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WHAT IS REVOLUTIONARY IN THE COPERNICUS' *REVOLUTIONS*

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1.

For a long time the name Copernicus was a synonym for revolution in astronomy. Moreover, for some historians of science, the year 1543 – the year of the publication of *De Revolutionibus* – marked the beginning of a new strain of scientific thought not only in the field of astronomy but natural science as a whole. According to this "'Vulgar Triumphalist' view," as R. S. Westman put it,[1] Copernicus is a revolutionary who decisively and completely broke with the ancient and medieval scientific principles; one who put an end to the finite universe of Aristotle and Ptolemy and replaced it with the infinite world of stars; one who, relying on extensive calculations, dealt a deathblow to the crystalline spheres that had carried the planets around the earth ever since antiquity; and one who, after all, made a bold move of radical simplification and reduced the inconvenient number of eighty (or so) epicycles, introduced by Ptolemy in order to be able to predict the position of the planets, to just forty (or so) epicycles.

However, a closer reading of Copernicus' work reveals an entirely different picture. It is not difficult to find elements that unmistakably point to the fact that, viewed from an epistemological perspective, Copernicus is a conservative rather than a revolutionary. Today, it is more or less known that Copernicus relied on the traditional technical apparatus used by Ptolemaic astronomy, including eccentrics, deferents, epicycles, and epicycles upon epicycles,[2] that he still believed in the solid celestial spheres (or orbs) whose

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[1] R. S. Westman, "Proof, Poetics, and Patronage: Copernicus's Preface to 'De revolutionibus'", in D. C. Lindberg and R. S. Westman (eds.), *Reappraisals of the Scientific Revolution,* Cambridge University Press, Cambridge 1990, p. 169.

[2] Cf. for example Derek, J.de S. Price, "Contra-Copernicus: A Critical Re-estimation of the Mathematical Planetary Theory of Ptolemy, Copernicus, and Kepler", in M. Clagett (ed.),

task was to bear celestial bodies,[3] and that his theory did not predict the positions of celestial bodies any better than that of Ptolemy. It is also well known that, by eliminating the Ptolemaic mechanism of equants, Copernicus did indeed eliminate several epicycles but also added new ones, meaning that his planetary system was no less entangled than that of Ptolemy.[4] Furthermore, although bigger in size than the Ptolemaic universe, Copernicus' universe was still finite, delimited by the sphere of fixed stars. Finally, Copernicus' physics was firmly rooted in the physics of high scholasticism although he partly transformed some of its concepts.[5]

Neither did Copernicus himself think of his work as revolutionary. On the contrary, his aim was by no means to "turn upside down the entire science of astronomy" ("die ganze Kunst Astronomiae umkehren"), as Luther is supposed to have accused him of doing in 1439 in his famous *Tischreden* (*Tabletalks*). His goal was the renewal of astronomy, a task on which he embarked by relying on the authentic principles and postulates of ancient astronomy that later came to be violated by the Ptolemaic astronomical tradition. Copernicus' motivation for this renewal was entirely conservative in character – he wished to preserve the principle of the uniformity of planetary motion that was distorted by the Ptolemaic astronomic tradition with its concept of the equant.[6] In addition, in his dedicatory letter to Pope Paul III, he also

Critical Problems in the History of Science, The University of Winsconsin Press, Madison 1969, p. 216: "… his work as a mathematical astronomer was uninspired. From this point of view his book is conservative and a mere re-shuffled version of the *Almagest*."

[3] There is practically no room left for doubt about this following the polemic between N. Swerdlow and E. Rosen. Cf. E. Rosen, "Copernicus' Spheres and Epicycles", *Archives internationales d'histoire des sciences* 25 (1975), pp. 82–92; N. Swerdlow, "Pseudoxia Copernicana: or, Inquiries Into Very Many Received Tenets and Commonly Presumed Truths, Mostly Concerning Spheres", *Archives internationales d'histoire des sciences* 26 (1976), pp. 108-158; E. Rosen, "Reply to N. Swerdlow", *Archives internationales d'histoire des sciences* 26 (1976), pp. 301–304.

[4] Cf. for example O. Neugebauer, "On the Planetary Theory of Copernicus", *Vistas in Astronomy* 10 (1968), p. 103: "Modern historians, making ample use of the advantage of hindsight, stress the revolutionary significance of the heliocentric system and the simplifications it had introduced. In fact, the actual computation of planetary positions follows exactly the ancient pattern and the results are the same."

[5] Cf. M. Wolff, "Impetus Mechanics as a Physical Argument for Copernicanism. Copernicus, Benedetti, Galileo", *Science in Context* 1 (2/1987), pp. 215–256.

[6] Cf. *Commentariolus*: "Nevertheless, the theories concerning these matters that have been put forth and wide by Ptolemy and most others, although they correspond numerically [with the apparent motions], also seemed quiete doubtful, for these theories were inadequate unless they envisioned certain *equant* circles, on account of which it appeared that the planet never moves with uniform velocity either in its deferent sphere or with respect to its proper center. Therefore a theory of this kind seemed neither perfect enough

mentions the fact that the astronomers of the Ptolemaic tradition were not able to "elicit or deduce" the most important thing: "the structure of the universe and the fixed symmetry of its parts."[7] However, in order to be able to renew astronomy by drawing on its correct, original principles, Copernicus had to sacrifice another fundamental premise governing practically all sciences of the time – the stationary earth at the center of the universe. He had to introduce the new and, for all contemporary articulations of knowledge – i.e. theology, philosophy and *sensus communis* – absurd concept of a moving earth.

2.

In this essay I argue that, despite all traditionalist elements in his astronomy and cosmology, and despite predominantly conservative motives for the introduction of the concept of the earth's motion into science, Copernicus did make a kind of radical, even revolutionary, rupture in natural philosophy, as science was called in his time. The nature of this rupture, or epistemological shift, can best be illuminated through an analysis of the introduction of this concept in Book 1 of *De Revolutionibus Orbium Coelestium.*

When considering the possibility of the earth's motion in Chapter 5 of Book 1, Copernicus's point of departure is the shape of the earth. In Chapter 2 he shows that the earth is spherical,[8] and in Chapter 4 he argues that "the motion appropriate to a sphere is rotation in a circle."[9] Since the earth is of the same shape as other celestial bodies, that is, spherical, and since "the motion appropriate to a sphere is rotation in a circle," the most natural question that arises at this point is whether the earth could also be ascribed circular motion, despite the fact that "there is general agreement among the authorities that the earth is at rest in the middle of the universe" and al-

nor sufficiently in accordance with reason." Quoted after N. M. Swerdlow, "The Derivation and First Draft of Copernicus's Planetary Theory. A Translation of the Commentariolus with Commentary", *Proceedings of the American Philosophical Society* 117 (6/1973), p. 434.

[7] "To his Holiness …", p. 6. All references from *De revolutionibus* are from E. Rosen's translation, sometimes slightly changed, of *On the Revolutions*, The Johns Hopkins University Press, Baltimore/London 1992.

[8] Cf. *De revolutionibus* I, 2: "The Earth too is spherical."

[9] Cf. ibid. I, 4: "I shall now recall to mind that the motion of the heavenly bodies is circular, since the motion appropriate to a sphere is rotation in a circle. By this very act the sphere expresses its form as the simplest body, wherein neither beginning nor end can be found, nor can the one be distinguished from the other, while the sphere itself traverses the same points to return upon itself."

though "they hold the contrary view to be inconceivable or downright silly."[10] Yet, what needed to be explained first is what motion actually is. Copernicus first briefly recapitulates the Euclidean theory of motion, albeit without citing the source:

> Every observed change of place is caused by motion of either the observed object or the observer or, of course, by an unequal displacement of each. For when things move with equal speed in the same direction, the motion is not perceived, as between the observed object and the observer, I mean.[11]

The question of the earth's motion is therefore subsumed under the more general question of what motion is in essence. According to Copernicus, when considering the nature of local motion, which is an issue relevant for the study of the earth's motion, the essential question is when one actually observes or sees that an object or a body is in motion, i.e. that it has changed its position. Accordingly, the point at issue here is not motion as such, but motion that one can see and perceive. In simple words, Copernicus is interested in the phenomenon (or appearance) of motion. There are three situations that cause us to perceive the phenomenon of motion, with the third one being irrelevant for our purpose.

In the first of those possible situations, it is the observed object that moves while the observer is stationary. Undoubtedly, this situation is the most "natural" one, so our natural consciousness, our *sensus communis*, accepts it as the only truthful one. If something appears to be in motion then it moves. But there is also another possible situation in which we perceive motion, one which is essential for Copernicus' purpose, which is diametrically opposite to the first. According to Euclid, whose postulate Copernicus summarizes here, motion also occurs when the observer moves and the observed object is motionless. In this case, too, if certain conditions are met, one experiences the phenomenon of motion, yet it is not the motion of a moving observer that is perceived but – and this is the crucial point – the motion of the observed object which is stationary in reality. No doubt both Euclid and Copernicus had in mind the common experience of a moving person who has the impression that he/she is motionless and that the object observed is in motion.

The motion then is a phenomenon, and since it is a phenomenon, immobility can be mistaken for motion: under certain circumstances, certain

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[10] Ibid., I, 5.
[11] Ibid.

motionless objects appear to us to move, although it is we who are actually moving. Copernicus hence concludes that the second phenomenon of motion is possible in the universe as well, that is to say, that a person who moves with the rotating earth perceives motion of the immovable heavens. Or, in other words, even if the earth moved and the heavens did not, we would see the same phenomena that we see while assuming that the heavens move and the earth is stationary:

> It is the earth, however, from which the celestial ballet is beheld in its repeated performances before our eyes. Therefore, if any motion is ascribed to the earth, in all things outside it the same motion will appear, but in the opposite direction, as though they were moving past it. Such in particular is the daily rotation, since it seems to involve the entire universe except the earth and what is around it. However, if you grant that the heavens have no part in this motion you will find that this is the actual situation concerning the apparent rising and setting of the sun, moon, stars and planets.[12]

This means that the motion we observe in the heavens can be the result of our own motion as well. It is the observer who moves, but to that observer it seems that the observed object is in motion. It is the earth that moves, but it seems that the heavens move. By applying the general rule of the relativity of motion perception to the earth-heavens relation, Copernicus rejects the existence of an *a priori* structure of motion in the universe: on the "phenomenological" level, the movement of the heavens can be explained by the motion of either the earth or heaven.

However, this is just the first step, and it does not yet bring Copernicus to assert categorically that the earth actually moves. The assertion that it is "more likely that the earth moves than that it is at rest" and that it "is especially true of the daily rotation, as particularly appropriate to the earth", comes later, in the renowned Chapter 8 of Book 1, where he again places the heavens and the earth in a comparative relationship. Even at this point, after exposing some inherent contradictions in peripatetic cosmology, and after stressing the spherical shape of the earth, Copernicus's presentation is a concretization of the abstract rules of the optical argument. In this famous comparison, he draws a parallel between the daily revolution of the heavens and earth and a ship that sails out of the harbor, where the sailors aboard the ship have the impression that the shore and the harbor are moving away from

[12] Ibid.

them. For the sailors, the movement of the ship is mirrored in the movement of the shore and city. Copernicus extends the comparison, saying that the appearance of a city moving away is an image of the ship's movement. And this image leads to the conclusion that the motion of the city is real. In other words, in this example the image replaces reality, and *vice versa.* The same happens, says Copernicus, in the case of the motion of the heavens. The motion of the heavens is an illusion (*apparentia*), the mirror image of the earth's motion; it is not reality – its reality is the motion of the earth. What happens in reality is that the earth revolves around its axis, while the heavens remain stationary:

> Why should we not admit, with regard to the daily rotation, that the appearance is in the heavens and the reality in the earth? This situation closely resembles what Vergil's Aeneas says: 'Forth from the harbor we sail, and the land and the cities slip backward.' For when a ship is floating calmly along, the sailors see its motion mirrored in everything outside, while on the other hand they suppose that they are stationary, together with everything on board. In the same way, the motion of the earth can unquestionably produce the impression that the entire universe is rotating.[13]

Copernicus uses the "optical argument" in both chapters, and while it seems that in Chapter 5 he uses it merely in order to point to the phenomenal, i.e. observational, equivalence between the hypothesis that the universe moves and the earth is stationary and the hypothesis that the universe is stationary and the earth is in motion, he is slightly more categorical in Chapter 8: the motion of the earth (its rotation) is reality whose mirror image is the motion of the heavens. In much the same way as it appears to the sailors that the shore and the harbor move away, to us, the inhabitants of the earth, it appears that the heavens move, although in both cases this phenomenon of motion is just a consequence, or an image, of the observer's own motion. It seems that Copernicus is no longer using the optical argument to argue just the general, observational (optical, phenomenal) equivalence of both hypotheses (immobility of the earth : motion of the heavens = motion of the earth : immobility of the heavens), but that this optical argument has now somehow enabled him to affirmatively conclude that the earth moves and the heavens do not (or that it is at least more probable that it moves than that it is at rest).

[13] Ibid. I, 8.

3.

The question that naturally occurs at this point is what legitimizes Copernicus to maintain that one motion is reality and the other only a mirror image of that reality? On what basis does he argue that the motion of the earth is reality and the motion of the heavens just an illusory effect of the earth's motion, in the same way that the phenomenon of the movement of the harbor and the shore is a mirror image of the ship's movement? Is it in the field of "optics" that Copernicus can find support and legitimacy for this shift, given that his affirmation of the earth's motion occurs within the context of the optical argument? How can the optical argument bring Copernicus to the conclusion that, in the case of daily rotation, "the appearance is in the heavens and the reality in the earth"? Is there any criterion that enables one to judge which movement is real and which only an illusion? In attempting to answer these questions, we will make use of the two examples of the illusion of movement analysed by Ptolemy in his *Optics,* as well as the example given by Buridan and Oresme.

Let us first consider Ptolemy's second (and less complex) example[14] of the illusion of movement which is similar to the one presented by Copernicus in Chapter 8. To a person gliding along the coast in a boat but not perceiving the movement of the boat, the shore and the trees on the shore appear to move. This situation is similar to that of the sailors to whom the shore and the city appear to move away, although it is the ship that moves. But how can these sailors know which is actually moving, the ship or the shore? The answer is: on the basis of their knowledge that the shore cannot move. Therefore, it must be they who move. So, when judging motion, the first possible criterion that can be used to distinguish between the illusion (image) and reality is banal. Common sense, supported by our own and others' experience, tells us what can and what can not be in motion. Since we already know that the shore is stationary, the fact that it appears to move can only be attributed to the mapping of the ship's movement onto the shore.

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[14] Cf. Ptolemy, *Optics* II, 132: "Likewise, if we sail in a boat along the shore during twilight, or if we move in something other than a boat, and if we do not sense the motion of the thing carrying us, than we judge the tress and typographical features of the shoreline to be moving. This illusion stems from the fact that, when the visual rays are displaced [laterally], we infer that the visible objects are moving because of the displacement of the visual ray. Although the visible objects are stationary, then, it is assumed that the apparent motion belongs to them." Quoted after A. M. Smith, *Ptolemy's Theory of Visual Perception: An English Translation of the Optics*, The American Philosophical Society, Philadelphia 1996, pp.124–125.

Ptolemy's first example[15] is somewhat more complex. To a person sitting in a motionless boat anchored in the middle of a huge river, with his gaze fixed on the water, the boat will appear to be moving against the current because of the movement of the water surface. Since the water appears to be calm, the boat appears to be in motion. So, how do we know which object is actually moving in this example? Is it we who move along with the boat, or is it the water surrounding us? In this case our advance knowledge cannot be of much help. While in the Ptolemy's second example it is clear that the shore as such cannot move, in this particular case both elements in the comparison are mobile as such. How, then, can one resolve this predicament? How can we know whether or not we are moving? In other words, how can we establish what is reality and what its mirror image? In this case, the illusion of our own movement can be dispelled by resorting to a "third point" – a referential point external to the relationship observer–observed object. This third point is the shore, about which we know with certainty that it is motionless by virtue of its nature. By referring to the shore, we can now establish whether or not we are in motion.

The third example is an interesting situation that transcends both examples mentioned above, although it is not found either in Ptolemy or Copernicus. It is the situation cited by Buridan in *Questiones In Aristotelis De caelo,* here recapitulated after Oresme's *Le Livre du ciel et du monde.*[16] Once again we

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[15] Cf. ibid. II, 131: "Furthermore, when a boat stands still in a calm, waveless river that flows swiftly, anyone in the boat who does not look at the shoreline beyond [but focuses on the river] judges that the boat is moving swiftly upriver while the water is standing still. The reason for this illusion is that the motion of the water sensed by the visual flux, being opposite to that with which the boat is assumed to move, is manifested by the contrast between the color of the boat and the color of water. Now the contrast created by the motion of the parts of water's surface alone is not clear to the senses because of the uniformity of the parts of the [water's] surface and similarity [throughout] of its color. Yet according to the motion of the visual flux upon the parts of the visible object's surface, it is necessary that either the water or the boat appear to move. Thus, since the water will appear calm, the motion must appear to belong to the boat. On the other hand, if we look at the water, the shoreline, and the boat all at the same time, and if we take cognizance of the fact that the shoreline is stationary, since the boat is seen by the same rays that see the shoreline. We will also see the water moving since we will have realized that the boat and the shorelines are stationary."

[16] Cf. *Le Livre du ciel et du monde* II, 25: "Now, I take as a fact that local motion can be perceived only if we see that one body assumes a different position relative to another body. For example, if a man is in a boat a, which is moving very smoothly either at rapid or slow speed, and if this man sees nothing except another boat b, which moves precisely like boat a, the one in which he is standing, I maintain that to this man it will appear that neither boat is moving. If a rests while b moves, he will be aware that b moving; if a moves and b rest, it will seem to the man in a that a is resting and b is moving, just as before. Thus, if

encounter the sailors and the ships, only in this case the sailor aboard ship A observes ship B in the open sea. Suppose that ship A is in motion while ship B is at rest. After some time, ship A slowly comes to a halt, but the sailor does not perceive this change, and ship B starts to move. Since the sailor still sees ship B moving away, it appears to him that he, along with ship A, is still moving and that ship B is motionless. The point is that the sailor can by no means know whether it is he or the observed object that is in motion. In fact, the sailor cannot make a valid judgment about which object is moving and which is at rest, either on the basis of advance knowledge (both ships can be in motion) or by referring to a third, immobile object, since there is no such referential object in the open sea. Consequently, there is no solution in this case: on the basis of "optical data" alone, the sailor cannot know whether he or the observed ship is in motion.

4.

This situation described by Oresme is identical to the one that causes the dilemma about the motion of the earth and the heavens. By admitting that the earth, too, is capable of motion, we find ourselves in a situation that prevents us from legitimately concluding, solely on the basis of what we can see, whether it is the earth or the universe that moves. Copernicus, too, is in the situation of a sailor in the open sea with no third point of reference available to legitimate his conclusion about the motion of one or the other. Being a sailor aboard the ship called earth, he cannot rely on any third, stationary object to legitimate his conclusion that it is he who moves along with the earth, or that it is the heavens that move: he cannot know which movement is an illusion and which reality. This means that it is not possible to draw conclusions legitimately about the motion of the earth, or the absence of motion thereof, solely on the basis of optical observations. The optical argument alone takes us only as far as the agnostic position, but it can by no means be

a rested an hour and b moved, and during the next hour it happened conversely that a moved and b rested, this man would not be able to sense this change or variation; it would seem to him that all this time b was moving. This fact is evident from experience, and the reason is that the two bodies a and b have a continual relationship to each other so that, when a moves, b rests, and, conversely, when b moves, a rests. It is stated in Book Four of The Perspective of Witelo that we do not perceive motion unless we notice that one body is in the process of assuming a different position relative to another." Quoted after Nicole Oresme, *Le Livre du ciel et du monde*, ed. A. D. Menut and A. J. Denomy, translated with an introduction by A. D. Menut, The University of Wisconsin Press, Madison/Milwaukee/London 1968, p. 523.

a decisive moment for Copernicus' affirmation of the earth's motion. Viewed from this perspective, his assertion in Chapter 8 of *De Revolutionibus* is even more surprising, i.e. that we should "admit, with regard to the daily rotation, that the appearance is in the heavens and the reality in the earth" and that "this situation closely resembles what Vergil's Aeneas says: 'Forth from the harbor we sail, and the land and the cities slip backward'".

On what grounds, then, does Copernicus assert that the revolution of the universe around the earth is actually an mirror image of the earth's rotation? Where does he find legitimacy for the comparison of the motion of the heavens with the apparent motion of a shore observed from a moving ship? Since Copernicus cannot rely on a third, stationary point as a reference when concluding that the earth moves, because he is a sailor on the ship called earth which determines his point of observation and from which he cannot step down, we can conclude that Copernicus is, in some way, convinced in advance that the earth moves and the heavens do not, in the same way that the sailors sailing out of the harbor towards the open sea are convinced that it is they who move despite the fact that the shore and the harbor appear to be moving away from them. However, what is the foundation of this conviction of Copernicus, if it is not "optics"?

The conviction of the sailors that it is they who move rather than the shore is, on the one hand, rooted in common sense, and on the other, it is a result of the general philosophical consensus that the shore, that is to say, the earth (in its natural place), is motionless (and that it can be displaced from its natural place only by force). The earth cannot move. But why can it not move? Why, according to Aristotle and the "peripatetic" tradition, is the earth stationary and the heavens in motion?

In his book *On the Heavens,* Aristotle seems to have arrived at this conclusion – one supported by all ancient science with only rare exceptions – by way of abstract deduction or of conceptual analysis. Both his arguments against the movement of the earth and his explanation of why the earth does not move are predominantly, although not fully, derived from his theory of the natural movement(s) and natural places of simple bodies (earth, water, air, fire and ether), which, in turn, are derived from the principles that could be described as being *a priori,* i.e. not based on perception. Aristotle speaks of them as "first assumptions"[17] (or "assumptions concerning

[17] Cf. *On the Heavens* I, 7, 274a34: "Now, that it cannot be made up from an unlimited number of kinds is clear if one allows us our first assumptions."; ibid. b11: "This, however, is impossible, if we are to lay down that our first assumptions are true." All references from *On the Heavens* are from Aristotle, *On the Heavens*, I and II, edited and translated by S. Leggatt, Aris and Phillips, Warminster 1995.

movements"),[18] by which he probably refers to the principles introduced in Chapters 2 and 3 (these pertain to the theory of natural movement)[19] and in Chapter 8 of Book 1 (pertaining to the theory of natural places).

In his first argument against the motion of the earth,[20] Aristotle relies on the theory of the earth's natural motion, i.e. motion in a straight line towards the center of the universe, and on the assumption that a part moves with the same motion as the whole. Since the natural motion of the earth is rectilinear motion towards the center, its rotation or revolution around the center, meaning circular motions, could only be forced motions; had these motions been natural rather than forced, every individual piece or portion of the earth would move in a circle. If the earth followed this circular, unnatural path, its motion would not be eternal because no forced motion is eternal, but this contradicts the eternal order of the universe.

Similarly in his third argument against the motion of the earth,[21] Aristotle relies on the assumption that the earth as a whole and all of its parts move towards the center of the universe. Or, to be more precise: if the earth moved at all it would move towards the center and not around the center of the universe. And if this were so, the earth at the center would be stationary. Aristotle finds confirmation that the earth actually lies at the center of the universe in "a sign," (*semeion*), as he himself calls it, or rather the fact that heavy objects that move towards the earth hit the earth at right angles. In addition, the central position of the earth in the universe and its immobility are also supported by the observational fact that objects thrown into the air return to the point whence they were thrown. For example, a stone thrown into the air at right angles falls to the earth precisely at the point from which it was thrown, but this phenomenon would not be possible if the earth moved, since in such a case the stone thrown at the right angles would hit the ground behind the point from which it was thrown.[22]

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[18] Cf. ibid. I, 8, 276b7–8: "That things must be so, however, is clear from the assumptions concerning movements."

[19] In his commentary on the treatise, Simplicius adduces seven "first assumptions", while S. Leggatt in his *Introduction* (p. 14, n. 26), argues that it is possible to list at least fourteen of these if not more. Let me quote just some of them: 1. There is such a thing as simple motion; 2. Movement in a circle is simple; 3. A simple body's movement is simple and a simple movement belongs to a simple body (269a2–4); 4. The natural motion of each natural body is unique (269a8–9); 5. Counter-natural movement is contrary to natural motion, etc.

[20] Cf. *On the Heavens* II, 14, 296a24–34.

[21] Cf. ibid., 296b6-25. Aristotle's third argument against the movement of the earth is not aimed directly at those supporting the opposite view, but rather serves to "state his considerate alternative to their conception of a moving earth." (Leggatt, p. 264).

[22] Cf. ibid., 296b21–25.

But the most typical example of the application of Aristotle's cosmological principles is his explanation of why the earth rests at the center of the universe. It is worth quoting in full:

> That, then, the earth neither moves nor lies outside the centre, is evident from these points; in addition to them, the reason for its rest is clear from what has been said. For it is such as to move by nature from anywhere towards the centre, as it is observed to do, and fire such as to move from the centre to the extremity, it is impossible for any part of it to move from the centre unless by being forced; for a single body has a single locomotion and a simple body has a simple locomotion, but not contrary locomotion, and locomotion from the centre is contrary to that to the centre. If, therefore, it is impossible for any part to move from the centre, it is evident that it is in fact still more impossible for the earth as a whole; for the place to which the part is such as to move is also the place to which the whole is such as to move; consequently, if it cannot move with a stronger force, it would have to stay at the centre.[23]

Therefore, Aristotle arrives at the conclusion that the earth rests at the center of the universe and that the universe is in motion primarily by way of a deductive, abstract method – on the basis of the theories of natural places and movement of things, both of which are in turn largely derived from "first assumptions" about movement and natural places. Although Aristotle does not expound much on the source of these "first assumptions", quite indicative is his mention of induction (*epagoge)*,[24] suggesting that he had in mind something similar to what we find at the end of the *Second Analytics,* i.e. that the point of departure for these assumptions is perception.[25]

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[23] Ibid., 296b25-297a1. For Aristotle, the fact that the earth is immobile at the center of the universe is also confirmed by astronomers' claims. Cf. ibid., 297a2–5: "What the mathematicians say in astronomy also testifies to this, since the apparent facts – that is, the changing of the configurations in terms of which the arrangement of the stars is determined – result from the supposition that the earth lies at the centre."

[24] Cf. ibid. II, 7, 276a12–15: "Further, if the place where a thing remains or to which it moves contrary to nature has to belong to something else according to nature (this can be believed on the basis of induction (*ek tes epagoges*), then necessarily not all things posses either weight or lightness, but some possess one, while others do not possess it".

[25] Cf. ibid. II, 4, 287a11, where he mentions observation (seeing) and "assumption" side by side: "Further, since the whole is seen, and being assumed, to rotate in a circle, and has been shown that outside of the outermost revolution is neither void nor place, it also must be therefore spherical." Cf. also *De caelo* 272a5–7: "But we see the heavens turning about in the circle, and we have determined by argument as well that movement in a circle belongs to some particular body."

That the point of departure for these "assumptions" and for the theories of natural movement and natural places is perception, or to be more precise, that which can be seen with the naked eye, is also confirmed by Aristotle's identification of upward movement with the movement of fire and air, and of downward movement with the movement of water and earth. In much the same way as one can observe that the earth always moves downwards, it is possible to notice that water, too, moves downwards, while fire and air always move upwards. Harmonious with these observable facts are the theory of natural movement (each simple body has one simple movement: ether moves in a circle, earth and water fall downwards and fire and air rise upwards), the theory of natural places (the natural places of elements are places towards which they naturally move: the natural place of the earth is at the center of the universe, that of fire at the extreme edge of the sub-lunar universe, of water above the earth, of air under fire and of ether above the sub-lunar sphere), and the theory of weight and lightness (light bodies have the impulse to move towards their natural place upwards, i.e. towards the periphery of the universe, while heavy ones have the impulse to move downwards towards their natural place, i.e. towards the center of the universe). All this clearly shows that the point of departure for "first assumptions" and for Aristotle's apparently abstract deduction is, as P. Moraux put it, "une vision du monde qui devait être, pour Aristote, d'evidence immédiat",[26] and that this "direct evidence" is a "vision d'un univers spherique, dont la terre, immobile, occupe le centre, lequel centre est à son tour pris comme point de référence pour la définition des mouvements simples."[27]

To sum up, it is possible to discern three interlinked lines of reasoning in Aristotle's argumentation against the movement of the earth and in his explanation of the earth's immobility. On the one hand, the immobility of the earth at the center of the universe is for Aristotle the result of direct, perceptual evidence: he sees that the heavens move and that the earth is at rest.[28] This is an example of the most direct *sensus communis,* relying on what can be seen. On the other hand, Aristotle also finds confirmation for the earth's im-

[26] P. Moraux, "Introduction", p. CXV, in Aristote, *Du ciel*, texte établi et traduit par P. Moraux, Les Belles Lettres, Paris 1965.

[27] Ibid., p. CXVI.

[28] Cf. *On the Heavens* II, 13, 295b16–23: "This is put cleverly, but not truly, since on this argument anything placed at the centre must stay put, and so fire will rest there as well; for what was mentioned is not a property of earth. Yet it is not necessary: for the earth is not just seen to remain at the centre but also moves to the centre. For where any part of it moves, there must the whole earth move too; and where it moves according to the nature, there it remains according to the nature as well."

mobility and the heavens' motion in what he does not see but would be able to see if the earth moved: a stone thrown into the air at right angles would touch ground behind the place from which it was thrown if the earth really moved. The third confirmation of the earth's immobility is furnished by theory (the theories of the natural motion and of the natural places of bodies), which, as we have seen, also relies on direct evidence of the motionless earth placed at the center of the spherical universe. In other words, Aristotle translates directly observable phenomena into theory, starting from a fundamental hypothesis upon which he does not reflect, but which lends sense to these theories – that the earth is stationary at the center of the spherical universe – and then uses this theory to explain that which he can see. His speculation is, despite various argumentative strategies, predominantly dependent on the theories of the natural motion of elements and their natural places, which are based on ordinary observation that heavy bodies fall and light bodies rise in the air. His discussion of the earth is in this respect well described, as S. Legatt put it, as "a common sense account."[29]

This "common sense account" of the earth can be observed in all pre-Copernican astronomical and cosmological traditions. One can find the same types of arguments against the rotation of the earth in Ptolemy's *Almagest* or in Buridan's *Quaestiones in Aristotelis De caelo* and Oresme's *Le livre du ciel et du monde*, where the question of the earth's movement is considered very seriously, but denied on theoretical or observational grounds. This means that the argumentation *pro* and *contra* earth's motion is basically always dependent on what could be seen[30] – either indirectly (in the form of the theory of natural motions and natural places of simple elements, which depended on the "direct evidence") or directly in the form of sensible experiments "here on earth and in the air." On a more abstract level, this means that the concept of a stationary, motionless earth around which celestial bodies revolve is based on direct and indirect perceptual experience. The geostatic and geocentric conception of the universe is a result of a non-explicated hypothesis that equates, to simplify somewhat, the *voir* and the *savoir* or, in other words, makes *savoir* dependent on *voir*. More precisely, knowledge is dependent, at least in the case of the hypothesis of the earth's immobility, on observation that is determined by a non-reflected-upon natural perspective – it is a viewpoint taken by the "natural", "perceptual", "common-sensical" consciousness that is placed on a stationary earth at the center of the universe. The observer

[29] S. Leggatt, p. 263.

[30] The only exception to my knowledge is Oresme, who concludes against the earth's movement on theological grounds.

located on the stationary earth is a stationary pole around which the entire universe revolves; and the criteria for distinguishing between appearance and truth (that is to say, whether it is the earth or the universe that moves) are derived from a vision of the world which is (for Aristotle and others) direct evidence.

5.

The radicalism of Copernicus's thesis about the movement of the earth, by which he challenged the "consensus of many centuries"[31] lies firstly in the fact that he puts a question mark over this "direct evidence": although we can see that the heavens are in motion and the earth is stationary at the center of the universe and that this is confirmed by theory and perception, this is not the truth but an illusion – in reality it is the earth that moves while the heavens are stationary. The instrument that enables him to question "direct evidence" is the optical argument, which maintains the relative nature of motion perception: what can be seen is explainable by two optically, phenomenologically equivalent hypotheses. That is the role of the optical argument in Copernicus' discourse: to refute apparent and *a priori* conviction and "knowledge" about the earth's immobility and the heavens' motion. This provides ample, even comfortably ample grounds, for a positive affirmation of earth's motion, but not sufficient grounds. If both hypothesis are possible, there must be "some third argument" that tips the scales to one side or the other.

This is where another radical dimension of Copernicus' achievement comes to light. What is radical, even revolutionary, in Copernicus is not just that he questions apparent evidence, but even more importantly, on what basis he does it.

As it happens, it was Ptolemy[32] who had already unambiguously stated that both possibilities (earth's motion while the heavens are at rest and *vice*

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[31] Cf. "To His Holiness ...", p. 3: "Those who know that the consensus of many centuries has sanctioned the conception that the earth remains at rest in the middle of the heaven as its centre, I reflected, regard it as an insane pronouncement if I made the opposite assertion that the earth moves."

[32] Ptolemy, *Almagest* I, 7: "However, they do not realise that, although there is perhaps nothing in the celestial phenomena which would count against that hypothesis, at least from simpler considerations, nevertheless from what would occur here on earth and in the air, one can see that such a notion is quite ridiculous." Quoted after *Ptolemy's Almagest*, translated and annotated by G. J. Toomer, Princeton University Press, New Jersey 1998, pp. 4–5.

versa) are optically equivalent, or, in his words: "there is perhaps nothing in the celestial phenomena which would count against that hypothesis" (i.e. against the hypothesis of the earth's rotation). However, for Ptolemy this optical equivalence is of secondary importance. It was introduced as a purely hypothetical possibility because, had the rotation of the earth been taken seriously, the entire complex system of established physics and cosmology would have been shaken. In addition to that, we should see "here on earth and in the air" phenomena which we do not see, *ergo* the earth rests.[33]

On the contrary, for Copernicus – as for Buridan and Oresme before him – the thesis of optical equivalence is an epistemological point of departure, one that in fact makes possible the contemplation of the earth's motion. Copernicus maintains from the very beginning that both possibilities are equivalent, while not allowing that any cosmological or physical principle could contradict these two possibilities. Since the relativity thesis is universal and applies to all motion in the universe, it must the basic principle from which one should start when contemplating the motion of the heavens and earth. But what, against the background of the optical equivalence, determines which possibility is real and which illusion?

Buridan, for example, concluded that the earth was stationary because of physical reasons derived from his theory of impetus. Copernicus's conviction that the earth moved and that the heavens was motionless stemmed not from physical but from astronomical arguments. Copernicus put behind him the spheres of cosmology and physics that relied on the non-reflected-upon and direct evidence, i.e. observation, as well as observational tests that similarly relied on what we should see but do not actually see "on the earth and in the air." Instead he transferred the discussion to the sphere of mathematical astronomy. Of course, this is not to say that Copernicus did not offer a physical explanation compatible with the hypothesis of the earth's motion. On the

[33] Cf. ibid.: "… the result would be that all objects not actually standing on the earth would appear to have the same motion, opposite to that of the earth; neither clouds nor other flying or thrown objects would ever be seen moving towards the east, since the earth's motion towards the east would always outrun and overtake them, so that all other objects would seem to move in the direction of the west and the rear. But if they said that the air is carried around in the same direction and with the same speed as the earth, the compound objects in the air would none the less always seem to be left behind by the motion of both [earth and air]; or if those objects too were carried around, fused, as it were, to the air, then they would never appear to have any motion either in advance or rearwards; they would always appear still, neither wandering about nor changing position, whether they were flying or thrown objects. Yet we quite plainly see that they do undergo all these kinds of motion, in such a way that they are not even slowed down or speeded up at all by any motion of the earth."

contrary, he did propose a type of physics compatible with his hypothesis, and he also responded to/countered all arguments against the earth's motion that were based on observational tests, i.e. observations as to what should happen "here on earth and in the air" if the earth really moved. However, as Wolff argues, Copernicus "justifies his system, not by showing that it can successfully explain physical facts, but rather by attempting to make the current and more or less traditional ways of explaining motion compatible with the earth's motion."[34] Copernicus was not primarily concerned with presenting physical arguments for his system, but rather with "the idea that the earth's motion is physically possible and not completely incompatible with reasonable views about nature."[35] To put it differently, Copernicus had to introduce physics into his argument because the earth, for astronomical, i.e. mathematical reasons, "simply must be in motion".

Copernicus's conviction that the earth moves and the heavens do not is rooted in astronomical reasons explained in more detail in Book 1 of *De Revolutionibus*, more precisely in Chapter 9 and particularly Chapter 10.[36] Copernicus is ("already") convinced that the earth moves because this thesis enables him to eliminate two, in his view crucial, deficiencies of the Ptolemaic astronomical tradition: the equant and an arbitrariness in the arrangement of the universe. For Copernicus, the earth's rotation is also the first step necessary to introduce the second kind of earthly motion – the earth's revolution around the sun.[37] If there is nothing that contradicts the rotation of the earth, he is perfectly legitimized to also raise the question of whether the earth can have different motions "so that it can be regarded as one of the planets."[38] Since the varying speeds of the movement of planets and their varying distances from the earth point to the fact that the earth is not the center around which the planets revolve, because there are several centers of their revolution, he can pose the question of whether the center of the earth (i.e. the center of earth's gravity) is also the center of the universe, or whether this center is occupied by the sun, around which the earth revolves along with other planets. Whether it is the earth that revolves around the stationary sun, or the sun that moves while the earth is motionless, the observable phenomena are the same:

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[34] M. Wolff, "Impetus Mechanics as a Physical Argument for Copernicanism. Copernicus, Benedetti, Galileo", p. 218.

[35] Ibid.

[36] This is also a chapter which was probably written before all the others chapters and books of *De revolutionibus*.

[37] And it is also an introduction to the motion of the earth's axis.

[38] *De revolutionibus* I, 9.

> For if this is transformed from a solar to a terrestrial movement, with the sun acknowledged to be at rest, the risings and settings which bring the zodiacal signs and fixed stars into view morning and evening will appear in the same way. The stations of the planets, moreover, as well as their retrogradations and [resumptions of] forward motion will be recognised as being, not movements of the planets, but a motion of the earth, which the planets borrow for their own appearances.[39]

But the revolution of the earth around the stationary sun located near the center of the universe is the premise that enables Copernicus to arrange the universe in a rational, non-arbitrary and harmonious manner that does not leave room for Ptolemy's equant that violates the principle of the uniformity of circular motion. For Copernicus, the crucial reason that the earth moves is the arrangement of the planets relative to the sun and the harmony of the entire universe. "All these facts are disclosed to us," says Copernicus, "by the principle governing the order in which the planets follow one another, and by the harmony of the entire universe, if we only look at the matter, as the saying goes, with both eyes."[40] In fact, insistence on the central position of the earth (and its immobility) leads to the irrational and arbitrary arrangement of the universe. "Then one of two alternatives will have to be true. Either the earth is not the center to which the order of the planets and spheres is referred, or there really is no principle of arrangement nor any apparent reason why the highest place belongs to Saturn rather than to Jupiter or any other planet."[41] By accounting for the movement of the earth, Copernicus is able to arrange the heavenly spheres in a way that in his view presents "a marvelous symmetry of the universe, and an established harmonious linkage between the motion of the spheres and their size, such as can be found in no other way."[42] In short, what makes Copernicus convinced that the earth is in motion is the "symmetry of the universe" and a firm "harmonious linkage between the motion of the spheres and their size."

By transposing the argumentation from the physical and cosmological sphere to the astronomical sphere, Copernicus rendered irrelevant the field of the observable, i.e. "observational evidence" in all of its forms that constituted the foundation of geocentric cosmology and astronomy. In fact, the essence of Copernicus' "Copernican revolution" lies precisely in the fact that he transcended the sensory-perceptional evidence. The law that applies to

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[39] Ibid.
[40] Ibid.
[41] Ibid. I, 10.
[42] Ibid.

the homogeneous universe in which the dividing line between the sub-lunar and supra-lunar spheres no longer exists, as well as the geometrized space of spheres which (in principle) obeys the same rules and laws and the universe in which the earth is just one among many planets, is the universal law of the relativity of motion perception. In such a universe it is not possible to judge whether or not the earth moves solely on the basis of what we see (i.e. phenomena); it is not possible to conclude whether or not the earth moves on the basis of our observation of either celestial or earthly phenomena. In order to be able to conclude which motion is an appearance and which reality in the earth-heavens relation, it is necessary to venture beyond direct sensory perception and observation. For Copernicus, the direct, sensory-perceptual evidence cannot govern knowledge; on the contrary, our knowledge determines what we see. He does not subscribe to the dictate of the body but shows that what we see is invariably dependent on what we know. He believes that the Aristotelian-Ptolemaic image of the world has nothing natural or extra-theoretical about it and that it is not supported by neutral, sensory-perceptual experience. His conviction that the earth moves does not stem from sensory-perceptual evidence, or "the eye of the body," but from a look at the universe through the "eye of reason" guided and legitimized by astronomy.

While the geocentric universe had been tailored to the needs of "natural" man, who by way of direct experience is part of an integral Whole along with the heavens and the earth, the heliocentric universe is a universe of the astronomer-mathematician who emerged as a result of the separation of reason from live, direct experience. We know that the sun, the planets and the earth do not rise and set, but that the earth rotates around its axis but our knowledge is not obtained through experience and cannot possibly be obtained through experience. Nor could science arrive at such a conclusion through direct experience, but by means of reason. The subject of the science of astronomy has to leave behind the "natural" viewpoint from which it observes phenomena, assume an "unnatural" position and from there observe and reflect on what one can see from a "natural" position. Or, in the words of Leibniz:[43]

> It is only with the eyes of the understanding that we can place ourselves in a point of view which the eyes of the body do not and can not occupy. For example, if we consider the course of the stars from where we stand on our earth's sphere, we obtain a wonderfully complicated structure,

[43] Leibniz, *Von dem Verhängnisse*, quoted after Leibniz, *Selections*, ed. by P. E. Wiener; Charles Scribner's Sons, New York 1951, pp. 572–73.

> which astronomers, just in the last few thousand years, have been able to reduce to a few certain laws, and these laws are so difficult and confusing that King Alfonso of Castille, having let tables be drawn up of celestial motions to fill up the lack of accurate knowledge, is supposed to have said that if he had been God's counsellor, the world would have been laid out better.
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> However, after it had been finally discovered that we must place our eye at the sun if we want to view the celestial motions correctly, and that as a result everything comes out wonderfully beautiful, then we see that the supposed disorder and complication were the fault of our understanding and not of nature.

What is appearance and what reality can according to Copernicus be determined only by employing the criteria of mathematical theoretical constructions and not on the basis of sensory-perceptual evidence. Hence Copernicus preserves the traditional disparity between reality and appearance, but on the conceptual level this dividing line is contemplated differently from that in the (Aristotelian-Ptolemaic) tradition. Copernicus replaces "direct evidence", which lies at the foundation of peripatetic cosmology and astronomy, by a theory in which the decisive role is played by the "eye of the mind", which means that the viewpoint that enables one to understand the truth of a phenomenon is theoretically constructed. Or, to put it differently, it is the mathematical astronomy which decides whether earth moves (or not), not cosmology or physics.[44]

[44] On this point see R. S. Westman, "The Astronomer's Role in the Sixteenth Century: a Preliminary Study", *History of Science* 18 (1980), pp. 105–147.