The concept of gravity before Newton

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Abstract. This paper briefly describes a non-Aristotelian theory of gravity developed in the Hellenistic period and discussed in Plutarch's dialogue *De Facie quae in Orbe Lunae apparet;* it also shows the influence of this dialogue on Copernicans before Newton.

Introduction

The subject suggested by the title of this paper would obviously cover a vast historical domain. I will simply focus on the origin and transmission of a non-Aristotelian concept of gravity from the Hellenistic epoch to the beginning of modern science, and I will only follow the history of a single but significant text. It is well known that Aristotelian physics played a dominant role before the modern scientific revolution.[1] According to Aristotle (384 BC – 322 BC), heavy bodies move according to their natural motion, i.e., towards the centre of the universe, which is coincident with the centre of the earth. Moreover, the speed of falling bodies is proportional to their weight and is the inverse of the resistance of the medium; therefore, in the absence of any medium, resistance would be zero and the speed would tend to infinity, an absurd conclusion which constitutes an argument against the existence of void space. Matter is made by the combination of four elements and each element is characterized by a couple of qualities: earth, cold and dry; water, cold and wet; air, hot and wet; fire, hot and dry. While the sublunar world is subject to change and corruption, celestial bodies follow their perfect and eternal circular motion and are made by a fifth element, called aether (or quintessence from the Latin *quinta essential*).[2] In order to describe these motions, Aristotle adapted the homocentric spheres of Eudoxus,

[1] A clear and well-balanced synthesis of Ancient and Medieval science (including Aristotle's physics) is in David C. Lindberg, *The Beginnings of Western Science (*The University of Chicago Press 2nd edition, 2007).

[2] These names have resurfaced in modern science to identify an invisible substance filling the space: first the aether in the nineteenth century, then the quintessence at the end of the twentieth century.

Alberto Cappi, 'The concept of gravity before Newton', eds. Nicholas Campion and Rolf Sinclair, *Culture and Cosmos*, Vol. 16 nos. 1 and 2, 2012, pp. 207-218.
www.CultureAndCosmos.org

transforming a purely geometrical model into a mechanical working system. The Aristotelian *kosmos* is finite, limited by the sphere of the fixed stars and nothing exists beyond this sphere.

Another interesting aspect of Aristotle's cosmology is that other universes cannot exist for physical reasons because: a) being spherical, voids would be left between them; b) with as many centres as *kosmoi,* it would be impossible to define the natural motion of heavy bodies in an unambiguous way. From an aesthetic point of view, the Aristotelian universe has its elegance: we can find its modern reincarnation in the first relativistic model of the universe proposed by Einstein in 1917, which is also eternal, finite and spherical ('spherical' has of course a different meaning in the two cases), with nothing outside.[3]

The Hellenistic scientific revolution

It is important to stress that Greek science was not limited to Aristotle. Concerning Greek cosmology, Furley identifies two main traditions, the first characterized by permanence and teleology and represented by the *Closed World* of Plato and Aristotle, the second characterized by evolution and mechanism and represented by the *Infinite Universe* of Democritus and the Atomists.[4] Properly speaking, the Atomists believed that our *kosmos* is limited by the sphere of the fixed stars, but as they assumed the existence of an infinite void, they postulated the existence of

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[3] The Italian poet Giacomo Leopardi, comparing the universe to the surface of the earth, seems to have anticipated an essential feature of Einstein's finite universe. In a note written in September 21, 1827 (*Zibaldone*, p. 4292 (www.leopardi.it/zibaldone14.php) he observed:

> Believing in the infinity of the universe is an optical illusion: at least this is my own opinion. […] -When I look at the sky-, someone told me, -and when I think that beyond those visible bodies there are other and still other bodies, my thoughts cannot find any limit, and the probability makes me to believe that there are other bodies without an end. The same, I say, happens to a child, or an ignorant, observing from a high tower or mountain, or in the sea. He looks at the horizon, knowing that beyond that horizon there is still earth or water, without an end; and concludes, or would like to conclude, that the earth or sea are infinite.

[4] D. Furley, *Greek Cosmologists* (Cambridge: Cambridge University Press, 1987); but we can also find intermediate conceptions. Moreover, for early Greek philosophy we should better speak of materialism instead of mechanism; see Sylvia Berryman, *The Mechanical Hypothesis in Ancient Greek Natural Philosophy (*Cambridge: Cambridge University Press, 2009).

other *kosmoi*; therefore from the point of view of the knowledge of their time, the Atomists believed in other universes; but from our point of view their universes correspond to other planetary systems. It is also worth mentioning that many natural philosophers before Aristotle did not separate the sublunar region from the other celestial bodies. For example, Empedocles of Acragas believed that the heavens are prevented from falling by the speed of their whirling motion.[5] Moreover, in late Antiquity we find criticisms to Aristotle's physics, such as the commentaries of Themistius (317-387), or Simplicius and particularly Philoponus in the 6th century (criticisms which were also known to Galileo).

Of special interest is the period immediately following the death of Aristotle (and Alexander the Great), that is, the first part of the Hellenistic epoch (third-second century BC), corresponding to the golden age of science and technology in Antiquity. Unfortunately, few works survived among those which did not support the (later) dominant Aristotelian and Ptolemaic systems, and/or among those which were too difficult and technical to be understood after the end of the Hellenistic science. This explains why we have Pliny's *Natural History* or Seneca's *Naturales Quaestiones*, but no work of Hipparchus (except his comments to the popular Aratus' *Phenomena*).

According to Lucio Russo, the first Hellenistic epoch saw the first true scientific revolution, whose recovery in modern times was crucial for the birth of modern science.[6] I will not enter in such a controversial debate, but it is out of question that Hellenistic science reached very important results in a relatively short time. When the explanations of Aristotle did not work, they were abandoned, even in his own school, the Lycaeum. For example, the successor of Theophrastus to the head of the Lycaeum, Strato of Lampsacus, considered the greatest 'physicist' of his time, claimed the existence of voids in matter and proved that falling bodies accelerate.[7] He was invited by Ptolemy Sother

[5] According to Aristotle, *De Caelo*, II.1.

[6] Lucio Russo, *The Forgotten Revolution* (Heidelberg and New York: Springer-Verlag, 2004).

[7] For Strato see Diogenes Laertius, *Lives of Eminent Philosophers*, trans. R.D. Hicks (Cambridge: Harvard University Press, 1972), Book V, ch. 3. From the fragmentary and indirect evidence, it is not clear what Strato had in mind when speaking about voids, and scholars have given different interpretations: see David Furley, *Cosmic Problems* (Cambridge: Cambridge University Press, 2009), pp.150-153. For the acceleration of falling bodies see Simplicius in his

to Alexandria, where he helped to organize the Museum, which can be considered as the first research institute funded by a state; one of his disciples was Aristarchus of Samos, the first proposer of the heliocentric system. This might not be a coincidence: the heliocentric system is inconsistent with Aristotelian physics, and Strato's critical attitude could have helped Aristarchus to be open-minded in seeking alternatives to the geocentric system. The *Mechanica (Mechanical Problems)*, attributed in the past to Aristotle (now generally considered a product of the Aristotelian school, perhaps with the contribution of Strato), also shows the progress of the science of mechanics within the Aristotelian school.[8]

Plutarch's *De Facie* and a new theory of gravity

Evidence for non-Aristotelian ideas is not limited to scientific texts. Let us consider the following quotation:

> Yet the moon is saved from falling by its very motion and the rapidity of its revolution, just as missiles placed in slings are kept from falling by being whirled around in a circle. For each thing is governed by its natural motion unless it be diverted by something else.[9]

Contrarily to its Newtonian appearance, these words were written nearly two thousand years ago by Plutarch (c. 46 – 120 CE) in his dialogue generally known under the Latin title *De Facie Quae in Orbe Lunae Apparet* ('Concerning the face which appears in the Orb of the Moon'), belonging to the *Moral Essays* (*Moralia*). The starting point of this dialogue is the cause of the apparent 'face' we see on the moon, which is in fact a pretext for a more general discussion on other subjects. Among them, an important place is given to non-Aristotelian physics. Plutarch

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Commentary on the Physics, and Edward Grant, *A Sourcebook in Medieval Physics* (Cambridge: Harvard University Press, 1974), p. 277, footnote 28.

[8] In Furley, *Greek Cosmologists*, p.196:

> At all events, his [Aristotle] notion of natural lightness was not found generally acceptable in the Hellenistic period. Like his definition of place, it appears to have been rejected by Strato, who was ready to accept a relativistic account of the distinction […]. There is evidence that the Stoics also abandoned the idea of natural lightness, and the Epicureans certainly rejected it.

[9] Plutarch, *De Facie quae in Orbe Lunae Apparet*, 923 E, in *Moralia, Vol .XII,* Loeb Classical Library.

was an intellectual with a wide range of interests, but neither a natural philosopher nor a mathematician[10]. Russo suggests that the Hellenistic astronomer Hipparchus (second century BC) could be the original source of the non-Aristotelian theory of gravity discussed by Plutarch. According to Simplicius, Hipparchus wrote a work (now lost) on gravity where he conceived a sort of theory of *impetus* (unfortunately Simplicius is not clear and does not give much detail).[11] This probably inspired the medieval theory and was rediscovered by Galileo in his treatise *De Motu.*[12] In any case, whoever was the author, we have to reconstruct this theory from fragmentary and indirect references. According to the theory described in the *De Facie*, the moon has the same nature as the earth, and gravity cannot be explained as the natural motion of heavy bodies towards the centre of the universe:

> […] <the downward tendency> of falling bodies proves not that the <earth> is in the centre of the cosmos but that those bodies which when thrust away from the earth fall back to her again have some affinity and cohesion with her. For as the sun attracts to itself the parts of which it consists so the earth too accepts as <her> own the stone that has properly a downward tendency, and consequently every such thing ultimately unites and coheres with her.

Gravity is therefore a universal property of matter. But this universality refers only to matter of the same kind: the moon is attracted by the earth, but not the sun, which has a different constitution. However, the sun and the other planets possess their gravity, and this property also implies that they have a spherical shape like the earth. Such a relativistic, polycentric theory of gravity, which represents a significant step towards Newton's idea of universal gravitation, abandons the belief in a centre of the world and has interesting implications for the existence of other worlds. In the *De Facie,* Plutarch makes a clear distinction between our world, in its

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[10] In S. Sambursky, *The Physical World of the Greeks 2nd edition (*London: Routledge, 1960), the *De Facie* is described in chapter IX, under the title 'The Beginnings of Astrophysics' (p. 204)!

[11] Simplicius, *Aristotelis De Caelo Commentaria*, Vol. VII 264:25-26. Simplicius gives us the title of Hipparchus work: *On bodies thrust down because of gravity (Περὶ τῶν διὰ βαρὺτητα κὰτω φερομένων*).

[12] Stillman Drake, *Galileo: Pioneer Scientist* (Toronto: University of Toronto Press, 1990), Chapter 4.

meaning of our universe limited by the celestial sphere, constituting the *kosmos* (ὁ κόσμος), and the sum of things, representing the totality of what exists, the *whole* (τὸ πάν):

> The sum of things is infinite […] He who asserts that the earth is in the middle not of the sum of things but of the cosmos is naïve if he supposes that the cosmos itself is not also involved in the very same difficulties.[13]

But the distinction between our universe and the sum of things opens the possibility that outside the limits of our *kosmos* something else exists. Plutarch discusses extensively the existence of other worlds in another dialogue of the *Moralia*, *De Defectu Oraculorum* (*The Obsolescence of Oracles*):

> But to make more worlds than one, each separate from the other, and to delimit and distinguish the parts belonging to each to go with the whole is not preposterous. For the land and sea and heavens in each will be placed to accord with nature, as is fitting; and each of the worlds has its above and below and its round about and centre, not with reference to another world or the outside, but in itself and with reference to itself.[14]
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> Thus one conclusion is left: when the centre is spoken of, it is not with reference to any place, but with reference to the bodies.[15]
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> For the law of reason over each world, having control over the matter assigned to each, will not allow anything to be carried away from it nor to wander about and crash into another world, nor anything from another world to crash into it, because Nature has neither unlimited and infinite magnitude nor irrational and disorganized movement.[16]

Notice the correlation between the theory of gravity and the hypothesis of other universes. Only abandoning Aristotelian physics, in particular its

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[13] *De Facie*, 925F.

[14] Plutarch, *De Defectu Oraculorum*, 425B-C, in *Moralia*, Vol. V, Loeb, Classical Library.

[15] Plutarch, *De Defectu Oraculorum*, 424-E.

[16] Plutarch, *De Defectu Oraculorum*, 424A-B.

idea of an absolute centre and its negation of the existence of void, it is possible to conceive other worlds. It is worth mentioning that there are also theological implications in this new vision: an example is given by the following quotation from the *De Defectu Oraculorum*:

> Then again, who could feel alarm at the other notions of the Stoics, who ask how there shall continue to be one Destiny and one Providence, and how there shall not be many supreme gods bearing the name of Zeus or Zen, if there are more worlds than one? For, in the first place, if it is preposterous that there should be many supreme gods bearing this name, then surely these persons' ideas will be far more preposterous; for they make an infinite number of suns and moons and Apollos and Artemises and Poseidons in the infinite cycle of worlds. But the second point is this: what is the need that there be many gods bearing the name of Zeus, if there be more worlds than one, and that there should not be in each world, god possessing sense and reason, such as the one who among us bears the name of Lord and Father of all? Or again, what shall prevent all worlds from being subject to the Destiny and Providence of Zeus, and what shall prevent his overseeing and directing them all in turn and supplying them all with first principles, material sources, and schemes of all that is being carried out?[17]

The heritage of Plutarch's *De Facie* from Copernicus to Newton

The *De Facie* survived, and it is fascinating to see its influence, or the resurgence of some ideas discussed in it, at a much later epoch. The heliocentric system requires a non-Aristotelian physics, and it is not surprising that the modern proposer of the this system, Nicolaus Copernicus (1473-1543), suggested an alternative to Aristotelian physics:

> For my part, I think that gravity is nothing but a certain natural striving with which parts have been endowed [...] so that by assembling in the form of a sphere they may join together in their unity and wholeness. This tendency may be believed to be present also in the sun, the moon, and the other bright planets, so that it makes them keep that roundness which they display[18].

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[17] Plutarch, *De Defectu Oraculorum,* 425E-F.
[18] *De Revolutionibus*, I, 9.

Concerning this initial part of the *De Revolutionibus*, Edward Rosen notes:

> Copernicus's theory of gravity postulated a separate process of gravitational cohesion for individual heavenly bodies, not only the earth but also the sun, moon, and planets, each of which maintained its spherical shape through the operation of this tendency. […] Copernicus made germinal contributions to what later developed into the concepts of universal gravitation and inertia[19].

However, the same 'germinal contributions' are already in Plutarch's *De Facie.* Moreover, the *De Facie* includes an explicit mention to Aristarchus and his heliocentric system; and in the manuscript of the *De Revolutionibus* we find the name of Aristarchus associated to the heliocentrism (even if finally Copernicus decided to omit this reference in the printed version). There is no proof that Copernicus read the *De Facie*[20], but given the circumstantial evidence, this seems to me quite plausible.

The same polycentric theory of gravity, with the idea that the earth is not at the centre of the universe, was also supported by William Gilbert (1544-1603), in his treatise *De Mundo*, published posthumously in 1651:

> It is evident that all the heavenly bodies, set as if in a destined place, are there formed unto spheres, that they tend to their own centres and that around them there is a confluence of all their parts. And if they have motion that motion will rather be that of each round its own centre, as that of the earth is, or a forward movement of the centre in an orbit as that of the moon.[21]

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[19] Edward Rosen, *Three Copernican Treatises 2nd edition* (Mineola: Dover Publications, 2004); quoted in I. Bernard Cohen, *The birth of a new physics 2nd edition* (New York: W.W. Norton & Company, 1985), p. 48.

[20] For a discussion and references concerning this point, see André Goddu, *Copernicus and the Aristotelian tradition* (Leiden: Brill Academic Publishers, 2010), pp. 234-236.

[21] William Gilbert, *De Mundo nostro sublunari philosophia nova*, Amstelodami, 1651; digitized text available on Google books; the quoted English translation is

Johannes Kepler (1571-1630) had a similar vision of gravity. In his *Astronomia Nova*, published in 1609, he wrote:

> Gravity is a mutual corporeal disposition among kindred bodies to unite or join together. […] Heavy bodies (most of all if we establish the earth in the center of the world) are not drawn towards the center of the world because it is the center of the world, but because it is the center of a kindred spherical body, namely, the earth.[22]

In his comments to the introduction of *Astronomia Nova*, William Donahue notes:

> Kepler's account of gravity may appear surprisingly modern, an anticipation of Newton's universal gravitation. We should beware of jumping to hasty conclusions, however. In Kepler's universe, the earth and moon occupy the same orbit around the sun, and are thus kindred bodies, and attract one another.

Indeed, as Copernicus before him, Kepler was not anticipating Newton but was inspired by a much older theory. While Kepler was influenced by William Gilbert, he knew and appreciated Plutarch's *De Facie*: when Kepler's *Somnium* ('Dream') was published posthumously in 1634, it was accompanied by Kepler's translation of the *De Facie* into Latin.

Concerning Galileo (1564 – 1642), his ideas on gravity are presented by Salviati in the *Dialogo sui Due Massimi Sistemi del Mondo:*

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in Alexandre Koyré, *From the Closed World to the Infinite Universe* (Baltimore: John Hopkins Press, 1957).

[22] *Gravitas est affection corporea mutua inter cognata corpora ad unionem su conjunctionem (quo rerum ordine est et facultas magnetica), ut multo magis Terra trahat lapidem, quam lapis petit Terram. Gravia (si maxime Terram in centro mundi collocemus) non feruntur ad centrum mundi, ut ad centrum mundi, sed ut ad centrum rotundi cognati corporis, Telluris scilicet.* From Kepler's introduction to *Astronomia Nova, AITIOΛOΓHTOΣ, seu Physica Coelestis tradita commentariis De Motibus Stellae Martis*, in *Joannis Kepleri Astronomi Opera Omnia*, ed. Ch. Fritsch, Vol. 3, p. 151. The English translation is in William H. Donahue (ed.), *Selections from Kepler's Astronomia Nova* (Santa Fe: Green Lion Press, 2004), p .13.

> Now just as all the parts of the earth mutually cooperate to form its whole, from which it follows that they have equal tendencies to come together in order to unite in the best possible way and adapt themselves by taking a spherical shape, why may we not believe that the sun, moon, and other world bodies are also round in shape merely by a concordant instinct and natural tendency of all their component parts? If at any time one of these parts were forcibly separated from the whole, is it not reasonable to believe that it would return spontaneously and by natural tendency? […] Now let us have the grace to abandon the argument that their [the parts of the earth] natural instinct is to go not toward the center of the earth, but toward the center of the universe; for we do not know where that may be, or whether it exists at all.[23]

There is no doubt that Galileo was following the same tradition originating from the *De Facie*, which he should have read: in fact he owned a copy of the Latin translation of the *Moralia* published in Venice in 1572[24], and an Italian translation of the *De Facie* was published in Venice in 1598[25].

But this is not the end of the story. In the preface to his *Astronomiae Physicae et Geometricae Elementa*, published in 1702, David Gregory (1659-1708), Savilian professor of Astronomy at the University of Oxford and friend of Newton, discusses a list of ancient authors and quotations aiming to show that 'the Ancients' knew the law

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[23] Galileo Galilei, *Dialogue concerning the two chief world systems*, translated by Stillman Drake (Berkeley: University of California, 1953), pp. 33-34, 37. The Italian original is in Galileo Galilei, *Dialogo sui due massimi sistemi del mondo tolemaico e copernicano*, 1632; in *Le Opere di Galileo Galilei* (Firenze: tipografia di G. Barbera, 1897), Vol.7, pp. 58, 61.

[24] Antonio Favaro, 'La libreria di Galileo Galilei descritta ed illustrata', in *Bullettino di bibliografia e di storia delle scienze matematiche e fisiche*, XIX (Rome, 1886), pp. 219 – 293; the catalogue of Galileo's library is available on-line at http://biblioteca.imss.fi.it/ilig_lv.html.

[25] The evidence that Galileo did know the *De Facie* is well resumed by William Shea, 'Looking at the moon as another earth: terrestrial analogies and seventeenth-century telescopes', in *Metaphor and Analogy in the Sciences*, ed. F. Hallyn (Dordrecht: Kluwer Academic Publishers, 2000), pp. 83 – 103 (see in particular his note no.2).

of gravity[26]. Stephen Peter Rigaud (1774-1839), also Savilian professor of geometry and astronomy at Oxford, was the first to examine the manuscripts of David Gregory, and in his *Historical essay on the first publication of Sir Isaac Newton's Principia*, published in 1838 he describes how the list of ancient authors was given to Gregory by Newton himself[27]. This list includes some significant quotations from Plutarch's *De Facie*. Newton believed that the law of gravitation was already known in Antiquity, and we can understand why he had such a belief.[28]

The *De Facie* in the nineteenth century

After Newton, the role of the *De Facie* as a source of inspiration for scientists came to an end. However, together with the *De Defectu Oraculorum*, it remained known to philosophers and scientists during the nineteenth century and was quoted for various reasons: for example, *De Defectu Oraculorum* is mentioned in Lyell's *Principles of Geology;* the *De Facie* by von Humboldt in the first volume of *Cosmos* and by Whewell in the first volume of his *History of the Inductive Sciences.* But I think that the most intriguing influence of the *De Facie* in the 19th century is found in the American literature.

Edgar Allan Poe's 'prose poem', *Eureka*, published in 1848, contains a fascinating, evolving Newtonian cosmology[29], which is discussed in another paper in this volume. I have suggested elsewhere that the metaphysical inspiration might come at least in part from Poe's

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[26] David Gregory, *Astronomiae, physicae & geometricae elementa* (Oxford: Sheldonian Theatre, 1702).

[27] Stephen Peter Rigaud, *Historical essay on the first publication of Sir Isaac Newton's Principia* (Oxford: Oxford University Press, 1838), p.101; a reference to Plutarch and to Rigaud's research on Gregory's papers is found in William Whewell, *History of the Inductive Sciences*, Vol.1 (New York: D. Appleton & Company, 1858), pp. 544-545.

[28] In the *Forgotten Revolution,* Russo claims that Hellenistic scientists did discover the inverse-square law, but he relies on strong extrapolations from a few extant texts.

[29] Edgar A. Poe, *Eureka: A Prose Poem* (New York: Putnam, 1848); text available on-line at www.eapoe.org/works/editions/eureka.htm; A. Cappi, 'Edgar Allan Poe's Physical Cosmology', *Quarterly Journal of the Royal Astronomical Society* 35, 177 (1994); A. Cappi, 'The Evolving Universe of Edgar Allan Poe', in *Cosmology through Time*, eds. S. Colafrancesco and G. Giobbi (Monte Porzio Catone, Roma: Mimesis, 2004), p. 239; Molaro and Cappi, this conference.

reading of Plutarch's *De Facie* (and possibly *De Defectu Oraculorum*)[30]. In fact, Poe and Plutarch share a number of common concepts, which are developed in different contexts (Poe's physics is Newtonian): attraction is a universal property of matter which tends to unity and not towards a center; worlds/universes which do not share a common nature/origin do not interact; the primordial, natural state of the universe *and* of God is unity; the present universe comes from the separation and diffusion both of matter *and* God himself; our universe is spherical and limited; other universes can exist and can have their own gods.

I suspect that this correspondence is not casual, because Poe knew the *De Facie: in* the tale *Some Words with a Mummy*, published in 1845, Poe explicitly mentions it. The story is about a groups of friends who resuscitate an Egyptian mummy through 'the application of electricity': in the ensuing dialogue with the mummy, the group tries (unsuccessfully) to demonstrate the superiority of the Moderns over the Ancients. Among the various disciplines used for the comparison, the narrator, a member of the group, chooses Astronomy:

> This put me a little out, but I began to make other inquiries in regard to his astronomical knowledge, when a member of the company, who had never as yet opened his mouth, whispered in my ear that, for information on this head, I had better consult Ptolemy (whoever Ptolemy is) as well as one Plutarch *de facie lunae*.[31]

Conclusions

I have briefly traced the origin and survival of a theory of gravity alternative to the Aristotelian one. The original text where this theory was exposed has been lost, but part of it is discussed in Plutarch's *De Facie,* which became a useful reference for Copernicans before Newton's *Principia* and was remarked by Newton himself. The *De Facie* is a nice example of a literary work which inspired philosophers and scientists for centuries, and belongs to a greater history: the transmission and recovery of ancient science which created the conditions for the birth of the modern world.

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[30] Alberto Cappi, *Non-interacting worlds in Poe's Eureka: from Plutarch to the Multiverse* (2010, submitted to *Poe Studies.*

[31] Edgar Allan Poe, 'Some Words with a Mummy', in the *American Whig Review*, No.1 (April 1845): pp. 363-370; the quoted text is at p. 369, 1st column.