THE OBSERVATORY

Vol. 143 2023 APRIL No. 1293

ANCIENT REPORTS OF THE ZODIACAL LIGHT AS VIEWED FROM MOUNTAIN TOPS

By Marinus Anthony van der Sluijs

Different perspectives on a drawn-out twilight

The Caucasus is a mountain system stretching between the Black Sea and the Caspian Sea. Connecting Europe and Asia, many of its peaks reach altitudes in excess of 4000 m. One of these, Elbrus, is considered to be the highest in Europe, at 5642 m. Aristotle (384–322 BC; *Meteorology*, 1.13 [350a]) conveyed the curious information that the Caucasus' vertiginous height exposed it to sunlight for several more hours than its surroundings: "The Caucasus is the largest mountain, both in extent and height, towards the summer sunrise. A proof of its height is the fact that it is visible both from the so-called Deeps and also as you sail into the lake; and also that its peak is sunlit for a third part of the night, both before sunrise and again after sunset"[1]. The words "towards the summer sunrise" (*pròs tèn héō tèn therinḗn*) are a parochial indication of place, correctly situating the Caucasus to the northeast of Greece. The 'Deeps' (*bathéōn*) were the 'deeps of Pontus' (*bathéa tou Póntou*) (Aristotle, *Meteorology*, 1.13 [351]). The lake is either Lake Maeotis, now the Sea of Azov, or the Caspian Sea[2].

At first glance, the extended illumination of the Caucasus' peaks matches the Alpenglow — a roseate light crowning mountains when the Sun is just below the horizon. However, sunrays do not strike even the highest peaks through any significant portion of the night, whether 'night' is defined as the period between civil, nautical, or astronomical twilights. It has been calculated that the Caucasus would have to be 5760 km high in order to meet Aristotle's description[3]. Yet before dismissing the latter as an exaggeration, it may be worth posing this fundamental question: was the light effect seen from afar? Reading closely, Aristotle only explicitly distanced observers from the mountain for the daytime settings on the water, not for the nighttime visibility. A revealing perspective on what could be the same phenomenon is afforded by the account that Pliny the Elder (AD *c.* 23–79; *Natural History*, 5.18 [80]) gave of Mount Casius: "… Casius, which is so extremely lofty that in the fourth quarter of the night it commands a view of the sun rising through the darkness, so presenting to the observer if he merely turns round a view of day and night simultaneously. The winding route to the summit measures 19 miles, the perpendicular height of the mountain being 4 miles"[4]. Spelling 'Cassius', the grammarian and geographer Solinus (3rd century AD; *Collection of Curiosities*, 36.3) repeated:

"… Mount Cassius … from the summit of which the orb of the sun is visible from the fourth watch of the night, and with a slight twist of the body — as the rays dissipate the gloom — one can see night on one side, day on the other. Such is the view from Cassius that you can already see the light before the day begins"[5]. Called Saphon in the Bible and Ǧebel al-Aqra' in Arabic, Casius is located on the Syrian–Turkish border. Here, according to Pliny and Solinus, day breaks much earlier than elsewhere, but as seen from the top of the mountain, not from a valley east of it. Perhaps this was also the import of the Aristotelian passage.

Owing to atmospheric refraction, sunrise normally appears to take place slightly earlier than its actual occurrence. Under exceptional circumstances, a category of mirage called the Novaya Zemlya effect can cause the apparent sunrise to happen much earlier still[6]. This is more pronounced at polar latitudes, however; at middle latitudes, the difference would only be a matter of seconds to minutes — a far cry from the multiple hours implied by the sources examined so far, which also suggest a more regular phenomenon. If, then, the Alpenglow and mirages fall short, what could be behind the ancient reports?

The zodiacal light

The zodiacal light is sunlight reflected off a cloud of dust particles in the inner Solar System. These straddle the ecliptic, defined by the plane of the Earth's orbit around the Sun. Consequently, the light is concentrated in the zodiac as seen from Earth and this gives it its name. At mid-northern latitudes, it typically appears as a tilted cone above the horizon in the direction of the Sun some time before sunrise in autumn and after sunset in spring — the so-called 'false dawn' and 'false dusk'. The sight of an imposing luminous cone on the eastern side of the sky while the west remains shrouded in darkness, nothing like the normal dawn, could easily have imbued a sense that day and night were present at once, as reported for Casius. It is well known that the purity of air and the absence of light pollution up in the mountains are highly conducive to seeing this dim light. Ignorant of its true nature, the Earth's size, and the distance to the Sun, someone beholding it from the top of a mountain could readily have inferred that not the rarefied air but the mountain's height facilitated its appearance. That may even have led some to imagine falsely that people at ground level, too, can see the eastern flank of the mountain top lit up hours before sunrise or the western one hours after sunset.

Circumstantial support for this interpretation of the ancient testimony comes from the fact that Islamic cosmographers were well aware of the 'false dawn' (*ṣubḥ-i kāẕib*) and sometimes involved the Caucasus in their explanation of it. In their worldview, Qāf — the Arabic name for this mountain range — encircled the entire flat Earth, at such a distance that its peaks do not rise above the horizon of the civilized world. Edward Warren Hastings Scott-Waring (1783–1821) was a Bengal civil servant who frequently observed the false dawn during his sojourn in Persia and India. This experience prompted him to relay the following piece of Persian folklore: "They account for this phenomenon in a most whimsical manner. They say, that as the sun rises from behind the Kohi Qaf (Mount Caucasus), it passes a hole perforated through the mountain, and that darting its rays through it, it is the cause of the *Soobhi Kazim*, or this temporary appearance of day-break. As it ascends the earth is again veiled in darkness, until the sun rises above the mountain, and brings with it the *Soobhi Sadiq*, or real morning"[7]. If people in the Middle East associated the zodiacal light with legendary properties of the Caucasus as late as the 18th or 19th

Century, it stands to reason that they could have done so long before, be it in different ways — with the mountain being nearer and sunlight from below the local horizon shining onto its top rather than through it. Reaching even further back in time than Aristotle, it has also been suggested that the zodiacal light was itself represented by Māšu, the twin mountain of Babylonian myth which led Gilgameš along the "path of the sun" to the spirit land beyond[8].

An 'Idaeal' view

There is a third Anatolian mountain for which a strikingly long twilight was reported in antiquity: Mount Ida in the Troad (northwestern Turkey). With emphasis again on the view from the peak, not of the peak, a smattering of authors reported that an observer could watch scattered 'flames' combine and contract to form the rising Sun. Thus Diodorus of Sicily (*fl.* 1st century BC; *Historical Library*, 17.7.5–7): "There is a singular and strange phenomenon associated with this mountain: at the time of the rising of the Dog Star, on the highest peak by the stillness of the surrounding air the peak gives the impression of being elevated above the swirling of the winds, and the sun is seen to rise while it is still night, with its rays not concentrated into a circular shape, but with its fire scattered in many places, so that it looks as though many fires touch the Earth's horizon. Then, a short while later, these draw together into one quantity with a diameter of three plethra. And finally, once day has dawned, the sun's manifest size is attained and produces the condition of the daytime"[9]. In this account, the spectacle features an intermediate stage in which the many scattered flames merge into 'one quantity' (*hèn mégethos*) with an apparent width of about 90 m — a *plethron* corresponding to *c.* 30 m — before the ordinary solar disc congeals.

A Roman contemporary of Diodorus, Lucretius (*c.*99–*c.*55 BC; *On the Nature of Things*, 5.656–665) integrated the anomaly of Ida into his didactic poem on nature: "At a fixed time also Matuta diffuses the rosy dawn through the regions of ether and spreads out her light, either because the same sun returning under the earth takes his first hold on the sky as he tries to kindle it with his rays, or because there is a gathering together of fires, and many seeds of heat are accustomed to flow together at a fixed time, which make each day the light of a new sun arise: just as it is said that from the lofty mountain of Ida at sunrise scattered fires are seen, and then as it were these gather together into one globe and together form an orb"[10]. Here, Lucretius cites the observation from Ida as evidence for a theory that the Sun does not travel continuously around the Earth but is produced anew every morning by the convergence of many small fires. This was the contention of Xenophanes of Colophon (*c.*570–*c.*478 BC)[11]. Heraclitus of Ephesus (*c.*535–*c.*475 BC), too, taught that the Sun is new every day (Aristotle, *Meteorology*, 2.2 [355a]), but that was a case of renewal by rekindling rather than a fresh creation (scholiast on Plato's *Republic*, 498a)[12].

In his *Description of the World* (1.18 [94–95]), published around AD 43, the Roman geographer Pomponius Mela elaborated on the same marvel, informing that it would begin around midnight: "The mountain itself … reveals the rising sun differently from the way it is usually viewed in other lands. In fact, for people watching from the very peak, more or less from the middle of the night on, scattered fires appear to shine. The nearer the light draws, the more those fires appear to come together and to fuse with one another, until, as a result of being gathered closer and closer together, fewer fires are burning, and until, at the end, they burn with a single flame. After that light has blazed brilliantly, like a fire, for a long time, it compresses itself, becomes round, and turns into a huge

sphere. For a long time that sphere appears sizable and tied to the earth. Then it decreases little by little, becoming brighter the more it decreases. Last of all, it dispels the night, and, turning into the sun now, it rises along with the day"[13]. Pliny (*Natural History*, 2.8 [50]) touched on the subject, too, when dealing with the Sun's size: "… when it is rising its breadth exceeds Mount Ida, overlapping it widely right and left — and that though it is separated from it by so great a distance"[14]. More tersely still, Solinus (*Collection of Curiosities*, 11.7) remarked that Ida "sees the sun before sunrise"[15], but he believed this to concern the mountain's namesake on Crete. This will have been an error on his part.

Ultimately, these writers were probably all drawing on a single literary source that is not extant. A 19th-Century scholar fingered the historian Ephorus of Cyme (*c.* 400–330 BC) as the one on whom Diodorus and Mela relied[16]. While that may be so, the tradition must be at least as old as 415 BC, when the famous tragedian Euripides (*Trojan Women*, 1069) portrayed Mount Ida as "the boundary first struck by the sun" (*térmona te prōtóbolon halíō*)[17]. Xenophanes' place of birth was in western Asia Minor, just over 100 km south of Ida. Could it not be the very scene on Ida that inspired his quirky theory of the Sun in the first place? That much was proposed in 1894 by the French Egyptologist Eugène Lefébure (1838–1908), who adduced the passages from Lucretius, Diodorus, and Mela[18]. More recently, his Hellenist compatriot Paul Goukowsky attributed Diodorus' information to Cleostratus of Tenedos[19], an astronomer known to have made observations from Ida[20], which can indeed be seen from his native island. Goukowsky was oblivious to the parallel passage in Lucretius, which surely alludes to Xenophanes. However, given that Cleostratus' *floruit* is usually dated to the late 6th Century BC but exact dates are unknown, it seems possible that Xenophanes drew on his observations as he formulated his solar theory.

Dead ends

In a lecture he gave to Paris' Académie Royale des Inscriptions et Belles-Lettres on 1754 November 19, Jean-Jacques d'Ortous de Mairan (1678–1771) argued that the goings-on at Ida, as told by Diodorus, were displays of the *aurora borealis* viewed over its top from a location to its south[21]. Considering also that the northern lights would be expected to appear sporadically and in a northern direction, this interpretation conflicts with the textual evidence that the phenomenon was seen upon ascent of the mountain, regularly and culminating in the direction of sunrise. In auroral terms the gathering of the 'flames' would have to be a corona, seen when the auroral oval passes through the zenith, yet the type of aurora showing at Mediterranean latitudes is generally no more spectacular than a diffuse red glow or stable arc over the horizon. Also, aurorae are potentially visible at any time of the night, with a general focus on the hours around midnight. By contrast, the 'strange sunrise' at Ida was confined to the latter half of the night, ending in sunrise.

Goukowsky saw in the cited passages a reference to parhelia followed by a halo, the Bosporus apparently being favourable for parhelia[22]. This is not tenable either. While these optical effects are indeed most common when the Sun is near the horizon, they require that at least a part of the Sun be above the horizon (Aristotle, *Meteorology*, 3.2 [372a]) — and yet the lights at Ida manifested during the nighttime, even as early as midnight. Haloes and parhelia, also known as sun dogs, are concurrent with the Sun and do not 'transform' into it — unlike the stable "huge sphere" (*ingens globus*) towards the end of the sequence at Ida, that shrank and brightened to become the Sun. That 'sphere' was perhaps nothing

more than the arc of rosy twilight seen when the sky is still quite dark, at the onset of the true dawn. Equally incompatible with a halo is that the 'sphere' formed from 'one quantity' or 'single flame' that, in Mela's words, "becomes round" (*rotundat*) and thus must have had a very different shape.

In Goukowsky's view, the parhelia at Ida were "singular and strange" because no one before Anaxagoras (*c.* 500–*c.* 428 BC) attempted to explain parhelia. Yet, apart from the fact that the quoted sources all postdate Anaxagoras, wouldn't the Greeks have been familiar with parhelia from other places and have had a word for them anyway?

As a final objection, Diodorus timed the event to the rising of the Dog Star. This is doubtless the heliacal rising of Sirius. The heliacal rising of a celestial body is the annual occasion when it first becomes visible above the eastern horizon at dawn, just before sunrise. That of Sirius was historically the most important one, notably in Egypt. Taking axial precession into account, it transpired at 18–20 July in classical times[23]. According to Goukowsky, the point was that the calm weather prevailing during these dog days increased the likelihood of sun dogs. Perhaps this seasonal tranquility of air provided the Greeks with a rationale for the annual timing of whatever the mountain's great altitude enabled men to see, but parhelia are not bound to any particular season.

Nor is confusion with the Milky Way plausible. It is too static to suggest any convergence of flames, bears no special relationship to sunrise or Sirius' heliacal rising, and was too familiar to the ancients to evade recognition.

Joining the dots

It is surprising that d'Ortous de Mairan settled for the aurora, as this savant was renowned for his pioneering work on that as well as the zodiacal light. The long-lived mass into which the scattered 'flames' coalesce before the appearance of the normal solar orb is arguably the characteristic cone of the zodiacal light. This has actually been claimed, but apparently only once and long ago — by Lefébure[24]. The suggestion did not catch on and deserves now to be revived.

If Ida's dispersed 'fires' appeared on the exact days of Sirius' heliacal rising, the star would only have risen after their merger into the light of the true dawn. It is perfectly conceivable that Diodorus meant to indicate the beginning of a longer period, in which Sirius would eventually rise much earlier. That would be the time of year which Homer (*Iliad*, 5.5–6) poetically hinted at with the words "the star of harvest-time that shines brightest of all others when he has bathed in the stream of Ocean"[25]. D'Ortous de Mairan, who made this connection, seized on it to prop up his auroral explanation, but whereas northern lights are as likely in the spring as in the autumn, late summer is the season *par excellence* for the zodiacal light's pre-dawn appearance.

The scattered 'flames' that precede the phase of a single light, as seen from Ida, obviously involve more than just the classic cone of zodiacal light. The cone is only the most iconic component of a whole complex of forms that, to be fair to d'Ortous de Mairan, had not yet been described in his day. On the opposite side of the sky to the main cone, atmospheric backscattering can produce a dimmer or smaller cone known as the false zodiacal light[26]. Backscattering off interplanetary dust outside the Earth's orbit is the cause of a diffuse glow called the *Gegenschein*, which is German for 'countershine' or 'counterglow'. Situated exactly at the antisolar point, its position changes with the Sun's invisible passage below the horizon. Best seen around midnight, when it appears highest in the sky, in months when it is not in front of the Milky Way[27], it varies in shape from "small and somewhat elongated" to "very large and round"[28]. The

zodiacal band is sunlight reflected off dust outside the Earth's orbit that forms a narrow extension from a cone along the ecliptic. It is fainter still than the *Gegenschein*, which it flanks when seen together. Naturally, these features are most conspicuous in a clear, moonless sky. They are not as elusive as is widely believed, however[28].

In addition to this family of zodiacal-light phenomena, eyes fully adapted to very dark and clear skies should be able to see patches of airglow. This is a faint background luminosity to the sky, mainly produced by ultraviolet radiation in sunlight exciting atoms and molecules in the atmosphere; this process of photoionization is different from the excitation by charged particles from the solar wind, which causes the aurora. Airglow, or nightglow in this case, can exhibit some slowly changing structure, but is fairly uniform through the atmosphere. It appears brightest at about 10° above the horizon because of the greater depth of atmosphere an observer looks through at that level; further down, atmospheric extinction renders it invisible. This is consistent with Diodorus' mention of fires that "touch the earth's horizon".

Conjointly, airglow and the zodiacal-light complex offer a compelling explanation for the display of lights atop Ida. As argued, the cases of Casius and Caucasus can be seen in the same — zodiacal — light. A consistent impression emerges of Anatolian mountains renowned for the protracted 'dawn' perceived from their tops. Reminded of the contemporary practice of tourists scaling popular peaks for a sunrise experience, Lefébure suspected that the zodiacal light may have acted as a similar draw in ancient times. It may be rewarding to put the present argument to the test by visiting these mountains.

The zodiacal light, let alone the associated features, has been notoriously hard to detect in classical texts, or any ancient documents. It is, therefore, of considerable interest for the history of astronomy that the Graeco-Roman authors cited above should have unwittingly testified to these fascinating glows in the night sky. In retrospect, their take was not even all that far-fetched. They discovered the benefit of elevated vantage points and, airglow aside, correctly intuited the lights' correlation with the Sun's whereabouts.

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GSC 03937-02349: A SHORT-PERIOD W UMA BINARY WITH A MASSIVE COMPANION

By Christopher Lloyd[1], *Wolfgang Moschner*[2], *Peter Frank*[2], *and Klaus Bernhard*[2]

[1]*School of Mathematical and Physical Sciences, University of Sussex*
[2]*Bundesdeutsche Arbeitsgemeinschaft für Veränderliche Sterne e. V.*

The saw-tooth pattern seen in the O–C residuals of GSC 03937-02349 is attributed to the effect of a third body in the system in a circular orbit with $P_3 = 3{\cdot}87 \pm 0{\cdot}03$ yr. The short period and light-travel time $A = 0^{d}{\cdot}00765(14)$ combine to suggest a minimum mass of the companion $m_3 = 0{\cdot}95\ M_\odot$. Such a large mass is comparable to the likely mass of the primary component of the W UMa star, or it may be a binary in its own right. The companion probably contributes 70% of the luminosity of the system.

Close binary stars are frequently found in multiple systems[1,2], with the proportion of those with close companions ranging from at least 20%[3] to about 60%[4,5] for short-period systems. From a sample of 700 systems Latković *et al.*[3] found the median third-body period $P_3 = 10$ years and there are 12 systems listed with P_3 between 2 and 5 years. However, the best observed is probably the quadruple system, VW LMi, which has a 2+2 hierarchy with a $0^{d}{\cdot}477$ W UMa eclipsing binary and another non-eclipsing $7^{d}{\cdot}93$ binary in a 355-day orbit[6]. Companions of W UMa binaries range from low-mass ($m_3 \sim 0{\cdot}15\ M_\odot$) third bodies, *e.g.*, AM Leo[7], YY Eri[8], through intermediate, *e.g.*, V523 Cas[9], and relatively high-mass ($m_3 \sim 0{\cdot}8\ M_\odot$) companions, *e.g.*, VW Cep[10], ER Ori[11], to quadruple systems with the 2+2 hierarchy, *e.g.*, TZ Boo, V2610 Oph[2], and VW LMi[6], where the two binaries are of comparable mass.