

Galileo's "Optical Theory" of Comets and Transients

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Abstract: In the light of a new set of sources, the "optical theory" of cometary transients advanced in *The Assayer* is presented against the background of coherent observations made earlier by Galileo and from the perspective of their subsequent development.

Keywords: Galileo Galilei, *Novae*, Comets, Neo-stoicism, Condensed vapours, Earthly exhalations, *Vapori crepuscolini*, Atmospheric refraction, Witelo, Jean Pena, Egnazio Danti, Optical theory, Telescope.

From an Optical Theory of *Novae* to a General Optical Theory of Transients

The topic of this brief contribution is the so-called "optical theory" of comets as received and developed by Galileo Galilei (1564-1642). I have adopted the label "optical theory of comets" from a seminal article by Professor Peter Barker, who has been analyzing the resurgence of Stoic theories about natural phenomena, including comets, between the sixteenth century and early seventeenth centuries (Barker 1994). I would like to integrate this line of research and approach the matter in a rather roundabout way, by showing the bigger picture that set the ground for the acceptance and development of the cometary theory by Galileo as part of a more general system of scientific explanation. Here, in particular, I focus on certain passages concerning Galileo's conjectures about the qualitative nature of the phenomena under analysis, while leaving in the background broader issues related to cosmology and planetary astronomy.

Following the chronological order, we shall start with an analysis of the surviving fragments of the lectures about the *stella nova* that Galileo gave in Padua. As known, in October 1604 what we have identified as the explosion of a dying star in the sky was witnessed with deep concern in lands and cities across the entire Northern hemisphere as an inexplicable and worrying event. In Padua as elsewhere, the leading mathematics lecturer was invited to publicly express his view. The observed decrease in luminosity suggested to Galileo that the nova might have had an upward receding motion. From its progressive uniform fading he deduced that its estimated motion was constant, while from the lack of any detectable angular parallax he deduced that the motion occurred in a straight line. The nova was therefore assumed to be in uniform rectilinear upward motion at constant velocity, far above the elementary region of the air. In Galileo's notes, we find a couple of undated plates on the nova. By the first plate, it is possible to see how Galileo originally intended to set his observation of the nova within a Copernican heliocentric framework. By the second plate, we learn how he intended to use the parallactic shifts that he expected for an observational confirmation of Earth's revolution around the Sun. Working on insights that he could read in Tycho's *Progymnasmata* and supposing that the nova moved steadily on along a line, as said, Galileo thought that the expected changing annual parallax could have falsified the geostatic hypothesis and confirmed the Copernican one (Cosci 2018).

In his teaching notes, after a rhetorical introduction, in which the planetary conjunction accompanying the bright phenomenon was mentioned, Galileo also reported to his audience an observation that he had made some time before. The memory that Galileo shared was about a phenomenon that he had witnessed while in Venice and that to his understanding could contribute to explaining the nature of the nova by analogy. He called it "aurora borealis", even if what he actually

meant was probably what Aristotle in his *Meteorology* had called “chasm” (χάσμα), i.e. a sort of diffused, nighttime light in the air also known as lower latitude Northern lights. He also offered his explanation of what was going on during the aurora:

it very often happens that vapors rise above the earth, and that in ascending, they reflect the light of the Sun, as when sometimes in the middle of the night the sky is in fact so greatly illuminated that it sheds more light on earth than does twilight. I have often observed this myself and always such a light appears towards the North. And the reason is obvious: it is because those vapors from the south that are trapped within the dark cone of the earth’s shadow either on the east or the west can, however, be seen above us to the north, such that they permit more diligent consideration. [...] very often vapors of this kind appear golden or reddish in colour (OG, II, p. 281. Tr. by E. Reeves).

For Galileo the nova was neither a star in the strict sense (“verum sidus”), nor a burning gas dwelling in the lower reaches of the elementary region of the air (“vapor ardens prope terram quaerentes”), as many of his colleagues believed. Galileo rather advanced the view that the *stella nova* might be illuminated exhalations (“esalazione illuminata”), whose matter was not a “solidissima substantia” (a solid object), but possessed the impalpability of the thinnest condensation (“levissima condensatio”) of smokes rising upwards because of the heat of the sun. The claim implicitly seemed to refer to the Aristotelian theory of exhalations (Cosci 2019) and to the Stoic doctrine of aerial condensations (Granada 1997a), while not being fully consistent with either of the two. A single ray of sun would have been sufficient to make that volatility shine, as happens – Galileo added – with clouds at the top of mountains, or even with more or less lucid or opaque objects, such as the stars and the moon respectively. After all, on earth objects made of different materials reflect light in different ways, he noted, so that it seemed reasonable to think that the same variety of reflections could also happen in the heavens. In this sense, condensed exhalations appeared to be a kind of rarefied, contingently aggregated substance that could cause light to bounce back in a bright and shining way, just like the phenomenon under observation (OG, II, pp. 282-283). Only fragmentary evidence of Galileo’s Paduan lectures on the topic is extant, but this is sufficient to reconstruct the theory. Besides, other documents confirm Galileo’s early views about the nature of nova. Both report on the lectures by Antonio Alberti and a pseudonymous *tacuinio* or meteorological pamphlet that was published in Padua and bears strong resemblances to Galileo’s teachings explain the nova as a cloudy, non-burning (i.e. reflected) exhalation. Even Pavan’s witty *Dialogo de Cecco da Ronchitti da Bruzene in perpuosito della stella nova*, which was most probably drafted by Galileo, has a line about this point: “Might it not be that the nova was generated in the air and then moved progressively upward?” (OG, II, p. 316). Peculiar as this theory may seem, even the Paduan Giovanni Antonio Magini, professor of mathematics in Bologna, maintained at that time that the nova was “ex vaporum materiam conflata”. The location of that condensation had to be superlunary, as this had been confirmed by parallactic measurements. According to Galileo, it was not implausible for condensation to occur in that higher region, by analogy to the aura or candour visible around the Moon. Therefore, Galileo first and foremost adopted what was known as the “optical theory” of comets as an explanatory conjecture for making sense of the visible nature the nova of 1604.

In the *Sidereus Nuncius*, Galileo also refers to the theory of vapours and exhalations at least in a couple of passages. First, when discussing so-called ashen light, or the secondary light of the Moon, he advances the idea of a sort of elementary region surrounding the Moon with a soft luminous effect. This description echoes the one given for the same phenomenon in the context of the analysis of the nova. The Moon’s secondary light (“secunda claritas”), Galileo says, “comes about because of the proximity of the solar rays falling upon some denser region which surrounds the Moon on all sides (“crassiozem quandam regionem, quae Lunam orbiculariter ambit”). Because of this contact a certain dawn light (“aurora”) is spread over nearby areas of the Moon, just as on Earth twilight is spread in the morning and evening (“crepusculinum spargitur lumen”)” (OG, III, p. 73). The observation is reiterated in the

very conclusion of the sidereal notice and extended to Jupiter too: “It is well known that because of the interposition of terrestrial vapours the Sun and the Moon appear larger [...] not only the Earth but also the Moon has its surrounding vaporous orb (“suum habere vaporosum orbem circumfusum”). And we can accordingly make the same judgement about the remaining planets, so that [for one] it does not appear inconceivable to put around Jupiter an orb denser than the rest of the ether (“densiorem reliquo aethere [...] orbem”) (OG, III, pp. 95-96). In all likelihood, Galileo consulted on this point his friend Paolo Sarpi, who in his private *Natural, Metaphysical, Mathematical Thoughts* had studied the “vapori crepuscolini” in relation to Cusano’s contribution, too. It should be stressed however that Galileo’s understanding of the dynamics of vapours within the twilight was based on the two medieval authorities on the topic, namely Pseudo-Alhazen’s *De Crepusculis et Nubium Asensionibus* and the tenth book of *De Perspectiva* by Witelo, or Vitellione (nicknamed *vedéo*, or “calf”, by Cecco). They were published together in the elegant Nuremberg print by Friedrich Risner and marketed as the *Opticae Thesaurus*, whose first edition Galileo owned in his personal library. In there he could read extensive geometrical discussions, among the other remarks, about how refraction of light changes through a more or less dense medium such as the condensation of air rising from the ground at sunrise or at sunset. The treatise on refraction by Witelo was the object of a much renowned commentary by Kepler, the *Astronomiae Pars Optica*, namely another book that Galileo possessed and consulted since the time of his studies on the nova. There Kepler condemned the belief according to which the body of a comet is something solid as an “enormous monstrosity”. Instead, the Imperial mathematician concluded that the body of a comet consists of a certain moist and pellucid substance denser than air. By “pellucid” (*pellucidum*) Kepler meant a transparency that becomes visible when shone through by some rays of light. One may reasonably argue that “pellucid” was exactly the adjective that Galileo was looking for in these regards.

Continuing our survey, in the *History and Demonstration Concerning Sunspots* (to not forget ... *and Their Accidents*), the mutability of sunspots is compared to the variability of our clouds. In Galileo’s terminology, sunspots are the clouds of the sun or, better put, what are clouds for the Earth are sunspots for the sun, namely exhalations from its incandescent surface. The fact that they appear dark to us is probably because these exhalations are illuminated from the back and their semi-magmatic density does not allow any light to pass. As Galileo wrote: “the spots appear and disappear around the Sun in a manner not dissimilar to that of clouds or other smoke-laden vapours around the Earth” (OG, V, p. 236). In an interesting subsequent passage, Galileo hints at the principle behind the cloud-analogy as a sort of extension to far-reaching astronomy of the more verifiable meteorological knowledge: “we mustn’t despair of understanding certain properties in the most remote bodies any more than in the closest ones” (OG, V, p. 183). Illuminated vapours and exhalations may offer an explanation of phenomena that are not immediately graspable through our senses or instruments.

In their *Discourse on comets* Galileo and Guiducci developed some ideas taken from Santucci’s astronomical *Trattato nuovo delle comete*, published eight years earlier, and shared his method of taking Aristotelian assumptions seriously and using them to find contradictions in Aristotelian doctrine itself. Their rejection of the theory of ignition and combustion of comets did not imply a rejection of the theory of exhalation, which was also assumed at the basis of their optical theory of comets. Indeed, they maintained that comets appeared whenever there was the right amount of condensed matter beyond the air and some solar rays hitting that condensation at the right angle. In short, to them comets were like clouds transversely illuminated by the sun. Likewise, in *The Assayer* Galileo wrote about the nova of 1604: “it is not impossible that sometimes there may be raised from earth exhalations and other such things so much subtler than usual that they would ascend even to the moon, and might be material for the formation of a comet; and that sometimes there occur unusual sublimations of the twilight material, as exemplified by the aurora borealis [...] Likewise, straighty motion upward is attributed to the same material” (Drake-O’Malley, 1960, p. 233). The proposal was advanced neither as a mere rhetorical strategy to contradict Grassi, nor as an *ad hoc* hypothesis, but as a genuine and legitimate scientific

conjecture, which was more plausible than than the Aristotelian or Tyconic alternatives according to its proponents (cf. Beltrán Marí 2016, pp. cxii-cxviii). The almost imperceptible “matter that constitutes a comet is thinner and more rarefied than fog or smoke”, Galileo specified (OG, V, p. 183). Consequently, he hypothesized that the thinning out of the illuminated vapours would cause the disappearance of what *we see as* a comet. According to him, the fading away of a comet is the same process that takes place when a rainbow disappears as soon as the clouds vanish. Galileo and Guiducci linked their theory to that of the ancient Pythagoreans, Hippocrates of Chios and Aeschylus, but as Grassi remarked in his *Libra*, those ancient Pythagoreans actually maintained that only the tail of the comet was the result of solar reflection, not the whole comet as Galileo and Guiducci claimed. In actual fact, that was rather the theory of a Peripatetic, namely Strato of Lampsacus, but Galileo probably had good reason to associate his theory with some Pythagoreans who were implicitly regarded as Proto-Copernicans. Grassi also claimed that Galileo’s optical theory was merely a reworking of the optical theory of unhorthodox thinkers such as Cardano and Telesio. Galileo denied this dependence, and we can believe him, because on closer inspection their theories differ in many details (Granada 1997b). As we shall see, other sources of influence can be proposed in their place.

I would venture to argue that in the *Discourse on Comets* and *The Assayer* Galileo tried to broaden the “optical theory” of comets into a sort of “general optical theory” of transitory phenomena. Starting from his conclusions on the nova, and having made use of them in his *History and Demonstration Concerning Sunspots*, he then intended to develop a consistent and unified explanation for different phenomena such as iridescences, halos, mock suns, sunspots, comets, and even “chasms” (χάσματα), i.e. a kind of aurorae borealis. Again, the physical constitution of all these phenomena, or optical reflections (which is what Galileo maintained they were), was essentially thought to be a solar-illuminated mass of exhalations rising from the Earth to the far recesses of the cosmos. Essentially, Galileo classified all those meta-meteorological transients under the Aristotelian category of φάσματα (*phasmata*) or illuminated appearances.

In this regard, I wish to emphasize and endorse the insight by Massimo Bucciantini according to which “Galileo’s studies on *novae*, like his writings on sunspots and comets, should be read as a chapter from the same book and as part of the same project. [...] The studies on *novae*, those about sunspots and what feeds them, and those on the matter of comets are intended to demonstrate the unity and homogeneity of the natural world, a necessary condition for the scientific foundation of Copernican cosmology” (Bucciantini 2000, pp. 270-271; my transl.). The interpreter asked himself what may have been the source of Galileo’s “optical theory of comets”. A good candidate might have been Christoph Rothman’s *Discourse on the Comet of 1585*, where one finds strong similarities with Galileo’s theory. However, this is not an exact match: the corporeal, or globular, nature of Rothman’s comets and their potentially divine origin are not consistent with Galileo’s view (OG, V, p. 272). I am rather persuaded that the actual source behind the Galilean optical theory of comets was another supporter of the neo-Stoic, or quasi-Stoic, view of the world, namely the French mathematician Jean Pena. This can be argued as follows.

In 1604, when the nova appeared, Galileo was teaching the course on geometrical planetary astronomy in Padua. As we know from the preserved *rotuli*, or syllabi for that year, his assigned textbooks were Sacrobosco’s *Sphere* and Euclides’ *Optics*. The standard Latin translation of the latter was the one by Ioannes Pena (Jean de La Pène), who also wrote the introduction entitled *De usu Optices*, originally in 1557. In that preface Pena observed, following Peter Apian and some of his contemporaries, that the tail of the comet always pointed in the opposite direction of the Sun. He concluded that the antisolarity of the cometary tails was a sign that they may have been just passing glares or optical illusions. Tails refracted in such a manner required cometary heads made of transparent substance denser than air, he maintain, that could not be fire, which was incapable of refracting sunlight. In all probability, then, that preface was indeed the source that inspired Galileo’s understanding of cometary phenomena.

The text by Pena and Euclide's *Optics* were available to Galileo (also in Egnazio Danti's vernacularization) in the early years of his Paduan lectureship, so they could have had an impact on all his subsequent studies on transients.

References to the theory of condensation and rarefaction of the air did not end with *The Assayer*, as has sometimes been stated. In the second day and the fourth, the *Dialogue Concerning the Two Chief World Systems* repeats an argument that Galileo had originally advanced in the *Discourse on the Tidal Flux and Reflux of the Sea*, which in turn was taken straight from Copernicus's *De Revolutionibus* (book I, chap. 8): "The air, at least that part of it which is lower than the highest mountains, must be swept and carried along by the unevenness of the Earth's surface [...] because it is a mixture of many vapours and exhalations coming from the Earth". According to both Copernicus and Galileo, this reason explains why we are unaware of the motion of our globe while we are on the ground and why we can perceive strong wind while far out at sea. Most significantly for our purposes, this argument confirms the presence of constant evaporation and exhalations arising from the earth: "those parts of the air that are close to the Earth's surface or do not extend far above the top of the highest mountains [...] are carried along by the roughness of the Earth's surface. This part of the air ought to be all the less resistant to following the Earth's rotation because it is full of vapours, fumes and exhalations, all of which partake of the qualities of earth, and so naturally follow the same motions" (OG, VII, p. 465). Copernicus (who had "aer terrea aqueave materia permixtus") seems to be quoted word by word by Galileo with regard to this point. Transitory natural phenomena seem to be made of this kind of matter, in the heavens as much as on earth. The alleged distinction between the alterable sublunary world and the incorruptible superlunary spheres therefore falls apart also from this point of view. Besides this passage, the discussion of atmospheric refraction and the nova of 1572 in the *Third Day* is still grounded on the optical theory of exhalations.

In the immediate aftermath of the publication of the *Dialogue*, Galileo filled the margins of his copy of the resentful *Philosophical Exercises* by Antonio Rocco with handwritten annotations. We can read Galileo's reiteration of his exhalation-based interpretation of the nova thirty years after its original formulation: "whatever matter – he wrote – can be seen, be it just a little or by no means transparent, will appear as bright as a star whenever it is exposed to sun rays" (OG, VII, p. 719). As before, the nova of 1604 was believed to have an ascending motion, due to its apparently receding path and the vaporous nature of its essence.

Among the papers on the *Astronomical Operations* from 1637 we find a meteorological fragment that also refers to the theory. Here Galileo answers the (apparently childish) question of why there are often storms on mountain tops. Unsurprisingly, he resorts to the Aristotelian distinction between wet and cold vapours and hot and dry exhalations. When in the summer the sun is at its highest point, the former arise from the south face of the mountains, the latter from the north. As often as the fluxes of the two different streams of air merge at the summits, storms take place. The effect – Galileo specifies – is stronger on the mountaintops than on plains or on surfaces of water, because on plains there is less contrast, while water disperses the heat faster (OG, VIII, pp. 630-631). Note that Galileo's explanation does not refer only to the difference in temperature, but also to the quality of air.

Such a distinction can also be found in Galileo's *Discourses and Mathematical Demonstrations Relating to Two New Sciences* from 1638. A passing reference to the power of bellows (*mantici*) to heat embers for melting metals, if the air that they blow is mixed "with thick, and not humid, vapours", confirms the persistence of the dichotomy (OG, VIII, pp. 87-89). In the same context, when trying to answer the difficult question of whether light has motion or is instantaneous, Galileo recalls an experiment he made at the time of the nova, once again proposing a comparison with observable cloudiness. The observation of a mass of clouds, such as a cumulonimbus, reflecting and diffusing the light of flashes and lightning through non-simultaneous propagation suggested to Galileo that the speed of light (or the expansion of the blaze, as he put it) does not happen instantaneously (OG, VIII, pp. 87-

89). Once again, observational meteorology, and particularly the model of illuminated clouds, offered him the solution to a problem of physics.

Finally, I wish to include in my analysis the astronomical *Considerations by Alimberto Mauri* on the new star of 1604. I shall make only a passing reference to the attribution process that over the last years has led me to ascertain Galileo's authorship of the pseudonymous treatise, as I instead wish to focus on a couple of passages of this treatise that are relevant for the present analysis. In short, the attribution was made possible, on the one hand, by the identification of a confusing letter as a forgery produced at the beginning of the twentieth century and, on the other hand, by my retrieval of a forgotten and unpublished private note in which Galileo disclosed his identity as Alimberto Mauri, who had been made an object of "contempt" in Delle Colombe's *Answers* (Ms.Gal.42, c.31r). Besides this, various other elements have confirmed the attribution, such as the additional contextual evidence collected by Stillman Drake in the 70s, a reasonable decoding of the pseudonym, multiple textual matches with other Galilean works, an autograph annotation, the exclusion of other potential authors of the text, and – last but not least – the fact that the name "Galileo Galilei" was plainly written by one of his colleagues' students on the frontispiece of his copy of the book under the name of Alimberto Mauri.¹

A first passage from this treatise which is relevant to the present topic is the observation that an object can reflect light regardless of the lucidity or opacity of its surface. Galileo-Mauri noted that in the heavens solar light can be reflected both by the stars that shine mainly by their own light, and by the Moon, which shines mainly by reflected light. As we have seen, we find the same remark in Galileo's fragments on the nova from 1604, where it is again used to justify the idea that a diaphanous amount of gas, such as vaporous exhalations, can diffuse and reflect light, giving the impression of a bright splendid star. The fact that stars, in particular, shed light through their own irradiated *aurae* or spheres of exhalations so that they appear to us larger than they really are, must be seen as a strong argument against the opponents of heliocentrism. For their main objection was that the size of the stars, as they appear, would be gigantic in comparison with the Sun, if the Copernican dimensions of the universe were accepted. But, Galileo-Mauri noted (with the support of Kepler's *De Stella nova*) that what we see are stars diffracting their light, and that therefore their real size must be much smaller and not as disproportionate as it may seem at first when adopting the Copernican system. This remark should be read together with the provocative suggestion that Copernicus can rather be understood in a non-hypothetical way (Mauri 1606, pp. 12v-13v; cfr. OG, VI, pp. 354-355).

A second passage from this treatise which is relevant in this context concerns the optical illusion of the Sun appearing larger at dawn and sunset. According to an ancient tradition dating back at least to Macrobius, the Sun seems larger when it is setting because it attracts more vapours and exhalations at twilight (*vapori crepuscolini*), so the condensation becomes denser around the earth and makes the image of the Sun seem bigger than at midday. Against this theory, Galileo-Mauri argues that the magnification is due not to the density of the transparent medium, but to the *concavity* of the interposed medium. In other words, it is the shape of the lenticular condensation, not its matter, that creates the impression of a visual enlargement of the observed object. Moreover, Galileo notes that another factor to account for is that the line of sight passing through such a medium is geometrically longer at the dawn and sunset. Optical experiences seem to explain why that factor is partly responsible for the solar illusion, as Witelo's *Perspectiva* had geometrically demonstrated before. Accordingly, Galileo-Mauri writes: "when we look at an object through a crystal of concave shape, experience teaches us that the farther we remove the said crystal from ourselves, the larger the object will appear to us, provided that there be between us and the crystal some quantity of water or other vaporous medium" (Mauri 1606, pp.

¹ Despite the astonishing silence surrounding the *Considerations by Alimberto Mauri*, this work can be regarded as the uncelebrated "Artist's Proof" from Galileo's Paduan period, as I like to call it, and as the missing prequel to the *Sidereus Nuncius*. A new edition of this pivotal work, which is not included in the National Edition of Galileo's works, is now in progress and it will include a commentary and a revision of the not always faithful English translation.

24r-v; cfr. OG, VI, p. 354). Regrettably, the accompanying image has been very often overlooked in the studies on Galileo's optics, but in my view, it illustrates *in nuce* the magnifying design of the optical ratio at the basis of the implementation of the Galilean telescope (Piccolino & Wade 2014, pp. 231-235).

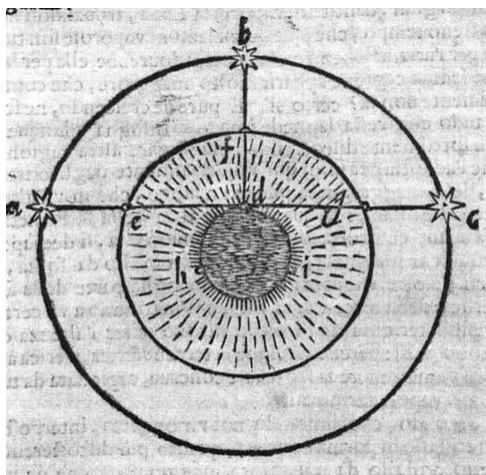


Fig. 1. “Here A represents the sun placed in the east; B, at noon; C, in the west; HDI, the surface of the earth; EFG, the concave surface caused by the vapors; D, our eye located on the surface of the earth. Thus it is clear that the visual rays leaving from point D to arrive at points A and C pass through points E and G, which are farther from point D than is point F, through which they pass to arrive at point B.” (Mauri 1606, p. 25r).

I must add that throughout the treatise Galileo-Mauri quotes Aristotle's *De generatione animalium*, which transmits the ancient belief according to which an observer can get a better view of the stars from a cave, or from the bottom of a pit, or through a *tube*, for that matter. The familiarity with *De generatione animalium* which Galileo makes quite plain, together with the solution to the Solar illusion, now allows us to read the following famous passage from the *Dialogue on the Two World Systems* as if Galileo were talking about himself (and not about Cesare Cremonini as has always been assumed):

[...] a doctor who taught at a famous university, on hearing a description of the telescope which he had never seen, said that its invention was derived from Aristotle. Calling for a copy of the text, he found where it explains why it is possible to see the stars in the sky in the daytime from the bottom of a very dark well. ‘Here’, he said to those standing around, ‘is the well, which represents the tube; here are the thick vapours, from which is taken the invention of the lenses; and here, finally, is how the sight is strengthened when the rays pass through a denser and darker transparent medium (OG, VII, p. 135).

According to my reading, this is precisely Galileo's description of *his own* reaction upon hearing of the invention of the Dutch telescope after his dispute with Delle Colombe. Aristotle as a source, thick vapours, Murano glass, corrective spectacles and the idea of a magnifying medium are all elements present in Mauri's neglected treatise. Famously, Sagredo replied to Salviati in a way that seemed to defend the unprecedented development represented by Galileo's most celebrated instrument: “saying that every kind of knowledge is ‘contained’ in this way is similar to the way a block of marble contains within it a beautiful statue, or rather a thousand beautiful statues: the key is being able to reveal them” (OG, VII, p. 135). Nonetheless, if read as an autobiographical statement, this passage shows that the acceptance of the Aristotelian theory of earthly exhalations not only helped Galileo to design a general theory of transitory natural phenomena, including comets, but also contributed to the development of

his *cannocchiale*, leading to the astronomical consequences we are all familiar with. The inclusion of “thick vapours” as an essential element in Galileo’s natural philosophy and cometary theory was not merely the residue of an outdated Aristotelian doctrine, but resulted in the atmospheric prototype of the Galilean telescope. As Salviati reported, it is “from thick vapours that the invention of the lenses derives”.

Acknowledgments

The research leading to this article has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 844152.

Bibliography

- Barker, P. (1994). “The Optical Theory of Comets from Apian to Kepler”, *Physis. Rivista Internazionale di Storia della Scienza*, XXX, pp. 1-25.
- Beltrán Marí, A. (ed.) (2016). *Cometas, ciencia y religión. La polémica Galileo-Grassi*. Madrid: Tecnos. [It develops: Beltrán Marí, A. (2011). “Tacite polemiche: Galileo, Orazio Grassi e la grande cometa del 1618”, *Giornale Critico della Filosofia Italiana*, XC, 2, pp. 237-273].
- Bucciantini, M. (2000). *Galileo e Keplero, Filosofia, cosmologia e teologia nell’Età della Controriforma*, Torino: Einaudi.
- Cosci, M. (2018), “Le fonti di Galileo Galilei per le *Lezioni e studi sulla stella nuova* del 1604”, *Archives internationales d’histoire des sciences*, 68, pp. 6-70.
- Cosci, M. (2019). “Aristotelian Cometary Theory in Italian: Effects of Comets from the Mid-Sixteenth Century to Galileo Galilei”, *Rivista di Storia della Filosofia*, 2019(2), pp. 343-360.
- Drake, S. & O’Malley, C.D. (eds.) (1960). *The Controversy on the Comets of 1618*. Philadelphia: University of Pennsylvania Press.
- Favino, F. (2004). “Contro Tycho. Per una lettura contestuale del *Discorso delle comete*”, *Galilæana*, XII, pp. 233-252.
- Gal, O. & Chen-Morris, R. (2011). “Galileo, the Jesuits, and the controversy over the comets: What was *The Assayer* really about?”, in Dascal M. & Boantz V.D. (eds.), *Controversies Within the Scientific Revolution*. Amsterdam: J. Benjamins, pp. 33-52.
- Galilei, G. (2023). *Il Saggiatore*. Edited by Camerota, M. & Giudice, F. Milano: Hoepli. [This last edition comes after those of Favaro, Pagnini, Sosio, and Besomi & Helbing].
- Granada, M.A. (1997a). “Giordano Bruno et ‘Le banquet de Zeus chez les Éthiopiens’: La transformation de la doctrine stoïcienne des exhalaisons humides de la terre”, *Bruniana & Campanelliana*, III(2), pp. 185-207.
- Granada, M.A. (ed.) (1997b). *Bernardino Telesio. Sobre los cometas y la Vía Láctea*, Madrid: Tecnos (in partic. pp. LXXVIII-C).
- Guerrini, L. (2010). *Galileo e gli aristotelici: storia di una disputa*. Roma: Carocci (in partic. Ch. 1, “Galileo, gli aristotelici e la cometa”, pp. 43-101).
- Heidarzadeh, T. (2009), *A History of Physical Theories of Comets, from Aristotle to Whipple*. New York: Springer (in partic. pp. 61-64).
- Mauri, A. (1606). *Considerazioni... sopra alcuni luoghi del discorso di Lodouico delle Colombe intorno alla stella apparita [nell’anno] 1604*. Firenze: G.A. Caneo.
- OG - *Le opere di Galileo Galilei*, Edizione Nazionale (20 vols.), a cura di Favaro, A. (1890-1909). Firenze: Barbera; ristampa 1962-1964.
- Piccolino, M. & Wade, N.J. (2014). *Galileo’s Visions. Piercing the Spheres of the Heavens by Eye and Mind*. Oxford-New York: Oxford University Press.