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NICOLAUS COPERNICUS:

On the Revolutions of the Heavenly Spheres

To the Most Holy Lord, Pope Paul III

THE PREFACE OF NICOLAUS COPERNICUS TO THE BOOKS OF THE REVOLUTIONS

I may well presume, most Holy Father, that certain people, as soon as they hear that in this book *On the Revolutions of the Spheres of the Universe* I ascribe movement to the earthly globe, will cry out that, holding such views, I should at once be hissed off the stage. For I am not so pleased with my own work that I should fail duly to weigh the judgment which others may pass thereon; and though I know that the speculations of a philosopher are far removed from the judgment of the multitude—for his aim is to seek truth in all things as far as God has permitted human reason so to do—yet I hold that opinions which are quite erroneous should be avoided.

Thinking therefore within myself that to ascribe movement to the Earth must indeed seem an absurd performance on my part to those who know that many centuries have consented to the establishment of the contrary judgment, namely that the Earth is placed immovably as the central point in the middle of the Universe, I hesitated long whether, on the one hand, I should give to the light these my Commentaries written to prove the Earth's motion, or whether, on the other hand, it were better to follow the example of the Pythagoreans and others who were wont to impart their philosophic mysteries only to intimates and friends, and then not in writing but by word of mouth, as the letter of Lysis to Hipparchus witnesses. In my judgment they did so not, as some would have it, through jealousy of sharing their doctrines, but as fearing lest these so noble and hardly won discoveries of the learned should be despised by such as either care not to study aught save for gain, or—if by the encouragement and example of others they are stimulated to philoso-

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phic liberal pursuits—yet by reason of the dulness of their wits are in the company of philosophers as drones among bees. Reflecting thus, the thought of the scorn which I had to fear on account of the novelty and incongruity of my theory, well-nigh induced me to abandon my project.

These misgivings and actual protests have been overcome by my friends. First among these was Nicolaus Schönberg, Cardinal of Capua, a man renowned in every department of learning. Next was one who loved me well, Tiedemann Giese, Bishop of Kulm, a devoted student of sacred and all other good literature, who often urged and even importuned me to publish this work which I had kept in store not for nine years only, but to a fourth period of nine years. The same request was made to me by many other eminent and learned men. They urged that I should not, on account of my fears, refuse any longer to contribute the fruits of my labours to the common advantage of those interested in mathematics. They insisted that, though my theory of the Earth's movement might at first seem strange, yet it would appear admirable and acceptable when the publication of my elucidatory comments should dispel the mists of paradox. Yielding then to their persuasion I at last permitted my friends to publish that work which they have so long demanded.

That I allow the publication of these my studies may surprise your Holiness the less in that, having been at such travail to attain them, I had already not scrupled to commit to writing my thoughts upon the motion of the Earth. How I came to dare to conceive such motion of the Earth, contrary to the received opinion of the Mathematicians and indeed contrary to the impression of the senses, is what your Holiness will rather expect to hear. So I should like your Holiness to know that I was induced to think of a method of computing the motions of the spheres by nothing else than the knowledge that the Mathematicians are inconsistent in these investigations.

For, first, the mathematicians are so unsure of the movements of the Sun and Moon that they cannot even explain or observe the constant length of the seasonal year. Secondly, in determining the motions of these and of the other five planets, they do not even use the same principles and hypotheses as in their proofs of seeming revolutions and motions. So some use only concentric circles, while others eccentrics and epicycles. Yet even by these means they do not completely attain their ends. Those who have relied on concentrics, though they have proven that some different motions can be compounded therefrom, have not thereby been able fully to establish a system which agrees with the phenomena. Those again who have devised eccentric systems, though they appear to have well-nigh established the seeming motions by calculations agreeable to their assumptions, have yet made many admissions which seem to violate the first principle of uniformity in motion. Nor have they been able thereby to discern or deduce the principal thing—namely the shape of the Universe and the unchangeable symmetry of its parts. With them it is as though an artist were to gather the hands, feet, head and other members for his images from divers models, each part excellently drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man. So in the course of their exposition, which the mathematicians call their system (μέθοδος) we find that they have either omitted some indispensable detail or introduced something foreign and wholly irrelevant. This would of a surety not have been so had they followed fixed principles; for if their hypotheses were not misleading, all inferences based thereon might be surely verified. Though my present assertions are obscure, they will be made clear in due course.

I pondered long upon this uncertainty of mathematical tradition in establishing the motions of the system of the spheres. At last I began to chafe that philosophers could by no means agree on any one certain theory of the mechanism of the Universe, wrought for us by a supremely good and orderly Creator, though in other respects they investigated with meticulous care the minutest points relating to its orbits. I therefore took pains to read again the works of all the philosophers on whom I could lay hand to seek out whether any of them had ever supposed that the motions of the spheres were other than those demanded by the mathematical schools. I found first in Cicero that Hicetas had realized that the Earth moved. Afterwards I found in Plutarch that certain others had held the like opinion. I think fit here to add Plutarch's own words, to make them accessible to all:—

> The rest hold the Earth to be stationary, but Philolaus the Pythagorean says that she moves around the (central) fire on an oblique circle like the Sun and Moon. Heraclides of Pontus and Ecphantus the Pythagorean also make the Earth to move, not indeed through space but by rotating round her own centre as a wheel on an axle from West to East.

Taking advantage of this I too began to think of the mobility of the Earth; and though the opinion seemed absurd, yet knowing now that others before me had been granted freedom to imagine such circles as they chose to explain the phenomena of the stars, I considered that I also might easily be allowed to try whether, by assuming some motion of the Earth, sounder explanations than theirs for the revolution of the celestial spheres might so be discovered.

Thus assuming motions, which in my work I ascribe to the Earth, by long and frequent observations I have at last discovered that, if the motions of the rest of the planets be brought into relation with the circulation of the Earth and be reckoned in proportion to the orbit of each planet, not only do their phenomena presently ensue, but the orders and magnitudes of all stars and spheres, nay the heavens themselves, become so bound together that nothing in any part thereof could be moved from its place without producing confusion of all the other parts and of the Universe as a whole.

In the course of the work the order which I have pursued is as here follows. In the first book I describe all positions of the spheres together with such movements as I ascribe to Earth; so that this book contains, as it were, the general system of the Universe. Afterwards, in the remaining books, I relate the motions of the other planets and all the spheres to the mobility of Earth,

that we may gather thereby how far the motions and appearances of the rest of the planets and spheres may be preserved, if related to the motions of the Earth.

I doubt not that gifted and learned mathematicians will agree with me if they are willing to comprehend and appreciate, not superficially but thoroughly, according to the demands of this science, such reasoning as I bring to bear in support of my judgment. But that learned and unlearned alike may see that I shrink not from any man's criticism, it is to your Holiness rather than anyone else that I have chosen to dedicate these studies of mine, since in this remote corner of Earth in which I live you are regarded as the most eminent by virtue alike of the dignity of your Office and of your love of letters and science. You by your influence and judgment can readily hold the slanderers from biting, though the proverb hath it that there is no remedy against a sycophant's tooth. It may fall out, too, that idle babblers, ignorant of mathematics, may claim a right to pronounce a judgment on my work, by reason of a certain passage of Scripture basely twisted to suit their purpose. Should any such venture to criticize and carp at my project, I make no account of them; I consider their judgment rash, and utterly despise it. I well know that even Lactantius, a writer in other ways distinguished but in no sense a mathematician, discourses in a most childish fashion touching the shape of the Earth, ridiculing even those who have stated the Earth to be a sphere. Thus my supporters need not be amazed if some people of like sort ridicule me too.

Mathematics are for mathematicians, and they, if I be not wholly deceived, will hold that these my labours contribute somewhat even to the Commonwealth of the Church, of which your Holiness is now Prince. For not long since, under Leo X, the question of correcting the ecclesiastical calendar was debated in the Council of the Lateran. It was left undecided for the sole cause that the lengths of the years and months and the motions of the Sun and Moon were not held to have been yet determined with sufficient exactness. From that time on I have given thought to their more accurate observation, by the advice of that eminent man Paul, Lord Bishop of Sempronia, sometime in charge of that business of the calendar. What results I have achieved therein, I leave to the judgment of learned mathematicians and of your Holiness in particular. And now, not to seem to promise your Holiness more than I can perform with regard to the usefulness of the work, I pass to my appointed task.

Nicolai Copernici Revolutionum

1. That the Universe Is Spherical[1]

In the first place we must observe that the Universe is spherical. This is either because that figure is the most perfect,[2] as not being articulated[3] but whole and complete in itself; or because it is the most capacious and therefore best suited for that which is to contain and preserve all things; or again because all the perfect parts of it, namely, Sun, Moon and Stars, are so formed; or because all things tend to assume this shape, as is seen in the case of drops of water and liquid bodies in general if freely formed.[4] No one doubts that such a shape has been assigned to the heavenly bodies.

1. This title, like that of many other chapters, is taken from the Almagest of Ptolemy. The work of Copernicus is so closely bound up with that of Ptolemy that it will be convenient here to review the history of the *Almagest*.

2. That the Earth Also Is Spherical[5]

The Earth also is spherical, since on all sides it inclines toward the centre. At first sight, the Earth does not appear absolutely spherical, because of the mountains and valleys; yet these make but little variation in its general roundness, as appears from what follows. As we pass from any point northward, the North Pole[6] of the daily rotation gradually rises, while the other pole sinks correspondingly and more stars near the North Pole cease to set, while certain stars in the South do not rise. Thus, *Canopus,* invisible in Italy, is visible in

The *Almagest* of Ptolemy was unknown in the earlier Middle Ages. Its first appearance in the West is in a translation made direct from the Greek in Sicily in the year 1160. Translation direct from the Greek was very unusual at the period. This translation was excessively rare and effectively without influence. About 1170 the Englishman Daniel of Morley was studying the Arabic text of Ptolemy at Toledo with the help of a native Arabic-speaking Christian, one Ibn Ghalib. Daniel tells us that he listened to Ibn Ghalib at work with the famous translator Gerard of Cremona (died 1187). Gerard's translation of the *Almagest* was completed about 1175 and was in use in the later Middle Ages. It was made from Arabic and not from Greek. The *Almagest* was again translated from Greek in the fifteenth century by George of Trebizond (1396–1486). In the same century an *Epitome*—also direct from the Greek—was commenced by George Purbach (1423–1461) and completed by his pupil Johann Müller of Königsberg, known as Regiomontanus (1436–1476). The earliest edition of this *Epitome* was printed at Venice in 1496. The first complete Latin edition is that of Liechtenstein, Venice 1515. Liechtenstein used the translation from the Arabic version. George of Trebizond's translation was printed at Venice in 1528 and the Greek text edited by Simon Grynaeus at Basel in 1538. There are many later editions of both Greek and Latin texts.

2. The conception of the sphere as the most perfect of all figures occurs in Plato's *Timaeus.* It became an Aristotelian commonplace which pervades the whole of subsequent Astronomy until Kepler. It is accepted as a matter of course by Copernicus. The *locus classicus* for the description of the spherical Universe is Aristotle's *De Coelo* I, §§ 5–12 and II, §§ 1, 4, 5, 6.

3. *Nulla indigens compagine.* The term *compago* is the usual mediaeval word for the fabric of the human body, *compagines membrorum.* The articulated human body, the *Microcosm,* is thus implicitly contrasted with the *Macrocosm,* the Universe, which is not thus articulated. The parallel between Macrocosm and Microcosm is the commonest basis of the mediaeval teaching concerning Man and the World. It is the key to mediaeval science in somewhat the same way that Evolution is the key to modern science. The work of Copernicus appeared in the same year as the great monograph on the structure of the human body by Vesalius. Thus in 1543 the axe was laid to the tree of Mediaeval Science from both sides. For Science, therefore, that year may be regarded as the opening of the modern period.

4. This idea, the comparison of the spherical world to drops of water, is taken from *Pliny* II, § 65. "As to whether there be *Antipodes* is in dispute between the learned and the vulgar. We maintain that there are men on every part of the earth. . . . If any should ask why those opposite to us do not fall off, we ask in return why those on the opposite side do not wonder that we do not fall off. . . . But what the vulgar most strenuously resist is the belief that water (which covers the surface of the earth) is forced into a rounded form. Yet nothing is more obvious. For we see everywhere that hanging drops assume the form of small globes . . . and are observed to be completely round."

5. *Almagest,* I, § 4.

6. The word *pole* in the writings of Copernicus and of his predecessors is used for the celestial pole, rather than for the pole of the Earth.

Egypt, while the last star of Eridanus, seen in Italy, is unknown in our colder zone. On the other hand, as we go southward, these stars appear higher, while those which are high for us appear lower. Further, the change in altitude of the pole is always proportional to the distance traversed on the Earth, which could not be save on a spherical figure.[7] Hence the Earth must be finite and spherical.

Furthermore, dwellers in the East do not see eclipses of the Sun and Moon which occur in the evening here, nor do they in the West see those which occur here in the morning. Yet mid-day eclipses here are seen later in the day by the eastward dwellers, earlier by the westerners. Sailors too have noted that the sea also assumes the same shape, since land invisible from the ship is often sighted from the mast-head. On the other hand, if some shining object on the mast-head be observed from the shore, it seems gradually to sink as the vessel leaves the land. It is also a sure fact that water free to flow always seeks a lower level, just as earth does, nor does the sea come higher up the shore than the convexity of the earth allows. It therefore follows that land, rising above the level of Ocean, is by so much further removed from the centre.

3. How Earth, with the Water on It, Forms One Sphere

The waters spread around the Earth form the seas and fill the lower declivities. The volume of the waters must be less than that of the Earth, else they would swallow up the land (since both, by their weight, press toward the same centre). Thus, for the safety of living things, stretches of the Earth are left uncovered, and also numerous islands widely scattered. Nay, what is a continent, and indeed the whole of the Mainland, but a vast island?

We must pass by certain Peripatetics who claim the volume of the waters to be ten times that of the earth.[8] They base themselves on a mere guess that in the transmutation of the elements, one part of earth is resolved into ten of water. They say, in fact, that the earth rises to a certain height above the water because, being full of cavities, it is not symmetrical as regards weight and therefore the centre of weight does not accord with the geometrical centre. Ignorance of geometry prevents them from seeing that the waters cannot be even seven times as great if some part of the earth is to be left dry, unless the earth, as being heavier, be quite removed from the centre of gravity to make room for the waters. For spheres are to each other as the cubes of their diameters. If, therefore, there had been seven parts of water to one of earth, the Earth's diameter could not be greater than the radius of the waters. Even less is it possible that the waters could be ten times as great as the Earth.[9]

7. The certainty of Copernicus that the form of the Earth is spherical and that the contour of its surface does not correspond to any other curve than that of a circle is of a piece with his general insistence on the sphere and the circle as characteristic of all cosmic form and movement.

8. This view is that of Alexander of Aphrodisias (*c.* 200 A.D.) whose works were very widely read in the North Italian Universities.

9. This argument requires little clarification. Assume that the land is in the form of a sphere of volume one-seventh that of the waters. Were one to plunge this sphere of land into the sphere of water and to restore the spherical form of the sphere of waters, the whole would be eight times as large as the sphere of land alone, and the sphere of land would in consequence *touch* the sphere of water only in the interior while the centre of the whole sphere would lie only on the circumference of the sphere of land. The sphere of land could thus no longer rise above the circumference of the sphere of water except by ceasing to touch the middle point of the whole water body.

There is, in fact, no difference between the Earth's centre of gravity and its geometric centre, since the height of the land above the Ocean does not increase continuously—for so it would utterly exclude the waters and there could be no great gulfs of seas between parts of the Mainland.[10] Further, the depth of Ocean would constantly increase from the shore outwards, and so neither island nor rock nor anything of the nature of land would be met by sailors, how far soever they ventured. Yet, we know that between the Egyptian Sea and the Arabian Gulf, well-nigh in the middle of the great land-mass, is a passage barely 15 stades wide. On the other hand, in his *Cosmography* Ptolemy would have it that the habitable land extends to the middle circle[11] with a *terra incognita* beyond where modern discovery has added Cathay and a very extensive region as far as 60° of longitude. Thus we know now that the Earth is inhabited to a greater longitude than is left for Ocean.

This will more evidently appear if we add the islands found in our own time under the Princes of Spain and Portugal, particularly America, a land named after the Captain who discovered it and, on account of its unexplored size, reckoned as another Mainland—besides many other islands hitherto unknown.[12] We thus wonder the less at the so-called Antipodes or Antichthones.[13] For geometrical argument demands that the Mainland of America on account of its position be diametrically opposite to the Ganges basin in India.

From such considerations then, it is clear that Land and Water have the same centre of gravity, which coincides with the centre of the Earth's volume. Yet since earth is the heavier, and its chasms filled with water, therefore the quantity of the water is but moderate as against earth, though, as to the surface, there may perhaps be more water. Moreover, the Earth, with the waters around

10. The meaning is that there is not one single uniform land mass collected on one side of the Earth making it lop-sided.

11. By "middle circle" Copernicus means the 180th degree of longitude reckoning eastward from the "islands of the blessed" in the Western Ocean. The authority of Copernicus is Ptolemy. In his *Geography* VI, § 16, where the position of Serica is discussed, Ptolemy says "Serica is bounded on the east by the unknown land and is between 35 and 63 degrees broad on a meridian which has a geographical length of 180°." Ptolemy reckons geographical longitude from the "islands of the blessed" (the Canaries). Elsewhere (*Geography* I, § 12) Ptolemy says that "the length (that is measurement from West to East) of the known world from the meridian in the islands of the blessed to (the chief town of) Serica is 177¼°." The latitude of the "Metropolis of Sera" is fixed at 38° 36′ (VI, § 16).

12. The newly discovered land of America was of course first regarded as part of Cathay of which the West Indies were outlying islands. Early in the sixteenth century it became suspected that America was a separate continent. This was confirmed by Vasco Minez de Balboa (*c.* 1475–1517) when he first sighted the Pacific Ocean (1513), and brought out in many maps, *e.g.* that of Johan Schöner (1515) in which a clear differentiation is exhibited between Cathay and America. The point was proved by the voyage and circumnavigation (1519–1522) by Ferdinand Magellan (*c.* 1480–1521). The matter became common knowledge with the publication of Antonio Pigafelta's account of the journey in 1524.

13. The *Antichthon* is strictly speaking the *counter-earth* of the Pythagorean system of the Universe. Aristotle *De Coelo* II, § 13, 2, Cicero and later Latin writers, however, use *antichthones* as equivalent to inhabitants of the other hemisphere.

it, must have a shape conformable with its shadow. Now, at the Moon's eclipse we see a perfect arc of a circle; the Earth therefore is not flat as Empedocles and Anaxagoras would have had it, nor drum-shaped as Leucippus held, nor bowl-shaped as Heraclitus said, nor yet concave in some other way as Democritus believed; nor again cylindrical as Anaximander maintained, nor yet infinitely thick with roots extending below as Xenophanes represented; but perfectly round, as the Philosophers rightly hold.[14]

4. That the Motion of the Heavenly Bodies Is Uniform, Circular, and Perpetual, or Composed of Circular Motions

We now note that the motion of heavenly bodies is circular. Rotation is natural to a sphere and by that very act is its shape expressed. For here we deal with the simplest kind of body, wherein neither beginning nor end may be discerned nor, if it rotate ever in the same place, may the one be distinguished from the other.

Now in the multitude of heavenly bodies various motions occur. Most evident to sense is the diurnal rotation, the νυχθήμερον, as the Greeks call it, marking day and night. By this motion the whole Universe, save Earth alone, is thought to glide from East to West.[15] This is the common measure of all motions, since Time itself is numbered in days. Next we see other revolutions in contest, as it were, with this daily motion and opposing it from West to East. Such opposing motions are those of Sun and Moon and the five planets. Of these the Sun portions out the year, the Moon the month, the common measures of time. In like manner the five planets define each his own independent period.

But these bodies exhibit various differences in their motion. First their axes are not that of the diurnal rotation, but of the Zodiac, which is oblique thereto. Secondly, they do not move uniformly even in their own orbits; for are not Sun and Moon found now slower, now swifter in their courses? Further, at times the five planets become stationary at one point and another and even go backward. While the Sun ever goes forward unswerving on his own course, they wander in divers ways, straying now southward, now northward. For this reason they are named *Planets*.[16] Furthermore, sometimes they approach Earth, being then in *Perigee*, while at other times receding they are in *Apogee*.

Nevertheless, despite these irregularities, we must conclude that the motions of these bodies are ever circular or compounded of circles. For the irregularities themselves are subject to a definite law and recur at stated times, and this could not happen if the motions were not circular, for a circle alone

14. In mediaeval phraseology *the philosopher* is a synonym for Aristotle. The *philosophers* to whom Copernicus here refers are the followers of Aristotle, the Peripatetics.
15. *Almagest*, I, § 8.
16. Greek πλανήτης = wanderer.

can thus restore the place of a body as it was. So with the Sun which, by a compounding of circular motions, brings ever again the changing days and nights and the four seasons of the year. Now therein it must be that divers motions are conjoined, since a simple celestial body cannot move irregularly in a single orbit. For such irregularity must come of unevenness either in the moving force (whether inherent or acquired) or in the form of the revolving body. Both these alike the mind abhors regarding the most perfectly disposed bodies.[17]

It is then generally agreed that the motions of Sun, Moon and Planets do but seem irregular either by reason of the divers directions of their axes of revolution, or else by reason that Earth is not the centre of the circles in which they revolve, so that to us on Earth the displacements of these bodies when near seem greater than when they are more remote, as is shown in the *Optics*.[18] If then we consider equal arcs in the paths of the planets we find that they seem to describe differing distances in equal periods of time. It is therefore above all needful to observe carefully the relation of the Earth toward the Heavens, lest, searching out the things on high, we should pass by those nearer at hand, and mistakenly ascribe earthly qualities to heavenly bodies.

5. Whether Circular Motion Belongs to the Earth; and Concerning Its Position

Since it has been shown that Earth is spherical, we now consider whether her motion is conformable to her shape and her position in the Universe. Without these we cannot construct a proper theory of the heavenly phenomena. Now authorities agree that Earth holds firm her place at the centre of the Universe, and they regard the contrary as unthinkable, nay as absurd. Yet if we examine more closely it will be seen that this question is not so settled, and needs wider consideration.

A seeming change of place may come of movement either of object or of observer, or again of unequal movements of the two (for between equal and parallel motions no movement is perceptible). Now it is Earth from which the rotation of the Heavens is seen. If then some motion of Earth be assumed it will be reproduced in external bodies, which will seem to move in the opposite direction.

Consider first the diurnal rotation. By it the whole Universe, save Earth alone and its contents, appears to move very swiftly. Yet grant that Earth revolves from West to East, and you will find, if you ponder it, that my con-

17. The passage is a remarkable illustration of the very firm hold that Aristotelian conceptions had taken. The incorruptible heavens, the necessity that all perfect movement must be in a circle, the eternal heavenly bodies as contrasted with this changeful, corruptible, temporal earth are ideas from which Copernicus, like all his contemporaries and predecessors, was quite unable to free himself.
18. For the book on *Optics* ascribed to Euclid and Theon's summary of it (edition by J. L. Heiberg, Leipzig, 1895, p. 41), see T. L. Heath, *Manual of Greek Mathematics*, p. 266, Oxford, 1931.

clusion is right. It is the vault of Heaven[19] that contains all things, and why should not motion be attributed rather to the contained than to the container, to the located than the locater? The latter view was certainly that of Heraclides[20] and Ecphantus the Pythagorean[21] and Hicetas of Syracuse (according to Cicero).[22] All of them made the Earth rotate in the midst of the Universe, believing that the Stars set owing to the Earth coming in the way, and rise again when it has passed on.

There is another difficulty, namely, the position of Earth. Nearly all have hitherto held that Earth is at the centre of the Universe. Now, grant that Earth is not at the exact centre but at a distance from it which, while small compared to the starry sphere, is yet considerable compared with the orbits of Sun and the other planets. Then calculate the consequent variations in their seeming motions, assuming these to be really uniform and about some centre other than the Earth's. One may then perhaps adduce a reasonable cause for these variable motions. And indeed since the Planets are seen at varying distances from the Earth, the centre of Earth is surely not the centre of their orbits. Nor is it certain whether the Planets move toward and away from Earth, or Earth toward and away from them. It is therefore justifiable to hold that the Earth has another motion in addition to the diurnal rotation. That the Earth, besides rotating, wanders with several motions and is indeed a Planet, is a view attributed to Philolaus the Pythagorean, no mean mathematician, and one whom Plato is said to have eagerly sought out in Italy.[23]

19. A pun is here involved which cannot be reproduced in English (*caelum caelat*).

20. Heracleides of Heracleia in Pontus was a pupil of Plato and his successor Speusippus and studied also with Aristotle and under the Pythagoreans. On Plato's death, being disappointed in not obtaining the headship of the Academy, he returned to his native town. He wrote many philosophical dialogues on ethical and physical topics which have now disappeared. It seems that he first taught the movement of the planets Venus and Mercury round the Sun and the movement of the Sun round the Earth. Later he showed how by the assumption of a real heliocentric system the celestial phenomena could be explained, but there is no evidence that he finally adopted this as the only possible explanation. Information about him has been collected by O. Voss, *De Heracleidis vita et scriptis*, Rostock, 1896.

As regards the works of Heracleides and the other Pythagoreans, the reader is referred to Sir T. L. Heath, *Aristarchus of Samos*, Oxford, 1913.

21. Ecphantus of Syracuse, a Pythagorean, was perhaps a pupil of Hicetas. The few references that survive concerning him are in Hippolytus and Aëtius (Diels, *Vorsokratiker*, I, p. 340, 1920), and all the little that is known of him has been put together by M. Wellmann in Pauly-Wissowa's *Real-Enkyklopädie*.

22. The reference to Cicero is to the *Quaestiones Academicae*, IV, § 29, where we read "Hicetas the Syracusan, so Theophrastus says, regarded the Heavens, the Sun, the Moon and the Stars, in fine all outside the Earth, as standing still, and that nothing in the world moves except the Earth which turns and revolves on its axis with great rapidity and produces exactly the same appearances as if the entire Heavens turned around an immobile Earth. Some think that Plato in his *Timaeus* expresses the same opinion but in more obscure terms."

This Hicetas was a Pythagorean the sole remains of whose works is this sentence and a reference to Aëtius (see Diels, *Vorsokratiker*, I, p. 340, 1922). All that we know of Hicetas has been put together by M. Wellmann in Pauly-Wissowa and amounts to hardly more than we have here.

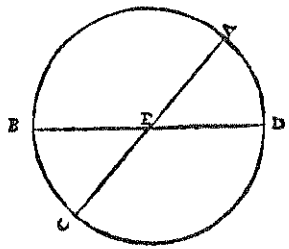
23. The statement that Plato visited Philolaus in Italy rests on the unsupported statement of Diogenes Laertius. It is probable that Philolaus was an older contemporary of Socrates. Substantial fragments of his works have come down to us (see H. Diels, *Vorsokratiker*, I, p. 301, 1922). Copernicus had probably gained his knowledge of Philolaus from Plato and Stobaeus.

Many, however, have thought that Earth could be shown by geometry to be at the centre and like a mere point in the vast Heavens. They have thought too that Earth, as centre, ever remains unmoved, since if the whole system move the centre must remain at rest, and the parts nearest the centre must move most slowly.

6. Of the Vastness of the Heavens Compared with the Size of the Earth[24]

That the size of Earth is insignificant in comparison with the Heavens, may be inferred thus.

The bounding Circles (interpreting the Greek word *horizons*) bisect the Celestial Sphere. This could not be if the size of the Earth or its distance from the centre were considerable compared with the Heavens—for a circle to bisect a sphere must pass through its centre and be in fact a "great circle." Let the circle ABCD represent the celestial horizon, and E that point of the Earth from which we observe. The "horizon" or boundary line between bodies visible and bodies invisible has its centre at this point. Suppose that from point E we observe with Dioptra or Astrolabe or Chorobates[25] the first point of the sign Cancer rising at C and at the same moment the first point of Capricorn setting at A. AEC, since it is observed as a straight line through the Dioptra, is a diameter of the Ecliptic, for six Zodiacal Signs form a semicircle and its centre E coincides with that of the horizon. Next, suppose that after some time the first point of Capricorn rises at B; then Cancer will be seen setting at D, and BED will be a straight line, again a diameter of the ecliptic. Hence, it is clear that E, the point of intersection of the two lines, is the centre of the horizon. Therefore the horizon always bisects the ecliptic, which is a great circle on the sphere. But a circle that bisects a great circle must itself be a great circle. Therefore the horizon is a great circle and its centre is that of the ecliptic.



It is true that a line from the surface of Earth cannot coincide with the one from its centre. Yet owing to their immense length compared to the size of Earth these lines are practically parallel. Moreover, owing to the great distance of their meeting point they are practically one line—for the distance between them is immeasurably small in comparison with their length—as is shown in the *Optics*.[26] It therefore follows that the Heavens are immeasurable in com-

24. *Almagest*, I, § 6.

25. The Dioptra was known to Copernicus from works circulating at the time in the names of Euclid and Heron of Alexandria. By *Horoscopium* he means not the familiar plan of astrologers but the instrument or instruments used to obtain it, *i.e.*, an astrolabe or armillary sphere; both these instruments had been familiar since the earlier Middle Ages. The Chorobates is described in *Vitruvius*, VIII, § 5, whose work was accessible to Copernicus.

26. *Cf.* note 18.

parison with the Earth. Thus the Earth appears as a mere point compared to the Heavens, as a finite thing to the infinite.[27]

Yet it does not follow that the Earth must be at rest at the centre of the Universe. Should we not be more surprised if the vast Universe revolved in twenty-four hours, than that little Earth should do so? For the idea that the centre is at rest and the parts nearest it move least does not imply that Earth remains still. It is merely as one should say that the Heavens revolve, but the poles are still, and the parts nearest them move least (as *Cynosura* moves slower than *Aquila* or *Procyon* because, being nearer the pole, it describes a smaller circle). These all belong to the same sphere, whose motion becomes zero at the axis. Such motion does not admit that all the parts have the same rate of motion, since the revolution of the whole brings back each point to the original position in the same time, though the distances moved are unequal.

So too, it may be said, Earth, as part of the celestial sphere, shares in the motion thereof, though being at the centre she moves but little. Being herself a body and not a mere point, she will therefore move through the same angle as the Heavens but with a smaller radius in any given period of time. The falsity of this is clear, for if true it would always be mid-day in one place and midnight in another, and the daily phenomena of rising and setting could not occur, for the motion of the whole and the part are one and inseparable. A quite different theory is required to explain the various motions observed, namely that bodies moving in smaller paths revolve more quickly than those moving in larger paths. Thus Saturn, most distant of the Planets, revolves in 30 years, and Moon, nearest the Earth, compasses her circuit in a month. Lastly, then, the Earth must be taken to go round in the course of a day and a night, and so doubt is again cast on the diurnal rotation of the Heavens.

Besides we have not yet fixed the exact position of the Earth, which as shown above, is quite uncertain. For what was proved is only the vast size of the Heavens compared with the Earth, but how far this immensity extends is quite unknown.

7. Why the Ancients Believed that the Earth Is at Rest, like a Centre, in the Middle of the Universe[28]

The ancient Philosophers tried by divers other methods to prove Earth fixed in the midst of the Universe. The most powerful argument was drawn from the doctrine of the heavy and the light. For, they argue, Earth is the heaviest element, and all things of weight move towards it, tending to its centre. Hence since the Earth is spherical, and heavy things more vertically to it, they would all rush together to the centre if not stopped at the surface. Now those things which move towards the centre must, on reaching it, remain at rest. Much more then will the whole Earth remain at rest at the centre of

27. The passage resembles one in the work of Archimedes *The sand-reckoner*. See T. L. Heath, *Works of Archimedes*, p. 222. Cambridge, 1897.
28. *Almagest*, I, § 7.

the Universe. Receiving all falling bodies, it will remain immovable by its own weight.[29]

Another argument is based on the supposed nature of motion. Aristotle says that the motion of a single and simple body is simple. A simple motion may be either straight, or circular. Again a straight motion may be either up or down. So every simple motion must be either toward the centre, namely downward, or away from the centre, namely upward, or round the centre, namely circular. Now it is a property only of the heavy elements earth and water to move downward, that is to seek the centre. But the light elements air and fire move upward away from the centre. Therefore we must ascribe rectilinear motion to these four elements. The celestial bodies however have circular motion. So far Aristotle.[30]

If then, says Ptolemy, Earth moves at least with a diurnal rotation, the result must be the reverse of that described above. For the motion must be of excessive rapidity, since in 24 hours it must impart a complete rotation to the Earth. Now things rotating very rapidly resist cohesion or, if united, are apt to disperse, unless firmly held together. Ptolemy therefore says that Earth would have been dissipated long ago, and (which is the height of absurdity) would have destroyed the Heavens themselves; and certainly all living creatures and other heavy bodies free to move could not have remained on its surface, but must have been shaken off. Neither could falling objects reach their appointed place vertically beneath, since in the meantime the Earth would have moved swiftly from under them. Moreover clouds and everything in the air would continually move westward.[31]

8. The Insufficiency of These Arguments, and Their Refutation

For these and like reasons, they say that Earth surely rests at the centre of the Universe. Now if one should say that the Earth *moves*, that is as much as to say that the motion is natural, not forced; and things which happen according to nature produce the opposite effects to those due to force. Things subjected to any force, gradual or sudden, must be disintegrated, and cannot long exist. But natural processes being adapted to their purpose work smoothly.

Idle therefore is the fear of Ptolemy that Earth and all thereon would be disintegrated by a natural rotation, a thing far different from an artificial act. Should he not fear even more for the Universe, whose motion must be as much more rapid as the Heavens are greater than the Earth? Have the Heavens become so vast because of the centrifugal force of their violent motion, and would they collapse if they stood still? If this were so the Heavens must be of infinite size. For the more they expand by the centrifugal force of their motion, the more rapid will become the motion because of the ever increasing distance to be traversed in 24 hours. And in turn, as the motion waxes, must the im-

29. The argument is drawn from Aristotle *De Coelo*, II, § 14; 296 *b*.
30. Aristotle, *De Coelo*, I, §§ 2–3, III, §§ 3–5.
31. *Almagest*, I, § 5.

mensity of the Heavens wax. Thus velocity and size would increase each the other to infinity—and as the infinite can neither be traversed nor moved, the Heavens must stand still![32]

They say too that outside the Heavens is no body, no space, nay not even void, in fact absolutely nothing, and therefore no room for the Heavens to expand.[33] Yet surely it is strange that something can be held by nothing. Perhaps indeed it will be easier to understand this nothingness outside the Heavens if we assume them to be infinite, and bounded internally only by their concavity, so that everything, however great, is contained in them, while the Heavens remain immovable. For the fact that it moves is the principal argument by which men have inferred that the Universe is finite.

Let us then leave to Physicists[34] the question whether the Universe be finite or no, holding only to this that Earth is finite and spherical. Why then hesitate to grant Earth that power of motion natural to its shape, rather than suppose a gliding round of the whole Universe, whose limits are unknown and unknowable? And why not grant that the diurnal rotation is only apparent in the Heavens but real in the Earth? It is but as the saying of Aeneas in Virgil—"We sail forth from the harbour, and lands and cities retire."[35] As the ship floats along in the calm, all external things seem to have the motion that is really that of the ship, while those within the ship feel that they and all its contents are at rest.

It may be asked what of the clouds and other objects suspended in the air, or sinking and rising in it? Surely not only the Earth, with the water on it, moves thus, but also a quantity of air and all things so associated with the Earth. Perhaps the contiguous air contains an admixture of earthy or watery matter and so follows the same natural law as the Earth, or perhaps the air acquires motion from the perpetually rotating Earth by propinquity and absence of resistance. So the Greeks thought that the higher regions of the air follow the celestial motion, as suggested by those swiftly moving bodies, the "Comets," or "Pogoniae" as they called them,[36] for whose origin they assign this region, for these bodies rise and set just like other stars. We observe that because of the great distance from the Earth that part of the air is deprived of terrestrial motion, while the air nearest Earth, with the objects suspended in it, will be stationary, unless disturbed by wind or other impulse which moves them this way or that—for a wind in the air is as a current in the sea.

We must admit the possibility of a double motion of objects which fall and rise in the Universe, namely the resultant of rectilinear and circular motion.

32. Aristotle, *Phys. Aus.* III, § 4. "First we must determine in how many ways the word *infinite* is employed. The first meaning is 'that which cannot be traversed.'" See also *De Coelo*, I, § 5, *Phys. Aus.* IV, § 4 and especially *De Coelo*, I, § 7.

33. Aristotle, *De Coelo*, I, § 9.

34. By the *Physicists* is meant the commentators on the *Physica* of Aristotle, a book very widely read in the North Italian schools.

35. *Aeneid*, III, 72.

36. Pogoniae = bearded. Comets are spoken of as *bearded stars* in Aristotle's *Meteorologica*, I, § 7, 4 and elsewhere.

Thus heavy falling objects, being specially earthy, must doubtless retain the nature of the whole to which they belong. So also there are objects which by their fiery force are carried up into the higher regions. This terrestrial fire is nourished particularly by earthy matter, and flame is simply burning smoke. Now it is a property of fire to expand that which it attacks, and this so violently that it cannot in any wise be restrained from breaking its prison and fulfilling its end. The motion is one of extension from the centre outward, and consequently any earthy parts set on fire are carried to the upper region.[37]

That the motion of a simple body must be simple is true then primarily of circular motion, and only so long as the simple body rests in its own natural place and state. In that state no motion save circular is possible, for such motion is wholly self-contained and similar to being at rest. But if objects move or are moved from their natural place rectilinear motion supervenes. Now it is inconsistent with the whole order and form of the Universe that it should be outside its own place. Therefore there is no rectilinear motion save of objects out of their right place, nor is such motion natural to perfect objects, since they would be separated from the whole to which they belong and thus would destroy its unity. Moreover, even apart from circular motion, things moving up and down do not move simply and uniformly; for they cannot avoid the influence of their lightness or weight. Thus all things which fall begin by moving slowly, but their speed is accelerated as they go. On the other hand earthly fire (the only kind we can observe) when carried aloft loses energy, owing to the influence of the earthy matter.

A circular motion must be uniform for it has a never failing cause of motion; but other motions have always a retarding factor, so that bodies having reached their natural place cease to be either heavy or light, and their motion too ceases.

Circular motion then is of things as a whole, parts may possess rectilinear motion as well. Circular motion, therefore, may be combined with the rectilinear—just as a creature may be at once animal and horse. Aristotle's method of dividing simple motion into three classes, from the centre, to the centre, and round the centre, is thus merely abstract reasoning; just as we form separate conceptions of a line, a point, and a surface, though one cannot exist without another, and none can exist without substance.

Further, we conceive immobility to be nobler and more divine than change and inconstancy, which latter is thus more appropriate to Earth than to the Universe. Would it not then seem absurd to ascribe motion to that which contains or locates, and not rather to that contained and located, namely the Earth?

Lastly, since the planets approach and recede from the Earth, both their

37. Comets, falling stars, and certain other celestial phenomena have, according to Aristotle, a less orderly arrangement than the events in what he regarded as the more distant heavens. They thus partook of a terrestrial nature. Aristotle assumes the existence of exhalations from the Earth which become ignited in consequence of the motions of the upper regions of the Cosmos. *Meteorologica*, I, § 4–5.

motion round the centre, which is held to be the Earth, and also their motion outward and inward are the motion of one body. Therefore we must accept this motion round the centre in a more general sense, and must be satisfied provided that every motion has a proper centre. From all these considerations it is more probable that the Earth moves than that it remains at rest. This is especially the case with the diurnal rotation, as being particularly a property of the Earth.

9. Whether More Than One Motion Can Be Attributed to the Earth, and of the Centre of the Universe

Since then there is no reason why the Earth should not possess the power of motion, we must consider whether in fact it has more motions than one, so as to be reckoned as a Planet.

That Earth is not the centre of all revolutions is proved by the apparently irregular motions of the planets and the variations in their distances from the Earth. These would be unintelligible if they moved in circles concentric with Earth. Since, therefore, there are more centres than one, we may discuss whether the centre of the Universe is or is not the Earth's centre of gravity.

Now it seems to me gravity is but a natural inclination, bestowed on the parts of bodies by the Creator so as to combine the parts in the form of a sphere and thus contribute to their unity and integrity. And we may believe this property present even in the Sun, Moon and Planets, so that thereby they retain their spherical form notwithstanding their various paths.[38] If, therefore, the Earth also has other motions, these must necessarily resemble the many outside motions having a yearly period. For if we transfer the motion of the Sun to the Earth, taking the Sun to be at rest, then morning and evening risings and settings of Stars will be unaffected, while the stationary points, retrogressions, and progressions of the Planets are due not to their own proper motions, but to that of the Earth, which they reflect. Finally we shall place the Sun himself at the centre of the Universe. All this is suggested by the systematic procession of events and the harmony of the whole Universe, if only we face the facts, as they say, "with both eyes open."

10. Of the Order of the Heavenly Bodies

No one doubts that the Sphere of the Fixed Stars is the most distant of visible things. As for the planets, the early Philosophers were inclined to

38. On this striking passage, Alexander von Humboldt remarks that "even the idea of universal gravitation or attraction toward the Sun as the centre of the world seems to have hovered before the mind of this great man." Yet the analogy to the Newtonian view, if it exists, is very distant. Copernicus presents us only with the activity of the parts of a single world body and has nothing to say as to the relation of the separate bodies with one another on all sides. Nor is his gravity an essential property of bodies but is present because they are not in the places to which they naturally belong.

believe that they form a series in order of magnitude of their orbits. They adduce the fact that of objects moving with equal speed, those further distant seem to move more slowly (as is proved in Euclid's *Optics*).[39] They think that the Moon describes her path in the shortest time because, being nearest to the Earth, she revolves in the smallest circle. Furthest they place Saturn, who in the longest time describes the greatest orbit. Nearer than his is Jupiter, and then Mars.

Opinions differ as to Venus and Mercury which, unlike the others, do not altogether leave the Sun. Some place them beyond the Sun, as Plato in his *Timaeus;*[40] others nearer than the Sun, as Ptolemy[41] and many of the moderns.[42] Alpetragius makes Venus nearer and Mercury further than the Sun.[43] If we agree with Plato in thinking that the planets are themselves dark bodies that do but reflect light from the Sun, it must follow, that if nearer than the Sun, on account of their proximity to him they would appear as half or partial circles; for they would generally reflect such light as they receive, upwards, that is toward the Sun, as with the waxing or waning Moon. Some think that since no eclipse even proportional to their size is ever caused by these planets they can never be between us and the Sun.

On the other hand, those who place Venus and Mercury nearer than the Sun adduce in support the great distance which they posit between Sun and Moon. For the maximum distance of Moon from Earth, namely 64 1/6 times Earth's radius, they calculate as about 1/18 of the minimum distance of the Sun from Earth, which is 1160 times Earth's radius. So the distance between the Sun and the Moon is 1096 such units.[44] So vast a space must not remain empty. By calculating the widths of the paths of these planets from their greatest and least distances from the Earth they find that the sum of the widths is approximately the same as this whole distance. Thus the perigee of Mercury comes immediately beyond the apogee of the Moon and the apogee of Mercury is followed by the perigee of Venus, who, finally, at her apogee practically reaches

39. *Optics*, § 56.

40. The order given in the *Timaeus* is Moon, Sun, Venus, Mercury, Mars, Jupiter, Saturn.

41. *Almagest*, IX, § 1.

42. Among the most widely read "moderns" who took this view was the Arabian Astronomer Alfraganus (Ahmed ben Muhammed ben Ketu al Fagani (d. *c.* 880), whose works had been rendered into Latin by Gerard of Cremona (died 1187) by the Jew Johannes Hispalensis (Avendeath *c.* 1150) by Hugo Sanctallensis (XIVth century) and Bencivenni Zucchero (1313). The work was edited by Melanchthon from the literary remains of Regiomontanus at Nuremberg in 1537.

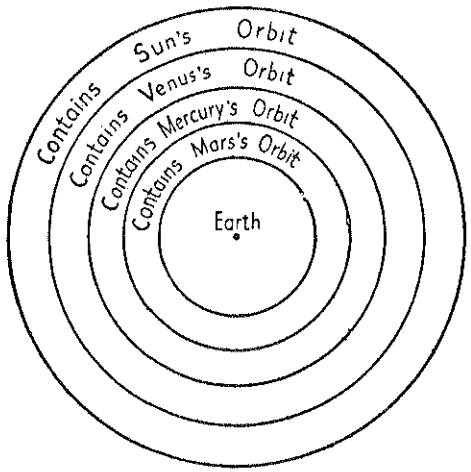
43. Alpetragius is the Spanish Arab Nured-din el Betrugi (fl. *c.* 1180) whose *Liber astronomiae* was translated in 1217 by Michael Scot (d. *c.* 1235) but never printed. It was translated into Hebrew by Moses ben Tibbon in 1259 and retranslated from Hebrew into Latin by the Jew Kolonymus ben David in 1529. This work, to which Copernicus here doubtless refers, was printed at Venice in 1531 along with Sacro Bosco with the following title *Alpetragii Arabis Theorica planetarum physicis comm. probata nuperrime ad latinos translata a Calo Calonymo hebraeo Neapolitano.*

44. This computation is attributed to Eratosthenes (276–194 B.C.) by Ptolemy *op. cit.* I, § 12, from whom Copernicus must have taken it, since the works of Eratosthenes were not available to him.

the perigee of the Sun.[45] For they estimate that the difference between the greatest and least distances of Mercury is nearly 177½ of the aforesaid units, and that the remaining space is very nearly filled up by the difference between the maximum and minimum distances of Venus, reckoned at 910 units.

They therefore deny that the planets are opaque like the Moon, but think that they either shine by their own light or that their bodies are completely pervaded by the light of the Sun. They also claim that the Sun is not obstructed by them for they are very rarely interposed between our eyes and the Sun since they usually differ from him in latitude. They are small, too, compared with the Sun. According to Albategni Aratensis[46] even Venus, which is greater than Mercury, can scarcely cover a hundredth part of the Sun. He estimates the Sun's diameter to be ten times that of Venus; and, therefore, so small a spot to be almost invisible in so powerful a light. Averroes indeed, in his Paraphrase of Ptolemy,[47] records that he saw a kind of black spot when in-

45. The idea was that the orbit of each planet was confined within two spheres, through the apogee and perigee respectively, and that the farther sphere of the planet coincided with the nearer sphere of the next one, thus:—



46. By Albategni Copernicus means Muhammed ben Sabir ben Sinan el Battani (died *c.* 919). Battan is a small place in the Hauran (Artensis) where he was born. Battani, Albattani, Albategni as he was variously known to the West, wrote a work *De motu stellarum* which was known in the Middle Ages by a Latin translation prepared by Plato of Tivoli about 1130. About the same date Robert of Retines translated into Latin the tables which accompanied this work. The translations were printed in 1537 at Nürnberg with the work of Regiomontanus on Alfraganus (see note 42) under the title *Mahometis Albatenii de scientias tellarum liber, cum aliquot additionibus Joannis Regiomantani ex bibliotheca Vaticana transcriptus.*

47. Averroes is the mediaeval Latin form of the name of the heretical Spanish writer Muhammed ibn Ahmed ibn Muhammed ibn Roschd (1126–1198). Averroes takes a very important part in the history of mediaeval philosophy by reason of his commentaries on the works of Aristotle which profoundly influenced the North Italian schools and especially Padua. Averroes wrote little on Astronomy, among his few works on this subject being an Epitome of the *Almagest*. This work is not known in Latin but was translated into Hebrew at Naples by Jacob Anatoli in 1231. It is not clear how Copernicus obtained access to this document. It may be that he is not quoting Averroes direct but from another writer.

vestigating the numerical relations between the Sun and Mercury. This is the evidence that these two planets are nearer than the Sun.

But this reasoning is weak and uncertain. Whereas the least distance of the Moon is 38 times Earth's radius, according to Ptolemy, but, according to a truer estimate, more than 52 (as will be shown later) yet we are not aware of anything in all that space except air, and, if you will, the so called "fiery element." Besides, the diameter of the orbit of Venus, by which she passes to a distance of 45 degrees more or less on either side of the Sun, must be six times the distance from the Earth's centre to her perigee, as will also be shown later. What then will they say is contained in the whole of that space, which is so much bigger than that which could contain the Earth, the Air, the Aether, the Moon and Mercury, in addition to the space that the huge epicycle of Venus would occupy if it revolved round the resting Earth?

Unconvincing too is Ptolemy's proof that the Sun moves between those bodies that do and those that do not recede from him completely. Consideration of the case of the Moon, which does so recede, exposes its falseness. Again, what cause can be alleged, by those who place Venus nearer than the Sun, and Mercury next, or in some other order? Why should not these planets also follow separate paths, distinct from that of the Sun, as do the other planets? and this might be said even if their relative swiftness and slowness does not belie their alleged order. Either then the Earth cannot be the centre to which the order of the planets and their orbits is related, or certainly their relative order is not observed, nor does it appear why a higher position should be assigned to Saturn than to Jupiter, or any other planet.

Therefore I think we must seriously consider the ingenious view held by Martianus Capella the author of the *Encyclopaedia*[48] and certain other Latins, that Venus and Mercury do not go round the Earth like the other planets but run their courses with the Sun as centre, and so do not depart from him further than the size of their orbits allows. What else can they mean than that the centre of these orbits is near the Sun? So certainly the orbit of Mercury must be within that of Venus, which, it is agreed, is more than twice as great.

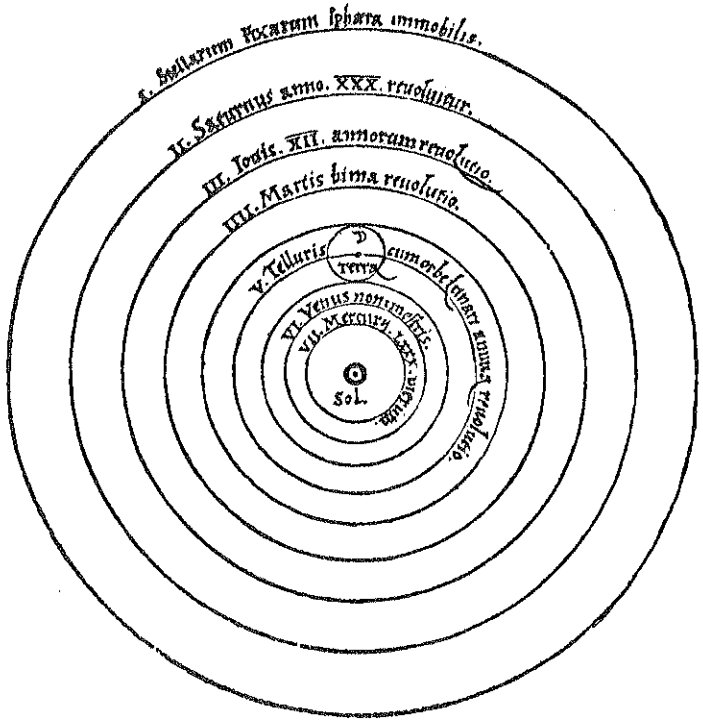
We may now extend this hypothesis to bring Saturn, Jupiter and Mars also into relation with this centre, making their orbits great enough to contain those of Venus and Mercury and the Earth; and their proportional motions according to the Table demonstrate this.[49] These outer planets are always nearer to the Earth about the time of their evening rising, that is, when they are in opposition to the Sun, and the Earth between them and the Sun. They are

48. Martianus Capella was a native of Madaura in Africa, who practised as a lawyer in Carthage about the beginning of the fifth century. His work *On the marriage of Philology and Mercury and on the Seven Liberal Arts* is a ridiculously strained and heavy allegory in difficult Latin treating of the nature and extent of human knowledge. The work was highly regarded in the Middle Ages during which the "Seven Liberal Arts" Grammar, Dialectic, Rhetoric, Geometry, Arithmetic, Astronomy and Music formed the basis of the Academic discipline. The work was frequently printed in the early sixteenth century beginning with 1499. The passage to which Copernicus refers is in Book VIII, Eyssenliant's edition, Leipzig, 1866, p. 317, line 14ff.

49. The Table is appended to Book V.

more distant from the Earth at the time of their evening setting, when they are in conjunction with the Sun and the Sun between them and the Earth. These indications prove that their centre pertains rather to the Sun than to the Earth, and that this is the same centre as that to which the revolutions of Venus and Mercury are related.

But since all these have one centre it is necessary that the space between the orbit Venus and the orbit of Mars must also be viewed as a Sphere concentric with the others, capable of receiving the Earth with her satellite the Moon and whatever is contained within the Sphere of the Moon—for we must not separate the Moon from the Earth, the former being beyond all doubt nearest to the latter, especially as in that space we find suitable and ample room for the Moon.



We therefore assert that the centre of the Earth, carrying the Moon's path, passes in a great orbit among the other planets in an annual revolution round the Sun; that near the Sun is the centre of the Universe; and that whereas the Sun is at rest, any apparent motion of the Sun can be better explained by motion of the Earth. Yet so great is the Universe that though the distance of the Earth from the Sun is not insignificant compared with the size of any

other planetary path, in accordance with the ratios of their sizes, it is insignificant compared with the distance of the Sphere of the Fixed Stars.

I think it is easier to believe this than to confuse the issue by assuming a vast number of Spheres, which those who keep Earth at the centre must do. We thus rather follow Nature, who producing nothing vain or superfluous often prefers to endow one cause with many effects. Though these views are difficult, contrary to expectation, and certainly unusual, yet in the sequel we shall, God willing, make them abundantly clear at least to mathematicians.

Given the above view—and there is none more reasonable—that the periodic times are proportional to the sizes of the orbits, then the order of the Spheres, beginning from the most distant, is as follows. Most distant of all is the Sphere of the Fixed Stars, containing all things, and being therefore itself immovable. It represents that to which the motion and position of all the other bodies must be referred. Some hold that it too changes in some way,[50] but we shall assign another reason for this apparent change, as will appear in the account of the Earth's motion.[51] Next is the planet Saturn, revolving in 30 years. Next comes Jupiter, moving in a 12 year circuit: then Mars, who goes round in 2 years. The fourth place is held by the annual revolution in which the Earth is contained, together with the orbit of the Moon as on an epicycle. Venus, whose period is 9 months, is in the fifth place, and sixth is Mercury, who goes round in the space of 80 days.

In the middle of all sits Sun enthroned. In this most beautiful temple could we place this luminary in any better position from which he can illuminate the whole at once? He is rightly called the Lamp, the Mind, the Ruler of the Universe; Hermes Trismegistus names him the Visible God,[52] Sophocles' Electra calls him the All-seeing.[53] So the Sun sits as upon a royal throne ruling his children the planets which circle round him. The Earth has the Moon at her service. As Aristotle says, in his *de Animalibus,* the Moon has the closest relationship with the Earth.[54] Meanwhile the Earth conceives by the Sun, and becomes pregnant with an annual rebirth.

So we find underlying this ordination an admirable symmetry in the Universe, and a clear bond of harmony in the motion and magnitude of the orbits such as can be discovered in no other wise. For here we may observe why the progression and retrogression appear greater for Jupiter than Saturn, and less than for Mars, but again greater for Venus than for Mercury; and why such oscillation appears more frequently in Saturn than in Jupiter, but less frequently in Mars and Venus than in Mercury; moreover why Saturn, Jupiter and Mars are nearer to the Earth at opposition to the Sun than when they are

50. This refers to the Precession of the Equinoxes.
51. See Book III.
52. Cf. *Hermetica,* Vol. I, Bk. V, 83, p. 159 (Ed. W. Scott, Oxford 1924). The Hermetic epistles were available to Copernicus, having been edited by Marsilius Ficinus, Treviso, 1472 and J. Schoeffer, 1503.
53. *Electra,* 826–832 is the nearest approach to the reference of Copernicus.
54. Copernicus perhaps means *De generatione animalium,* IV, § 10.

lost in or emerge from the Sun's rays.[55] Particularly Mars, when he shines all night, appears to rival Jupiter in magnitude, being only distinguishable by his ruddy colour; otherwise he is scarce equal to a star of the second magnitude, and can be recognised only when his movements are carefully followed. All these phenomena proceed from the same cause, namely Earth's motion.

That there are no such phenomena for the fixed stars proves their immeasurable distance, compared to which even the size of the Earth's orbit is negligible and the parallactic effect unnoticeable. For every visible object has a certain distance beyond which it can no more be seen (as is proved in the *Optics*).[56] The twinkling of the stars, also, shows that there is still a vast distance between the furthest of the planets, Saturn, and the Sphere of the Fixed Stars, and it is chiefly by this indication that they are distinguished from the planets. Further, there must necessarily be a great difference between moving and non-moving bodies. So great is this divine work of the Great and Noble Creator!

11. Explanation of the Threefold Motion of the Earth

Since then planets agree in witnessing to the possibility that Earth moves, we shall now briefly discuss the motion itself, in so far as the phenomena can be explained by this hypothesis. This motion we must take to be threefold. The first defines the Greek *nychthēmerinon,* the cycle of night and day. It is produced by the rotation of the Earth on its axis from West to East, corresponding to the opposite motion by which the Universe appears to move round the equinoctial circle, that is the equator, which some call the "equidial" circle, translating the Greek expression *isēmerinos*. The second is the annual revolution of the centre of the Earth, together with all things on the Earth. This describes the ecliptic round the Sun, also from West to East, that is, backwards,[57] between the orbits of Venus and Mars. So it comes about that the Sun himself seems to traverse the ecliptic with a similar motion. For instance, when the centre of the Earth passes over Capricorn, as seen from the Sun, the Sun appears to pass over Cancer as seen from the Earth; but seen from Aquarius, he would seem to pass over Leo, and so on. The equator and Earth's axis are variably inclined[58] to this circle, which passes through the middle of the Zodiac, and to its plane, since if they were fixed and followed simply the motion of the Earth's centre there would be no inequality of days and nights.[59] Then there is a third motion, of declination, which is also an annual revolution, but forwards, that is, tending in opposition to the motion of the Earth's centre; and thus, as they are nearly equal and opposite, it comes about that the axis of the

55. *Acronyct* when the planet rises at sunset and sets at sunrise, being visible all night (Greek "high night").

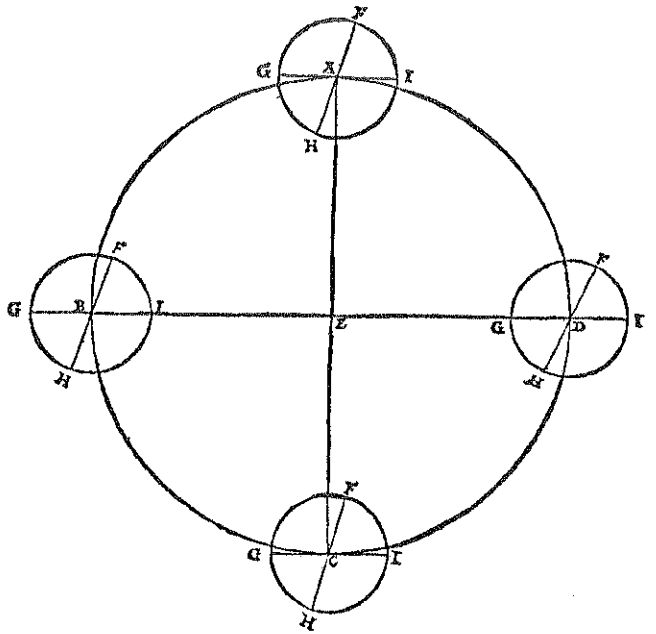
56. *Cf.* note 18.

57. Backwards, that is, compared to the diurnal rotation of the stars.

58. *Convertibilem habere inclinationem.*

59. The text here repeats itself by saying that the season would remain unchanged.

Earth, and its greatest parallel, the equator, point in an almost constant direction, as if they were fixed.[60] But meantime the Sun is seen to move along the oblique direction of the Ecliptic with that motion which is really due to the centre of the Earth (just as if the Earth were the centre of the Universe, remembering that we see the line joining Sun and Earth projected on the Sphere of the Fixed Stars).

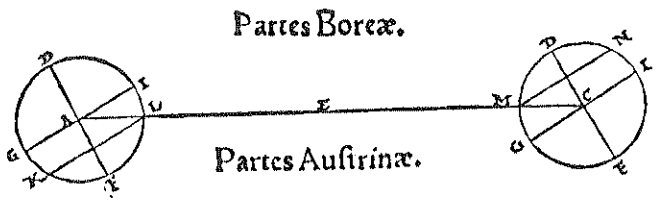


To express it graphically, draw a circle ABCD to represent the annual path of Earth's centre in the plane of the Ecliptic. Let E near its centre be the Sun. Divide this circle into four equal parts by the diameters AEC and BED. Let the first point of Cancer be at A, of Libra at B, of Capricorn at C and of Aries at D. Now let the centre of the Earth be first at A and round it draw the terrestrial Equator FGHI. This circle FGHI however is not in the same plane as the Ecliptic but its diameter GAI is the line of intersection with the ecliptic. Draw the diameter FAH, at right angles to GAI, and let F be the point of the greatest declination to the South, H to the North. This being so the inhabitants of the Earth will see the Sun near the centre E at its winter solstice in Capricorn, owing to the turning towards the Sun of the point of greatest Northern declination H. Hence in the diurnal rotation the inclination of the

60. The "motion of declination" as Copernicus calls it is his own discovery and a matter in which he had no forerunner. The idea follows on the conception of the motion of the Earth as related to the natural attraction of the Sun.

equator to AE makes the Sun move along the tropic of Capricorn, which is distant from the equator by an angle equal to EAH.

Now let the centre of the Earth travel forwards and let F, the point of greatest declination, move to the same extent backwards until both have completed quadrants of their circles at B. During this time the angle EAI remains always equal to the angle AEB, on account of the equality of the motions. The diameters FAH, FBH and GAI, GBI are also always parallel each to each, and the Equator remains parallel to itself. These parallel lines appear coincident in the immensity of the Heavens as has often been mentioned. Therefore, from the first point of Libra, E will appear to be in Aries, and the intersection of the planes will be the line GBIE, so that the diurnal rotation will give no declination, and all motion of the Sun will be lateral [in the plane of the Ecliptic]. The Sun is now at the vernal equinox. Further, suppose that the centre of the Earth continues its course. When it has completed a semi-circle at C, the Sun will appear to be entering Cancer. F, the point of greatest southern declination of the Equator, is now turned towards the Sun, and he will appear to be running along the Tropic of Cancer, distant from the Equator by an angle equal to ECF. Again, when F has turned through its third quadrant, the line of intersection GI will once more fall along the line ED, and from this position the Sun will be seen in Libra at the autumnal equinox. As the process continues and HF gradually turns towards the Sun, it will produce a return of the same phenomena as we observed at the starting-point.



We can explain it otherwise as follows. Take the diameter AEC in the plane of the paper. AEC is the line of intersection by this plane of a circle perpendicular to it. At points A and C, that is at Cancer and Capricorn respectively, describe in this plane a circle of longitude of the Earth DFGI. Let DF be the axis of the Earth, D the North Pole, F the South, and GI a diameter of the equator. Since then F turns towards the Sun at E, and the northern inclination of the Equator is the angle IAE, the rotation round the axis will describe a parallel south of the equator with diameter KL and at a distance from the equator equal to LI, the apparent distance from the equator of the Sun in Capricorn. Or better, by this rotation round the axis the line of sight AE describes a conical surface, with vertex at Earth's centre and as base a circle parallel to the equator. At the opposite point C the same phenomena occur, but conversely. Thus the contrary effects of the two motions, that of the

centre and that of declination, constrain the axis of the Earth to remain in a constant direction, and produce all the phenomena of Solar motions.

We were saying that the annual revolution of the centre and of declination were *almost* equal. If they tallied exactly the equinoctial and solstitial points and the whole obliquity of the Ecliptic with reference to the Sphere of the Fixed Stars would be unchangeable. There is, however, a slight discrepancy, which has only become apparent as it accumulated in the course of ages. Between Ptolemy's time and ours it has reached nearly 21°, the amount by which the equinoxes have precessed. For this reason some have thought that the Sphere of the Fixed Stars also moves, and they have therefore postulated a ninth sphere. This being found insufficient, modern authorities now add a tenth. Yet they have still not attained the result which we hope to attain by the motion of the Earth. We shall assume this motion as a hypothesis and follow its consequences.[61]

61. In the original manuscript there follow on this chapter two and a half pages which have been heavily scored out. The translation of this section is as follows:

"Should we allow that the course of Sun and Moon could be diverted with Earth immovable it would yet be less allowable for the other planets. From these and similar causes Philolaus regarded Earth as movable. Some also say that Aristarchus of Samos though not moved by the reasoning that Aristotle advances and rejects (*De Coelo*, II, § 14) was of the same view. But since this cannot be understood, save by the bestowal of wit and industry, it has, as Plato would say, remained hidden from philosophers. There were thus but few who recognised the cause of motion of the stars. Yet if known to Philolaus or any other Pythagorean it is not probable that they would have published it. For it was not the habit of the Pythagoreans to vaunt their philosophical secrets in books nor indeed to reveal them at all but to entrust them to the faith of friends and intimates and so pass it on from hand to hand. In proof thereof is a letter from Lysis to Hipparchus."

Here Copernicus gives the text of the long and spurious letter of Lysis to Hipparchus which is to be found in *Iamblichus*, V, p. 75. It deals with the custom of the Pythagoreans and is without astronomical bearing.