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On Philolaus' astronomy

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Abstract In Philolaus' cosmology, the earth revolves around a central fire along with the other heavenly bodies, including a planet called the counter-earth which orbits below the earth. His theory can account for most astronomical phenomena. A common criticism of his theory since ancient times is that his counter-earth does no work in the system. Yet ancient sources say the planet was supposed to account for some lunar eclipses. A reconstruction of Philolaus' cosmology shows how lunar eclipses occurring at certain times of day cannot be explained by earth blocking the sun's light. The counter-earth could explain these eclipses.

> Concerning the location of the earth not everyone holds the same view, but while most maintain that it lies at the middle, namely, those who say the heaven is finite in extent, members of the Italian school called Pythagoreans say the opposite. They say there is fire at the center and the earth, acting as one of the heavenly bodies, is carried around the center in a circle so as to produce night and day. Further, they posit another earth opposite this one, which they call the counter-earth—not seeking explanations and causes in light of observations, but trying to make the observations fit their own preconceived theories. (Aristotle *Cael.* 293a17-27)[1]

In his magisterial reconstruction of Pythagorean thought, Walter Burkert separated true from false fragments of Philolaus and firmly established the Crotonian's place as a major thinker of the later fifth century BC. As a result of Burkert's work, it became

[1] Translations will be my own unless otherwise specified.

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clear that the Pythagorean cosmology Aristotle and others referred to was that of Philolaus. "There is nothing of [mathematical astronomy] in Philolaus," said Burkert,

> only an invisible central fire, an equally invisible counter-earth, unobservable movements of the earth and stars—mythology in scientific clothing, rather than an effort, in accord with scientific method, to "save the phenomena." ... The system of Philolaus is not a scientific astronomy, and there is no reason to set it late chronologically on grounds of its sophisticated and advanced nature. (1972 [1962]:342)

Thus, Burkert defended the authenticity of Philolaus' cosmology in part by denying its scientific character. In Philolaus, "shamanistic myths take concrete form as specific components of the world" (348). In recent years, however, Carl Huffman has shown how the "attempt to turn the Philolaic system into a myth or fantasy is misguided." On the contrary, Philolaus' model "is in fact the most impressive example of Presocratic speculative astronomy" (1993:241).[2] Huffman shows how Philolaus' theory draws on available knowledge of the time and saves the phenomena. Thus, Philolaus' theory is scientific, but scientific in a way that harmonizes with the assumptions and knowledge of the fifth century BC. There remain, however, features of Philolaus' theory that seem irreducibly a priori and, as Aristotle objected, without empirical justification, namely the central fire around which all the other heavenly bodies move, and the counter-earth, an earth-like planet that orbits the central fire inside the orbit of the earth (244-47). To that extent, Philolaus' system turns out to be a kind of hybrid between a speculation driven by a priori metaphysics and a physical model designed to explain appearances.[3]

In this paper, I look at how Philolaus' model functions with attention to the much-maligned counter-earth. Does it do any work at all, or is it a mere accessory, an ornament with only aesthetic or numerological value? Aristotle and others report one function that it allegedly filled: to explain some lunar eclipses. I attempt to show how it can do just that, and, moreover, how without the counter-earth, some eclipses would remain inexplicable. This paper provides a scientific analysis of the Philolaic system relative to some historical assumptions, rather than a philological or historical reconstruction. (The paucity of details given for his system seems to make a full-blown historical reconstruction impossible.) My objective is not to read Philolaus' mind but to see how his system might make sense to an astronomer constrained by certain assumptions.[4] According to the received opinion from Aristotle onward, this

[2] Contrast Furley's view just a few years earlier (1987:58): "the system as a whole makes very little astronomical sense, and it is hard to believe it was intended to do so."

[3] Nor are recent commentators all as generous to Philolaus as Huffman. Concerning Philolaus' cosmology Couprie says, "I would rather call it fantasy than creative imagination, and certainly not 'a triumph of thought over mere appearance' (Huffman 1993:259)" (2011:172, cf. 170–173, xxxi).

[4] Barnes observes, "the fact is that we do not know what considerations led Philolaus to propound his startling innovations, and without such knowledge, we cannot pass judgment. Astronomically, of course, the Philolaic system is inadequate, but so are all the admirable astronomical systems of antiquity" (1982 [1979]:284). His first statement is quite correct, but the criterion of adequacy (presumably empirical adequacy) mentioned in the second provides a way to frame at least a relative judgment.

project is doomed from the outset. To the extent this account succeeds, it will tend to vindicate Philolaus as an empirical astronomer.

Some historians may object that subjecting an ancient theory to modern evaluations is blatantly anachronistic. If the objector means that testing theories against empirical evidence is a modern innovation, I protest that it is not; certainly by the fifth century, thinkers, including historians and physicians, were used to testing the empirical adequacy of theories.[5] If the objector means that testing ancient theories against modern astronomical knowledge is anachronistic, I would agree; my procedure here will be to test Philolaus' theory against what was known and accepted in *his own* time. That Philolaus' innovative model accounts for appearances surprisingly well, in relation to the astronomical knowledge of the fifth century BC, has been amply shown already.[6] I hope to extend the fit of theory to phenomena into a new area. I shall use modern scientific knowledge only in the background as a control on ancient beliefs and assumptions.

1 Philolaus' astronomy

First, a refresher course on Philolaus' astronomy. In this section, I shall draw heavily from Huffman's reconstruction, which I think solves most of the previous problems raised against Philolaus' model. At the center of the universe is a central fire, or hearth (*hestia*), around which the other heavenly bodies revolve. I shall call this universe "hestiocentric."[7] In the innermost orbit is the counter-earth,[8] followed by the earth, then the moon, the sun, and the five planets. Around the circumference lies a circle of "fixed" stars which, as Huffman has plausibly argued, do not move but remain motionless.[9] (See Fig. 1.)

What makes this model work as an explanation of the phenomena is the motion of the earth. The earth completes a revolution every day, moving eastward or, seen from a perspective above the north pole, counter-clockwise (Fig. 1). The earth also rotates on its axis once every day, so that those of us facing outward from the central fire

[5] See, e.g., Herodotus on theories of the Nile floods, 2.19-29; "Hippocrates" on scientific explanation, *Ancient Medicine* chs. 1–3, 16, 22. Both authors are responding to philosophical/scientific theories using philosophical tools. In the early fourth century, Plato studies the hypothetical method, *Meno* 86e-87b, *Phaedo* 100a, which allows the possibility of comparing conclusions to appearances; see Robinson (1953). To recognize an interplay between theory and observation is not to presuppose that facts are given a priori, or that there is a fixed boundary between theory and observation, only that the two realms must interact in theory construction and testing. For a study of Greek theory and observation, see Lloyd (1979), ch. 3.

[6] Most notably in Huffman (1993), ch. 4. In his reconstruction, he has been meticulous in attention to historical appropriateness.

[7] Maniatis (2009) calls it "pyrocentric," which is apt in one way, but fire is not confined to the center of Philolaus' cosmos, whereas the hearth has a unique location.

[8] Burch (1954) among others puts the counter-earth on the same orbit as the earth, positioned opposite it, so as to counter-balance its mass. Aristotle, however, makes it clear that the orbit of the counter-earth is *inside* that of the earth: Alexander of Aphrodisias *in Metaph.* 39.1-3 = Aristotle fr. 203; Simplicius *in Cael.* 511.19-22 = Aristotle fr. 204; cf. Aetius 2.7.7 = DK 44A16; Aet. 3.11.3 = A17.

[9] 254-7. For a history of views about the motion of the stars, and the problems the question causes, see Heath 1913:101–105.

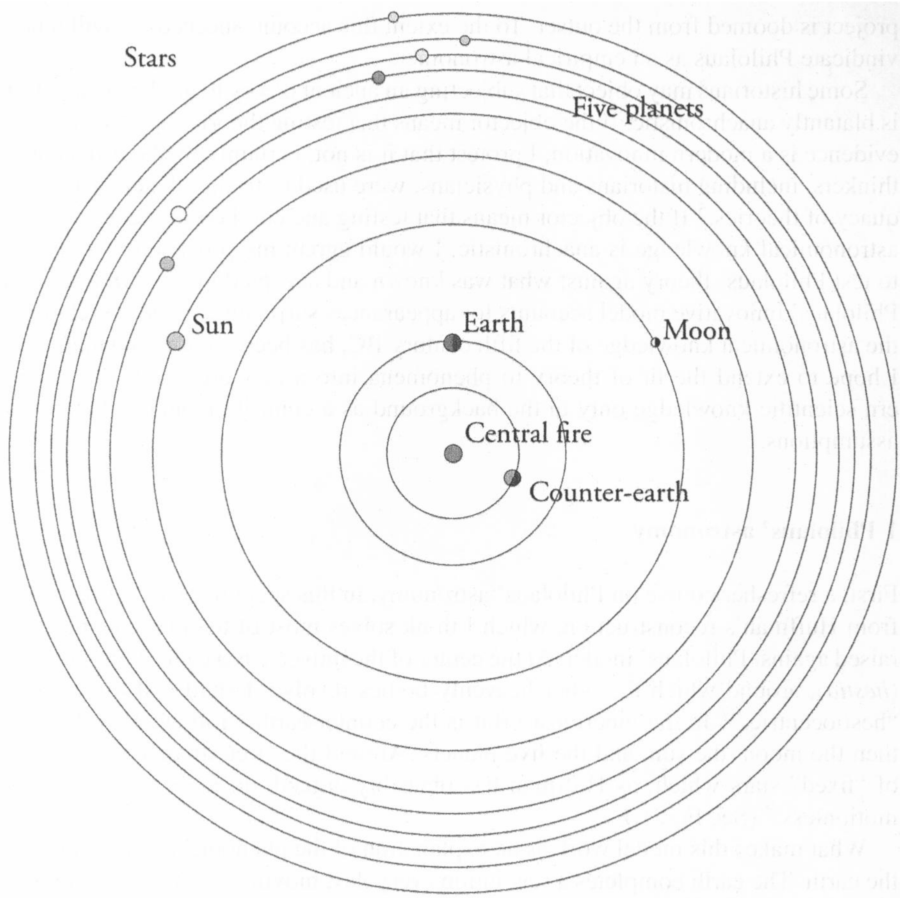

Fig. 1 Philolaus's system

are always facing outward; we can never see inside our planet's orbit to the counter-earth or central fire. Incidentally, I will assume that we observers are located at a position approximately in opposition to the central fire, which we must be in order to see the sun as sometimes (in summer at midday) almost overhead. Meanwhile, the moon completes an orbit once per month, or more precisely, completes its longitudinal period, which means that it travels eastward about 12° per day.[10] The five planets for their part move slowly at different rates of speed around the central fire. The sun moves slowly around the central fire, completing an orbit in a year, or about 1° per day. On these assumptions, the earth overtakes the sun, the moon (also the planets, and of

[10] To use Babylonian units, which were not introduced into Greece until the time of Hipparchus. But of course Greek geometry could represent the angular distance as 1/30th of a circle. In fact, Philolaus had a (mean synodic) month of 29 1/2 days (see Censorinus 18.8, 19.2 = A22 with Huffman 1993:276–279); the modern figure is 29.53059; he had a solar year of 364 1/2 days. But for purposes of the present exercise, it is enough to approximate the periods in question.

course the stationary stars) once a day. What appears to us, then, as the rising of the sun and moon (and planets and stars at night) in the east and their setting in the west is in fact the result of the earth's overtaking them in its rapid progression toward the east.[11]

Philolaus is the first Greek source in our records to recognize the five visible planets. They had been identified by Babylonian observers over a thousand years earlier, but the Greeks had not, so far as we know, identified them before Philolaus. To that extent, he made a major contribution to empirical astronomy in the Greek world.[12]

Inside the orbit of the earth, as already noted, is the counter-earth (*antichthōn*), which is variously reported to be placed opposite to or move opposite to the earth. What exactly its position and motion is relative to the earth I leave an open question. The present study will have some implications for that question. For now, it suffices to recognize it as moving on an orbit inside the earth's orbit. Whether the central fire illuminates any portion of the cosmos remains unclear; I shall leave its power of illumination an open question and consider it only as the focal point of the cosmos. Philolaus' model presents attractive features for most of the heavenly bodies: The stars, being motionless, do not need to travel at breathtaking speed around the circumference of the cosmos. The other heavenly bodies perform a slow and stately "dance" about the hearth.[13] Only the earth travels rapidly. The heavenly bodies seem to be spherical (though we do not get an explicit statement of this shape); I shall assume that they are. Only the counter-earth and the hearth remain problematic constructs: They seem to perform no explanatory function and seem capable of no empirical verification, either direct or indirect.[14]

2 Eclipse theory

Although Anaxagoras assumed a geocentric cosmology and a flat earth, he seems to be the first theorist to account correctly for eclipses, both solar and lunar, probably between 478 and 466 BC.[15] Solar eclipses are caused by the moon's interposition between the earth and the sun, producing an occultation of the sun. Solar eclipses can happen only at the time of the new moon, as Anaxagoras recognized. Lunar eclipses are caused by the interposition of the earth between the sun and the moon, whereby the moon passes into the shadow of the earth. Lunar eclipses can happen only at the time of the full moon, as Anaxagoras also recognized. I shall call this explanation the "antiphraxis theory," using Aristotle's word for interposition or blocking.

[11] For the reconstruction, see Huffman 1993, ch. 4, and Heath 1913:98–101.

[12] Eudemus attributes recognition of the five planets to the Pythagoreans. Philolaus provides the ultimate source; Simplicius *in Cael.* 471.2-6 = Eudemus fr. 146 Wehrli. See Dicks 1970:66; Vlastos 1975:46 and n. 65, 103. Zhmud 2003:258 attributes the recognition to some Pythagorean before Philolaus.

[13] *choreuein* Aetius 2.7.7 = 44A16.

[14] Huffman 2007 provides a strong cosmological and cosmogonical motivation for the hearth and even a biological analogy, in rejecting the interpretation of Kingsley 1995, chs. 13–14, who identifies the central fire with the mythological Tartarus in a religious context. But Huffman's account does not entail any astronomical advantages.

[15] Hippolytus *Haer.* 1.8.9-10 = 59A42; Graham and Hintz (2007) and Graham and Hintz (2010), Graham (2013a).

Anaxagoras' explanation seems to have resulted from his application to the problem of eclipses of Parmenides' insight that the moon gets its light from the sun (B14, B15), a thesis I shall call "heliophotism," following Alexander Mourelatos' terminology.[16] If the moon gets its light by reflecting sunlight, an obstruction of that light would cause the moon to go dark, and since the earth is relatively large and lies between the sun and moon precisely when the moon is full—for the moon appears full precisely when the sun is 180° away from it—the earth could be in a position to cause a lunar eclipse at the time of the full moon. Since the moon is new, or dark, precisely when it is approximately 0° from the sun, it is always in principle able to block the sun's light to earth at the time of the new moon. Anaxagoras' theory seems to have caught on quickly, first with Empedocles and then with other philosophers of the fifth century, including Philolaus.[17] In the fourth century, the antiphraxis theory is cited by Aristotle as a paradigm of scientific explanation.[18]

For Philolaus, however, the theory is more complicated because not only are the sun and the moon in motion, but the earth as well. I shall focus on lunar eclipses, which raise special problems for Philolaus. Several scholars have in fact claimed that lunar eclipses motivate Philolaus' introduction of the counter-earth. None, however, has taken a detailed look at how the counter-earth might be necessary for these eclipses.[19] In one kind of lunar eclipse, the theory works unproblematically. If the moon is eclipsed late at night, the sun, the earth, and the moon are in alignment or syzygy, and the earth's interposition clearly causes the eclipse (See Fig. 2).

But now suppose that the eclipse happens around dawn or dusk. In this case, the sun and moon must each be at about right angles to the earth, while the earth itself is traveling around the center of the cosmos. How do we explain this situation?

3 Crepuscular eclipses

Call a lunar eclipse at around dawn or sunset a "crepuscular eclipse." I want to show that the geometry of eclipses causes problems for Philolaus' hestiocentric cosmos. Suppose that the sun, the earth, and the moon are located on a line tangent to the earth's orbit. The line forms a chord of the cosmos, that is, it joins points on the circumference of the orbits of (e.g.,) the sun which are not a diameter (since the line is by hypothesis tangent to the earth's orbit). Suppose the eclipse occurs at dawn (See Fig. 3).

The sun is at S, the earth at E_1, and the moon at M_1. Now let the earth travel on its daily path counter-clockwise past the sun until another tangent can be drawn from the sun to the earth's new position at E_2, which occurs at sunset. Continue that tangent until it intersects the moon's orbit at M_2. The moon is not here, but has moved a

[16] See Wöhrle (1995), Graham (2002) and Mourelatos (2012).

[17] See Graham and Hintz 2007, Graham 2013b:177 ff. On Philolaus' astronomy as *au courant* of the latest theoretical developments, see Guthrie 1962:286–287; Huffman 1993:241, 250.

[18] *APo.* 90a15-18; 93a30-b7; 98b16-24; 87b39-88a2; *Metaph.* 1044b9-15.

[19] Heath 1913:99–100, 119; Burnet 1930 [1892]:305–306; Cherniss 1935:198–199. For contrary views, see n. 25 below.

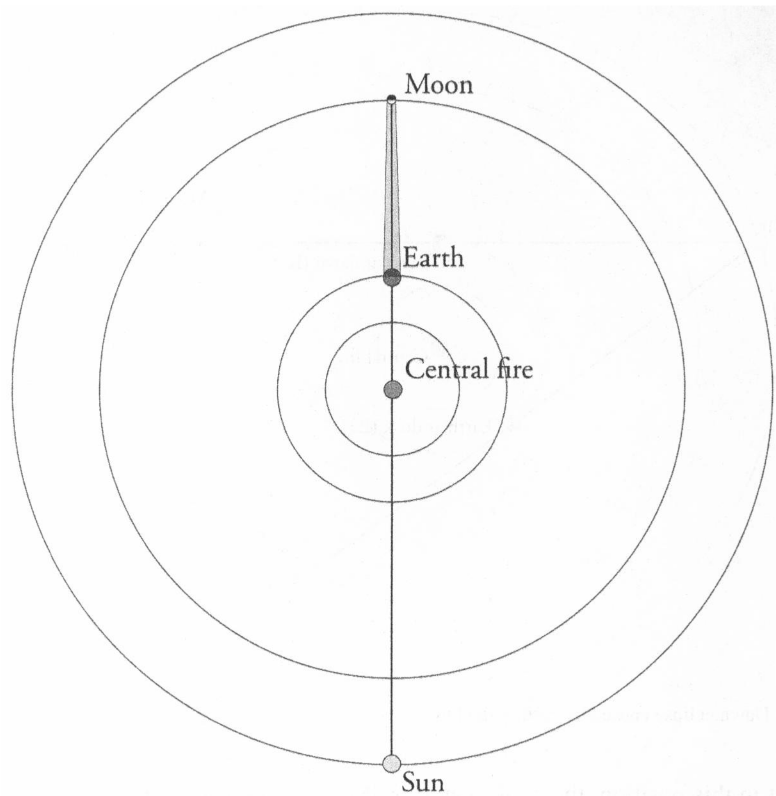

Fig. 2 Midnight eclipse

few degrees east (counter-clockwise) from M_1 to M_3, according to the model. The problem at this point is one of prediction. At sunset, the model predicts that the moon will not be visible. But experience tells us that the moon will rise just a few minutes after sunset. It remains almost 180° from the sun; to be precise, twelve hours after the full moon, it will appear to be about 6° retarded, or about 186° from the sun. But our model predicts a distance of much more than that, namely $\angle SE_2M_3$ (whose measure will be dependent on the radii of the orbits).

There is only one way to save the appearances using the hestiocentric model. We must stipulate that the moon is full when the sun and moon lie on the same *diameter* rather than on a chord of the cosmos (or of the sun's orbit), that is, the line joining sun and moon must run through the center of the cosmos, which is occupied by the central fire. Thus, they will always be 180° apart at the precise time of the full moon, and an observer on earth will always see the sun and moon at about the correct angle. But now look what happens to the earth on this model. For a crepuscular eclipse, the earth must be at about a right angle to both the sun and the moon. Accordingly, it will be either at the top or the bottom of its orbit when the sun is on the left and the moon on the right (See Fig. 4).

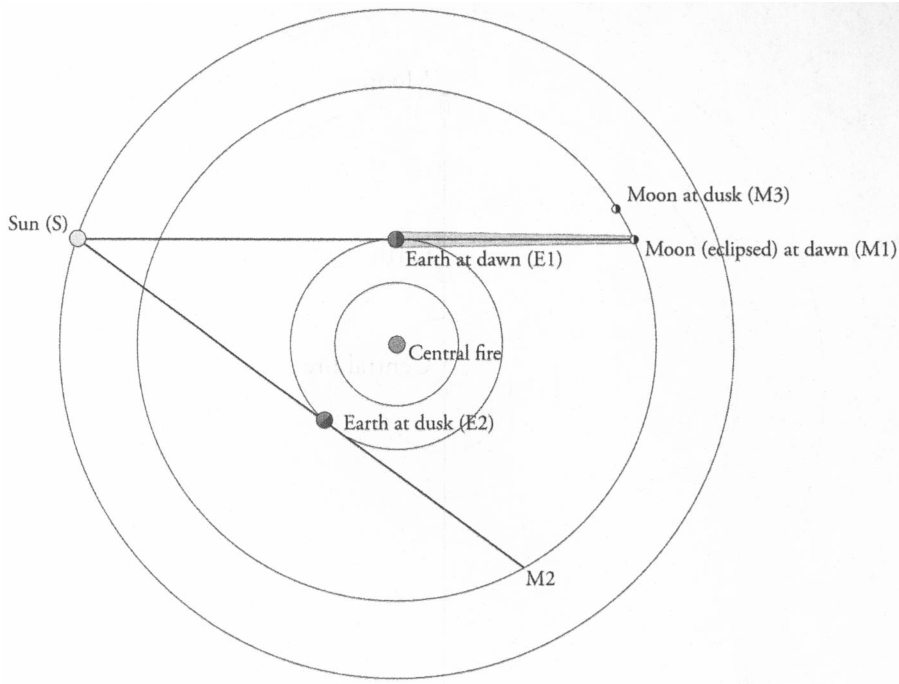

Fig. 3 Dawn eclipse caused by earth's shadow

But in this position, the earth is not itself on the diameter joining the sun and the moon. Accordingly, it is not in a position to block the sun's light to the moon, and hence to cause an eclipse according to the antiphraxis theory. The geometry of Philolaus' model precludes a crepuscular eclipse caused by the earth's interposition.

If we accept the antiphraxis theory, we need some other opaque body to perform the interposition between the sun and the moon. Let us posit another earth-like body to perform the task. Call it the "counter-earth." Suppose further that all bodies in the cosmos must travel in a circle with the central fire as its center. This requirement, I take it, follows the logic of the model. Now the counter-earth cannot travel in an orbit above the earth, for then we would be able to observe it, which we cannot. It could conceivably travel on the earth's own orbit 180° from the earth—in that case we should be unable to observe it—but then it would be useless to account for crepuscular eclipses. For it would still be out of position to block the sun's light. Finally, it could travel in an orbit that falls inside the earth's orbit so that it could at times block the sun's light to the moon. Then, it could in principle explain crepuscular eclipses (See Fig. 5).[20]

If there are in fact crepuscular eclipses, then only a model like Philolaus' that posited a counter-earth would be adequate to account for them. And in fact there are

[20] One question that arises is what role the central fire might play in the illumination of the moon. We get no information about whether it might by itself light up the moon. But as long as the counter-earth lies between the central fire and the moon it could block the light from both the central fire and the sun.

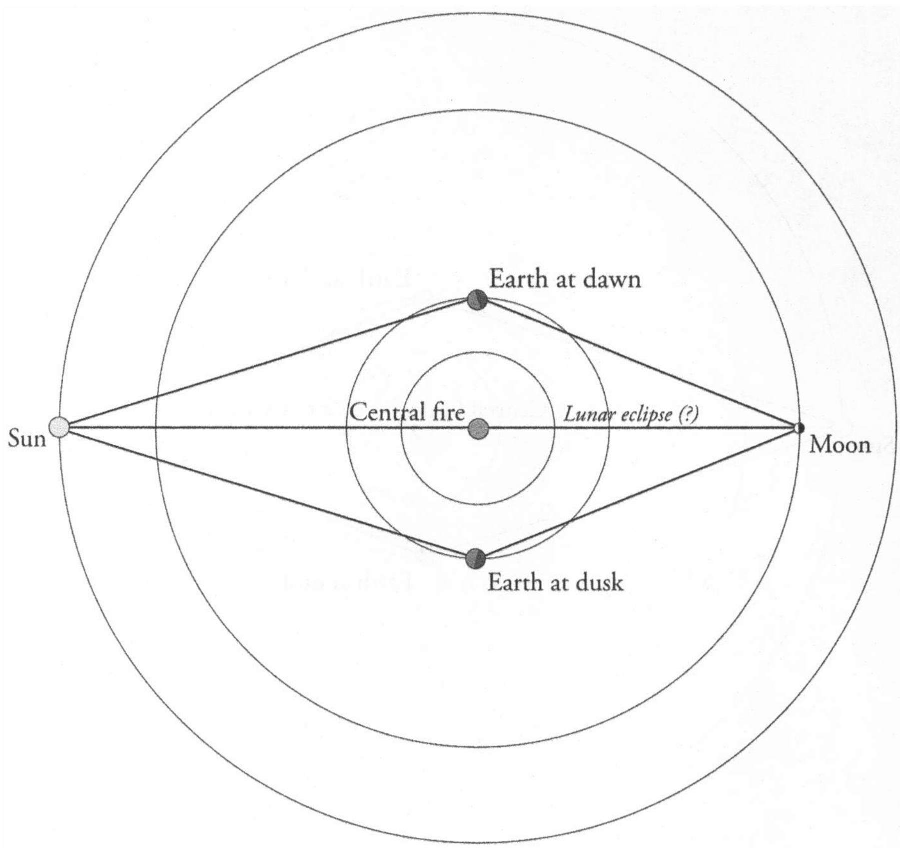

Fig. 4 Dawn eclipse?

crepuscular eclipses.[21] Of course, lunar eclipses can happen at any time of day or night; they are visible only from dusk to night to dawn, but they are visible to anyone on the hemisphere facing away from the sun (weather conditions permitting). So Philolaus' model needs a counter-earth to allow for the full range of phenomena possible with lunar eclipses.

Now in fact, we are told on the authority of early sources that the counter-earth causes lunar eclipses:

> Some of the Pythagoreans, according to the reports of Aristotle and Philip of Opus, maintain that [the moon is eclipsed] by reflection and interposition (*antiphraxis*),[22] sometimes of the earth, sometimes of the counter-earth. (Aetius 2.29.4, Stobaeus 1.26.3 = 58B36)

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[21] I observed such an eclipse on Dec. 10, 2011 in Utah, commencing at about 6 a.m. local time.

[22] *epiphraxis* Eusebius.

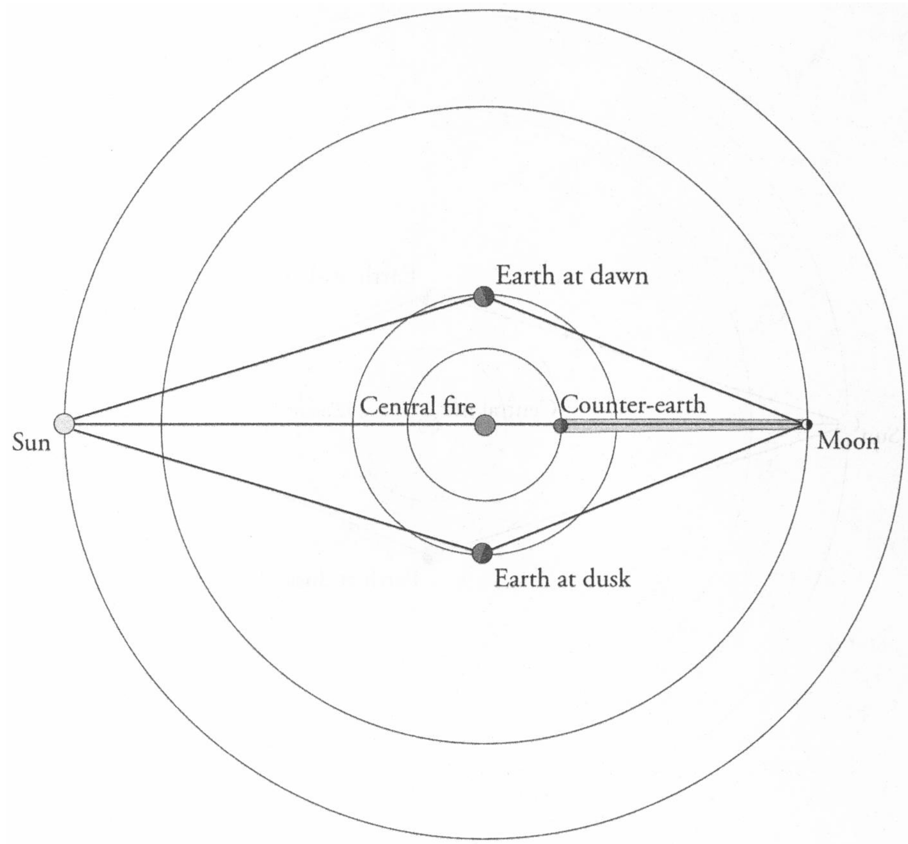

Fig. 5 Dawn eclipse

Since the counter-earth is attested only in Philolaus, it appears that Philolaus assigned to the counter-earth just the role that it would need to play in order to account for some eclipses (which ones are not specified here). We can read at least one of Aristotle's own expositions of Pythagorean theory:

> Those who say the earth is not located at the center say it moves around this in a circle, and not only the earth but the counter-earth as well, as we pointed out earlier. Some think that several such bodies may travel about the center but they are invisible to us because the earth blocks our vision of them. That is supposedly why eclipses of the moon occur more frequently than eclipses of the sun. For each of these moving bodies blocks [the sun's light to] the moon, and not just the earth. (*Cael.* 293b18-25)

Aristotle knows perfectly well that the counter-earth is used to account for lunar eclipses. He mentions in addition some thinkers who posited a plurality of such bodies. Who these thinkers are we do not know—unless he has in mind Anaxagoras with his geocentric cosmos (on which see below). In any case, these invisible bodies, presumably including Philolaus' single counter-earth, are claimed to be responsible for the relatively high frequency of lunar as contrasted with solar eclipses. Yet when it comes to his assessment of Philolaus' theory, as we have seen, Aristotle dismisses the counter-earth as a purely theoretical construct. But we have now seen that Aristotle's dismissal is hasty.

Let us turn for a minute to Anaxagoras' theory of eclipses. As mentioned, Anaxagoras seems to have discovered the correct explanation of eclipses, both solar and lunar. But because of peculiarities in his own cosmology, his account of lunar eclipses has complications. According to him

> The moon is eclipsed when the earth blocks it, or sometimes one of the bodies below the moon. (Hippolytus *Haer.* 1.8.9 = 59A42)

Not only does the earth block the sun's light to the moon, but also other bodies below it can block the sun's light: "there are below the stars certain bodies invisible to us which are carried around with the sun and moon" (ibid. 6). These dark bodies are stony, and when a meteor fell near Aegospotami around 467 BC, the event was taken to be a confirmation of Anaxagoras' cosmology. These unnamed bodies I shall call by their modern name, asteroids, with the caveat that for Anaxagoras they are found below the moon rather than predominantly between the planets Mars and Jupiter.

Why does Anaxagoras need asteroids? Because his earth is flat, relatively large, and at the center of the cosmos, he can explain eclipses that happen at night as the result of the moon's moving into the shadow of the earth. At night, the moon is above the earth (from the viewer's perspective), while the sun is below; the moon presents itself as a circle to both the sun and moon, so that the sun must project a circular shape onto the surface of the moon, as is observed. But for a crepuscular eclipse, Anaxagoras is at a loss: The earth presents only its elevation to the sun and moon, so the sun could only cast a straight line upon the moon. Hence, some other body or bodies are needed to account for crepuscular eclipses. Asteroids provide a plausible expedient, and one that seems to work with his general account of the generation and destruction of heavenly bodies.

Here, what I want to point out is that when Anaxagoras posits asteroids to account for crepuscular eclipses, no one accuses him of a priori speculations. If anything, he is guilty of ad hoc hypotheses to save the phenomena—of being too empirically oriented. Yet when Philolaus does much the same thing—at least on the present interpretation—he is accused of letting numerology run away with his theory. In one respect, Philolaus' cosmology is more respectable than Anaxagoras': He posits the minimum number of entities necessary to do the job: one, not an indeterminately large number. If *entia praeter necessitatem non multiplicanda sunt*, Philolaus' theory is better. Of course, Anaxagoras had the meteorite of Aegospotami on his side, as evidence of asteroids. But on the other hand, at least Philolaus can tell us why the counter-earth is invisible to us, whereas Anaxagoras' theory has trouble with invisibility. For Anaxagoras' theory seems to entail that we should sometimes see dark bodies, for instance silhouetted against the moon—which we do not.[23]

[23] Bicknell (1968) speculated that Anaxagoras interpreted a sunspot as a fragment broken off from the sun, but this seems far-fetched.

The critical point to recognize is that if Anaxagoras has empirical reasons for positing asteroids, Philolaus has empirical reasons for positing a counter-earth. If Anaxagoras' asteroids fit in with his general cosmology, by which boulders can be ripped away from the earth by the vortex acting on the circumference of the earth, the counter-earth fits with Philolaus' cosmology, which envisages a series of planets circling a central fire. In each case, the theorist draws on the resources of his model to provide an explanation for an otherwise unexplained phenomenon.

As Aristotle reports, there is one important corollary of positing the counter-earth: Philolaus can also explain why lunar eclipses are more frequent than solar eclipses. There are two bodies that can block the sun's light to the moon, and both of them are relatively near the center of the cosmos where they are often in a position to interrupt light from the sun to the moon. This brings us to a point at which the phenomena can perhaps put additional constraints on the model.

According to the model, at the time of a crepuscular eclipse, the sun and moon are 180° apart, as seen from outside the solar system (see Fig. 5). Yet the heavenly bodies *appear* to be more than 180° apart from the position of the earth. This provides a potential criticism of the theory, and an opportunity. The criticism is that on this model the sun and moon should not appear as they do at sunset or sunrise at the time of a full moon, where we see the moon rising as the sun sets or vice versa. The opportunity is that to make the model a plausible approximation of the phenomena, we need to shrink the orbit of the earth and expand the orbits of moon and sun so that the angle between the sun, earth, and moon approaches a straight angle.[24] Thus, the phenomena dictate parameters for the model. In fact, the early Greeks had no sophisticated instruments to observe the heavens and were little interested in measurement for the sake of measurement—indeed Greek astronomers did not import the Babylonian scheme of 360° in a circle for several centuries. So a predicted variation from a straight angle might not provoke an immediate objection. In any case, the notion of a moving earth probably drew the most fire from critics, who presumably did not attend to the fine points of the model. But note that, as we contract the orbits of the earth and counter-earth toward the center of the cosmos, we increase the likelihood of (crepuscular) lunar eclipses. For as the radius of the counter-earth's orbit gets smaller, it stays closer to the diameter that connects sun and moon at the time of the full moon.

The major objection against the counter-earth's causing eclipses has been that, since it moves inside the earth's orbit, it could not cause lunar eclipses.[25] But if lunar eclipses happen when the sun and moon are on opposite sides of a cosmic diameter,

[24] Heath 1913:100–101 notes that the lack of observed parallax of the planets would suggest the same result.

[25] "It has been suggested that the counter-earth might have performed the same function [of causing lunar eclipses] in the Philolaic scheme. This, however, is impossible, since the orbit of the moon is outside the earth's, while that of the counter-earth is inside it ..." (Dicks 1970:66–67). "[S]ince the counter-earth is inside the orbit of the earth and the moon is outside the orbit of the earth, there is no way that it could serve such a function [of causing a lunar eclipse]" (Huffman 1993:247). "[O]n any account of the relative orbits of the sun, moon, and earth, it is hard to see how the counter-earth could interpose itself between sun and moon ..." (Hankinson 1998:41). "[I]t is hard to see how the counter-earth that is supposed to orbit between the earth and the central fire could ever cause an eclipse of the moon, as Dicks rightly remarks" (Couprie 2011:171).

then the counter-earth is precisely where it should be to have the highest probability of causing a lunar eclipse. The alleged problem has become an advantage.

We find, then, that what Aristotle mentions by the way as a motivation for the counter-earth provides an empirical justification for hypothesizing it. Without the counter-earth, Philolaus' theory would be defective—unable to account for crepuscular eclipses. Given that the earth can account for some lunar eclipses, and that, on the model, all heavenly bodies are like planets orbiting the central fire, the most consistent hypothesis is another planet. And since the planet is invisible to us, it must orbit inside earth's orbit and closer to the center of the cosmos, where in fact it can do its job best. I might also note that, while I have focused on crepuscular eclipses as the extreme cases, we might find that other eclipses that happen in the evening but not late at night that are better explained by the counter-earth than the earth, on Philolaus' model.

A number of questions remain unanswered, notably the position and motion of the counter-earth relative to the earth: Is it located opposite the earth?[26] Does it move opposite the earth in direction?[27] If this study provides some empirical justification for the counter-earth, it suggests that this body will function best if it moves independently of the earth so that it can be wherever it needs to be to block the sun's light just when a crepuscular eclipse occurs. In a philosopher accused of excessive speculation, and in a tradition where speculations about his theory are often excessive, I offer a conjecture of my own. In the *antichthōn*, the prefix is almost universally taken to denote some sort of opposition or contrariety to the earth in position or direction. But what if, as often in compounds, *anti-* signifies 'taking the place of'? Or perhaps it signifies what is equal to or like, as in *antitheos*.[28] The *antichthōn* is an alter-earth that does the work of the earth.[29] What Philolaus gives us is not a counter- or anti-earth, but a quasi-earth, an earth-like planet that can do what the earth does in blocking sunlight to the moon. Indeed, Aristotle himself calls it "another earth" (*allēn … gēn*, *Cael.* 293a23-24). There is evidence that Philolaus may have posited his quasi-earth in an effort to save the phenomena by explaining crepuscular eclipses. If so, he may be faulted for advancing an ad hoc hypothesis driven by empirical considerations, but not for airy speculations driven by numerology. He may, then, be more of an astronomer and less of a metaphysician than has so far been recognized.

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[26] Aristotle *Cael.* 293a23-24, which Guthrie translates, "they invent another earth, *lying* opposite our own" (my italics). The Greek, however, is not clear as to what sense of opposition is meant and has no verb or participle corresponding to 'lying.'

[27] Alexander Aphr. *in Metaph.* 40.32 = Aristotle fr. 203. "The counter-earth always remains and moves opposite to the earth, as denoted by its name …" (Maniatis 2009:404).

[28] In fact, the meaning 'taking the place of' appears only in relatively late nominal compounds, but the meaning 'like' is suitably early; *antitheos* is found in Homer *Il.* 5.663 et passim.

[29] Thus the Pythagoreans called the moon *antichthōn* as being a heavenly earth and blocking (*antiphrattousa*) sunlight (Simplicius *in Cael.* 512.17-20).

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