one of my instruments testify more than enough: they are built so elaborately and exquisitely that nothing whatever could be found wanting in any of them. But we are straying too far from the path; let us return to the divisions.

[Margin: How one may arrive at the divisions safely.]

And so, with everything thus prepared as we said, in order to come to the examination itself, I first brought the ruler, together with the director fixed to it, by hand alone to some particular degree of the quadrant's limb. Next I fixed the little pipe *k* to the limb in the usual way with its clamping screw *g*, and only then, by means of the directing screw *a b*, did I set the ruler exactly on that whole degree; but it makes no difference from which degree of the limb you attempt this. When this had been done, I began to turn the directing screw, at first with a continuous motion toward the preceding signs [in antecedentia], until I had reached the line marking the whole degree quite precisely.

[Margin: A whole degree of the instrument is to be measured by the tongues in hundredth parts of their own circle.]

Then, with the directing screw brought to rest and the small index wheel *i* standing still, I ascertained how many times the faster and longer tongue *u* had turned round its circle, and how many small spaces it had completed in its circle besides. I found that in our great revolving horizontal quadrant it had completed 68 periods, or revolutions, going round the whole circle: for the

slower, lower pointer *vv* stood precisely at the number 6800, while the upper pointer *u* was at the beginning of its circle, so that no further hundredth parts could be added to this number 6800.

[Margin: When the ruler spans one whole degree in our quadrant, the principal pointer shows how many revolutions it completes in its circle.]

It should be known, however (something I had forgotten to point out above), that when you set about measuring some whole degree of the quadrant with this director of ours, it is absolutely necessary first to bring both pointers *u* and *vv* correctly and accurately to their proper place (with the ruler, that is, already standing precisely on the line of some whole degree). That is, you must set the upper pointer *u* at the very place where 100, or

[Margin: When you begin to observe, the tongues must first be duly reset.]

the first hundredth part, begins, and the other, lower pointer *vv* exactly beneath one and the same line, where the first number of the thousandth parts begins. Otherwise you will certainly never determine the divisions on that small wheel correctly.

[Margin: The motion of the ruler in our director must be checked most rigorously.]

But there is no reason to rest content with a single investigation for determining the size of one degree on the small index wheel. The same examination must be repeated several times, turning the directing screw both forward and back again; and, for the sake of greater certainty, you must test most diligently several times, not only in one particular part of the limb but one whole degree after another, whether the size of the director's motion agrees in any degrees whatever, or whether the pointers *u* and *vv* complete equally the same number of revolutions in each circle of divisions, and so always agree in the numbers themselves.

[Margin: Just as the size of each degree must always be the same, so their motion through the whole quadrant must be entirely equal.]

For if the limb of the instrument has been divided equally and correctly throughout, in every part, then it is certainly necessary too that every degree should have an exactly equal interval, and consequently that the same number of hundredth parts should be shown on the small index wheel — provided, that is, that the workmanship of the little wheels has been duly constructed, and that this director (which should be well noted) is firm enough in every part, especially at the curved arm *l*, that it cannot bend in the least or yield to the motion of the directing screw. Of this director of my quadrant I can affirm that whenever I have set about examining and detecting the size of one degree on the horizontal quadrant already mentioned by means of this director, the upper pointer *u* has always completed 68 whole periods, that is, 6800 hundredth parts.

[Margin: From the measure and motion of one degree the remaining finer subdivisions take their origin.]

This, then, is now to be taken as the rule and foundation for these finer divisions in this horizontal quadrant. For if a single degree, or 60′, contains 6800

hundredth parts, then 45′ comprise, or make up, 5100; 30′, 3400 hundredth parts; and 15′, 1700 hundredth parts. Therefore, lest much time during observation, on each occasion, the due proportion of any observations whatever in determining should be wasted, I at once constructed two different tables and attached them to the quadrant, so that they would be ready to hand. With their help one learns without any trouble how many minutes, seconds, and even thirds, if you wish, are to be added further to the degrees determined by the ruler, or sometimes taken away from them.

[Margin: The subdivisions are readily recognised from certain tables.]

The first table, A, contains the whole minutes up to 60, together with the hundredth parts that correspond to them. For example, suppose you had found the lower pointer *vv* standing at the number 4000 and the upper pointer *u* at the number 80 — that is, that the pointers *u* and *vv* had completed 4080 hundredth parts on the small wheel — and the question is how many minutes and seconds correspond, or are equivalent, to these hundredth parts. Look, then, in the body of Table A to see whether some number corresponds exactly to this one. Since a number of precisely that size is found there, it is at once evident from the margin of the table that 36 minutes belong to this number, to be added to, or subtracted from, the degrees indicated by the ruler, according as the pointers of the small wheel were turned towards the right or towards the left.

[Margin: By what method.]

But you may ask how to proceed if this whole number being sought is not found in the body of the table, and some further hundredth parts are attached to it. This too is found out without much trouble. You subtract from the given number (for example, let it be 4130) the next smaller number found in the body of the table, and look up the difference between the given number and the number 4080 found in the table — that is, the 50 surplus hundredth parts — again in the following Table B and its margin. In the adjoining body of that table you will at once find the seconds and thirds themselves that correspond to these 50 hundredth parts, namely 36″ 30‴; so that you would discover that, besides those 36 whole minutes, 36″ 30‴ were also attached.

[Margin: How the seconds and thirds are found from the tables.]

You will certainly never detect such fineness of divisions on the arc of any quadrant whatever, even if it has a more accurate checker and you yourself are lynx-eyed. For by that method one can get no further than to five seconds. Meanwhile, however, if the limb of the instrument is correctly divided, and the director properly fitted and marked, all the numbers in every part must agree at least to within five seconds; but

[Margin: Without the director such extremely fine divisions are never reached.]

beyond that one cannot advance to the seconds themselves, or even to thirds, as can indeed be done on the small wheel of the director.

And I have summed all this up as briefly as I ever could: namely, in what way the divisions are inscribed on the small wheel, and how by its means minutes, seconds and thirds — indeed fourths, if you wish — are derived from the two attached tables. But before I set out the tables themselves here, it is useful to explain somewhat more fully the inner divisions of the shorter pointer *x*, from which the seconds themselves are recognised at once, at a single glance, provided the difference of the angle does not exceed 53 seconds.

[Margin: How, without the tables, the individual seconds are obtained at once from the small index wheel itself.]

The basis lies in this. Since I have thoroughly established that a whole degree, or 60 minutes, gives 6800 hundredth parts, it also does not escape me that 113⅓ hundredth parts make up a single minute. I therefore divided that many hundredth parts, in the inner circle, into 60 entirely equal parts, and in this way those little spaces of the inner circle were produced, each indicating one second. A whole revolution of the pointer *x*, however, comprises only 53 seconds, since they do not contain more than a hundred particles; so that one may not go further in this circle. And hence, when the difference of the angle is greater, it is better to go to the tables and determine the altitudes from them. Here you should note that the numbers in the third circle do not take their beginning where the other pointers do, namely from the upper part, but at the exactly opposite point, from the lower part. The reason is that this same pointer *x* is also the pointer *u*, as is easily understood.

[Margin: How many seconds one revolution of the pointer gives.]

Now, when one wishes to use that little directing machine (as we have already touched on lightly above), it is worthwhile first to bring the ruler by hand, freely, as close as possible to the desired distance or altitude; then to clamp the little pipe very firmly to the limb of the instrument, and also to set both pointers *u* and *vv* precisely at their starting points. These pointers are so fitted that you can direct them this way and that, lightly and gently, to the proper mark, without moving the little wheels and with the little axles entirely at rest. It is not necessary, however (as it is in the examinations), always to bring the ruler first to the nearest whole degree; but

[Margin: How observations are made with the help of our director.]

it is enough if you set it at the nearer line marking five whole minutes. It makes no difference, however, at which line this is done, whether the preceding one or the one immediately following, provided you note whether the minutes and seconds to be derived must be subtracted from the whole degrees or added to them. For example, let the altitude to be taken be about 43° 22′. Here you do not need to place the ruler at the whole degree 43, but at the little interval 43° 20′, since that is nearer. When this has been done, and the director with its pointers has been duly fitted, turn the directing screw *a b*. If it moves in the order of the signs [in consequentia], the minutes and seconds that result are to be added to the degrees; if instead the screw goes toward the preceding

signs [in antecedentia], those minutes and seconds are to be subtracted from the degrees.

[Margin: Note well towards which side you turn the directing screw.]

For example, suppose the lower pointer had completed only a single little space in its orbit, that is, 100 hundredth parts, and the other, upper one had stopped at the number 83 — that is, 183 hundredth parts had been turned through. Look for this number in Table A, and subtract from this 183 the next smaller number, namely 113⅓, which belongs to a single whole minute: 70 will remain. From Table B these hundredth parts give 37″ 6‴, which are of course to be added to that 1′ (since the screw has gone forward), so that 1′ 37″ 6‴ results; this is to be added in turn to 43° 20′, and so the whole altitude from our director will be 43° 21′ 37″ 6‴. But if the screw had been turned the opposite way, namely toward the preceding signs [in antecedentia], the minutes found, with the seconds and thirds attached to them, must be taken away from that altitude of 43° 20′, so that the true altitude then comes out as 43° 18′ 22″ 54‴.

From all this, curious lover of the stars, you will understand, if not fully, at least in part, how our little machine for directing the subdivisions, already mentioned, is constructed, fitted, divided and put to use. If perhaps some points still remain that you do not yet sufficiently understand from this description, please take the trouble to work out the rest by your own ingenuity. I do not doubt that it will now be much easier for you to understand this matter, laid open in so many figures, than it was for me at the beginning first to devise it in my mind and build it, since in this field I had no forerunner at all. How

[Margin: Whoever perhaps does not yet fully grasp this matter must explore it himself by deeper investigation.]

excellent, moreover, and how very well suited to all astronomical instruments this aid that we have discovered is, and how conveniently and readily it can be fitted to them, provided it has been properly made in every part, experience itself will teach you abundantly.

TABELLA A

Table A

For the great revolving horizontal quadrant.

[Margin: Tables for the divisions of our horizontal quadrant.]

Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel
1	113⅓	11	1246⅔	21	2380	31	3513⅓	41	4646⅔	51	5789 [recte: 5780, per the book's errata]
2	226⅔	12	1360	22	2493⅓	32	3626⅔	42	4760	52	5893⅓
3	340	13	1473⅓	23	2606⅔	33	3740	43	4873⅓	53	6006⅔
4	453⅓	14	1586⅔	24	2720	34	3853⅓	44	4986⅔	54	6120
5	566⅔	15	1700	25	2833⅓	35	3966⅔	45	5100	55	6233⅓
6	680	16	1813⅓	26	2946⅔	36	4080	46	5213⅓	56	6346⅔
7	793⅓	17	1926⅔	27	3060	37	4193⅓	47	5326⅔	57	6460
8	906⅔	18	2040	28	3173⅓	38	4306⅔	48	5440	58	6573⅓
9	1020	19	2153⅓	29	3286⅔	39	4420	49	5553⅓	59	6686⅔
10	1133⅓	20	2266⅔	30	3400	40	4533⅓	50	5666⅔	60	6800

TABELLA B

Table B

[Margin: Table for finding the seconds and thirds.]

Hundredth parts on the wheel	Seconds ″	Thirds ‴	Hundredth parts on the wheel	Seconds ″	Thirds ‴	Hundredth parts on the wheel	Seconds ″	Thirds ‴	Hundredth parts on the wheel	Seconds ″	Thirds ‴
1	0	32	31	16	26	61	32	20	91	48	14
2	1	4	32	16	58	62	32	52	92	48	46
3	1	36	33	17	30	63	33	23	93	49	18
4	2	8	34	18	1	64	33	55	94	49	49
5	2	39	35	18	33	65	34	27	95	50	21
6	3	11	36	19	5	66	34	59	96	50	53
7	3	42	37	19	37	67	35	31	97	51	25
8	4	14	38	20	9	68	36	3	98	51	57
9	4	46	39	20	40	69	36	34	99	52	29
10	5	18	40	21	12	70	37	6	100	53	0
11	5	50	41	21	42	71	37	38	101	53	32
12	6	22	42	22	14	72	38	10	102	54	4
13	6	54	43	22	46	73	38	41	103	54	36
14	7	26	44	23	17	74	39	13	104	55	8
15	7	57	45	23	49	75	39	45	105	55	40
16	8	29	46	24	22	76	40	17	106	56	12
17	9	1	47	24	54	77	40	49	107	56	44
18	9	32	48	25	26	78	41	20	108	57	16
19	10	4	49	25	58	79	41	52	109	57	48

TABELLA B

Hundredth parts on the wheel	Seconds ″	Thirds ‴	Hundredth parts on the wheel	Seconds ″	Thirds ‴	Hundredth parts on the wheel	Seconds ″	Thirds ‴	Hundredth parts on the wheel	Seconds ″	Thirds ‴
20	10	36	50	26	30	80	42	24	110	58	20
21	11	8	51	27	2	81	42	56	111	58	52
22	11	40	52	27	34	82	43	28	112	59	20
23	12	11	53	28	6	83	44	0	113	59	40
24	12	43	54	28	37	84	44	31	113⅓	60	0
25	13	15	55	29	9	85	45	3			
26	13	47	56	29	41	86	45	35			
27	14	19	57	30	13	87	46	7			
28	14	50	58	30	44	88	46	39			
29	15	22	59	31	16	89	47	10			
30	15	54	60	31	48	90	47	42			

Let us now go further and consider the remaining directors of our principal instruments. Each instrument claims for itself its own particular director, firmly fixed beneath the ruler to the directing screw; this director is not built with one and the same arrangement of little wheels, nor is the small index wheel attached to the little machine in one and the same way. For it is put together in one way for the larger quadrants, which have a ruler, in another for the smaller ones, which are fitted with a plumb line, and in another for the sextants and octants, as will soon be perceived more clearly.[7]

[Margin: Directors of this kind are built in different ways to suit the instruments.]

In Figure T*, at No. 1, we have first shown the director of our larger brass sextant, described in Chapter XI. In almost all its parts it is indeed not unlike the earlier one of the quadrant, as regards both the little wheels and the grooved little axles and their number of teeth; except that here the small index wheel is attached to the little machine somewhat differently with respect to the limb of the sextant: at right angles, directly beneath the pinnule, along a parallel course. In this way the small index wheel lies open to the observer at once and from every side, without any obstruction at all, even though you draw the little pipe back from the limb and move it to and fro together with the ruler. In the quadrant above, by contrast, the director is attached directly beneath the limb, but likewise with its face toward the observer, where the pointers meet the eye openly and no less immediately.

[Margin: The director of our large brass sextant.]

The divisions in this director of the sextant, however, differ in part from the earlier one of the quadrant. For since the sextant is a little smaller than the quadrant in its radius, the faster little pointer measures out a whole degree in fewer revolutions, although the index disc is of the same size as the previous one. For the smaller the instrument, the fewer hundredth parts the pointer *u* completes for one minute. Having made due inquiry, I found that the

[7]the word *mox*, "soon", is printed twice.

faster pointer completes only 61½ revolutions, that is, 6150 hundredth parts, in running through a whole degree, or 60 minutes. Therefore 4612½ hundredth parts give 45′, 3075 hundredth parts 30′, and 537½ hundredth parts yield 15′[8]. Consequently the tables must, on an altogether different and separate plan, be

[Margin: In what respects the director of the sextant differs from the earlier one of the quadrant.]

[Margin: How many revolutions the principal pointer makes on the sextant over the space of one degree.]

composed. In this figure I have not drawn the small index wheel itself, seen from the front, at all — for lack of space, that is, and chiefly because there was no need. It is enough, I think, if I point out to the reader in just a few words where the tables differ from one another: namely, that in this director of the sextant (although likewise, as in that of the quadrant, only

TABELLA A

Table A

For the great brass sextant.

[Margin: Tables for the divisions of our large brass sextant.]

Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel
1	102½	11	1127½	21	2152½	31	3177½	41	4202½	51	5272½ [recte: 5227½, per the book's errata]
2	205	12	1230	22	2255	32	3280	42	4305	52	5330
3	307½	13	1332½	23	2357½	33	3382½	43	4407½	53	5432½
4	410	14	1435	24	2460	34	3485	44	4510	54	5535
5	512½	15	1537½	25	2562½	35	3587½	45	4612½	55	5637½
6	615	16	1640	26	2665	36	3690	46	4715	56	5740
7	717½	17	1742½	27	2767 3⁄2 [recte: 2767½]	37	3792½	47	4817½	57	5842½
8	820	18	1845	28	2870	38	3895	48	4920	58	5945
9	922½	19	1947½	29	2972½	39	3997½	49	5022½	59	6047½
10	1025	20	2050	30	3075	40	4100	50	5125	60	6150

[8] 15′ is a quarter of the 6150 parts to a degree, which is 1537½; the page prints 537½

TABELLA B

Table B

[Margin: Table for finding the seconds, thirds and fourths.]

Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗
1	0	35	7	27	15	48	9	53	31	1	11	79	46	14	13
2	1	10	14	28	16	23	16	54	31	36	18	80	46	49	20
3	1	45	21	29	16	58	23	55	32	11	25	81	47	24	27
4	2	20	28	30	17	33	30	56	32	46	32	82	47	59	34
5	2	55	35	31	18	8	37	57	33	21	39	83	48	34	41
6	3	30	42	32	18	43	44	58	33	56	46	84	49	9	48
7	4	5	49	33	19	18	51	59	34	31	53	85	49	44	55
8	4	40	56	34	19	53	58	60	35	7	0	86	50	20	2
9	5	16	3	35	20	29	5	61	35	42	7	87	50	55	9
10	5	51	10	36	21	4	12	62	36	17	14	88	51	30	16
11	6	26	17	37	21	39	19	63	36	52	21	89	52	5	23
12	7	1	24	38	22	14	26	64	37	27	28	90	52	40	30
13	7	36	31	39	22	49	33	65	38	2	35	91	53	15	37
14	8	11	38	40	23	24	40	66	38	37	42	92	53	50	44
15	8	46	45	41	23	59	47	67	39	12	49	93	54	25	51
16	9	21	52	42	24	34	54	68	39	47	56	94	55	0	58
17	9	56	59	43	25	10	1	69	40	23	3	95	55	36	5
18	10	32	6	44	25	45	8	70	40	58	10	96	56	11	12
19	11	7	13	45	26	20	15	71	41	33	17	97	56	46	19
20	11	42	20	46	26	55	22	72	42	8	24	98	57	21	26
21	12	17	27	47	27	30	29	73	42	43	31	99	57	56	33
22	12	52	34	48	28	5	36	74	43	18	38	100	58	31	40
23	13	27	41	49	28	40	43	75	43	53	45	101	59	7	0
24	14	2	48	50	29	15	50	76	44	28	52	102	59	42	10
25	14	37	55	51	29	50	57	77	45	3	59	102½	60	0	0
26	15	13	2	52	30	26	4	78	45	39	6				

divided into hundredth parts) a whole minute shows only 102⅓ hundredth parts, and so a whole revolution of the upper pointer comprises only 58″ 31‴ 40⁗. This, then, is the basis on which the preceding Tables A and B rest. They therefore differ only in proportion, namely, as we have said, because this instrument is somewhat smaller in its radius. For although an entirely similar directing screw is applied to it, the different size of the instruments nevertheless alters the proportion of the motion somewhat. For the rest, the use of the tables in no way differs from that of the earlier ones, so that it needs no further explanation.

[Margin: How many hundredth parts on the small wheel correspond to a whole minute.]

[Margin: The size of the instruments speeds up or slows down the motion of the tongues in the director.]

But to come now to the director of our very large octant, which is seen neatly sketched in the preceding Figure T*, at Nos. 2 and 3. Its structure is likewise made with almost the same arrangement of little wheels as the preceding ones, except that the individual parts have been made somewhat larger and wider (the instrument being, that is, also not a little larger), above all the small index wheel *i*, so that in this way I might make the divisions the more evident. That wheel is shown here, at No. 3, at exactly the same size as that at which it was actually built in our director. The proportion of the teeth of the little wheels and little axles, however, is in part different: the crown wheel *m* has 60 teeth and the larger grooved little axle *n* 20, so that I might thereby obtain a gentler advance of the directing screw; but the smaller little axles, namely the index axle and the subsidiary one, *o* and *γ*, are in their grooves entirely equal to the earlier ones and have only 6; no less, the little index wheel *p* and the subsidiary wheel *q* have 60 teeth, just like those. Hence the motion of the tongues is just as fast as in those two earlier directors of the quadrant and the sextant. So, besides, I have almost nothing to point out on this occasion, since it is fitted out, tested and attached to the instrument in the same way, with exactly the same face, as that director of the sextant, so that the whole small index wheel, like the limb itself, lies freely open on every side. And so nothing more seems to remain than for me to show in what

[Margin: The director of our very large brass octant.]

[Margin: The ratio of the teeth and grooves for the little wheels and little axles of this director.]

[Margin: However many more teeth some little wheels in this director carry, the motion of the tongues relative to the directing screw is nevertheless exactly the same as in those mentioned above.]

way the small index wheel is distributed into its small parts, how many hundredth parts make up one whole degree and one minute, and then what kind of tables have been computed for distinguishing minutes, seconds and thirds, if you wish.

[Margin: In what way the small wheel is distributed into its small parts.]

TABELLA A

Table A

For the great brass octant.

[Margin: Table for determining whole minutes.]

Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel	Minutes ′	Hundredth parts marked on the small wheel
1	126⅔	11	1393⅓	21	2660	31	3966⅔ [recte: 3926⅔, per the book's errata]	41	5193⅓	51	6460
2	253⅓	12	1520	22	2786⅔	32	4053⅓	42	5320	52	6586⅔
3	380	13	1646⅔	23	2913⅓	33	4180	43	5446⅔	53	6713⅓
4	506⅔	14	1773⅓	24	3040	34	4306⅔	44	5573⅓	54	6840
5	633⅓	15	1900	25	3166⅔	35	4433⅓	45	5700	55	6966⅔
6	760	16	2026⅔	26	3293⅓	36	4560	46	5826⅔	56	7093⅓
7	886⅔	17	2153⅓	27	3420	37	4686⅔	47	5953⅓	57	7220
8	1013⅓	18	2280	28	3546⅔	38	4813⅓	48	6080	58	7346⅔
9	1140	19	2406⅔	29	3673⅓	39	4940	49	6206⅔	59	7473⅓
10	1266⅔	20	2533⅓	30	3800	40	5066⅔	50	6333⅓	60	7600

TABELLA B

Table B

[Margin: Table for finding the seconds, thirds and fourths.]

Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗
1	0	28	25	33	15	37	45	65	30	47	5	97	45	56	25
2	0	56	50	34	16	6	10	66	31	15	30	98	46	24	50
3	1	25	15	35	16	34	35	67	31	43	55	99	46	53	15
4	1	53	40	36	17	3	0	68	32	12	20	100	47	21	40
5	2	22	5	37	17	31	25	69	32	40	45	101	47	50	5
6	2	50	30	38	17	59	50	70	33	9	10	102	48	18	30
7	3	18	55	39	18	28	15	71	33	37	35	103	48	46	55
8	3	47	20	40	18	56	40	72	34	6	0	104	49	15	20
9	4	15	45	41	19	25	5	73	34	34	25	105	49	43	45
10	4	44	10	42	19	53	30	74	35	2	50	106	50	12	10
11	5	12	35	43	20	21	55	75	35	31	15	107	50	40	35
12	5	41	0	44	20	50	20	76	35	59	40	108	51	9	0
13	6	9	25	45	21	18	45	77	36	28	5	109	51	37	25
14	6	37	50	46	21	47	10	78	36	56	30	110	52	5	50
15	7	6	15	47	22	15	35	79	37	24	55	111	52	34	15
16	7	34	40	48	22	44	0	80	37	53	20	112	53	2	40
17	8	3	5	49	23	12	25	81	38	21	45	113	53	31	5
18	8	31	30	50	23	40	50	82	38	50	10	114	53	59	30

TABELLA B

Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗	Hundredth parts on the wheel	″	‴	⁗
19	8	59	55	51	24	9	15	83	39	18	35	115	54	27	55
20	9	28	20	52	24	37	40	84	39	47	0	116	54	56	20
21	9	56	45	53	25	6	5	85	40	15	25	117	55	24	45
22	10	25	10	54	25	34	30	86	40	43	50	118	55	53	10
23	10	53	35	55	26	2	55	87	41	12	15	119	56	21	35
24	11	22	0	56	26	31	20	88	41	40	40	120	56	50	0
25	11	50	25	57	26	59	45	89	42	9	5	121	57	18	35
26	12	18	50	58	27	28	10	90	42	37	30	122	57	47	0
27	12	47	15	59	27	56	35	91	43	5	55	123	58	15	25
28	13	15	40	60	28	25	0	92	43	34	20	124	58	43	50
29	13	44	5	61	28	53	25	93	44	2	45	125	59	12	15
30	14	12	30	62	29	21	50	94	44	31	10	126	59	41	10
31	14	40	55	63	29	50	15	95	44	59	35	126½	60	0	0
32	15	9	20	64	30	18	40	96	45	28	0				

After careful investigation and a stricter examination, however, I found that it is not 61½ revolutions, nor 68, of the upper pointer *u* that make up a whole degree, as in those earlier instruments, but 76 revolutions; that is, the pointer, running through 7600 hundredth parts, completes 60 whole minutes, and so 126⅔ hundredth parts show a single minute. Hence it follows that 1900 hundredth parts show 15′, 3800 hundredth parts 30′, and 5700 hundredth parts 45′. From these I constructed and computed the tables above. But how the small index wheel itself is actually divided, how large the intervals are that each circuit of divisions carries, and that even a quarter of one second could readily have been distinguished by the third pointer *x*, had I wished, you can make out from the small wheel *i* itself, shown at No. 3. Had I made the small wheel larger still, as could also conveniently have been done, the divisions would have come out far more evident still; but I considered that wholly superfluous.

[Margin: How many revolutions the principal pointer in this director of the octant completes while the ruler runs through a whole degree in its circuit.]

Next follows the director of our smaller brass quadrant, of one foot in radius, which has otherwise already been described clearly enough in Chapter VIII, page 145, and by whose aid the smaller quadrants of this kind, as we have already pointed out more than once, are governed and directed with wonderful ease, most accurately and most smoothly. To this director, I say, or rather to its directing screw, I have now also attached our little machine, for showing the small parts of the finer divisions, so that at the same time (although this quadrant is of slight size, and its limb is consequently divided only into half-degrees) every ten seconds can nevertheless be marked most distinctly. As to that directing screw, and how it advances through the buttresses *b* and *c*, there is no need to say more here, since we have already dealt fully with all these

matters elsewhere, so that nothing more remains to add than how the little machine for minutes and seconds is fixed to it.

[Margin: The minutes director of the quadrant built with a brass plumb line.]

At No. 4 of picture T* above, this director is seen from the front: namely, how it is divided, and by which pointers the divisions are marked; although in this sketch the diameter of the small index wheel

[Margin: Front view of this director.]

is shown much smaller than it otherwise actually is in our little machine; for in reality it is no smaller than that of the other preceding directors, and consequently the little intervals between the divisions are in reality also much larger and more evident; but the space on that small sheet T* did not allow the small wheel the same size. At No. 5 I have set the same director before your eyes from the back, so that you can see the whole arrangement of little wheels.

[Margin: The back side.]

Like the preceding ones, it carries a crown wheel *m* at the directing screw, but with only 36 teeth, and its larger grooved little axle *n* consists of only 12 grooves; yet the rate of motion, that is, the speed of the tongues, is nevertheless just as fast, since with one revolution of the directing screw the upper pointer *u* flies three times round its whole circle. As for the rest, the index wheel *p* and the other, subordinate wheel *q* likewise have 60 teeth, and their little axles 6 grooves; so there is scarcely any other difference, except that the small index wheel is attached in an altogether different position, by means of the joining plate *e*, to the little pipe *k*. This is so that this small wheel lies against the plane of the quadrant's limb on a wholly parallel course, and indeed very close to it; and so the small index wheel meets the eye openly together with the limb of divisions itself and the divided plumb line, and the divisions on both are open to every observer with equal clarity.

[Margin: The whole construction.]

[Margin: This director is attached to the quadrant in an altogether different way.]

Indeed, had I so wished, I could certainly have made the small index wheel *i* not as it actually is now, 3½ digits in diameter, but much larger; for in these smaller quadrants nothing at all stands in our way of making it much larger. Had it been built 6 digits across, I would have carried the divisions down to single seconds, to be distinctly discerned on some very small instrument, and with such clarity indeed that each little space of one second would have been spread out to nearly a quarter of an inch. At No. 4 I did divide that small wheel smaller than it should be, namely in proportion to the size of the disc; but, as we were saying, in my director the little spaces are much larger.

[Margin: The directors of these smaller quadrants can also be carried down to single seconds.]

How that directing screw is fitted and adapted to a certain steel arc, made from a conic section, and then to the quadrant by means of the little pipe, we

have already shown fully in its proper place, on pages 145 and 146; let that suffice for this occasion. I think only this needs to be added, so that you are not unaware: that the plumb line must first be brought to some definite degree, either a whole degree or a half-degree, before you bring both tongues on the small wheel exactly to the beginning of the divisions and numbers, and begin to move and direct the directing screw.

[Margin: What is chiefly to be observed.]

The rule for the divisions of the small wheel is this. It was established with the greatest diligence and care that the faster tongue *u* completes 41 revolutions within the space of five whole degrees, and this was repeated many times, both by turning the screw forwards at very many places on the limb and by driving it backwards; so that 820 hundredth parts correspond to one degree, 1640 to two degrees, 2460 to three, 3280 to four, and 4100 hundredth parts to five degrees, while 13⅔ hundredth parts belong to a single minute. On this ratio we have now constructed the tables that follow, whose use is exactly the same as that of the earlier ones: namely, that with their help you can at once determine the minutes themselves, down to every ten seconds, with the greatest ease.

[Margin: In this quadrant a motion of the plumb line through five degrees equals 41 revolutions of the principal pointer.]

[Margin: How many hundredth parts of the circuit belong to one whole minute.]

From the inner circuit of divisions, however, and the shorter pointer, the minutes and seconds themselves are evident even at a single glance, without any table; but on this express condition, that the variation of the directing screw and of the tongues does not exceed seven whole minutes. You will wonder at this, though: that a single minute in the said inner circuit comes close to the space of one inch. The divisions of these minutes and seconds, however, start not in the same place, at the upper part of the small wheel where those two longer pointers *u* and *vv* take their start, but at the lower part, directly opposite. For the shorter tongue *x* and the longer one (as we said) are wholly joined and move together; they differ only in this, that the small parts for each ten seconds are much larger than the other hundredth parts in those upper circles: for 10 seconds show 2¼ hundredth parts.

[Margin: With this director we can descend to every ten seconds on that very small quadrant, since the space of one minute extends to a whole digit.]

[Margin: One and the same tongue shows different divisions.]

If you use this very small quadrant and its director, you can manage the business with practically a single little table, if you are willing to be content with minutes. For once the plumb line has first been directed to some definite degree of the limb, with the difference no greater than one degree (and anyone at all, surely, can direct a quadrant that far, even with rather rough skill), the attached minutes are at once evident from Table A. But if you also want the seconds, the business must be done in the following way. Suppose you had found that the longer tongue had gone round its circle twice and in addition

marked 52 hundredth parts, that is, had completed 252 hundredth parts. Look for this number, or the one next below it, in the adjoining Table A, and you will find 246 hundredth parts, showing 18 whole minutes. Then subtract this number from the 252 observed above: there will remain 6 hundredth parts, to be looked for in the body of the other table, B, against which 25″ stands in the margin; so that the altitude, beyond those degrees marked by the ruler, comes to 18′ 25″.

[Margin: Use of this director.]

TABELLA A

Table A

For the smaller quadrant.

[Margin: Tables for the director of the smaller quadrant.]

Minutes ′	Hundredth parts on the small wheel	Minutes ′	Hundredth parts on the small wheel	Minutes ′	Hundredth parts on the small wheel	Minutes ′	Hundredth parts on the small wheel
1	13⅔	16	218⅔	31	423⅔	46	628⅔
2	27⅓	17	232⅓	32	437⅓	47	642⅓
3	41	18	246	33	451	48	656
4	54⅔	19	259⅔	34	464⅔	49	669⅔
5	68⅓	20	273⅓	35	478⅓	50	683⅓
6	82	21	287	36	492	51	697
7	95⅔	22	300⅔	37	505⅔	52	710⅔
8	109⅓	23	314⅓	38	519⅓	53	724⅓
9	123	24	328	39	533	54	738
10	136⅔	25	341⅔	40	546⅔	55	751⅔
11	150⅓	26	355⅓	41	560⅓	56	765⅓
12	164	27	369	42	574	57	779
13	177⅔	28	382⅔	43	587⅔	58	792⅔
14	191⅓	29	396⅓	44	601⅓	59	806⅓
15	205	30	410	45	615	60	820

TABELLA B

Table B

Seconds ″	Hundredth parts on the small wheel
5	1 1/7
10	2¼
15	3 1/12
20	4 5/9
25	6 nearly
30	7 nearly
35	8⅛
40	9¼

TABELLA B

Seconds ″	Hundredth parts on the small wheel
45	10¾
50	12 nearly
55	13 nearly
60	13⅔

In short, in any instruments whatever, with the help of this director and of the tables, the operation is one and the same, provided, that is, that the small wheels are divided into hundredth parts; except that the tables, according to the size of the instruments and to the wider, or narrower and finer grooves of the directing screw, differ entirely from one another.

[Margin: This director is governed very gently indeed.]

The screw of this director, which we are now discussing, is quite slender and also has finer grooves; it therefore advances very easily and gently, so that you hardly feel it, just as if it had only the bare quadrant to direct and did not at the same time have minutes and seconds to show. The directors of the other, larger instruments likewise move very lightly indeed; nevertheless they move somewhat more stiffly than if, as you readily understand, they had only the rulers to move. For in larger instruments of this kind the directing screw has, as you have seen, its own thickness, and the little wheels and little axles have their own weight; moreover, the teeth of the little wheels grip the grooved little axles very tightly, leaving no superfluous gap, and bite into one another. It follows that the directing screw, together with this director, cannot advance quite as easily as it does without the director; yet in any instruments whatever it is so ready and free that it can be moved and directed back and forth even by the very slight impulse of a tap of two fingers, so that it can be a burden to no one.

[Margin: And the directors of the other instruments readily obey every direction.]

At No. 6 of the picture T* above, I have chosen to set before the student of mechanics once more that little machine for directing the ruler of my azimuthal quadrant, and indeed somewhat more accurately and distinctly still than it was possible to do at the time in Fig. I. For in my opinion it deserves to have its construction shown more fully, especially since I have also added to that little instrument a director of the subdivisions, by attaching a small index wheel to its endless screw, so that it can not only direct the ruler but at the same time indicate and distinguish the finer divisions, namely of the minutes and seconds, far more accurately than on the limb of the quadrant itself.

[Margin: The director of our azimuthal quadrant.]

But how it is constructed by itself, without the small index wheel — namely from a certain larger intermediate little wheel p and two attached grooved little

axles o and n, which are to be directed by the endless screw h, and from other parts — this is not the place to repeat at length, since in Chap. IX, p. 170, it has already been fully

[Margin: The construction of this little machine.]

shown; I refer you there. In that place not only is the whole construction clearly described, but its use is also amply set out. Indeed, everything will become clearer still if you compare that description with this drawing at No. 6 of the figure T* above (since this director is marked with the same letters).

[Margin: A far easier route has been taken.]

It therefore seems that nothing at all remains but for me to add how the divisions are shown by means of the directing screw, and how the small index wheel z is fixed to that screw. The fabric of this director, moreover, was far easier to construct than that of all the others, since it needs no crown wheel m and no grooved little axle n, by whose help the pointers had to be made quicker and faster. For this director by itself already has almost too great a speed, on account of that endless screw h: the screw turns roughly twelve times, gripping only a single tooth of the intermediate little wheel p, before the windlasses m and l turn once, and consequently the principal, longer pointer of the small wheel also becomes twelve times faster than the motion of the windlasses. It was therefore open to me to attach the small index wheel directly to the nose of the screw h and, together with it, both tongues (fitting a little axle s at the same place); so that we had nothing further to add but the two little wheels — namely the index wheel t and, as you see, the one beneath it, u — each likewise furnished with 60 teeth. In this way the pointers are also carried with the same motion and the same speed as the earlier ones.

[Margin: By means of the endless screw the pointer becomes very fast.]

The size of the small wheel z in this director can also be taken at will, space permitting; and hence, with the very rapid motion of the screw added to it, the small gaps between the divisions are indeed wonderfully widened on the small wheel of this director. What motion the tongues show with respect to the quadrant and its degrees has been established by rather strict examination and frequent investigation: namely, that 22 revolutions of the faster pointer complete one whole degree on the small wheel. Hence 1650 hundredth parts make 45′, 1100 make 30′, and 550 hundredth parts make 15′; likewise 36⅔ hundredth parts represent a single

[Margin: The ratio of the pointer to the intervals of the degrees of the azimuthal quadrant.]

[Margin: How many parts a single minute amounts to on the small wheel.]

minute, while one hundredth part is 1″ 38‴. From these figures I likewise constructed tables, but I considered it superfluous to set them down here, since they are of use to no one but myself, for our azimuthal quadrant.

Finally, before we pass on to other matters, I think it worthwhile to add a few further points about that longer screw armed with two revolving little balls, which has already been described fully enough in Chap. X, p. 215, and

also neatly drawn in the figure S above. This screw, namely, can conveniently serve not only the sextant, as on p. 227 and p. 248, and also the revolving horizontal quadrant, as we showed fully enough on p. 215, and no less the azimuthal quadrant, as we touched on briefly in Chap. IX, p. 162; it can also, at the same stroke, detect and separate the azimuths on azimuthal quadrants far more finely and distinctly, in larger subdivisions, than is otherwise possible on the azimuthal arc itself — that is, by attaching a director built by the device disclosed above. So I have amply established that this screw can be used for quite different tasks, to the very great benefit of astronomy; and it therefore certainly deserves that we draw it neatly once more, together with its attached director of the divisions, in the preceding figure T*, at No. 7.

[Margin: That longer screw, furnished with little balls, is very well suited to various tasks.]

[Margin: At the same time also for determining the azimuths themselves accurately in the finest small parts.]

There is no call to pour out more words on the construction itself, since we have already discharged our task fully in that matter in many places — except that I would remind you once more that the rear plate, armed with a little ball, has three little pipes, or dovetails, namely b, i and h, fixed to the handle a, as can be seen at No. 7 of the said figure T*: b belongs to the revolving horizontal quadrant, i to the sextant, and h to our azimuthal quadrant. The screw, it is true, needs only to govern the horizontal quadrant and the sextant (although, if we wished and it were necessary, it could also show the subdivisions there in a particular way), and so there it can be used bare, without the small index wheel. But with this aid you can direct the azimuthal quadrant not only as accurately and as gently as possible

[Margin: We have already discussed its construction in its proper place.]

[Margin: The said screw only governs the horizontal quadrant and the sextant; but on the azimuthal quadrant it also shows the subdivisions at the same time.]

along the azimuth, but equally discern the azimuth itself in its very minutes and seconds, and indeed divided into their small parts, without regard to the azimuthal arc.

[Margin: How this was achieved.]

For that purpose, therefore, I added a special lever to the end of the said screw, extended the screw a little further, as you see at No. 7, and at the same time fixed to it the whole little directing machine with its little wheels, little axles and pointers, so that the subdivisions might in this way be recognised on its small index wheel with equal ease and clarity — so that they would be distinguished not only for the azimuth itself on its azimuthal circle in the usual way, but also, still more clearly and correctly, from our small index wheel, by the method already often mentioned. This proves most especially convenient for azimuthal quadrants, and for the observations themselves.

[Margin: An outstanding aid for azimuthal quadrants.]

For although those quadrants are 5 or 6 feet in radius, they mostly have far smaller azimuthal circles, just like our quadrant described above in Chap. IX, so that beyond whole minutes you can scarcely make out the subdivisions into portions of seconds, however lynx-eyed you may be. But by means of the director fixed to this longer armed screw we can make good that defect fully and amply, since from the small index wheel we can distinguish even the seconds themselves — not to mention, if you wish, thirds and fourths — most precisely, and indeed with a light touch.

[Margin: The director for separating azimuths is not built so easily.]

This director, believe me, was far harder to build than all those above, and so it also exercised my ingenuity much more before I had brought everything properly to completion. For on all the other directors it was possible, with less trouble, to fix the small index wheel straight onto the little pipe *k* by means of a combining plate; but on this longer screw, armed with little balls, that could in no way be done in this manner.

[Margin: Difficulties that confronted the making of this director.]

For the said screw serves not one single instrument but very different ones — now the revolving horizontal quadrant, now the sextant, now again the azimuthal quadrant — and so it necessarily required two revolving little balls, so that to every direction and inclination, as we indicated in its proper place, without any resistance it would obey most readily. Besides this, in this director it was necessary to set the small index wheel well away from the little pipe *k* and from the plate *g*, that is, from the revolving ball, so that the said wheel could move together with the balls and tilt in any direction. I therefore fixed a slenderer steel lever *l* to the nose of the directing screw, and fitted the small index wheel to its end.

[Margin: In this director the small index wheel must be able to revolve.]

But even this was not yet enough for the work, since in this arrangement, when the directing screw was turned, not only the pointers but the whole small wheel would turn at the same time, so that nothing certain could ever be determined from the turning of the pointers. For that reason it was absolutely necessary for me first to work out how to clamp the small wheel beforehand to the little pipe *k*, whatever the direction and inclination of the balls, before the pointers on the small wheel were set to the starting mark; otherwise, believe me, every effort would have been entirely in vain.

[Margin: By what aids the small index wheel was made movable.]

I therefore took an altogether different route, namely attaching two separate arcs to the little pipe *k*, so that the small index wheel could readily yield to and accommodate itself to every direction of the balls and the screw, and also be brought fully to rest by the observer in any position and made fast with respect to the little pipe *k*; and so that the pointers could be set properly, so as to be ready at any moment to separate the divisions. First, then, we fixed a segment of a circle *m m* (which I choose to call the declining arc [arcus declinans]), made of steel, to the little pipe *k* with little clamping screws. The size of this

arc, however, could not be made at will; its extent depends on the centre of the revolving ball *g*, or on the point of the screw where that slenderer lever *l* is attached. That is, I described this arc from that point, namely the centre of the ball *g*, as the centre of the circle, and so obtained its true size and curvature, suited to this purpose.

[Margin: Of what section each arc carrying the small wheel consists.]

Second, onto this segment of a circle, or arc *m*, I put a dovetail that moves very freely from one end of the arc to the other, so that it could be attached to the arc at any place you like by its two little clamping screws. Third, a further arc *n* (which we call the inclining arc [arcus inclinans]) to the said dovetail I fixed. This arc is described not from a circle but from a conic section: that is, by marking any points you like on that arc at the dovetail *f* as you draw the arc through this dovetail from one end to the other. Not everyone, I think, will grasp this at once; but this time, to save time, we were not permitted to reveal the matter more clearly. It is therefore up to you to weigh the matter all the more deeply.

[Margin: The small wheel, yielding to the motion of the balls, is readily directed.]

Further, I passed this arc *n n*, on that other arc *m m*, which is itself movable, through a special dovetail *f* fixed to the small wheel, so that the small index wheel could likewise be moved this way and that along this arc *n*, just as arc *n* moves on arc *m*, as the directing screw, armed with its little balls, and its inclination might require. In this way the small index wheel is now able to take up any directions and inclinations whatever, so that the said small wheel need not always stand in a position parallel to the little pipe *k* and always keep the same position; instead anyone can at any time easily direct the small wheel in any way. For since the dovetail of the inclining arc *n* moves on the declining arc *m*, and this arc in turn likewise in the dovetail *f* of the small wheel, the small wheel itself certainly obeys every direction very lightly, and can also be clamped at any place by means of the little clamping screws, as is clear from figure 7 of the figure T* above.

[Margin: How the device of the little wheels was devised.]

As for the device of the little wheels of this director, it is constructed in an entirely different way from the preceding ones. For in this director the directing screw runs straight toward the centre of the small wheel, and not, as in the other directors of the quadrants, sextants and octants, along a course parallel to the disc of the small wheel. Hence I could fit neither any crown wheel nor the pointers of the small wheel directly to the nose of the directing screw, as we managed in the director at No. 6; instead it was first necessary to build a special lever, or windlass, to be moved and directed by the directing screw.

[Margin: It requires more little axles and sockets.]

For this purpose, far more little axles and sockets [cheloniae] now to the director, before I got so far that the faster pointer went three times round its circle relative to the directing screw, I was compelled to apply.

[Margin: The whole construction and proportion of this device.]

You can indeed see this structure from the back side of the small wheel itself, namely how all these parts are arranged and fitted out; but because of the multitude of parts and the lack of space, I was not able to reveal the whole business so fully and distinctly. For that reason, for the benefit of those who cultivate astronomy, I have gladly chosen to set the whole matter somewhat more clearly before the eyes at Nos. 8 and 9.

Now the true construction is this. This director does indeed have two similar little wheels, namely a little index wheel *p* and another, subsidiary one *q*, and also a little axle made with 6 notches. But it differs in this: the little index wheel *p* has its own socket *t*, just as the subsidiary little wheel *q* has the socket *r*. Then, on the plate *t* another socket *u* is set in turn, so that the nose of the lever of the directing screw, to which the toothed little wheel *o* with 18 teeth is fitted, might be allowed to move in that socket *u*, and at the same time be clamped by a nut from the inner side of the said socket *u*. Further, the said toothed little wheel *o* moves the little axle *x*, likewise made with 6 grooves and fitted to a shorter windlass, at whose other end a somewhat larger little axle of 12 notches is fixed; and these two little axles *x* and *z* are carried in a separate socket *s*, that is, off the centre of the small wheel. But so that this same motion of the little axles might be carried to the centre of the small index wheel, I applied yet another little axle *y*, made with the same number of grooves, namely 12, to direct the faster pointer. And since the main toothed little wheel *o* has 18 teeth and the little axle *x* only 6 grooves, and since the little axle *x* also governs the remaining little axles, namely *z* and *y*, it necessarily follows that the faster pointer also goes three times round its circle before the directing screw turns round once.

[Margin: On the small wheel likewise the faster pointer flies three times round its circle relative to the directing screw.]

But how the other, slower pointer and the remaining parts are fitted out and governed is abundantly clear to everyone from the sufficiently full description above, to which I refer the reader.

[Margin: Unless they are exquisitely fitted together]

You therefore have the whole structure of this director; but I would have you note that it is altogether necessary that, neatly, skilfully and

[Margin: [?] all of them, you are measuring sand [?].]

as carefully as possible, everything be worked out: namely, that all the little wheels and little axles be made without any superfluous little gap, so that the teeth do not nod or wobble in the slightest in any groove whatever, but bite into one another and move along tightly and closely on every side, yet very smoothly and lightly, without any resistance — exactly like this director of ours, which has been made so elaborately that it obeys every direction at a nod, so that nothing can be found wanting in it.

[Margin: The small wheel of this director has similar tongues and divisions.]

For the rest, the small index wheel likewise has three tongues, as the preceding directors do, and is also divided in a similar way, namely into hundredth parts. But it rests on quite different tables when this director is to be used with our azimuthal quadrant, described in Chap. IX, for dividing off the azimuths; these tables likewise show distinctly not only the individual minutes but also the seconds. Moreover, the diameter of this small wheel equals the size of the one otherwise made for the octant, so that the divisions would be clearer in this way.

[Margin: How great the motion of the tongues is relative to the degrees on the azimuth circle, and how many parts make up a whole degree.]

After due examination I found the measure of the motion of this director to be as follows: 24 revolutions of the faster tongue, or 2400 hundredth parts, make up a whole degree, and so 1800 make 45′, 1200 make 30′, and 600 hundredth parts make 15′. Hence it follows that 40 hundredth parts give a single minute, so that the individual seconds are obtained distinctly and very well. It is on this basis, then, that our tables for distinguishing the azimuths on that azimuthal quadrant of ours rest. I have not, however, added the tables themselves here, since they cannot be applied to any instrument whatever except this quadrant of ours.

[Margin: The use of this director, and how it is to be applied to the azimuthal quadrant.]

The use of this director, moreover, is as follows. First fasten the little pipe *k* to the lower leg that lies on the azimuth circle, namely at the headed pin that clamps the ruler, between the centre of the quadrant and the azimuth circle, as we have already pointed out in its place. Then likewise clamp the other little pipe *h* firmly to the azimuthal rim by means of the little clamping screws. When this is done, the small wheel is directed according to the inclination of the little balls, and finally the pointers are set in their proper place, and then everything is ready for making observations, so that you can ascertain the azimuths excellently, not only from the rim of the azimuth circle itself, in the minutes themselves and their quarter parts, but also from this director in the individual seconds themselves. But — to impress it on you again and again — if you are anxious to carry out each operation as you would wish and with the greatest ease, the whole structure must be made exactly true.

[Margin: This screw, fitted with little balls, can serve various instruments.]

Finally, how this longer screw, armed with those two rolling little balls, together with its directors of the divisions, can likewise be fitted aptly to vertical quadrants, sextants and other instruments, I have already said abundantly enough in various places. I therefore do not wish to be more prolix here, since I have already dwelt on this matter longer than was due, and longer even than I had hoped.

[Margin: Experience will teach how wonderful the use of these directors of ours is.]

I would only like to add this by way of a supplement: any searcher of the stars will find out amply, by actual experience, how useful and how supremely necessary these directing screws of ours, with the small wheels attached to them, are for undertaking the more exalted celestial observations, and that without them no one could ever reach such precision in this business of observation, however lynx-eyed he may be and whatever effort he applies.

[Margin: How, thanks to these directors, the altitude or distance is always known, even in the very darkest night.]

Besides this — which should be noted — any observer, even a less skilled one, provided he knows how to direct this director and in which degree, or at which place on the rim, the ruler stands, has it in his power even in the dark, on the darkest night, with every candle removed, to recognise and ascertain close to the truth how great the observed altitude is, together with the azimuth and the distance; that is, of how many degrees and minutes, down to 15 seconds, the observations consist. And this indeed on the basis that each instrument has its own director, equipped with special little tables; from these we know for certain how many hundredth parts make up a single minute. For example, on our larger brass sextant 102 hundredth parts — that is, almost one entire revolution of the faster pointer — measure out a whole minute; therefore a half-revolution shows 30″, and a quarter of it 15″. Next, if at the beginning of the observa- tion you have set the ruler at 40′ 15″, then, as you turn the directing screw to the left or to the right, keep a finger on the faster pointer, which has been set at the beginning of the numbers, and watch toward which side the said pointer moves, and how far. If it makes one whole revolution in the order of the signs [in consequentia], that is a sure sign that the ruler has been advanced by exactly one whole minute and that the angle has become larger; if it has completed two, three or four revolutions, the angle has become larger by just as many minutes. Conversely, if the pointer has moved the opposite way, that is, toward the preceding signs [in antecedentia], the observation is smaller by as many minutes as the pointer has made revolutions. But if the pointer has advanced only half of its circle, you have no more than 30″ to add or subtract, and if it has covered only a quarter, only 15″.

[Margin: On our larger sextant one whole revolution of the faster pointer shows almost a whole minute.]

From this you understand clearly enough that no one is so dull that, even while he is in the dark, he would not at once detect in this way — by touch, that is — whether the pointer is moving to the left or to the right, and whether it completes a whole revolution, a half, or only a quarter of one. So it is entirely certain that, if you use this director, you can always, if you wish, state each observation in advance, before you bring a candle near. Many a person to whom this secret had not yet become known (although to one who knows it, it is indeed the simplest thing) would surely be astonished at this; and yet, as I said just now, hardly anything could be plainer and lighter, or at the same time easier to do. But let this suffice on these matters too, for we have lingered

too long over our little inventions. Let us move on to other things which, in my judgement at least, will contribute something no less to the business of observation.

[Margin: To judge observations on the darkest night, with the candle removed, is with our aid a matter of slight moment.]

CAPUT XVI.

Chapter XVI.

De Inſtrumentis quibusdam, pro inveniendâ Lineâ Meridianâ, & explorandâ Magnetis Declinatione

On certain instruments for finding the meridian line and for investigating the declination of the magnet

In the preceding picture R, several instruments — small indeed, and of lighter construction, yet of excellent use in astronomical matters — I wished to sketch at the same time. Above all, they serve to determine the meridian line with the greatest exactness. Unless you know this line well, you can neither set up an azimuthal quadrant correctly, nor determine the azimuths themselves, together with the meridian altitudes and the declinations, except with great labour and loss of time — much less use horizontal sundials conveniently. And yet we can by no means do without these sundials for observations, if the other clocks [Automata], whether those governed by a balance [irrequieto] or those governed by a pendulum, are to be corrected and reset accurately to the motion of the Sun.

[Margin: It matters very greatly to know the meridian line correctly.]

As for investigating the meridian line, not a few most learned men — such as Petrus Nonius [Pedro Nunes], Father Clavius [Christoph Clavius] and Athanasius Kircher, to say nothing of others — have, I think, already treated it abundantly, and I do not wish to repeat their methods here or pass judgement on them. Nevertheless, since the occasion offers, let us also show here several different methods of our own, which in actual practice we have found far more suitable and more certain than the one Clavius describes in his Commentary on the *Sphere* of Johannes de Sacrobusco [Johannes de Sacrobosco], p. 165. In that method, first, quite different circles are drawn from one and the same centre; then the meridian line itself is found from the shadow of a style erected perpendicularly at that same centre, observed repeatedly both before and after noon — that is, if the points on any one circle are duly bisected and a line is drawn through that point and the centre. Likewise Kircher, in Book III of the *Ars magna lucis et umbrae* [*The Great Art of Light and Shadow*], p. 260, proposes still other, different methods following Grünberger [Christoph Grienberger]; but for this once, to save time, I leave them all at their own value.

[Margin: Very many have written on finding the meridian line.]

We, however, have so far used the following aids for marking out the meridian line whenever we did not choose to find it by means of the large azimuthal quadrants. All of them rest on the same foundation, namely very many circles drawn from one centre, though far larger ones; but we do not rely on any erected style, as people were formerly accustomed to do. For to erect such a style exactly true to the square is a very uncertain business, since by this

[Margin: The way in which the author has usually described the meridian line.]

older method, of course — that of Clavius, namely, and of others — we can conveniently use only a shorter style, if the tip of the shadow is to be determined distinctly enough; but the shorter the style is, the more uncertain the result becomes. For this reason, in place of that style we use a quite different remedy, which is certainly more effective than a style of about two feet. Moreover, attention must be paid not to the shadow, which always fades away at its edges, but to the vivid light of the Sun itself; and this can be done in three ways.

[Margin: The first way of finding the meridian line.]

First, to a four-sided, squared piece of wood, 6, 7 or 8 in length but one digit in width (as you see at No. 17 in the preceding figure R), a small plate with two or three very tiny holes is fixed exactly at its middle, so that the Sun can cast its rays through these holes onto the circles lying beneath. This square [norma] is erected so that its middle line, drawn down from the upper holes, can stand at the centre of the circles — and indeed to the point where the Sun lights both sides of the square equally at once and casts no shadow at all to one side or the other. When it has been so directed, the Sun's light, passing through any one of the holes, is carefully marked with a needle on the circle it strikes; indeed, one may examine the same thing through the three holes at once, and much more safely. A little later this is repeated at different times, both before and after noon, on various other circles, according to the Sun's different altitude at that time. Then the two points on each circle are bisected; if all these bisections fall on one and the same line, you have determined the matter entirely correctly; if not, the business must be repeated on another day until all the points agree better. But this method is, in my opinion, merely the inferior one of these three.

[Margin: The author's second way of finding the meridian line.]

The second way is more certain and more suitable in that, to a small square much like the former one, another plate with a hole made in it is fixed at the other end, that is, at its base, as can be seen at No. 18. The purpose is that, with a needle passed through this hole, the square may be attached at the centre of the circles, yet in such a way that it can be turned round quite freely. And then, with this small square set out facing the Sun, and directed so that the Sun lights both of its sides with perfect evenness, and so that the thread stretched over the middle of the small square also touches the line beneath exactly with its shadow. The Sun's ray, passing through the very tiny hole, is then marked with the greatest care on the proper circle that it strikes, as above; and this is done fairly

often, with the small square shifted at different times — namely from about nine o'clock until about eleven, while the variation in the Sun's altitude is still evident. For around noon, where the Sun's altitude changes less noticeably, the observations are quite uncertain. Even though this little instrument is so small that it scarcely exceeds 6 in length and one digit in height, it nevertheless equals a gnomon [stylus] of a whole foot at a solar altitude of 60°. The reason is that the hole stands far from the centre; and so, since the hole overhangs the circles, it also shows the Sun's ray much more distinctly. For a gnomon of a whole foot, because its tip, which marks the shadow, is too far removed, will certainly never determine the Sun's altitude so precisely — to say nothing of what happens if the gnomon bends even slightly from a straight line, however little, as can easily happen.

[Margin: The third way, the best of all.]

The third instrument surpasses nearly all the others, provided it is constructed properly and accurately; otherwise it constantly departs from the truth. It rests on almost the same foundation, except that it has the benefit of more aids that show its true direction with respect to the Sun, as well as several holes, which, according to the Sun's altitude and the elevation of the pole, are now raised higher and higher, now lowered for the different seasons of the year. Even so, it is safer to make these observations at the time of the summer solstice, when the Sun's declination varies very little and is clear of refraction. The instrument itself is made of a brass plate 14 or 15 digits long and 1½ digits wide. At one of its two ends, as appears from drawing 19 of the preceding figure R, it is bent at a right angle. Further, to the part of that little machine that is erected at right angles and cut out, another plate — a double one, in fact — is fixed obliquely by a hinge at the elevation of the equator, so that the Sun

[Margin: The construction of the little machine itself.]

may always pass its rays straight through — namely through the very tiny hole of a separate plate, which is inserted into that other, double, bent plate. For this bent part is built so that it can be opened and closed, so that now one plate, now another, each provided with a different hole — now narrower, now wider, now higher, now lower — may be used, as the occasion and the circles drawn require.

At the other end of the instrument a hole is bored, right in the middle, that is, on the middle line, so that the instrument itself can be fixed with a needle on the board at the centre of the circles. The circles beneath, however, must be much larger than with the preceding little machines, since this instrument of ours corresponds, as it were, to a gnomon of about two or three feet. The result is that we can determine the meridian line with it much more accurately than with the smaller ones just described. And so that it may do its job all the better, I set a pinnule with a single slit at right angles at the narrower end, not far from the hole.

[Margin: When the Sun's light is to be marked.]

The purpose is that not only are both sides lit equally by the Sun when it is directed toward the Sun, but at the same time the Sun's light itself can fall onto the line drawn down the middle of the longer plate — a line the Sun reaches fully when the Sun's shadow vanishes completely at the sides. Beyond this, so that we may be still more secure in directing this device, I added, in the manner you see, two very fine silk threads, or horsehairs, so that from their shadows, falling onto the lines beneath them, you may recognise the direction all the more accurately.

[Margin: The instrument must be set up with the greatest exactness.]

For it matters greatly, when you undertake these observations, that this instrument be turned toward the Sun with the utmost care, and that the plane on which it stands, and on which the circles are drawn, be set perfectly level; otherwise you will certainly stray very far from the truth. It is correctly directed, however, when, as we said, the Sun's shadow vanishes from both sides of the instrument, the Sun's light falls through the pinnule onto the diagonal line, and the threads cast their shadow straight onto the lines beneath. And then the Sun's light, falling through the hole onto a certain circle, must be marked with a needle with the greatest care — and indeed as often as you wish, both before and after noon, as we have already indicated above. When everything has been carried out properly in this way, you will have the meridian line determined and drawn as exactly as can ever be done with little machines of this kind.

On this occasion, on which I wanted to show the little machines I have so far been accustomed to use for finding the meridian line — both for sundial instruments and also for discovering the declination of the magnet — I also wanted to indicate at the same time (something I think will please more than one reader) how large the declination of the magnet is here in Danzig at present.

[Margin: The declination of the magnet varies in almost every place.]

For, as is by now known to almost all learned men, the direction of the magnet is constant almost nowhere, apart from a very few places; rather, it varies differently at every place on the whole terrestrial globe. The magnetic needle, whatever magnet it has been strengthened or rubbed with, is deflected from the north, now toward the east in one place, now toward the west in another, so that it very rarely points exactly north. Indeed, even if this does sometimes happen, the direction nevertheless changes a little later, after some years have passed; and so it is almost perpetually in motion — but, as it seems, in an oscillating motion, and one that is for the most part variable. The moderns, who are somewhat more inquisitive than the rest, have already to some extent perceived this in various places, especially in the present century.

[Margin: The declination and variation of the magnet not yet fully uncovered throughout the whole world.]

But since this matter has not yet been fully uncovered everywhere, and since knowing it correctly is of the greatest service to navigation, it would be desirable for energetic investigators of nature to take up this business in every place with a greater effort than hitherto. I do not doubt that in this way, in the

course of time, the matter would be uncovered more clearly: if not the very cause from which this deflection and variation of the magnet arises, then at least its motion and its limits would become better and better known throughout the whole world.

[Margin: The author's observations made on the declination of the magnet.]

And so that investigators of nature may be all the more stirred to do this, I have gladly decided to set down here my own observations in this field too, such as they are, which I have made over almost 30 years, so that posterity may not be unaware of what the variation of the magnetic needle has been here at Danzig too in our age, and how far it now departs from the north toward the west, so that posterity may then the more readily grasp when it will turn its course back again.

[Margin: The author's letter to Oldenburg, Secretary of the Royal Society.]

On this same matter I wrote a letter on 1670 July 5 to London, to the most celebrated Henricus Oldenburgius [Henry Oldenburg], Secretary of our Illustrious Royal Society. Since in it I have already set out each and every point fully enough, I have decided to append that very letter here:

Recently (namely in 1670), on July 22, new style, around the solstice, I again investigated the declination of the magnet, which I had likewise observed here at Danzig with the greatest care in 1642, twenty-eight years before. At that same time the very distinguished Albertus Linnemannus [Albert Linemann], formerly professor of mathematics there, also observed it along with me, but at Königsberg; we both found that the magnetic needle then deflected from the north toward the west by 3° 5′. Now, however, the matter stands very differently: the declination, which I set out to investigate with the greatest diligence, now inclines toward the same quarter by fully 7° 20′, so that in the space of 28 years it has increased by 4° 15′.

[Margin: What the declination of the magnet was at Danzig in 1635.]

In 1635 I found it to be only 2°, and in 1628, if I remember rightly, nearly 1° — to the west, that is.

[Margin: What it was at the beginning of this century.]

Yet the distinguished Petrus Crügerus, formerly my most venerable teacher, used to assert consistently that at the beginning of this century, or at the end of the last, this declination was toward the east, and indeed 8° 30′. Moreover, he always used that declination, toward the east, in drawing sundials, as can be seen clearly from the little work he wrote on sundials.

[Margin: In 1670 it was greatly changed.]

From this it may be gathered that the magnet here at Danzig once declined toward the east by 8° 30′ (though by whom, and in what year, this was observed is not very certain to me), whereas now, in 1670, it runs out toward the west by 7° 20′.

[Margin: How great the variation of the magnet is in each year.]

Further, it is also by no means unclear from our more recent observations that this declination of the magnet here at Danzig, in roughly every seven years

— or, to speak more precisely, in 6 years and 7 months — by a whole degree, and so in one year by 9′ 6″.

[Margin: Observations of the English.]

The observations of the English, made at Limehouse [Lymhouſii] near London — first by the most distinguished Burrusius [William Borough] in 1580, then by the distinguished Gonterus [Edmund Gunter] in 1622, and finally by the distinguished Gillebrandus [Henry Gellibrand] in 1634 — seem to confirm this more than sufficiently. For the first found the declination to be 11° 16′; the second, 5° 56′ 30″; and the third, 4° 3′ 30″ — toward the east, that is. From the first two observations, namely those of 1580 and 1622, the annual motion of progression comes out at 10′ 37″; but from the observations of 1622 and 1634 the same annual motion comes to only 9′ 25″.

[Margin: The motion of the declination seems more or less to be decreasing.]

From this I have an inkling that this annual motion is, as it were, decreasing at this time — especially since it is clear from my own observations, made in 1642 and 1670, that this motion is now only 9′ 6″. For the rest, it is most certain that a variation of the magnet's declination occurs even in one and the same place, so that no one can doubt this matter any longer.

[Margin: More will be uncovered as time goes on.]

But how far this deflection will proceed, and at what place, or at what distance from the true meridian, the limits of the declination lie hidden, the observations of the following years will teach — above all, whether this libration and variation will be the same at every time and in every place, and wholly constant with itself; further, whether it will become retrograde; or whether, and for how long, it will remain stationary. I wish with all my heart that all these things may be properly uncovered in their own time throughout the whole world.

Please communicate to me what you have found so far on this same matter — especially how great the deviation of the magnet is at London at present, and in which direction it inclines.

[Margin: Whether the author has divined nearly correctly, the observations of the English will show.]

For my part, if one may divine from the earlier observations, both yours and ours, I would venture to say that the same declination which in 1634 was 4° 3′ 30″ toward the east is now, this year, toward the west, and indeed by nearly 2°. Whether I divine correctly, however, or how far I stray from the truth, will be shown precisely by your observations, once they are made.

CAPUT XVII.

Chapter XVII.

De Horologiis.

On Clocks

[Margin: Exquisite clocks contribute very greatly to observations.]

It is abundantly and amply known to all who cultivate astronomy that observations of celestial things call for clocks, or automata, that are altogether most exquisite and in every respect most perfect — both for determining eclipses, transits and occultations of the stars most accurately at any time whatever, and also for correctly determining the motion of the planets. For it is not always possible to investigate the times by the altitudes and azimuths of the Sun and the stars, and also by transits through the meridian; nor are instruments at hand at every time with which this can properly be worked out.

[Margin: The ancients laboured in various ways to distinguish days and hours duly.]

For this reason, long ago, the Egyptians, for example, and others laboured very greatly so that they could properly define and distinguish days and hours by some definite method. They first attempted this with hydrologia, or water clocks, about which one may read in Cleomedes, Proclus and other later writers. But by that device they by no means attained equality of all the hours and an exact measure of the times, nor did they precisely follow the course of the heavens, although they spared no labour in making and fitting out those clocks — as Nicol. Cabæus [Niccolò Cabeo], Book II, Question 13, admirably bears us out on this point. Nor do sand-glasses [Clepſydræ], even when they are made up of any sand however fine (as Capella, Rivaltus and others, among others, maintain), measure single minutes and parts of an hour entirely equally — as we could show more fully, without great trouble, were this the place for it.

[Margin: Why sundials do not fully satisfy observations.]

Indeed, even sundials — some of which I own, also divided distinctly into the very minutes — though they are made with every art and the greatest fineness, are nevertheless not immune to inequalities of every kind: because they cannot be distinguished so finely in the minutest particles, just as the Sun's shadow too cannot be marked so accurately; above all because of the solar refraction, which is not always one and the same at every altitude — to say nothing of the rest. For near the horizon, in the lower positions, it runs out to nearly half a degree; in the higher altitudes of the Sun, however, it diminishes gradually, little by little, and at last vanishes altogether. As a result, the shadow itself on sundials [Sciaterica] is sometimes noticeably distorted in various ways, so that these sundials by no means do their duty in minutes, let alone in seconds, as celestial observations do indeed demand. Tycho too agrees with us entirely on this matter, as one may read on p. 148 of Book I of the *Progymnasmata*: "And although (he says) both the Most Illustrious Prince and I laboured very hard at this — to have certain most accurate clocks made that would indicate, by a constant law, not only the hours but also the minutes and seconds — nevertheless, for many reasons, these cannot be so precise, and correspond to the celestial norm at all times with a perpetual and equal course, as is necessary in so subtle a matter."

[Margin: Tycho agrees with the Author.]

The other automata, however — those that in the course of time have been built from toothed little wheels, balances [irrequietis], springs, little chains, fusees [cochleis æquatoreis] or weights, whose construction is as marvellously ingenious and skilful as it is supremely useful and most convenient to the whole world — these, I say, are of various kinds, and from day to day have been made immensely more perfect. Nevertheless they cannot manage to produce an entirely equable motion and keep it up. For now at this hour or that, now at the beginning, now in the middle, now towards the end, they slow their course, or on the contrary hurry it. With the variation of the air, that is, with more intense heat or cold, they are moved now one way, now another: both the wheels running round in their circles and the little axles and the balancing members [libramenta] (about which perhaps more fully later) are driven in different ways, by whatever most excellent craftsman and clockmaker's work and skill those clocks may have been built. So these automata too readily admit some alteration and variation in their motion — as I myself have also abundantly experienced, no less, over very many years in our observations, although I always tried my very hardest to avoid it. For that reason, not only very many clocks — and indeed of different construction and different size, driven both by a weight and by a spring —

[Margin: Nor can automata, of whatever kind they may be, keep a perfectly equable motion at all times.]

[Margin: The Author has likewise experienced this more than enough.]

did I have skilfully made for me, which are still in my possession; but I also applied every effort that anyone ever could — let me not boast — to correct them, restore them and remove all the faults of inequality. Yet we could by no means bring them to the point where they satisfied me in every respect, and at every time and place.

Very many most distinguished men complained long ago about this inequality of clocks, above all Tycho Brahe, as you have already partly gathered and as will become clearer still from the passages about to be cited. For he says on p. 428 of Book II of the *Progymnasmata*: "How prone to error the path has been in this matter (that is, in determining the true time) is well known to those who have made themselves familiar with the making and long use even of those clocks that finely divide the single minutes. For although everything in them is worked with skill to the most exact rule, nevertheless even the mere alteration in the quality of the air can induce an unequal motion and slip in a hidden error. So the single hours do not turn out exactly equal to one another, even if perhaps all 24, completed and taken together, sometimes correspond fairly aptly to the diurnal revolution of the Sun — although even this is very rarely granted, over several consecutive days, so precisely that not one or another minute falls away from the correct restitution." So he says, and rightly. For everything really does turn out for us observers in such a way that it is beyond all dispute that we can by no means rely on these bare toothed clocks — whether they are

driven by the force of a weight or of a spring — in the minutes themselves and in the very smallest parts of minutes.

[Margin: Tycho too complained long ago about this inequality of clocks.]

[Margin: The air contributes most to the inequality of clocks.]

[Margin: Automata do not do their duty in every respect.]

The most noble Tycho, moreover, out of his supreme devotion to astronomy, tried with great effort and sparing no expense to build certain clocks that would measure time entirely equally and also most constantly, by means of quicksilver sublimed three or four times, and also of Saturn[9], well purged of impurities and reduced by calcination to the finest powder. But every attempt was utterly in vain, as he himself freely admits on p. 151 of Book I of the *Progymnasmata*: "But truly (he says), to tell the matter as it is, not only has that crafty Mercury — who eludes astronomers in the heavens just as he eludes chemists on earth — made our efforts vain as well; but

[Margin: Tycho tried in various ways to bring clocks to equality, but in vain.]

also that heavy and otherwise constant Saturn gave up nothing of his sly and secretive ways; and, however laborious he may be, he nevertheless shirked every labour."

Hence it becomes abundantly clear that neither Tycho nor we, his successors, have in any way yet been able to obtain such clocks as would show and keep a perfect equality of time. From the very beginning of my observations, that is, from the year 1630 and 1640, I used the most diverse clocks for celestial work — hanging, standing and portable — and these again of different composition, size and shape, showing not only whole hours but also single minutes and seconds. Indeed, I sometimes used clepsydras [Clepſydras] that indicated single minutes fairly precisely, and I also called the pulse of the veins to my aid. But, to confess the truth, I could never find any clock, by whatever art it might have been made — even if it boasted a double balance [duplici irrequieto] — that avoided all anomalies absolutely.

[Margin: Others have tried the same thing in vain until now.]

[Margin: The Author never found a clock that would shed all inequalities entirely.]

Accordingly, in about the year 1640, I had learned from the *Dialogue on the System of the World* of the most ingenious Galileo Galilei that the vibrations of a pendulum [Perpendiculi], whether large or small, always take place with the same frequency; that the motion of pendulums, the very longest as well as the very shortest, is therefore entirely equal, whether they are moved with the greatest or the least motion; and that intervals of time can thus truly be determined most certainly and most exquisitely. For that reason I also used string pendulums [funependula] in observations more frequently at that time, as can be seen from our observations of eclipses as well as occultations made in

[9]the chemists' name for lead

the years 1640 and 1650. In 1649, in recording a lunar eclipse, I used a pendulum of such a length that 43¼ of its oscillations equalled one whole minute. I sometimes had others too, longer and shorter, some of which completed only a single minute in 60 oscillations, so that a single vibration made one second. These pendulums, moreover, by certain students most diligently, though with great trouble

[Margin: The Author at length used the string pendulum in observations.]

[Margin: By what method, namely.]

and anxious care, both counted and recorded.

At the beginning of every observation, however, and also frequently throughout the time of the observation, I used to observe the altitudes of the Sun and the sundials [Sciaterica] by day, that is, and by night the altitudes of certain stars, so that the oscillations might be bound most correctly to the course of the heavens; and then, once the observations were finished, all the times of the remaining clocks could be corrected most exactly. In this way I drew out the true times far more safely and accurately than from any bare clocks and automata [Automatis] whatever. And so at that time I was brought to the opinion (as indeed the matter wholly is) that this method of determining times is more certain than the others, since pendulums are always carried with the same motion; as indeed I did not hesitate to testify publicly in the Letter to the distinguished Eichstadius published in the year 1649. For I asserted that these oscillations of the pendulum, if rightly applied and managed, carry off the palm from all automata in showing the time.

[Margin: By vibrations times are determined far more accurately.]

To count and record the vibrations of these pendulums continually, with no delay interposed, in all observations and most exquisitely, was, however, a laborious and tiresome business: it meant spending whole days and whole nights on that task, and taking great care that no oscillation at all should be missed at one time or another, and that no error should be committed in writing them down. Therefore, right at the beginning of the year 1650 above all, we were anxious to apply the oscillations to observations without that most troublesome counting — namely, so that they would count themselves precisely and show their number distinctly at any time. This seemed to me at first very difficult, just as the thing might also have seemed to anyone else a matter of much labour and effort: to bring this very thing to effect without any foreknowledge at all. Nevertheless this thing too, by the inspiration of divine grace, at length succeeded happily, in this way: in place of the weight itself I hung from a cord or little chain a certain very small mechanism, which was constructed with special art, namely with little wheels and certain

[Margin: It was a troublesome business to sit by the vibrations and record them.]

[Margin: The Author tried at the outset to avoid the trouble of counting.]

[Margin: By what way he approached it.]

little springs, or little plates that give way and spring back, and a certain little ball that rolls backwards; by means of these, when the pendulum was set in motion, the vibrations were at once made known by the pointer of an outer small wheel fixed to the same mechanism. So there was no longer any need to count the vibrations continuously, since the pendulum of its own accord both counted each of its movements and oscillations and showed them at every moment, just as clocks show hours and minutes by their pointers. This was certainly far easier for observers than reckoning and recording the single vibrations.

Yet even then I did not rest content with these things, but turned over in my mind how I might bring it about that the pendulum already mentioned, which now both counted and showed its oscillations, could be set in motion of its own accord by some power, either external or internal, without any force or movement of hands; for in this way I hoped that this string pendulum [funependulum] could be made much more accurate and perfect. And so that the work might succeed the more readily, as I thought, I used, in place of cords, strings or little chains, a slender steel rod, not very thick, about six feet long, to whose lower end I attached the mechanism already mentioned. The other, upper end of this rod turned on a hinge, so that it could be moved only toward two opposite quarters of the sky. Other pendulums, by contrast, often deviate to the sides and almost never keep always the same course. I intended, by a special contrivance, to bring this pendulum, built from that steel rod and that mechanism, to the point where it could also move itself without any hands, as I was just saying, and keep itself in continuous motion, so that it would show not only the number of oscillations but also the hours, minutes and single seconds.

[Margin: The Author strove to make the string pendulum move itself.]

But when I had already taken this business in hand in the work itself, behold, my craftsman and instrument-maker [Automathurgus], otherwise most skilled in his art, died. And so I was compelled — since some of my larger instruments, such as the quadrant, the sextant and the octant, he had not yet

[Margin: When the Author was in the midst of the work itself, the instrument-maker to whom he had entrusted the matter died.]

entirely finished — to take into my house his companion [Socium], a Swede by nation and a man well versed in clockwork [Rei Automatariæ], so that by his work both the instruments already mentioned and that pendulum might be brought happily to completion. With this Swede, therefore, I took up the pendulum already mentioned again, so that it might at last both move itself and, as we said, show the moments of time most exactly of its own accord. At first, indeed, that clockmaker [Automatarius] could be induced only with great difficulty to undertake the work, being thoroughly convinced that it was scarcely possible to do. Yet when I pressed it seriously and tried it at my own expense, he at last set his hand to the work, and with the happiest success, so that it turned into a clock — yet without a balance [irrequieto], a spring, an equalizing pyramid [pyramide æquatoreâ], or a cord or little chain

wound round it — that is, with the pendulum alone, one weight, and only a few toothed little wheels.

[Margin: At length it was worked out that the string pendulum could count and move itself of its own accord.]

The clockmaker already mentioned, while he lived for some years in my house and in continuous work, at length made two pendulum clocks of this kind; they were built, with a weight attached, the larger with only two notched little wheels, the other with four. The smaller of these I offered most humbly and dutifully to the Most Serene Casimir, King of Poland, who was staying at Danzig [Dantiſci] at that time and was then also honouring my house, when I saw that this little invention pleased His Royal Majesty somewhat. Afterwards I at once had another made of almost the same kind, except that the pendulum was partly altered; and this I still carefully keep by me in memory of that occasion.

[Margin: The first vibration clock, which was made here at Danzig, the Author offered to the King of Poland.]

At almost the same time, while those two clocks with pendulums were in the craftsman's hands and were not yet entirely finished (for the craftsman was only seldom free, from finishing those principal larger astronomical instruments, to complete this work), it happened that the most celebrated and most ingenious Christianus Hugenius, with an equally happy venture, invented similar clocks in the year 1657, and a little later, namely in the year 1658, published that very invention with a drawing, to the very great benefit of the republic of letters; and on this I most heartily congratulate him. For this most excellent invention

[Margin: The most celebrated Hugenius was the first to bring to light the construction of clocks with pendulums.]

provides an outstanding remedy for all the automata made up to now, and removes the greatest part of their inequalities, both those that lay hidden in the balancing members [libramentis] and those in the little axles, the little springs [plumulis] and the little wheels.

Therefore I much prefer these newly invented clocks made with a pendulum [perpendiculo] — whether they are built with a weight or with a spring [elatere] — to all the others, whether those were built with a little chain and a drum [tympano], an equalizing pyramid, yielding little plates [lamellis ceſſilibus], or weights, or even with a double balancing member crossing over itself crosswise; and this regardless of whether they are hanging or standing, or those smaller portable ones, of whatever construction they may be. For all clocks, each and every one, show absolutely no constant and most equable motion in the measurement of times, as we touched on above — although someone who has given very little attention to restoring clocks may perhaps think otherwise: namely, that provided the automata have been most exquisitely made, they can be brought to complete equality. But I must confess that I have not yet been so fortunate — although I possess a great many, and have devoted no little effort to them for very many years — as to obtain even a single clock of this kind

that answered my wish perfectly. It can hardly be said how much time I have truly lost in rectifying those smaller portable automata; but nonetheless all the labour was always in vain, since I could never bring them to such correctness that, from every side or face, however they leaned and rested, this way or that, they would always have kept the same motion of the Sun. If you correct them by those sundials while they hang, they stray again when they rest, by leaning — and indeed in a very different way, according as they stand on this side or on that: now, in this position of the clock, the motion is increased by very many minutes; on the contrary, in some other, transverse position it is slowed, now in one way, now in another. Indeed, even if they hang perpetually from one and the same side, and are at this moment most correct, a little later they nevertheless either accelerate or check their motion, and they give so much trouble to the curious — to the surveyors of the heavens, I say — that to give attention to correction almost continually, to the point of nausea,

[Margin: Pendulum clocks [Horologia vibratoria] are to be preferred to all the others.]

[Margin: The other clocks used up to now can never be brought to complete equality.]

[Margin: This the Author has abundantly experienced through long experience.]

is necessary. What the principal causes of these inequalities are could indeed be investigated and pointed out in a light way; but since that would take too long, and this is also not the place for it, I am forced to pass over them for now.

[Margin: Pendulum clocks, however far more perfect they are than the others, are nevertheless not perfect in every respect.]

But truly, these clocks made with pendulums [pendulis] are vastly more perfect than the others; yet they are not yet entirely and in every respect perfect, nor do they follow the diurnal motion altogether most perfectly, as most celestial observations indeed demand — notwithstanding that someone may perhaps think otherwise on this matter. Although I possess very different clocks of this kind, skilfully worked with great diligence, I have nevertheless found by continuous use up to now that even these pendulums do not yet match the most perfect course of the stars with a most constant progress of time. The pendulums do indeed give out vibrations far more equable than balances [irrequieta] or balancing members, of whatever kind these may be; nonetheless it happens very rarely that, after a span of 24 hours has passed, they coincide most exquisitely with the celestial motion to the very minute, let alone to seconds. For on one day they depart from the true motion in some small parts in one way, on another day in another — now by falling short, now by excess. This, indeed, I ascribe not to the pendulum but to the oil, to heat, to cold and to the air. For according as the air is lighter and thinner, denser and heavier, moister and drier, so assuredly must these clocks too vary in certain very small parts. Indeed, since the air is in almost continual alteration, it assuredly cannot happen otherwise than that these automata too vary, however

little that may be. Hence I can affirm with complete certainty that, although I possess various pendulums of this kind skilfully built, and every single day keep them, as far as possible, wholly in step [integra] with the celestial motion, they have nevertheless never — when I examined the matter on a more exact balance — been able to keep a complete equality through several whole months; rather, now this one has partly quickened its course, now that one has slowed it again. So much so that it is abundantly established for me that observations of the more sublime celestial things, in those more abstruse and subtler matters — however much these clocks,

[Margin: Why the clocks already mentioned cannot shed all anomalies in every respect.]

[Margin: The longitudes of places cannot be investigated altogether most accurately with these pendulums.]

built with a pendulum, are far better than all the others, as I was just saying — cannot be carried out with them so securely as if they could never deviate at all from the right path and from the course of the stars, as some perhaps maintain.

Certainly some things seem to be perfect in theory which afterwards, in practice, turn out far otherwise. Some had the hope that by means of these pendulum clocks the differences of meridians, or the longitudes of places, would at last be exactly discovered; but in my judgement, such as it is, this work — done in that way, at least — will never truly succeed as wished, especially on those very long sea voyages, when we scarcely reach land once within several months. How, I ask, is that oscillation clock [Horologium oscillatorium] to be set at the start, on ships, so accurately to the Sun or to the motion of the heavens? Indeed, granted that this can be done the first time, before you board the ship, yet how are we to restore it, since, as you have learned, it in no way keeps its motion altogether most constant at all times — above all amid so great and so very varied a motion of the ship? By the direction of the magnet this is impossible to do; for we do not yet know the magnetic deviation well enough in every place, much less its annual variation. If you say that this can be done by means of the mariner's compass [pyxidis nauticæ], or some sundial, or even an astrolabe such as sailors generally use, or by the rising and setting of the Sun, you are very far wrong. For those attempts too are so slippery that nothing whatever is to be credited to them in those very minutes and seconds. Those sundials are far too small to be able to show the times at all correctly; and with that latter astrolabe — to say nothing of the other reasons — on account of the uncertain elevation of the pole of the place at that time, which we can in no way obtain so precisely on a ship (since even to determine it exquisitely in a steadier place is truly a matter of skill), we can by no means attain the thing with such subtlety as it indeed requires. If you think that the observations are to be carried out with larger instruments and quadrants, how, I ask, that very thing — on a ship, which is in perpetual motion — to be set out towards the stars,

[Margin: Difficulties on account of which the business of longitude cannot succeed by means of pendulum clocks.]

[Margin: Oscillation clocks cannot be rectified on ships.]

and directed — how will that be possible? Assuredly, however much diligence you apply, you will depart from the truth not only by some minutes but by half a degree, if not a whole one, and you will never extract the true time from calculation, even if you had obtained the altitude itself most exquisitely; for you do not have the elevation of the pole of that place corrected, nor can you investigate it in so small an interval of time. Therefore, since the oscillation clock in fact cannot indicate the times always, altogether most uniformly and most constantly, in the very minutes — not to say the seconds — over very many continuous days, let alone some months; and since it cannot be restored on a ship in any way as exquisitely as this business indeed requires, neither by sundials (which also suffer their own variations on account of the refractions of the Sun and the slippery establishment of the meridian line), nor by the magnetic needle, much less by instruments of whatever size and construction they may be: what, then, is to be promised us from these clocks in obtaining the longitudes of places?

Nevertheless it is beyond doubt, and should certainly be denied by no one, that pendulum clocks [Horologia vibratoria] are more certain and more uniform than all the others that have ever been constructed up to now. Whether more excellent ones will yet be invented in the course of time I would not indeed dare to promise; yet I do not altogether despair. For although the pendulums already mentioned cannot emulate the celestial motion with a perpetual and most constant course, they can nevertheless measure the hours, and consequently even the minutes and seconds themselves, more uniformly. For the other clocks show the times differently now at the beginning, now in the middle of the journey, now towards the end — something that never fails to throw observations into the greatest confusion. Beyond this, the oscillation clocks already mentioned can certainly be restored much more readily, even though they sometimes go astray, than the others, made in the older way. For if you correct a single hour only, you have at one stroke rectified all 24 hours together uniformly — which certainly cannot be done in the others. For the restoration of that oscillation clock, in the pendulum alone

[Margin: The author does not despair that more correct clocks may perhaps yet be found in the course of time.]

[Margin: Pendulums measure the times far more uniformly than the other automata and clocks.]

[Margin: They can also be corrected more quickly.]

and its little weight, as this is either raised or lowered, is all it consists in; but in the others the fault lies hidden — to pass over the remaining parts — now in the spring [elater] and the yielding little plates, now in the teeth of the wheels and the grooved little axles, now in the balancing members or turning parts, now in the equalizing pyramids; and it is not granted to detect it, or to

correct it, so easily. Indeed, even if you do at last notice it after a long time has elapsed, yet more often than not it can scarcely be eliminated, even by the most excellent craftsman of all, so precisely that in the course of time it always constantly keeps its correctness and the same tenor of motion.

[Margin: Why the usual automata cannot be restored so readily.]

I therefore urge all searchers into celestial things who are anxious to draw something solid and accurate from the heavens to credit no clock more than this oscillation clock. And I also prefer this very one to that which has two balances crossing each other crosswise — although we can conveniently use that one too: I possess one of that kind with which I am always very well content, which fulfils its function abundantly, and which also maintains a fairly uniform course.

[Margin: Pendulum clocks are better suited to observations than the others.]

But granted that all clocks somewhat retard or accelerate the times, it matters very little, provided they proceed uniformly. For we rely chiefly on astronomical instruments, and indeed the larger ones; if these have been correctly and accurately constructed and divided in every part, they will certainly never deceive practised observers — that is, in deriving the true time and in rectifying the clocks. Moreover, the clocks are set right with quadrants at the start, and very many altitudes are taken between the observations and also after they have been completed; once the calculation has been made from these, the deviations of any automata whatever immediately become clearly evident afterwards, even if they have departed by as much as half an hour, and they can very well be restored most exquisitely.

[Margin: Observers are little concerned whether they have clocks that keep their whole motion precisely, provided they proceed most uniformly.]

Finally, as regards the automata and clocks that we have procured for carrying out the observations, they have been made, believe me, with the diligence they ought to have, since we never neglect anything — if I may say so without boasting — by which it may be possible to obtain the most accurate of all. We have ten principal ones among them: some not very large, yet showing the minutes, and indeed even single seconds, like the other, larger ones. Of the larger ones, one has a double balancing member intersecting itself crosswise, as I was just saying; the rest are made either with a pendulum and a weight, or with a spring and an equalizing pyramid. Nevertheless, however exactly they may have been made, and however exquisite a measurement of time they may show, so far as that can be done, I never put my faith in them alone in the more sublime observations. Rather, so that any error they might perhaps commit can be detected at once, I compare them, as we have said, with the altitudes and the motions of the stars, and then examine them most rigidly against that standard; and so I always proceed safely. As for the other clocks, although I have a large apparatus of them of different kinds — namely those smaller sundials: solar, lunar, polar, horizontal, declining and vertical ones, and ones composed from the declinations and altitudes of the Sun, both hanging

ones and ones lying on the horizon — and very varied armillae, I by no means use them for observations. For I do not hold them in such esteem that they could serve serious matters; but for recreation, when we have no need of time so accurate in the very minutes and seconds, we can amuse ourselves with them as with toy treasures. And let this likewise suffice concerning those clocks and automata which, above others, best suit our astronomical observations and have been in use with us up to now.

[Margin: The author likewise possesses some automata which [?] deserve some place even among the more excellent ones.]

[Margin: The author does not trust any clocks entirely.]

CAPUT XVIII.

Chapter XVIII.

De Peculiari Machinulâ Helioſcopicâ, pro Eclipſibus, Maculiſq; Solaribus exquiſitè determinandis.

On a special little helioscopic machine for determining solar eclipses and spots exquisitely

Thanks to that helioscopic machine, long ago discovered by us and also described fairly fully on page 98 of the *Selenography*, the spots and eclipses of the Sun, much

[Margin: Solar eclipses and spots far more accurately than formerly] more precisely than hitherto, can be observed and drawn — as experience itself has taught, so everyone, I think, will readily grant.

[Margin (continued): … are now observed with the helioscopic machine.]

Since, however, the whole apparatus of that helioscopic machine — namely the ball turning or revolving in the small window, with the bench, the board [tabella], and everything belonging to them — is set out clearly enough in that same place, I do not wish to say more about these things here, but refer the reader there. Nevertheless, since the machine just mentioned, drawn in our *Selenography*, is as it were the foundation for sketching this recent one, I think it worthwhile at least to set a picture of it here. In this way not only will the matter itself be much easier for me to describe, but everything about this recent machine will also be far easier for you to understand.

[Margin: The apparatus of this little machine has already been partly disclosed in the *Selenography*.]

So you have that earlier helioscopic machine, kind reader, accurately drawn in the accompanying picture. I do not doubt that the devotees of the stars will understand everything without great trouble — namely, in what manner the spots and eclipses of the Sun ought to be observed; and if anything should perhaps be less clear, it will be easy to learn it from the Prolegomena of our *Selenography*. Indeed, this drawing already shows abundantly very many parts that would otherwise have to be described, and that we still use even now.

Among the rest, the same turning ball is still in use with me; so is the bench, which has two uprights set up perpendicularly and spirally grooved, with their two nuts [pericochleae], by means of which that plank on which the board is laid can be raised and lowered for any altitude of the Sun. Likewise the telescope, set in a channel and fitted at right angles to the board by means of a four-sided bar, so that the Sun may fall straight onto the board — by direct rays, that is — and paint its disc on the paper. So up to now I have not yet made this method of observing more correct, except in one single part: namely as regards the board *h*, on which the Sun's disc is received and to which the paper bearing the circle or disc *ſ vv u z* is attached.

[Margin: How the author formerly built the machine just mentioned.]

[Margin: The author's method of observing is still almost the same, except that he has furnished the board with a special device for adjusting it.]

This machine, I say, is assuredly the means, as we have found by trial, for capturing the spots and eclipses of the Sun

[Margin: What drawback the earlier machine suffered from.]

and determining them — the most longed-for means — except that the Sun, on account of its very swift motion, above all the daily one, never stands still on the board, or rather in the little circle, for even a moment of time. Because of that motion it not only continually rises or sinks but is also carried from west towards east (to speak in the Peripatetic manner), and is in perpetual motion. So if anything accurate is to be caught, you are absolutely obliged to keep the board in continual movement and to direct the turning ball now this way, now that, raising or lowering it more and more. In this work, unless you have someone very practised as a helper and a pair of hands, you are truly measuring the sand — above all if you alone must both keep moving the machine without pause and at the same time mark down the phenomena.

Seeing this drawback clearly, therefore, I strove, particularly in the year 1661 at the solar eclipse, in the presence of the excellent Bullialdus, then a most eagerly awaited guest, to find a way of removing those difficulties entirely and fittingly, and of bringing the matter to the point where the Sun could stand as if motionless on the board placed before it and in the little circle drawn on it — or, what comes to the same thing, how the Sun might be held continually motionless in the little circle, so that the spots and the phases of eclipses could be marked down most exquisitely, without any wavering. At that time the most distinguished Bullialdus urged me not a little to carry out this plan, so that I might complete it as quickly as possible for the good of all observers. To someone, indeed — however well versed otherwise in mathematical matters — it seemed not only a thing of great difficulty but almost impossible to bring conveniently into practice itself. To me, however, the thing did not seem so absurd. For I was not unaware that, just as it was already in my power to hold the Sun firmly in the pinnules of the quadrants so that it never left the little circle, I too, aided by divine help, would without any doubt achieve this

successfully — as indeed the business turned out, according to our wish, shortly afterwards.

[Margin: The author entirely removed the trouble of the earlier way of observing.]

[Margin: To keep the Sun continually motionless in the little observing circle is a thing of some moment.]

The whole device, however, lies hidden in nothing but that board fixed to the turning ball or to the telescope. For the earlier board of that little helioscopic machine described in the *Selenography*,

[Margin: The whole secret lies in the observing board.]

Diagram. Engraved plate, numbered "fig V." (no artist's or engraver's signature is engraved), showing the earlier helioscopic machine set up in a darkened, beamed room. At upper left a ball is mounted in a round port in the window shutter, with a telescope running from it; a long bar runs from the telescope down across the room to a board standing on a plank. On the board is a circle with four letters round it, a vertical diameter drawn through it and a small dark spot inside near its upper right; a plumb line with a small bob hangs in front of the board, left of the circle. The plank rides on two tall threaded uprights fixed in a bench at right, beside an open window. A quadrant and, to its right, a narrower sector hang on the back wall [?], each with a plumb line, and between them a cross-staff (a plain staff hung from a ring, with one crossbar on a sliding sleeve); a long toothed rack hangs from the sector's arc, slanting down toward the board; a table with a small dial stands at left. On the floor lie the parts of the apparatus taken apart: the ball, a ring with lenses, a threaded tube with two clamps, a second telescope and a toothed bar; a pair of compasses stands open on the bench, with a rod lying across it.

- f (upper left, on the shutter above the mounted ball)
- f (upper left, at the bracket below the ball)
- a (on the mounted ball in the window)
- b (on the telescope next to the ball)
- c (on the telescope, nearer the eyepiece)
- s (top of the circle on the board)
- z (left of the circle)
- w (right of the circle)
- u (foot of the circle)
- n (at the left threaded upright, above the plank)
- n (at the right threaded upright, on the plank)
- y (at the foot of the left threaded upright, on the bench)
- m (on the bench, below y)
- m (on the bench, further down)
- x (at the foot of the right threaded upright, on the bench)
- i (on the toothed bar on the floor)
- a (on the dismounted ball on the floor)

- k (twice, at the right and lower left of the ring on the floor); a letter at the upper left of the ring, k, l or i [?]
- d (on the lens at the top of the ring)
- d (on the disc at the foot of the ring)
- h or b [?] (twice, on the threaded tube on the floor)
- r (twice, under the two clamps of the tube)
- c (on the telescope lying on the floor)
- [?] (on the long bar, mid-length)
- [?] (small mark at the left threaded upright, below n)
- [?] (small mark at the lower right corner of the board)
- [?] (small letters on the rim of the mounted ring round the ball)

Blank page (verso of the plate fig V; the plate shows through in reverse).

Diagram. Engraved plate, captioned "Fig. W.", signed at lower left "[?]ec[?] del." and at lower right "J. Saal ſculps." It shows the helioscopic machine in use in a room. At upper left a telescope projects from a ball set into the wall; it is held by two bracket arms fixed to a long bar that runs down at a slant towards the right, where its lower end rests in a stand at the foot of a board. A threaded upright rises from a wooden bench to carry the bar. The Sun's rays are drawn as dotted lines running from the telescope's eyepiece to the board. A man standing at left traces on the board with a pen; a second man, standing on a step-stool at right, holds the board and leans on a long rod. On the floor in the foreground lie dismounted parts: at left, boards and a semicircular plate with screws and fittings; in the centre, a round plate with a toothed wheel and two screws; at right, a large ring or short tube and a square framed plate with a round opening and loose screws.

- c (upper left, on the first bracket arm holding the telescope)
- c (on the second bracket arm)
- [?] (on the long inclined bar, below the brackets; z, ξ, ζ, c, e or f)
- [?] (lower on the same bar; z, ε or e)
- a (at the lower end of the bar, by the board's stand)
- n (in the middle of the board)
- [?] (small letters at the head of the board beside the plumb line)
- d (at the foot of the board)
- o (on the long rod at right)
- b, b, k, c, e, k, g, g, f, f, g, a, a (on the parts lying on the floor at left)
- f, e, f, c, c, i, m, c, f, e (on the parts lying on the floor in the centre; a small mark stands beside m)

Blank page (verso of the plate Fig. W; the plate shows through in reverse).

resting only on the bench, can always be moved along the same longitude of the Sun, unless you raise or lower the plank sitting on the nuts [pericochleae] by means of them. But to do this while at the same time moving the board so quickly that you keep up with the Sun's motion entirely is scarcely ever possible.

But this newly invented board, which I now use, is guided to follow the Sun's motion in every respect and with the greatest exactness by the control of two very small screws, even though the bench is kept always at the same height and in the same position. As a result the Sun appears to stay perpetually within the little circle and not to depart from it by even a point.

This circular board *g* is made up of various parts. As far as possible, we shall describe them one by one for the sake of better understanding. Those that cannot be described so clearly will become plain from the accompanying drawing of the individual parts, outlined distinctly enough; or, if you prefer, you will easily grasp them by your own ingenuity and by setting your hand to the work.

[Margin: The structure of the more recent helioscopic machine.]

First, it was absolutely necessary that the board *g*, to which the paper with its observing circle must be fixed, should be moved back and forth as gently and at the same time as swiftly as possible to follow the Sun's azimuthal motion — that is, with a straight-line motion. Second, it was also no less supremely necessary that the same board, together with its little circle drawn on it, could at the same time be turned about with a circular motion — round in a circle, that is — equally readily and very swiftly. To accomplish this properly, two special wooden small wheels [orbiculi] of different size are required, in my judgement, so that the larger *g* is joined to the smaller *c* by means of the little axle *m* — if, that is, this double motion, rectilinear and circular, is to be obtained together and at once.

[Margin: Various motions are required in this machine.]

So I took two very light little boards of lime wood, glued together at right angles, about 16 inches long, as you see at *a*. To the upper part of the upright little board a plate is fastened by certain other, smaller screws, a longer endless screw *b* being fitted to it, which passes through two clasps. Next, through the smaller small wheel *c* I passed a little iron column *m*, fitting to it, on the back of the small wheel *c*, a little axle *i*, which is grooved. In this way I firmly fastened this little column *m* — passed crosswise, together with the whole small wheel *c*, through the hole *k* of the upright little board *a* — at the back of that little board with a nut. With these parts thus joined to one another, when the endless screw [cochlea perennis] *b* is turned (since its teeth bite into the grooves of the little axle *i* in continuous motion), it is absolutely necessary that this whole smaller small wheel *c* turns round in a circle, following the turning and rotation of the endless screw, pressed this way or that.

Next, on the front side of the smaller small wheel *c*, I fixed a special little instrument *d*, entirely similar to the one which I had formerly applied (Chapter V, p. 115) to the horizontal quadrant — or rather to its column, to which that quadrant was then fixed — so that it could be directed and adjusted to balance, that is, to the level. But since this has been described amply in that place, I do not wish to dwell on it any longer; for the rest, it consists of one single screw *e*, which moves a sturdier middle part back and forth. To this middle part *d*, to

which the screw *e* already mentioned is attached, two props *ff*, bent at a right angle, are soldered, for the purpose that the larger circular board *g* can be set on these two props *ff* and firmly fixed with tiny screws.

And then, with those two small wheels *c* and *g* combined, anyone will be free to move the larger disc back and forth in a straight motion at will by turning the screw *e*; and by guiding the other endless screw *b*, to carry both small wheels, *c* as well as *g*, round in a circle together — and that so gently and readily that scarcely anything could ever be more refined or swifter.

This, then, is the whole structure of this recent helioscopic machine. Guided by it, you will be free to follow and accompany the whole motion of the Sun most exactly, in longitude as well as in altitude, with almost no trouble. In this way the Sun is forced, as I said above, to stay entirely motionless in the observing circle and not to depart from it even by a nail's breadth, as will shortly be shown more fully.

[Margin: To hold the Sun motionless in the observing circle by means of two screws.]

It is necessary, however, that you fit this whole little machine to a staff or square bar *h*, namely by inserting the bar through the square hole *a*, so that the machine already mentioned, fastened with wedges, rests very firmly at an exactly right angle to the line of the channel — that is, of the telescope inserted in the turning ball.

Next, this whole little machine, with its two small wheels fixed to it — the smaller *c* and the larger *g*, to which the paper with its observing circle drawn on it is attached with little nails — is to be set on the helioscopic bench, as is clear from Figure W; and, by moving both small wheels this way and that by means of the nuts, it is to be directed to the Sun only roughly, so that the solar rays nearly fill the little circle *n*.

[Margin: The use of this more recent helioscopic machine.]

Only then do I bid the companion climb the ladder at the back. He takes hold, with his left hand, of the one screw *e*, which guides the larger board *g* together with the observing circle in a straight motion, and with his right hand of the other screw *b*, which moves the smaller disc *c* together with the larger *g* round in a circle. By turning this screw or that one, this way or that, he will be able with wonderful ease to take out the whole of the Sun's motion so very finely and gently that the Sun itself seems not to leave the limits of the observing circle *n* even in the least, but to stand as if motionless or fixed in the little circle.

[Margin: Two observers are required for these observations.]

So the one who assists the principal director of the observations does nothing whatever more during the whole observation than keep his eyes fixed constantly on the Sun's disc and the observing circle, so that the solar rays do not go beyond the limits at any point at all, but remain perpetually enclosed and completely fenced in. This, indeed, is very easy for anyone to do, and it is also amply understood from the figure above.

[Margin: The task of the assistant.]

In this way any observer will be able to draw the solar spots as well as the eclipses themselves most promptly and most correctly, without any trouble in guiding and without hindrance from the Sun's motion, with the greatest pleasure, as if at play — and indeed far more scrupulously than ever before — and to take up and correct the same observation again as often as he likes.

[Margin: With the greatest pleasure both the spots and the solar eclipses are dealt with in this way.]

When everything has been sketched in this way, it is also necessary at the same time to mark the vertical point on the rim of the upper observing circle, so as to obtain the Sun's inclination, by means of the plumb line, to one of the clasps, serrated and movable, hung, so as to obtain the inclination of the Sun — just as we have already shown fully in its proper place in our *Selenography*.

So that the whole little helioscopic machine, with all its iron apparatus, does not tip over backwards, and so that its excessive weight does not bend or twist the bar *h*, together with the telescope itself inserted in the ball, the matter requires that the assistant — the one, that is, who works the screws — prop the whole little machine from behind with a pole *o* right at the start, setting one end of the pole at a slant against the floor. In this way you will keep the whole instrument securely in its true position for as long as you wish.

[Margin: The matter requires that the helioscopic machine be propped up.]

For the rest, I would have you note that, since the small wheel *g* is fairly large (although it is enough for its diameter to equal just one whole foot), in this more recent little helioscopic machine you need a double bar, *b* and *l*: a shorter one, *l*, and a longer one, *b*. This is so distinctly evident from the picture that the matter needs no fuller explanation. And although the little instrument is governed by this double bar, the guiding, or the observation itself, does not become in the least more difficult on that account than with that one single bar; everything is done just as easily. For when those two screws are turned, both the small wheels and the turning ball with its tube give way and move at will.

[Margin: The machine described is governed by a double bar.]

How apt and how exquisite this device is, above all for recording eclipses of the Sun, it is not for me to extol at length here; others, who will one day put it to use in observations, will without doubt recognise it fully. I am indeed quite certain that this method has been known to no one up to now (if I may say so), much less used. And so I hope that it will not be altogether unwelcome to all students of the stars, for whom observations in so lofty a business can never be too exquisite — above all if they understand everything correctly and have every part built according to the pattern and this description of ours, or to the one already given in our *Selenography*.

[Margin: As this machine is entirely new and most suited to observations, so it surely deserves some place among the principal astronomical apparatus.]

I break off, therefore, and gird myself for the telescopes and optical tubes, since, as will be abundantly clear from what is to be said, they render excellent service in discovering and contemplating astronomical matters.

CAPUT XIX.

Chapter XIX.

De quibusdam Teleſcopiis, eorumq́; Directionibus.

On certain telescopes, and on their guiding

At the very beginning, when the telescope had just been invented, it was not at all very surprising that some people — especially those devoted to the Peripatetic philosophy — were found to attribute very little to optical tubes and to the observations discovered with their help. For at that time both the construction and the powers of telescopes [Tubofpicillorum] were known only to very few, and hardly any excellent telescope, adequate for celestial contemplation, fell into the hands of one person or another.

[Margin: That in former times there were some who despised telescopes is not so very surprising.]

Now, however, telescopes are met with everywhere in great numbers, and there is none among the learned to whom it is not very well known what, above all, the longer ones, and those more accurate than the rest, accomplish and have accomplished with respect to the faces of the planets and the celestial phenomena. Nevertheless I truly cannot wonder enough that even among the learned themselves someone is still to be found who mocks the use of telescopes in contemplating celestial things. Most of all, however, I wonder that even now some experts in the stars — among others Elias de Leonibus [Elias von Löwen], husband of the most celebrated Maria Cunitia [Maria Cunitz], author of the *Tabulae Propitiae*, to pass over the rest for the moment — cling to the opinion that telescopes rather often cheat us, impose on us and sell us a sham, and that astronomy can do perfectly well without them. This is clear from his letter to me written on 1650 January 24.

[Margin: Even in this age of ours some people think nothing of telescopes.]

For when I had firmly asserted in the *Selenography*, Chapter 56, page 453, *that the reliability of all eclipses whatever, by whomever observed, that are carried out without the aid of the telescope wavers, and that nothing certain can be drawn from them, however very accurately they may seem to have been observed*, the said De Leonibus replied in these words: *that astronomy, the queen of the arts, just as it was discovered, handled, cultivated and refined without the telescope, so now has no need whatever of the telescope for its perfection; for by itself the telescope can show the position in longitude and latitude of no little star, not even of the smallest, nor correct the lunar semidiameters, and merely to curious physical and cosmographical questions*

[Margin: The perverse opinion of Elias de Leonibus about telescopes.]

offer an occasion, etc. And this is the first thing (he continues) *that I had to warn you of, my friend. The second is the very deceptiveness of the telescope. For since the formal principle of this instrument is to delude and impose on the eyes by a learned fraud, what else, I ask, shall we expect from it than a deception of the sight?*

Franciscus Levera [Francesco Levera], too, speaks in much this sense in his *Prodromus* of restored astronomy, and indeed contemptuously of telescopes, Book I, Chapter 3 (perhaps because they run entirely counter to his hypotheses): *And therefore neither Venus nor Mercury can eclipse the Sun, nor spot it in any small part of it, whatever the more recent writers of this age may have perceived through telescopes.* Likewise: *as has been said at length about the hallucinations that arise and are introduced into the Republic of Letters by telescopes concerning the appearances in the Sun, and in the Moon and the other planets — namely concerning the spots and faculae.*

[Margin: Francesco Levera stabs at telescopes far too sharply.]

To all this we could certainly reply, abundantly and amply, that the matter stands far otherwise, and that it is rather they who have been egregiously deceived and have been hallucinating — indeed, that they almost offer themselves to be laughed at by the whole learned world. The latter in particular was not afraid to declare so boldly that neither Venus nor Mercury can ever eclipse the Sun, and, what is more, that almost all the observations made of the spots of the Sun, of the Moon and of the other planets are nothing but sheer illusions and impostures.

[Margin: As though all those who carried out those observations had been out of their minds.]

The former — that is, the most learned Elias de Leonibus — I already answered more than sufficiently at the time, on 1650 February 12, in a reply of a good length; but to the latter I consider it entirely superfluous to retort anything to such absurdities. For the whole learned world, both present and future, will maintain the entire opposite. Indeed, although one or another may be found in this age of ours who harbours such persuasions in his mind perhaps more out of a zeal for contradiction, from a preconceived Aristotelian opinion, than from the truth of the matter and scrupulous investigation, yet I think that six hundred will be found in turn who, with us, will never extol the telescope — so useful and admirable an invention — enough in words and praises, and who will exalt its virtues in discovering those more sublime things that were hitherto entirely hidden. Petrus Borellus [Pierre Borel] pursues this very point at some length in his *History of Spectacles* [Conſpiciliorũ Hiſtoriâ], page 47: *Certainly those are worthy of eternal honours who, to so divine a thing and to pro-*

[Margin: The greatest part of the learned always hold telescopes in the highest esteem.]

[Margin: Pierre Borel's opinion on telescopes.]

pagating the truth, were the first to apply themselves to a useful invention, and will continue to apply themselves to it hereafter. Likewise: *How great the benefits are that will come to the human race from it, it is not enough to say.*

Indeed, how very meagrely did the ancients philosophise about a great many ethereal things before telescopes were discovered and perfected! They did not even rightly understand the Milky Way. Who among them, I ask, would ever have come to know the solar faculae, luculae and spots, and the lunar ones? Who would ever have let himself be persuaded that there are more than seven wandering stars [Errones]; that some of them besides the Moon also have their own changes of phase and undergo increases and decreases of light; and in particular that one of them, namely Saturn, appears with an admirable face by reason of its ring, which it is never without and within which it revolves most freely about its axis? Who would ever have observed and detected so precisely the eclipses of the luminaries and the occultations of the stars, the companions of Jupiter and Saturn, and the spots of Jupiter and Mars — to say nothing of the rest?

[Margin: With telescopes a very great many things have indeed been explored that scarcely entered the minds of the ancients.]

Beyond these, how admirable and hidden are the things that — as has become known to the whole world — have recently been detected and explored, above all by our illustrious Royal Societies, in physics, in medicine and in natural things: namely in a great many little animals, herbs, flowers and metals, things that until now would not have entered our minds even in a dream. This is thanks, of course, to that most excellent microscope, the offspring of the telescope, through which those great works of God are uncovered more and more to the greater glory of His Name, and above all the doors to the abyss of the Divine Wisdom are thrown open wider and wider — an abyss into which until now it has been granted us only to peer, as it were, through a lattice.

[Margin: Not a few things have also been detected with the help of the microscope.]

Therefore it must be granted again and again — unless we wish to be blinder than the Egyptians — that we owe undying thanks to God, Best and Greatest, for the discovery of that telescope. By its help a great many sciences grow daily; indeed, they will take all the greater increase, the further the perfection of optical tubes is advanced. And there shines out a great hope that this can indeed come about in the course of time, with the favour of the Divine Power. For from the very beginning, when telescopes [Tubospicilla] first appeared, down to the present, almost year by year, to an extraordinary degree

[Margin: We have good reason to give thanks to God for that excellent invention of telescopes.]

[Margin: The author is convinced that telescopes can be made more perfect in the course of time.]

they have been made more perfect.

At first they were built only a few digits long, or one or two feet; then they were worked up to 4, 5 and 6 feet; but after some years telescopes were composed of the most diverse lenses, 12, 20, 30, 40, 50 and 60 feet long. At first they consisted of one convex and one concave lens; afterwards, however, they

were fitted with three, four, indeed five convex lenses; and now, among others, I possess one of 140 feet. Moreover, all telescopes show objects the more clearly and accurately, and magnify them the more, the brighter and more perfect the lenses they consist of — the objectives, that is, worked from a larger segment of a sphere. But we do not yet rest content with these: every effort is being made so that we may render them still more perfect, and indeed shorten them to the point where shorter ones produce the same effect as longer ones.

[Margin: Work goes on daily so that telescopes can be made more perfect.]

I should have a great deal to say and write about these things if the plan of our undertaking allowed it, and if I had decided to publish a complete work on the whole construction of telescopes, the polishing of lenses, and everything bearing on them. But it is not my purpose to treat all these matters deliberately on this occasion, and so I do not wish to dwell long on them either. Instead we have decided only to touch briefly on our telescopes, whether polished by our own hand or made by the work of other most excellent craftsmen — and above all on how their tubes are built; how they are set up by us toward the stars and directed; and what apparatus I have fitted out, by a special and most convenient contrivance, for a tube of any length, so that each operation can be carried out all the more readily. The result is that even the longest and heaviest tubes of all can be moved, raised, lowered and steered in every direction very readily and very lightly by anyone at all, even someone wholly ignorant of these matters.

[Margin: The author has not proposed on this occasion to compose a whole booklet on the polishing of lenses.]

[Margin: But only how they are to be set up and directed for observations.]

Since, then, it is entirely beyond doubt that for astronomers — who, more than others, wish to cultivate Urania more deeply and to look into the heavens — not only the most diverse astronomical instruments [Organis Astronomicis], such as quadrants, sextants, octants, and

[Margin: Those who survey the celestial things have the greatest need of exquisite telescopes as well.]

Diagram. Full-page engraved plate, *Fig. X.*, signed lower left "A. Stech Delin." [drawn by A. Stech] and lower right "J. Saal ſculps." [engraved by J. Saal]. It shows a plank-floored observing gallery enclosed by a balustrade. At centre a tall mast carries a pulley rig at its head and a block lower down, from which an inclined wooden beam is slung by cords; at left a second mast holds a long telescope tube by a cord, and a slotted upright supports another long tube. A small stand with an arc-shaped head stands at centre; a tripod with a toothed rack and a trestle with two threaded posts each support the eye end of a tube. To the right, a table carries an upright frame in which a short tube hangs, with a cord and weight below, and an engraved instrument with a sector-shaped, ornamented head stands on a post by the balustrade. In the foreground lie a toothed rod with a cross-handle, a short tube with a strap, a ring, a long open box, a square plate with a circular opening, a dish-shaped object and a cross-shaped base with a slotted upright.

- z (head of the tall mast, at the pulley): label only
- g (lower pulley block on the tall mast): label only
- h, ζ, ξ or ε [?] (beneath g on the same mast): label only
- y (upper end of the inclined beam): label only
- n (along the inclined beam): label only
- x (along the inclined beam, below n): label only
- o (where the cord binds the inclined beam lower down): label only
- b (slotted upright, left): label only
- a (small stand with the arc, centre): label only
- d (left post): label only
- e (toothed rack of the tripod): label only
- c (trestle beam): label only
- w [?] (low on the inclined beam): label only
- r (device in the frame on the table): label only
- m (short tube hung in the frame on the table): label only
- t (foot of that frame): label only
- s (cord with its weight): label only
- u (edge of the table): label only
- f (toothed rod on the floor): label only
- m (tube lying on the floor): label only
- p [?] (left end of the tube on the floor): label only
- [?] (right end of the tube on the floor; p, ρ or r): label only
- l (above the ring on the floor): label only
- [?] (small mark on the ring): not read
- i (long box): label only
- k (beneath the square plate with the circular opening): label only
- (mark at the left edge of the plate, beside the leftmost tube): not a letter

— the sling loop of the hanging cord other instruments of this kind (such as you have seen, kind Reader, in this little work), but also, and quite certainly, for contemplating and detecting the more sublime and abstruse phenomena of the aether, the most excellent telescopes are absolutely necessary; and the more excellent they are, the greater and more accurate the results you will obtain and achieve.

[Margin: The author also took the very greatest pains to obtain excellent optical tubes for himself by every means.]

For this reason, from the very beginning of my observations up to now, I have striven with all my strength, sparing no expense, to procure for myself too the most exquisite optical tubes I could; and those that could not be had for money were in the end made with my own hands and sweat. So it was that, straight from my youth, I took up this art of polishing lenses with the greatest care, and spent a very great deal of time on it before I had learned it properly. In that period I built a great many telescopes, both for my own use and so that I could fittingly offer them to patrons, supporters and friends who ordered and requested them, and give them gladly.

[Margin: He polished and made a great many lenses with his own hand.]

The first of all that I fitted out, and with which I made my observations of the lunar spots, were only six and twelve feet long; after that I built progressively somewhat longer ones, as will shortly be seen more fully. But to come to the matter itself: on this occasion I have resolved only to show how those tubes are pointed at the stars in the observatory, and that I have taken no less pains to undertake and accomplish some things worth noting with telescopes, for the good of the Republic of Letters, than with those other instruments.

[Margin: The telescopes with which the author explored the lunar spots.]

[Margin: As with the other astronomical instruments, so too with telescopes the author has never failed to make observations.]

Therefore, for the benefit of lovers of the stars, and to set the matter out all the more clearly, I have first shown the shorter tubes, of 8, 12 and 20 feet, in the attached picture. From it, even without any further description, those only moderately versed in these mechanical matters will easily understand how each tube is to be built, fitted out and properly directed according to its length. Yet for the sake of the rawer beginners in optical matters I shall touch briefly on each and every point, so that it may likewise become clear by what path I advanced step by step in this field too, how I gradually improved my equipment and the tubes themselves,

[Margin: By what means telescopes are directed.]

[Margin: The aids for moving and directing tubes of any kind] and day by day discovered more convenient means of moving and directing them all the more readily and aptly.

[Margin: have been made more perfect day by day.]

And you, and the other surveyors of the heavens, do not fail to strive likewise as time goes on, and to leave no stone unturned in making all the things I have shown here still readier and more perfect; for I have no doubt at all that in the years to come some more excellent things can indeed be found.

[Margin: The kind of support the author once applied to his tubes.]

First, as long ago as the year 1647, I showed a special support on page 40 of my *Selenography*: namely, how, by means of a prop standing on its four feet on a support arranged crosswise, a number of tubes not exceeding twelve feet can very well be pointed at the stars most conveniently and directed every way at any altitude. I also tried this at the beginning, with happy success, on the Moon, Jupiter's satellites [Joviales], the planets and the fixed stars. In almost the same way I have also directed those tubes without a pedestal, simply setting the prop on a round wooden pole which, in place of the support, is fastened to the enclosure or parapet of the observatory by a holder tightened with iron wedges, as can be seen in Figure X at *a*. You can still use this support for directing tubes if nothing more suitable is to hand.

[Margin: How somewhat longer tubes are pointed at the stars.]

Second, whenever a tube of about fifteen feet, as is shown at *b*, is to be pointed at the sky, I lay it on a planed piece of wood, partly hollowed out

on one side to suit the width and roundness of that tube, and tie it on with bindings so that it can rest firmly in it on every side and cannot sag in the least. Next, a square wooden upright, with a great many square holes made in one side — that is, on the pattern of my yielding chairs [sellae cessiles], which I have mentioned rather often and also described on page 228, Chapter XI — to this upright, fastened to the parapet in my usual way, is fitted a yielding crosswise support with its stop, like the turning chair whose figure I added in the preceding picture for better understanding. Once the stop is loosened, this support is now raised, now lowered, to suit the altitude of any phenomenon, at which position it at once stands immovable of its own accord, and indeed as firmly as if you had bound it to the upright with cords.

On this crosswise yielding support the telescope is now laid, together with the board set beneath it, one end of which carries the objective lens. The other end of the tube, however, must rest as if on a yielding bench fitted with two round uprights, or grooved columns, and their nuts — a bench which we have already fully described in its place, especially in the preceding chapter, and also in our *Selenography*, Chapter V, page 101, and have also given drawn in the preceding Figure W. In this way that end of the tube can, as occasion requires, be raised little by little to the observer's eye and lowered again by means of the two nuts, and so be directed with perfect precision and most conveniently at any object whatever; and thus observers, either standing or sitting most comfortably with the help of our yielding chairs, have it in their power to carry out any observations they please.

[Margin: A yielding bench.]

The body of the tube itself, however, consists of a great many lighter and thinner turned wooden tubes, whose rear parts can conveniently be lengthened now, and now shortened, to suit the distance of any lenses whatever, by drawing them out and pushing them in towards the eyepiece. Sometimes, however, these tubes are also made of thin plates coated with tin, and indeed even of rather thick paper, so that all the parts can take one another up the more readily as they are inserted and pulled out, and the tubes can be contracted and extended the more conveniently, and also be the better suited for carrying and moving about. But channels of this kind — if, that is, they consist of such very diverse yielding small tubes and parts — suffer in turn from this drawback: they readily bend and twist. As a result the visual rays are confused to a remarkable degree, so that nothing accurate at all is perceived, however excellent the lenses may otherwise be, because of the refractions of the rays which are introduced by the distortion of the lenses. This evil, however, is remedied if to these paper tubes, or to those made of thin plates, and indeed of very diverse parts that can be drawn apart, a planed piece of wood, or a rather thick little board, of equal length

[Margin: The construction of some tubes.]

to the whole of that telescope, you lay beneath them and fasten to them. In this way you will best avoid all bending and distortion of the small tubes,

so that you can handle even the thinnest channels of all quite safely — on this condition, however, that the telescopes do not exceed 15 or 18 feet; otherwise, indeed, they become less manageable on account of the heavier board laid beneath them. I therefore advise you to use another way of directing them, which I shall now describe.

[Margin: Another way of directing telescopes.]

Third: in the preceding figure, at *d*, I set up a very tall pole, or small tree, likewise at the parapet of the observatory, at the place the observations then demand. At its top you see a pulley fixed, and through it a cord of the required thickness and length passed over. With this cord attached to the tube, you can most conveniently raise and direct the tube, however heavy it may be, provided it does not exceed 18 or 20 feet — but only with the use of a certain prop inserted in a tripod *e*. This prop is constructed as follows. To a round, perforated piece of wood three supports are fixed on a revolving hinge, as is seen at *e*, so that it stands the more firmly. Then another round piece of wood, *f*, somewhat thinner, of three or four feet, is armed with a toothed steel strip from one end to the other, and so inserted into the hole of that sturdier piece of wood which rests on its three feet. This hole, moreover, is fitted at the front, or upper part, with a planed little plate likewise perforated, with a brake added, so that the said prop, with its longer toothed little column passed through it, can be stopped at any altitude, and, with the brake or stop engaging the teeth of the plate on the longer round wood, can be held firmly without any wobbling. So you can draw this three-footed [tripedaneum] prop out to extend it for any direction of the telescopes, and push it in to contract it, as is clear from the figure at *e*.

[Margin: A special three-footed yielding prop.]

This way of directing, however light its construction may seem, is nevertheless not so very unsuitable, since optical tubes, even rather heavy ones, can in any case be moved most readily and most lightly in any position [omni ſede] (especially if you have tied the cord near the centre of gravity); indeed, even in the said prop — namely, on the wood fixed crosswise to the saw-toothed little column, which has its own projection — they rest firmly, and can also be steered this way and that, even though the whole tripod stays unmoved. Since this is very useful and convenient for making observations, I do not doubt that this way of directing tubes will please every devotee of optical matters — above all because it needs neither a heavy nor a costly apparatus, but can be procured by anyone with the greatest ease.

Fourth: when, however, longer tubes are to be used for the phenomena — namely of 25, 30 and 35 feet — we use another special machine, devised by us not long ago. By its help you have it in your power to raise and direct, with one hand and with almost no labour, very easily indeed and most readily, any tubes whatever, even the very tallest and of the greatest weight, though they would call for many hands — and indeed more easily and conveniently still than those earlier tubes, which were smaller and far lighter. That machine, or rather

that contrivance (a name it rightly bears because of its excellent use), we have likewise given drawn in the preceding drawing W, for better understanding.

[Margin: How tubes of any length whatever are directed.]

It is necessary, moreover, that you set up a somewhat taller and thicker tree at the parapet of the enclosure, since this tube is also somewhat longer and heavier; it is with the help of this tree and of certain pulleys that the tube is to be raised. The channel itself, however, is constructed of four whole little boards of equal width or height, in such a way that it can be lengthened and contracted again only near the end at the eye, by means of a small tube that can be drawn out, as more fully hereafter.

[Margin: The construction of the channel.]

Moreover, to this wooden channel I attach a rather slack rope *n h o*, in the way you see, so that while it is being raised it can draw itself taut up to *h*, where it is led through a pulley. For in this way the tube, being fastened in two places, namely at *n* and *o*, bends itself less than if it were tied around the middle at a single point *x* with a simple rope. For the parts of the cord *n h* and *h o* act as holders, relieving the weight of the channel. Furthermore, to the pulley *h* attach another pulley *g*, likewise to the top of the tree *z*; through these pulleys another, somewhat thicker hauling rope is passed doubled, so that the whole telescope may be raised the more readily and lightly. For the more small wheels a hauling rope passes through, the less power it takes to move the weight, as statics teaches.

Since, then, this whole channel is built of whole little boards in square form, it cannot readily bend; above all because the cord *n h o* is attached at two different places well apart from each other, where the force is greater. Hence, once the channel has been built level, there is no reason to fear that it may in the course of time take on any curvature: it will always keep its straightness perfectly.

[Margin: A little tube is to be fixed to the square channel.]

Since, however, every telescope requires its own particular draw, I have fastened to the end of the channel *r* a special little tube *m*, of almost one and a half feet, of paper or leather, fitted with a threaded ring. In this little tube two convex glasses are usually kept (that is, when the telescope consists of three lenses): the larger and flatter lens sits at *p*, and the smaller and more convex at *q*. And so that the little tube *m* should not easily fall off, and the lenses break, if the spirally threaded rings at *p* and *l*, by which it is fastened to the channel *r*, should give way unexpectedly, we have also tied this tube *m* to the channel *r* with four leather straps, by means of as many buckles. With these aids we have amply guarded against every accident of breaking the tube and the lenses set in it.

[Margin: The revolving telescopic table.]

With the telescope thus far equipped and raised aloft, it also needs some support. In place of that bench *b*, made with two upright posts carved with twisted spirals, and of the tripod *e*, we have devised an altogether different

machine, or revolving telescopic table [menſam Teleſcopicam verſatilem]. At first sight it will hardly seem to promise you what in fact it performs excellently beyond all your hope, even with the very largest tubes of all, though they exceed a hundred feet and more. It therefore deserves to have this telescopic table described fully and distinctly part by part; but since the preceding picture, on account of the very many things already drawn there, all of them very different, by no means permits it, let us defer that labour to the next plate *Y* and the following Chapter XX, where the same machine and its whole apparatus can be sketched more clearly, and consequently also described and explained more fully. For now we shall only touch on a few things in general, as far as is allowed, so that the matter may later be set out the more clearly.

[Margin: Construction of the machine just mentioned.]

From the picture above, then, it is evident that on a board or table standing on four feet a little seat [ſedeculam] of two upright posts is erected, namely upon a wooden base *t*. This little seat is movable between two dovetails [ſecuriculas] on a wooden base of its own. For each base is first joined by a screw passed through the centre, with a nut [pericochleâ] put on top of it; then the bases are moved back and forth most readily by another, endless screw *u*. Into this little seat, namely between those two upright posts, that square wooden tube is inserted, after the upper transverse holder has first been removed. Then the holder is closed again, and a small pulley with a double wheel is hung from it, and another quite like it on the tube *r*; a cord is led fourfold through those four wheels, and a small weight *s* is attached to the end of the cord. It is then easy to move even the heaviest and largest telescope of all as lightly as can be (since it rests, as it were at its centre of gravity, against the upright tree, where weights are governed by even the smallest power).

[Margin: How, by means of this machine, even the largest tubes of all are steered very easily.]

We go about this as follows: we take hold of the cord *s* with the left hand, and turn the endless screw *u* with the right. For with that cord we can raise and lower the tube at will, and with the endless screw [cochleâ verò perenni] we can draw it this way and that along the course of the horizon — and indeed so readily, gently and swiftly that we do not even feel the motion, while the tube stays at once motionless in any direction and altitude, without any wobbling or tottering. In this way you will find any very small object in a moment, and also keep it continually for as long as you wish: which is a matter of great moment indeed for finding things at once with the largest tubes.

[Margin: By what contrivance we find any object at once, at a single glance of the eye, with the longest tubes.]

This very thing, however, to achieve this the more readily, I use a special device, though a rather crude and simple one.

[Margin: This aid seems rather crude, admittedly, but it is very well suited to the work.]

Namely, I have fixed with screws three or four thin, planed little slips of wood [ligilla], equally thick — one inch — and equally long — eight or ten inches — on the surface of the covering of that square tube, which is of uniform width, as you see at *γ x* and *vv*. They are fixed so that you can lay them along the length of the tube, where they will be no hindrance to anyone when the tube is taken down and stored; but when directing it you can turn their points outward at right angles, so that all the slips project at least six or seven inches. Hence, since the said slips stand at their points equally distant from the side of the tube, and the tube itself is also of uniform width, you need only sight with one eye along the points of the slips *vv x γ* towards the star you intend to observe (as if they were proper pinnules of instruments fixed there for that purpose), and direct the tube, by both the cord and the endless screw, until you find all the points of the slips in the same straight line with the star. Once that is done, you will have the star itself very plainly in view in the tube, and can keep it there for as long as you wish, by means of the guidance and control of the cord and the endless screw, as we noted above.

[Margin: How the objective lens is inserted into the tube.]

Finally, I think I should also point out how the objective lens is to be inserted into this square tube. To make this the more convenient, the covering of the tube is so arranged that a certain part near the end, between *γ* and *n*, can be opened. When it is opened, a small square box *i*, in which the convex lens *k* is set by means of a hollowed square little board, is let in — and indeed at the proper distance between the lenses. Unless you know that distance well beforehand, you must search out the interval very carefully by moving the box this way and that; otherwise you will certainly achieve nothing at all accurate with that telescope.

[Margin: The eyepieces are kept in a special little draw-tube.]

The eyepiece glasses, however, are enclosed in the little tube *m*, as we noted. Before this little tube is fitted to the channel, a fairly wide wooden ring *l*, turned with projecting threads at its outer end, is to be inserted into the round opening of the channel at *r*, and with four little wooden pins, so that it does not come out or totter, it is to be fastened; so that this little tube, by means of its own ring fixed at the end *p* and threaded spirally on the inside (of the projecting crown), can be tightened by turning onto the first, wider ring *l* fitted to the channel, and afterwards, as we touched on above, can also be tied with those four leather straps; so that it is not easily knocked off by some blow, and the lenses — so precious, such as are required in those longer and very large tubes — broken.

Let this much suffice, then, about these medium-sized telescopes and their equipment; now let us consider our larger optical tubes of 50 and 60 feet.

CAPUT XX.

Chapter XX.

De Tubi Optici ſexaginta pedum Conſtructione & Directione.

On the Construction and Direction of the Optical Tube of Sixty Feet.

[Margin: The author took the greatest pains to procure for himself the most excellent telescopes of all.]

It is beyond all dispute, then, that longer telescopes, if they are constructed in the best way by this known method, and their lenses obtain a due and perfect section and are also well combined with one another, can do more in observations than shorter ones. For very many years, therefore, there was almost nothing I held more important — sparing no expense at all — than to procure for myself not only some more excellent instruments of this kind made by my own hand, but also some made by the work of other most outstanding craftsmen. In this way I have successfully obtained a great variety of telescopes [Tubospicilla], 30, 40, 50, indeed 60, 70 and 140 feet long — with no lighter labour and cost, to be sure — with two, three and four as well as five convex lenses. How great their power is, and what they achieve in detecting the phenomena of the heavens, it is not the business of this place to relate at length, since the observations themselves speak abundantly enough.

[Margin: Very long optical tubes of 60 and 70 feet are not met with everywhere.]

It is indeed reported by rumour that optical tubes of such length, 60 and 70 feet, are found everywhere; but, as far as I have learned, if you except at most two, hardly any others, equipped with the most convenient aids for guiding them, have so far been applied to the stars with any profit and success, nor are they applied even now: most of them only 17, 20, 30 and 36 feet long, or 36, 45 or 54 palms, with which students of the stars [Astrosophi] contemplate and examine the stars.

[Margin: What kind of tubes, or channels, and what kind of apparatus for directing them the author has constructed.]

Having therefore worked and procured lenses of this kind, of good quality, for 50, 60 and 70 feet, as I was just saying, I also took diligent pains to construct for myself both equally well-suited tubes, or channels, and a most fitting machine — such, indeed, that with the help of one or two people they could be conveniently set out, guided and directed without great labour and trouble in the upper observatory of my house. To make this succeed the more readily, I set up a good thick, tall tree trunk [arbor], in the usual way, at the parapet of the enclosure [Lorica Sepimenti], and fastened it with its iron wedges. The tube itself consists of two parts and is put together from rather slender little boards of fir, as is also the practice among the English, unless I am mistaken; in the rest of the apparatus, however, we depart from them not a little, since I have discovered and learned by practice itself that the matter can be handled somewhat more readily and conveniently.

[Margin: The structure of the tube itself, of 60 feet.]

Each part of this square channel is 30 feet long, namely from *a* to *b*, or from *b* to *c*; its inner width is almost nine inches, and indeed equal from one end to

the other. Moreover, on the inside, at intervals of three or at most four feet, square little boards with a wide hole are firmly glued to the sides at right angles, both to strengthen the tube all the more firmly and to keep superfluous light from the observer's eye.

[Margin: How the parts of the tube are to be combined.]

These two parts of the tube, however, must be joined properly, and indeed so exactly in line [ad libellam] that they suffer not even the slightest curvature; otherwise you will certainly by no means be able to look straight through all the inner holes in turn. I therefore had a very strong box made from rather thick boards, likewise of fir, square in form and oblong, almost eight or nine feet long, and had it reinforced all round with very strong iron holders, so that it cannot widen in the least, much less gape open or burst apart. Into this box *d* of the adjoining figure Y one end of each of the two parts is inserted; but it is necessary that the channels be fitted and matched to the box with complete exactness, so that nothing whatever in it

Diagram. Fold-out engraved plate, Fig. Y, wider than a text page: the sixty-foot optical tube and its directing apparatus set up on the balustraded observatory platform. A long square tube in two parts, joined at a box, rises from lower right to upper left; it hangs by cords from a tall mast with a pulley at its head, and a cord runs down from it to a windlass with spokes. At the lower end an observer sits at the eyepiece on a seat with a back, beside the railed bench under the eyepiece, and beside an upright frame carrying a hanging pulley; a second hanging frame with a pulley stands on the left, beside a table bearing a slanting board and a long notched rail, worked by a cranked rod with a handle. In the foreground lie loose parts: an eyepiece tube, rings and a turned piece, a small box, a long open box, an upright stand, a set of hinged bars with pegs and wedges, an angled iron bracket, and two square plates with round holes (one at the centre of the floor, one by the bench). An ornamental cartouche at the upper right shows further fittings: a block on a tube with handspikes radiating from it, three of them resting on the ground like legs, two plank-pieces, two eyed bars, two loose fittings and a small bell-shaped weight, with an unlettered hasp, a small wedge and a wing-nut. Engraved at the foot: "AStech delin." and "Fig. Y." (left), "J. Saal Sculps." (right) — drawn by A. Stech, engraved by J. Saal.

- c (upper-left end of the tube); m (twice, along the upper part of the tube); h [?] (where a cord meets the upper part); b, d (at the box joining the two parts); z (at the top of that box)
- g (pulley at the head of the mast); l (on the mast, upper and lower)
- i, k (where a cord meets the lower part of the tube); n (over the stirrup-shaped hanger)
- Cartouche: k, i (two loose fittings); t (hub with spokes); s (two plank-pieces); u (two eyed bars); e (bell-shaped weight)

- Left half: ε (top of the tall left post); a letter over the top bar of the left hanging frame [?]; λ, λ (its uprights); π (hanging pulley block); H (slanting board); ε (on the table); a further letter on the table [?]
- s, t, u (windlass and its cord); ω (at the foot of that cord)
- Right half: a letter over the top bar of the right frame [?]; λ, λ (its uprights); m (lower part of the tube); an m-form in the binding fold above a peg, m or n [?]; π (right pulley); α, z (the two letters on the eyepiece tube); c [?] (eyepiece; c, C, ε or e); H (observer's bench); a letter on the floor beside the square plate [?]; l (head of the upright stand); f (its foot); e (small weight under the bench)
- Foot: λ, λ under the left table with a letter between them [?]; θ (handle); c (by the loose eyepiece tube); a barred Z-form on that tube, capital or small [?]; x (small box); d (long box); f [?] (not found at the lower right on two later readings; perhaps one of the g's); r (lower right); g [?] (on each of the three perforated bars at the lower right, and on the floor between them)
- Further labels: a (on the face of the block at the right-hand end of the beam); ε (at the foot of the mast, at the right end of the table); ε, ε (on the right bench); ε (at the foot of the leaning staff); α (on the eyepiece tube — one of the two letters marked [?] above; the other remains open); α (on the loose floor tube, beside the letter marked [?] above, which remains open)

Blank page (verso of the fold-out plate Fig. Y; the engraving shows through in mirror image).

wobbles or totters, but they cling tightly on every side, as far as they have been inserted into the box. Next, these channels, once inserted into the box, are covered with a lid *ff*, on which stands an upright *l*, strengthened by two buttresses so that it firmly keeps its erect, right-angled position. At the same time they are bound very firmly to the box *d* itself by four very strong iron bars, with the help of those four holders (with which, as I said above, the box is fitted) and of eight wedges, likewise of iron, so that the two parts of the tube can in no way come apart, separate or shift.

[Margin: The ends of the tube are drawn together by a cable.]

At the end of the upright *l* there is fitted a small wheel turning about an axle, over which a cable is led. One end of the cable is fastened to the iron holder at *h*; to the other end, *i*, a good strong screw is tied. This screw is inserted into a nut, or case, *k*, threaded spirally on the inside and hung from a hook, and it is turned until the cable *h l i* is stretched hard — with this aim, namely, that the whole tube can be brought into an entirely straight line and held firmly straight. For unless you apply this cable in this way to this tube 60 feet long, it is certainly raised, guided and directed with no success at all; on the contrary, it easily takes on an evident curvature, so that there is no possibility whatever of seeing through it, even though this channel is put together from very strong

boards — if, that is, it has to be suspended only about its middle *p*. Indeed, as is easily understood, it would break altogether.

[Margin: How you may recognize that the tube is stretched out in an entirely straight line.]

So that you are not left unaware, even for a moment, whether the tube stands in a perfectly straight line (even when you are not looking through it), and so that in directing it you err neither by excess nor by defect, I therefore fixed four markers [sigilla], all of exactly the same length, in turn to the covering of the channel with screws *m m m m* (as was done on that 20-foot tube above). If their points are not found to lie exactly in a straight line, that is a sure sign that the tube is bending.

[Margin: If it is bent, how it is to be straightened.]

Hence the cable must be either slackened or tightened by means of the grooved screw *i k*: slackened if the two end markers appear higher than the two remaining intermediate ones; tightened, on the other hand, if the two end ones are lower. In this way it is possible to straighten and direct this whole tube, this very heavy machine, perfectly true to the level [ad libellam], even if it were as much as 20 feet longer. Any mechanic will easily understand the basis of this: namely, that the upright *l*, standing firmly on the box, contributes a great deal to this direction. For while the tube is drawn up and raised at *h* and *k*, the middle part *b* is pressed down by means of the upright *l*, so that the whole channel is brought straight all the more readily. But the crucial point lies in this: that the length of the upright *l* suit the tube, and above all the distance *h k*; and then that the ends of the cable, *h* and *i*, be fixed to the channel in their proper places. For unless you observe all these things well, all your labour will be in vain, and you will steer the whole tube only with the greatest labour and weariness.

[Margin: On the fork of the channel.]

Furthermore, once these two parts of the tube had thus been joined, and the cable *h l k* had also been properly led over the upright and its small wheel *l* and sufficiently stretched, it used to be my custom, before I raised the channel, first to fit the fork [angina] *n* — built of two wooden uprights and a very strong bent iron holder — to a very strong iron axle lying under the box *d*. The purpose was that the whole telescope could be raised by a cord with the help of this fork, or shears [trutina], and its revolving ring.

[Margin: This tube is compared with a balance.]

For, to conceive the matter rightly, the whole tube is, as it were, the beam, the upright *l* the erect tongue [examen] of a balance, and so *n* is the fork. And in this way it will be easy for you to steer and direct this very long tube like a balance (since it rests in equilibrium alike about the axle *d*) as readily and as lightly as possible while it is raised.

[Margin: The fork is an obstacle in certain observations.]

This method of raising and moving is not, indeed, so very unsuitable; but it suffers from a certain inconvenience, very ill-suited to observations. Namely,

since this fork *n* must necessarily be ten feet high, so that the tongue of the balance *l*, which equals at least nine feet, can move freely through it, it follows that the whole telescope can at no time be raised except as far as the ring *n* and the upper part of the fork, until, namely, the upper pulley, attached to the end of the tree trunk, and the ring *n*, or the pulley hanging from it, touch each other; so that the whole tube can be carried up to a height 12, or indeed 15, feet less. In this way we can observe phenomena scarcely 30 degrees high, even though the tree trunk is high enough. Moreover, since the fork itself is made of thick, strong wood and is also reinforced with a great deal of iron, it adds remarkably to the burden of the whole machine, which already has a very great weight from its very construction.

[Margin: With the fork removed, the tube is raised much higher.]

For this reason I strove by every means to remove this fork *n* from the tubes altogether; and I have accomplished this fittingly, and indeed by a plainer and easier route. In place of this extremely heavy and extremely troublesome fork *n*, namely, I fitted and fixed to the axle *d* a piece of thicker cable [rudens] having iron clasps very firmly bound to each end, as can be seen at *o*; and I also took good care, with a small wheel, that it should not in any way slip off the axle. Afterwards I fastened to this shorter cable *o* a pulley *p* with a single small wheel, similar to the one I attached at the end of the tree trunk *q*. So, with a hauling rope [funis ductarius] led through both pulleys *p* and *q*, you will be able to raise and lower this telescope just as readily and most conveniently as if you used the fork *n* — and indeed with this singular advantage, that you can raise the tube much higher, by a great many degrees, since you are able to draw the rope until the two pulleys *p* and *q* meet each other. This, however, is not granted with the fork, which rises as much as ten or eleven feet in height. Moreover, with this shorter cable *o* alone, the tube itself comes out lighter by a good many pounds, and more manageable, than if you were to use the fork.

[Margin: On the tree trunk with whose help the tube is raised here.]

However, the tree trunk, or column, with whose help the telescope is to be raised must be strong enough to bear the load. Its length could run to 60, 70, or indeed 100 feet, if it were always kept in its own place — above all if it stood permanently immovable about the centre of the observatory, and the space were so large that the tube with all its apparatus could be carried round the tree trunk. But since our observatory, built on the top of our house, does not extend beyond a hundred feet, we could not, about its middle, place the tree trunk, but only at the parapet of the enclosure [Lorica Sepimenti], so that this tube would not get in the way of the other instruments, nor block the view.

[Margin: The tree trunk must be erected afresh for each observation, and fitted out with all its apparatus.]

I was therefore compelled to arrange everything so that at any time, and on every occasion when observations were to be made with this tube, I could conveniently move the tree trunk to its place and fix it to the parapet of the observatory; and then, once the observations were done, take it away again

and keep it duly in its place, together with the ropes, the pulleys and the whole apparatus. This, moreover, has turned out very conveniently. For if that tree trunk stayed permanently in the same place, both the ropes and the pulleys would be ruined in a very short time by the weather. For who, I ask, would climb up there and, at every observation, loosen and take down the upper pulley with a hauling rope of such weight, and then fasten it again at every observation?

[Margin: Making observations with very long telescopes is a matter of some labour.]

It must indeed be granted that it is truly a great deal of labour to bring out a tube of such size so often from the chest in which it is kept; to join its two parts with the help of holders and bars [repagula]; to secure it with a rope stretched over it; to erect a tree trunk of such bulk at the parapet of the observatory and fit it with its hauling ropes and pulleys; to set up a windlass with a revolving cross-shaped handle to support the machine; and then, once the observations are finished, to loosen everything again, take it down, and bring each thing to its place and keep it there. Nevertheless, those who study celestial matters can scarcely avoid these things, however extremely troublesome and costly it may be for a private person, on account of the excessive expenses that must be paid out.

[Margin: How a most convenient observatory could be built for the longest tubes.]

If one of the great men and princes were to supply the expense for this purpose, it would certainly not be difficult to fit out a special and most convenient observatory, even if the telescope ran to 150 feet. There the tree trunk by whose help the telescope is otherwise erected could stand permanently in its place, and the hauling ropes with their pulleys could hang from it, always attached, and indeed safe from all inclemency of the weather. Likewise the tube itself would be ready at all times, fully joined and fitted out with all its apparatus — and moreover, what matters most, in the very place where it is to be raised and set out towards the stars; so that we should have no need at all to carry it from one place to another with the help of many men, nor to take it apart, bind up all its gear and lay it away in its place, but always, whenever we liked, to raise the telescope at once and direct it wherever you wished — and that, indeed, without great labour and trouble. But we shall deal with this matter expressly in the next chapter, for the sake of the lovers of the stars who have not yet devised a more convenient method.

[Margin: We should be freed from great trouble if we were granted the use of an observatory of this kind.]

It is truly beyond doubt that it would be a singular aid, and also most welcome to every one of the cultivators of astronomy, and that very great trouble could be avoided in this way, if the telescope did not have to be fitted out beforehand on each occasion with so much labour, so laboriously, and with such a loss of time. Believe me, we would turn to such observations more often if, namely,

we had the telescope at all times fully set out at its station and ready, so that nothing but the eyes and hands had to be brought to the tube.

[Margin: The tree trunk is fastened to the parapet of the enclosure.]

But to return to our column, or tree trunk, which supports the tube: its height is as great as seemed to us sufficient for this sixty-foot telescope, and also such that with the help of three or four men we can erect it at the parapet of the enclosure, fix it, bind it and take it down. This trunk, I say, is fastened very firmly to the parapet, wherever you please (since on every side of the sky there is a place suited to the task), by a bent holder *r* and by fixed bars [repagula]. Next, the bearing block [chilonia], built of wood, in which the windlass turns, is likewise fixed crosswise to this tree trunk and to the parapet, as is seen at *s t*.

[Margin: How the tube is raised and held in position.]

And so that this bearing block [chelonia], together with its windlass with the cross-shaped handle, may stand all the more firmly, I set beneath it, or built under it, an iron dovetail [subscus], or buttress, to brace it; and I secured it to the tree trunk with its wedges in such a way that the turning of the windlass and the pull of the hauling ropes (although a tube of sixty or seventy feet is raised by the strength of one man) should neither bend the bearing block and windlass *s t* nor break them outright, but that it can very well be turned gently, and the tube itself thus drawn up smoothly [molli articulo] by means of the hauling rope. When, however, the telescope now has reached its proper height, it is held completely still by some rope *vv* tied to the lower part of the tree trunk in place of a brake — that is, by fastening this rope to the cross-shaped handle of the windlass. In this way the whole machine, however very heavy it may be, is braked so firmly that it cannot yield even the least amount, much less fall, or in any way cause or sustain damage.

This is indeed also required of necessity, so that we may be entirely safe in carrying out observations of this kind with so great a machine. For in matters of such moment, and in safeguarding such precious lenses (which are valued very dearly, and which we buy for a great sum of money), it is above all necessary that we guard carefully against every loss — and first of all, that none of the observers or spectators be injured without warning, or indeed killed outright. For if so great a mass were suddenly to fall from on high, it would break and destroy whatever it struck.

[Margin: The hauling machine.]

So that you may examine more fully the bearing block [chelonia] *s* already mentioned, in which the windlass turns with its four-armed revolving handle *t*, I wished to set all of this before your eyes in the upper panel of the preceding Fig. Y, in a somewhat larger drawing. From it you will easily see how the bearing block *s* is built, and in what way the windlass *t* — that is, the wooden yoke with its levers — is set crosswise on the bearing block, with a buttress bracing against it.

[Margin: The clamping screw.]

Moreover, I also thought fit to add in the same place the screw *i* that we mentioned above, and also its case *k*, threaded spirally on the inside, so that I might set everything out clearly for anyone to whom it might perhaps some day matter. And let this suffice for now concerning the construction, connection, tensioning and all the apparatus of this tube of sixty or seventy feet, by which it is raised and lowered.

[Margin: The method of directing telescopes.]

Now let us come to its direction: that is, how it may be guided as readily and as lightly as possible, and directed to any quarter. Whether anyone anywhere else will in time devise a still more convenient machine, time will tell. Up to now, as everyone will admit with me, nothing of the kind has yet occurred to anyone, nor has anyone put it to work, so that I am plainly the first (be it said without boasting) to have built this telescopic contrivance and brought it into use.

Before this tube is drawn up and raised by the hauling rope, however, you must loosen and open the lid between *c* and *h* at the end of the preceding tube, so that you can put the little box *x*, which carries the objective lens *y*, back in its due place according to the required distance between the lenses.

[Margin: The objective glass is to be set in its due place.]

For unless you set the objective glass correctly, you will certainly achieve very little, especially if two eyepieces are to be used together, since by drawing out and pushing in the little tubes *z* you will not obtain the interval of the objective lens at all accurately — as everyone skilled in this art will readily acknowledge.

[Margin: The little tube of two pipes.]

Next, once this little box has been inserted with its lens and secured well so that it does not leave its proper place, I fasten the little tube *z* — made of two sections [cicutae], that is, of two ducts of paper with leather laid over it — to the channel by its internal screw: namely, to a ring inserted in the channel and threaded spirally on the outside, γ, which we already mentioned in the preceding Chapter XIX, p. 388. And so that this ring does not come out of the channel, letting the whole little tube fall with its lenses and the lenses break, I secured it with four wooden pins driven through the channel, and at the same time bound it to the buckles [fibulae] with four leather straps. But before this little tube *z* is fastened to the channel, the two eyepiece lenses must first be inserted into it: the larger and flatter with the help of the ring δ and α, and the smaller and more convex at β by means of that tube.

[Margin: Without the telescopic table, the largest tube can scarcely be steered.]

To steer and direct the entire machine of the optical tube, with all its apparatus, without the revolving telescopic table [mensa versatilis Telescopica], is truly a matter of much labour and effort: one must keep moving so very vast and so very heavy an instrument continually by free hand, without any aid, and keep it always on the same point. As a result very many people have been

altogether deterred from observations of this kind, which have quite often to be undertaken with very long telescopes. For, as has happened to me too, what had sometimes been found with the greatest trouble was lost again in the blink of an eye. I therefore thought nothing more important than to bring a remedy for this inconvenience and to devise a revolving telescopic table, by whose help every one of the observers may carry out everything as he wishes and at his command — as you yourself, once you have examined the matter properly, will no doubt acknowledge.

[Margin: The construction of the telescopic table.]

So that the whole contrivance may be seen all the more clearly, I chose to give this telescopic table drawn in a somewhat larger figure in the preceding Delineation Y. How the lower body itself is put together and from what parts, and with what supports, crossbars, stays and crosspieces it is joined, is abundantly clear from the figure. Along the middle of the board [tabula] of this table I let in, lengthwise from one end to the other, a toothed, rod-like strip of plate iron ξ, and fixed it firmly with screws. At the two edges of the board I set two rails [cantherii] ε ε, made with a groove, as you see, and likewise attached them with screws, so that a fairly thick plank [assamentum], fitted with a projection on each side, could be moved to and fro in the grooves of the rails.

[Margin: Almost the whole contrivance lies in a single endless screw.]

Since, however, that plank η is not conveniently steered by bare hand, nor very easily — especially if it has to bear a considerable load — I therefore fixed to the rear side of the plank η, the side that is to rest on the board, a fairly thick and long endless screw [cochlea perennis], made with its own revolving handle. I fixed it by means of two buckles [fibulae], which were to serve as bearing blocks for it to turn in, not crosswise [decussatim] but in a transverse position with respect to the grooved axle.

[Margin: The action of the endless screw.]

Since this endless screw has its threads, as is evident, and that iron bar running along the middle of the board has its teeth, it follows of necessity — once this plank η with its screw has been set on this small toothed iron beam and bound to its rails ε ε — that the threads of the endless screw θ engage, biting, with the grooved teeth of that iron axle ξ, and receive and bite one another in turn; so that by the turning and steering of the said screw that plank η is forced to travel, giving way [cessim], entirely along the line of the board, and indeed as readily and as gently as possible. Next I built another plank μ, of nearly the same size and shape, on the model of η, and indeed with its own projections, so that it could be neatly joined to the plank η and inserted into it; in which I erected two uprights λ λ, almost four feet in length, and joined them with a crosspiece [transversarium] γ, but set them so far apart from each other that a square channel could conveniently be inserted between these two uprights.

[Margin: The little seat of the telescopic table.]

When this has been done, the whole little seat [sedecula] μ λ γ λ is first clamped to the wooden base η by a screw passed through its centre, so that it

can be turned round neatly by its projections within the grooves η. In this way, even while the telescopic table stays unmoved, the little seat can nevertheless adapt itself to the turning of the channel — that is, whenever the tube is directed in a somewhat oblique position with respect to the table. Next, this whole little seat, with both its bases μ and η, is set on the table and fitted within those dovetails [securiculae] ε ε in such a way that the endless screw θ engages, properly and as well as possible, with the toothed axle ξ that runs along the middle of the board, and can seize the teeth of that axle with a silent bite.

[Margin: The use of this telescopic machine.]

Afterwards the transverse holder γ is removed, and the telescope is let into the little seat between those two uprights λ λ. Then, with that holder γ closed again, a little pulley [trochleola] with a double small wheel is hung there, and another similar little pulley is also attached at π to the channel, by its hook, to rings fixed there — of which there are very many — and indeed at whatever place reason and convenience demand. Again, by running a fourfold directing cord through these two little pulleys and hanging on it a small weight of two or at most three pounds — according, that is, to the weight of the whole machine to be steered — you have the whole contrivance that is in every way required for moving and directing a telescope of sixty or seventy feet finished and equipped.

[Margin: How the telescope is steered and directed on the telescopic table.]

With all these things arranged in this way, I have that whole telescopic table, together with the telescope inserted and fixed by means of the two pulleys, carried round to the side facing the phenomenon to be observed. This too is done with very little effort, since the tube hangs at its centre of gravity, entirely about its own middle and point of balance, where in any case the heaviest loads of all are moved as lightly as can be. Accordingly the tube, by drawing in or slackening the principal guiding rope in a rough-and-ready way [rudiori Minervâ], then by turning the steering screw θ that is attached to the telescopic table, the tube is directed with the help of those four wooden strips [ligilla] *m m m m* fixed to the cover of the channel (as we have already said on page 390 and page 393), so that you can catch the object or phenomenon you want with the tube itself, and so view it very well through the lenses.

[Margin: Sometimes certain things are accomplished just as accurately by a rather rough method as by another, far more refined and anxiously sought one.]

This method of directing the tube by such very plain wooden strips may indeed seem very crude and commonplace for even the smallest star; but, believe me, you will find in practice that no more accurate contrivance is needed here. If, however, you want something finer, fix some suitable pinnules to the tube in place of the strips, and then direct the telescope with their help. But I doubt whether — though they are finer aids — you will catch the star more readily and more quickly; on the contrary, it is quite certain that those finer pinnules can be put out of true far more easily, even by a single rather light knock.

[Margin: With this telescopic machine all observations are carried out most readily and most conveniently.]

But to return to making the observation itself: I would not have you unaware that you can carry out any observations, in any position and elevation, most conveniently, whether standing or sitting, by means of our yielding chairs [sellae cessiles] (as is more than clear from the picture above), and can then steer and direct the tube as you wish, very readily and very smoothly, without any labour or trouble. That is, with the left hand you hold the cord and its little weight *e*, and with the right the handle θ of the endless screw — drawing in or slackening the cord, and turning the screw forward and back — while the telescope always stays entirely unmoved in any position, without any further shaking or wobbling.

[Margin: How, with this contrivance of ours, every motion of the heavenly bodies can be avoided.]

And in this way, even though every star and every celestial phenomenon has a different motion — now its proper motion, now the diurnal; now in longitude, now in altitude; now toward its rising or setting, now toward the south and the north — you will nonetheless, however swift the motion that carries it, very readily keep any object most exactly in the centre of the telescope, or rather of the lenses, for as long as you like: namely by the directing of that cord and of the endless screw, and by their continuous movement

[Margin: The tube stays always unmoved on any object.]

Indeed, if you find the phenomenon tending and climbing higher and higher, lower the tube a very little by slackening the cord for a moment; if it descends, draw the cord in, and you will at once bring the phenomenon back and lead it to its former place. And even if you take your hand right off the cord, the tube will nonetheless stand very firmly in that position, since the small weight answers exactly to the weight of the whole machine and holds it steadily and constantly at every elevation, so that it does not nod even in the least. Again, if the phenomenon is moving toward the east, twist or tighten the endless screw to the right; but if it runs off toward the west, turn it back to the left. In this way you will take every motion away from the phenomenon most exactly, to a hair, and will hold and keep it, as it were, perpetually unmoved in the tube — as anyone will learn very easily from practice itself.

[Margin: It seems to the author that this method of directing is not so unsuitable.]

How pleasant this method of directing the telescope is, and how very well suited to the observations themselves, others will acknowledge once they have tried the thing themselves. For even if you leave the tube and the phenomenon slips away meanwhile, on returning you will still be able, with the help of the wooden strips — all their points, that is, being directed in one and the same straight line at the object — to restore the telescope at once and bring even the smallest star to the lenses. So even all those quite inexperienced in these matters, and wholly unaccustomed to observations, can overtake any phenomenon at

once, however swift it is, with the greatest pleasure and delight, and hold it in the tube to their heart's content. Thus this revolving telescopic table of ours is an outstanding aid for any telescopes, even the longest of all; without which, truly, I do not see how such enormous machines could be steered and directed at will and as need requires, most conveniently and so very exquisitely.

CAPUT XXI.

Chapter XXI.

De Teleſcopio noſtro maximo.

On our largest telescope.

[Margin: Very many in this age apply themselves]

Since it has now at last been abundantly established how much, by very many celestial observations, for the Republic of Letters

[Margin: to producing ever more excellent telescopes day by day.]

to be undertaken for its good, exquisite and perfect telescopes contribute above others. Hence every one of the lovers of the stars and of the opticians has nothing more at heart than to make and build, day by day, telescopes that are more perfect and, moreover, longer. Yet telescopes longer than sixty or seventy feet, so far as I know, have scarcely anywhere been brought to bear on the stars until now with good fortune and with any success — however much people here and there may perhaps have polished lenses for longer tubes.

[Margin: Why the longest tubes have so rarely been applied to the stars until now.]

The reason is that until now they have not yet been able to devise and assemble a suitable machine and a tube for inserting the lenses — and such a one, moreover, as would readily obey every movement and every direction, and would not burden observers in the least with its bulk. Indeed, very many of the learned had almost despaired of this very thing ever being discovered by so easy a way. Nevertheless I by no means cast away all hope; I was entirely confident that, God favouring, a very large machine of this kind could certainly be worked out to carry lenses of a hundred, indeed a hundred and fifty, feet, and brought into convenient use.

[Margin: The illustrious Burattini especially roused the author to build a machine for the longest telescopes.]

What fired me above all to undertake this work was the illustrious Lord Titus Livius Burattinus [Tito Livio Burattini], most skilled and most practised in all mechanical matters, and so also in these optical ones. For he not only most readily promised me lenses polished by his own hand for a telescope of 140 feet, but shortly afterwards also generously supplied them.

[Margin: To build such a machine is indeed a matter of some labour.]

At the outset, however, I confess that I foresaw very well that this business had a great many difficulties. For suppose I were to tackle the task in the

earlier way — that is, by building a square channel out of four boards, and out of four parts to be joined together, each, if you like, forty feet long. These individual parts, I grant, could be joined together both in the way disclosed earlier and in yet another, different way, and brought to straightness by means of certain chests [cistae] and ropes — provided, that is, one did not shrink from uncommon expense, nor from the exceptional power needed to assemble and steer the machine. But sixteen boards forty feet in length, of sufficient thickness and breadth, together with three so exceedingly sturdy chests at least fifteen feet long, so much iron reinforcing them, and also so many ropes, with pulleys added on top, and so great an apparatus — how great a bulk, I ask, would they make, and how much labour and effort would it take to join all of them together, bring them into a straight line, raise them, move them, and keep them always in their position and straightness?

[Margin: The author undertook this construction by an entirely new method.]

Foreseeing this considerable trouble, therefore, I attempted the business by another, quite singular method: namely, to build a machine of this kind for lenses of 140 feet out of only eight boards of fir, and those much narrower and thinner. Such a machine would be lighter, and likewise far more convenient and easier both to build and to direct — above all because it would be assembled with all the intermediate chests entirely removed and, what matters most, without any iron at all, not even a single iron nail worth one obol being used (which should be noted).

[Margin: To make the tube from two boards only, all iron being entirely removed, indeed not even a single iron nail being used.]

In short, I took pains to make the machine out of two rather slender boards alone, presenting, as it were, a round tube. At first this seemed almost absurd, indeed like a paradox, to certain people who were otherwise not altogether unskilled: to build and fit out a channel from only two perfectly flat boards. For it is entirely beyond dispute that two planed boards can never be so combined and joined together that they represent a closed tube and shut out the light on every side. Nevertheless, with God, the work turned out happily, so that I achieved the desired end and can use it conveniently as a true tube — although, as you will easily understand, building this very machine, and then steering and directing it, is a matter of some difficulty.

[Margin: Construction of the machine for a telescope of 150 feet.]

I assembled the machine itself from four boards forty feet long, so as to obtain the required length of about 150 feet. First, a plank [assamentum] about ten or eleven inches wide and one and a quarter inches thick, evenly planed and stretched out, with its sides raised, upon another plank only eight or nine [noven, recte: novem] inches wide and scarcely three quarters of a digit thick, at almost the middle of its planed side, as if onto a base, I set up and fixed at right angles, as can be seen in the attached picture at a B a.

And so that these two planks, joined in this way, might stand all the more firmly, I propped and strengthened them with a great many wooden buttresses and holders c placed along their length, three or four feet apart from one another: one side of the buttresses c was brought against the base, that is, the lower board b, and the other side against the second plank, set upright at right angles — on the back side of that upright board, in fact — and there they were bound very firmly with wooden nails and glued. In this way these two boards, the underlying one as well as the upright one, could not shift even in the least one from the other, or twist, but would be kept permanently together in that position.

[Margin: Boards joined and combined in a particular way do not let themselves bend in the least.]

For, as we already mentioned in Chapter VIII in connection with that quadrant, the plank a B a, set up by its breadth upon the other, planed one b b, in no way allows the lower one — namely the underlying base b b — to bend, although that plank is otherwise rather narrow and slender. Conversely, this underlying plank b b, since it is firmly fixed by its flat face to the upright one, in no way permits the upper, upright one a a to skew in any manner. So these two planks, forty feet long, combined and coupled very firmly with each other in the way described, can always keep themselves most strictly in an entirely straight line and can in no way bend; indeed, even applying the greatest force, you will sooner break those boards so assembled than skew them — as is easily understood.

[Margin: For what purpose the perforated square boards are fixed.]

On the other side of that upright board a a, moreover, as is evident at A and D, opposite the buttresses and holders c, I also set up at right angles small square boards d, about one foot in size but provided with a wide hole, and fixed them properly with wooden nails to both planks, the underlying one b as well as the upright one a, and glued them. The purpose was not only that they should bind and strengthen both planks more and more, but above all — to say nothing for now of the rest — that stray light coming from outside should be entirely prevented from falling on the lenses, and the eyes

Diagram. A fold-out engraved plate of the great telescope, photographed open across two leaves. Across the top stand two framed panels, each drawn like a cloth hung from a rod. The left panel, signed *A. Stech delin.* [A. Stech drew it], shows the parts laid out on the ground: a short tripod, the long squared tube with a square opening, a lighter bar, a cylindrical tube in pieces, and small fittings. The right panel, signed *J. Saal sculpsit* [J. Saal engraved it], shows the head of the mast with its fittings, a coil of rope, pulleys and hooks, a toothed rack, and the long box set on two uprights. Below these spreads a landscape: a tall mast braced by stays and a ladder, with a man climbing it; the long tube, supported on blocks, being raised by its cables; workmen at the near end; a group of onlookers; houses and trees behind a fence. Along the foot of the

landscape runs the box in section, and beneath it, in a separate register marked *Fig.* Z, the middle tube A and the lower beam B with its buttresses.

- Upper-left panel: f, n, N, G, H; f above the second lever; h twice, either side of the tripod leg; small letters at the fittings read as e (twice) and g (uncertain); a form on the ground right of the levers read as o, a or d, or a drawn ring [?]
- Upper-right panel: i, k at the head of the mast; F on the mast; D, E, C on the long box; e and f on each upright
- Landscape: D, E, C on the box in the foreground; f twice, and h twice beside the two stacks of blocks; e at the top of each of the two clamp uprights
- Bottom register: A on the middle tube; B, a (twice), b (twice), c (three times), d (twice) on the lower beam

This page is blank: the back of the fold-out plate, with the engraving showing through in mirror image.

of the observers from being shone upon.

So, once those four parts A B C D have been combined and assembled, the skill now lies in joining them to one another lengthwise and binding them together in such a way that the work needs not even the smallest piece of iron, and nevertheless has its proper firmness, and can also at once be unbound again and taken apart without much labour or loss of time.

[Margin: By what method the very different parts of this machine are joined and combined.]

For accomplishing exactly this, however, I could find no more convenient remedy at all than to make special wooden binding or clamping forks, of the kind cabinet-makers [Scriniarii] otherwise use when they join and glue boards together. I have given them, drawn, in the preceding figure, and in the upper panel on the left, at f.

[Margin: Special clamping forks.]

There is only this difference: the cabinet-makers' forks are firmly closed and glued at both ends, and whatever is to be bound and tightened in them has to be inserted within the opening, that is, between the two legs; whereas these clamping forks of ours, for assembling this machine of ours, are closed and glued at one end only. At the other end they are shut by a special small square block, cut with dovetails [subscudes] (in place of a dovetail [securicula]) and let in through grooves on both sides of the fork, with a wooden pin driven through so that this block does not come out; and so that it may be all the stronger in resisting, and also, at any time, whenever needed, can at once be taken out again.

Into these two forks f the ends of the two upright boards D and C are inserted together, tightly, from above, into the opened forks — but only after the blocks e have first been taken out of the forks — since the slit of the fork corresponds exactly to the thickness of both upright boards. Or, which is better, these two forks f are driven upward from below through holes made to fit them in

the underlying board b, that is, the base of the machine. Then the forks just mentioned are closed with those square blocks e, so that they can in no way spring out or burst, and are made fast with their pins.

Afterwards, between the dovetail e, that is, and the two joined boards, I insert and drive into each fork two very strong wooden wedges, shaped exactly to the width of the fork but turned to face each other; and with a mallet I force these wedges in so far and so very forcefully until they refuse to give way any further, and each of the two planks, D and C, is more than sufficiently squeezed and pressed together: as can be seen at E, especially in the small panel above, set at the right. In this way two parts of this machine are duly joined, so that no force can disjoin and separate them unless you open and loosen the wedges. In the same way the remaining parts, A and B, are now also clamped to each other with four similar forks and wedges, so that all four parts, A B C D, hold together in order along a straight line by means of three pairs of forks.

[Margin: On the special upright, to be erected over the middle.]

It should be carefully noted, however, that in the middle of the machine, at E, an upright F, erected on a crossed base G, must be set on beams raised at right angles and laid over them, and embraced with forks, and at the same time squeezed with those wedges, so that it holds firmly to the machine there and in no way comes away from it. This upright is twelve feet high and well strengthened with two buttresses and stays, as is clear from the drawing above. At the top of the upright, two small wheels turning on an axle are fitted at i and k; their purpose will be explained later.

So, with all these things arranged, the parts of this machine firmly joined to each other, and that upright set on top of it on its crossed base; and further, with the whole machine brought to the tree trunk by which it is to be raised, and there stretched out level on blocks, or seats, in an entirely straight line, and all curvatures of the machine removed (so that the view lies quite freely open through the individual openings d from one end to the other), a great many different cables and ropes, and also very many pulleys of various kinds, are applied and fastened to the machine: as is clear from the figure above, and above all, somewhat more clearly still, from this one placed here, where the machine now hangs raised.

[Margin: The pulleys must be attached to the machine at the proper place.]

But it matters a great deal at what place the pulleys are fastened, so that you find the point of balance along the length, namely, and so that the carrying ropes, or bearing ropes, take hold of the machine with equal force and support it equally everywhere. For if those two intermediate pulleys b and c, to the column, too near have been attached, in relation to the upright f, the machine will curve toward the ground at both ends, presenting, that is, a convexity upward about the middle. You will experience the opposite, however, if you have tied those two pulleys b and c farther out than is proper: the ends will rise, and the whole machine will take on a convexity toward the ground. So it is plainly a matter of skill, at the outset, when the machine is first being fitted out,

to arrange and apply not only the pulleys b and c but also the remaining ones, a and d, in such a way that the carrying ropes support the whole machine with equal force everywhere and hold it up in a straight line.

[Margin: The carrying ropes.]

It will add very great weight to this, moreover, if you have properly learned and tested from which side of the raised beams, the front or the back, the pulleys are to be attached, or which are to be fastened from one side and which, in turn, from the other. For unless you have tested all these things thoroughly, you will in no way bring the whole machine to level, so that all the small square perforated boards d stand upright parallel to the line of the horizon; instead you will find various curvatures arising from the inclination. It matters little, though, whether this machine turns and tilts a little, provided that it always presents an entirely straight line along its length. Even so, it is better to have the whole machine not only stretched out perfectly straight but also set upright, plumb, everywhere. In this way you will find any objects more readily than if the machine hangs in some oblique and tilted position. I therefore urge you to apply every effort to set the machine properly and with the greatest exactness, first both as to its length and as to its inclination; and this can certainly be done, if only you do not shrink from the labour.

[Margin: Order and arrangement of the pulleys.]

But how, and where, all the pulleys are tied in proportion to our machine as shown, you will learn more readily from the drawing itself than from a lengthy explanation. First we attached four pulleys to the upright beams: namely the first at a, the forward forks, the second at b, the third at c, and the fourth at d; through their small wheels a very strong cable, which we otherwise call the carrying cable, was passed, in such a way that I passed one end of the cable first through d, then c, again through the lower small wheel of the double pulley e, then through the pulley b and a, and finally once more through the small wheel of that double pulley, but the upper one, the ends being made fast at f.

[Margin: Length of the carrying cable.]

The length of the cable, moreover, must be entirely suited to the work. For if it is too short, it in no way supports the machine firmly enough; and again, if it is longer than it should be, so that it extends beyond the upright k, the tube is kept in its raised position only with great difficulty: for the upright F would easily pass below the double pulley e and turn over, to the very great damage of the machine. If, however, you keep to the proper length of this cable, the upright F can lean back against the cable; or, what is the same thing, the cable, passed doubly through the double pulley e, supports the upright F so that it does not overturn and come away from the tree trunk, but keeps its position all the better.

So, once this double pulley e has been raised aloft by means of the hauling rope y x, the carrying cable d c e b a e f at once takes hold of the machine quite evenly everywhere in its places and lifts it: for that cable runs perfectly freely through all the small wheels and is held back nowhere; indeed, for

different elevations it yields most readily to the double pulley e, as those skilled in mechanics readily understand.

[Margin: Unless this machine is helped by the carrying cable, it readily bends.]

If, however, I had tied two separate ropes, one at b and c and the other at a and d, and had led them only through those two small wheels e, it certainly could not have happened that the machine would be raised so evenly and held firm in a straight line. For now this rope, now that one, would be slacker, now tighter, and this would at once give the machine an obliquity. For I would have you know that this enormous machine, because of its excessive length, readily takes on a curvature and departs from a straight line, however thoroughly strong the fitting together and construction of its parts may be. Hence, unless you remedy this drawback, namely by raising the machine as evenly as possible on every side by means of ropes that yield to one another through several pulleys, you will surely waste your effort completely, and lose it.

Diagram. Fold-out engraved plate, *Fig. AA*, spread across a full opening: the great telescope being hoisted in the open field outside the city. A tall mast stands at centre, its head carrying a pulley block with a figure at the very top; from blocks on the mast, cables run to the long open-framed tube, which rises obliquely from lower right to upper left, its square frames (stops) set at intervals along it and horizontal rests carried out from it at several points. Lower right, the eye end of the tube is held in a trestle frame with a windlass; ropes run down to the ground. In the foreground a large crowd of men in long coats, hats in hand, greets and gestures toward the machine; at left a horse-drawn cart stands with its driver, workmen climb a ladder against the mast, and a dog runs at right. Behind, the skyline of the city with its towers and churches, cattle in the fields, a horseman and coaches, and on the right a long hill. Signed bottom left *A. Stech Delin.* [A. Stech drew it], bottom right *J. Saal Sculps.* [J. Saal engraved it]; the caption *Fig. AA.* stands at the foot, centre.

- x (top of the mast, beside the pulley block): label
- m, a, n (upper left, along the upper part of the tube and the rest carried from it): labels
- ω [?] (beside the horizontal rests, recurring at least four times): label-like mark
- e (on the mast, at the double pulley block): label
- b (on the tube, at the small pulley below e): label
- o (below the tube, upper left of centre): label
- z (below the tube, left of the mast): label
- f (on the cables right of the mast): label
- g or q [?] (at the upper left of the tube): label
- c (on the tube right of the mast, at a pulley): label
- r, s (along the tube right of the mast): labels
- d (at the stop on the tube, right of centre): label

- t (at the left end of the lower right rest): label
- S [?] (script capital, on the pulley at the head of the mast): label
- Z, Z, Z [?] (cursive capitals, on the sections of the tube near the trestle) and H [?] (script capital, on the last section, at the trestle): labels
- a letter just above the rope-block on the lower tube, right of the rope [?] (ζ, ʒ, ε, ξ or h): label
- M (script capital, lying along the far, upper-left end of the tube): label
- k (below the tube, with a swash tail): label
- l (below the tube left of the mast, above the toothed rack): label
- g (below the toothed rack, left of the mast, with a long leader): label
- k (on the bracket right of the mast, beside the upper wheels): label

But indeed this single cable, passed through those six small wheels, though it is very nearly the most important of all, is still by no means sufficient on its own for this purpose: namely, to keep this whole machine in its proper straightness. For although it does its work around the middle of the machine, at a b c d, it is by no means able to hold the extremities g and i themselves together so that they do not bend quite conspicuously toward the horizon.

[Margin: We need several ropes to raise this machine.]

Therefore, to remedy this as well, I decided first to set that upright F, erected on its base G, on the machine about its middle, to clamp it there with a double fork [angina], and to secure it with other bracing holders, so that it would not easily overturn. In what way all these were made and fitted together, however, I could neither show so very clearly in the figure nor, to spare paper, describe in words; so, if you please, you must work out the rest for yourself.

Over the upper small wheel k of this upright, then, just as was done for the preceding sixty-foot tube, I led another fairly thick cable (which I like to call the directing cable [rudens directarius]) toward the end g of the machine. There, namely where the weight requires it, I fastened one end of that cable, or hung it on a hook fastened there. The other end h of that cable I tied very firmly to the capstan [Ergata], which is built with a toothed bar about three feet long, a grooved little axle and other internal mechanism, and which is fastened at i, about the other, lower end of the machine. But if this directing cable is new, it must first be stretched thoroughly beforehand, so that it cannot afterwards stretch and lengthen too much.

[Margin: The directing rope.]

[Margin: The carrying rope is drawn tight by means of a capstan.]

Since this cable g y h has been added for this reason, so that both ends of the machine, upper and lower, can be controlled and raised far enough to rise again by as much as they fall short of the machine's straightness, this too is very easily done. For while you turn the capstan, or its serrated bar h i, which serves in place of an endless screw, by means of a handle (for better understanding I have given a drawing of its face in the earlier picture Z), that cable g y h is stretched and drawn in so far that of necessity, as a result, both

[Margin: How the machine is brought to straightness by means of the capstan.]

ends of the machine are forced to lift and raise themselves. This is done with that instrument, the capstan [Ergata], very gently, with almost no labour, by one hand. In this way you can, remarkably, bring the whole machine back to straightness with the greatest exactness if it falls short of it in anything — even after the machine has been raised and carried aloft, at any time you wish and whenever you see that it needs some correction and adjustment. For the capstan sits at the lower part of the tube, where it is always ready to hand for you to grasp it and turn its handle.

In this way, then, and with this capstan, by this single cable led from g through k to h, we are able to draw in and tighten amply at its ends this whole very large machine, one hundred and forty — indeed one hundred and fifty — feet long and of the greatest bulk.

[Margin: A singular aid for controlling this very vast machine.]

But if this machine were fifty feet longer still and extended to two hundred feet (and I am fully confident that I too could build such a one, with the help of the Divine Power), the directing cable g k h alone would not suffice, and a much longer one would be needed. I would likewise lead it through four pulleys to be placed about the ends of the machine, as we did for the central main cable, and also through another, lower, small wheel of the upright F, and between the two ends of the cable I would attach the capstan or that endless screw. With that aid the length and heaviness of the machine could be relieved far better still. Indeed, if these were not yet strong enough to bear the load, you could carry the central carrying cable, which passes through four pulleys, through six pulleys and a third small wheel of the upright F; all of which would bring no slight help to this very vast machine. In short, I say this so that you may see that I can build and control such a mass in many ways. Our present machine of one hundred and fifty feet, however, needs neither another method nor longer ropes, since with these, as has been shown, it can be very well secured and supported.

[Margin: How a machine of 200 ft could be controlled.]

Let this be a brief account, as far as it could be given, of the stretching and raising of this machine along its length. But, you will say, not everything is settled by this, nor have we reached the goal. For this construction is made of only two planed boards; and so, even though each quarter of this machine does not in itself, in fact, readily give way to any lateral bending, nevertheless, once those four parts are combined and joined by means of the forks, the machine will without doubt very easily bend and twist by a considerable amount because of its slenderness. I certainly grant that that excessive length and the extreme slenderness of the body produce some lateral curvature, namely when the machine is drawn up aloft and moved — above all if you control the whole machine by one end. This, however, I admit, must necessarily be avoided with

the greatest care if you are trying to accomplish anything accurate with this tube.

[Margin: How so very long a machine is to be tightened on every side.]

But how, you will ask, is this inconvenience to be forestalled? Very easily, I reply, and indeed with some lighter and simpler aid. For since the machine's greatest weakness lies where the ends of the parts are united and tightened by those forks and wedges, I attached a well-stretched light cord, tied at m, likewise firmly at o, and continued it again from p to r and from s as far as u, so that the joints of the boards and the tightening forks fall in the middle of the cord. At that place I applied to the base of the machine — that is, to the planed board — a wooden strip [ligillum], or small toothed beam, about four feet long but very thin, of fir, barely one and a half inches wide and one inch thick, as is clear from the preceding picture AA at n q t. Next, with these small toothed wooden strips [ligilla] set up like brakes on both sides, front as well as back (for a cord is attached there too in the way described), then, on whichever side the machine bends, I draw in and tighten the cord on the opposite side until it is enough, and set it under tension into the appropriate notch of the toothed strips (just as if you were drawing a bow), so that it does not run back or slip back. And indeed this is to be done on every side where a bending presents itself,

[Margin: By what means all lateral bending can be avoided.]

until you find that the machine has been brought back entirely to a straight line. This is easily recognized even without those sighting strips [ligilla visoria] which otherwise serve our tubes in place of pinnules, as was said in the preceding chapter, pp. 390 and 393: if you merely sight along the length of the machine to the points of the square perforated little boards, every curvature will at once reveal itself. But if you notice that, by tightening a cord — for example n — an error of excess has been made on one side, at once tighten the opposite cord vv and correct the excess again, and do the same in turn for the remaining curvatures, so that in this way you can look quite freely through all the holes, from the beginning, that is, to the very end of the machine. By this device you will not only bring the machine to complete straightness, but will also strengthen it at its parts, about the combinations and joints, so well that, taking hold of one end, where the eyepiece lenses are placed, you can move the other, most distant end, turned away from the eye, without any trouble just as you wish, while the machine always remains quite unbent and undamaged. It is necessary, however, that you raise and handle this machine in calm air; for otherwise the wind, because of its very great height, buffets it remarkably and keeps swinging it to and fro.

[Margin: Bringing the machine back to straightness even without the wooden strips [ligilla].]

You see, then, kind reader, how sometimes a very slight thing, of almost no importance, brings help to a great and arduous task, provided, that is, it is applied properly, rationally, and at its proper time. An example is ready to

hand: with a slender light cord, tightened by one finger onto so very thin and fragile a toothed wooden strip [ligillum], we can govern and direct so immense a mass with, that is, a very slight force — so much so that, when the cord is set into one or another more advanced notch, you at once feel that the whole machine has been noticeably changed.

[Margin: In the proper place and at the proper time even the smallest things are of very great value.]

So, once the whole machine has been straightened exactly, and it has also been well tested whether, in raising and drawing up as well, it departs in any way from its perfection or twists itself, those two boxes made of very light and very thin planks, namely H and M — the one fitted with the extensible little tube made, namely, of two sections [cicutae] z,

[Margin: The lenses are fitted to the machine in special boxes.]

and the other, M, into which the objective lens is set — I fasten to the two ends of the machine, one at each, with wooden holders and dovetails, so that they do not tilt in any way at all, much less fall off. But you must have found out and tested thoroughly in advance at what place the upper box M, with its convex lens, is to be fixed with respect to the distance between the lenses. For to search for the distance only once the tube has been raised, and to lower so great a machine and raise it again so many times, would be far too much labour. It is better, therefore, to test and find the true extension against terrestrial objects while the machine is lying down.

When, moreover, all these things have been done and observed, the whole machine stands ready to be raised and to display the phenomena. But since this machine is a huge mass, and runs on continuously to a great length, and needs a very large space in which it is to be joined together, fitted out and raised, I cannot handle it in the observatory of my house — above all because of the very thick and very tall tree trunk [arbor], which would have to be erected each time. I was therefore compelled to choose another place and a shelter for it, on a small suburban estate not far from our city, on a fine plain where a completely free view lies open on every side; above all because there the best facility is afforded for keeping both the machine itself and all its apparatus.

[Margin: This very large machine is set out toward the stars not in our house, but in a certain open field outside the city.]

In this place, under the open sky, I erected and set up a huge, very thick and very tall tree trunk, almost ninety feet long. It was first sunk deep into the ground and set upon a crossed base built of very strong beams, with its four stays [retinacula] bracing against it; and this indeed in such a way that it could not in any way be shaken by the force of storms or give way from its place, but would always stand unmoved. Holes have been bored in order upward along this trunk for inserting rungs, so that a carpenter, or someone else used to this work, may climb up and fasten that upper pulley, fitted with two small wheels, to the top of the trunk, and afterwards that very long and quite thick hauling rope through the four small wheels

[Margin: On the tree trunk by which the machine is suspended.]

of the two pulleys x and y — this he may then thread the more conveniently, so that the mass may be moved with the greatest ease and promptness. For the more small wheels the hauling rope passes through, the less power it takes to move and raise the weights, though somewhat more slowly.

[Margin: The hauling rope is led through several small wheels.]

With these things fitted out, it is now necessary that pulley y be tied to that other, double pulley e, through which the carrying cable otherwise runs. But this must be done in such a way that the upright k, with its directing rope g k h, remains between the said screws y and e and the tree trunk — for this reason: that the upright F may not lean to any side, and so the whole machine may not deviate even in the least from its more upright position. This is prevented all the more if the greater part of the pulleys a b c d is tied on the side away from us, toward the trunk, though with particular control; and then the upright, with its directing rope drawn over it and stretched, rests securely on the fourfold carrying cable, so that it cannot in any way be overturned together with the machine.

Moreover, below, at the foot of the trunk, I placed a windlass [succula], that is, a wooden beam [jugum] of cylindrical shape, laid crosswise on two upright supports and turning on its hinges [cardines], furnished with crossed bars [vectes]. By means of it that whole, most vast machine is raised promptly, with the help of only two men, as high as the phenomena require.

[Margin: The capstan [Ergata] by which the machine is raised.]

Then, when the machine has been brought up aloft, and that smaller little tube — built of two sections [cicutae] and usually armed with two eyepiece lenses — has been fixed to box H by its screw and properly tied fast with bindings, as we usually do, I apply to the machine that same revolving telescopic table of ours already described in the preceding chapter, and insert the machine between the two uprights of that table in the same way as we said in Chap. XX. And when I hang the two pulleys, furnished with a little hauling cord and its little weight, or counterweight [sacoma], in their proper place, without neglecting the remaining things to be applied besides, you will find it easy to direct even the greatest tube of all, namely this one of a hundred and fifty feet, just as gently, easily and quickly, and toward any object however small, no otherwise than if it were a tube twenty feet long, or a smaller one, not

[Margin: This 150-foot machine is moved and directed by the same device as the other, somewhat shorter, telescopes.]

Diagram. Engraved fold-out plate, Fig. BB, wider than a text page, signed *And. Stech del.* at lower left and *Saal Scu* at lower right (the last letters cut at the frame edge). At the centre stands a tall cylindrical masonry tower in cut-away view, crowned by a bell-shaped roof with a finial (A); inside are several storeys with ladders and men at work. From the tower a long square beam carrying a row of square-pierced blocks rises diagonally to the upper right and descends to the lower left, braced by ropes and pulleys hung from

the roof, with a spar crossing it at the tower; a second, plain beam runs from the tower down to the right, and a shorter tube runs from a tripod-mounted eyepiece at middle left up to the tower. The tower stands on a broad boarded platform with observers at benches and chairs with pierced backs: at the left a man stands with arms flung out beside the bench at the lower end of the long beam; a man stands looking up through the tripod-mounted tube; at the right a man crouches at the eyepiece of the right-hand bench, and two men in broad hats stand together, one pointing upward; two men at the right lift a long plank at the platform's edge. Beneath the platform, in a cut-away, is the tower's round foundation with two men at a long track of blocks, one kneeling and working at it with a rope, the other standing. Four insets surround the tower: at upper left, numbered 2, a horizontal toothed wheel crossed by bars, with pulley blocks hanging from its ends; at middle left, its number not read [?], a ring frame crossed by bars with a small toothed wheel on a plate, standing on a leg; at upper right, numbered 4, a winch frame with two worm-screws, worked by cranks, on a round base; at lower right, a walled pit containing a crown wheel on an upright shaft, with gearing and a framework.

- Beside the finial of the tower roof: A
- Right of the tower, from the top down: H, G, E, D (engraved reversed), C
- Inside the tower, beside the upper figure of a man: F; inside the lower storey: F
- At the tower foot, inside the cut-away: *m*
- On the platform, left and right of the tower: I, I
- On the front edge of the platform, left and right: B, B
- At right, beside the platform: Fig. BB.
- Upper-left inset: numeral 2.; small *f* at the four ends of the two long bars; small *e* at the ends of the three shorter bars (five or six [?]); *n* along the bars near the centre (three or four [?]); *d* three times, with leaders to the toothed rack
- Middle-left inset: number not read [?]; small *c* four times on the rim; *a* on the small toothed wheel; *b* on the plate under the small wheel; F below, at the leg
- Upper-right inset: numeral 4.; K under the base
- Lower-right inset: F at the top of the shaft; C at left; small *l* and *m* at the upper rim; a letter beside the pinion, d or g [?]; a letter under the lower wheel, f or l [?]; *l* on the frame post at right with greater labour, indeed, to direct. For that counterweight and that endless screw perform the same operation in the largest tubes as in the smaller ones. The whole machine, in fact, is supported at its centre of gravity, except that the lower part of the machine is made by design to outweigh the other, upper part, so that the counterweight — a little hanging weight of five or six pounds (though this varies from one tube to another) — can hold the machine very gently at any altitude.

Since I have already spoken abundantly and fully about this telescopic table of ours and its use in the preceding chapter, I forgo saying more here and refer the reader there. But you may perhaps add: "You have indeed shown a machine with two boxes fixed at either end for inserting the lenses; but how, I ask, are that whole machine and its intermediate parts to be covered? Will the said machine do its work when it is entirely open on every side? Will the light not pass through to the lenses and to the observer's eyes? Does this machine resemble a tube or channel closed on every side?"

[Margin: Whether this machine, open on every side, must also be covered when the lenses are to be inserted in it.]

I answer that the machine is indeed not really a completely covered tube; nevertheless it performs that tube's function fully, just as if it were actually covered on every side. For since those square pierced little boards stand only some three or four feet apart from one another, they keep absolutely all light away from the lenses and from the observer's eye. So when you bring your eye to H, the first opening, you find nothing but a very dark and very black tube or channel, and at its end only a single, perfectly round opening; for all those pierced boards are thoroughly blackened on their front side, toward the observer, so that you see nothing but a tube coated in black.

If the matter had demanded it, it would have been easy for me to make a true round tube out of this machine — namely by inserting very light paper tubes, three feet long, from one opening to the next and from one end to the other; just as in this machine of ours, near its beginning, starting from that square box H up to the fourth

[Margin: The said machine can, if it seems good, be covered and veiled without difficulty.]

opening, as can be seen at z, z, z. In that way you would certainly have a true tube covered on every side. Besides, I could also have produced the same effect another way: by covering and veiling the whole machine with a very fine and very light black linen cloth, or with a silk covering. But although this can easily be done, we have no need of any of these things — provided that at the beginning, starting namely from box H, three or four intervals, up to about ten feet, are closed with little tubes, so that the observer's eye does not stray at once at the start, nor outside light pass through to the eye. The rest, as I was just saying, we can very well do without, as you will indeed find by experience if you try it.

Lastly, I still have this to point out about the openings. Since the machine is of the greatest length, the openings have been made unequal on purpose: the preceding ones a little smaller, and the following ones successively somewhat larger, so that when one looks through they all appear entirely equal. Otherwise, assuredly, if they had been altogether equal, those set farthest from the eye would have appeared much smaller. Accordingly I made the first ones only eight inches, and the following ones nine, ten, up to eleven inches. It would, indeed, have made very little difference whether they had been quite equal,

provided the machine were nonetheless kept in a straight line, so that we could have looked through it perfectly; yet it is better that the foremost ones be somewhat wider than the others, nearer ones — for this reason: that the view should not be blocked at once whenever the machine bent itself a little. In addition, if the preceding ones are wider, it matters little whether the machine bends itself slightly about its middle.

[Margin: Why the openings fixed to the machine are of different sizes.]

Finally, just as it is altogether laborious, and cannot be done without some expense and loss of time — because of the work of very many men, which we cannot do without — to join together this most vast machine, to bind it, fit it out, raise, move and direct it; so too to let it down, unbind it, take it apart, remove its apparatus, and bring everything back to its place and keep it there, is no ordinary labour. But in this business it cannot be done otherwise; nor ought this to be, to any cultivator of the stars,

[Margin: It is indeed laborious to fit out this machine, and likewise to unbind it again and take it apart.]

troublesome and tedious. For since the tree trunk [arbor] stands in an open field, the machine, with its pulleys, ropes and all its gear, cannot remain there; rather, it is very necessary that each and every part be loosened, removed, and put back in order in its appointed place. Otherwise, assuredly, all those things that were procured and built at no slight expense and labour would easily be consumed by the harmful weather of the seasons, and go to ruin.

How this trouble might be avoided we mentioned in the preceding chapter: namely, if some convenient place were fitted out, suited to these machines and observations. But to bring this very thing into effect is not the business of any private man. There must be some Prince, a great Maecenas [Mecœnas] of celestial things, who would supply the costs most liberally and promote the whole undertaking. Then, I am fully confident, an observatory [Specula] and place of observation [Observatorium] could be founded and fitted out, where one could always, at any time whatever and as often as one pleased, go to fully equipped telescopes standing in perfect readiness, whether they are twenty, forty, sixty, a hundred, or even a hundred and fifty feet long. You would need nothing more (since the hauling ropes [funes ductarii] always hang deployed in their place) than to raise whichever one you wish — or even two or three of the very largest at once — and expose it to the stars; and in turn, whenever you wish, to put each one back at once, with its whole apparatus, in its proper place, without removing or altering anything in it. There each can rest safely, very little exposed to the inclemency of the air, and they are in no way an obstruction either to one another or to the observations. I pass over for now the other advantages; all of them, however, we shall treat fully in the next chapter, XXII, and we shall demonstrate by a clear drawing [Designatio] that the thing can succeed in this way.

[Margin: By building a more convenient observatory, all that trouble just mentioned can be avoided.]

CAPUT XXII.

Chapter 22.

De Peculiari Obſervatorio, maximis Teleſcopiis conveniẽtiſſimo.

On a special observatory, most suitable for the largest telescopes.

An observatory of this kind, for bringing longer telescopes of every kind to the sky and deploying them, most

[Margin: To build an observatory of this kind is granted to none but a Prince.]

suitable, can be conveniently built in the manner about to be disclosed, and furnished with the necessary apparatus: of this I am thoroughly persuaded. But, as we touched on above, this is not a matter for any private man; it is a matter for a great Prince, who would lack neither a convenient site, nor wealth, still less the zeal to promote so lofty an undertaking for the good of astronomy [Res Siderea]. For, believe me, the work would be laborious and costly at the outset; yet once it was fitted out, it would be easy to avoid the very greatest inconveniences in this business of observing. We would always go to telescopes standing in perfect readiness, and would never need first to assemble and fit out those very long and very heavy telescopes with such loss of time and such trouble.

Let there be built, then, according to our design, in some place open on every side and quite unobstructed, a round tower — not tapering, however, but equally thick on every side from the bottom right up to the top — either of joined timbers or of bricks, that is, of masonry (as each shall think fit), 100 or 120 feet high, if, that is, it is also to serve telescopes of 150 feet; otherwise the height of the tower can certainly be less. Let its width be at anyone's discretion, according to the convenience of the work and the required proportion; although, if no other consideration has to be taken into account, it can be as narrow as possible. For if only the telescopes are to be considered, it is enough for its diameter to run to 12, or at most 15 feet. For then the interior space would be large enough not only for all the things that, in our view, are to be dealt with there, but also for building various vaulted chambers and storeys [contignationes].

[Margin: In what manner this observatory is to be built.]

[Margin: The proportions of this observatory.]

In order that you may understand my plan the more fully and clearly, I have gladly chosen to set it distinctly before your eyes in the accompanying drawing B B; from it anyone at all who is even slightly versed in mechanical matters will at once readily understand the whole business, and amply. Namely, I would build, as I was just saying, in a field or some very open yard, a tower of that kind, as you see at A, and surround it all round with a quadrangular platform [Tabulatum], rising somewhat in height and resting on certain wooden supports, like some

[Margin: The tower surrounded by a platform.]

forecourt [Procestrium] or very spacious theatre. Its sides, so that they may match the length of the telescopes, should be at least 150 feet; and let the height of this proscenium [Proscenium] be 15, or at most 18, feet, so that the intermediate uprights [statumina] of the telescopes, set erect, over which the clamping cable [rudens adstrictarius] is otherwise led, can stand there. On the columns or uprights very strong beams are to be laid, in such a way that thicker boards can very well be laid on them and the whole forecourt conveniently roofed over. In this platform, moreover, close to the tower itself, let an opening be cut, so that a gap lies open through which the telescope, resting on the lower floor and fitted out with all its apparatus, can pass freely when it is drawn up, and which can afterwards be covered again with wooden covers, so that neither rain nor any of the observers and spectators walking about in the dark may chance to fall into that vault.

[Margin: The size of the proscenium.]

In the tower itself you may fit out as many storeys [contignationes] as you wish and need. Let the lowest room be a storeroom for the telescope gear; the remaining upper ones can be reserved for various purposes, as will shortly be said more fully. Above all, however, the tower must be so constructed that its whole upper roof, together with those four transverse carrying beams from which the pulleys are otherwise suspended, can turn round. For telescopes, even once they have been directed at the phenomena, cannot be held and kept in one and the same position and place, nor at one and the same elevation; they must continually be turned and directed according to the varying motion and position of the object. It is therefore necessary that the roof of this tower too be so contrived that it can be directed in every direction as easily as possible, and turned round without much labour with the help of one or two servants.

[Margin: The tower has several storeys.]

So that you may grasp everything the more clearly, I have not been reluctant to set the whole matter before your eyes in several figures [Schemata]. First, then, know that at the top of the wall of this tower, where the roof begins, I a very strong wooden ring, hollowed out in part, namely with a special groove or projection

[Margin: The whole business is explained in pictures.]

worked as can be seen at No. 1 — have set in place. To this ring, moreover, four crossbars [tranſtra] are fixed at right angles: partly so that this wooden ring might be the firmer, partly so that a grooved wooden little axle *a* could conveniently be fitted to the circumference of the ring by means of a board *b*. At *c c*, on the other hand, I hollowed out the ring for this purpose: so that another wooden ring of the same size, toothed on its inner side, as is shown at No. 2, could be let in and carried round in the same groove *c c*.

[Margin: On the movable toothed ring placed on top of the tower.]

To make this ring the sturdier — for it supports not only those four transverse carrying beams *ffff*, to which the pulley and ropes are attached together with

telescopes of such great bulk, but also the whole roof — I further strengthened this ring *d* with four crossbars *e e* fixed to it crosswise (on which the small joists [tigilla] of the roof otherwise rest); and also so that the whole roof, together with the carrying beams, the telescopes and the entire apparatus, might be turned round the more readily, and that with the help of one or two men.

[Margin: The whole roof of the tower is movable.]

To carry this out the more promptly, I fitted the grooved little axle *a* so that it engages the teeth of the larger wheel *d* exactly, and so carries that wheel round this way and that. There is no need, however, to turn the grooved little axle *a* by a capstan or a drawing machine [Machinâ attrectoriâ] from some upper storey H or G; it makes no difference in what place this is done. Here, in the accompanying figure BB, this little axle *a* is conveniently governed from room C, where for this purpose I set a drum on small beams fitted crosswise to upright supports. Into this drum, or yoke, which turns in its own sockets, another grooved little axle *b* is set, to be turned, namely, by the larger crown wheel *g*; through the centre of that wheel a very tall tree trunk F has been passed, which turns like a spindle with one point — its beak, that is — in the socket *k*. The other end of this upright trunk, which rises through all the storeys, carries the grooved little axle *a* at the top; so that in this way that larger upper wheel *d*, together with those bearing beams [portatariis] *f f* and the other four crosspieces *e e e e* on which the rafters of the roof stand, can be set in motion and carried round. This

[Margin: How the roof of the tower, together with the carrying beams, is guided and turned round.]

is now done by anyone, without much trouble, by means of a handle *m*, or lever, so that on every occasion we can direct and turn even the very largest and heaviest telescopes towards every region of the sky, very easily and very quickly. But if you prefer to use a shorter trunk for this purpose, it is advantageous to move the capstan from room C to some upper storey, or vault, G or H.

[Margin: By this machine the telescopes can be directed to any phenomenon of the sky.]

To lift the telescopes themselves, however, and haul them up aloft, I built a special drawing machine [Machinam attractoriam] out of four separate drums, as you see in storey E, or as is seen more clearly at No. 4, so that in this way four telescopes too may be raised aloft at once. For since the pulleys with their ropes hang from four different beams, it is also necessary that there be as many drawing machines at hand for raising and directing each tube. The leading rope [funis ductarius], moreover, is led through the pulley *f* and again through *n*, so that the whole business can be carried out under cover in the tower itself, except for the observations themselves, which the observer himself carries out in the open air, in that wide-open theatre.

[Margin: On the fourfold drawing machine.]

And in this way it is now possible to keep any telescopes whatever, fitted with all their apparatus, and all the other equipment as well, conveniently under

that most spacious platform [Tabulato], which is closed on every side. And again, when occasion arises, as often as one likes, it is possible to draw out any one of them, of whatever length it may be, from the vault or covered gallery — that is, by at once letting down the leading rope from those carrying beams *f* and tying the telescope to it properly — and to set it out for observations at pleasure with no great labour. So you can direct not merely a single telescope but four at once to the stars — indeed more, if need be, provided you fix and fit as many bearing beams to the wheel *d*.

[Margin: When observations are finished, the telescopes always lie hidden under the roof.]

How each telescope is bound with ropes and hauled up, and then governed at will by means of the little directing table [Menſulæ directoriæ], there is no need to recount here at length; for we have already discussed all these matters fully enough above, in their proper place, so that nothing more remains except to point out that, once

[Margin: How the telescopes are kept secure.]

the observations have been completed, you need do nothing but let the telescopes down into the vault through the opening, or door, B and I, take the ropes off the upper storey, and finally cover the openings of the platform with the covers intended for the purpose. And then you have stowed and secured each and every thing in such a way that not only are they kept safe and in good repair against all decay and damage from the air, but you also have everything fully ready again at any time, whenever one must return to observing.

In this way, indeed, we can avoid all that very heavy trouble, so that we have not the least need first to hunt out such huge machines from every hiding place, to assemble and combine them out of so many parts, and to construct, bind and fit them out with so many ropes, pulleys and capstans; and also, a little later, when the observations are done and an hour or two has passed, in turn to loosen, disconnect and carry back each and every thing to its own place, at the cost of very great labour to the observers and, above all, of time. For these reasons many excellent observations are quite often abandoned and neglected by observers — because, that is, of these most troublesome and most costly undertakings — which otherwise, to the greatest pleasure and the benefit of astronomy, would surely by no means be lost or slip by unobserved, if so very convenient an observatory of this kind were available.

[Margin: It is no ordinary help to possess an observatory of this kind.]

But truly, you will perhaps say, what private person will be equal to building this work? For, as I must freely admit myself, that tower itself is built only by princes. Yet so that you may see that this is not altogether impossible even for a private man of moderate fortune, such as you and I, I shall here disclose a still plainer method, which we can also procure for ourselves at far lighter cost, with the very same convenience and usefulness, as we have said, in almost the same way as if you had built such a most splendid and most costly tower with its open theatre or proscenium. It is done in this way: if at the foot of the tree

trunk described in Chapter XXI, page 415, and erected in some open courtyard wherever it seems convenient to you, a vault of some kind, enclosed on every side with boards and uprights,

[Margin: An observatory almost the same, and equally convenient, can be built at smaller expense.]

[Margin: A special enclosure [Secluſorium] to be built for keeping the telescopes.]

Diagram. Full-page engraved plate, captioned *Fig. Cc* at lower right. A tall vertical post stands at the right, pierced with a row of round holes. From it a horizontal arm projects to the left near the top, carrying a toothed quadrant arc, a hub, a small graduated disc on a vertical spindle with a worm, and loose parts (two pierced plates and a small screw) drawn beside it; at the arm's left end is a roundel on an upright block. Lower down, a second horizontal arm, held in a bracket with a scroll support on the post, carries a collar through which a vertical rod rises. At lower left a second, smaller assembly stands on a turned column: an upright block with a roundel, a short arm clamped to the rod by a screw with a ring head, a quadrant arc, and a perforated arc. The column rises from a base set on an oval floor, with a ground line receding in perspective. The plate shows a figure only; it carries no letterpress.

- P (upper toothed arc; also on the lower perforated arc)
- O (beside the upper hub; also below the lower arm)
- Q [?] (right of the upper hub; cursive form)
- B (on the tall post, upper and lower)
- K (on the upper upright block; also on the lower upright block)
- G (on the vertical rod, upper and lower)
- N (on the upper quadrant arc); N. (on the lower arc, with a point after it)
- F (on the collar)
- D (on the lower horizontal arm)
- C (on the bracket at the post)
- I (on the lower roundel)
- H (on the lower short arm)
- R (on the collar of the turned column, and on its lower shaft)
- S (on the neck above the base)
- L (on the base)
- M (on the oval floor)
- A (right of the oval) you were to build, of such a length and breadth, namely, that a telescope of some 150 feet, if you delight in one, could be kept and covered in it. This chamber [conclavium], however, must be closed on every side and, at the top, as we have said, well roofed and joined with boards — except that it should have certain openings of its own, or little doors [foriculae], at the top, so that the telescopes are given the freest passage, as is seen in the theatre above at B and I. In my opinion this chamber would suffice for keeping the telescopes and all their necessary apparatus, so that in this arrangement you would have

scarcely anything left to wish for, except that at every observation the hauling rope with its pulleys has to be untied from that upright tree trunk and carried away. It cannot be denied, then, that in this way we can avoid very many difficulties and troubles.

But this observatory is made far more apt still, and more convenient, if you run a trench of such size up to the trunk that you could construct in it an underground crypt, or cryptoporticus, sufficient in length, breadth and depth for storing and keeping the telescopes. The sides of this underground crypt must be either lined with wood or built of small bricks set in mortar; the upper part, however, should be closely covered with boards level with the floor, yet in such a way that little doors remain through which the telescopes are drawn out and put back in again. By this means, I think, you would have at hand whatever you could wish for in this respect, or could expect from that sumptuous tower described above. For you would be free to store the whole apparatus in that underground cryptoporticus, built at far smaller cost, so that nothing at all would remain but to open the little doors, tie the ropes to the trunk, and then go straight to telescopes [Tubospicia] of various kinds, fully prepared and fully equipped.

[Margin: If an underground cryptoporticus is built at the foot of the trunk, it would be the most convenient of all for observations.]

Meanwhile, however, if these observatories I have just disclosed perhaps do not yet please you, kind reader, you will, if you please, be able to devise others for the benefit of our goddess Urania and disclose them to us too: you will be doing something, believe me, altogether by far the most welcome to the surveyors of the stars [Astrorum Metatoribus].

[Margin: One must always labour on further still.]

CAPUT XXIII.

Chapter 23.

De Lentibus Conicis elaborandis & expoliendis.

On Working and Polishing Conic Lenses.

[Margin: What hyperbolic lenses can achieve, Descartes showed clearly long ago.]

What effect hyperbolic lenses can give when they are properly worked and perfected in every respect was demonstrated long ago, abundantly and fully, by the most celebrated Descartes [Carthesius], with none of the learned objecting. No less did he strive with all his might to hand down at the same time a certain machine and a definite method, by whose aid it would be possible to polish and finish lenses of that kind, as is evident from Book 10 of the *Dioptrics* [Dioptrices]. Following this author's lead, a great many learned men and distinguished craftsmen at once also left no stone unturned to achieve the same

thing by the method he had proposed. As for me, I too left nothing untried to perfect those conic lenses by the said Cartesian technique.

[Margin: The polishing of hyperbolic lenses by the Cartesian method did not succeed at all.]

But in truth this business succeeded happily neither for me nor for others, although we spared no expense and no labour, as is plain to all. Therefore, after some years had passed, almost all the learned came to the opinion that the Cartesian business of working hyperbolic lenses rests indeed on a most firm demonstration, but in actual practice, because of the double and contrary motion that has to be carried out, wholly lacks success; and so they gave up almost all thought of polishing those lenses.

[Margin: Almost all the learned despaired of working conic lenses.]

Others, and still others, did come along, attempting those hyperbolic lenses toward the desired end now by this method, now by that. But since most of them, as far as we have learned, took the matter up by that very route, through conic sections and a double motion, I think the business turned out thoroughly badly: for nothing whatever about it has been recorded or come to notice, much less have telescopes been constructed with lenses of that kind.

[Margin: By what method the Author at first thought to work those lenses.]

At first I too was stuck in almost the same opinion: that provided a certain hyperbolic segment perfected in every respect were obtained, the whole matter would without doubt turn out successfully. For that reason I was doing nothing other than trying to devise the said conic segments by another technique, plainly more certain than that Cartesian one: namely, to cut out and work any conic segment whatever, of the most perfect figure, from brass plates of any thickness. This work did indeed at last succeed for me as I wished; but, as will be said shortly, it contributed nothing whatever toward our working of conic lenses.

[Margin: By what route any conic segments whatever are to be cut out of bronze plates without any risk of error.]

Nevertheless, since such segments can conveniently be applied to burning mirrors, it will by no means be out of place to set out for students of optics this method of cutting out any conic segments whatever, by which one can work and perfect exactly not only hyperbolic sections in wood, bronze or iron, but also any parabolic and elliptic ones.

[Margin: Sections of every kind are made by that method.]

First, out of the hardest wood, I made and turned a right cone, and indeed a right-angled one, whose base was 30 digits and its axis 15 digits. But since I had no need of a pointed cone, I truncated it, so that its smaller diameter remained only 18 digits. This truncated cone, however, was by no means made from a single whole piece of wood, but was composed of several parts: one of them was so arranged that it represented a parabola exactly, another a hyperbola, while the larger, middle part represented a parabola and a hyperbola together, so that the wood from which this truncated cone was to be built consisted of three parts. Moreover, those parts were firmly joined with wooden pegs, but

in such a way that they could be separated again neatly and undamaged when needed. Then, once this wood had been turned most perfectly into a truncated cone, I again separated those two outer parts, which were attached to little wooden columns and then presented in every respect a parabolic section on one side and a hyperbolic one on the other. And then, following the edges of these segments, I first traced those very sections on brass plates, well hammered and strong enough, and also worked them, though only roughly; afterwards those plates, by means of the little columns already mentioned, between those parts of the truncated cone (the wooden parts), I inserted them, and joined and fitted them firmly together again. With these two plates inserted, I put the cone back on the lathe and removed and scraped off with a file the greatest part of its unevenness, its projections and its roughness. Next, with the utmost evenness and the greatest care, I turned this truncated cone, together with the plates inserted in it, true for both the parabolic and the hyperbolic section at once, and smoothed it properly. When this was done, I took the cone apart and drew the two inserted plates off the little columns, or little axles, to which they had been fastened; and so I had both a parabolic and a hyperbolic section, made and filed most exactly. And so you see by what method it is now easy for you to work sections even of the most widely differing kinds (according as you take a larger or a smaller cone, a more obtuse or a more acute one), and at the same time, at a single stroke, ellipses of the most varied kinds too, without any risk of error.

[Margin: This method of making any conic sections whatever has, I think, scarcely been known until now.]

Whether this way of bringing any bronze plates whatever to the figure of any of the conic sections was already known before is quite unknown to me, for I have neither read anything on the subject nor ever heard of it. Unless my opinion deceives me, I think conic sections can be fashioned far more perfectly by this method than by the Cartesian one. Be that as it may, and although these segments worked by our method come near enough to perfection itself, they nevertheless contributed nothing whatever, as we have already touched on above, toward our working conic lenses exactly; rather, the whole matter came to nothing entirely, by whatever route I attempted it.

[Margin: The Author set about working conic lenses by another technique.]

Having learned by experience, therefore, and seeing that we were labouring in vain in that way, I set about this business quite differently, namely by means of a certain singular machine [Machinamentum]. With it I successfully polished, many years ago now, several conic lenses, which I still keep with me even now. But since, with the passage of time, a great many other occupations and celestial contemplations came along, I worked no more of them, nor did I toil over improving this technique further; as indeed I am fully confident it can also be done:

especially by those investigators and craftsmen of optical matters who are intent solely on such things. Without doubt, if only it is taken to heart by some,

this invention will be made far more perfect still, so that we may obtain glasses of this kind no less for the very longest tubes of all. To put it more plainly: the one I myself once made serves only a telescope of nearly two feet; and yet I have learned by experience that it far surpasses the other glasses worked from a spherical section for tubes of the same length.

[Margin: Making conic lenses on any spherical dish, or on any plate whatever flattened perfectly level.]

This very method of polishing conic lenses seems to me (unless my opinion deceives me) the simplest and plainest, and not so very difficult. For we have no need of any conic sections, nor of pans or dishes of that same figure, much less of a special lathe, skilfully and expensively equipped, and above all of a drum hollowed out to a conic form. Rather, any conic lenses at all, for shorter as well as longer telescopes, are worked by free hand in any dish whatever prepared from a spherical section; and best of all on some perfectly flat bronze plate or table, with one single, simple, continuous circular motion alone. At first sight this will seem to some almost strange, indeed altogether absurd. Nevertheless, as will be clear from what is to be said, the work turns out successfully, provided that each and every part is most suitably fitted out, actually turns freely, and is moreover put together with a rather light construction.

[Margin: Construction of the machine for working conic lenses.]

Upon the table A, therefore, intended for preparing glasses, standing very firmly on its feet and well secured on every side, erect a square wooden upright B, in the manner that can be seen from the accompanying figure Cc, and that perpendicularly and very tightly, so that it may in no way nod or wobble. To this upright B the arm D is fitted by a channelled clasp C; at its end the arm is furnished with a round, perforated piece of wood F. Through this hole F there passes in turn a round piece of wood G G, namely a spindle [fusaria], so that it can be turned round most lightly and smoothly. Each and every part is made of wood; but it would serve this business better if this spindle G G were cast of brass, and that opening F were lined with a plate, so that it might yield to the revolving the more gently and freely. For very nearly the whole business turns on this part.

[Margin: This little machine must turn most freely.]

Moreover, at the lower end G a little head, or projection, has been left, pierced by a square hole. Through this hole in turn the square crosspiece H is inserted so as to turn, and at its other end, at I, it is joined by a hinge to another square piece of wood K, namely the trailing spindle [fusus raptitarius]. The spindle K just mentioned is inserted from the upper side into the perforated piece of wood R; from the lower side, in turn, goes the little headed column S, to which head, or hilt [Capitellum sive Capulum], L the glass, which is in any case to be polished, is fixed with prepared pitch [bitumen]. All the little columns must turn most freely in their little channels, so that they follow and yield very readily to any turning round and rotation. And so that this may succeed the better and as one wishes, it is advisable that both the channels and

the little columns be protected and lined with plates, so that they may turn the more freely in motion. To the wood K, moreover, is attached the arc N O P, passing through the crosspiece H. Its purpose is that the whole lower part K R S L, or trailing spindle, can be spread apart and set at a definite angle, at any inclination whatever, and be fastened there most exactly, either by means of some clamping screw at O, or by driving a pin through, or in another way by means of some small wheel and its endless screw Q.

[Margin: How the operation itself is carried out.]

When, therefore, as we have just said, everything has been made and fitted out, and the arm D has been duly fixed in its place by a pin driven through it, set under this little machine some dish, of whatever spherical section it may be, if it is all the same to you whether you make a more or a less pyramidal conic lens. For the larger the segment from which that dish or pan has been prepared, the less humped the lens to be polished will become, as is easily understood. Indeed, it is better to set under it a bronze plate, entirely flat and good and wide, so that afterwards, in the operation itself, you are not forced to keep so strictly within the limits of the dish, but can move this flat plate from its place as often as you wish, so that the glass L is not turned round at all times always in the same place or circle. The plate itself, this flat one, must also be fixed firmly in its place on the table A with little nails, so that it may in no way shift or wobble. On this plate M, then, the glass L that is to be polished is driven round very swiftly, together with the whole lower apparatus S R K H G, or trailing spindle; but it is necessary that you first fasten H at G with a little screw, and also fasten the arc firmly at H at a definite inclination. For if you set the trailing spindle K R S L wholly perpendicular, along the line G F G of the spindle [Fusaria], you will obtain nothing but an entirely spherical lens in a spherical pan, or, on the plate, if the thing turns out well, a flat glass.

[Margin: With a different setting of the machine you will make conic lenses now more obtuse, now more acute, even in that very spherical dish.]

But if the angle K I H is set somewhat more obtuse than a right angle, you will make in a spherical dish, or on a flat plate, conic lenses to any segments whatever of any cone whatever, according as that angle departs more or less from the right angle. For if the angle K I H differs less from a right angle, you will produce more obtuse, or flatter, conic lenses; the contrary will happen if the angle exceeds the right angle by a notable amount, or falls short of it, as you will easily learn by use and practice. Taking hold, therefore, of the hilt L, to which the glass has been glued with pitch, as we mentioned above, drive this little machine round with the other hand until you have entirely finished the lens. For since the spindle G G, above all a bronze one, turns very freely in its little channel F lined with bronze, especially when smeared with oil, this can be done without any trouble.

[Margin: What is to be observed in the very operation of polishing lenses.]

But note that while you drive the glass round in this way, it is most necessary that you often at the same time, indeed with an almost continuous movement,

turn the little column S in its little channel R, in the same way as we are accustomed to prepare spherical glasses by free hand in their dishes; otherwise you will certainly go astray continually and will scarcely ever reach the goal. But if you undertake the thing with a nimble hand, and properly, as we have said, you will see that at first the glass glued to L is edged [marginari] around its margin at its outermost parts, just as happens with all spherical lenses; and that thereafter it verges successively more and more toward the conic section, as indeed it cannot happen otherwise. For since the glass, along the perpendicular or line of the spindle G F G, deviates somewhat, it cannot at once touch the flat plate with its whole surface, nor any dish whatever curved to a circle; rather, its margins must first be worn away. I would also have you note here that during polishing the glass L S must quite often be taken out together with its little column, by lifting the spindle G, and examined: namely, to see whether the glass is being edged uniformly on every side — that is, whether it is being gripped and worn away on the plate laid beneath it, so that its point tends exactly to the centre — or whether something is still lacking besides, as usually happens with other lenses. It will especially help in this if from time to time you also move forward the flat plate set beneath, as I said just now, so that the glass does not run continually in one and the same track but marks out one track after another, and also so that you keep the plate in its evenness. For unless you watch over everything carefully, as you readily understand, you will sooner ruin the glass than bring it to perfection.

[Margin: The author, hindered by other business, could not develop this art further.]

A good many years ago now, by the method described, I made and polished several conic lenses, with fair accuracy, I believe; I still keep them by me. I also hoped, as time went on, to advance somewhat further in this art and to make more lenses of the kind. But since other business came upon me, entirely different and quite laborious, I was forced to abandon these efforts entirely; nor do I see how or when I could find time for them, since, besides, the weightiest celestial contemplations always keep me most fully occupied.

[Margin: The author is persuaded that in the course of time this business can be made more perfect by others.]

I shall therefore entrust this task to others who have more leisure, and who are without doubt far more practised in this business, who have moreover already achieved a great deal in polishing lenses — indeed have spent almost their whole lives in that work. I am thoroughly convinced that if they follow these footsteps and apply this rule, then, with God and time, still more excellent and more perfect things may perhaps be discovered in this kind. For this reason I have now gladly chosen, as the occasion offers, to share this invention, such as it is, with each and every expert in mechanical and optical matters, for them to examine it and test its powers; but above all for it to be more and more developed, so that at last, as all of us wish, we may successfully obtain those most desired lenses not only for smaller telescopes — such as, God willing, we

already have ready — but also for the very largest of all. Nor do I in the least despair of this: that in this business those craftsmen most practised in optical matters will at last reach the hoped-for end; and indeed that this very little machine for working conic lenses can be made more perfect in various ways. And to see that this too is not altogether so absurd, look at what I myself have attempted further, and how I obtained the same operations with the machine above partly altered. I cut the arc N O P into a saw, that is, fitted it with teeth, and set an endless screw Q at H, so that at any time you can place and set the lower leg K — that is, the trailing spindle with its apparatus R S L — to a hair, most exactly, at the proper inclination and at a definite angle K I O, by means of that small wheel which is mounted on the drum of the endless screw and divided into its small parts, as is clearly evident from the preceding picture. But in my view we have no need of this refinement, provided that the holes in the arc N O P are bored exactly and the arc does not wobble at H at all.

[Margin: Polishing those same conic lenses by another method.]

For the rest, these conic lenses are prepared in yet another way, which rests on the same foundation as the one above, however entirely different it may look. In place of H R of the preceding figure Cc, and of the arc N O P, a cone Z has been substituted and fixed to that round piece of wood, namely the spindle G, as can be seen from the accompanying Fig. Dd. Next, the same cone is hollowed out on one side at X, so that you can very well spread apart and draw together the trailing spindle K — which at V is joined by means of a hinge to the iron W, to the spindle G and to the cone Z — under the guidance, namely, of the longer screw T. For since the cone is hollowed out at X, the trailing spindle just mentioned can certainly be set wholly perpendicular together with the spindle G; in that position you will make nothing but spherical glasses, namely in spherical dishes, and on a flat plate nothing but flat ones. Therefore, with the trailing spindle K and its apparatus R L set at some angle, that is, departing a very little from the perpendicular, it is altogether necessary that you make the conic lenses from this inclined position. The trailing spindle K, moreover, as is evident, has likewise been inserted into the channel R, just as the hilt L with its attached glass has been, by means of its little column S. And so, once the work has been duly done, you will obtain the same operation and will work the same lenses.

[Margin: Which method is superior to the other you will find out by setting your hand to the work.]

Which of the two methods is now to be preferred to the other I leave to experts in these matters to decide. Without doubt, in the course of time it will be possible to make these inventions still easier and more perfect, especially if anyone devotes their whole mind to that work. I, for my part, have done my duty as far as has been granted me; and, given this occasion, I have most gladly chosen to reveal everything whatever to each and every one — but above all to give the more practised opticians an opening, and to rouse them to develop these things further and to devise better ones.

[Margin: Those who are intent on one single thing achieve greater things than those intent on very many.]

For those who are devoted to no other studies, and give all their strength to this one thing — why should they not in time bring it about that, by an equally very easy method as that by which lenses are now made from any spherical section, they at last make and assemble hyperbolic lenses too, for any of the very largest telescopes, to the very great benefit of astronomy? I am indeed thoroughly convinced that, although with our largest telescopes we have so far revealed a great many things most worthy of note, far greater things will nevertheless be disclosed once hyperbolic lenses are used; and we pray from the heart that this may succeed as we wish, as quickly as possible!

[Margin: By means of mirrors telescopes will without doubt be made more perfect.]

Lastly, I also hold great hope not only that our celestial contemplations will grow more and more once these hyperbolic lenses have been duly worked, but also that beyond doubt they can be advanced in a wonderful way by yet another, different method — namely with the aid of mirrors, flat and spherical as well as parabolic, if these were applied and fixed duly and suitably to tubes already armed with their lenses. So we see that the distinguished Newton [Isaac Newton] made a quite successful beginning in this field not so long ago, namely by assembling a shorter little tube

Diagram. Engraved plate, captioned *Fig. DD.* at the lower right, occupying the leaf within a ruled frame. At the upper left stands an apparatus on two truncated-cone bases: a tall cylinder (F) carrying a rod (G) is set in the left base, and a slender post (G) in the right base; a horizontal arm (D) joins the cylinder to a square box (C), pierced with a round hole, at the top of the right post, with a small scroll bracket under the arm. From an eye (V) at the top of the left base, beside a collar (W), an inclined rod (K) runs down into a long handle (R, S) whose lower end swells into a knob (L), resting on a large oval plate (M) whose rim is milled. A round knob (T) is screwed into the left base by a threaded stem. Dotted construction lines inside the bases are marked Z, X, Y on the left base and Z, X on the right. Below, lying on the plate, are two detached pieces: an eyed strap (W) and a rod (K) with an eye at its end (V).

- F (upper left, on the tall cylinder)
- D (horizontal arm)
- C (box at the end of the arm)
- G (rod beneath the cylinder; also on the right-hand post)
- V (eye at the top of the left base; also at the eye of the detached rod)
- W (collar on the left base; also on the detached eyed strap)
- Z, X, Y (inside the left base); Z, X (inside the right base)
- K (inclined rod; also on the detached rod)
- T (round knob at the left)
- R, S (the long handle)
- L (knob at the lower end of the handle)

• M (the large oval plate)

Blank page (verso of the plate; the engraving shows through in mirror image).

from two mirrors and one plano-convex lens, by means of which, as they think, the usual telescopes can be greatly shortened.

[Margin: That mirrors may be applied to telescopes has not been discovered only now; it was already successfully attempted by the author 35 years ago.]

Of this new invention, however — inserting mirrors into tubes and building tubes with them — a certain most distinguished man writes that no one up to this year 1672 had attempted the same thing, unless you except the noble Hugenius [Christiaan Huygens], who had applied a certain small bronze mirror to tubes; when it was removed, all objects otherwise appeared in inverted order. But, if I may say so with that man's leave, either it has perhaps slipped his memory, or he has not read at all what is set out in the *Selenography*, published as long ago as the year 1647: namely, that the author of the *Selenography* — the first discoverer, that is, of that polemoscope [Polemoscopium] — already in the year 1637, that is, 35 years before, applied to tubes with the most fortunate success two mirrors at once, of glass as well as of metal, and at the same time two lenses, one convex and the other concave, with the mirrors placed between them. As this is before everyone's eyes, so it is also abundantly and plainly evident from the *Selenography* itself, page 26: "This tube, then," says the author, "is prepared on catoptric as well as dioptric foundations: for it consists of two plane mirrors and a pair of dioptric glasses, namely a concave and a convex one." So it may be asserted with the utmost truth that mirrors were already successfully applied to tubes 35 years ago — but never earlier by Europeans, so far as I know.

[Margin: Without doubt the first invention — joining mirrors to lenses — is owed to the author of the *Selenography*.]

Hence it is beyond all controversy that the first invention of this thing is to be ascribed entirely, and before anyone else, to the author of the *Selenography*, since he was the first to put mirrors into tubes. "But," you will say, "only into polemoscopes, and by no means into telescopes?" But, I ask, is not the polemoscope a species of telescope, and nothing but a bent telescope [Tubospicillum], by whose help — as the *Selenography* attests — you can view objects with direct rays (if you wish) as well as with oblique ones? Beyond this I am fully of the opinion, unless I am mistaken, that the construction of the polemoscope certainly showed the distinguished Newton the whole way to building his shortened little tube. For consider, I beg you, picture B on page 26 of the *Selenography*, in which all the parts of the polemoscope are set out one by one; above all the front part *b*, by the observer's eye *a*, where the other mirror is kept, and its opening, made in the side of the little tube, through which one is to look: is it not of exactly the same construction as the distinguished Newton's little tube?

[Margin: The author of the *Selenography* also knew perfectly well that telescopes can be shortened by means of mirrors.]

Moreover, it by no means escaped the author of the *Selenography*, as one may read on page 27, that mirrors, if they are applied to telescopes, can shorten the tubes considerably while keeping the same effect (which, unless I am mistaken, is also why the distinguished Newton undertook that construction of a telescope with mirrors). For the said author of the *Selenography* says: "Two further precautions are necessary for the maker of this polemoscope, if you do not wish to go wrong. The first is that the position of the two lenses, the concave and the convex, requires here a different separation from that in other telescopes: for in this instrument the distance must plainly be shorter, if it is to meet expectation."

[Margin: The author is fully persuaded that with the help of parabolic mirrors this business can be carried still further.]

I am also fully persuaded that if not only metal mirrors with a single dioptric glass, but parabolic mirrors, together with those usual spherical lenses — or rather with suitable hyperbolic ones — were applied to the construction of the longest telescopes and combined with one another, something still more sublime would without doubt be discovered. This I by no means count among absurdities. But the work requires craftsmen capable in these matters and free from business, who would weigh it, examine it, explore it and bring it to light: those who are committed to a great many other occupations will accomplish it only with great difficulty. For there is need not only of leisure but also of long experience of things, since these matters have to be drawn from many experiments, and they are obtained more readily from practice itself than from theory.

[Margin: What mirrors can do in a darkened chamber for showing the images of objects.]

Lastly: that mirrors — both glass ones, convex on one side and laid over sheets and quicksilver, and those cast from bronze — are also more effective than bare dioptric glasses in darkened chambers for presenting the images of objects, I have tested amply and more than amply by experience itself for 30 years now, and have quite often shown it to a great many guests who visited me. But since this matter has perhaps become known to very few as yet, I wished on this occasion likewise to disclose it gladly; above all for this reason, to see whether it might give some investigator of optical matters an occasion to develop this further, especially of applying mirrors to telescopes, so that we may at last achieve in building telescopes what we have already successfully accomplished in all darkened chambers.

[Margin: When a convex lens is applied to the opening, objects are presented very clearly.]

For we know for certain that if a convex glass is applied to the opening in a darkened chamber, the images of visible things outside, falling through the said lens onto a white board, are represented much more clearly and brightly, with

all their colours, than if they are let in through the bare opening; and all the more accurately, the more perfectly that convex glass has been worked from the segment of a smaller or a larger sphere — so that you would swear that nothing could ever be shown more lucidly, more distinctly or more perfectly.

[Margin: But still far more clearly with a concave mirror properly applied.]

But truly, you will hardly believe me unless you have tested the thing yourself and put it before your own eyes, how much better, more clearly, more distinctly and more brightly the images of all visible things are shown by means of a concave mirror set in place of the board. Indeed they are shown so distinctly that at a distance of several hundred paces I can both make out and count the bricks of towers, and even letters of some size, in the darkened chamber, exactly as if the Sun were lighting the whole place fully, even though the sky is covered with clouds on every side.

[Margin: How this may be arranged.]

This is done in the following way. In exactly the same place where the white board that receives the images of visible things was set up, put a concave mirror, worked from the segment of some larger sphere and cast from metal; or, if you have none available, in its place a plano-convex mirror of glass (for it comes to almost the same thing), covered with quicksilver [Hydragyro] on its convex side. But do it in such a way (which will doubtless seem difficult at first to someone unpractised) that while you look into the mirror you at the same time look through the opening of the window, fitted with a convex lens. Then whatever you perceive in that opening, shown in the mirror, will — believe me — appear wonderfully clear and lucid, so much so that the same images falling through the bare convex lens onto the usual board cannot be compared with those in the mirror in any way at all. Something almost similar, also by means of some

[Margin: Almost the same is achieved with some convex dioptric glass.]

dioptric glass, convex on both sides, somewhat larger — six or seven digits in size — and moreover polished from the segment of some larger sphere, you will obtain; provided, that is, that with one hand you likewise bring this glass, in place of the mirror, up to the board on which the images otherwise fall, and direct that glass at a certain distance, relative to the eye of the viewer, so that either you yourself or anyone else, while you look at that glass, can perceive by means of the rays reflected through the opening of the window whatever is set before it and whatever you wish. And then you will make out the individual objects that present themselves outside the darkened chamber almost as accurately, clearly and brightly as by means of a concave mirror.

[Margin: From which it may be gathered that telescopes can be assisted by mirrors rightly applied.]

Therefore, since it is more certain than certain, and also well founded and demonstrated in optics, that concave mirrors assist all convex glasses wonderfully, make them clearer and more perfect, and also increase and intensify in wonderful ways their powers for making out the images in a darkened chamber

at any distance — in respect of convex lenses — more accurately and more exquisitely, indeed much more clearly: it must certainly also be granted that if only concave mirrors, above all parabolic ones, were applied rightly and suitably to any tubes, however long, combined, that is, with those usual convex lenses — altered either all of them or in part, and arranged in one way and another — then all telescopes could indeed be made enormously more perfect.

[Margin: An exhortation to experts in optical matters.]

For that reason I wish each and every expert in optical matters to be asked, again and again, in the public name and for the good of the republic of letters, that each of them, according to the gifts of his talent, should come to the aid of this undertaking and do his duty. I do so relying on the most certain hope that God, Best and Greatest, will in His own time grant happy success: since this study of ours is undertaken by us solely for the fuller knowledge of His wonderful works, and redounds most widely to His honour and glory, so that we may at last be made masters of that most desired thing.

CAPUT XXIV.

Chapter XXIV.

De Stellæburgo noſtro, diverſisq; Speculis Aſtronomicis.

On our Stellaeburgum, and various astronomical observatories.

[Margin: Now that all the instruments have been drawn, it is also worthwhile to put our Stellaeburgum itself before the eyes, by way of an appendix.]

With God's help, and according to our modest ability, all our instruments — astronomical as well as optical — that I have used until now and still use have been exhibited, drawn and described, abundantly and fully, and none of the things that seem to bear on their construction, use and improvement has been neglected. I now think it worthwhile as well, before I bring this First Part of the *Machina Coelestis*, or the *Organography*, wholly to an end, likewise to show lovers of the stars our Stellaeburgum, such as it is, with its observatories and certain little cabins [Tabernulae]. In this way it may be clear how that Stellaeburgum was founded and built, and in what order all its parts hang together, as the sequence of these matters altogether requires.

[Margin: Astronomical instruments also require a convenient observatory for themselves.]

For once astronomical instruments for exhibiting the stars have been built and supplied, it is also altogether necessary that there be a convenient place — a lofty and very open observatory — where, with all obstacles removed, the individual instruments can be arranged so that they are a hindrance neither to one another nor to the observers, when they may happen to have to be set up and directed for observations at the same time (each, of course, in its own way).

[Margin: This Stellaeburgum of ours falls far short, in splendour, of Tycho's most splendid Uraniburgum.]

But truly, kind reader, there is no reason for you to persuade yourself that I am going to set before your eyes an Uraniburgum [Uraniborg] so magnificent and splendid, so very ample, indeed so royal — such as the most noble Tycho possessed, built for the greatest part by royal command and at royal expense — that it could be matched with his, much less preferred to it. By no means. For you will see not a royal but merely a civic Stellaeburgum, belonging to a man hardly more than private, a modest cultivator of the stars, who had to draw all the expenses whatever, for the buildings and likewise for making the instruments, from his own purse alone, and to measure and direct the whole undertaking by the scale of his slender means — and indeed by the lie of the site and the position of the buildings already standing, on top of which everything had to be built and arranged.

[Margin: In convenience this Stellaeburgum of ours hardly yields to others more eminent.]

Yet I have no doubt at all that, given our modest condition as God has granted it, this Stellaeburgum of ours — although it by no means consists of splendid marble, built magnificently, with very many towers, palaces, crypts, galleries and terraces built in the Corinthian manner and proudly adorned in various ways — is nevertheless just as fit and most convenient for celestial observations and contemplations, that is, for housing and arranging the most diverse instruments, both astronomical and optical, as some other one far more splendid, more magnificent and raised at much greater cost.

[Margin: The convenience of the site.]

For this observatory of ours has not only an entirely free prospect on every side — although it rises only moderately high — so that the horizon lies fully open almost all round, but also a most convenient means of directing any of our instruments. So in that respect, as regards its capacity and situation and above all its convenience, it hardly yields — let there be no boasting — to certain observatories far larger and higher.

[Margin: Less lofty observatories are often more convenient than higher ones.]

For astronomical observatories, although they may be far loftier — indeed, granted that they are as high as can be — in no way achieve anything more than some place that rises moderately and offers a free horizon all round. Moreover, such remarkably high towers and very lofty buildings are seldom found in the neighbourhood of the observers' dwellings and studies. Hence, if one has to go so often, by day and night, to an observatory so far from the house, and climb it by so many stairs, above all in uncertain and adverse weather, it is certainly very tiresome and troublesome for the observers, and even harmful to the observations themselves. For much time slips by before we get there, climb up, come down again and return home, so that a great deal of time is used up before we approach the observations themselves.

[Margin: It is better to have an observatory very close to one's study.]

Therefore I am thoroughly convinced — and very many will also agree with me on this point — that it is better, and much more convenient for observers of the heavens, especially those intent on these matters constantly and every night, that they should have an observatory

Diagram. Upper left panel of a fold-out plate, in a draped and fringed frame: a row of three gabled house fronts with steps to their doors, and behind them a long roof carrying a railed rooftop platform with small pavilions and a taller wooden housing. No reference letters are legible on this panel. Engraved at its foot:

- lower centre: A. Stech Delin. ("A. Stech drew it")
- lower right: J. Saal Sculpſit. ("J. Saal engraved it")

Diagram. Upper right panel of the same plate, in a matching frame: a pavilion on the roof with its shutters opened round a central mast, with trees and a river beyond; below, two opened gable housings each hold an instrument (a sextant-like frame and a quadrant-like frame), unlettered.

- A (beside the top of the mast)
- A (beside the right-hand opened shutter)

Diagram. Lower panorama running across the fold: a view over the roofs of the town, with a church tower at the left, a long railed platform on the rooftops carrying instruments and observers, a long telescope slung from a mast, and shipping on the river beyond. The figure designation is engraved in script at the lower right; its first letter cannot be told apart between E and L.

- D (on the tall wooden housing, left of centre)
- C (on the small cabin at the left)
- B (on the front of the platform, left)
- B (on the front of the platform, at the fold)
- E (on the gabled structure at the left)
- F (below the E)
- a small mark at the extreme left edge near the foot of the tower, not settled as a letter [?]
- Fig. EE. (lower right) of the heavens [Uranicam], very close by — indeed in the house itself, not far from the study — most convenient for observations of every kind, enjoying a free outlook, and in fact not excessively high; above all one where the whole apparatus of instruments need not be sought far off, but everything is ready to hand. For now these things, now those are needed for observations: now books, instruments, clocks and telescopes, now the most varied equipment, very necessary for the business of observing. If all this always had to be fetched from very distant buildings, would you not use up a great deal of time on such side-matters before you could even undertake anything worth recording, let alone carry it through?

[Margin: Uraniborgs must be as well suited as possible to observations of every kind.]

In building any Uraniborg, however, the chief thing to be noted is that it should be (as we have already touched on) equally apt and suitable at all times for all observations of every kind — not that it should strike the eye in an outstanding and remarkable way, shine from its façade, and have royal rooftops, splendid roofing, ingenious towers, galleries and terraces, and illustrious projecting eaves [Protecta], built with wonderful art. Such things do contribute much to ornament and magnificence, and they also please the great. But what do all these things contribute to the celestial observations themselves, when the façades, galleries, towers and cornices of buildings stand in the way of the primary business and of the view?

[Margin: Tycho's Uraniborg (if one may speak freely) suffered from many disadvantages.]

The most celebrated Tycho, as is plain from his *Mechanica*, possessed the most splendid Uraniborg on the island of Hven [Huenna], which from every side of its exterior strikingly dazzled the eyes of spectators. Nor do I doubt that within its roofs, deep in its interior, as the author himself affirms, it had most commodious living quarters, chambers and studies wonderfully adorned. But if you look at the upper observatories and the open-air courts of that castle, where the most varied instruments for searching out the stars were set up — then truly, to say it with the leave of that eminent man, and if I may speak my mind, it seems to me that that most spacious and most august castle, given its site and the advantages of its location, and the very great sums spent on it, certainly in our own time, if it now had to be founded and built, for observations of any kind could have been built far more commodious and convenient.

[Margin: For observations it is fitting that Uraniborgs should command as free a view as possible.]

I, for my part, would certainly have removed altogether so many rooftops, so many turrets, galleries, and so many chimneys projecting for ornament, or at least avoided them, and would have raised the principal observatory above the rooftops themselves, so that nothing whatever of that castle would have been an obstacle to observations on any side — that is, by constructing a perfectly level platform open on all sides. Nonetheless, the most varied storeys [contignationes] and special vaults for certain instruments could still have been built.

[Margin: Hence Tycho could not observe with just any instrument at all times.]

But since Tycho had in his Uraniborg no general platform free on all sides, but instead the high and very large roof of the main building rising in the middle, the observers were certainly in no way free, with all those instruments placed toward the south, to discover and observe whatever lay toward the north; and again, with those instruments set up toward the north, they could by no means perceive what was visible toward the south, apart from certain phenomena and the higher stars raised to 40°, 50°, 60°. This was truly most vexing for the observers: they could not, with the same instrument, whenever they pleased,

search out and measure the same phenomenon in every region of the sky and in every position, higher and lower. Instead they were compelled at first, if some star appeared in the south, to go to the instruments situated on that side; and shortly afterwards, as the star moved off and advanced toward the north, to hurry through so many windings of the building and through chambers to those instruments that were set out in that place. How long an interval of time, I ask, passed meanwhile before they got there and the instruments were uncovered, made ready and properly set up? Did not the principal moment of the observation quite often pass and slip away in the meantime — to say nothing of the fact that the instruments were not always equally fit on every side?

[Margin: It is sometimes safer to observe with one single instrument than with several.]

For it is very often safer to carry out observations with one and the same instrument, whose capabilities we know more than well, than with various instruments that sometimes waver. For I could hardly believe that each and every one of Tycho's instruments had the same perfection, as we have already said above in its place.

[Margin: How astronomical observatories should be built.]

I therefore hold to my opinion: observatories [Speculae sive Observatoria] should be built in such a way that, whenever you please, it is in your power to detect and measure any phenomenon, with any instrument, in any part of the sky. But I confess that this rarely falls to anyone who uses a great many instruments in one single observatory. It is therefore advantageous for us to have, attached to the principal observatory, various separate observatories and little cabins, each so furnished with every apparatus that the instruments placed there and set out toward the stars in no way obstruct or inconvenience the rest.

[Margin: Princes build Stellaeburgs as they wish; but private persons only as they can.]

All of this princes and magnates, who lack neither a suitable site nor funds, have it in their power to establish through the zeal and labour of the most ingenious craftsmen. But for a townsman, who does not get to choose his site but must seize with both hands the one that fortune has granted him, and who has his means to spend on his household affairs so that he may provide properly for himself and his family — for him, I say, it is no slight matter to procure for himself an astronomical observatory fit in every respect for any celestial observations whatever, and most fully furnished with everything.

[Margin: It was very laborious for the author before he obtained all the conveniences and all the apparatus for carrying out any observations whatever.]

Since I too, then, must deservedly be counted among such men, it was certainly a very hard matter for me as well before I had obtained suitable sites, built suitable observatories on them, and at the same time furnished each observatory with varied and proper apparatus, so that I should always be free to undertake and carry out there, as I wished, whatever was to be observed.

At the beginning, indeed, around the year 1640, no such observatory, most convenient in every respect, was yet at hand. But in the course of time, by God's bounty, I first happily obtained one more convenient and thoroughly suited to our purpose, and at length, by the favour of divine grace, I found one of that suitable kind even in my own house.

[Margin: At length the author built a convenient observatory in his own house.]

Since with it I am amply provided for, given my way of life, my studies and my contemplations, I can also be content with it. Indeed — be it said without boasting — nothing whatever can at any time arise in observations of the heavens that I am not permitted to observe and search out properly; indeed, all things equally accurately and promptly as in some other observatory far higher, more spacious and more splendid. For the business of astronomical observations does not depend solely on a lofty, sumptuous observatory built magnificently in every way, but on one properly suited to it, on thoroughly accurate instruments — bronze, very large and revolving — and also on suitable apparatus and the diligence of skilled observers.

[Margin: In what year the first observatory was built.]

From 1635 to 1641, as I was just saying, I was only slightly equipped with all those things, and all the nets I had were thin; but at that time I had to accommodate myself to the circumstances. For on each occasion I would climb now these houses, now those, and look for a suitable spot wherever one was to be had. Thus in 1641 I built the first observatory in my rear house, as the opportunity of the time allowed — namely on the very spacious upper floor [contignatio superior]. There I not only made quite high and wide windows toward all four principal quarters of the sky, and conveniently moved and placed various instruments at them, such as quadrants, sextants and octants, as can be seen from the upper panel of the accompanying picture, E E at A;

[Margin: The author built a special tower on the roof-ridge of the house.]

but shortly afterwards I also built a whole tower on the roof-ridge of those houses, namely for our brass azimuthal quadrant — matters we have already dealt with fully in their place, in Chapter IX.

[Margin: When the larger observatory was built.]

The foundations of our other, larger and principal observatory were first laid after the year 1650, and indeed above the roof-ridges of three of our houses, which by good luck stood at equal height. For if the roofs had not been entirely level in height (which, however, was by no means done deliberately by the builder of the houses), the construction of this observatory would certainly not have turned out as intended.

[Margin: Description of the larger observatory.]

Yet the whole mass of the building does not rest on the roof-ridges at all; rather, this observatory is supported solely by the intermediate stone walls, and is moreover underbuilt with a great many supports, buttresses [anterides], crosspieces, crossbars and holders, and most firmly braced on every side. The

structure is thus extremely strong in every part, so that in it, although it is raised quite high, we can move about and carry on our work safely and without any danger, and also safely handle any instruments, even the largest of all.

[Margin: Size of the observatory.]

Besides, this observatory of ours offers an area ample enough, more than 50 feet long and 25 feet wide. It is enclosed all round by an enclosure and a parapet surmounted by columns, so that one may walk about there safely even on dark nights and carry out one's tasks in safety, even with both eyes closed. For in such elevated places one must act with complete circumspection, lest either the instruments come to harm or the observers themselves run into danger of their lives.

In this larger observatory of ours, then, or Stellaeburgum, which faces the principal quarters of the sky with its four sides, we placed toward the north the little cabin D (which we have already fully described and sketched above, in Chapter XI, in connection with the quadrant), in which the sextant and octant are otherwise kept, and are also set out toward the stars.

[Margin: A special gallery built on the observatory itself.]

Not far from this little cabin, toward the west, on that very platform, we built a small room, roofed and walled in on every side, yet with windows on every side. Its purpose is to keep the necessary apparatus of the instruments, and to set out the clocks so that they would not be exposed to the injuries of the weather; and also so that the individual observations could be conveniently noted down there, and likewise so that, when storms come on, the observers may withdraw to this gallery [pergula], sit on the benches, and even, if they please, lie down comfortably on a couch — when, that is, either the time of the observation is not yet at hand, or the phenomena must be watched for.

[Margin: The little cabin in which the sextant and octant are kept.]

Moreover, this little cabin D is movable on four wheels (as you have already learned in its place) and can conveniently be turned round when the matter requires. The remaining part of the Stellaeburgum itself, facing south, is entirely empty and free, so that in due time there would be room to put away the most varied instruments, and to erect and direct tubes even running to 60 or 70 feet.

[Margin: The area of the observatory suffices for tubes of 60 feet.]

For the space of this observatory does not permit the handling of longer telescopes, which approach 140 feet. In addition, beneath the platform of this Stellaeburgum tubes of 20, 30 and 40 feet are kept in special boxes; but because the page is too narrow these are not visible in the picture above. But on the western side of the observatory a very long box B B, covered with its own lid, is fixed — 32 feet long, that is — in which the two parts of the 60-foot telescope are kept safe from the inclemency of the air and from rain, so that they can be taken out of it again when needed, and afterwards joined together.

[Margin: Description of the observatory and little cabin for the horizontal quadrant.]

Facing the street, toward each of the two fronts of the house, between the roof-ridges, on top of a stone wall, I built yet another observatory F, or little cabin E, likewise revolving, but somewhat lower than the other one, D (which was already mentioned in Chapter X, and also described quite fully there), to house that splendid horizontal quadrant of ours. For this purpose the little cabin just mentioned was placed in a somewhat lower-lying spot, so that this one, E, would not obstruct the other, D, and above all would not block the view of the observers busy on the upper observatory. Even so, it rises high enough that the sky lies quite freely open to it, particularly to the south and the north (the position in which the meridian altitudes of the stars are most often observed with this quadrant).

[Margin: How many observatories the author possesses.]

There are, then, three principal observatories — namely D, E, and the tower A — all of them contained within the bounds of our houses, so that you have no need at all to leave the houses or cross the street whenever you must go to another observatory. The first two, D and E, set on the same houses, are very close to each other. Under the third observatory, the tower A of the rear houses, an old observatory can be seen in the upper storey [contignatio], in which those Tychonic instruments, built of wood, used to be kept.

[Margin: Under the tower and the old observatory our printing house was set up.]

On the second storey, beneath this observatory of that building, our printing house is located; the press for printing the bronze plates [Tabulas æneas], however, is fitted out under observatory F of the front house, together with certain other little rooms. In these, above all, the chief instrumental apparatus is kept — namely that of some instruments, both larger and smaller, which are used for the stars only now and then — and also that of various tubes, as well as whatever else concerns the business of observation. One of these little rooms, moreover, can also be completely darkened, so that, whenever you wish, you can very well observe and record solar eclipses too, if it does not seem so convenient to do so in the upper movable little cabin D. As a result it cannot be denied that each and every thing that concerns observations of any kind is very close at hand to our Stellaeburgum — kept apart, admittedly, but ready in the same houses — so that you have no need at all to dig out and hunt for now this, now that, whether among the instruments or the accessories, anxiously from every hiding-place. For everything is already put back in order in its own place, so that it can always be found at once, even at night, and be ready to hand.

[Margin: Height of our larger observatory.]

The highest observatory of all, together with all the smaller observatories, is separated from our study [Museum] itself by only four flights of stairs or spiral staircases [cochleis].

[Margin: For the author's circumstances everything is quite convenient.]

In short, as far as the circumstances of a householder or a thrifty citizen allow, each and every thing required for astronomical observations, of whatever kind they may be, is always kept at hand and need by no means be looked for far off. Moreover, you can climb to the observatories with almost no effort — indeed in complete safety, even on the darkest night — so that observations are carried out in this Stellaeburgum of ours with the greatest pleasure and delight: above all because of the most charming view it offers, far and wide, around the city as far as the Baltic Sea, and of the horizon itself.

[Margin: Our Stellaeburgum has a most charming and very far-reaching view.]

Toward the east and north, near the city, you see the Vistula with the open meadows lying beside it, the woods, the fortress of Münde [Fortalitio Mũndano] situated on the shore of the Fistula, and the whole sea as far as the eye can reach, as far as the Hel Peninsula, and also all the ships under sail together, departing and returning. On the other side, to the south and west, the whole city lies open to you, with its suburbs, the Nehrung [Neringia], the Lesser Island [Insula minor], and also the most charming hills nearby, rising very gently. The towers and churches of our city, although in their way they rise quite high, are nevertheless not so close to this Stellaeburgum of ours that they could in any way much obstruct the view of the stars. Likewise the hills lying toward the west and south-west, although they face our observatory, since even the highest of them scarcely rise above one degree, do not detract in any way from the observations, nor can they cut off or obstruct our view.

[Margin: On what account the author congratulates himself.]

So much so that in this respect I count myself fortunate that our Stellaeburgum enjoys this excellent and rare advantage — one I could scarcely have found anywhere else in our whole city, however carefully I searched — and that in it I have been able to carry out so very many, and most diverse, observations to my heart's content for twenty, indeed nearly thirty, years.

[Margin: The appearance of the tower for the azimuthal quadrant.]

What the tower A, built up on the rear houses, looks like from a distance, with its two windows open, together with the azimuthal quadrant kept there; no less the larger observatory on the front houses, together with the remaining two observatories or little cabins D and E, and also the gallery C; and then what view it offers toward the east — all this is more than sufficiently clear to anyone from the preceding picture E E, so that no fuller description is needed.

[Margin: Conclusion of this organographic work.]

I therefore come to an end. This is everything that I wished — and indeed quite simply was bound — to bring before the public concerning this Organography of ours, that is, the First Part, or Book I, of the *Machina Coelestis*, before I set its Second Part — that is, Books II, III and IV, with each and every one of our observations of the planets and the fixed stars, and also of other phenomena — before the eyes of those skilled in the stars and of the devotees of celestial things. By this, above all, there will be no one who does not see quite clearly

how earnestly and carefully — be it said without boasting — I have applied myself to this business up to now, and with what instruments I undertook the celestial contemplations that have been carried on successfully for so very many years until now. Since all of this has been undertaken and carried through by us for no other end than the glory of Almighty God and the advancement of astronomy, we trust wholeheartedly that the Supreme Deity, the Director of the stars, will further most graciously grant that we may now also, for the same end, at last bring successfully to its conclusion the other Part of this *Machina Coelestis*, born of the First Part and already almost entirely printed.

FINIS.

The End.

CONDITORI MACHINÆ MUNDANÆ UNIVERSÆ O. M. SIT HONOR ET GLORIA.

To the Founder of the whole machine of the world, best and greatest, be honour and glory.

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ERRATA.

Errata

Page	Line	Error	Correction	English gloss
14	21	*integra & ſalva conſervari*	*integram & ſalvam cõſervare*	”to be preserved whole and safe” → ”to preserve whole and safe”
37	15	*conſcius*	*co[[n/r]]ſcium* [?]	
39	4	*ſolo*	*ſoli*	
39	36	*Catoptices*	*Catoptrices*	
42	last	*requirenur* [?]	*requirerentur*	
44	23	*ſolo*	*ſoli*	
97	6	*penioris*	*penitioris*	
186	5	*Tabernacula*	*Tabernulâ*	”tabernacles” → ”little cabin”
137	3	*conſtructa*	*conſtructum*	
191	31	*popoſcat*	*poſcat*	
262	1	162	262	
264	1	164	264	
264	29	*Scienrum*	*Scientiarum*	
308	36	*lineola aliqua*	*lineolam aliquam*	

ERRATA.

Page	Line	Error	Correction	English gloss
310	last	*diſcribere*	*deſcribere*	
315	22	*illuc*	*illud*	"there" → "that"
316	8	*in*	*à*	"in" → "from"
316	9	*priori ſubſequens*	*priori versùs ſubſequens*	inserts "toward"
334	11	5789	5780	
336	13	5272½	5227½	
338	9	3966⅔	3926⅔	
375	28	*conjungantur*	*conjungatur*	

Blank flyleaf with a later owner's pencil notes — not part of the book.

Endpaper — not part of the book.

Back pastedown with a ribbon marker — not part of the book.

[Back cover of the binding: brown leather, gilt-tooled with a border fillet and a central lozenge; no text.]