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The Heliocentrism of the Ancient: between Geometry and Physics

Abstract: Geocentrism remained a fundamental characteristic of ancient astronomy, though there were moments in the history of this discipline when they argued for the orbital movement of the Earth around the Sun and even its rotation around its own axis. Practically, at the crossroads between physics and geometry, astronomy rejected a correct thesis in geometric terms, based on seemingly arguable physical theories. In this paper, my goal is to present from a synthetic and diachronic perspective several elements of the cosmologic model developed by the Greeks until the time of Aristarchus of Samos, thus highlighting several aspects of physics that made it impossible to accept heliocentrism, explainable in mathematical terms, which he promoted.

Keywords: astronomy, geometry, physics, geocentrism, failed interdisciplinarity.

1. Introduction

It suffices to mention here the anecdote recounted by Diogenes Laertius about Thales of Miletus (the first author appraised in his monumental *Vit. phil.*, I, 34) to understand that the movement of divine bodies and the anticipation of astronomical events was one of the major concerns of ancient philosophy, from its inception. Astronomy ("the law of the asters") tries to provide answers to several issues, thus speculating at the same time notions from physics and mathematics (more precisely, geometry). Such matters were: the matter making up the planets, the Sun and the Moon included; the laws governing movement, the shape of planets and their place in the Universe; the place of the Earth within this system; how eclipses occur and how they may be "predicted".

The infinity of the Universe seems incontestable nowadays, like a postulate. But, however striking that may be, a brilliant mind such as Aristotle, for instance, sought arguments to demonstrate the contrary: the fact that the sky makes a complete rotation around the Earth proves that it is finite (*De caelo*, II, 4). Hence, the finite character of the Universe, at least in this excerpt, is related to the centrality and immovability of the Earth. Moreover,

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in an infinite space, the idea of a centre is illogical, just like the idea of ascribing a certain shape to this space.

2. The theory of spheres

The school of Miletus and the Elatic school had focused on the idea of the constitutive elements of the universe: earth, water, air, fire, aether. Despite the observations, simply insufficient (Dreyer 1977, 31), on which they based their suppositions, these schools hold the merit of having imagined the universe as a sphere. This practically led to the idea of the geometric pattern described by the concentric spheres based on which one may describe and approximate the path of the divine bodies and may predict astronomic phenomena. Philolaus (and the school of Pythagoras in general) believed that in the centre of the universe there was the central fire (not the Sun) around which, on their own orbits, the planets gravitated (the Earth included) in a circular motion, opposite to the sphere of fixed stars. The central fire was not visible due to the interposition of the Anti-Earth[1] – a supposed planet that the Pythagoreans had introduced in the system because of the belief that 10 was the perfect number –, and to the fact that it was situated on the opposite side of the discovered world. According to Philolaus, the Earth did not revolve around its own axis.

Whereas Plato was not highly interested in physics in general and in cosmography in particular, the great philosopher did utter a well-articulated opinion in his work concerning the shape and composition of the universe. Spherical, "ensouled, rational living being" (*Tim.*, 30c), copy of a rational model, agent and patient of all its actions (*Tim.*, 28b; 33d), the universe is based on four constitutive elements – earth, water, air, fire (*Tim.*, 53b; aether was considered "the brightest part": *Tim.*, 58d) – and it divides into a Hyperuranion ("place beyond heaven") and Infrauranion (*Phaidr.*, 246d-248e). T The divine bodies (that measure time: *Tim.*, 38d) have fraction-like patterns (in geometrical progression: 1, 2, 4, 8 and 1, 3, 9, 27 – the importance provided to the number has a Pythagorean origin), and among the movements, the rotation one being specific. It has different speeds according to the "spindle of Necessity" by eight distinct orbits "wheels": the sphere of fixed stars, Saturn, Jupiter, Mars, Mercury, Venus, the Sun and the Moon. For Plato, *Aplanes* ("the identical" whose dominant motion is manifested at the level of all the divine bodies) – the sphere of fixed stars – revolves in a motion opposite to the one of the other divine bodies, and their revolution is accompanied by the song of the Sirens (another Pythagorean idea reprised by Plato) and continued by Moire (*Republica*, 614b-621c). The difference between the movements "of the planets" is that – being situated at various distances from the Earth (immobile, spherical and huge, situated in the centre of the universe) around which they revolved – they fulfilled their revolutions in various periods: Saturn, in 30 "solar years", the Sun, in one year, the Moon, in almost 30 days, etc.

The rotation of the divine bodies around the Earth seems to be the fundamental element of the universe described by Plato (Dreyer 1977, 63), but a well-grounded geometrical model had to account not only for the apparent movements of the divine bodies as they may be seen from a certain point of our planet, but also it had to provide the framework for more pragmatic purposes. I refer here to an explanation for the irregularities of the paths based on which one may predict the astronomic events.

Eudoxus of Cnidus believed that the movement of the "wandering stars" may be explained through concentric spheres[2] (the Earth being situated in the centre). Namely, all divine bodies are located on the equator of a sphere that revolves evenly around its own axis. The poles of this sphere are on the internal surface of another sphere revolving reversely around its own axis, inclined in relation to the axis of the first sphere, etc, reason for which the movement of any body is the result of combining the three (or four) rotation movements. Eudoxus imagined 27 such spheres: three for the Moon and Sun, four for each planet (Mercury, Venus, Mars, Jupiter, Saturn) and one for the sphere of fixed stars. From among them, the outer one reproduced the movement of the sphere of fixed stars, from the East to the West (the diurnal movement of divine bodies). The second one had a 20° and 30' inclination (its equator being in the plane of the ecliptic) and it provided the "annual" movement of all the "planets" (respecting "the year" specific for each "planet", namely the period of its complete revolution around the Earth), from the West to the East, in opposition to the movement of the sphere of fixed stars. The others were meant to describe the particularities (accelerations, decelerations, precession, retrocession) of the motion specific to each "planet". Thus, all the divine bodies revolve around the Earth, situated in the centre of the universe, independently from one another and from the sphere of fixed stars.

Callippus of Cyzicus – a student of Eudoxus – attempted to eliminate the inaccuracies related to the longitudinal and latitudinal movements inherent to the system, thus imagining a larger number of concentric spheres, with the help of which he managed, for the movement of the Sun, to determine the duration of seasons, with an approximation of less than a day[3].

Whereas the universe according to Callippus had 33 spheres (among which, for instance, five for the Sun and five for the Moon), the one imagined by Aristotle comprised 55 (for instance, nine for the Sun, five for the Moon) by adding 22 additional spheres that revolve in a motion contrary to the spheres of Eudoxus and Callipus (*Metaphysics*, XII, 8). Eternal and divine, spherical (specific configuration because "clearly they have no movement of their own […] nature has bestowed upon them no organ appropriate to such movement" – *De caelo*, II, 11), the stars comprise a matter (for which the movement of rotation is natural) that is not earth, nor water, nor air, nor fire. Moreover, the friction set up in the air by their motion (De caelo, II, 7) causes warmth and light that proceed from them. According to Aristotle, the most ample and rapid sphere – the sphere of fixed stars – is directly influenced by the higher divine cause and it has a circular and uniform motion: the sky is moved evenly (*De caelo*, II, 6), in a circular pattern (a noble movement, without contrary, specific to the aether – *De caelo*, II, 4-5) from the right (local determination more noble than the left) to the left (noble direction – *De caelo*, II, 5). Hence, the visible pole is actually "the lower side" of the sky, and the visible pole is the "upper side" of it (*De caelo*, II, 2). "The planets", on the other hand, fixed on their own spheres, also have a circular motion, but contrary to the rotation direction of the sphere of fixed stars. In case of these trajectories, it is necessary to reverse the poles to the "upper side" and "the lower side" of the sphere of fixed stars (*De caelo*, II, 2). Their compound movement – of their own spheres on which they are at rest (*De caelo*, II, 8), as the Earth is at rest (*De caelo*, II, 3), situated in the centre of the universe (*De caelo*, II, 14) – becomes simpler ("have fewer movements" – *De caelo*, II, 12) as it gets closer to the centre. Thus, the concentric spheres of Eudoxus and Callippus are no longer a mathematical model, but a physical representation of the cosmos (Dreyer 1977, 110), material and finite (for "outside the farthest circumference there is neither void nor place": *De caelo*, II, 4), for it could not make a full rotation in a finite period otherwise. As for the shape of the Earth, the depiction of the eclipse in *De caelo*, II, 14 suggests that, because the shadow of the Earth described an arc on the Moon disc, its shape is necessarily spherical.

This model, which made the sphere (the assertion "The shape of the heaven is of necessity spherical; for that is the shape most appropriate to its substance and also by nature primary" in *De caelo*, II, 4, is followed by four arguments) the fundamental element of the cosmic structure, of its elements and of the description of their motions – though it had become ever more complicated – managed to remain rather easy to use. It also managed to approximate in a satisfactory manner the observable phenomena. However, as long as it was based on the uniform rotation of concentric spheres, it failed to account for the luminosity variations of the "planets" (Dreyer 1977, 129; Kuhn 2000, 76) – as they were closer or farther away from the Earth. It also failed to account for their movement (orbital or "annual") seemingly retrograde in certain instances, or for the uneven character of the angular motion speeds.

3. The centrality and immobility of the Earth

The assertion of the spherical model of the universe also imposed the thesis that the Earth is immobile; because in a sphere that revolves only the centre[4] stays still and because if something moves permanently, something else must always stay still (Aristotle, *De caelo*, II, 3)[5].

Within the universe whose outer limit was the sphere of fixed stars, the order of the mobile divine bodies was also a controversial topic. Macrobius talks about a *Chaldean order* and an *Egyptian order*.

In the myth of Er within the *Republic*, Plato – of whom Macrobius (*In Somn. Scip.*, I, 19, 5) says that he follows the *ordo Ægiptiorum* – proposes the following structure: the sphere of fixed stars, Saturn, Jupiter, Mars, Mercury, Venus, the Sun, the Moon. *Ordo Chaldeorum*, on the other hand, as Macrobius calls it, adopted by Archimedes and Cicero and accepted by several others, was the following: Saturn, Jupiter, Mars, Sun, Mercury, Venus, the Moon, with the Sun in median position. Hence, the difference would consist only in the position of the Sun, Venus and Mercury, of which Plato said, "overtake and are overtaken by one another" (*Tim.,* 38d). Through this statement, he tried to explain the very close trajectories (the duration of their own "years", implicitly) and the irregularities noticeable in the movement of the three bodies, and not so much the fact that sometimes Venus and Mercury seemed to be visible on one side or the other of the Sun. The last idea led Heraclides Ponticus to the ingenious solution of the semi-heliocentric system: the Sun, just as the other divine bodies revolve around the Earth situated in the centre of the universe, but around the Sun, as its satellites, revolve Venus and Mercury. Practically, for Heraclides, both the Chaldean order, and the Platonic order (*Egyptian*) were correct, but alternatively – according to the position, as seen from the Earth, of Mercury and Venus on their orbital path on one side or the other of the Sun. Aristotle may not have known of this solution, given that he fails to mention it in *De caelo*. There (II, 10), he states that – while the mobile stars move contrary to the sphere of fixed stars – the latter makes the movement of the first slow down as they are farther away from the Earth. Therefore, the calculation "of the years" for each "planet" also determines their order: Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, the sphere of fixed stars practically, a version of *ordo Chaldeorum*, found in Hipparchus, Ptolemy or in the Latin authors Pliny, *Nat. hist.*, II, 6, 32-36, or Bed the Venerable, *De rer. nat.*, XIII.

The semi-heliocentric model of Heraclides Ponticus was not a denial of centrality of the Earth in the system. Nonetheless, there was only a step to the heliocentric theory by Aristarchus of Samos[6]. Before him, the Pythagorean School had proposed a model where the divine bodies, the Earth included (and the Anti-Earth), rotated around the central fire that –

like the Anti-Earth – could only be seen from the inhabited side of the world. This model contrasted with some previous opinions (of the Miletus or Eleatic school) that saw the centrality of the Earth not only in terms of Spatiality but also – down to its last consequences – placed it at the origin of certain cosmic phenomena. For Heraclitus of Ephesus, the Sun and the Moon were like two bowls that, the concave side facing our direction, captured the moist exhalations of the Earth, and this "fuel" lit up at sunrise and set down at sunset (Aristotle, *Meteor.*, II, 2, 355a; *Plac. phil.*, II, 28). For Anaxagoras of Clazomenae, the stars were fragments set off the Earth that remained in space only due to the rotation of aether (*Plac. phil.*, II, 13).

For Aristarchus however, in the centre of the universe there was the Sun, a visible point of reference and a subject of the most common astronomic events, the eclipses. Compared to the theory of the central fire specific to the Pythagorean School, the one uttered by Aristarchus could be confronted with the direct observation of the phenomena. Unfortunately, no accurate presentation of Aristarchus' theory was preserved, which may have allowed us to understand his cosmological ideas correctly. The very brief presentation made by Archimedes in *Arenarius* (I, 4-5) shows that the Earth makes an orbital movement around the Sun, immobile in the centre of the universe, around which revolves the sphere of fixed stars. We find out nothing about the movements of the other bodies. However, given that the Moon rotated, as per Aristarchus, too, around the Earth, this would have generated similar difficulties with the ones of the semi-heliocentric theory by Heraclides – two divine bodies (the Sun and the Earth) around which revolve other divine bodies –, but at least it could have allowed the correct explanation of the eclipses. Or, for Aristarchus, the solar eclipse was due to the inclination of the Earth – at least this may be deduced from the brief enumeration of opinions concerning the solar eclipse, in *Plac. phil.*, II, 24.

The hypothesis that the Earth, though in the centre of the universe, would revolve around its own axis from the West to the East (as an explanation for the diurnal movement of the sphere of fixed stars), does not have – according to the sources – a definite author and is not given much credit, being rejected by Ptolemy. Diogenes Laertius (*Vit. phil.*, VIII, 85) ascribes to Philolaus the opinion that the Earth revolves in a circle (κατὰ κύκλον), a vague expression, but which – corroborated with the idea of the central fire being invisible and with the mention that it revolves in a circle (κύκλῳ περιφέρεσθαι) around the fire, as per an oblique orbit (κατὰ κύκλον λοξὸν), the same as the Sun and the Moon, stated in *Plac. phil.*, III, 13 – only allows one interpretation. Namely, the solely orbital movement (around its own axis) of the Earth made the central fire remain invisible (and the Anti-Earth of the Pythagoreans). Diogenes Laertius (*Vit. phil.*, IX, 30) ascribes to Leucippus the idea that the Earth, shaped like a tambour, revolves around the centre, but it is unclear whether he refers to the orbital movement or to the one around its own axis. Concerning the latter, Cicero (*Acad. Priora*, II, 39, 123) is far more explicit: supporting Theophrastus, he believed that Icetus of Syracuse would have launched the opinion that the diurnal movement of the sphere of fixed stars is only apparent, as a consequence of the rotation of the Earth around its own axis[7]. On the other hand, *Plac. phil.* (III, 13) credits Heraclides Ponticus and Ecphantus with this belief. Naturally, the rotation direction of the Earth was from the West to the East, if the constellations were considered motionless. Upon invoking the scarcity of sources, but also the deductions made by H. Martin (Martin 1881), Schiaparelli believes that Heraclides Ponticus had in common with the Pythagorean School the idea of the movement of the observation point around the centre of the universe. Along with Icetus and Ecphantus, he agreed with the thesis according to which the sky would not revolve around the Earth, but the Earth around its own axis, the only original hypothesis being the one of the orbital movements of Venus and Mercury around the Sun (Schiaparelli 1926, vol. II, 121-122). If – as stated by Schiaparelli – with the system of Tycho Brahe (the Earth revolves around its own axis; the Moon is a satellite of the Earth; the other planets – Venus, Mercury, Mars, Jupiter, Saturn – have as centre of their orbits the Sun, along with which they revolve around the Earth) they agreed even during the times of Heraclides Ponticus[8] and if Aristarchus only assumed that the Earth revolves around the Sun just like the other planets, then the statement (rather late, of the 1st-2nd century AD) made in *Plac. phil.*, II, 24 is at least confusing.

The idea of the centrality and immobility of the Earth survived the theses by Aristarchus [9] and the symbolical thought of the first Christian centuries, thus crossing the entire Middle Ages. Thus, it may be found in Cassiodorus, Isidore of Seville, Bede (reprised through Pliny the Elder) or Dungal (reprised from Macrobius). Th. Kuhn – based on an ample passage (which he cites) from Aristotle, *De caelo* (II, 14) – considers that such opinions as those uttered by the Pythagoreans or by Heraclides or by Aristarchus, "though astronomically persuasive", could not be accepted. The reason is that they were in opposition with a series of beliefs subjected to physics, as it was not a distinct field from astronomy (Kuhn 2000, 108-111). Th. Kuhn also cites the answer (Kuhn 2000, 111), equally relevant for this statement, by Ptolemy of *Almagesta* to the theory uttered by Heraclides, according to which the sphere of fixed stars is immobile, and the Earth would revolve around its own axis from the West to the East. Earlier in the book, in the conclusions to the volume *Scritti sulla storia della astronomia antica* (1926, vol. II, 173), Schiaparelli believed that rejecting the hypotheses of Heraclides and Aristarchus also came after the success of "mathematical astrology", arrived to Greece from Asia Minor through Berosus the Chaldean.

To support Schiaparelli's statement, Ptolemy himself was known for both *Almagesta* (an astronomy treatise) and *Tetrabiblos* (an astrology treatise).

4. Conclusions

Upon commenting the paragraph in *Arenarios* featuring the heliocentric of Aristarchus of Samos, Schiaparelli (1926, vol. II, 168) states that Archimedes uses the term γραφάς cthat may refer to a graphic presentation or demonstration. Hence, whereas, geometrically one could prove that the heliocentric system was capable of accounting for observable astronomical events that had not been solved previously within the geocentric system, Aristarchus' ideas must have been rejected using other arguments than mathematical. The new theory involved, on one hand, that the Earth was a satellite of the Sun, which contradicted the traditional order of the elements (starting from the lowest point of the sphere, the centre: earth, water, air, fire, aether) in the universe. The new theory stated, on the other hand, that not the sky of fixed stars revolved around the Earth, but that the planet revolved around its own axis. This questioned the idea of finite Universe and, had we admitted the thesis of Universe infinity, the idea of a centre and of (spherical) forms hereof would have become unsustainable. Therefore, heliocentrism was unacceptable pursuant to fundamental theses of physics in that period. To it, we add astrology, a rather new pseudoscience for the Greeks, but which had conquered the Greco-Roman world, who claimed to foretell destinies based on the astral configurations at the moment the individuals were born or conceived. There were also the meteorological phenomena, (invoked by Ptolemy in *Almagesta*): if the Earth revolved around its own axis from the West to the East, should not we see how the clouds remained behind, thus "making" a seeming movement in the other direction, towards the West?

Aristarchus' ideas were rejected, which led to an intensification of the efforts to explain the irregularities observable in the movement of "planets" through increasingly complex mathematical calculations and models: epicycles, deferents, mobile eccentric circles, "equants" (< lat. *aequans*)[10]. Subsequently featured by Ptolemy in *Almagesta*, they represented the articulations of the geocentric model used throughout the Middle Ages.

Notes

[1] The interposition of the Earth and the Anti-Earth also explained the higher frequency of Moon eclipses compared to Sun eclipses.

[2] *Plac. phil.*, II, 16, attributes to Anaximander the idea that stars move along with the spheres or circles where they are situated. Given that the uniform circular motion failed to depict the real motion of the mobile stars, Eudoxus proposed to combine several rotations as a solution.

[3] In *Metaphysics*, XII, 8, Aristotle provides a description of the system imagined by Eudoxus and Callipus.
[4] Diogenes Laertious (*Vit. phil.*, IX, 21) ascribed to Parmenides the idea of the Earth's centrality.
[5] Anaxagoras, Democritus or Cleanthes, according to whom the stars move from the East to the West (*Plac. phil.*, II, 16), also feature versions of the same idea according to which they would all revolve around the Earth. The same may be found in "Alcmaeon and mathematicians", who pinpointed that they moved from the west to the East in relation to the sphere of fixed stars (*Plac. phil.*, II, 16).
[6] Schiaparelli, upon analysing a fragment of Simplicius (Διὸ καὶ παρελθών τις φησὶν Ἡρακλεἰδης ὁ Ποντικὸς ὅτι καὶ κινουμένης πως τῆς γῆς, τοῦ δ΄ ἡλίου μένοντός πως, δύναται ἡ περὶ τὸν ἥλιον φαινομένη ἀνωμαλία σώζεσθαι – Simplicius 1882, 292) who in his turn reprises a fragment from Geminus of Rhodes, *Meteorologica*, deduces that Heraclides Ponticus had launched (or at least he could have) even the idea of the Earth revolving around the Sun. See also Schiaparelli 1873, 31, 55.
[7] This makes Dreyer (1977, 46) assume that Icetus, a Pythagorean, did not share the idea of the central fire, which – in case of the Earth's rotation around its own axis – would be visible. *Cf.* also Diogenes Laertius, *Vit. phil.*, VIII, 85.
[8] The author may have been even Heraclides Ponticus or a contemporary: see Schiaparelli (1926), vol. II, 126.
[9] As Pliny synthesised in *Nat. hist.*, II, 4, 11: *...ita solam inmobilem circa eam volubili universitate*.
[10] The epicycles and mobile eccentric circles were the expression of another level of abstraction: their centres no longer coincided with the position of divine bodies, as with the model of concentric spheres. Schiaparelli demonstrates that both the epicycles and the mobile eccentric circles were "diverse forms of the same construction, and the calculation of the planet's position remains essentially the same" (Schiaparelli 1926, vol. II, 132-133). However, the epicycles had the advantage "of being applied to inferior planets, too" (Venus and Mars), reason for which the Greek geometry experts preferred them to mobile eccentric circles.

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