[I]t is the job of the astronomer to use painstaking and skilled observation in gathering together the history of the celestial movements, and then—since he cannot by any line of reasoning reach the true causes of these movements—to think up or construct whatever . . . hypotheses he pleases such that . . . those same movements can be calculated from the principles of geometry for the past and for the future too.

- Preface, De Revolutionibus (1543)

Moreover, [astronomers] have not been able to discover or to infer the chief point of all, i.e., the form of the world and the certain commensurability of its parts. But they are in exactly the same fix as someone taking from different places hands, feet, head, and the other limbs—shaped very beautifully but not with reference to one body and without correspondence to one another—so that such parts made up a monster rather than a man.

- Copernicus, De Revolutionibus (1543)

3-3P) Nicolas Copernicus (1473-1543), “On the Revolutions of the Heavenly Spheres” (1543)¹

Fig. 3-P3.1) Nicholas Copernicus (1473-1543)

[Despite having been born in northern Poland and far from the centers of Renaissance culture, Copernicus obtained an excellent humanist education in classics (his first publication was a translation from Greek into Latin of the work of a minor Greek poet), law, medicine, and of course mathematics. In 1491 he matriculated at the University of Cracow, then considered the best university in central Europe. There were two chairs in astronomy, one in mathematical astronomy and one in astrology, with a century-long tradition of critical. Thus even as an undergraduate Copernicus had probably learned something about the strengths and weaknesses of Ptolemaic planetary theory. It was also in Cracow that the young Copernicus became a member of the secret learned society known as the ‘Brotherhood of the Vistula’ (named after the river that runs through the city), dedicated in part to the revival of the Pythagorean philosophy. Copernicus continued his education in northern Italy, first in law at the University of]
Bologna (where he also studied with the Italian astronomer Domenico Maria da Novara), then medicine at the University of Padua, and finally canon law at the University of Ferrara. He returned permanently to Poland in 1503 and took up his duties as a canon (or church administrator) attached to the cathedral in Frombork in Varmia (Poland) where his maternal uncle had recently been named bishop. His earliest account of the heliocentric system, the Commentariolus (or ‘Little Commentary”) was written and circulated among friends in manuscript form soon after 1512. By 1531 he had transformed the qualitative sketch of the Commentariolus into a mathematical model capable of predictions. Yet he published his masterpiece only in 1543, reviewing the proofs while lying on his deathbed.]

To the Reader Concerning the Hypotheses of this Work

Since the newness of the hypotheses of this work—which sets the earth in motion and puts an immovable sun at the center of the universe—has already received a great deal of publicity, I have no doubt that certain of the savants have taken grave offense and think it wrong to raise any disturbance among liberal disciplines which have had the right set-up for a long time now. If, however, they are willing to weigh the matter scrupulously, they will find that the author of this work has done nothing which merits blame. For it is the job of the astronomer to use painstaking and skilled observation in gathering together the history of the celestial movements, and then—since he cannot by any line of reasoning reach the true causes of these movements—to think up or construct whatever causes or hypotheses he pleases such that, by the assumption of these causes, those same movements can be calculated from the principles of geometry for the past and for the future too. This artist is markedly outstanding in both of these respects: for it is not necessary that these hypotheses should be true, or even probably; but it is enough if they provide a calculus which fits the observations—unless by some chance there is anyone so ignorant of geometry and optics as to hold the epicycle of Venus as probable and to believe this to be a cause why Venus alternately precedes and follows the sun at an angular distance of up to 40 degrees or more. For who does not see that it necessarily follows from this
assumption that the diameter of the planet in its perigee should appear more than four times greater, and the body of the planet more than sixteen times greater, than in its apogee? Nevertheless the experience of all the ages is opposed to that. There are also other things in this discipline which are just as absurd, but it is not necessary to examine them right now. For it is sufficiently clear that this art is absolutely and profoundly ignorant of the causes of the apparent irregular movements. And if it constructs and thinks up causes—and it has certainly thought up a good many—nevertheless it does not think them up in order to persuade anyone of their truth but only in order that they may provide a correct basis for calculation. But since for one and the same movement varying hypotheses are proposed from time to time, as eccentricity or epicycle for the movement of the sun, the astronomer much prefers to take the one which is easiest to grasp. Maybe the philosopher demands probability instead; but neither of them will grasp anything certain or hand it on, unless it has been divinely revealed to him. Therefore let us permit these new hypotheses to make a public appearance among old ones which are themselves no more probable, especially since they are wonderful and easy and bring with them a vast storehouse of learned observations. And as far as hypotheses go, let no one expect anything in the way of certainty from astronomy, since astronomy can offer us nothing certain, lest, if anyone take as true that which has been constructed for another use, he go away from this discipline a bigger fool than when he came to it. Farewell.  

2 Copernicus only published his work after the insistent prompting of Joachim Rheticus (????-????), a young Lutheran theologian who had traveled from Wittenberg to assist the aging astronomer in the arduous task of seeing the treatise through the press. Called back to Wittenberg and assigned to a teaching post elsewhere, Rheticus turned the project over to ???Osiander (????-????), a fellow-Lutheran but one without training in astronomy. In one of the great ironies of the story is that it was neither Copernicus (who had died) nor Rheticus (who was far away) who wrote the preface to De revolutionibus but Osiander. Because the preface was unsigned, readers were left to assume that it was from the hand of Copernicus—and that it was his opinion that astronomers cannot ascertain the “true causes” behind celestial motions but can only hope to construct useful mathematical fictions. It was Kepler, half a century later,
Preface and Dedication to Pope Paul III

I can reckon easily enough, Most Holy Father, that as soon as certain people learn that in these books of mine which I have written about the revolutions of the spheres of the world I attribute certain motions to the terrestrial globe, they will immediately shout to have me and my opinion hooted off the stage. For my own works do not please me so much that I do not weigh what judgments others will pronounce concerning them. And although I realize that the conceptions of a philosopher are placed beyond the judgment of the crowd, because it is his loving duty to seek the truth in all things, in so far as God has granted that to human reason; nevertheless I think we should avoid opinions utterly foreign to rightness. And when I considered how absurd this “lecture” would be held by those who know that the opinion that the Earth rests immovable in the middle of the heavens as if their center had been confirmed by the judgments of many ages—if I were to assert to the contrary that the Earth moves; for a long time I was in great difficulty as to whether I should bring to light my commentaries written to demonstrate the Earth’s movement, or whether it would not be better to follow the example of the Pythagoreans and certain others who used to hand down the mysteries of their philosophy not in writing but by word of mouth and only to their relatives and friends—witness the letter of Lysis to Hipparchus. They however seem to me to have done that not, as some judge, out of a jealous unwillingness to communicate their doctrines but in order that things of very great beauty which have been investigated by the loving care of great men should not be scorned by those who find it a bother to expend any great energy on letters—except on the money-making variety—or who are provoked by the exhortations and examples of others to the liberal study of philosophy but on account of their natural stupidity hold the position among philosophers that drones hold among bees. Therefore, when I weighed these things in my mind, the scorn which I had to fear on account of the newness and absurdity of my opinion almost drove me to abandon a work already undertaken.

But my friends made me change my course in spite of my long-continued

who first correctly attributed the preface to Osiander, thereby rescuing Copernicus from the
hesitation and even resistance. First among them was Nicholas Schonberg, Cardinal of Capua, a man distinguished in all branches of learning; next to him was my devoted friend Tiedeman Giese, Bishop of Culm, a man filled with the greatest zeal for the divine and liberal arts: for he in particular urged me frequently and even spurred me on by added reproaches into publishing this hook and letting come to light a work which I had kept hidden among my things for not merely nine years, but for almost four times nine years. Not a few other learned and distinguished men demanded the same thing of me, urging me to refuse no longer—on account of the fear which I felt—to contribute my work to the common utility of those who are really interested in mathematics: they said that the abuser my teaching about the movement of the Earth now seems to very many persons, the more wonder and thanksgiving will it be the object of, when after the publication of my commentaries those same persons see the fog of absurdity dissipated by my luminous demonstrations. Accordingly I was led by such persuasion and by that hope finally to permit my friends to undertake the publication of a work which they had long sought from me.

But perhaps Your Holiness will not be so much surprised at my giving the results of my nocturnal study to the light—after having taken such care in working them out that I did not hesitate to put in writing my conceptions as to the movement of the Earth—as you will be eager to hear from me what came into my mind that in opposition to the general opinion of mathematicians and almost in opposition to common sense I should dare to imagine some movement of the Earth. And so I am unwilling to hide from Your Holiness that nothing except my knowledge that mathematicians have not agreed with one another in their researches moved me to think out a different scheme of drawing up the movements of the spheres of the world. For in the first place mathematicians are so uncertain about the movements of the sun and moon that they can neither demonstrate nor observe the unchanging magnitude of the revolving year. Then in setting up the solar and lunar movements and those of the other five wandering stars, they do not employ the same principles, assumptions, or demonstrations for the revolutions and

‘fictionalist’ camp.
apparent movements. For some make use of homocentric circles only, others of
eccentric circles and epicycles, by means of which however they do not fully attain what
they seek. For although those who have put their trust in homocentric circles have
shown that various different movements can be composed of such circles, nevertheless
they have not been able to establish anything for certain that would fully correspond to
the phenomena. But even if those who have thought up eccentric circles seem to have
been able for the most part to compute the apparent movements numerically by those
means, they have in the meanwhile admitted a great deal which seems to contradict the
first principles of regularity of movement. Moreover, they have not been able to
discover or to infer the chief point of all, i.e., the form of the world and the certain
commensurability of its parts. But they are in exactly the same fix as someone taking
from different places hands, feet, head, and the other limbs—shaped very beautifully
but not with reference to one body and without correspondence to one another—so that
such parts made up a monster rather than a man. And so, in the process of
demonstration which they call “method,” they are found either to have omitted
something necessary or to have admitted something foreign which by no means
pertains to the matter; and they would by no means have been in this fix, if they had
followed sure principles. For if the hypotheses they assumed were not false, everything
which followed from the hypotheses would have been verified without fail; and though
what I am saying may be obscure right now, nevertheless it will become clearer in the
proper place.

Accordingly, when I had meditated upon this lack of certitude in the traditional
mathematics concerning the composition of movements of the spheres of the world, I
began to be annoyed that the philosophers, who in other respects had made a very
careful scrutiny of the least details of the world, had discovered no sure scheme for the
movements of the machinery of the world, which has been built for us by the Best and
Most Orderly Workman of all. Wherefore I took the trouble to reread all the books by
philosophers which I could get hold of, to see if any of them even supposed that the
movements of the spheres of the world were different from those laid down by those
who taught mathematics in the schools. And as a matter of fact, I found first in Cicero
that Nicetas thought that the Earth moved. And afterwards I found in Plutarch that there were some others of the same opinion: I shall copy out his words here, so that they may be known to all:

Some think that the Earth is at rest; but Philolaus$^3$ the Pythagorean says that it moves around the fire with an obliquely circular motion, like the sun and moon. Herakleides of Pontus$^4$ and Ekphantus the Pythagorean do not give the Earth any movement of locomotion, but rather a limited movement of rising and setting around its center, like a wheel.

Therefore I also, having found occasion, began to meditate upon the mobility of the Earth. And although the opinion seemed absurd, nevertheless because I knew that others before me had been granted the liberty of constructing whatever circles they pleased in order to demonstrate astral phenomena, I thought that I too would be readily permitted to test whether or not, by the laying down that the Earth had some movement, demonstrations less shaky than those of my predecessors could be found for the revolutions of the celestial spheres.

And so, having laid down the movements which I attribute to the Earth farther on in the work, I finally discovered by the help of long and numerous observations that if the movements of the other wandering stars are correlated with the circular movement of the Earth, and if the movements are computed in accordance with the revolution of each planet, not only do all their phenomena follow from that but also this correlation binds together so closely the order and magnitudes of all the planets and of their

$^3$ Philolaus (c. 450-400 B.C.E.) was perhaps the famous Pythagorean after Pythagoras himself. Several ancient sources attribute to him the 'Pythagorean system' in astronomy: a central fire, or 'Hearth of the Universe' directs the motions of the planets and stars in a series of concentric orbits: the earth and 'counter-earth' (a companion planet that can never be seen since it is always on the opposite side of the Hearth) are in the inner-most orbits, then the moon, sun, five planets, and the sphere of fixed star all of which reside in an infinite void space.

$^4$ Herakleides of Pontus (c. 388-315 B.C.E.) mantained, in contradiction to Plato (and the majority of Greek astronomers), that the daily motion of the stars and planets from east to west could be explained in terms of the earth rotating once a day west to east—thus leaving celestial sphere stationary. He also argued that Mars and Venus orbit the sun. Obviously, both hypotheses were critical elements in Copernicus' heliocentric theory.
spheres or orbital circles and the heavens themselves that nothing can be shifted around in any part of them without disrupting the remaining parts and the universe as a whole.

Accordingly, in composing my work I adopted the following order: in the first book I describe all the locations of the spheres or orbital circles together with the movements which I attribute to the earth, so that this hook contains as it were the general set-up of the universe. But afterwards in the remaining books I correlate all the movements of the other planets and their spheres or orbital circles with the mobility of the Earth, so that it can be gathered from that how far the apparent movements of the remaining planets and their orbital circles can be saved by being correlated with the movements of the Earth. And I have no doubt that talented and learned mathematicians will agree with me, if—as philosophy demands in the first place—they are willing to give not superficial but profound thought and effort to what I bring forward in this work in demonstrating these things. And in order that the unlearned as well as the learned might see that I was not seeking to flee from the judgment of any man, I preferred to dedicate these results of my nocturnal study to Your Holiness rather than to anyone else; because, even in this remote corner of the earth where I live, you are held to be most eminent both in the dignity of your order and in your love of letters and even of mathematics; hence, by the authority of your judgment you can easily provide a guard against the bites of slanderers, despite the proverb that there is no medicine for the bite of a sycophant.

But if perchance there are certain “idle talkers” who take it upon themselves to pronounce judgment, although wholly ignorant of mathematics, and if by shamelessly distorting the sense of some passage in Holy Writ to suit their purpose, they dare to reprehend and to attack my work; they worry me so little that I shall even scorn their judgments as foolhardy. For it is not unknown that Lactantius, otherwise a distinguished writer but hardly a mathematician, speaks in an utterly childish fashion concerning the shape of the Earth, when he laughs at those who have affirmed that the Earth has the form of a globe. And so the studious need not be surprised if people like that laugh at us. Mathematics is written for mathematicians; and among them, if I am not mistaken,
my labors will be seen to contribute something to the ecclesiastical commonwealth, the principate of which Your Holiness now holds. For not many years ago under Leo X when the Lateran Council was considering the question of reforming the Ecclesiastical Calendar, no decision was reached, for the sole reason that the magnitude of the year and the months and the movements of the sun and moon had not yet been measured with sufficient accuracy. From that time on I gave attention to making more exact observations of these things and was encouraged to do so by that most distinguished man, Paul, Bishop of Fossombrone who had been present at those deliberations. But what have I accomplished in this matter I leave to the judgment of Your Holiness in particular and to that of all other learned mathematicians. And so as not to appear to Your Holiness to make more promises concerning the utility of this book than I can fulfill, I now pass on to the body of the work. [ . . . ]

Book One, 5. Does the Earth have a Circular Movement? And of its Place

Now that it has been shown that the Earth too has the form of a globe, I think we must see whether or not a movement follows upon its form and what the place of the Earth is in the universe. For without doing that it will not be possible to find a sure reason for the movements appearing in the heavens. Although there are so many authorities for saying that the Earth rests in the center of the world that people think the contrary supposition inoponable and even ridiculous; if however we consider the thing attentively, we will see that the question has not yet been decided and accordingly is by no means to be scorned. For every apparent change in place occurs on account of the movement either of the thing seen or of the spectator, or on account of the necessarily unequal movement of both. For no movement is perceptible relatively to things moved equally in the same directions—I mean relatively to the thing seen and the spectator. Now it is from the Earth that the celestial circuit is beheld and presented to our sight. Therefore, if some movement should belong to the Earth it will appear, in the parts of the universe which are outside, as the same movement but in the opposite direction, as though the things outside were passing over. And the daily revolution in especial is such a movement. For the daily revolution appears to carry the whole universe along,
with the exception of the Earth and the things around it. And if you admit that the heavens possess none of this movement but that the Earth turns from west to east, you will find—if you make a serious examination—that as regards the apparent rising and setting of the sun, moon, and stars the case is so. And since it is the heavens which contain and embrace all things as the place common to the universe it will not be clear at once why movement should not be assigned to the contained rather than to the container, to the thing placed rather than to the thing providing the place.

As a matter of fact, the Pythagoreans Herakleides and Ekphantus were of this opinion and so was Hicetas the Syracusan in Cicero; they made the Earth to revolve at the center of the world. For they believed that the stars set by reason of the interposition of the Earth and that with cessation of that they rose again. Now upon this assumption there follow other things, and a no smaller problem concerning the place of the Earth, though it is taken for granted and believed by nearly all that the Earth is the center of the world. For if anyone denies that the Earth occupies the midpoint or center of the world yet does not admit that the distance [between the two] is great enough to be compared with [the distance to] the sphere of the fixed stars but is considerable and quite apparent in relation to the orbital circles of the sun and the planets; and if for that reason he thought that their movements appeared irregular because they are organized around a different center from the center of the Earth, he might perhaps be able to bring forward a perfectly sound reason for movement which appears irregular. For the fact that the wandering stars are seen to be sometimes nearer the Earth and at other times farther away necessarily argues that the center of the Earth is not the center of their circles. It is not yet clear whether the Earth draws near to them and moves away or they draw near to the Earth and move away.

And so it would not be very surprising if someone attributed some other movement to the earth in addition to the daily revolution. As a matter of fact, Philolaus the Pythagorean—no ordinary mathematician, whom Plato’s biographers say Plato went to Italy for the sake of seeing—is supposed to have held that the Earth moved in a circle and wandered in some other movements and was one of the planets.

Many however have believed that they could show by geometrical reasoning that
the Earth is in the middle of the world; that it has the proportionality of a point in relation to the immensity of the heavens, occupies the central position, and for this reason is immovable, because, when the universe moves, the center remains unmoved and the things which are closest to the center are moved the most slowly.
Fig. 3-P3.2) Copernicus' Heliocentric Plan (1543)

[This illustration of the simplified heliocentric plan is from the first edition of Copernicus' *De revolutionibus*, published in 1543. Except for the exchange of positions of the Earth
and sun and the transformation of the moon from a planet into a satellite orbiting the Earth, the ordering of the planets and the encompassing stellar sphere are consistent with traditional geocentric cosmography. Following the name of each planet, Copernicus gives its period of revolution. Although one advantage of the Copernican system over the Ptolemaic was its ability to provide the relative sizes of the planetary orbits, they have not been drawn to scale here. Note that the first (outermost) sphere is labeled stellarum fixarum sphaera immobilis, or, “immobile sphere of fixed stars.”

Book I, 6. On the Immensity of the Heavens in Relation to the Magnitude of the Earth

It can be understood that this great mass which is the Earth is not comparable with the magnitude of the heavens, from the fact that the boundary circles—for that is the translation of the Greek ὥριζαντες—cut the whole celestial sphere into two halves; for that could not take place if the magnitude of the Earth in comparison with the heavens, or its distance from the center of the world were considerable. For the circle bisecting a sphere goes through the center of the sphere, and is the greatest circle which it is possible to circumscribe.

From this argument it is certainly clear enough that the heavens are immense in comparison with the Earth and present the aspect of an infinite magnitude, and that in the judgment of sense-perception the Earth is to the heavens as a point to a body and as a finite to an infinite magnitude. But we see that nothing more than that has been shown, and it does not follow that the Earth must rest at the center of the world. And we should be even more surprised if such a vast world should wheel completely around during the space of twenty-four hours rather than that its least part, the Earth, should. For saying that the center is immovable and that those things which are closest to the center are moved least does not argue that the Earth rests at the center of the world. [. . .]

The argument which maintains that the Earth, as a part of the celestial sphere and as sharing in the same form and movement, moves very little because very near to its center advances to the following position: therefore the Earth will move, as being a body and not a center, and will describe in the same time arcs similar to, but smaller
than, the arcs of the celestial circle. It is clearer than daylight how false that is; for there would necessarily always be noon at one place and midnight at another, and so the daily risings and settings could not take place, since the movement of the whole and the part would be one and inseparable.

But the ratio between things separated by diversity of nature is so entirely different that those which describe a smaller circle turn more quickly than those which describe a greater circle. In this way Saturn, the highest of the wandering stars, completes its revolution in thirty years, and the moon which is without doubt the closest to the Earth completes its circuit in a month, and finally the Earth itself will be considered to complete a circular movement in the space of a day and a night. So this same problem concerning the daily revolution comes up again. And also the question about the place of the Earth becomes even less certain on account of what was just said. For that demonstration proves nothing except that the heavens are of an indefinite magnitude with respect to the Earth. But it is not at all clear how far this immensity stretches out. On the contrary, since the minimal and indivisible corpuscles, which are called atoms, are not perceptible to sense, they do not, when taken in twos or in some small number, constitute a visible body; but they can be taken in such a large quantity that there will at last be enough to form a visible magnitude. So it is as regards the place of the earth; for although it is not at the center of the world, nevertheless the distance is as nothing, particularly in comparison with the sphere of the fixed stars.

Book I, 7. Why the Ancients Thought the Earth was at Rest at the Middle of the World as its Center

Wherefore for other reasons the ancient philosophers have tried to affirm that the Earth is at rest at the middle of the world, and as principal cause they put forward heaviness and lightness. For Earth is the heaviest element; and all things of any weight are borne towards it and strive to move towards the very center of it.

For since the Earth is a globe towards which from every direction heavy things by their own nature are borne at right angles to its surface, the heavy things would fall on one another at the center if they were not held back at the surface; since a straight line
making right angles with a plane surface where it touches a sphere leads to the center. And those things which are borne toward the center seem to follow along in order to be at rest at the center. All the more then will the Earth be at rest at the center; and, as being the receptacle for falling bodies, it will remain immovable because of its weight.

They strive similarly to prove this by reason of movement and its nature. For Aristotle says that the movement of a body which is one and simple is simple, and the simple movements are the rectilinear and the circular. And of rectilinear movements, one is upward, and the other is downward. As a consequence, every simple movement is either toward the center, i.e., downward, or away from the center, i.e., upward, or around the center, i.e., circular. Now it belongs to earth and water, which are considered heavy, to be borne downward, i.e., to seek the center: for air and fire, which are endowed with lightness, move upward, i.e., away from the center. It seems fitting to grant rectilinear movement to these four elements and to give the heavenly bodies a circular movement around the center. So Aristotle. Therefore, said Ptolemy of Alexandria, if the Earth moved, even if only by its daily rotation, the contrary of what was said above would necessarily take place. For this movement which would traverse the total circuit of the Earth in twenty-four hours would necessarily be very headlong and of an unsurpassable velocity. Now things which are suddenly and violently whirled around are seen to be utterly unfitted for reuniting, and the more unified are seen to become dispersed, unless some constant force constrains them to stick together. And a long time ago, he says, the scattered Earth would have passed beyond the heavens, as is certainly ridiculous; and a fortiori so would all the living creatures and all the other separate masses which could by no means remain unshaken. Moreover, freely falling bodies would not arrive at the places appointed them, and certainly not along the perpendicular line which they assume so quickly. And we would see clouds and other things floating in the air always borne toward the west.

Book I, 8. Answer to the Aforesaid Reasons and Their Inadequacy

For these and similar reasons they say that the Earth remains at rest at the middle of the world and that there is no doubt about this. But if someone opines that the
Earth revolves, he will also say that the movement is natural and not violent. Now things which are according to nature produce effects contrary to those which are violent. For things to which force or violence is applied get broken up and are unable to subsist for a long time. But things which are caused by nature are in a right condition and are kept in their best organization. Therefore Ptolemy had no reason to fear that the Earth and all things on the Earth would be scattered in a revolution caused by the efficacy of nature, which is greatly different from that of art or from that which can result from the genius of man. But why didn’t he feel anxiety about the world instead, whose movement must necessarily be of greater velocity, the greater the heavens are than the Earth? Or have the heavens become so immense, because an unspeakably vehement motion has pulled them away from the center, and because the heavens would fall if they came to rest anywhere else?

Surely if this reasoning were tenable, the magnitude of the heavens would extend infinitely. For the farther the movement is borne upward by the vehement force, the faster will the movement be, on account of the ever-increasing circumference which must be traversed every twenty-four hours: and conversely, the immensity of the sky would increase with the increase in movement. In this way, the velocity would make the magnitude increase infinitely, and the magnitude the velocity. And in accordance with the axiom of physics that that which is infinite cannot be traversed or moved in any way, then the heavens will necessarily come to rest;

But they say that beyond the heavens there isn’t any body or place or void or anything at all; and accordingly it is not possible for the heavens to move outward: in that case it is rather surprising that something can be held together by nothing.⁵ But if the heavens were infinite and were finite only with respect to a hollow space inside, then it will be said with more truth that there is nothing outside the heavens, since anything which occupied any space would be in them; but the heavens will remain immobile. For movement is the most powerful reason wherewith they try to conclude that the universe

is finite.

But let us leave to the philosophers of nature the dispute as to whether the world is finite or infinite, and let us hold as certain that the Earth is held together between its two poles and terminates in a spherical surface. Why therefore should we hesitate any longer to grant to it the movement which accords naturally with its form, rather than put the whole world in a commotion—the world whose limits we do not and cannot know? And why not admit that the appearance of daily revolution belongs to the heavens but the reality belongs to the Earth? And things are as when Aeneas said in Virgil: “We sail out of the harbor, and the land and the cities move away.” As a matter of fact, when a ship floats on over a tranquil sea, all the things outside seem to the voyagers to be moving in a movement which is the image of their own, and they think on the contrary that they themselves and all the things with them are at rest. So it can easily happen in the case of the movement of the Earth that the whole world should be believed to be moving in a circle. Then what would we say about the clouds and the other things floating in the air or falling or rising up, except that not only the Earth and the watery element with which it is conjoined are moved in this way but also no small part of the air and whatever other things have a similar kinship with the Earth? whether because the neighboring air, which is mixed with earthly and watery matter, obeys the same nature as the Earth or because the movement of the air is an acquired one, in which it participates without resistance on account of the contiguity and perpetual rotation of the Earth. [. . .]

In addition, there is the fact that the state of immobility is regarded as more noble and godlike than that of change and instability, which for that reason should belong to the Earth rather than to the world. I add that it seems rather absurd to ascribe movement to the container on to that which provides the place and not rather to that which is contained and has a place, i.e., the Earth. And lastly, since it is clear that the wandering stars are sometimes nearer and sometimes farther away from the Earth, then the movement of one and the same body around the center—and they mean the center of the Earth—will be both away from the center and toward the center. Therefore it is necessary that movement around the center should be taken more
generally; and it should be enough if each movement is in accord with its own center. You see therefore that for all these reasons it is more probable that the Earth moves than that it is at rest—especially in the case of the daily revolution, as it is the Earth’s very own. And I think that is enough as regards the first part of the question.

Book I, 9. Whether Many Movements can be Attributed to the Earth, And Concerning the Center of the World

Therefore, since nothing hinders the mobility of the Earth, I think we should now see whether more than one movement belongs to it, so that it can be regarded as one of the wandering stars. For the apparent irregular movement of the planets and their variable distances from the Earth—which cannot be understood as occurring in circles homocentric with the Earth—make it clear that the Earth is not the center of their circular movements. Therefore, since there are many centers, it is not foolhardy to doubt whether the center of gravity of the Earth rather than some other is the center of the world. I myself think that gravity or heaviness is nothing except a certain natural appetency implanted in the parts by the divine providence of the universal Artisan, in order that they should unite with one another in their oneness and wholeness and come together in the form of a globe. It is believable that this affect is present in the sun, moon, and the other bright planets and that through its efficacy they remain in the spherical figure in which they are visible, though they nevertheless accomplish their circular movements in many different ways. Therefore if the Earth too possesses movements different from the one around its center, then they will necessarily be movements which similarly appear on the outside in the many bodies; and we find the yearly revolution among these movements. For if the annual revolution were changed from being solar to being terrestrial, and immobility were granted to the sun, the risings and settings of the signs and of the fixed stars—whereby they become morning or evening stars—will appear in the same way; and it will be seen that the stoppings, retrogressions, and progressions of the wandering stars are not their own, but are a movement of the Earth and that they borrow the appearances of this movement. Lastly, the sun will be regarded as occupying the center of the world. And the ratio of order in
which these bodies succeed one another and the harmony of the whole world teaches us their truth, if only—as they say—we would look at the thing with both eyes.

Book I, 10. On the Order of the Celestial Orbital Circles

[. . .] Therefore if anyone should take this as an occasion to refer Saturn, Jupiter, and Mars also to this same center, provided he understands the magnitude of those orbital circles to be such as to comprehend and encircle the Earth remaining within them, he would not be in error, as the table of ratios of their movements makes clear. For it is manifest that the planets are always nearer the Earth at the time of their evening rising, i.e., when they are opposite to the sun and the Earth is in the middle between them and the sun. But they are farthest away from the Earth at the time of their evening setting, i.e., when they are occulted in the neighborhood of the sun, namely, when we have the sun between them and the Earth. All that shows clearly enough that their center is more directly related to the sun and is the same as that to which Venus and Mercury refer their revolutions. But as they all have one common center, it is necessary that the space left between the convex orbital circle of Venus and the concave orbital circle of Mars should be viewed as an orbital circle or sphere homocentric with them in respect to both surfaces, and that it should receive the Earth and its satellite the moon and whatever is contained beneath the lunar globe. For we can by no means separate the moon from the Earth, as the moon is incontestably very near to the Earth—especially since we find in this expanse a place for the moon which is proper enough and sufficiently large. Therefore we are not ashamed to maintain that this totality—which the moon embraces—and the center of the Earth too traverse that great orbital circle among the other wandering stars in an annual revolution around the sun; and that the center of the world is around the sun. I also say that the sun remains forever immobile and that whatever apparent movement belongs to it can be verified of the mobility of the Earth; that the magnitude of the world is such that, although the distance from the sun to the Earth in relation to whatsoever planetary sphere you please possesses magnitude which is sufficiently manifest in proportion to these dimensions, this distance, as compared with the sphere of the fixed stars, is imperceptible. I find it
much more easy to grant that than to unhinge the understanding by an almost infinite multitude of spheres—as those who keep the earth at the center of the world are forced to do. But we should rather follow the wisdom of nature, which, as it takes very great care not to have produced anything superfluous or useless, often prefers to endow one thing with many effects. And though all these things are difficult, almost inconceivable, and quite contrary to the opinion of the multitude, nevertheless in what follows we will with God’s help make them clearer than day—at least for those who are not ignorant of the art of mathematics.

Therefore if the first law is still safe—for no one will bring forward a better one than that the magnitude of the orbital circles should be measured by the magnitude of time—then the order of the spheres will follow in this way—beginning with the highest: the first and highest of all is the sphere of the fixed stars, which comprehends itself and all things, and is accordingly immovable. In fact it is the place of the universe, i.e., it is that to which the movement and position of all the other stars are referred. For in the deduction of terrestrial movement, we will however give the cause why there are appearances such as to make people believe that even the sphere of the fixed stars somehow moves. Saturn, the first of the wandering stars follows; it completes its circuit in 30 years. After it comes Jupiter moving in a 12-year period of revolution. Then Mars, which completes a revolution every 2 years. The place fourth in order is occupied by the annual revolution in which we said the Earth together with the orbital circle of the moon as an epicycle is comprehended. In the fifth place, Venus, which completes its revolution in 7 1/2 months. The sixth and final place is occupied by Mercury, which completes its revolution in a period of 88 days. In the center of all rests the sun. For who would place this lamp of a very beautiful temple in another or better place than this wherefrom it can illuminate everything at the same time? As a matter of fact, not unhappily do some call it the lantern; others, the mind and still others, the pilot of the world. Trismegistus calls it a “visible god”; Sophocles’ Electra, “that which gazes upon all things.” And so the sun, as if resting on a kingly throne, governs the family of stars which wheel around. Moreover, the Earth is by no means cheated of the services of the moon; but, as Aristotle says in the De Animalibus, the Earth has the closest kinship with
the moon. The Earth moreover is fertilized by the sun and conceives offspring every year.

Fig. 3-P3.3) Thomas Digges and the Copernican System (1576)

[Thomas Digges (c. 1546-1595), son of the mathematician Leonard Digges with whom he published several astrological and mathematical works (including a treatise on the Platonic solids), emerged as the greatest champion of the heliocentric theory in Elizabethan England. The younger Digges appended to his father’s astrological ‘Prognostication’ (1576) the first depiction of heliocentric cosmography embedded in a celestial sphere of infinite thickness. The sun is at the center, surrounded by the orbs of the planets in their Copernican order and periods (e.g., ‘The orbe of Saturne making his
revolution in 30 yeares'). The inscription between the orbit of Saturn and the beginning of the stellar region reads: "This orbe of starres fixed infinitely up extendeth hit self [itself] in altitude sphericalle, and therefore/ immovable[]. The pallace of foelicitye [felicity] garnished with perpetuall shininge glorious lightes innumerable/ farr excellinge our sonne both in quantitye and qualitye the very court of coelestial angeles/ devoid of greife and replenished with perfite [perfect] endlesse ioye [joy] the habitacle [habitation] for the elect." Near the orbit of the Earth the inscription reads: "The great orbe carryinge this globe of mortalitie." Note finally that the engraving is entitled (at the very top): "A perfite description of the Caelestiall orbes, according to the most ancient doctrine of the Pythagoreans, & etc." The identification of the Copernican system with the Pythagorean system (despite their differences) would continue throughout the seventeenth century.] [Note: Digges' title cut off, re-do image]

Therefore in this ordering we find that the world has a wonderful commensurability and that there is a sure bond of harmony for the movement and magnitude of the orbital circles such as cannot be found in any other way. For now the careful observer can note why progression and retrogradation appear greater in Jupiter than in Saturn and smaller than in Mars; and in turn greater in Venus than in Mercury. And why these reciprocal events appear more often in Saturn than in Jupiter, and even less often in Mars and Venus than in Mercury. In addition, why when Saturn, Jupiter, and Mars are in opposition (to the mean position of the sun) they are nearer to the Earth than at the time of their occultation and their reappearance. And especially why at the tines when Mars is in opposition to the sun, it seems to equal Jupiter in magnitude and to be distinguished from Jupiter only by a reddish color, but when discovered through careful observation by means of a sextant is found with difficulty among the stars of second magnitude? All these things proceed from the same cause, which resides in the movement of the Earth.
Fig. 3-P3.4) The Tusi Couple

[Nasir al-Din al-Tusi (d. 1274) was one of the most important mathematicians and astronomers of the Islamic Middle Ages. Among his most important contributions to planetary theory was a geometrical construction called the 'Tusi couple'. In the diagram above and to the right, the inner circle is exactly half the size of the outer circle and rolls without slipping around the inside of the larger circle. A point on the rim of the smaller circle will execute simple harmonic motion along the diameter of the larger circle—this is the fundamental motion of the Tusi couple. If the larger circle of the Tusi couple is attached to the rim of a deferent as an epicycle (as in the diagram above and to the left and below) and if it is given a diameter equal to the distance between the equant point and Earth, then the combined motion of the Tusi couple and deferent results in a simple displacement of the circular planetary orbit upward by a distance equal to the radius of the epicycle. In other words, the Tusi couple effectively shifts the center of deferent upward and places it on the equant point, thereby eliminating the need for the equant. Copernicus learned of the Tusi couple most likely during his prolonged stay in Italy, and he used it to eliminate the equant construction from his heliocentric theory.]
Fig. 3-P3.5) From Equant to Epicycle