GEOCENTRISM, HELIOCENTRISM, AND THE CIRCULAR ORBITS OF THE HEAVENLY BODIES: SOME CONCEPTUAL PROBLEMS IN EARLY GREEK ASTRONOMY

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Someplace in the train of thinking there arises a sense of wonder, eventually formulated into the question "Does the sun revolve around the earth? or the earth around the sun? or neither, but rather both revolve around some third thing or place?" Where and how does that thought arise? The hypothesis of geocentricity, or non-geocentricity (of which heliocentricity is one possible case) arises in the context of comprehending the motions of stellar bodies. Determining the nature of the motions certainly arose from the serious need to measure the passage of time, to determine the most opportune time of year to plant the crops in order to survive, and to fix the dates of religious festivals, the celebrations for the divinities whose providence needed to be secured.

Geocentricity is *prima facie* plausible. Together with the obvious psychological comfort, familiar expressions such as "*sun-rising*" and "*sun-setting*" are not aberrant interpretations of the sense-experience; geocentricity may not be the only description, but it plausibly accounts for several central phenomena. Whatever it accounts for, the underlying assumptions seem to be (1) that heavenly bodies are perfect and their perfect motion is both uniform and *circular* and (2) that the universe is not infinitely extended — otherwise, of course, there would be no center, hence no geocentricity, and hence no uniform or circular motion of the perfect heavenly bodies around it, but rather the universe is of only finite extension, the center of which is at or near the center of the earth. Geocentricity provides some account for the solar year, the period of time it takes to make a singular pass through the zodiac, the stellar constellations in the revolving firmament. The hypothesis makes it possible to detect overall circular movement of those special heavenly bodies that "*wandered*" through the constellations at varying speeds the planets - unlike the celestial sphere of fixed stars which always remained in the same configurations. This claim, that the planets revolve around the earth in circular orbits, is approximately confirmed if one attempts to plot the positions of the observed planets over the course of time. The discovery, then, of these divine or heavenly bodies, whose motion was perfect and circular, was a discovery of the first-order, given the assumptions whose restrictions determined what could even count as a possible and acceptable theory.

Geocentricity, however, has its problems; but any nongeocentric theory must first overcome the implausible presupposition that the earth is in motion. Insisting that the earth is in motion is not so easy to accept *prima facie*. For if the earth is revolving around something else, it is also rotating upon its axis. It is obvious, then, that given the immense size of the earth, and the brevity in length of the daily rotation, the earth must be spinning on its axis at an incredible speed, and it's very hard to understand how it is that everything does not simply fly off the earth as we would expect all the dishes to fly off the waiter's tray as our meal is delivered on a spinning and rotating tray at a scant 1,000 miles per hour. The simple awareness that "heavy" or "earth" and "liquid" bodies tend to fall downward was generally interpreted in the context that heavy bodies tend to move toward the center of the universe, at or near the center of the earth. The rejection of geocentrism must reject the explanation that heavy bodies fall downward *because* heavy objects tend to fall to the center of the universe. They still fall downward, but not for that reason. And the nongeocentrist must also overcome the dilemma posed by the failure to detect and determine a parallax between the extremes of the diameter of the earth's orbit and a position of any one of the fixed stars. Finally, the non-geocentrist must embrace what must first serve as rather discomforting news, that we humans are not at the center of the universe, that we are revolving about some other central focus. In a word, we learn that we are no longer the "number 1" that we supposed we were. Having been willing to put the earth in motion, however, it is yet to be decided what the focus of the orbit is, and the varying consequences which follow from that identification.

The critic of geocentrism need not propose a superior theory; it would seem enough to reject geocentrism as sufficient given the inadequate correlation between the theory and the observations. The geocentric hypothesis only accounts for the movement of the sun, moon, and planets along the zodiac. But since the daily rotation follows the plane of the equator, whereas the observed movements of the planets also varied northerly and southerly, along the lines of the ecliptic (i.e. the 23½° variation between the observed extreme positions of the sun northerly and southerly with regard to the equatorial plane), it was clear that the proclamation of the earth as the center of the universe—whether exerting a force on the planets which varied with distance or not—was incapable, alone, of accounting for the phenomena.[1] The two different motions could not be satisfactorily explained on the single hypothesis of geocentricity. The geocentrists were already challenged by the readily apparent observation that the size, brightness, and apparent speed of the planets varied during their orbits, suggesting that the earth was not always at the center of the focus for the orbiting planets. It was further objected that the division of the seasons marked by the northerly and southerly extremes of the sun's apparent position, and the passing overhead in the equatorial plane, could not satisfactorily account for the unequal lengths of the seasons.

A non-geocentric theory represents one significant attempt to resolve the anomolies of geocentrism. Historically, for the early developments of Greek astronomy, there is a doctrine attributed to the Pythagorean Philolaus, which locates the center of the universe and the focus of the orbits at the ''hearth'' (hestia), around which both the moving earth and sun proceeded.[2] In addition, the theory of Philolaus postulates a counter-earth, not visible from our present location, but whose motions were counter-balanced in harmony with that of the earth.

The Philolaun theory rapidly fell into disfavor. This was due to several contributing blows. First, the extension of demographic knowledge, made possible by developments in sailing and trade, brought forth the awareness of India, to the far east, and Africa through the pillars of Heracles. Navigated by Hanno the Carthaginian, it was surely thought that if there were this ''counter-earth'' it would clearly have been visible from one of these extreme points, but, of course, it was not. The postulation of a counter-earth was inspired, in part, by the Pythagorean adulation of the perfect number 10 and the desire to identify 10 moving bodies. But it is really more significant to underscore that the same hypothesis of a ''counter-earth'' attempts to offer some explanation of the visible eclipses of the moon, which were far more numerous than that of the sun.[3] The Philolaun theory fell into disfavor as did orthodox religious practice among the majority of Greeks through the fifth century. The close of the fifth century, with the rise of technology and the exact sciences, brought increasing secularization in Greek society. Religion, as the source of satisfactory explanation of physical phenomena, became increasingly discredited. At the Panhellenic site of Nemea, for example, the stadium for athletic games was located directly next to the temple. In the late part of the fifth century, a new stadium was constructed almost onehalf mile away. Evident attempts were already underway to save the athletic games from being identified with traditional religion—and so vilified, becoming the appropriate object of scorn.

As Burkert put it, on the supposition of perfect, circular-moving heavenly bodies, only two approximately correct explanations of stellar motion can be found—geocentrism and that peculiar kind of non-geocentrism called heliocentrism.[4] The theory attributed to Philolaus, which assumes a third location that is the focus of the orbits of the sun and earth, could not even approximately account for the phenomena while still supposing that the heavenly bodies move in uniform and circular orbits. The hypothesis of Philolaus, however, sufficed to encourage thinkers to entertain the idea of the earth-in-motion.

There can be little doubt that the diurnal rotation of the earth was claimed by Heraclides of Pontus, although, on his account, the earth still assumed a place in the center. According to Simplicius, in the commentary on *De Caelo*, Aristotle criticized positions held by Heraclides, a contemporary of the peripatetic master. But Heraclides also declared that Mercury and Venus orbit the sun, and thereby only indirectly orbit the earth.[5] As the moon was believed to revolve around the earth, so Mercury and Venus were believed to orbit the sun; the sun, in turn orbited the earth. Confirmation of this development comes from several reliable sources, Vitruvius, Martianus Capella, Cicero, and most especially Chalcidius, who finally mentions Heraclides of Pontus by name as the discoverer.[6] In agreement with both Heath and Burkert, it is, however, most unreasonable to think that Heraclides advanced a doctrine of epicyclical motion; the reason is that the system Aristotle adopts, the theory of concentric spheres, originated by Eudoxus and modified by Menaechmus and Callipus, is hopelessly inferior to a system of epicycles; and if Heraclides had promulgated such a theory, those like Aristotle could never have seriously maintained the theory of concentric spheres. The theory of epicycles clearly in use by 200 B.C. in the work of Apollonius of Perga, in no way violated the crucial assumption of the cultural *weltanschaaung*, that the movements of the celestial bodies were uniform, perfect, and *circular*.

Even with the theory of epicycles, the geocentrist cannot better explain the unequal lengths of the seasons, as they can offer a descriptive explanation of the retrogradations of the planets. But then again, neither could heliocentrism, first introduced into classical antiquity by Aristarchus of Samos, who flourished in the late fourth and third centuries B.C. From the point of view of a ''Copernican Revolution,'' one wonders why the heliocentrism of Aristarchus did not gain currency although it did offer the prospect of eliminating a theory of geocentrism with its epicyclical motions and retrogradations. The great astronomers Hipparchus and Ptolemy both rejected the hypothesis according to Dercyllides; on the authority of Theon of Symrna, Seleucus alone championed Aristarchus' theory.[7]

Heliocentricity succeeds in presenting an approximate description of stellar movement which eliminates the need to account for retrogradations while preserving the condition that the stellar motions are perfect circles. The hypothesis also makes possible an explanation of the motions of planets around the sun, and thereby the earth through the observed zodiac, as its diurnal rotation follows the plane of the equator. At the same time, the observed positions of the planets following the plane of the ecliptic, together with the observed positions of the sun, receive thoughtful consideration. The supposition of revolutionary movement of the earth offered partial explanation, declaring the sun as the focus of the orbit. The rotary movement of the earth about an inclined axis partially explained the location of the planets following the plane of the ecliptic.

Aristarchus' heliocentrism received little support due to a series of charges which could not be adequately defended. First, the possible kinship to Pythagoreanism, which had little favorable currency, was no asset. The hypothesis could offer no better explanation of the unequal lengths of the seasons. In fact, in and of itself, it offers little which is descriptively superior to geocentrism. The diurnal rotation together with the apparently stable condition of material objects on a rapidly spinning sphere did not reduce the problem nor invite commonsense appeal. The failure to detect and measure a parallax were equally uninspiring reasons to support heliocentrism. Finally, the failure to detect a parallax between the extremes of the diameter of the earth's orbit and the position of a fixed star required that we suppose a universe of staggering immensity, particularly in comparison with the earlier miniscule approximation in which the size of the universe was represented as a sphere whose radius was equal to the distance of the earth to the sun. The awakening to a much clearer appreciation of the vastness of the heavens deserves additional attention.

In surviving work by Aristarchus, *On the Sizes and Distances of the Sun and Moon*, the ratio between the diameter of the sun and the diameter of the earth is determined. By virtue of this assessment, the volume of the sun turns out to be more than 300 times the volume of the earth. Schiaparelli, followed by Heath, suggests that Aristarchus' awareness of the enormous size of the sun in relation to the earth led him to suppose that the larger, not the smaller, was the focus of the orbit. Even without a developed theory of dynamics, the supposition of the immense sun at the center and the tiny earth in orbit around it is certainly more plausible. The relation surely bears a resemblance to the interaction between a piece of loadstone and some iron fillings—the larger is at the focus and the smaller parts move in relation to it. It is interesting to note, however, that although Archimedes in the *Sand-Reckoner* provides the reliable testimony of Aristarchus' heliocentric hypothesis, there is no evidence in the surviving work, *On the Sizes and Distances of the Sun and Moon*, which attests to this position. It has been supposed that either this work was developed prior to the heliocentric hypothesis or that the more familiar geocentrism was supposed as a noncontroversial basis for determining problems of measurement which could be conducted quite independently of deciding which stellar body was located at the center of the other orbiting bodies.[8]

If developments in ancient Greek science seem peculiar to us today it is probably because fundamental assumptions of their *weltanschaaung* are no longer part of ours. It must strike the modern reader as curious that Aristotle's physics proceeds not by identifying a material element and them ascertaining its motion, but rather by supposing the motion is fundamental

and thereby arrives at an assessment of the material constitution of a thing. The heavenly bodies must be made of a different element, a fifth element—the aether, concludes Aristotle in *De Caelo*, since the uniform circular motion expresses the material nature. None of the terrestrial elements behave this way. And rather than suppose that the celestial bodies were constituted by terrestrial elements behaving in a different way, Aristotle insists that objects which move in perfect circles (and not rectilinearly) cannot be made of the same terrestrial stuff. The stellar bodies were heavenly bodies, and the divine is characterized by the most perfect behavior.

For Aristotle, all imperfect things are in a state of motion; all things in motion seek to come to a completed rest. Motion was the problem; rest was the solution. Circular motion was most nearly like rest; circular motion was the most perfect of all motions. And this supposition about the primacy of circular motion seems to permeate the history of early Greek astronomy. It is surely for this reason that no one thought to account for the small discrepancy in the unequal lengths of the seasons by suggesting that perhaps the orbits of the moving celestial bodies were ellipses. With all the enormous successes that mathematics had specifically brought to astronomy, no one, evidently, sought to apply a theory of conic sections to the specific shape of the orbits.

On good authority, it is reported that Menaechmus, whose astronomical suggestions were incorporated into Eudoxus' theory of concentric spheres, embraced by Aristotle, distinguished between three types of conic sections —ellipse, parabola, hyperbola — in the process of trying to construct the so-called double-mean proportional. Democritus and Edoxus were aware of the ellipse, as a plane in a conic section. Later, Archimedes and then Appollonius of Perga developed the theory greatly. Nevertheless, though willing to place the massive sun at the center of the orbits of the earth and other planets contrary to tradition, Aristarchus never attempted to re-describe the possible shape of the orbits, as he did with the proper location of the focus. Even much later, Copernicus, clearly recognizing that, descriptively, the heliocentric hypothesis is really no better off than the geocentric, by itself, was entirely preoccupied with the *prima principia de motus aequalitate*, that "*the first principle of motion is uniformity*." As a result he, too, never grasped the elliptical orbit of the revolving bodies. From this perspective, then, it was Kepler who ushered in the key to the conceptual advance. Once the insistence for circular motion was abandoned, a satisfactory resolution was not far-off. In fact, without this insight on the geometry of the orbits by Kepler, the heliocentric hypothesis is hardly compelling. But given this perspective, Newton's classical mechanics merely works out the details of heliocentric astronomy. This is not meant as denigration, but it does indicate that the significant conceptual hurdle had already been overcome.

We began by wondering when and how does the question emerge: Is the sun moving around the earth, or the earth around the sun? The question emerges from a context in which a careful study of the heavens is required for accurate time-telling. In the midst of determining the time to plant the crops and set the religious festivals, we begin to wonder how the varied and complex motions in the sky fit together best. At the same time, the question is raised as to where we are — we human beings — and what precisely is our fateful lot within this great design. In order to produce a satisfying reply to the question: Geocentrism or Heliocentrism? we must carefully look at how we raise the question, because the manner of looking more often than not determines the object found. Have we been asking the right question after all? Is the distinction between geocentrism and heliocentrism the crucial distinction for making sense of the broad context in which we determine just where we are? Perhaps not. What of this dichotomy of accounts in the context of general relativity? The difference and its import vanishes. What is a significant distinction within one paradigmatic world view dissolves within another.

We have been asking about a specific issue in the history of science, focusing specifically upon an historical chapter in the development of early astronomy. To resolve conflicts between competing theories, supposedly we examine the evidence. But the meaning of "evidence" has been the stumbling block all along. The different presuppositions with which we equip ourselves before taking on an examination already determines what does and does not count as a significant objection. Supposing that heavenly bodies move only in perfect circles, the failure to observe those circular movements does *not* count as evidence against the theory. Rather, the observational intricacies are attributed to the recalcitrance of the material world, not to a defect in the theory or explanation. This brief paper has been an attempt to sketch out conceptual dilemmas which arise in one small quadrant of the history and philosophy of science. The task which still awaits is a full-blown exegesis of ancient science, its paradigmatic presuppositions, and its historical struggle with evidence and explanation.

NOTES

1. Cf. Thomas Heath, *Aristarchus of Samos*. Oxford, 1959, pp. 94-95.

2. Cf. Heath, pp. 94-120. Also Walther Burkert, *Lore and Science in Ancient Pythagoreanism*, Harvard 1972, pp. 218-99.

3. Heath, 1959, pp. 96, based upon testimonia in Aristotle, *De Caelo*. ii. 13, 293a18-b30.

4. Burkert, 1972, pp. 322-23.

5. Simplicius, *In Aristotelis De Caelo commentaria*, ed. J. L. Heiberg (Berlin 1894; CAG XI) p. 512. 9-20.

6. Heath, 1959, pp. 253-55.

7. *Ibid*, pp. 306-308.

8. The discussion in Heath (1959) is the most thorough, pp. 298-414, including Aristarchus' text and calculations.