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PRESOCRATICS ON THE LIGHT AND PHASES OF THE MOON

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Abstract

In this paper, I outline the background to the struggle of Presocratic cosmologists in explaining the light and phases of the moon. I summarize how, according to Aëtius, the Presocratics thought that the light of the celestial bodies and more specifically that of the moon was considered to be somehow fiery. I focus in particular on two problems that have been ignored by modern scholars, but which undoubtedly confronted the ancient cosmologists: the color of the unlit part of the moon and the moon tilt illusion. I also argue that the idea of a flat earth prevented the Presocratics to find the true cause of the moon's phases. I critically discuss Parmenides, Anaxagoras, and Empedocles, who are considered in recent literature to be proponents of the correct explanation of the moon's light and phases. Finally, I argue that the discovery of the true cause of the lunar light and phases was only possible once the earth and the celestial bodies, including the moon, were conceived as spherical, while the two problems mentioned above were ignored.

Keywords: Moon, Unlit Part of the Moon, Moon Tilt Illusion, Presocratics, Parmenides, Anaxagoras, Empedocles.

PRESOCRATICS ON THE LIGHT AND PHASES OF THE MOON

1. *Aëtius on the light of the celestial bodies*

Most information on the substance of the heavenly bodies (ἡ οὐσία τῶν ἄστρων) according to the Presocratics can be found in Aëtius, *Placita* 2.13, which deals with the planets and the fixed stars (πλανητῶν καὶ ἀπλανῶν).[1] Thales says that the heavenly bodies are earthy but inflamed (γεώδη μὲν, ἔμπυρα δὲ).[2] Anaximander says that they are cloudy wheels filled with fire (πυρὸς ἔμπλεα), whose flames are blown out of openings (ἀπὸ στομίων ἐκπνέοντα φλόγας).[3] Parmenides and Heraclitus say that they are condensations of fire (πιλήματα πυρός).[4] According to Anaximenes their nature is fiery (πυρίνην).[5] Xenophanes says that they originate from ignited clouds like coals (ἐκ νεφῶν πεπυρωμένων (… καθάπερ τοὺς ἄνθρακας).[6] Empedocles says that the heavenly bodies are fiery, made from fiery material (πύρινα ἐκ τοῦ πυρῶδους).[7] Anaxagoras states that they are rocks torn from the earth and ignited by the power of the cosmic whirl of the fiery aether (πύρινος αἰθήρ; τῇ δ᾽ εὐτονίᾳ τῆς περιδινήσεως ἀναρπάσαντα πέτρους ἀπὸ τῆς γῆς).[8] According to Diogenes they are like pumice, but fiery (κισηρώδη, εἶναι δὲ διάπυρα).[9] Democritus says that they are stones (πέτρους), but Aëtius also reports that he says that the sun is a fiery stone (πέτρον διάπυρον) and the moon a fiery solid body (στερέωμα διάπυρον).[10] Archelaus says that the heavenly bodies are red-hot fiery stones (μύδρους διάπυρους).[11]

2. *Aëtius on the light of the moon*

When we focus on the light of the moon, we find in Aëtius, *Placita* 2.25 that the Presocratics consider the moon to be fiery as well. Anaximander says that the moon resembles a chariot

[1] This article is the extended version of a paper read at the 19th London Ancient Science Conference 2026, April 22–24. I thank especially Andrew Gregory, who read the paper for me, since I was not able to join the conference because of illness.
[2] Thales: Aët. 2.13.1 in MR 5.2 = DK 11A17a = TP1 Th 157.
[3] Anaximander: Aët. 2.13.7 in MR 5.2 = DK 12A18 = TP2 Ar 148.
[4] Parmenides: Aët. 2.13.8 in MR 5.2 = DK 28A39. Heraclitus: Aët. 2.13.8 in MR 5.2 = DK 22A11.
[5] Anaximenes: Aët. 2.13.9 in MR 5.2 = DK 13A14.= TP2 As 124.
[6] Xenophanes: Aët. 2.13.14 in MR 5.2 = DK 21A38 = TP3 Xen 69. Gr Xns 60 abusively refers to this *doxa* as DK 21A8. Cf. also Mourelatos 2008, who translates πεπυρομένος as "incandescent".
[7] Empedocles: Aët. 2.13.2 in MR 5.2 = DK 31A53.
[8] Anaxagoras: Aët. 2.13.3 in MR 5.2 = DK 59A71.
[9] Diogenes: Aët. 2.13.4 in MR 5.2 = DK 64 A12.
[10] Democritus: Aët. 2.13.5 in MR 5.2 = DK 68A85. For the sun, see Aët. 2.20.8 in MR 5.2 = DK 68A87. For the moon, see section 2.
[11] Archelaus: Aët. 2.13.6 in MR 5.2 = DK 60A15.

wheel with a hollow rim and full of fire (πυρὸς πλήρη), while we see that fire through a blowhole in the rim, like a beam of lightning.[12] Anaximenes, Parmenides, and Heraclitus say that the moon is fiery (πυρίνην).[13] More specifically, Parmenides says that the moon is a composite of both air and fire (συμμιγῆ δ' ἐξ ἀμφοῖν τοῦ τ' ἀέρος καὶ τοῦ πυρός).[14] Xenophanes says that it is or originates from an incandescent compressed cloud (νέφος πεπυρωμένον πεπιλημένον).[15] Empedocles says that it is cloud-like, fixed by fire (νεφοειδῆ, πεπηγότα ὑπὸ πυρός).[16] Anaxagoras and Democritus say that it is an inflamed solid mass (στερέωμα διάπυρον).[17] Diogenes says that it is an ignited mass of pumice (κισηροειδὲς ἄναμμα).[18] A curious exception seems to be Thales, according to whom the moon is earthy (γεώδη).[19] However, as we have seen above, elsewhere Aëtius reports that Thales says that the heavenly bodies, i.e. planets and fixed stars are earthy but also fiery (γεώδη μὲν, ἔμπυρα δὲ). Since the ancient Greeks regarded the moon and the sun as planets, we may conclude that according to Thales they are fiery as well.

The only one of whom is said something that perhaps comes close to our understanding of the moon's light is Pythagoras, who in Stobaeus' version of Aëtius says that it is a mirror-like body (κατοπτροειδὲς σῶμα).[20] But the reading of this text is uncertain. It can also be read κατὰ τὸ πυροειδὲς σῶμα σελήνης (the body of the moon is like that which is fiery), which is Ps-Plutarch's version of Aëtius. Huffman comments on the text about Pythagoras: "it is tempting to see the reference to reflection in Aetius' account as a misunderstanding". Laks and Most omit it because it would contain a later exegesis in terms reminiscent of Empedocles' theory of the two suns, which can be found in the immediately following *doxa*.[21] However, Mansfeld and Runia follow Diels and prefer Stobaeus' version. One of their arguments is that it would fit in with the Pythagorean *doxai* on reflection.[22] They refer to a very difficult-to-understand text

[12] Anaximander: Aët. 2.25.1 in MR 5.2 = DK 12A22 = TP2 Ar 151. For the translation "beam of lightning", see Graham 2013, 59 and 68. I defended this translation in Couprie 2001 and in Couprie 2011, 145–152. I can add a confirmation from Plato's etymology of the word ἄστρα ("stars", or "celestial bodies"), which he derives from ἄστραπη, lightning (*Cra.* 409 C). Plato's etymology was, after all, not so strange as it is usually thought to be.
[13] Anaximenes: Aët. 2.25.2 in MR 5.2 = DK 13A16 = TP2 As 126. Parmenides: Aët. 2.25.2 in MR 5.2 = DK 28A42. Heraclitus: Aët. 2.25.2 in MR 5.2, not in DK.
[14] Aët. 2.7.1 in MR 5.2 = DK 28A37.
[15] Xenophanes: Aët. 2.25.3 in MR 5.2 = DK 21A43 = TP3 Xen 101 (the latter two leaving out πεπυρωμένον).
[16] Empedocles: Aët. 2.25.6 in MR 5.2 = DK 31A60.
[17] Anaxagoras: Aët. 2.25.10 in MR 5.2 = DK 59A77. Democritus: Aët. 2. 25.10 in MR 5.2 = DK 68A90.
[18] Diogenes: Aët. 2.25.11 in MR 5.2 = DK 64A14.
[19] Thales: Aët. 2.25.9 in MR 5.2 = TP1 Th 356.
[20] Pythagoras: Aët. 2.25.15 in MR 5.2, not in DK. The confusing idea of the moon as a mirror returns in Plut. *De fac.*, see the discussion below in section 8.
[21] See Huffman 1993, 269 and LM note at PHILOL. D22. For the *doxa* on Empedocles' theory of the two suns, see Aët. 2.20.13 in MR 5.2 = DK 31A56.
[22] See MR 5.2, 1044.

about the light of the sun as a reflection of the cosmic fire according to Philolaus, which implies that there are "in a way two suns".[23] The other reference in Mansfeld and Runia is to a strange text on anonymi, who hold that the appearance on the moon is a reflection (ἀνάκλασις) of the sea beyond the Torrid Zone of our inhabited earth.[24] It is not sure that by the unnamed "others" Pythagoreans are meant.[25] Rather, it seems to refer to the Peripatetic Clearchus of Soli (4th to 3rd century B.C.), to which Plutarch attributes exactly the same theory.[26] Moreover, Mansfeld and Runia themselves comment on the texts that attribute theories of mirrors to Pythagoras or the Pythagoreans: "Pythagoras and his followers are mentioned honoris causa".[27] For these reasons, I assume that Ps-Plutarch's version, κατὰ τὸ πυροειδὲς σῶμα σελήνης (the body of the moon is like that which is fiery), is the correct one.

The conclusion of this section is that all of the Presocratics mentioned thought that the moon was somehow fiery in nature, even those (such as Parmenides and Anaxagoras), who are claimed to have discovered the true cause of lunar phases. We should take seriously that the fiery nature of the moon, at least at first glance, contradicts that claim.

3. *The disappearance of the unlit part of the moon*

This section deals with the phenomenon that during the moon's phases the unlit part of the moon seems to disappear.[28] Or rather, it takes on the color of the surrounding air, blue by day and black at night. During most of the month, the moon is seen as a regularly increasing and decreasing object. Until the present day, we speak of a waxing and waning moon, as if the moon is growing and shrinking during the lunar month. This phenomenon has been neglected by modern authors. Graham, for example, uses expressions such as "*The fact* that the moon is *partially dark* during some phases", "the *dark portion* of the moon", and even "*a shadow passing over the face of the moon*".[29] Graham completely neglects that what we *see* is not a

[23] The reference in MR 5.2, 1044 §15, to Philolaus is abusively 2.20.13; this should be Aët. 2.20.12 in MR 5.2 = DK 44A19 = LM PHILOL. D22 (only partly, see their note at this lemma) = Gr Phs 30 = KRS 448 = Huffman 1993, 269, Testimonium A19.
[24] The reference is to Aët. 2.30.2 in MR 5.2, not in DK. See also DG 361 and Bottler 2014, 475–476. The translation "the sea inhabited by us (which is located) beyond the circle of the Torrid zone" in MR 5.4, 2106 makes this text nonsensical. In MR 2.2, 632, they still had "the sea beyond the Torrid zone of our inhabited world". See also Bottler 2014, 476: "[das Meer] jenseits der verbrannten Zone der von uns bewohnten Welt".
[25] See MR 2.2, 627: "a second group of Pythagoreans (…) or an independent group". In MR 5.2,1096, however, we read with a reference to Aët. 2.25.15 in MR 5.2: "it might be concluded that these 'others' are also Pythagoreans", which is not very convincing.
[26] Plut. *De fac.* 920F–921A, see also MR 5.2, 1099–1100, ad §2.
[27] MR 5.3, 1658 note at §3.
[28] See also Couprie 2018, 65–68 and Figs. 5.1a, 5.1b, and 5.2 on p. 66.
[29] Graham 2013, 111 and 112 (my italics).

dark part of the moon or a shadow passing over its face, but that the unlit part of the moon has *disappeared*, taking on the color of the surrounding air: blue by day and black at night.

It can be argued that the phenomenon whereby the unlit part of the moon takes on the color of the surrounding air was one of the reasons that Anaximander put forward his seemingly strange theory about the moon's phases as the closing and opening of the aperture in the moon wheel.[30] In my opinion, Parmenides was aware of the phenomenon, for he seems to refer to it, as attested by Aëtius' account:

> Παρμενίδης (…) συμμιγῆ δ' ἐξ ἀμφοῖν εἶναι τὴν σελήνην, τοῦ τ' ἀέρος καὶ τοῦ πυρός.[31]
> Parmenides says that the moon is a composite of both air and fire.

The quoted text is usually interpreted as referring to the bright and less bright areas on the surface of the visible part of the moon ("the face on the moon"). But it is somewhat strange to call the less bright areas of the moon "air".[32] I would like to suggest a more natural interpretation, namely that the moon is a combination of air and fire side by side, as can be seen during the lunar phases, when the unlit part of the moon has the same color as the surrounding *air*, while the illuminated part retains its *fiery* appearance. The words ἐξ ἀμφοῖν seem to indicate; that there are two combined parts of the moon, one consisting of air, the other of fire. Ἀμφοῖν is the genitivus of ἄμφω, meaning "both"; the preposition ἀμφί originally means "on both sides of". The translation "mixture" for συμμιγῆ is less appropriate, so I opt for the word "composite". How and for what reason the sizes of these two parts wane and wax during the lunar month Parmenides does not further indicate.

In another text by Aëtius, this phenomenon seems to be indicated by the word ψευδοφανῆ:

> Παρμενίδης διὰ τὸ παραμεμῖχθαι τῷ περὶ αὐτὴν πυρώδει τὸ ζοφῶδες, ὅθεν ψευδοφανῆ λέγεσθαι τὸν ἀστέρα.[33]

[30] The phenomenon of what is nowadays called "earthshine" (when the unlit part of the moon is faintly visible) Anaximander could also have easily explained by the sometimes thinner and thus transparent cover of air, through which shone the fire that was inside the celestial wheel. See also Couprie 2018, 66–68 and Fig. 5.4 on p. 68.
[31] Aët. 2.7.1 in MR 5.2 = DK 28A37; see also Bottler 2014, 325. Later, Posidonius and most of the Stoics seem to have held the same idea that the moon is a composite of fire and air. See Aët. (2.25.5 in MR 5.2) in his chapter "On the substance of the moon" (περὶ οὐσίας σελήνης): " the moon is composed of fire and air" (μικτὴν ἐκ πυρὸς καὶ ἀέρος). The verb μίγνυμι here should be understood as "to join", "bring together", rather than "to mix", no matter whether this text is understood as referring to the bright and less bright areas on the moon (the face on the moon), or, as I believe, as referring to the lit and unlit parts of the moon.
[32] In Plut. *De fac.*922 (Lesage Gárriga 2021, 39–41), Lamprias argues against the assumption, there ascribed to the Peripatetic Clearchus, that the "face on the moon" is a mixture of air and fire.
[33] Aët. 2.30.5 in MR5.2 = DK 28B21.

> Parmenides (explains the appearance of the moon's surface) by saying that the fiery (part) is combined with the unlit (part) of it; for this reason this celestial body is called 'deceitfully appearing'.

Diels places this *doxa* on Parmenides under the heading "Falsches". This is probably why Wöhrle, Panchenko, Graham, and Mourelatos do not mention it in their publications on the light of the moon. But Mansfeld and Runia have convincingly argued that it is an authentic fragment.[34] This text on Parmenides, too, is usually interpreted as referring to the bright and less bright areas on the surface of the moon ("the face on the moon"), perhaps all the more so because the word ἀήρ (air) is here replaced by τὸ ζοφῶδες. I would like, however, to propose the translations "the unlit (part)" for τὸ ζοφῶδες and "combined with" for παραμεμῖχθαι. With regard to the latter translation, I take into account not only the prefix παρα- meaning "next to", but also the other text quoted above, in which Parmenides speaks of the moon being a composite of air and fire side by side. In both texts, Aëtius refers to the visible part of the moon with the words "fire" (πῦρ) or "fiery" (πυρώδης), which he also uses elsewhere for the moon's light (πυρίνη, see section 2). The words "περὶ αὐτὴν" can be translated as "with regard to it" or simply "of it" (sc. the moon's disk)".[35] As for the word ψευδοφανῆ, I take it to mean that the moon's light is deceitful, because the moon looks like a regularly increasing and decreasing fiery object, whereas in reality the moon is round all the time. If my interpretation of the two above-quoted texts is correct, this means that Parmenides was aware of the phenomenon whereby the unlit part of the moon disappears and takes on the color of the surrounding air.

An almost similar *doxa* is attributed to Anaxagoras.[36] Mansfeld and Runia place it within parentheses, arguing that it is a doublet, erroneously included in anticipation of the Parmenidean *doxa*.[37] This is also the reason why Laks and Most do not adopt it, but refer in a footnote to the *doxa* on Parmenides.[38] Graham, however, only refers to the duplicate text in Anaxagoras. He combines it with its authentic part which is on mountains and valleys and paraphrases: "The moon has mountains and valleys (…) and its mottled appearances is caused by its topography and the resulting shadows".[39] Apparently, Graham wants to say that the mountains on the moon cause the less bright areas on the moon through their shadows. Graham's interpretation is strange, because shadows change and move in accordance with the position of their light source

[34] See MR 5.2, 1095 and 1098–1099. See also the arguments pro and contra in Bottler 2014, 478– 479.
[35] MR 5.4 2106 translate "in it". Dumont's "qui l'entourne", LM's "that surrounds it" and Reale's "que le sta attorno" are certainly not right.
[36] Aët. 2.30.3 (second half) in MR 5.2 = DK 59A77.
[37] See MR 5.2, 1095 and MR 2.2, 627–628.
[38] See footnote at LM ANAXAG. D44.
[39] Graham 2013, 200.

(in this case: the sun), but the less bright parts on the moon's surface remain always the same (the "face on the moon"). Moreover, the shadows of mountains on the moon can only be seen with a telescope.

Modern authors tend to misunderstand the phenomenon of the moon's gradually disappearance and growth. Popper, for example, thinks he can explain the phases of the moon using a small-scale model: "(…) as anybody can see who holds a sphere into the Sun and observes *the play of light and shadow* on it when he moves round the sphere".[40] But Popper fails to see that the moon behaves differently from a spherical model held up to the sun. The unlit part of the moon disappears and takes on the color of the surrounding air, whereas the unlit part of a sphere held into the sun remains clearly visible, nor does it take on the color of its surroundings.[41] Popper confusingly uses the word "shadow" for the unlit part of the moon: "The apparent bodily change[s] of the Moon turn out to be a mere *play of shadows*", and: "the waxing and waning of the Moon (…) are *shadow play*".[42] Rather strangely, Graham uses the word "shadow" not only for the "face on the moon", but also for the unlit part of the moon. He writes, for example: "The dark portion of the moon is explained by heliophotism as a *shadow*", and "the *shadow* of the sort we observe passing over the face of the moon.[43] Elsewhere, he writes: "the *pattern of shadows* that moved across its [sc. the moon's] face".[44] And yet elsewhere: "The *shadow* (…) retreat[s] gradually from circular to gibbous to half to crescent to nothing".[45] However, the word "shadow" is commonly used to refer to a shadow cast by an object onto another object (e.g., the ground). No one has ever called the unilluminated part of my body a shadow. Graham and Popper completely ignore that *we do not see* a dark part of the moon or a pattern of shadows, but what we *see* is that the unlit part of the moon disappears and adopts the color of the sky.

4. *The moon tilt illusion*

[40] Popper 2012, 96, see also 91 and 99.
[41] Today, we can explain this difference: in the case of a hand-held sphere, light is scattered by atmospheric particulates, while there is no atmosphere about the moon. To think that the ancient Greeks had this or a similar explanation would be a serious anachronism.
[42] Popper 2012, 96 and 91; similar words on 92, 99, 100, and 108.
[43] Graham 2013, 112 (my italics).
[44] Graham 2013, 105.
[45] Graham 2013, 113. Here Graham adds to his rather idiosyncratic terminology by using the terms "gibbous" and "crescent" for the invisible part of the moon (which he calls "the shadow"), whereas these terms are commonly used for the illuminated part of the moon.

This illusion in sometimes called "the half-moon illusion, which is not entirely correct, because the illusion is also visible during other phases of the moon.[46] The term "half-moon illusion" is used, for example, by Papathomas in a keynote address, in which he discusses two celestial illusions that must have worried ancient Greek astronomers.[47] One of them is the "half-moon illusion", which refers to the fact that the illuminated half of the moon *does not point toward the sun*, but significantly above the sun (see Figure 1). This illusion should not be confused with the well-known optical illusion that causes the moon to appear larger near the horizon than it does higher up in the sky. The latter illusion disappears on a photo that shows that the angular diameter of the moon at the horizon is exactly the same as the angular diameter of the moon high in the sky, namely about 0.5°. But the half-moon illusion does not disappear on a photo.

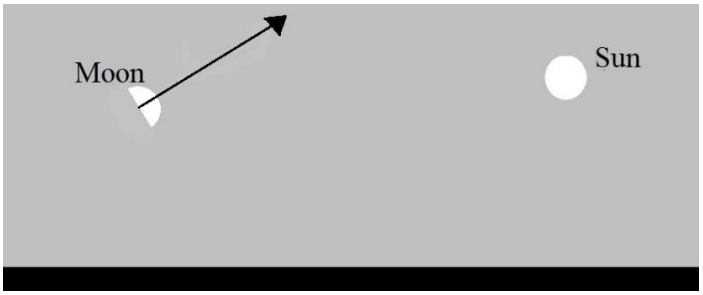

Figure 1 The half-moon illusion (after Papathomas)

The half-moon illusion increases with the moon's altitude. Figure 2, based on Myers-Beaghton and Myers, shows the first quarter moon at different altitudes. In this picture, it is assumed that the half-moon is in the southern sky, while the sun sets in the west, its upper half being at the horizon somewhere to the right of the picture, at 0° altitude. The azimuths of the sun and moon differ by 90°, which is a quarter of the total horizon.[48] For example on March 28, 500 B.C., in Athens, the first quarter moon was more than 70° above the horizon at sunset and thus pointed to a point 70° above the setting sun.

[46] Other names for this illusion, used in the literature, are: "the moon tilt illusion". "the moon phase-angle-illumination discrepancy", "the lunar terminator illusion", or "die falsche Mondneigung".
[47] See Papathomas 2005, 4–5; Figure 1 is made after his Figure 1 on p. 4.
[48] See Myers-Beaghton and Myers 2014, Figure 3 (= Figure 10 in their *Internet* article).

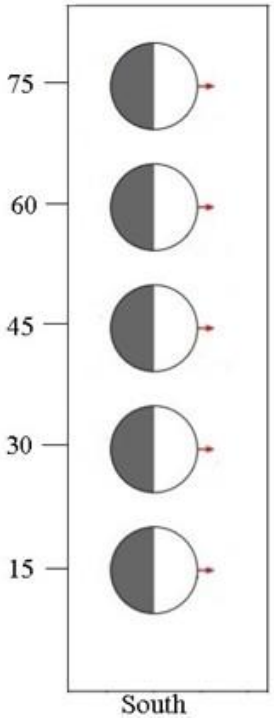

Figure 2 The half-moon illusion increases with the altitude of the moon

But the illusion is not confined to the half-moon. This is why it is also called "the moon tilt illusion". The illusion increases with the size of the moon's illuminated part, as shown in Figure 3 for five different lunar phases at the altitude of 45°.[49] Looking at this picture one should realize that all five moons are at 45° altitude between south and east, while the sun sets again at the western horizon, with its upper half being at the horizon somewhere to the right of the picture, at 0° altitude.[50]

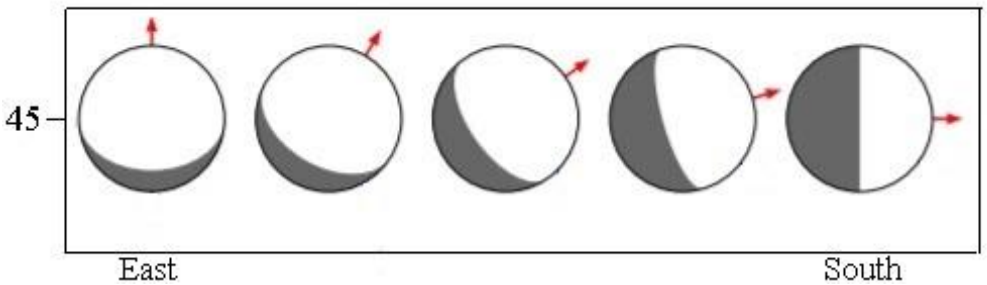

Figure 3 The moon tilt illusion increases with the size of the moon's illuminated part

To my knowledge, there is no text by or about the Presocratics that mentions the moon tilt illusion. However, the phenomenon is so easy to observe and so striking, that they cannot possibly have overlooked it. But as long as the moon was thought to be fiery, the moon tilt

[49] Figure 3 is also made after Myers-Beaghton and Myers 2014, Figure 3 (= Figure 10 in their Internet article).
[50] I observed the moon tilt illusion several times, for example on May 18, 2024, in Amsterdam (52°21' N, 4°54' E) at sunset (9.34 pm; altitude of the sun 0°). At the moment of sunset, the waxing gibbous moon was at 35°24' altitude and clearly pointing upwards and not downwards (pointing to the setting sun), as we would expect.

illusion was irrelevant. For example, Anaximander's closing and opening of the moon wheel circumvented the problem of the moon tilt illusion. The moon tilt illusion was also irrelevant to those anonymous people who thought that the moon's fire was kindled by the sun. I will discuss this explanation in the next section.

5. *When the earth is flat, the sun must be nearby*

All (or most) Presocratics believed that the earth was flat. If the earth is considered flat, the sun must be close by (and the moon as well). This can be demonstrated by means of the shadow of a two-meter-long gnomon in places that lie roughly on the same meridian and were well-known to the Milesians: Apollonia (a colony at the Black Sea, founded by Anaximander, 42º25′ N, 27°42′E), Miletus (37°32′N, 27°17′E), and Naucratis (a trading-post of the Milesians in ancient Egypt, 30°54′N, 30°36′E). Table 1 shows the altitude of the sun and the shadow-length of the gnomon at noon during the summer solstice in these cities.

Table 1 altitude of the sun and shadow-length of a 2-meter gnomon

city	altitude sun	shadow-length
Apollonia 42º25′ N	71°	72 cm
Miletus 37°32′N	76°	50 cm
Naucratis 30°54′N	82°	28 cm
(Syene) (23°30′N)	90°	0

The ancient Greeks could have surmised that somewhere in the south there must be a place where the sun stands in the zenith at noon during the summer solstice and where a gnomon throws no shadow at all. They may have heard that such a place really existed in southern Egypt. Traditionally, this place was called Syene, although it was not located exactly on the Tropic of Cancer. That is why in Table 1 the name and coordinates of Syene are placed within parentheses.

Figure 4 illustrates what this means for the distance to the sun on a flat earth. The distance between Apollonia and Syene is about 2100 kilometers, and thus the distance from the earth to the sun must be about 6000 kilometers, while the size of the sun must be rather small, in comparison to the earth. That is why Anaxagoras compared the size of the sun to that of the

Peloponnesus. Accordingly, the moon (which is below the sun) must be not far from the sun and the earth either.

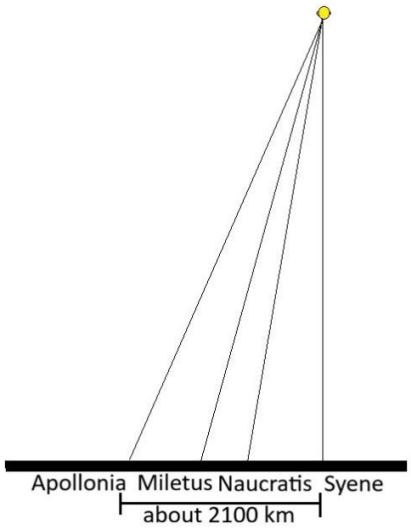

Figure 5 When the earth is flat, the sun must be close by

When the sun is close by, it can ignite the moon's back side during New Moon. This is described in a text, according to which anonymous thinkers are said to defend a theory about how such ignition of the moon by the sun proceeds during the lunar month:

> τῶν δὲ νεωτέρων εἰσί τινες οἷς ἔδσξε κατ' ἐπινέμησιν φλογὸς κατὰ μικρὸν ἐξαπτομένης τεταγμένως, ἕως ἂν τὴν τελείαν πανσέληνον ἀποδῷ, καὶ πάλιν ἀναλόγως μειουμένης μέχρι τῆς συνόδου καθ' ἣν τελείως σβέννυται.[51]
>
> But among more recent thinkers there are some who say (that the phases of the moon appear) in accordance with the spread of a flame that is kindled little by little in an orderly manner until it produces the complete full moon, and analogously diminishes again until the conjunction (sc. of the sun and the moon), when it is completely extinguished.

Scholars agree that the *doxa* is not about lunar eclipses, as the title of Aëtius' chapter says, but about the phases of the moon. This is clearly indicated by the sequence "full moon – until the conjunction (of the sun and the moon)".[52] The words τῶν δὲ νεωτέρων εἰσί τινες are usually understood as "some younger Pythagoreans", because this text immediately comes after one about the Pythagorean interpretation of the lunar phases. That is why DK included it in their chapter on the Pythagoreans. But Dumont already noted, "il n'est pas sûre que ses modernes

[51] Aët. 2.29.5 in MR 5.2 = DK 58B36. See also Bottler 2014, 471.
[52] See Dumont 1988, 1405 n. 5 at p. 581.

soient eux aussi des pythagoriens".[53] Consequently, he translated: "d'autres, plus modernes".[54] I followed Mansfeld and Runia's translation "among more recent thinkers".[55] The dictionary (LSJ) has for ἐξάπτομαι: "set fire to, kindle, inflame". Graham, however, sees this account as "a straightforward description of heliophotism". Symptomatically, he comments: "*It is odd* that the increase is described in terms of fire rather than light".[56] In my opinion, there is nothing odd with this text. It is not about "heliophotism", but on the contrary, it shows how some thinkers tried to make sense of the idea that the phases of a fiery moon result from the moon being kindled by the sun. The idea of the waning moon as an extinguishing fire was not entirely new, for Aëtius attributes a similar idea to Xenophanes:

> Ξενοφάνης καὶ τὴν μηνιαίαν ἀπόκρυψιν κατὰ σβέσιν.[57]
> Xenophanes (says that) the moon's monthly disappearance too (comes about) as a result of quenching.

The "more recent thinkers" made the idea of a quenching moon into a theory of how the moon was kindled and extinguished every month again. The far side of the moon, which is invisible to us, is kindled during New Moon. Little by little, the fire creeps over the rand of the moon and becomes visible to us as a small crescent moon. Then the fire grows, until at Full Moon it covers the whole visible side of the moon. Since at that time the moon is farthest away from the sun, the fire diminishes and slowly shrinks until only a small crescent can be seen and then, when the moon is again in conjunction with the moon (i.e. during New Moon), the whole cycle starts all over again. Figure 6 shows the beginning of this process: during New Moon, the sun kindles the back side of the moon, which is invisible to us.

[53] Dumont 1988, 1405 n. 5 at p. 581. See also Huffman 1993, 237 and 240. In MR 5.2. 1078, it is made a separate *doxa*, and on page 1086 they write, somewhat cryptically: "The phrasing of the name-labels does not support this view" (sc. that it would concern another group of Pythagoreans).
[54] Dumont 1988, 581.
[55] See MR 5.4, 2105. Perhaps, Plato is hinting at this opinion in his cryptic text in *Cra.* 409A7–B8 (= DK 59A76), which would imply that these "recent thinkers were apprentices of Anaxagoras. This would underline the suggested interpretation in Couprie 2018, 206 and 214–217, that the "recent thinkers" mentioned in *Placita* 2.29.5 in MR 5.2 were not Pythagoreans but Anaxagoreans.
[56] Graham 2013, 197, my italics.
[57] Aët. 2.29.6 in MR 5.2 = DK 21A43 = TP3 Xs 213.

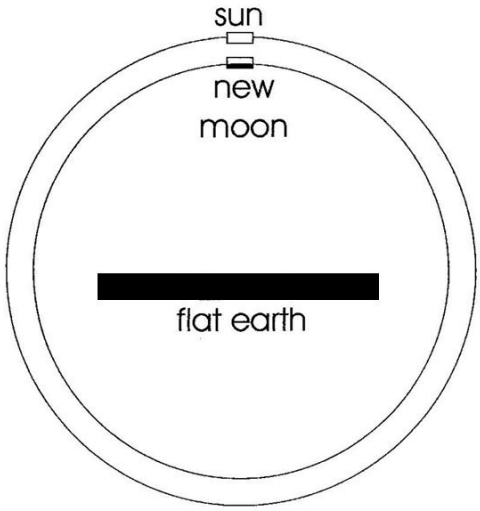

Figure 6 When the sun is close by, it can ignite the back side of the moon

6. *Parmenides on the light and phases of the moon*

Mourelatos coined the term "heliophotism" for the correct theory that we still adhere to, and the term was adopted by Graham.[58] Above I already said that this is at odds with Aëtius' report that Parmenides calls the moon "fiery", or more specifically a composite of both air and fire (συμμιγῆ δ' ἐξ ἀμφοῖν τοῦ τ' ἀέρος καὶ τοῦ πυρός). I also argued that the implication of the latter is that Parmenides was aware of the fact that the moon behaves differently from an object that is illuminated by a light source. Yet there are scholars who defend the idea that some Presocratics, and above all Parmenides, had found the correct solution, that the moon is not fiery and has no light of itself, but is illuminated by the sun. The most explicit are Mourelatos and Graham, both referring to Popper. There are two texts from Parmenides' poem, to which these authors refer. The first is this line from Parmenides' poem:

> αἰεὶ παπταίνουσα πρὸς αὐγὰς ἠελίοιο.[59]
> Always peering toward the rays of the sun.

Graham comments on this text: "the luminous part of the moon is always facing the sun". This observation was, he says, "familiar to any Greek who watched the moon, as probably most Greeks did". Graham also states that Parmenides' text means that "its luminous part is *always facing* the sun.[60] Mourelatos asserts that "the convex side of the waxing meniscus *continues to*

[58] Mourelatos 2012, 26; see also Graham, 2013, 88 n.2.
[59] Plut. *De fac*. 929b = Lesage Gárriga 2021, 60–61= DK 28B15.
[60] Graham 2013, 98, my italics.

be oriented in the direction of the sun" and that this is the case with "*all its phases*".[61] And he concludes: "Anyone who has realized that these (…) observations (…) admit of no exception has (…) grasped (…) the fact that the moon gets its light from the sun.[62] Graham, too, states that the hypothesis of heliophotism predicts that the luminous part of the moon is always facing the sun.[63]

However, as I argued when discussing the moon tilt illusion, it is simply not true that the illuminated face of the moon always points toward the sun. The moon tilt illusion is so obvious, so easy to observe, and so striking, that the Presocratics, unlike these authors, could not possibly have overlooked it. Moreover, an unbiased reading of this text from Parmenides' poem reveals that it is not about "heliophotism". The moon is said to look toward the sun, but even if it were true, this is definitely different from "the moon has no light of itself but is illuminated by the sun".[64] We should seriously consider the possibility that Parmenides just used a loose, or if you prefer a poetic, way of expressing himself, without further astronomical implications.

The other text from Parmenides' poem cited by the defenders of his supposed "heliophotism" is this one, in which he says of the moon:

> νυκτιφαές, περὶ γαῖαν ἀλώμενον ἀλλότριον φῶς.[65]
> shining by night, a strange light wandering around the earth.

The word νυκτιφαές is in the manuscripts νυκτὶ φαός. Mourelatos has devoted an article in defense of the reading νυκτὶ φαός, which he translates as "the light of day by night" or "daylight into the night".[66]As far as I know, however, Mourelatos' translation has not been adopted by other scholars who read νυκτὶ φαός instead of νυκτιφαές. Noteworthy is Graham, who in 2010 still read νυκτιφαές and translated "shining by night", while in 2013 he reads νυκτὶ φαός and translates "a light by night", which makes little difference.[67] No matter which reading one accepts, here Parmenides neglects that during much of the lunar month the moon is visible by day as well. If Parmenides were interested in astronomical observations, he would have noticed it, whereas the moon at night is mainly poetically or romantically interesting.

[61] Mourelatos 2013, 100, sub β, and 2012, 46 (my italics).
[62] Mourelatos 2013, 101.
[63] Graham 2013, 99.
[64] See also Heath 1913, 76.
[65] Plut. *Adv. Col*, 1116a = DK 28B14.
[66] Mourelatos 2012, 28 and Mourelatos 2013, 98.
[67] See Gr Prm 32 versus Graham 2013, 91 n.12.

The words ἀλλότριον φῶς are, as scholars have noted many times, both a pun with φῶς (light) and φώς (man), and an echo of Homer's ἀλλότριος φώς (a stranger).[68] I think the natural reading of these words is "ein fremdes Licht", as Diels/Kranz, Mansfeld, Wöhrle, and Gemelli Marciano have, or "un éclat étranger", as in Bollack, or "a foreign light", as in KRS, and in Heath and Guthrie.[69] I prefer "a strange light", because the moon's light behaves strangely (and even deceitfully, ψευδοφανῆ (as in another text, quoted above), by increasing and decreasing in a regular way during the lunar month (i.e. "wandering around the earth"), while hiding its unlit part. I fully agree with Heath, who remarks at this text that it does not imply that Parmenides recognized that the moon was illuminated by the sun: " 'foreign' (ἀλλότριον) need not have meant 'borrowed' ".[70] I surmise that without the text quoted above, which says that the moon always looks at the sun, no one would have translated ἀλλότριον φῶς as "with borrowed light". Only those engaged in finding texts that might support the idea that Parmenides discovered "heliophotism" could come up with the translation "with borrowed light" for ἀλλότριον φῶς.[71]

There are two other texts, in which Parmenides and others seem to have stated that the moon is illuminated by the sun. The first text is:

> Θαλῆς πρῶτος ἔφη ὑπὸ τοῦ ἡλίου φωτίζεσθαι.
> Πυθαγόρας, Παρμενίδης, Ἐμπεδοκλῆς, Ἀναξαγόρας, Μητρόδωρος ὁμοίως.[72]
> Thales was the first to say that (the moon) is kindled by the sun.
> Pythagoras, Parmenides, Empedocles, Anaxagoras, and Metrodorus (say) likewise.

I will leave aside Thales and Pythagoras, who probably have been mentioned *honoris causa*, and Metrodorus of Chios, a minor atomist, of whom is little known, except that he was a skeptic.[73] About Anaxagoras and Empedocles I will speak in the next section. According to Graham, who translates the word φωτίζεσθαι as "being illuminated", this text unhesitatingly provides further evidence of Parmenides' alleged "heliophotism".[74] However, the word

[68] Hom. *Il.* 5.214 and *Od.* 18.219.
[69] DK 28B14 ("ein fremdes Licht"); Mansfeld 1983, 329 (idem); Wöhrle 1995, 245 (idem, although on the same page he seems to interpret "ein fremdes Licht" as "borrowed light"); Gemelli Marciano 2013, 33 (idem); Bollack 2006, 269 ("un éclat étranger"); KRS 259 ("a foreign light"); Heath 1913, 75 (idem); Guthrie 1965, 66 (idem).
[70] Heath 191, 76:.
[71] Graham 2010, Prm 32. See also Tarán 1965, 168 ("with borrowed light"); Mourelatos 2012, 28 and 2013, 98 ("a light from elsewhere"); Reale 2017, 499 ("di luce che le proviene di altro"); Dumont 1988, 269 ("un éclat emprunté").
[72] Aët. 2.28.5 and 2.28.6 in MR 5.2 = DK28A42 = Gr Prm 36, not in LM and KRS. See also Bottler 2014, 465.
[73] We may, however, not exclude too soon the possibility that Thales and Pythagoras meant that the moon was *kindled* by the sun.
[74] See Graham 2013, 51 and 89.

φωτίζεσθαι is ambiguous, for it can also mean "being kindled", as some scholars have remarked earlier.[75] The words ὑπὸ τοῦ ἡλίου φωτίζεσθαι can also mean that the moon is *kindled* by the sun. This interpretation would be in accordance with the moon's fiery nature, which is also said of Parmenides' moon, as shown in section 2. We might imagine that the moon is kindled by the sun and then has its own fire, just as it can be said of a candle that it is kindled by a flame and then has its own fire.

In another text, again the same ambiguous word φωτίζεσθαι is used. Moreover, this text can be read as confirming that Parmenides held the idea that the earth was flat and the sun close by and thus quite small. The sun being close by is a precondition of a moon ignited by the sun, as we saw in section 5.

> Παρμενίδης ἴσην τῷ ἡλίῳ, καὶ γὰρ ἀπ' αὐτοῦ φωτίζεσθαι.[76]
> Parmenides (says the moon) is equal to the sun (in size) and indeed that it is kindled by it.

I conclude that an unbiased reading of the texts from Parmenides' poem shows that neither of them is about "heliophotism": in the first text, the moon is said to look toward the sun, which is not correct and also something different from "the moon is illuminated by the sun". The second text says that the light of the moon is a light that behaves strangely, different from other lights, whether celestial or not. The translation "with borrowed light" for ἀλλότριον φῶς smells like an anachronism. In the two other texts by Aëtius, the word φωτίζεσθαι is ambiguous and can also mean that the moon is kindled by the sun.

7. *Anaxagoras and Empedocles on the light and phases of the moon*

To the interpretation of a text of Aëtius, quoted in section 6, in which the word φωτίζεσθαι is used and in which the names of Anaxagoras and Empedocles appear, similar remarks as made above can be put forward. Diels/Kranz considered the line quoted below to be a genuine fragment from Anaxagoras' book, in which they were followed by several commentators and handbooks:

> ἥλιος ἐντίθησι τῇ σελήνῃ τὸ λαμπρόν.[77]

[75] See Ferguson 1968, 100; O'Brien 1968, 122; MR 5.2, 1098.
[76] Aët. 2.26.2 in MR 5.2 = DK 28A42.
[77] Plut. *De fac.* 929B = DK 59B18.

> The sun puts brightness into the moon.

This fragment is usually read as a proof of Anaxagoras' "heliophotism". Graham, for example, declares: "Indeed, we have his cognition of heliophotism in his own words, as recorded by Plutarch".[78] But Anaxagoras' words are at least ambiguous, for they can also mean that the moon is *kindled* by the sun.[79] The verb ἐντίθημι means "to put into", "to insert", while the adjective λαμπρός (here substantivized) means "bright", "radiant", and can be said not only of the moon, but also of the sun and stars, which were regarded as fiery bodies. The word λαμπρός is akin to the noun λαμπάς ("torch"). It could be argued, then, that the verb ἐντίθημι and the noun τὸ λαμπρόν point to kindling.

Other reports seem to refer to this text, using different and more mundane words. Hippolytus, for example, reports that according to Anaxagoras the moon has its light from the sun:

> τὸ δὲ φῶς τὴν σελήνην μὴ ἴδιον ἔχειν, ἀλλὰ ἀπὸ τοῦ ἡλίου.[80]
> (Anaxagoras says that) the moon does not have its own light but gets it from the sun.

Hippolytus adds the clause "the moon does not have its own light", which is not in Anaxagoras' quotation It is added, probably because Hippolytus thinks this necessarily follows from "the moon gets its light from the sun". Note also the subtle alteration of meaning that results from changing the subject of the sentence: "the moon has ... from (σελήνη ἔχει)," instead of "the sun puts into" (ἥλιος ἐντίθησι). Perhaps Hippolytus just echoed Plato's words: "the moon has its light from the sun" (ἡ σελήνη ἀπὸ τοῦ ἡλίου ἔχει τὸ φῶς).[81]

Anaxagoras thought that the earth was flat.[82] As Panchenko has convincingly shown, he tried to prove it by arguing that the horizon is always seen as a straight line, while it should be curved if the earth were spherical.[83] That the earth was flat implies that the sun must be relatively close by (see Figures 5 and 6) and thus ignites the moon. This is contrary to the opinion of the proponents of "heliophotism", for whom the earth, the moon, and the sun must be spherical.[84]

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[78] Graham 2013, 124.
[79] See O'Brien 1968, 123 and 125; Sider 2005, 158 and 159; Panchenko 2018, 330.
[80] Hippol. *Her.* 1.8.8 = DK 59A42. See also Aët. 2.28.6 in MR 5.2 = DK 59A77.
[81] Pl. *Cra*. 409B.
[82] See Diog. Laërt. 2.8 = DK 59A1(8). Hippolytus, Hippol. *Her.* 1.8.3 = DK 59A42(3) 2. *Scholia on Apoll. Rh.* 1.498 = DK 59A77.
[83] See Panchenko 1997. This argument is until today used by the defenders of a flat earth, as can be seen in several publications on the Internet.
[84] See, e.g., Graham 2013, 103 (quoting Popper), and 105–106.

In section 6, I already quoted a text of Aëtius, in which Empedocles is mentioned. Ps-Plutarch repeats these words, to the interpretation of which similar remarks can be put forward:

> τὸ δὲ φῶς αὐτὴν ἔχειν ἀπὸ τοῦ ἡλίου.[85]
> (the moon) has its light from the sun.

The claim that Empedocles advocated "heliophotism" is mainly based on three texts from his poem.[86] The first of these is embedded in an argument of Plutarch, in which he ascribes to Empedocles a theory of the moon's light:

> τὸ τοῦ Ἐμπεδοκλέους ἀνακλάσει τινὶ τοῦ ἡλίου πρὸς τὴν σελήνην γίνεσθαι τὸν ἐνταῦθα αφωτισμόν ἀπ' αὐτῆς. ὅθεν οὐδὲ θερμὸν οὐδὲ λαμπρὸν ἀφικνεῖται πρὸς ἡμᾶς, ὥσπερ ἦν εἰκὸς ἐξάψεως (…) ὡς αὐγὴ τύψασα σεληναίης κύκλον εὐρύν ἀσθενῆ καὶ ἀμυδρὰν ἀνάρροιαν ἴσχει πρὸς ἡμᾶς, διὰ τὴν κλάσιν ἐκλυομένης τῆς δυνάμεως.[87]
> Empedocles' theory, that it is by some kind of reflection of the sun unto the moon that the illumination is produced that comes from it. That is also why it does not reach us hot nor bright, as would be likely if there were kindling (…). Like the ray that strikes the broad circle of the moon reaches us in a reflux that is weak and faint, since its power has been dissolved by the reflection.

The words ὡς αὐγὴ τύψασα σεληναίης κύκλον εὐρύν ("like the ray that strikes the broad circle of the moon") are commonly supposed to be a quotation from Empedocles' poem. We must avoid the trap of not distinguishing between Plutarch's remarks and the quotation of Empedocles, on which Plutarch bases his interpretation. Plutarch uses, for example, three times the word "reflection" (ἀνάκλασις, κλάσις, and ἀνάρροια), which the Presocratics used for mirrors ("catoptrics"), but not for objects that were made visible by sunlight ("optics"). Plutarch's remark that the moon, when kindled, it would likely radiate heat, makes sense. But the anonymous Presocratics who developed a full-fledged kindling theory, as we saw above, clearly did not bother about the argument that we cannot feel the heat of the moon's fire. Maybe they could have argued that the heat of a kindled fire, like that of a candle, does not reach as far as that of the fire that ignites it.

In the quoted text, the manuscripts have αὐτὴ, which was already in the 16th century corrected into αὐγὴ. The quotation looks like an unfinished sentence, perhaps a simile as the word ὥς ("like") suggests. Even if this word is not part of the quotation from Empedocles but belongs to the text of Plutarch, the sentence looks unfinished. Be that as it may, the quotation

[85] Ps-Plut. *Strom.* 10 = Eus. *PE.* 1.8.10 = DK 31A30.
[86] See Graham 2013, 186.
[87] Plut. *De fac.* 929D–E = DK31B43.

as such is as ambiguous as a phrase like "the moon receives its light from the sun". It can as easily denote inflammation of the moon by the sun as "heliophotism".

The two other texts that are adduced to support the claim that Empedocles knew "heliophotism" are again quotations from his book:

> ἀθρεῖ μὲν γὰρ ἄνακτος ἐναντίον ἀγέα κύκλον.[88]
> [the moon] gazes into the bright circle of the Lord's face (i.e. the sun) opposite her.

> κυκλοτερὲς, περὶ γαῖαν ἐλίσσεται ἀλλότριον φῶς.[89]
> Circular, she (sc. the moon) turns around the earth, a strange light wandering around the earth.

Empedocles copied these two texts more or less literally from Parmenides. In section 6, I argued that they have nothing to do with "heliophotism". Moreover, in the first text, Empedocles deletes Parmenides' word αἰεί ("always"), which Mourelatos said was crucial, and adds the word ἐναντίον ("opposite"). The result is that his text says no more than that the full moon is opposite the sun, for during its other phases, the moon is not opposite the sun. Significantly, Graham leaves out a translation of the word ἐναντίον when he discusses this text in *Science Before Socrates*. And he comments: "in other words, her luminous face is *always* turned towards the sun", even though the word "always" is in none of his quoted texts.[90] As to the second text, as said in section 6, it is far-fetched to translate the words ἀλλότριον φῶς as "borrowed light".[91] The word κυκλοτερὲς must here be taken literally, for Empedocles considered the moon disk-shaped, as Aëtius reports in his chapter *On the Shape of the Moon* (Περὶ σχήματος σελήνης):

> Ἐμπεδοκλῆς δισκοειδῆ.[92]
> Empedocles (says it is) disk-shaped.

This is repeated by Diogenes Laërtius:

> φησι (…) τὴν δὲ σελήνην δισκοειδῆ.[93]

[88] DK 31B47. Cf. Bollack 1969, II 116–117 and III 282–283. He argues, not very convincingly, that the word κύκλον not has to do with the shape of the sun, but with the shape of its orbit. As far as I know, this is not adopted by other scholars. Most handbooks have ἀγέα, except Gemelli Marciano (2013, 220), who has ἀγέα, just like LSJ, s.v. ἀγής. See also εὐαγής as an epithet of the sun in Parmenides: Clem. Al. *Strom.* 5.138 = DK 28B10.
[89] Ach. Tat. *In Arat.* 16 = DK 31 B45.
[90] See Graham 2013, 186–187 (my italics); in Gr Emp 80 he still had the translation "opposite her".
[91] For this interpretation of Empedocles' texts, see Graham 2013, 186 and Gr Emp 81. See also LM EMP. D139.
[92] Aët. 2.27.5 in MR 5.2 = DK 31A60. See Bollack 1969, II 102–103 and III 257.
[93] Diog. Laërt. 8.77 = DK 31A1.

> He says that the moon is disk-shaped.

Plutarch has a slightly expanded version:

> γὰρ φαινόμενον σχῆμα τῆς σελήνης, ὅταν διχόμηνος, οὐ σφαιροειδές ἄλλα φαοειδές ἐστι, καὶ δισκοειδές, ὡς Ἐμπεδοκλῆς οἴεται καὶ τὸ ὑποκείμενον.[94]
> The apparent shape of the full moon is not that of a sphere, but of a lentil, or a disk, as Empedocles thinks that it really is.

In Plutarch's text. I inserted a comma before καὶ δισκοειδές, given the texts of Aëtius and Diogenes Laërtius. It can be argued that "disk-shaped" (δισκοειδές) is what Empedocles called the full moon, while "lentoid" (φαοειδές) is an insertion of Plutarch, probably as a result of his interpretation of the moon reflecting the sun's rays. Therefore, I translated the word καὶ before δισκοειδές as "or".[95] For the same reason, I deleted the comma after οἴεται, as in the translation of Laks/Most. In "heliophotism", a disk-shaped moon never can show the phases of the moon as we see them. In order to behave like it does, the moon needs to be spherical. In his discussion of Empedocles' alleged "heliophotism". Graham does not mention Aëtius' and Diogenes Laërtius' texts, while in his paraphrase of Plutarch in *Science Before Socrates*, he leaves out the word "disk-like" and only keeps the word "lentoid", commenting: "Since Empedocles makes the moon lentoid, he flattens it but keeps enough convexity to allow for the shadows on its surface".[96] Two pages further, Graham even changes from "lentoid" to "spheroid".[97] I would call this molding a text to suit your prejudices.

Empedocles considered the moon not only disk-like, but also (or at least its visible part) fiery:

> Ἐμπεδοκλῆς ἀέρα συνεστραμμένον, νεφοειδῆ, πεπηγότα ὑπὸ πυρός, ὥστε σύμμικτον.[98]
> Empedocles (says that the moon is) compacted air, cloud-like, solidified by fire, so that it forms a composite.

[94] Plut. *Quaest. Rom.* 288B = DK 31A60.
[95] In this, I followed Gr Emp 85.
[96] Graham 2013, 188; it should also be noted that Graham constantly speaks of "shadows" to indicate the invisible part of the moon.
[97] See Graham 2013, 190: "He resists a completely spherical moon (…), but keeps it spheroid".
[98] Aët. 2.25.6 in MR 5.2 = DK 31A60. See also Bollack 1969, II no. 305 and III 256; see also Plut. *De fac.* 922c (Lesage Gárriga 2021, 38–39 (= DK 31A60 = Bollack 1969, II no. 306), in which the two elements (air and fire) that characterize the unlit and the lit parts of the moon appear.

I read this text as an indication that Empedocles, like Parmenides, had observed that the unlit part of the moon is invisible and takes the color of the surrounding air, black at night and blue by day. The moon as such, during New Moon and its unlit part during its phases, is (compacted) *air*. Only when the moon is set on fire by the sun it becomes more or less solidified *by fire* (baked as it were) during its phases, until it is completely *fiery* during Full Moon.

The moon being spherical and not fiery are two necessary requirements for "heliophotism", but neither of them was advocated by Empedocles. There is no text clearly stating whether Empedocles considered the shape of the earth flat or spherical. Several arguments, however, suggest that Empedocles' earth must be thought of as flat.[99] My conclusion is that nothing in the texts from Empedocles'' poem nor in the testimonies about his astronomical views supports the interpretation of "heliophotism". The question remains: if it was not Parmenides, Anaxagoras, or Empedocles, who was it to discover the true cause of the light and phases of the moon?

8. *The true cause of the light and phases of the moon and what its advocates must have neglected*

We may state that there are three necessary conditions for the correct explanation of the light and phases of the moon: 1) the moon must not be fiery, 2) the moon must be spherical, 3) the earth must also be spherical, so that the sun can be at a great distance and cannot set the moon on fire. It could be argued that we must look among the Pythagoreans for the discoverer of the real cause of the moon's phases. Philolaus did not consider the moon to be fiery, which follows from the fact that he thought the moon was inhabited.[100] Unfortunately, we lack information regarding Philolaus' opinion on the spherical shape of the moon and the earth, although it can be argued from his celestial system that the earth must be spherical. Philolaus was a contemporary of Socrates. At that time, it was discovered that the earth was spherical, for in the *Phaedo*, Socrates says that someone has convinced him that the earth was spherical.[101] Socrates refrains from naming the arguments that convinced him, because it would take more time than he had available. We can conjecture, however, that the kind of argument that would have convinced Socrates would have made use of the concept of the sphere as the most perfect body, because it was better for the earth to have that shape than any other. It was this kind of

[99] This is especially the case with Ps-Plutarch's version of Aët. 2.31.1: "(the moon) touches the earth in a certain sense and revolves near it" (ἥς δὲ γῆς τρόπον τινὰ ψαύει καὶ περιφερομένη πλησίον; see also MR 5.2, 635). See also Couprie 2020, 21.
[100] Aët. 2.30.1 in MR 5.2 = DK 44A20; see also Huffman 1993, 27 and 240, and Graham 2013, 194–195.
[101] Pl. *Phd.* 108C5–8 and 108E4–109A8.

argument he had expected to find in Anaxagoras. An indication of the complexity of this kind of argument could be found in the surprising comparison of the shape of the earth with a dodecahedron, visualized by a children's ball consisting of twelve pieces of leather.[102] Both the sphericity of the earth (and thus a distant sun) and the moon no longer considered as fiery are preconditions for the correct interpretation of the causes of the moon's light and phases.

More interesting than the question of who exactly discovered the sphericity of the earth is what the advocates "heliophotism" must have neglected. This concerns the issues for which the ancient Greeks could not provide a good explanation: the unlit side of the moon disappearing and taking on the color of the surrounding air, and the moon tilt illusion. As we have seen, some Presocratics were aware of the first problem. We may infer that those who adopted the correct interpretation of the moon's light and phases were aware of it, but willingly ignored it. As to the second problem, I found a text in Plutarch, in which he mentions exactly what was depicted in my picture of the half-moon illusion (see Figure 2): The moon at its first quarter (half-moon) and the setting sun on the western horizon at an altitude of 0˚: "When the half-moon is in midheaven (ὅταν ἡ σελήνη διχότομος οὖσα μεσουρανῇ) and the sun is on the horizon (ὁ γὰρ ἥλιος ἐπὶ τοῦ ὁρίζοντος ὢν)."[103] The problem of the half-moon (τὸ πρὸς τὴν διχότομον ἀπορούμενον) is even called "the strongest point (ἰσχυρότατόν τῶν ἀντιπιπτόντων) against" heliophotism (i.e. the theory that the moon receives its light from the sun). It is even said that the problem also arises with the gibbous and crescent phases (μετὰ τῆς ἀμφικύρτου καὶ τῆς μηνοειδοῦς). Unfortunately, however, this text is confusing because it focuses on reflection (as in mirrors) rather than illumination. The confusion between these two concepts also occurs in recent publications. But to dwell on that would distract us too much from our topic in this paper.

Apparently, the theoretical and empirical arguments in favor of the sphericity of the earth and the resulting consequence, the great distance of the sun, as formulated by Aristotle,[104] were so strong that they paved the way for another explanation of the moon's light and phases, and they overruled the inexplicability of the unlit side of the moon and the moon tilt illusion.

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[102] Pl. *Phd.* 110B.
[103] Plut. *De fac.*, Ch. 17 and 18.
[104] See Arist, *Cael.* 296b7, 297a22-26, 297b20, 297b31ff, 297b34ff, and 298a9-16.

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