Ammianus Marcellinus and Three-Dimensional Rainbows

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Abstract. We examine Ammianus Marcellinus' scientific digression on the rainbow, where the rainbow colors are listed in an unusual order. We suggest an explanation for the order and conclude that, according to a scientific theory current at the time, the rainbow was viewed as a three-dimensional arrangement in the sky, with colored bands positioned at different distances from the observer. This perspective aligns with the rejection of the Aristotelean rainbow theory, which is an evolution of ideas observable in its intermediate stages in Seneca's "Natural Questions" and in the commentary on Aristotle's "Meteorology" written by Alexander of Aphrodisias.

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Ammianus Marcellinus' description of the rainbow (Amm. 20.11.26-29) stands out for its presentation of rainbow colors, listing them in an unusual order: *prima lutea visitur, secunda flavescens vel fulva, punicea tertia, quarta purpurea, postrema caerulo concreta et viridi* ("the first is yellow, the second golden or orange, the third red, the fourth violet and the last one is approaching blue and green").[1] While translating color lexemes across cultures is notoriously problematic, the difficulty here lies not in the precise colors or their number, but in their order. How did Ammianus and other people of comparable education perceive the rainbow?

As far as extant literary sources go, ancient Greek and Roman descriptions of rainbow colors are scarce. The earliest is a poetic fragment of Xenophanes, which

[1] The English translation by J.C. Rolfe (Ammianus 2006) gives the colors as yellow, golden or tawny, red, violet, blue verging upon green. A Russian translation (Ammianus 2000) renders the first color (lutea) as "красный," which seems to be an editing error.

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lists three rainbow colors: πορφύρεον καὶ φοινίκεον καὶ χλωρὸν ἰδέσθαι (Xenophanes Frag. 13, Fairbanks 1898, 68), that is "violet, red, green." The order does not agree with the solar spectrum, but this may not mean anything. For one thing, hexameter would not allow "χλωρὸν" in the second position while keeping the overall phrase structure.

The first extant theory of the rainbow colors belongs to Aristotle (Arist. Meteor. 3.4 = 372a-375b, especially 374b31-375a4). Seneca's discussion of the rainbow (Sen. Nat. Q. 1.3) references Aristotle. A short treatment of the rainbow is preserved in Pliny (Plin. Nat. 2.60), although he does not delve into the specifics of the rainbow colors and merely observes that "*…colorumque varietatem mixtura nubium, ignium, aeris fieri*" ("…and the variety of colors is made by a mixture of clouds, fire and air"), a notion shared by Seneca. A long exposition on rainbow colors is found in the work of Alexander of Aphrodisias, in his commentary to the theory of Aristotle. Naturally, it is mostly a restating of Aristotle. But Ammianus is unique in that he earnestly lays out an explanation for the rainbow colors, one that is quite different from Aristotle's.

Aristotle recognizes four rainbow colors in an order that aligns with the modern view: τὸ φοινικοῦν, τὸ δὲ ξανθόν, τὸ πράσινον, τὸ ἁλουργόν (red, yellow, green, and violet)[2], from the outermost to the innermost part of the primary rainbow, while in the secondary rainbow the order is reversed. But his explanation of this pattern contains an odd twist. He begins with the general notion that colors are gradations of brightness. More exactly, colors are produced by differing degrees of attenuation of opsis.[3] Traveling through a semi-opaque medium, such as a cloud, opsis is naturally growing weaker with distance. The strongest, unattenuated opsis creates the perception of white, the embodiment of brightness. But under the circumstances of the rainbow, where opsis has to penetrate at least some water spray, the strongest remaining degree of opsis produces red, followed by weaker versions producing green and violet, after which no visible color is produced. Up to this point everything is quite logical, but now Aristotle runs into a problem: he cannot explain from geometry why a lower band of the primary rainbow requires opsis to travel a significantly longer distance. In other words, his theory explains the existence of rainbow colors, but not their spatial arrangement. To address this, Aristotle introduces an ad hoc idea that opsis attenuation depends on the size of the reflecting

[2] Aristotle declares that yellow is not a true color (see the next paragraph). For this reason, it is sometimes stated that Aristotle recognized only three colors in the rainbow.

[3] Gr. ὄψις, which can be translated as "sight." See Smith 2019 for details. It travels from the eye of the observer to the observed object. In the case of the rainbow it travels to the cloud, where it undergoes a reflection and then travels to the sun.

body: the opsis reflected by a greater arc, the top one in the primary rainbow, is the strongest (ἀπὸ μεγίστης γὰρ περιφερείας πλείστη προσπίπτει ὄψις πρὸς τὸν ἥλιον, μεγίστη δ' ἡ ἔξω, Arist. Meteor. 375a.4). This feels wrong (surely, a bigger body should not appear redder just because it is bigger), but it allows Aristotle to solve the problem: the order of colors in the primary rainbow is due to the angular sizes of the colored arcs. The explanation for the reversed order of colors in the secondary rainbow is yet again different, based on their proximity to the primary rainbow.

This line of thinking leads Aristotle into another difficulty: it does not explain the yellow. Yellow is a bright color, there is a lot of "whiteness" to it, it seems that it should not follow red. Aristotle resolves this by declaring that yellow is not a true color of the rainbow but is merely the result of mixing red and green. He says that in this mixing the red is whitened by the green: τὸ γὰρ φοινικοῦν παρὰ τὸ πράσινον λευκὸν φαίνεται. Hence, the thesis that yellow does not count is crucial to Aristotle, which explains why he repeatedly stresses the seemingly innocuous point that red, green, and violet – these and only these – are the true colors of the rainbow.

In this fashion, Aristotle arrives at the requisite outcome: the list of the three colors in the order of decreasing opsis (we might equivalently say, brightness) is the same as their spatial arrangement in the rainbow, though this comes from a rather tortuous argument. This did not go unnoticed. Indeed, Seneca's refusal to explain the rainbow color pattern shows that Aristotle's ideas were challenged. Seneca cites Aristotle and initially follows his lead, but he does not accept Aristotle's explanation of the color sequence. He writes at length that, as a general matter, reflection from water particles in the cloud produces various colors, sometimes one, sometimes another. Yet he flatly declines to speculate further (Sen. Nat. Q. 1.3.14): "*in aliis rebus vaga inquisitio est, ubi non habemus, quod manu tenere possimus, et late coniectura mittenda est*" ("in other matters it is a vague inquiry, where we do not have a firm grasp on anything, so it must be left largely to conjecture."). It is also significant that Seneca's colors are different and more numerous than Aristotle's three: "*umor modo caeruleas lineas, modo virides, modo purpurae similes et luteas aut igneas ducit*" (Sen. Nat. Q. 1.3.12), without saying that some of them are less true than others. In another passage (Sen. Nat. Q. 1.3.4) he lists three colors ("*videmus in eo aliquid flammei, aliquid lutei, aliquid caerulei*"), which are, perhaps, "red, yellow, blue." While these translations are only approximate, it is hard to imagine how to reconcile Seneca's language with Aristotle's φοινικοῦν, πράσινον, ἁλουργόν. This, too, looks like a tacit departure from Aristotle, which could be due in part to a cultural difference between the two authors.[4]

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[4] Whether Aristotle would admit that each of his colors could be subdivided into a number of varieties, is unknown. Therefore, when we see a 10-colored rainbow mosaic in

Seneca's testimony serves as an indication that Aristotle's theory of the rainbow pattern – though not necessarily his general theory of color – began to be discarded later in antiquity. This was done respectfully: Seneca never says explicitly that he is not giving credence to Aristotle, even though this is exactly what he is doing. The dissenting process, no doubt, continued, as seen in the case of Alexander of Aphrodisias (fl. 200 AD), the loyal commentator of Aristotle. While he does not protest against Aristotle's sleight of hand with the arc sizes, he raises a very sensible question (Alexandri in Arist. Meteor. 120v44 = Hayduck 1899:160): if, per Aristotle, the red in the secondary rainbow is due to the proximity to the primary rainbow, why isn't the entire region between the two rainbows also red?[5]

This brings us to Ammianus, who offers a glimpse into the state of thought in the 4th century. In line with the first part of his self-characterization as "miles quondam et Graecus," Ammianus makes no claim to original thinking. As in all his scientific digressions,[6] he merely conveys what he learned: "some people say that..." This is just as well, since we are interested not in his personal views, but in the science that was generally taught in his time. Here is the entire passage:

> Accedebant arcus caelestis conspectus assidui. Quae species unde ita figurari est solita, expositio brevis ostendet. Halitus terrae calidiores et umoris spiramina conglobata in nubes, exindeque disiecta in aspergines parvas, ac radiorum fusione splendida facta, supinantur volubiliter contra ipsum igneum orbem, irimque conformant, ideo spatioso curvamine sinuosam, quod in nostro panditur mundo, quem sphaerae dimidiae parti rationes physicae superponunt. Cuius species quantum mortalis oculus contuetur, prima lutea visitur, secunda flavescens vel fulva, punicea tertia, quarta purpurea, postrema caerulo concreta et viridi. Hac autem mixta pulchritudine temperatur, ideo ut terrenae existimant mentes, quod prima eius pars dilutior cernitur, aeri concolor circumfuso, sequens fulva, id est paulo excitatior quam lutea, punicea tertia, quod solis obnoxia claritudini, pro reciprocatione spiritus fulgores eius purissime e regione deflorat, quarta ideo purpurat, quod intermicante asperginum densitate, per quas oritur, radiorum splendor concipiens ostendit aspectum flammeo propiorem, qui color quanto magis diffunditur, concedit in caerulum et virentem.
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> Arbitrantur alii tune iridis formam rebus apparere mundanis, cum altius delatae nubi crassae radii solis infusi, lucem iniecerint liquidam, quae non reperiens exitum, in se

the II century BC Pergamon (Kiilerich 2021), it remains uncertain whether this is a challenge to Aristotelean science. In any event, the publication makes it clear that depictions of rainbows in late antiquity were chromatically varied.

[5] In recognition of this, that darker region is now known as Alexander's band.

[6] Other such digressions: earthquakes (Amm. 17.7.9-13), plagues (Amm. 19.4.2-7), eclipses and related phenomena (Amm. 20.3.2-12), meteors (Amm. 25.2.5-6), comets (Amm. 25.10.3), atoms (Amm. 26.1.1-2), calendar intricacies (Amm. 26.1.8-14).

> conglobata nimio splendescit attritu, et proximos quidem albo colores a sole sublimiore decerpit, subvirides vero a nubis similitudine superiectae, ut in mari solet usu venire, ubi candidae sunt undae quae litoribus illiduntur, interiores sine ulla concretione caerulae. (Amm. 20.11.26-29)

> More than this, rainbows were constantly seen; and how that phenomenon is wont to occur, a brief explanation will show. The warmer exhalations of the earth and its moist vapors are condensed into clouds; these are then dissipated into a fine spray, which, made brilliant by the sun's rays that fall upon it, rises swiftly and, coming opposite the fiery orb itself, forms the rainbow. And the bow is rounded into a great curve, because it extends over our world, which the science of natural philosophy tells us rests upon a hemisphere. Its first color, so far as mortal eye can discern, is yellow, the second golden or tawny, the third red, the fourth violet, and the last blue verging upon green. It shows this combination of beautiful colors, as earthborn minds conceive, for the reason that its first part, corresponding in color with the surrounding air, appears paler; the second is tawny, that is, somewhat more vivid than yellow; the third is red, because it is exposed to the brightness of the sun, and in proportion to alternation in the air absorbs its brilliance most purely, being just opposite; the fourth is violet, because receiving the brightness of the sun's rays with a thick rain of spray glittering between, through which it rises, it shows an appearance more like fire; and that color, the more it spreads, passes over into blue and green.
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> Others think that the form of the rainbow appears to earthly sight when the rays of the sun penetrate a thick and lofty cloud and fill it with clear light. Since this does not find an outlet, it forms itself into a mass and glows from the intense friction; and it takes the colors nearest to white from the sun higher up, but the greenish shades from resemblance to the cloud just above it. The same thing usually happens with the sea, where the waters that dash upon the shore are white, and those further out without any admixture are blue. (Trans. J.C. Rolfe, Ammianus 2006, 84–87).

We now understand why Ammianus lists the colors in such an order. It is the order of decreasing brightness or saturation, essentially the same notion as Aristotle's order of diminishing opsis. They are also in agreement on which colors are brighter than others. The difference lies in how this order is reconciled with the spatial pattern of the rainbow. It is achieved by introducing a curious but logically straightforward idea: the order of colors is spatial in the sense of progressing away from the observer (and the sun, which is behind the observer) into the cloud of water droplets. This can be seen from Ammianus' reasoning. The first and brightest color is yellow. Aristotle would clearly agree: this was the cause of a problem for him. Ammianus appropriately points out that yellow is close to the color of air itself – no significant attenuation by the water spray has happened yet. Then, as light (or opsis) penetrates deeper into the cloud, we naturally find a darker, more saturated version of yellow (*paulo excitatior quam lutea* – "tawny, … somewhat more vivid than yellow"). Next comes red, which for Aristotle, who treated yellow separately, was the first color of the attenuation scale. Ammianus' comment there is just along the lines of Aristotle: this layer is exposed to the sun and absorbs its brilliance. After that Ammianus skips the green color (this is what τὸ πράσινον of Aristotle is bound to be, since Aristotle locates it between yellow and violet) and arrives at a version of violet, similarly to Aristotle.[7] The explanation is consistent with Aristotle's theory: it receives light only after passing through "a thick rain of spray" – the condition which in Aristotelean terms means a thoroughly attenuated opsis.[8] Ammianus goes beyond violet, but employs a markedly different expression: "that color, *the more it spreads, passes over* (*quanto magis diffunditur, concedit*) into blue and green." He is speaking about the indistinct boundary between the proper rainbow and the sky.[9] At this point the explanation is finished. To this Ammianus adds an alternative explanation, less detailed and quite compatible with both Aristotle and Seneca, as it does not describe any specific color pattern.

It seems to us that the only plausible interpretation of Ammianus' words is that different color bands in the rainbow are situated at different distances from the observer and the sun. The rainbow, perceived as an object in the sky, is seen as three-dimensional – an arrangement of *voluminous* colored regions, some of which are at the forefront and others are farther back. This is an ingenious idea, although it runs contrary to the way most people (including, apparently, Aristotle) see a rainbow. The human brain typically perceives it as an object that faces us, as it were, with a flat[10] frontier. But in Ammianus' rainbow, the yellow band is the closest to us, the orange and especially red regions are farther back, and the violet is still farther. Perhaps, the rainbow was perceived as a sort of colored half-pipe,

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[7] We are not trying to match colors of Aristotle and Ammianus one-to-one. Color perception is culture-dependent and varies from one person to another. Moreover, even when studied with a spectroscope, a real-world rainbow is not equivalent to the solar spectrum: it is a rather complex atmospheric phenomenon.

[8] It is possible (and requires no modification to the argument) that the "violet" ("purpureus") of Ammianus referred to two bands on either side of the rainbow: the spectral violet color at the bottom and the transitional region between red and the darkened sky above it (known as Alexander's band). That second "violet" is essentially dark red, but it is perceived by some people as almost identical to the true violet. The author of this note admits to being one of those people.

[9] It may also be significant that the Latin word "caerulus" (blue) is etymologically related to "caelum" (sky).

[10] Not necessarily in the sense of a geometrical plane. Technically, a geometrical theory like Aristotle's may have maintained that the surface is slightly curved, being part of a very large sphere.

whose yellow middle bulges out towards us. Another possibility is that it was regarded as a collection of colored layers, some of which partially cover others.

That some people in antiquity adopted this counterintuitive concept is quite remarkable, as the adoption would have happened on purely rational grounds: following from the scientific principles of optics by inescapable logic. It is safe to assume that the idea was prevalent only among the literati, people who studied natural philosophy, although their occupation could be something entirely different, as in the case of Ammianus himself. Perhaps, it was the same class of people as those who viewed solar eclipses as natural phenomena and were not afraid of them, unlike the hoi polloi (Amm. 20.3.1).

Between the time of Aristotle and the time of Ammianus the theory of the rainbow had undergone a major transformation. Seneca neatly represents an intermediate stage of that process: he ignores Aristotle's explanation but does not yet suggest a replacement. In our view, the change is exactly what we should expect. On the one hand, the general principle of the Aristotelean theory (i.e., color as an expression of brightness, which is attenuated by distance traveled through a semi-opaque medium) was more or less kept, or at least not rejected outright.[11] On the other hand, it was noticed that Aristotle's application of that theory to the rainbow colors was unsatisfactory, and so this part of his work was politely omitted and eventually replaced by one or several alternative theories. We do not know whether Ammianus represents the final stage of the ancient theory of the rainbow or whether it continued to evolve.

Admittedly, perceiving the rainbow as anything other than a flat colorful band may seem like a strange notion. However, we can personally attest that once you see the rainbow this way, it becomes impossible to unsee.

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[11] The theory of colors evolved, but continuously, without breaking connection to Aristotle. Thus, the discussion of colors in Ptolemy's Optics (Ptol. Opt. 2.13-17; 2.23-25) is different from, but not in opposition to, Aristotle.

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