

equal right, that the terrestrial senses of the inhabitants of earth lack reason.

*Kepler, A New Astronomy Based upon Causes, or Celestial Physics, Treated by Means of Commentaries on the Motions of Mars, 1609*<sup>fni</sup>

*When Kepler joined Tycho Brahe in Prague, where Tycho had moved to serve Emperor Rudolph II, he had hoped to use Tycho's observational data to assess and modify the theory of Platonic solids from the Cosmographic Mystery. Initially he was only given Tycho's data on Mars, and his battle with that planet's tricky orbit ultimately became the 1609 New Astronomy. Yet the book was not just about Mars, but was rather an entirely new way of doing astronomy, which he referred to in his title as 'celestial physics'. Kepler argued in the book that planetary motions needed to have physical causes and explanations; in his view,*

*inspired in part by applying William Gilbert's theories of magnetism from the earth to the sun, a force coming from the sun might be the cause of the planetary orbits. In the course of exploring that theory with the data from Mars, Kepler discovered what became known as his first two laws. The second law (though he discovered it first) stated that the area swept out by a planet as it moves along its orbit is equal in equal time intervals; this meant that planets move faster the closer they are to the sun and slower the further from it they are. The first law (discovered second) stated that planetary orbits were shaped like ellipses with two foci, and that the sun occupied one of those foci. His approach thus broke from tradition in two ways: the insistence that astronomy was physical, and the move away from perfect circles, which even Copernicus had embraced.*

## Introduction

It is extremely hard these days to write mathematical books, especially astronomical ones. For unless one maintains the truly rigorous sequence of proposition, construction, demonstration and conclusion, the book will not be mathematical;

but maintaining that sequence makes the reading most tiresome. I myself, who am known as a mathematician, find my mental forces wearying when, upon rereading my own work, I recall from the 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.

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

There are many points that should be brought together here at the beginning which are presented bit by bit through 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, 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 shall 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 that are found to be common to their motions. The latter school I again subdivide. 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.

For each of these three options concerning the world there are several other peculiarities which themselves also serve to distinguish the 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 the motion of Mars) in all three forms of hypotheses, so that what we compute from the tables may 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 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: The planes of the eccentrics intersect in the sun*

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, but the motion of some point whose distance from that centre, in proportion to the diameter, is the same as 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 great many 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.

### *The second step: there is an equant in the theory of the sun*

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 planets' 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 these 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 toward Capricorn, while the sun's eccentric circuit tends toward 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 toward Cancer, but only by 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 toward 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.

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

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

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 non-uniform

manner, that is, slowly when it is further 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 condemned. 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?

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

1. 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 an exception arising from the circumstances of observation. Thus the motions are still multiplied to no purpose by Brahe, as they were before by Ptolemy.

2. Second, if there are no orbs, 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, namely magnetic ones. But these are more general points. There follow others arising specifically from demonstrations, upon which we now begin.

3. For if the earth is moved, it has been demonstrated that the increases and decreases of its velocity are governed by its approaching toward 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.

4. That, on the other hand, the sun remains in place in the centre of the world, is most prob-

ably 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. 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.

5. 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 of 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.

6. 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 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 intro-

duced here.

7. 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 *On the Heavens*, 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*, Chapter 1, p. 7, and also Chapter 6, especially p. 225.
8. 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 people'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 plan-

ets' motion, which I discuss chiefly in parts three and four of the present work [chapters 22–60].

### *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 toward which they tend. Let the physicist prove that this force is in a point which is neither a body nor is grasped otherwise than through mere relation.

It is impossible that, in moving its body, the form of a stone seeks 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 toward 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 toward 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.

### *The true theory of gravity*

The true theory of gravity rests upon the following axioms.

Every corporeal 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 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 as the centre of the world) are not drawn toward the centre of the world because it is the centre of the world, but because it is the 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 toward it.

If the earth were not round, heavy bodies would not everywhere be drawn in straight lines toward the middle point of the earth, but would be drawn toward 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 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 toward the moon by one fifty-fourth part of the interval, and the moon would descend toward 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.

If the earth should cease to attract its waters to itself, all these waters 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 oceans 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 waters 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 flow 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 toward 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 by 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.

*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, 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 earthly

matter to the very least extent, achieve an altitude of a thousandth part of the semi-diameter. 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 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.

#### *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, *On the New Star*, chapters 15 and 16, [pp. 82 and 84](#).

#### *To objections concerning the immensity of the heavens*

In the same place, you will find the full-sail voyage along the world's immense orbit, which, in objection to Copernicus, is usually held to be unnatural. 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.

*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.

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.*

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

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 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' saffron-coloured bed.'

The psalmist was aware that the sun does not go forth from the 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 psalmist'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, because when he was at the Jordan it appeared so to him. Yet each writer was in perfect control of his meaning. Joshua meant that the sun should be held back in its place in the middle of the sky for an entire day with respect of 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.

But see Chapter 10 of the *Astronomiae Pars Optica*, where you will find reasons why, to absolutely everyone, 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 unformed 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 presented 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.’

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 psalmist 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.

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?

A generation passes away (says Ecclesiastes), and a generation comes, but the earth stands for ever. Does it seem here as if Solomon wanted to argue with the astronomers? No; rather, he wanted to warn people 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 people 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.

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'. But in fact, nothing could be further from the psalmist'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. It is clear that he is not writing as an astronomer here.

#### *Advice to astronomers*

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 psalmist 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's, 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.

*To objections concerning the authority of the pious*  
So much for the authority of Holy Scripture. As for the opinions of the pious on these matters, 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, Augustine is pious, who, though admitting the roundness, denied the antipodes, and their Inquisition 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. 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 eccentricities 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 toward the physical explanation. 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 for 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 emanation of its body, analogous to the immaterial emanation of its light. This emanation 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 year, 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 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 opinion. Restrained by such fetters, the movers could not do their work.

#### *Fourth step to the physical explanation. The planet describes an oval path*

But my exhausting task was not complete: I had a fourth step yet to make toward the physical hypotheses. By most laborious proofs and by computations upon 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 thought 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 toward 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 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. These people would have to allow the mind to make use of the sun's apparent diameter as a measure of reciprocation, and to be able to sense the angles that astronomers require.

## Kepler, Orbit of Mars, from *New Astronomy*, 1609

Kepler used this diagram of the orbit of Mars in the Ptolemaic and Tychonic systems to demonstrate the differences between the three world systems and the reason to prefer the Copernican. Though the three world systems were geometrically equivalent and equally capable of accounting for planetary motion, the Ptolemaic and Tychonic systems produced orbital paths that looked extremely complicated, much like this pretzel-shaped diagram. The Copernican paths were much more physically simple – not circular, but close to it – and linked to the physical presence of the sun; this, Kepler argued, was proof that the Copernican system was preferable to the others, as it was the only system that made physical sense.

DE MOTIB. STELLÆ MARTIS

