ASTRONOMIA NOVA
AITIOΛOΓHTOΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex obſervationibus G. V.
TYCHONIS BRAHE:

Juſſu & ſumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:

Plurium annorum pertinaci ſtudio
elaborata Pragæ,

A Sᵉ. Cᵉ. Mᵀⁱᵘ Sᵉ. Mathematico
JOANNE KEPLERO,

Cum ejusdem Cᵉ. Mᵀⁱᵘ privilegio ſpeciali
Anno æræ Dionyſianæ clɔ ·Iɔ c ix.

NEW ASTRONOMY

BASED UPON CAUSES
OR
CELESTIAL PHYSICS
treated by means of commentaries
ON THE MOTIONS OF THE STAR
MARS
from the observations of
TYCHO BRAHE, GENT.

BY ORDER AND MUNIFICENCE OF
RUDOLPH II
EMPEROR OF THE ROMANS, &c.

Worked out at Prague
in a tenacious study lasting many years

By His Holy Imperial Majesty's Mathematician
JOANNES KEPLER

With the same Imperial Majesty's special privilege
In the Year of the Dionysian era MDCIX

P. RAMUS, Scholae Mathematicae Book II, p. 50

Thus the contrivance of hypotheses is absurd; nevertheless, in Eudoxus, Aristotle, and Callippus[1], the contrivance is simpler, as they supposed the hypotheses to be true – indeed, they have been venerated as if they were the gods of the starless orbs. In later times, on the other hand, the tale is by far the most absurd, the demonstration of the truth of natural phenomena through false causes. For this reason, Logic above all, as well as the Mathematical elements of Arithmetic and Geometry, will provide the greatest assistance in establishing the purity and dignity of the most noble art[2]. Would that Copernicus had been more inclined towards this idea of establishing an astronomy without hypotheses! For it would have been far easier for him to describe an astronomy corresponding to the truth about its stars, than to move the earth, a task like the labour of some giant, so that in consequence of the earth's being moved, we might observe the stars at rest. Why could there not rather arise someone from among the great number of celebrated schools of Germany, a philosopher as well as a mathematician, who would attain the prize of eternal praise that is publically offered? And if any fruit of transitory usefulness can be offered to compare with a prize of such power, I will solemnly promise you the Regius Professorship at Paris as a prize for an astronomy constructed without hypotheses, and will fulfil this promise with the greatest pleasure, even by resigning our professorship.

The Author to Ramus

Conveniently for you, Ramus, you have abandoned this surety by departing both life and professorship. Had you still held the latter, I would, in my judgement, have won it indeed, inasmuch as, in this work, I have at length succeeded, even by the judgement of your own Logic. As you ask the assistance of Logic and Mathematics for the noblest art, I would only ask you not to exclude the support of Physics, which it can by no means forego. And unless I am mistaken, you readily grant this, seeing that you surround your *Conformator* with Philosophy as well as Mathematics. Thus with the same facility I, too, admit something commonly considered most absurd philosophically, defending[3] it, not with a gigantic effort, but with the best arguments. For when it functions, it effects nothing new, nothing unaccustomed, but only fulfils the function for which it was invented.

It is a most absurd business, I admit, to demonstrate natural phenomena through false causes, but this is not what is happening in Copernicus. For he too considered his hypotheses true, no less than those whom you mention considered their old ones true, but he did not just consider them true, but demonstrates it; as evidence of which I offer this work.

But would you like to know who originated this tale, at which you wax so wroth? 'Andreas Osiander'[4] is written in my copy [sc. of Copernicus's *De revolutionibus*], in the hand of Hieronymus Schreiber of Nurnberg. This Andreas, when he was in charge of publishing Copernicus, thought this preface most prudent which you consider so absurd (as may be gathered from his letters to Copernicus), and placed it upon the frontispiece of the book, Copernicus himself being dead, or certainly unaware of this. Thus Copernicus does not mythologize, but seriously presents paradoxes; that is, he philosophizes. Which is what you wish of the astronomer.

1 Eudoxus, a pupil of Plato (as was Aristotle), attempted to account for planetary motion through a nest of concentric spheres each of which imparted its motion to the axis of the sphere it immediately contained. Callippus later tried to bring Eudoxus's rather unsatisfactory attempt more nearly into accord with the phenomena by adding more concentric spheres to the schema. Aristotle subsequently gave the Eudoxian-Callippian homocentric system his blessing, adding intelligent beings whose task was to move the spheres, most of which were starless – hence, Ramus's sarcastic remark. See Aristotle, *Metaphysics*, Book XII ch. 8.

2 Logic, Arithmetic, Geometry, and Astronomy are four of the seven 'Liberal Arts', the other three being Grammar, Rhetoric, and Music. Astronomy was frequently regarded as the noblest of the arts because of the excellence of the objects of its study.

3 Reading *defendens* instead of *defendentem*.

4 For more on the theologian Osiander (1498–1552) and his notorious 'instrumentalist' preface to Copernicus's work, see N. Jardine, *The Birth of History and Philosophy of Science* (Cambridge 1984) pp. 150–154.

(**) r

To Rudolph II
The Ever August Emperor of the Romans
King of Germany, Hungary, Bohemia, &c.
Archduke of Austria, &c.

Most August Emperor

In order that Your Holy Imperial Majesty, as well as the entire House of Austria, might be happy and prosperous in most serene renown, I am now at last exhibiting for the view of the public a most Noble Captive, who has been taken for a long time now through a difficult and strenuous war waged by me under the auspices of Your Majesty. I do not think he will object to the name of Captive, since for some time he has been accustomed to dropping his vaulted shield and his
(**) v arms and giving himself over freely and playfully to capture and bondage, whenever custody, prison, or chains are ordered.

The brilliance of this spectacle could not be greater than if I were to write a panegyric upon this most distinguished captive, and shout it out loudly and publicly.

However, one who ventures forth upon this battlefield encounters an astonishing brightness, and averts his squinting eyes, made accustomed to the feeble light of Night, and to scholastic shadows.

I therefore leave it to the writers of history books to describe the greatness of our Stranger, which he acquired in the art of war.

They would certainly say that it is he through whom all armies conquer, all military leaders triumph, and all kings rule, without whose aid no one ever honourably took a single captive. Let them now feast their eyes with looking upon him, captured through my martial efforts.

Those who admire Roman greatness would say that he is the begetter of the Kings Romulus and Remus, the preserver of the City,

protector of the Citizens, Supporter of the Empire, by which favour the Romans discovered military discipline, improved and perfected it, and subjugated the orb of the world. Let them therefore give thanks at his being confined and at his being acquired as a happy omen for the House of Austria.

I, for my part, retreat hence to other ground better suited to my powers. Nor will I set foot upon that part of my profession in which strife arises between me and my fellow soldiers.

(**) 2 r They, for their part, would surely rejoice with a different joy: he has been restrained by the bonds of Calculation, who, so often escaping their hands and eyes, was accustomed to deliver vain prophecies of the greatest moment, concerning War, Victory, Empire, Military Greatness, Civil Authority, Sport, and even the cutting off or calling forth of Life itself. Let them congratulate Your Majesty that the Master of the Horoscope[1] has been brought under control, and even made to be friendly, for by their account Mars rules Scorpio, which contains the Heart of Heaven[2]; in Capricorn, which is rising, he is exalted; in Cancer, into which the moon was entering, he customarily plays the triangular game with knucklebones; in Leo, where the Sun plays host, he is recognized as being one of the family; and finally, he is the ruler of Aries, beneath which Germany is supposed to be, over which he rules in complete harmony with Your Holy Imperial Majesty.

Let them be occupied in this part of the triumph; I do not mind. I shall give them no cause for quarreling on such a festive day: let this impertinence pass as a soldiers' joke. I myself shall occupy myself with Astronomy, and, riding in the triumphal car, will display the remaining glories of our captive that are particularly known to me, as well as all the aspects of the war, both in its waging and in its conclusion.

For he is not to be held without honour among us, whom the eternal Architect of this world, and the Father of Heavens and Humans in common, Jupiter, located in the front lines of the visible

[1] It is undoubtedly the Emperor's horoscope that Kepler means, and the details mentioned (such as the rising sign and the moon sign) are probably those of the time of his birth. The translator has been unable to find information on the '*astragalis lusum trigonicum*', here translated 'the triangular game with knucklebones'. '*Astragalus*' is a Greek word, denoting (among other things) any of a number of different bones, and by derivation, a knucklebone used as a die in gaming.

[2] The Heart of Scorpio is the star Antares. 'Ant-Ares', that is, 'counterpart of Mars', was so named because of its red colour. Astrologers supposed it to have a particular affinity for Mars.

bodies, so that he might serve as a soldier for the glory of his Creator through his perennial course through the ethereal regions, and so that he might raise human minds, lulled to sleep by a deep somnolence, from the slanderous reproach of idleness and ignorance, arouse them
(**) 2 v to venture forth, and provoke them forcefully to carry out investigations in the heavens for the praise of their Creator.

It is he who is the most potent conqueror of human inventions, who, ridiculing all the sallies of the Astronomers, escaping their devices, and striking down the hostile throngs, kept safe the secret of his empire, well guarded throughout all ages past, and performed his rounds in perfect freedom with no restraints: hence, the chief complaint registered by that Priest of Nature's Mysteries and most distinguished of the Latins, C. Pliny, that 'Mars is the untrackable star'[3].

It is said that Georg Joachim Rheticus (a disciple of Copernicus not lacking honour in the memory of our forebears, and who, as the first to dare to yearn for a reconstruction of Astronomy, thereupon strove for it through observations and discoveries that are not to be scorned), when he was brought up short in amazement by the motion of Mars, and did not disentangle himself, fled to the oracle of his familiar Genius, either intending (the gods willing) to explore that being's erudition, or driven by a headstrong desire for the truth, whereupon that stern patron, exasperated, alternately caught the importunate inquirer by the hair and stretched his head towards the low-hanging panelled ceiling, and then threw him down, flattening him on the paved floor, adding the reply: 'This is the motion of Mars.' The story is a bad thing: there is nothing else more injurious to good reputation, for it is as tenacious of deception and distortion as it is informative of the truth. It is nevertheless not unbelievable that Rheticus himself, when his speculations were not succeeding and his spirit was in turmoil, leapt up in fury and pounded his head against
(**) 3 r the wall. For what wonder would it be if the same thing happened to Rheticus, who provoked Mars, as once happened to C. Octavius Augustus Caesar when he lost five legions under the command of Quintilius Varus, surrounded by his enemy Arminius, protege of our Germanic Mars?

Nevertheless, here too, as in other kingdoms, the ruling influence of our enemy has been sustained and supported, more than any other

[3] Pliny, *Natural History*, II. 17.

thing, by the persuasion and confusion of the multitude of people, the defiance of which I have always considered the path to victory. Indeed, when I was but indifferently well versed in this theater of Nature, I formed the opinion, with practice [*usus*] as my teacher, that, just as one human being does not greatly differ from another, neither does one star differ much from another, nor one opponent from another, and hence, no account is to be received easily that says something unusual about a single individual of the same kind.

In this place chief praise is to be given to the diligence of Tycho Brahe, the commander-in-chief in this war, who, under the auspices of Frederic II and Christian, Kings of Denmark, and finally of Your Holy Imperial Majesty as well, explored the habits of this enemy of ours nearly every night for twenty years, observed every aspect of the campaign, detected every stratagem, and left them fully described in books as he was dying.

I, instructed by those books as I succeeded Brahe in this charge, first of all ceased to fear [the enemy] whom I had to some extent come to know, and then, having diligently noted the moments of time at
(**) 3 v which he was accustomed to arrive at his former positions, as if going to bed, I directed the Brahean machines thither, equipped with precise sights, as if aiming at a particular target, and besieged each position with my enquiry as the chariots of the great Mother Earth were driven around in their circuit.

The campaign did not, however, succeed without sweat, since it frequently happened that machines were lacking where they were most needed, or that they were transported over muddy roads by inexperienced charioteers at great expense of time and material, or that the launching of some of them, where I had not yet investigated the matter, occurred in other directions than I had had in mind. Often the brightness of the sun or of the moon, and often an overcast sky, cheated the commander's eyes; and more often the interposition of vapourous air deflected the globe, forcing it from the straight path. Also not infrequently, the walls, where they were presented most obliquely, received ineffectual blows, however numerous they might be. Add to this the enemy's enterprise in making sallies, and his vigilance for ambuscades, while we were frequently asleep. Also, his constancy in defence: whenever he was driven or fled from one castle, he repaired to another, all of which required different means to be conquered, and none of which was connected to the rest by an easy path – either rivers lay in the way, or brambles impeded the attack,

but most of the time the route was unknown. Each of these things is thoroughly described in its own place in this commentary.

Meanwhile, in my camp, is there any sort of defeat, any kind of disaster that has not occurred? The overthrow of the Most Distinguished Leader, rebellion, plague, pestilences, domestic matters both good and bad, destined in either case to take time; a new, unforeseen, and terrifying rear attack by the enemy, as I have recounted in the book *On the New Star*[4]; at another time, an enormous Dragon with a very long tail, vomiting fire and attacking
(**) 4 r my camp; desertion and poverty of the soldiers; the inexperience of novices; and, at the head of all, the extreme deficiency of provisions.

At last, when he saw that I held fast to my goal, while there was no place in the circuit of his kingdom where he was safe or secure, the enemy turned his attention to plans for peace: sending off his parent Nature, he offered to allow me the victory; and, having bargained for liberty within limits subject to negotiation, he shortly thereafter moved over most agreeably into my camp with Arithmetic and Geometry pressing closely at his sides.

However, from the time when, after surrendering, he abode by our house's fair laws of friendship, he, through hidden illusions (being unaccustomed to rest), did not cease to incite among us I know not what further fears of war, and if we happened to become terrified, we would give him much to laugh at. But, seeing us strong in spirit, he agreed to live with us in earnest, and, dropping the appearance of hostility, confirmed his faith with us.

This one thing he begs of Your Majesty: since his alliance in the ethereal regions is great (for indeed, his father is Jupiter, his grandfather Saturn, Venus is his sister as well as his mistress, and from now on the chief alleviation of his chains, Mercury his brother and faithful herald); and since he is possessed by desire of them, and they of him, owing to their similar ways, he wishes that they too might live among humanity, becoming partakers of the honour with which he is bestowed; and that Your Majesty might give them to him as soon as possible, since the remnants of this expedition are severely dimin-
(**) 4 v ished, and, as they have surrendered themselves, no longer pose any threat. To this end, I readily offer Your Majesty a work that is not

[4] In the autumn of 1604 a nova appeared in Ophiuchus, about which Kepler wrote the pioneering work *De stella nova in pede Serpentarii,* (Prague 1606). According to Caspar, the 'Dragon' is the comet that appeared in the winter of 1607, about which Kepler wrote *Ausfuhrlicher Bericht von dem . . . Cometen . . .*, (Hall/Sachsen 1608).

without usefulness (it being trained in the most combative circumstances, and well acquainted with the terrain) and no less trustworthy than its predecessor[5]. I pray and beseech you for this one favour (seeing that throughout these nine years, conversation in this hall, packed with soldiers, centurions, and commanders, has supplied me with the word 'beseech', as well as the rest of the oration): that Your Imperial Majesty command the chiefs of the treasury to take thought for the sinews of war and supply me with new funds to enlist the army. I pray thus, seeing that I both know that these things already are approved by Your Majesty, and consider that they promote the glory of God and the immortality of the Name of Your August Majesty, to Whom I have devoted all my work for a long time, and to Him I now most humbly commend myself.

March the 28th, in the year of the Dionysian[6] era 1609,
Your Holy Imperial Majesty's

Most Humble Mathematician
Joannes Keppler[7]

[5] A reference to the *Tabulae Rudolphinae* (not published until 1627), which applied the conclusions of the present work to the other planets.

[6] Here and on the title page, Kepler refers to the Roman Abbot Dionysius Exiguus, who established the commonly used Christian chronology in the early sixth century.

[7] Spelled as in the original.

Republic of letters shows compassion for it all, it is as if we were by this fact blessed with a precursor of the Tables, and after them the observations (seeing the light of day later); and, more zealous for the further progress of the work so fervently desired, also pray with us to God for more felicitous times.

Franz Gansneb Tengnagel von Campp.
His Imperial Majesty's Councillor

(***) 2 r

Introduction to this work

On the difficulty of reading and writing astronomical books.

It is extremely hard these days to write mathematical books, especially astronomical ones. For unless one maintains the truly rigourous sequence of proposition, construction, demonstration, and conclusion[1], the book will not be mathematical; but maintaining that sequence makes the reading most tiresome, especially in Latin, which lacks the articles and that gracefulness possessed by Greek when it is expressed in written symbols. Moreover, there are very few suitably prepared readers these days: the rest generally reject such works. How many mathematicians are there who put up with the trouble of working through the *Conics* of Apollonius of Perga? And yet that subject matter is the sort of thing which can be expressed much more easily in diagrams and lines than can astronomy.

I myself, who am known as a mathematician, find my mental forces wearying when, upon rereading my own work, I recall from the

[1] Kepler here refers to the formal procedure of Euclidean geometry. First, the theorem is stated in its general form; for example (in Euclid I. 17), 'In any triangle two angles taken together in any manner are less than two right angles'. Then, the appropriate construction is performed and the theorem is restated as expressed in the construction. For example, 'Let ABC be a triangle; I say that two angles of the triangle ABC taken together in any manner are less than two right angles.' Next, the theorem is demonstrated. And finally, it is restated exactly as originally proposed, with the word 'therefore' inserted at the beginning, and a phrase or abbreviation at the end indicating that this is what was to be proven (English translations use the abbreviation 'Q. E. D.', which stands for '*quod erat demonstrandum*', the Latin equivalent of Euclid's phrase, 'ὅπερ ἔδει δεῖχαι'). Since it is understood that the conclusion is a restatement of the proposition, it is usual to omit the full conclusion, representing it briefly with the words, 'Therefore etc. Q. E. D.'. Although Kepler occasionally reverts to this formality (as in chapter 60 proposition 4), he usually omits it, for the reason given here. However, he distinguishes the mathematical arguments from the rest of the text by having the mathematics set in italics, as he explains in the opening section of the 'Summaries of the Individual chapters'.

diagrams the sense of the proofs, which I myself had originally introduced from my own mind into the diagrams and the text. But then when I remedy the obscurity of the subject matter by inserting explanations, it seems to me that I commit the opposite fault, of waxing verbose in a mathematical context.

Furthermore, prolixity of phrases has its own obscurity, no less than terse brevity. The latter evades the mind's eye while the former distracts it; the one lacks light while the other overwhelms with superfluous glitter; the latter does not arouse the sight while the former quite dazzles it.

These considerations led me to the idea of including a kind of elucidating introduction to this work, to assist the reader's comprehension as much as possible.

I conceived this introduction as having two parts. In the first I present a synoptic table of all the chapters in the book. I think this is going to be useful, because the subject matter is unfamiliar to most people, and the various terms and various procedures used here are very much alike, and are closely related, both in general and in specific details. So when all the terms and all the procedures are juxtaposed and presented in a single display, they will be mutually explanatory. For example, I discuss the natural causes which led the ancients, though ignorant of them, to suppose an equant circle or equalizing point. However, I do this in two places, namely, in parts three and four. A reader who encounters this subject in part three might think I am dealing here with the first inequality, which is a property of the motions of each of the planets individually. And indeed, this is the case in part four. However, in the third part, as the summary indicates, I am discussing that equant which, under the name of the second inequality, varies the motion of all the planets in common, and primarily governs the theory of the sun. Thus the synoptic table will serve to make this distinction clear.

Nevertheless, the synopsis will not be of equal assistance to all. There will be those to whom this table (which I present as a thread leading through the labyrinth of the work) will appear more tangled than the Gordian Knot. For their sake, therefore, there are many points that should be brought together here at the beginning which are presented bit by bit throughout the work, and are therefore not so easy to attend to in passing. Furthermore, I shall reveal, especially for the sake of those professors of the physical sciences who are irate with me, as well as with Copernicus and even with the remotest antiquity,

The introduction to this work is aimed at those who study the physical sciences.

on account of our having shaken the foundations of the sciences with the motion of the earth – I shall, I say, reveal faithfully the intent of the principal chapters which deal with this subject, and to propose for inspection all the principles of the proofs upon which my conclusions, so repugnant to them, are based.

For when they see that this is done faithfully, they will then have the free choice either of reading through and understanding the proofs themselves with much exertion, or of trusting me, a professional mathematician, concerning the sound and geometrical method presented. Meanwhile, they, for their part, will turn to the principles of the proofs thus gathered for their inspection, and will examine them thoroughly, knowing that unless they are refuted the proof erected upon them will not topple. I shall also do the same where, as is customary in the physical sciences, I mingle the probable with the necessary and draw a plausible conclusion from the mixture. For since I have mingled celestial physics with astronomy in this work, no one should be surprised at a certain amount of conjecture. This is the nature of physics, of medicine, and of all the sciences which make use of other axioms besides the most certain evidence of the eyes.

On the schools of thought in astronomy.

The reader should be aware that there are two schools of thought among astronomers, one distinguished by its chief, Ptolemy, and by the assent of the large majority of the ancients, and the other attributed to more recent proponents, although it is the most ancient. The former treats the individual planets separately and assigns causes to the motions of each in its own orb, while the latter relates the planets to one another, and deduces from a single common cause those characteristics which are found to be common to their motions. The latter school is again subdivided. Copernicus, with Aristarchus of remotest antiquity, ascribes to the translational motion of our home the earth the cause of the planets' appearing stationary and retrograde. Tycho Brahe, on the other hand, ascribes this cause to the sun, in whose vicinity he says the eccentric circles of all five planets are connected as if by a kind of knot (not physical, of course, but only quantitative). Further, he says that this knot, as it were, revolves about the motionless earth, along with the solar body.

(***) 2 v

For each of these three opinions concerning the world[2] there are several other peculiarities which themselves also serve to distinguish

[2] *Mundus*, in Latin. This comprises the entire corporeal universe, including the fixed stars.

these schools, but these peculiarities can each be easily altered and amended in such a way that, so far as astronomy, or the celestial appearances, are concerned, the three opinions are for practical purposes equivalent to a hair's breadth, and produce the same results.

The twofold aim of the work.

My aim in the present work is chiefly to reform astronomical theory (especially of the motion of Mars) in all three forms of hypotheses, so that our computations from the tables correspond to the celestial phenomena. Hitherto, it has not been possible to do this with sufficient certainty. In fact, in August of 1608, Mars was a little less than four degrees beyond the position given by calculation from the Prutenic tables. In August and September of 1593 this error was a little less than five degrees, while in my new calculation the error is entirely suppressed.

On the physical causes of the motions.

Meanwhile, although I place this goal first and pursue it cheerfully, I also make an excursion into Aristotle's *Metaphysics*, or rather, I inquire into celestial physics and the natural causes of the motions. The eventual result of this consideration is the formulation of very clear arguments showing that only Copernicus's opinion concerning the world (with a few small changes) is true, that the other two are false, and so on.

Indeed, all things are so interconnected, involved, and intertwined with one another that after trying many different approaches to the reform of astronomical calculations, some well trodden by the ancients and others constructed in emulation of them and by their example, none other could succeed than the one founded upon the motions' physical causes themselves, which I establish in this work.

The first step towards those causes is taken. The planes of all six eccentrics intersect at a single point, namely, the centre of the solar body.

Now my first step in investigating the physical causes of the motions was to demonstrate that [the planes of] all the eccentrics intersect in no other place than the very centre of the solar body (not some nearby point), contrary to what Copernicus and Brahe thought. If this correction of mine is carried over into the Ptolemaic theory, Ptolemy will have to investigate not the motion of the centre of the epicycle, about which the epicycle proceeds uniformly[3], but the motion of some point whose distance from that centre bears the same

[3] In the Ptolemaic theory of Mars, the epicycle represents the sun's motion, which is carried out uniformly about the epicycle's centre. Although this would not have to change, the line of intersection of the planes of the epicycle and the eccentric would in general not pass through the centre of the epicycle, but through the other nearby point described by Kepler. Thus when he says 'about which the epicycle proceeds uniformly', he means that the planet is proceeding uniformly on the epicycle about that point.

ratio to the diameter [of the eccentric] as does the distance of the centre of the solar orb from the earth for Ptolemy, which point is also on the same line, or one parallel to it.

Here the Braheans could have raised the objection against me that I am a rash innovator, for they, while holding to the opinion received from the ancients and placing the intersection of the [planes of the] eccentrics not in the sun but near the sun, nevertheless construct on this basis a calculation that corresponds to the heavens. And in translating the Brahean numbers into the Ptolemaic form, Ptolemy could have said to me that as long as he upheld and expressed the phenomena, he would not consider any eccentric other than the one described by the centre of the epicycle, about which the epicycle proceeds uniformly. Therefore I have to look again and again at what I am doing, so as to avoid setting up a new method which would not do what was already done by the old method.

So to counter this objection, I have demonstrated in the first part of the work that exactly the same things can result or be presented by this new method as are presented by their ancient method.

In the second part of the work I take up the main subject, and describe the positions of Mars at apparent opposition to the sun, not worse, but indeed much better, with my method than they expressed the positions of Mars at mean opposition to the sun with the old method.

Meanwhile, throughout the entire second part (as far as concerns geometrical demonstrations from the observations) I leave in suspense the question of whose procedure is better, theirs or mine, seeing that we both match a number of observations (this is, indeed, a basic requirement for our theorizing). However, my method is in agreement with physical causes, and their old one is in disagreement, as I have partly shown in the first part, especially chapter 6.

But finally in the fourth part of the work, in chapter 52, I consider certain other observations, no less trustworthy than the previous ones were, which their old method could not match, but which mine matches most beautifully. I thereby demonstrate most soundly that Mars's eccentric is so situated that the centre of the solar body lies upon its line of apsides, and not any nearby point, and hence, that all the [planes of the] eccentrics intersect in the sun itself.

This should, however, hold not just for the longitude, but for the latitude as well. Therefore, in the fifth part I have demonstrated the same from the observed latitudes, in chapter 67.

(***) 3r
The second step towards the physical causes of the motions is taken: there is also an equant in the theory of the sun or the earth, and thus the solar eccentricity must be bisected.

This could not have been demonstrated earlier in the work, because one of the constituents of these astronomical demonstrations is an exact knowledge of the causes of the second inequality in the planet's motion, for which some other new thing had likewise to be discovered in the third part, unknown to our predecessors, and so on.

For I have demonstrated in the third part that whether the old method, which depends upon the sun's mean motion, is valid, or my new one, which uses the apparent motion, nevertheless, in either case there is something from the causes of the first inequality that is mixed in with the second, which pertains to all planets in common. Thus for Ptolemy I have demonstrated that his epicycles do not have as centres those points about which their motion is uniform. Similarly for Copernicus I have demonstrated that the circle in which the earth is moved around the sun does not have as its centre that point about which its motion is regular and uniform. Similarly for Tycho Brahe I have demonstrated that the circle on which the common point or knot of the eccentrics mentioned above moves does not have as its centre that point about which its motion is regular and uniform. For if I concede to Brahe that the common point of the eccentrics may be different from the centre of the sun, he must grant that the circuit of that common point, which in magnitude and period exactly equals the orbit of the sun, is eccentric and tends towards Capricorn, while the sun's eccentric circuit tends towards Cancer. The same thing befalls Ptolemy's epicycles.

However, if I place the common point or knot of the eccentrics in the centre of the solar body, then the common circuit of both the knot and the sun is indeed eccentric with respect to the earth, and tends towards Cancer, but by only half the eccentricity shown by the point about which the sun's motion is regular and uniform.

And in Copernicus, the earth's eccentric still tends towards Capricorn, but by only half the eccentricity of the point about which the earth's motion is uniform, also in the direction of Capricorn.

Likewise, in Ptolemy, on each of the diameters of the epicycles that run from Capricorn to Cancer, there are three points, the outer two of which are at the same distance from the middle ones; and their distances from one another have the same ratio to the diameters as the whole eccentricity of the sun has to the diameter of its circuit. And of these three points, the middle ones are the centres of their epicycles, those that lie toward Cancer are the points about which the

motions on the epicycles are uniform, and finally those that lie toward Capricorn are the ones whose eccentrics (described by them) we would be tracing out *if instead of the sun's mean motion we follow the apparent motion,* just as if those were the points at which the epicycles were attached to the eccentric. The result of this is that each planetary epicycle contains the theory of the sun in its entirety, with all the properties of its motions and circles.

With these things thus demonstrated by a reliable method, the previous step towards the physical causes is now confirmed, and a new step is taken towards them, most clearly in the theories of Copernicus and Brahe, and more obscurely but at least plausibly in the Ptolemaic theory.

The earth is moved and the sun stands still. Physico-astronomical arguments.

For whether it is the earth or the sun that is moved, it has certainly been demonstrated that the body that is moved is moved in a nonuniform manner, that is, slowly when it is farther from the body at rest, and more swiftly when it has approached this body.

Thus the physical difference is now immediately apparent, by way of conjecture, it is true, but yielding nothing in certainty to conjectures of doctors on physiology or to any other natural science.

First, Ptolemy is certainly exploded. For who would believe that there are as many theories of the sun (so closely resembling one another that they are in fact equal) as there are planets, when he sees that for Brahe a single solar theory suffices for the same task, and it is the most widely accepted axiom in the natural sciences that Nature makes use of the fewest possible means?

*Of whom, in all fairness, most honest and grateful mention is made, and recognition given, since I build this entire structure from the bottom up upon his work, all the materials being borrowed from him.

That Copernicus is better able than Brahe* to deal with celestial physics is proven in many ways.

First, although Brahe did indeed take up those five solar theories from the theories of the planets, bringing them down to the centres of the eccentrics, hiding them there, and conflating them into one, he nevertheless left in the world the effects produced by those theories. For Brahe no less than for Ptolemy, besides that motion which is proper to it, each planet is still actually moved with the sun's motion, the two being mixed into one, the result being a spiral. That it results from this that there are no solid orbs, Brahe has demonstrated most firmly. Copernicus, on the other hand, entirely removed this extrinsic motion from the five planets, assigning its cause to a deception arising from the circumstances of observation. Thus the motions are still multiplied to no purpose by Brahe, as they were before by Ptolemy.

II. Second, if there are no orbs[4], the conditions under which the intelligences and moving souls must operate are made very difficult, since they have to attend to so many things to introduce to the planet two intermingled motions. They would at least have to attend at one and the same time to the principles, centres, and periods of the two motions. But if the earth is moved, I show that most of this can be done with physical rather than animate faculties[5], namely, magnetic ones. But these are more general points. There follow others arising specifically from demonstrations, upon which we now begin.

(***) 3 v III. For if the earth is moved, it has been demonstrated that the increases and decreases of its velocity are governed by its approaching towards and receding from the sun. And in fact the same happens with the rest of the planets: they are urged on or held back according to the approach toward or recession from the sun. So far, the demonstration is geometrical.

And now, from this very reliable demonstration, the conclusion is drawn, using a physical conjecture, that the source of the five planets' motion is in the sun itself. It is therefore very likely that the source of the earth's motion is in the same place as the source of the other five planets' motion, namely, in the sun as well. It is therefore likely that the earth is moved, since a likely cause of its motion is apparent.

IV. That, on the other hand, the sun remains in place in the centre of the world, is most probably shown by (among other things) its being the source of motion for at least five planets. For whether you follow Copernicus or Brahe, the source of motion for five of the planets is in the sun, and in Copernicus, for a sixth as well, namely, the earth. And it is more likely that the source of all motion should remain in place rather than move.

[4] It is telling that Kepler omits the word 'solid' here. He implies that if there are any orbs, they must be solid (that is, hard and impenetrable). Earlier natural philosophers would have been less likely to have jumped to this conclusion. Instead it was commonly held that the orbs might be made of some substance so utterly unlike terrestrial matter that they could not be characterized as either solid or not solid. Indeed, there was considerable doubt whether the heavens were made of any material at all. For further discussion of the orbs in astronomy and natural philosophy, see Nicholas Jardine, *The Birth of History and Philosophy of Science,* Cambridge University Press, Cambridge, 1984, and 'The Significance of the Copernican Orbs', *Journal for the History of Astronomy* 13 (1982), pp. 168–194, as well as the translator's essay, 'The Solid Planetary Spheres in Post-Copernican Natural Philosophy', in Robert S. Westman, editor, *The Copernican Achievement,* University of California Press, Berkeley, 1975.

[5] Latin, *facultas animalis,* a term borrowed from physiology and psychology, whose meaning varies from author to author. It is clear from chapter 57 of this work that Kepler held to a threefold division of faculties: natural, animal, and mental. These appear to correspond to Aristotle's three faculties of soul: vegetative, sensitive, and rational. If so, then the animate faculty would govern both perception and motion from place to place. See chapter 57 footnote 9, and Aristotle's *On the Soul,* book I chapter 2. Also, footnotes 32 and 33 below.

V. But if we follow Brahe's theory and say that the sun moves, this first conclusion still remains valid, that the sun moves slowly when it is more distant from the earth and swiftly when it approaches, and this not only in appearance, but in fact. For this is the effect of the circle of the equant, which, by an inescapable demonstration, I have introduced into the theory of the sun.

Upon this most valid conclusion, making use of the physical conjecture introduced above, might be based the following theorem of natural philosophy: the sun, and with it the whole huge burden (to speak coarsely) of the five eccentrics, is moved by the earth; or the source of the motion of the sun and the five eccentrics attached to the sun is in the earth.

Now let us consider the bodies of the sun and the earth, and decide which is better suited to being the source of motion for the other body. Does the sun, which moves the rest of the planets, move the earth, or does the earth move the sun, which moves the rest, and which is so many times greater? Unless we are to be forced to admit the absurd conclusion that the sun is moved by the earth, we must allow the sun to be fixed and the earth to move.

VI. What shall I say of the motion's periodic time of 365 days, intermediate in quantity between the periodic time of Mars of 687 days and that of Venus of 225 days? Does not the nature of things cry out with a great voice that the circuit in which these 365 days are used up[6] also occupies a place intermediate between those of Mars and Venus about the sun, and thus itself also encircles the sun, and hence, that this circuit is a circuit of the earth about the sun, and not of the sun about the earth? These points are, however, more appropriate to my *Mysterium cosmographicum,* and arguments that are not going to be repeated in this work should not be introduced here.

VII. For other metaphysical arguments that favour the sun's position in the centre of the world, derived from its dignity or its illumination, see my little book just mentioned, or look in Copernicus. There is also something in Aristotle's *De coelo,* Book II, in the passage on the Pythagoreans, who used the name 'fire' to signify the sun. I have touched upon a few points in the *Astronomiae pars optica* ch. 1 p. 7, and also ch. 6, especially p. 225.

[6] Behind this odd phrase lies Kepler's peculiar treatment of time as a dependent variable: he makes consistent use of the amount of time to traverse a unit of distance, rather than considering the distance traversed in a unit of time (as Galileo and his successors did). It is quite likely that this different viewpoint was of importance in developing the 'area law' which later became known as Kepler's Second Law. See especially the beginning of chapter 40.

VIII. But on the earth's being suited to a circular motion in some place other than the centre of the world, you will find a metaphysical argument in chapter 9 p. 322 of that book.

Objections to the earth's motion.

I trust the reader's indulgence if I take this opportunity to present a few brief replies to a number of objections which, capturing men's minds, use the following arguments to shed darkness. For these replies are by no means irrelevant to matters that concern the physical causes of the planets' motion, which I discuss chiefly in parts three and four of the present work.

I. On the motion of heavy bodies.

Many are prevented by the motion of heavy bodies from believing that the earth is moved by an animate motion, or better, by a magnetic one. They should ponder the following propositions.

The theory of gravity is in error.

A mathematical point, whether or not it is the centre of the world, can neither effect the motion of heavy bodies nor act as an object towards which they tend. Let the physicists prove that this force is in a point which neither is a body nor is grasped otherwise than through mere relation.

It is impossible that, in moving its body, the form of a stone seek out a mathematical point (in this instance, the centre of the world), without respect to the body in which this point is located. Let the physicists prove that natural things have a sympathy for that which is nothing.

It is likewise impossible for heavy bodies to tend towards the centre of the world simply because they are seeking to avoid its spherical extremities. For, compared with their distance from the extremities of the world, the proportional part by which they are removed from the world's centre is imperceptible and of no account. Also, what would be the cause of such antipathy? With how much force and wisdom would heavy bodies have to be endowed in order to be able to flee so precisely an enemy surrounding them on all sides? Or what ingenuity would the extremities of the world have to possess in order to pursue their enemy with such exactitude?

Nor are heavy bodies driven in towards the middle by the rapid whirling of the *primum mobile,* as objects in whirlpools are. That motion (if we suppose it to exist) does not carry all the way down to these lower regions. If it did, we would feel it, and would be caught up by it along with the very earth itself; indeed, we would be carried ahead, and the earth would follow. All these absurdities are consequences of our opponents' view, and it therefore appears that the common theory of gravity is in error.

(***) 4 r

True theory of gravity.

The true theory of gravity rests upon the following axioms[7].

Every corporeal[8] substance, to the extent that it is corporeal, has been so made as to be suited to rest in every place in which it is put by itself, outside the sphere of influence of a kindred[9] body.

Gravity is a mutual corporeal disposition among kindred bodies to unite or join together; thus, the earth attracts a stone much more than the stone seeks the earth. (The magnetic faculty is another example of this sort).

Heavy bodies (most of all if we establish the earth in the centre of the world) are not drawn towards the centre of the world *qua* centre of the world, but *qua* centre of a kindred spherical body, namely, the earth. Consequently, wherever the earth be established, or whithersoever it be carried by its animate faculty, heavy bodies are drawn towards it.

If the earth were not round, heavy bodies would not everywhere be drawn in straight lines towards the middle point of the earth, but would be drawn towards different points from different sides.

If two stones were set near one another in some place in the world outside the sphere of influence of a third kindred body, these stones, like two magnetic bodies, would come together in an intermediate place, each approaching the other by an interval proportional to the bulk [*moles*] of the other.

If the moon and the earth were not each held back in its own circuit by an animate force or something else equivalent to it, the earth would ascend towards the moon by one fifty-fourth part of the interval, and the moon would descend towards the earth about fifty-three parts of the interval, and there they would be joined together; provided, that is, that the substance of each is of the same density.

[7] As Max Caspar notes in his edition of the *Astronomia Nova,* the theory presented in these terse statements constitutes a complete rejection of the Aristotelian view of gravity and plays a fundamental role in Kepler's physical thought. In later works Kepler refers back to them, especially in Book I part 4 of the *Epitome of Copernican Astronomy,* where he develops them further. Especially important in providing an insight into Kepler's early thoughts on the subject are his letters to David Fabricius of 11 October 1605 and 10 November 1608 (KGW 15 p. 240 and 16 p. 194). In the former, he likens gravity to magnetism, and says, '. . . not only does a stone approach the earth, but the earth also approaches the stone, and they divide the space between them in the inverse ratio of their weights.' Also illuminating is Kepler's letter to Herwart of January 1607 (KGW 15 p. 386).

[8] Latin, *corporea.* There is a close relation in Kepler's thought here between *corpus* (body) and *corporea* which is not made entirely clear in this translation. Other possible renderings would be 'physical' or 'bodily'. The former would not adequately represent Kepler's meaning in the first axiom, while the latter is sufficiently at odds with correct usage to lead the translator to reject it, though with some regret.

[9] Latin, *cognata,* 'of the same origin'.

If the earth should cease to attract its waters to itself, all the sea water would be lifted up, and would flow onto the body of the moon.

Reason for the ebb and flow of the sea.

The sphere of influence of the attractive power in the moon is extended all the way to the earth, and in the torrid zone calls the waters forth, particularly when it comes to be overhead in one or another of its passages. This is imperceptible in enclosed seas, but noticeable where the beds of the ocean are widest and there is much free space for the waters' reciprocation. It thus happens that the shores of the temperate latitudes are laid bare, and to some extent even in the torrid regions the neighbouring oceans diminish the size of the bays. And thus when the waters rise in the wider ocean beds, the moon being present, it can happen that in the narrower bays, if they are not too closely surrounded, the water might even seem to be fleeing the moon, though in fact they are subsiding because a quantity of water is being carried off elsewhere.

But the moon passes the zenith swiftly, and the waters are unable to follow so swiftly. Therefore, a current arises in the ocean of the torrid zone, which, when it strikes upon the far shores, is thereby deflected. But when the moon departs, this congress of the waters, or army on the march towards the torrid zone, now abandoned by the traction that had called it forth, is dissolved. But since it has acquired impetus, it flows back (as in a water vessel) and assaults its own shore, inundating it. In the moon's absence, this impetus gives rise to another impetus until the moon returns and the impetus is restrained, moderated, and carried along with the moon's motion. So all shores that are equally accessible are flooded at the same time, while those more remote are flooded later, some in different ways because of their various degrees of accessibility to the ocean.

Effects of the sea's ebb and flow.

I will point out in passing that the sand dunes of the Syrtes[10] are heaped up in this way; that thus are created or destroyed countless islands in bays full of eddies (such as the Gulf of Mexico); that it seems that the soft, fertile, and friable earth of the Indies was thus at length broached and penetrated by this current, this perpetual inundation, with help from a certain all-pervading motion of the earth. For it is said that India was once continuous from the Golden Chersonnese towards the east and south, but now the ocean, which was once farther back between China and America, has flowed in, and the shores of the Moluccas and of other neighbouring islands,

[10] Shoals off North Africa.

which are now raised on high because of the subsidence of the surface of the sea, bear witness[11] to this event.

The Taprobane of the ancients is lost today.

Taprobane[12], too, seems to have been submerged through this cause (as is consistent with the account of the Calcuttans that several localities there were once submerged), when the China Sea burst in through breaches into the Indian Ocean, with the result that nowadays nothing of Taprobane remains but the peaks of the mountains, which take the form of the innumerable islands known as the Maldives. For it is easy to prove, from the geographers and Diodorus Siculus, that that was once the site of Taprobane, namely, to the south opposite the mouths of the Indus and the promontory of Corium. Moreover, in ecclesiastical history one individual is said to have been bishop of Arabia and Taprobane together, and so the latter must surely have been nearby and not five hundred German miles to the east (indeed, more than a thousand, following the roundabout routes used in those days). The island of Sumatra, nowadays considered to be Taprobane, I think was once the Golden Chersonnese, joined to the Indian isthmus at the city of Malacca. For Chersonnesus[13], which nowadays we believe to be the Golden, seems to have no more right than Italy to the name 'Chersonnese'.

Although these things are appropriate to a different place, I wanted to present them all in one context in order to make more credible the ocean tide and through it the moon's attractive power.

For it follows that if the moon's power of attraction extends to the earth, the earth's power of attraction will be much more likely to extend to the moon and far beyond, and accordingly, that nothing that consists to any extent whatever of terrestrial material, carried up on high, ever escapes the grasp of this mighty power of attraction.

(***) 4 v

True theory of levity.

Nothing that consists of corporeal material is absolutely light. It is only comparatively lighter, because it is less dense, either by its own nature or through an influx of heat. By 'less dense' I do not just mean that which is porous and divided into many cavities, but in general that which, while occupying a place of the same magnitude as that occupied by some heavier body, contains a lesser quantity of corporeal material.

The motion of light things also follows from their definition. For it should not be thought that they flee all the way to the surface of the

[11] Reading, with Caspar, 'approbant' for 'opprimunt'.
[12] The island now known as Sri Lanka.
[13] The Thracian Chersonnese (Gallipoli).

world when they are carried upwards, or that they are not attracted by the earth. Rather, they are less attracted than heavy bodies, and are thus displaced by heavy bodies, whereupon they come to rest and are kept in their place by the earth.

To the objection that objects projected vertically fall back to their places.

But even if the earth's power of attraction is extended very far upwards, as was said, nevertheless, if a stone were at a distance that was perceptible in relation to the earth's diameter, it is true that, the earth being moved, such a stone would not simply follow, but its forces of resistance would mingle with the earth's forces of attraction, and it would thus detach itself somewhat from the earth's grasp. In just the same way, violent motion detaches projectiles somewhat from the earth's grasp, so that they either run on ahead if they are shot eastwards, or are left behind if shot westwards, thus leaving the place from which they are shot, under the compulsion of force. Nor can the earth's revolving effect impede this violent motion all at once, as long as the violent motion is at its full strength.

But no projectile is separated from the surface of the earth by even a hundred thousandth part of the earth's diameter, and not even the clouds themselves, or smoke, which partake of earthy matter to the very least extent, achieve an altitude of a thousandth part of the semidiameter. Therefore, none of the clouds, smokes, or objects shot vertically upwards can make any resistance, nor, I say, can the natural inclination to rest do anything to impede this grasp of the earth's, at least where this resistance is negligible in proportion to that grasp. Consequently, anything shot vertically upwards falls back to its place, the motion of the earth notwithstanding. For the earth cannot be pulled out from under it, since the earth carries with it anything sailing through the air, linked to it by the magnetic force no less firmly than if those bodies were actually in contact with it.

When these propositions have been grasped by the understanding and pondered carefully, not only do the absurdity and falsely conceived physical impossibility of the earth's motion vanish, but it also becomes clear how to reply to the physical objections, however they are framed.

The opinion of Copernicus.

Copernicus preferred to think that the earth and all terrestrial bodies (even those cast away from the earth) are informed by one and the same motive soul, which, while rotating its body the earth, also rotates those particles cast away from it. He thus held it to be this soul, spread throughout the particles, that acquires force through

violent[14] motions, while I hold that it is a corporeal faculty (which we call gravity, or the magnetic faculty), that acquires the force in the same way, namely, through violent motions.

Nevertheless, this corporeal faculty is sufficient for anything removed from the earth: the animate faculty is superfluous.

II. To objections concerning the swiftness of the earth's motion.

Although many people fear the worst for themselves and for all earth's creatures on account of the extreme rapidity of this motion, they have no cause for alarm. On this point see my book, *De stella nova,* chapters 15 and 16, pp. 82 and 84[15]

III. To objections concerning the immensity of the heavens.

In the same place, you will find that full-sail voyage along the world's immense orbit, which is usually held to be unnatural, in objection to Copernicus. There it is demonstrated to be well-proportioned, and that, on the contrary, the speed of the heavens would become ill-proportioned and unnatural were the earth ordered to remain quite motionless in its place.

IV. To objections concerning the dissent of holy scripture, and its authority.

There are, however, many more people who are moved by piety to withhold assent from Copernicus, fearing that falsehood might be charged against the Holy Spirit speaking in the scriptures if we say that the earth is moved and the sun stands still[16].

But let them consider that since we acquire most of our information, both in quality and quantity, through the sense of sight, it is impossible for us to abstract our speech from this ocular sense. Thus, many times each day we speak in accordance with the sense of sight, although we are quite certain that the truth of the matter is otherwise. This verse of Virgil furnishes an example:

> We are carried from the port, and the land and cities recede.[17]

Thus, when we emerge from the narrow part of some valley, we say that a great plain is opening itself out before us.

[14] A technical Aristotelian term, for which there is no satisfactory modern equivalent. Aristotle categorized all motions as being either 'natural' or 'violent', depending upon whether they are carried out in accordance with some inner principle or are caused by something external. Here, the 'natural' motion is the coming together of all terrestrial bodies, while the 'violent' motion is the separation of those bodies. Kepler is arguing that when a body is separated from kindred bodies, there is some faculty that brings into action a force tending to bring the bodies back together.

[15] In KGW 1.

[16] The following arguments on the interpretation of scripture were to become the most widely read of Kepler's writings. They were often reprinted from the seventeenth century on, and translated into modern languages. Indeed, this part of the Introduction was the only work of Kepler's to appear in English before 1700.

[17] *Aeneid* III. 72. This line was also quoted by Copernicus, *De revolutionibus* I. 8.

Thus Christ said to Peter, 'Lead forth on high'[18], as if the sea were higher than the shores. It does seem so to the eyes, but optics shows the cause of this fallacy. Christ was only making use of the common idiom, which nonetheless arose from this visual deception.

Thus, we call the rising and setting of the stars 'ascent' and 'descent', though at the same time that we say the sun ascends, others say it descends. See the *Astronomiae pars optica* Ch. 10 p. 327[19].

Thus, the Ptolemaic astronomers even now say that the planets are stationary when they are seen to stay near the same fixed stars for several days, even though they think the planets are then really moving downwards in a straight line, or upwards away from the earth.

Thus writers of all nations use the word 'solstice', even though they in fact deny that the sun stands still.

Thus there has not yet been anyone so doggedly Copernican as to avoid saying that the sun is entering Cancer or Leo, even though he wishes to signify that the earth is entering Capricorn or Aquarius. And there are other like examples.

(***) 5 r Now the holy scriptures, too, when treating common things (concerning which it is not their purpose to instruct humanity), speak with humans in the human manner, in order to be understood by them. They make use of what is generally acknowledged, in order to weave in other things more lofty and divine.

No wonder, then, if scripture also speaks in accordance with human perception when the truth of things is at odds with the senses, whether or not humans are aware of this. Who is unaware that the allusion in Psalm 19 is poetical? Here, under the image of the sun, are sung the spreading of the Gospel and even the sojourn of Christ the Lord in this world on our behalf, and in the singing the sun is said to emerge from the tabernacle of the horizon like a bridegroom from his marriage bed, exuberant as a strong man for the race. Which Virgil imitates thus:

Aurora leaving Tithonus's saffron-coloured bed[20]

(The Hebrew poetry was, of course, earlier.)

The psalmodist was aware that the sun does not go forth from the

[18] Luke 5: 4. The Latin *altum* can mean either 'high' or 'deep'. However, Kepler cannot have been unaware that the original Greek verse unambiguously has the latter meaning, and hence must be charged with making a rather silly distortion in order to prove a point.
[19] In KGW 2 p. 281.
[20] *Aeneid* IV. 585.

horizon as from a tabernacle (even though it may appear so to the eyes). On the other hand, he considered the sun to move for the precise reason that it appears so to the eyes. In either case, he expressed it so because in either case it appeared so to the eyes. He should not be judged to have spoken falsely in either case, for the perception of the eyes also has its truth, well suited to the psalmodist's more hidden aim, the adumbration of the Gospel and also of the Son of God. Likewise, Joshua makes mention of the valleys against which the sun and moon moved[21], because when he was at the Jordan it appeared so to him. Yet each writer was in perfect control of his meaning. David was describing the magnificence of God made manifest (and Syracides with him), which he expressed so as to exhibit them to the eyes, and possibly also for the sake of a mystical sense spelled out through these visible things. Joshua meant that the sun should be held back in its place in the middle of the sky for an entire day with respect to the sense of his eyes, since for other people during the same interval of time it would remain beneath the earth.

But thoughtless persons pay attention only to the verbal contradiction, 'the sun stood still' versus 'the earth stood still', not considering that this contradiction can only arise in an optical and astronomical context, and does not carry over into common usage. Nor are these thoughtless ones willing to see that Joshua was simply praying that the mountains not remove the sunlight from him, which prayer he expressed in words conforming to the sense of sight, as it would be quite inappropriate to think, at that moment, of astronomy and of visual errors. For if someone had admonished him that the sun doesn't really move against the valley of Ajalon, but only appears to do so, wouldn't Joshua have exclaimed that he only asked for the day to be lengthened, however that might be done? He would therefore have replied in the same way if anyone had begun to present him with arguments for the sun's perpetual rest and the earth's motion.

Now God easily understood from Joshua's words what he meant, and responded by stopping the motion of the earth, so that the sun might appear to him to stop. For the gist of Joshua's petition comes to this, that it might appear so to him, whatever the reality might meanwhile be. Indeed, that this appearance should come about was not vain and purposeless, but quite conjoined with the desired effect.

[21] Joshua 10: 12 ff.

But see Chapter 10 of the *Astronomiae pars optica,* where you will find reasons why, to absolutely all men, the sun appears to move and not the earth: it is because the sun appears small and the earth large, and also because, owing to its apparent slowness, the sun's motion is perceived, not by sight, but by reasoning alone, through its change of distance from the mountains over a period of time. It is therefore impossible for a previously uninformed reason to imagine anything but that the earth, along with the arch of heaven set over it, is like a great house, immobile, in which the sun, so small in stature, travels from one side to the other like a bird flying in the air.

What absolutely all men imagine, the first line of holy scripture presents. 'In the beginning,' says Moses, 'God created the heaven and the earth,' because it is these two parts that chiefly present themselves to the sense of sight. It is as though Moses were to say to man, 'This whole worldly edifice that you see, light above and dark and widely spread out below, upon which you are standing and by which you are roofed over, has been created by God.'

In another passage, Man is asked whether he has learned how to seek out the height of heaven above, or the depths of the earth below[22], because to the ordinary man both appear to extend through equally infinite spaces. Nevertheless, there is no one in his right mind who, upon hearing these words, would use them to limit astronomers' diligence either in showing the contemptible smallness of the earth in comparison with the heavens, or in investigating astronomical distances. For these words do not concern measurements arrived at by reasoning. Rather, they concern real exploration, which is utterly impossible for the human body, fixed upon the land and drawing upon the free air. Read all of Chapter 38 of Job, and compare it with matters discussed in astronomy and in physics.

Suppose someone were to assert, from Psalm 24, that the earth is founded upon rivers, in order to support the novel and absurd philosophical conclusion that the earth floats upon rivers. Would it not be correct to say to him that he should regard the Holy Spirit as a divine messenger, and refrain from wantonly dragging Him into physics class? For in that passage the psalmodist intends nothing but what men already know and experience daily, namely, that the land, raised on high after the separation of the waters, has great rivers flowing through it and seas surrounding it. Not surprisingly, the same

[22] Jeremiah 31: 37.

figure of speech is adopted in another passage, where the Israelites sing that they were seated upon the waters of Babylon[23], that is, by the riverside, or on the banks of the Euphrates and Tigris.

If this be easily accepted, why can it not also be accepted that in other passages usually cited in opposition to the earth's motion we should likewise turn our eyes from physics to the aims of scripture?

(***) 5 v A generation passes away (says Ecclesiastes)[24], and a generation comes, but the earth stands forever. Does it seem here as if Solomon wanted to argue with the astronomers? No; rather, he wanted to warn men of their own mutability, while the earth, home of the human race, remains always the same, the motion of the sun perpetually returns to the same place, the wind blows in a circle and returns to its starting point, rivers flow from their sources into the sea, and from the sea return to the sources, and finally, as these men perish, others are born. Life's tale is ever the same; there is nothing new under the sun.

You do not hear any physical dogma here. The message is a moral one, concerning something self-evident and seen by all eyes but seldom pondered. Solomon therefore urges us to ponder. Who is unaware that the earth is always the same? Who does not see the sun return daily to its place of rising, rivers perennially flowing towards the sea, the winds returning in regular alternation, and men succeeding one another? But who really considers that the same drama of life is always being played, only with different characters, and that not a single thing in human affairs is new? So Solomon, by mentioning what is evident to all, warns of that which almost everyone wrongly neglects.

It is said, however, that psalm 104, in its entirety, is a physical discussion, since the whole of it is concerned with physical matters, And in it, God is said to have 'founded the earth upon its stability, that it not be laid low unto the ages of ages[25].' But in fact, nothing could be farther from the psalmodist's intention than speculation about physical causes. For the whole thing is an exultation upon the greatness of God, who made all these things: the author has composed a hymn to God the creator, in which he treats the world in order, as it appears to the eyes.

If you consider carefully, you will see that it is a commentary upon

[23] Psalm 137.
[24] Ecclestiastes 1: 4.
[25] The Latin of the Vulgate, quoted by Kepler, differs markedly from the Greek (and hence from most English translations) here.

the six days of creation in Genesis. For in the latter, the first three days are given to the separation of the regions: first, the region of light from the exterior darkness; second, the waters from the waters by the interposition of an extended region; and third, the land from the seas, where the earth is clothed with plants and shrubs. The last three days, on the other hand, are devoted to the filling of the regions so distinguished: the fourth, of the heavens; the fifth, of the seas and the air; and the sixth, of the land. And in this psalm there are likewise the same number of distinct parts, analogous to the works of the six days.

In the second verse, he enfolds the Creator with the vestment of light, first of created things, and the work of the first day.

The second part begins with the third verse, and concerns the waters above the heavens, the extended region of the heavens, and atmospheric phenomena that the psalmodist ascribes to the waters above the heavens, namely, clouds, winds, tornadoes, and lightning.

The third part begins with the sixth verse, and celebrates the earth as the foundation of the things being considered. The psalmodist relates everything to the earth and to the things that live on it, because, in the judgement of sight, the chief parts of the world are two: heaven and earth. He therefore considers that for so many ages now the earth has neither sunk nor cracked apart nor tumbled down, yet no one has certain knowledge of what it is founded upon.

He does not wish to teach things of which men are ignorant, but to recall to mind something they neglect, namely, God's greatness and potency in a creation of such magnitude[26], so solid and stable. If an astronomer teaches that the earth is carried through the heavens, he is not spurning what the psalmodist says here, nor does he contradict human experience. For it is still true that the land, the work of God the architect, has not toppled as our buildings usually do, consumed by age and rot; that it has not slumped to one side; that the dwelling places of living thing have not been set in disarray; that the mountains and coasts have stood firm, unmoved against the blast of wind and wave, as they were from the beginning. And then the psalmodist adds a beautiful sketch of the separation of the waters by the continents, and adorns his account by adding springs and the amenities that springs and crags provide for bird and beast. He also does not fail to mention the adorning of the earth's surface, included by Moses among the works of the third day, although the psalmodist derives it

[26] Cf. Virgil, *Aeneid*, I. 33

from its prior cause, namely, a humidification arising in the heavens, and embellishes his account by bringing to mind the benefits accruing from that adornment for the nurture and pleasure of humans and for the lairs of the beasts.

The fourth part begins with verse 20, and celebrates the work of the fourth day, the sun and the moon, but chiefly the benefit that the division of times brings to humans and other living things. It is this benefit that is his subject matter: it is clear that he is not writing as an astronomer here.

If he were, he would not fail to mention the five planets, than whose motion nothing is more admirable, nothing more beautiful, and nothing a better witness to the Creator's wisdom, for those who take note of it.

The fifth part, in verse 26, concerns the work of the fifth day, where he fills the sea with fish and ornaments it with sea voyages.

The sixth is added, though obscurely, in verse 28, and concerns the animals living on land, created on the sixth day. At the end, in conclusion, he declares the general goodness of God in sustaining all things and creating new things. So everything the psalmodist said of the world relates to living things. He tells nothing that is not generally acknowledged, because his purpose was to praise things that are known, not to seek out the unknown. It was his wish to invite men to consider the benefits accruing to them from each of these works of the six days.

Advice to astronomers. (***) 6 r

I, too, implore my reader, when he departs from the temple and enters astronomical studies, not to forget the divine goodness conferred upon men, to the consideration of which the psalmodist chiefly invites. I hope that, with me, he will praise and celebrate the Creator's wisdom and greatness, which I unfold for him in the more perspicacious explanation of the world's form, the investigation of causes, and the detection of errors of vision. Let him not only extol the Creator's divine beneficence in His concern for the well-being of all living things, expressed in the firmness and stability of the earth, but also acknowledge His wisdom expressed in its motion, at once so well hidden and so admirable.

Advice for idiots.

But whoever is too stupid to understand astronomical science, or too weak to believe Copernicus without affecting his faith, I would advise him that, having dismissed astronomical studies and having damned whatever philosophical opinions he pleases, he mind his own business and betake himself home to scratch in his own dirt patch,

abandoning this wandering about the world. He should raise his eyes (his only means of vision) to this visible heaven and with his whole heart burst forth in giving thanks and praising God the Creator. He can be sure that he worships God no less than the astronomer, to whom God has granted the more penetrating vision of the mind's eye, and an ability and desire to celebrate his God above those things he has discovered.

Commendation of the Brahean hypothesis.

At this point, a modest (though not too modest) commendation to the learned should be made on behalf of Brahe's opinion of the form of the world, since in a way it follows a middle path. On the one hand, it frees the astronomers as much as possible from the useless apparatus of so many epicycles and, with Copernicus, it includes the causes of motion, unknown to Ptolemy, giving some place to physical theory in accepting the sun as the centre of the planetary system. And on the other hand, it serves the mob of literalists and eliminates the motion of the earth, so hard to believe, although many difficulties are thereby insinuated into the theories of the planets in astronomical discussions and demonstrations, and the physics of the heavens is no less disturbed.

V. To objections concerning the authority of the pious.

So much for the authority of holy scripture. As for the opinions of the pious[27] on these matters of nature, I have just one thing to say: while in theology it is authority that carries the most weight, in philosophy it is reason. Therefore, Lactantius is pious, who denied that the earth is round[28], Augustine is pious, who, though admitting the roundness, denied the antipodes, and the Inquisition[29] nowadays is pious, which, though allowing the earth's smallness, denies its motion. To me, however, the truth is more pious still, and (with all due respect for the Doctors of the Church) I prove philosophically not only that the earth is round, not only that it is inhabited all the way around at the antipodes, not only that it is contemptibly small, but also that it is carried along among the stars.

But enough about the truth of the Copernican hypothesis. Let us return to the plan I proposed at the beginning of this introduction.

[27] Latin, *Sancti,* literally, 'the Saints', or 'the Holy'. Context shows, however, that in modern usage 'pious' or 'saintly' fits Kepler's meaning better, even though it does miss his verbal play on *Sanctum Officium* (see note 29, below).

[28] In *De Revolutionibus,* in his dedicatory letter to Pope Paul III, Copernicus also mentions Lactantius as a revered theologian whose cosmological opinions are acknowledged as false. See Lactantius, *Institut. Divin.,* III. 24, and Augustine, *The City of God,* XVI. 9.

[29] Latin, *Officium,* the so-called 'Holy Office', by which name the Inquisition was officially known. Kepler literally says, 'the Office is Holy', referring to its name and implying approval.

I had begun to say that in this work I treat all of astronomy by means of physical causes rather than fictitious hypotheses, and that I had taken two steps in my effort to reach this central goal: first, that I had discovered that the planetary eccentrics all intersect in the body of the sun, and second, that I had understood that in the theory of the earth there is an equant circle, and that its eccentricity is to be bisected.

The third step towards the physical hypotheses of the motions. The eccentricity of Mars's equant is to be precisely bisected.

Now we come to the third step, namely, that it has been demonstrated with certainty, by a comparison of the conclusions of parts 2 and 4, that the eccentricity of Mars's equant is also to be precisely bisected, a fact long held in doubt by Brahe and Copernicus.

Therefore, by induction extending to all the planets (carried out in part 3 by way of anticipation), since there are (of course) no solid orbs, as Brahe demonstrated from the paths of comets, the body of the sun is the source of the power that drives all the planets around. Moreover, I have specified the manner [in which this occurs] as follows: that the sun, although it stays in one place, rotates as if on a lathe, and out of itself sends into the space of the world an immaterial *species*[30] of its body, analogous to the immaterial *species* of its light. This *species* itself, as a consequence of the rotation of the solar body, also rotates like a very rapid whirlpool throughout the whole breadth of the world, and carries the bodies of the planets along with itself in a gyre, its grasp stronger or weaker according to the greater density or rarity it acquires through the law governing its diffusion.

Once this common power was proposed, by which all the planets, each in its own circle, are driven around the sun, the next step in my argument was to give each of the planets its own mover, seated in the planet's globe (you will recall that, following Brahe's opinion, I had already rejected solid orbs). And this, too, I have accomplished in part 3.

By this train of argument, the existence of the movers was established. The amount of work they occasioned me in part 4 is incredible, when, in producing the planet-sun distances and the eccentric equations[31] that were required, the results came out full of flaws and in disagreement with the observations. This is not because they should not have been introduced, but because I had bound them to the millstones (as it were) of circularity, under the spell of common

[30] For the meaning of this untranslatable term, see the Glossary.

[31] For an explanation of this and related terms, see the Glossary.

opinion. Restrained by such fetters, the movers could not do their work.

Fourth step to the physical hypotheses. The course that a planet describes in the heavens, is an oval path.

(***) 6 v

But my exhausting task was not complete: I had a fourth step yet to make towards the physical hypotheses. By most labourious proofs and by computations on a very large number of observations, I discovered that the course of a planet in the heavens is not a circle, but an oval path, perfectly elliptical.

Geometry gave assent to this, and taught that such a path will result if we assign to the planet's own movers the task of making the planet's body reciprocate along a straight line extended towards the sun. Not only this, but also the correct eccentric equations, agreeing with the observations, resulted from such a reciprocation.

Finally, the pediment was added to the structure, and proven geometrically: that it is in the order of things for such a reciprocation to be the result of a magnetic corporeal faculty. Consequently, these movers belonging to the planets individually are shown with great probability to be nothing but properties of the planetary bodies themselves, like the magnet's property of seeking the pole and catching up iron. As a result, every detail of the celestial motions is caused and regulated by faculties of a purely corporeal nature, that is, magnetic, with the sole exception of the whirling of the solar body as it remains fixed in its space. For this, a vital faculty[32] seems required.

Next, in part 5, it was demonstrated that the physical hypotheses we just introduced also give a satisfactory account of the latitudes.

There are some, however, who are put off by a few extraneous and seemingly valid objections and do not wish to put such great trust in the nature of bodies. Therefore, in parts 3 and 4, some room was left for Mind, so that the planet's proper mover could attach the faculty of Reason to the animate faculty of moving its globe[33]. These people would have to allow the mind to make use of the sun's apparent diameter as a measure of the reciprocation, and to be able to sense the angles that astronomers require.

All this has been said for the sake of the physicists. The astronomers and geometers will find the rest in the following summaries of the individual chapters, each in its proper place. I intentionally made this rather detailed, partly so that it might serve as an index, and partly so that a reader who gets stuck here and there in the synoptic table, whether because of the obscurity of the material or of the style, might seek some additional light from these summaries. If the reasons for the order and the coherence of topics lumped together in the same chapter turn out to be hard to see in the text itself, the reader might perceive them more readily among the summaries, which are divided into paragraphs. I therefore ask the reader to consider it well.

The Synoptic Table.

[32] *Facultas vitalis.* This faculty does not fit into the threefold division of physiological and psychological faculties mentioned in footnote 5 above. It comes from a different tradition, Galenic rather than Aristotelian. Although it is rather like the animate faculty, it does not include the power of perception.

[33] Kepler has clearly returned to the Aristotelian schema. Aristotle argued that the faculties of perception and locomotion are always conjoined, and consequently placed them under a single aspect of soul, the sensitive. His highest faculty was the rational. Clearly, Kepler follows Aristotle in considering the animal and vital faculties to be the same or similar, and subordinate to reason.