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Platonic Astronomy and the Development of Ancient *Sphairopoiia*

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Abstract: Plato's views on astronomy are still somehow debated, however various scholars have associated his name with the project of "saving the appearances", which is thought to have aimed at offering a precise geometrical account of celestial motions. A passage from Theon of Smyrna's treatise on Platonic mathematics relates this project with the construction of mechanical models of the cosmos. New information deriving from the study of the so-called Antikythera mechanism, found nearly 100 years ago in an ancient shipwreck in the Aegean, seems to provide important technical evidence illustrating the evolution of this endeavour during the Hellenistic period.

Keywords: *Sōzein ta phainomena*, observation, mathematical models, mechanical models, instruments, *sphairopoiia*,

Plato's attitude towards astronomy has been a matter of considerable controversy during the past years, mainly on the basis of a passage from the seventh book of the *Republic* (528E1–530C2) where a reformed type of astronomy is recommended as the fourth study in the education of the Guardians of his ideal city. This novel type is sharply contrasted to the way this science is said to have been "practiced at the time by those who teach philosophy", because, in Socrates' words, "if anyone attempts to learn something about sensible things whether by gaping upward or squinting downward, I'd claim – since there's no knowledge of such things – that he never learns anything and that, even if he studies lying on his back on the ground or floating on it in the sea, his soul is looking not up but down" (tr. Grube – Reeve). Socrates goes on to point out that "we should consider the decorations in the sky to be the most beautiful and most exact of visible things, seeing that they're embroidered on a visible surface. But we should consider their motions to fall far short of the true ones – motions that are really fast or slow as measured in true numbers, that trace out true geometrical figures, that are all in relation to one another, and that are the true motions of the things carried along with them.

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And these, of course, must be grasped by reason and thought, not by sight." The upshot is that one should "use the embroidery in the sky (only) as an illustration (παράδειγμα) for the study of these other things. … For if we are to engage in true astronomy so as to make the naturally intelligent part of the soul useful instead of useless, we must study astronomy by means of problems (προβλήμασιν), as we do geometry, and leave the things in the sky aside."[1]

This final remark has provoked a torrent of abusive remarks to be heaped upon Plato's alleged disavowal of empirical observation as a necessary component of scientific research. The disdainful air in the following comment by the great Otto Neugebauer, for example, is almost palpable: "[Plato's] advice to the astronomers to replace observations by speculation would have destroyed one of the most important contributions of the Greeks to the exact sciences."[2] Such assessments are mostly based on the assumption that Plato, when speaking of "true motions", "true numbers" and "true geometrical figures" intends to refer to ideal intelligible objects that can only be grasped by intellectual insight, just as it is the case with his well-known intelligible forms of, say, justice or beauty.[3] However, this assumption can hardly stand in the face of the parallel he draws in the above passage with geometry. For, although this in turn is said to pertain to "what always is, not what comes into being and passes away", it is further described as "drawing the soul towards truth and producing philosophic thought (φιλοσόφου διανοίας) by directing upwards what we now wrongly direct downwards" (527b4–10). The reference to "thought" (διάνοια) is here unmistakable: it clearly points back to the discussion at the end of book VI of the *Republic* (510b2–511b1), where geometry is said to treat objects that occupy an intermediate region between the sensible figures drawn by geometers and the ideal forms, that can be grasped

1 In my opinion, the terms παράδειγμα and πρόβλημα in this context refer to two distinct but strongly correlated types of object. Παράδειγμα is the visible exhibit or diagram drawn by the geometer while examining a specific geometrical problem in order to deliberate about something else, namely the πρόβλημα, that is, the theoretical construct grasped by his reasoning. The latter is not very different from the notion of πρόβλημα analyzed by Mourelatos (1980), pp. 60–62, as referring to "the timeless and non-tensed truths that underlie the possibility of [geometrical] constructions".

2 Neugebauer (1969), p. 152. See further the scathing remarks quoted by Shorey in a footnote to his Loeb translation of the above passage.

3 This is implied, for example, by T. Heath's description of them as "objects of pure thought" (Heath 1913, p. 137) and, more recently, by A. Bowen, who adduces that Plato's view is that "the planets and their motions are patently not forms or what it is to be something, and so there is no scientific knowledge of them and no place for a program in astronomy to *explain* or even to save them" (Bowen 2013, p. 232, author's emphasis).

only by the supreme cognitive power of the intellect.[4] The kind of cognition that pertains to such objects is said there to be "discursive thought" (διάνοια), and it is surely no accident that in the passage cited at the beginning of my paper the "true motions" studied by the real astronomer are said to be grasped "by reason and thought" (λόγῳ καὶ διανοίᾳ). This is further corroborated in what follows, during the discussion of the science of harmonics, where another parallel is drawn, this time between this science and astronomy (531B7–C4). Here the practitioners of harmonics are advised not "to seek out the numbers that are to be found in the audible consonances, but to make the ascent to problems (προβλήματα, again) by examining, for example, which numbers are consonant and which aren't, or what the explanation for this is." It is quite obvious that such an examination of the numerical ratios relating the various musical intervals should deal neither with the numbers embedded in the "audible consonances",[5] nor with the ideal forms of the numbers themselves, since the latter can bear no harmonic relation with each other, being purely intelligible principles on the basis of which countable numbers acquire their status as objects of mathematical speculation. Hence in the previous passage Plato is not asking us to dismiss or to disregard the visible motions of the heavenly bodies, but rather to leave them aside in order to focus on the proper objects that will enable us to understand the reasons determining the visible phenomena, namely the revolutions carrying them across the heaven.

Of course, the question remains what exactly is the nature of the objects studied by this refined type of scientific astronomy that Plato appears to envisage here. These cannot be pure mental abstractions, since they are said to be "the true motions of the things carried along with them", the latter, presumably, being the heavenly bodies observable in the sky and said to be "the most beautiful and most exact (κάλλιστα καὶ ἀκριβέστατα) of visible things". They must therefore be physical objects of some kind, albeit "graspable by reason and thought and not

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4 It is, of course, a matter of serious debate whether the objects studied by geometry are to be identified with the mathematical "intermediates" ascribed by Aristotle, *Meta*. A.6 987^{b}15–18, to Plato. Cf. also ibid. 987^{b}29, A.9 991^{a}4, ^{b}29, Z.2 1028^{b}19–20 etc. See the opposed views defended by Ross (1951), pp. 59–67, and Burnyeat (1987), pp. 220–32. For our present purposes, the following concessive formulation by Ross seems sufficient: "The conclusion to be drawn surely is that [Plato] thought of Ideas as falling into two divisions, a lower division consisting of Ideas involving number *or space*, and a higher division not involving these" (p. 64, my emphasis). Such ideal objects involving space and motion correspond exactly to the ones Aristotle is arguing against, e.g. in *Meta*. B.2 997^{b}14–26, by questioning their status as "beings".

5 According to the *Phaedrus*, 268D7–E6, knowing these would constitute only a "necessary" preliminary to the proper study of harmony: cf. Vlastos (1980), pp. 11 and 17–18.

by sight". In his analysis of solar motion in the *Timaeus* (38B–39C), G. Vlastos (1980, pp. 7–14) has forcefully maintained the parallel with the passage from the *Republic*, arguing that the method of the "true astronomy" far from discounts the evidence of astronomical observation. On the contrary, it takes over from it "the mass of empirical data" which the astronomer regards as "a set of true opinions" on the basis of which he can formulate his own considered scientific theory. In Vlastos's words, "he does the work by identifying [a] set of assumptions from which … follows by geometrical reasoning that the sun's true motion is a closed spiral tangent on the tropics at either end; and this accounts for the observed phenomena", that is, the appearances perceived in the sky. However, Plato provides no further information concerning the nature of the objects involved in such mathematical considerations within the immediate context of the present passage,[6] so we must look elsewhere in order to figure out what he has in mind.

The obvious place to look is none other than the account of celestial mechanics contained in the final book of the *Republic*, yet intricately enveloped within the mythical elaborations of the famous myth of Er (*Rep*. 616C4 ff.). For, certainly, the astronomical details contained in it are meant to represent much more than idle poetic fantasy.[7] There the disembodied souls are said to encounter the universe in such a way as to discern its inner structure that makes it revolve in an orderly manner, which accounts for the motions of the heavenly bodies as observed from the earth. To be sure, as Cornford notes (in his tr., p. 350), "what the souls actually see in their vision is not the universe itself, but a model", nonetheless this only serves to clarify that what they perceive is not graspable by the senses but by some act of reasoning or thought.[8] The spindle and the whorls making up the complicated structure on which the heavenly bodies are said to reside are obviously introduced in order to explain the manner in which the motions of the stars are related to each other and how they combine together in such a way as to produce

6 On the other hand, Aristotle seems to envisage such objects in his criticism of Plato in *Meta*. M.2 1077[a]1–4 (ROT): "For besides the sensible things, there will be … the things with which astronomy and those with which geometry deals; but how is it possible that a heaven and its parts – or indeed anything which has movement – should exist apart from the sensible heaven?" There could certainly be no question here of an "astronomy" – however theoretical or "abstract" – that would purport to deal with pure Platonic ideas!

7 As Adam (1902), vol. 2, p. 442, appears to suggest. I find preferable Cook Wilson's assessment (which Adam reports) according to which the entire description should be regarded as "essentially a symbolic representation" of reality. Kalfas (1996), pp. 10–16, seems to be one of the few modern scholars prepared to take the relation between books VII and X of the *Republic* quite seriously.

8 In Kalfas' words, (1996), p. 13, "the souls 'see' only what cannot actually be seen".

the orderly array of celestial phenomena. They thus form parts of an elaborate mechanism, which is regarded as governing the movements of all the heavenly bodies that are carried along with them, presumably in perfectly circular orbits, as the term "revolutions" (περιφοραί) used for them implies. No precise indication is provided concerning the numerical relations underlying this arrangement, however the cosmic "concord" (ἁρμονία: 617B7) that is said to combine the sounds emitted by the revolutions of the "whorls" as well as the fact that the motions of the various revolutions of the spindle are controlled by the three Fates "singing in accordance to the concord emitted by the Sirens" (617C3–4), attest to their consonant mathematical underpinnings. On the other hand, the intermittent (διαλείπουσα) action of the Fates, especially of the one by Lachesis, is to be understood as producing the oscillating effect observable in the rotation of the planets and thus accounting for the resulting irregularities in their courses.[9] I believe it is clear that all this imagery is intended as a graphic representation of the structure underlying the "true motions" said in our previous passage to carry along the "decorations of the sky". It is thereby to be understood as a sort of εἰκὼς μῦθος, not in the sense of a "likely guess", but rather as that of an "appropriate" or "reasonable account"[10] of celestial mechanics, given, of course, the restrictions concerning any description of things inaccessible to direct cognition.

If we turn now to the *Timaeus*, we find Plato being preoccupied with similar concerns, as he has the cosmic Demiurge placing the planets in the sky "into the orbits (περιφοράς) traced by the period of the Other" (38C7–8), the latter being one of the motions of the world soul (36C5–D7). The planetary orbits are here referred to as "circles" (κύκλοι: 39A2, A7, C3–5) and are said to move forward in two contrary directions at once (39A6–B1) by combining the motion of the Other with that of the Same. In this way Plato purports to explain the oscillations or "irregularities" in the courses of the planets as the effect of the combination of two different motions. It is to be noted that his description is meant to apply not to the observed celestial bodies themselves, but to the underlying motions of the world soul. There is no direct evidence, however, that Plato had at this time the resources, or even the intention, to reduce the irregularities in the observed motion of the planets to a system of uniform rotation performed by the world soul.[11] The motion of the Other in particular is said to be recalcitrant to mixing with its opposite (δύσμεικτος) and thus to require some force (βία) to be exercised before it yields (35A8).

9 So Knorr (1990), pp. 316–17. For a somewhat different view, see Vlastos (1975), p. 34.
10 Cf. on this Burnyeat (2005), pp. 153–56.
11 This is rightly emphasized by Knorr (1990), pp. 320–21.

The correspondence between the theoretical presuppositions governing the basic assumptions of “true” astronomy, on the one hand, and the actual facts observed in the sky, on the other, appears as a serious concern of Plato also in his last important discussion of astronomy in book VII of the *Laws* (820e8–822c5). He maintains there that unless someone is prepared to explain the motions of the wandering stars in terms of their being carried by combined movements, one would end up confusing the fastest moving “planet”, namely the Moon, as being the slowest, because it appears to “stay behind” the rest with respect to the fixed stars moving in the opposite direction: cf. *Tim*. 38e3–39b2. But he now goes as far as to reject the idea that the planets are actually “wandering” (πλανᾶται) at all, claiming that in fact each of them follows always a precise circular orbit, “one and the same, not many, although it appears to move along many paths” (822a4–9).[12] There is still, however, no indication that the motions involved are uniform (i. e. maintaining a constant angular velocity). All that is said is that each planet follows its own circular orbit that remains always the same. It has to be noted, nonetheless, that such an additional premise might be reasonable to assume in view of the fact that, later in the *Laws* (X 898a3–6), Plato introduces the idea that “a motion that is regular, uniform (ὡσαύτως), in the same place, around the same and in relation to the same, according to one rule[13] and one order” is the most akin and most alike to the revolution of the intellect. In fact, the notorious fact that the Athenian Stranger has introduced two world souls in order to account for the government of the heaven (896d10–e6) might be seen to serve exactly this purpose, namely, to explain the fact that the two underlying motions of the celestial spheres do not appear to conform in the same degree to the orderliness dictated by the intellect.[14]

Now, an explanation of the apparent irregularities in the observable movements of the planets in terms of an underlying combination of uniform heavenly motions is commonly believed to be one of the major contributions of Eudoxus of Cnidus in ancient astronomical theory,[15] whereas it is questionable whether Plato had been fully aware of such developments in contemporary scientific speculations. In a famous passage of Simplicius’ *Commentary on Aristotle’s De caelo* (488.14–20), the author records that

12 See the comments on this passage given by Tarán (1975), pp. 103–4.

13 Reading with Ast and Bury <καθ’> ἕνα λόγον.

14 Cf. *Laws* X 897b7–d2.

15 See Neugebauer (1969), pp. 153–54.

> because [Aristotle's contemporaries] were unable to grasp precisely how [the planets] must be disposed in order to produce their effects (τὰ συμβαίνοντα), even if not in truth but only in appearance (φαντασία), they were contented (ἠγάπησαν) with finding out which uniform, ordered and circular motions should be posited (ὑποτεθέντων) in order to be possible to save the phenomena related to the motions of the so-called "wanderers". The first among the Greeks [to attempt this] was Eudoxus of Cnidus, as Eudemus reports in the second book of his *History of Astronomy*.[16]

Simplicius goes on to assert, based on a contention made by the 2nd cent. AD Peripatetic Sosigenes, that Plato had been the mastermind who set out the project of "saving the phenomena" (διασωθῇ τὰ φαινόμενα) by assigning to his astronomical colleagues the task of discovering "by the assumption of what uniform and ordered motions can the apparent motions of the planets be accounted for?" (op. cit. 488.20–24).

However, Plato's role in promoting the development of astronomical investigation in the Academy along such lines has been the subject of a long controversy. It has to be acknowledged that Sosigenes' testimony provides insufficient ground on which one might safely establish lofty speculations about a comprehensive program of scientific research designed by the head of the school, such as the ones advanced by Duhem more than a century ago in his otherwise pioneering study on the subject.[17] On the other hand, the report about Eudoxus' contribution in promoting contemporary astronomical inquiry in the direction of analyzing observable data by means of suitable geometrical models designed to offer an account of them as the combined effect of the uniform motion of two or more concentric celestial spheres and thus to "save the phenomena" has never been seriously challenged.[18] Indeed, we have further independent testimony that "Eudoxus was the first to introduce into Greece the sphere of the Assyrians, which

16 This text is partly reproduced by F. Wehrli as Eudemus' fr. 148, and by F. Lasserre as Eudoxus' fr. 121, however, as it stands, the testimony makes little sense without Simplicius' introductory remarks. Cf. further Simpl., loc. cit. 492.31–493.5 = Eudoxus, fr. 124.

17 See Duhem (1982), pp. 3–6, along with the critical assessment of the evidence by Zhmud (1998), pp. 217–18, who maintains that this story, along with the parallel contained in Philodemus' *Academic History*, col. Y, in Dorandi (1991), p. 126, derives not from Peripatetic circles (viz. from Dicaearchus, fr. 46B Mirhady), but from later Academic propaganda and is therefore devoid of historical credibility; however, even he has to concede that the project of "saving the appearances" most probably had originated in the fourth century BC, possibly through Eudoxus of Cnidus and his followers.

18 See, e.g., Neugebauer (1969), pp. 153–54, Bodnár (2012), p. 270.

one should hold up in display while exhibiting the phenomena".[19] And anyway, there is substantial evidence that, during the fourth century BC, cognate views about the character of scientific research were very much in the air.[20]

Nonetheless, as it happens, the earliest record of the precise formulation of "saving the phenomena" (τὰ φαινόμενα σωθήσεται) is to be found in a passage from a work by the astronomer Attalus of Rhodes (first half of the 2nd cent. BC) quoted by his younger contemporary Hipparchus of Bithynia in his *Commentary on Aratus' and Eudoxus' Phaenomena* (II.3.23). It also occurs in a passage from Geminus' *Summary of Posidonius' Meteorology* quoted by Alexander of Aphrodisias apud Simplicium, *In Phys.* 292.13–20, probably reflecting a statement he had found in Posidonius (= Posidonius, fr. 18.30–39 E.-K.).[21] Its clearest formulation, however, is to be found in a treatise of the second century AD, Theon of Smyrna's *On Mathematical Issues Useful for the Reading of Plato*,[22] where it is explicitly associated with the analysis of the Platonic myth of Er. This work is preserved by two apparently not directly related manuscripts, the first of which contains the sections pertaining to arithmetical theory and harmony, while the second the one dealing with astronomical issues. This last section is by far the most elaborate and developed of the three and seems to represent more precisely the author's main interests. It relies heavily on the work of the famous Peripatetic Adrastus of Aphrodisias but, as its title suggests, maintains a basically Platonic outlook by focusing on topics that had been treated by Plato in the *Republic* and by taking further into account other dialogues, such as the *Timaeus* and the *Epinomis*. Theon also seems to draw substantially on the works of a prominent Platonic authority, Thrasyllus of Tralles – the notorious court astrologer of the emperor Tiberius, who introduced the system of the so-called "tetralogies" in his

19 Ὅτι Εὔδοξον τὴν Ἀσσυρίαν (corr. Lasserre: τὸν Ἀσσύριον codd.) λέγουσι πρῶτον εἰς Ἑλλάδα κομίσαι σφαῖραν, ἣν δεῖ κρατεῖν τὸν ἐπιδεικνύντα τὰ φαινόμενα: Anon., *Prol. in Arati Phaenomena* 16, 27.10–12 Martin = fr. 2 Lasserre. Cf. Cic., *De re publ.* I.22.

20 They were certainly known to Aristotle (see *Meta.* Λ.8 1073^{b}38–1074^{a}5, *GC* I.5 321^{a}17–18, *PA* I.1 639^{b}8–11) and it seems that the formula itself was mentioned by some character (a Pythagorean?) making a passing appearance (παρελθών) in a dialogue by Heracleides of Pontus (fr. 110, following the Aldine reading of the text adopted by Wehrli; the argument against this reading advanced by Gottschalk (1980), pp. 64–65, seems to me inconclusive). See Mittelstrass (1963), pp. 141–58, Vlastos (1975), pp. 110–12, Sedley (1976), p. 42, Bulmer-Thomas (1984), p. 110, Zhmud (1998), pp. 217–44, and (2005), pp. 21–22.

21 On this see Lloyd (1978), pp. 213–14.

22 Edited by E. Hiller, Leipzig 1878. All the following references are to this edition. We learn from this work that its author had also written "commentaries" on Plato's *Republic* (146.3–4), while al-Nadīm in his *Fihrist* (Dodge 1970, pp. 592–94) relates that he had produced his own arrangement of Plato's dialogues.

influential edition of the works of Plato – as well as on those of the somewhat nebulous Platonist (with possibly, like Thrasyllus, Neopythagorean allegiances) Dercyllides.[23] Nonetheless, he is also capable of contributing some original ideas and arguments of his own.

Theon begins the astronomical section of his treatise (120.1 ff.) with an account of the spherical shape of the earth, its position at the center of the universe and its minimal size with respect to the cosmos as a whole. He then offers a description of the divisions of the sky in circles and spheres, the arrangement of which determines the cosmic harmony and the way this influences terrestrial events. The author gives a list of the order and the names of the planets (130.22–131.3) according to the Pythagorean system and supplements it with a relatively long excerpt from a poem he attributes to Alexander of Aetolia, but most probably is to be ascribed to Alexander of Ephesus (139.1–141.4).[24] The order and names given by Theon are as follows: Moon (σελήνη), Mercury (Ἑρμῆς, or στίλβων), Venus (Ἀφροδίτη,[25] or φωσφόρος), Sun (ἥλιος), Mars (Ἄρης, or πυρόεις), Jupiter (Ζεύς, or φαέθων), and Saturn (Κρόνος, or φαίνων). It must be noted here that this so-called "Chaldean" ordering of the planets was well established among the astronomers of the later Hellenistic and Graeco-Roman periods, but not before the second century B. C.[26] It differed from the one adopted by Plato, Eudoxus, Aristotle and Eratosthenes that placed the moon and the sun at the lowest spheres above the earth.

Theon subsequently embarks on a rather elaborate exegesis of the astronomical component of Plato's myth of Er from the final book of the *Republic* (616B1 ff.: see Theon 143.7 ff.). He makes a reference to his more extensive treatment of the subject in his commentaries (ὑπομνήματα) on that work and adds that he himself had constructed a mechanical device (σφαιροποιία) illustrating his views. He points out that in doing this he was adhering to Plato's injunction implicit in a phrase from the *Timaeus*, 40D1–3, according to which "to tell all this [sc. to describe the movements and the positions of the heavenly bodies] without using

23 See Tarrant (1993), pp. 78–84. Thrasyllus has been associated with the concoction of the preudo-Platonic *Second Epistle*, which, at 312D2, contains a rather cryptic reference to a σφαιρίον (maybe an orrery?); see Keyser (1998), pp. 250–51.

24 Indeed two of these verses are also quoted by the Homeric allegorist Heraclitus *All.* 12, who gives as their author Alexander of Ephesus (1st cent. BC), while he too relates them with the Platonic myth of Er. See Powell (1925), p. 129, and von Fritz (1934), col. 2070. Theon's confusion may be due to the fact that both Alexanders are said to have composed poems titled *Phaenomena*: see Anon., *Arati Vita* II, 12.19–13.1 Martin.

25 Alexander uses the more poetic equivalent Κυθέρεια.

26 See Cumont (1935), pp. 20–24.

visible models[27] would be a labor spent in vain."[28] Based on Adrastus' exposition on this topic, he introduces epicycles in order to account for the irregularities (ἀνωμαλίαι) in the observable motion (φαντασία) of the planets in a manner that, as he repeatedly insists, would save the appearances (σώσει τὰ φαινόμενα).[29]

According to Theon, in the course of his argument Adrastus had insisted that all the variegated movements observed in the planets form one unified system or *cosmos* meant to conform to "what is optimal and best (τοῦ βελτίστου καὶ ἀρίστου χάριν)" (148.13–17). This, of course, alludes to the teleological cosmology of the *Timaeus*[30] that already had been developed by Cicero into an argument from design in a well-known passage from the *Tusculan Disputations* (I 63).

However, the main aspect of the issue Theon is trying to establish is that the apparent disorder noticed in the movements of the planets is only phenomenal,[31] since it can be reduced to the perfectly regular, uniform and circular motions of the underlying celestial spheres. The system of epicycles is specifically introduced in order to explain how a combination of such orderly movements can produce the seemingly irregular motions observed in the courses of the planets. This is once more attributed to Pythagoras who is said to have been "the first to realize (πρῶτος ἐνόησε) that an orderly, simple and uniform movement [of the spheres] may produce, *per accidens*, a variegated and irregular (ἀνώμαλος) motion" (150.16–18).[32] The project of "saving the appearances" is then duly set

27 ἄνευ τῶν δι' ὄψεως μιμημάτων: this is the reading of Theon, whereas Plato's text has ἄνευ δι' ὄψεως (thus Burnet, following Proclus: most MSS have ἄνευ διόψεως) τούτων αὖ τῶν μιμημάτων, which gives a slightly different meaning. Procl. *in Ti.* III 149.22 Diehl, describes such models as "instrumental" (ὀργανικά).

28 Translation by D. J. Zeyl, in Cooper, ed. (1997), p. 1244. Commenting on the above passage, Duhem (1982), p. 16, remarks: "For Adrastus of Aphrodisias and for Theon of Smyrna, apparently also for Dercyllides, the mathematician should adopt an astronomical hypothesis that conforms to the nature of things. However, for these philosophers, this conformity is not to be evaluated by reference to the principles of physics adduced by Aristotle; it is ascertained by the possibility of constructing, by means of suitably encased solid spheres, a mechanism representing the celestial motions."

29 Theon 150.7–20. The concluding formula is repeated no less than ten times in the course of the work: see 154.12–13, 157.12, 160.12, 161.3, 163.3–4, 164.13–14, 166.5–6, 175.4, 177.8, 182.8–9.

30 See, e.g., Pl. *Ti.* 30B5–6, 40B2–4, 48A3, 53B5–6, 68E1–2 etc.

31 And hence its consequences in the sublunary region are merely *per accidens* (κατὰ συμβεβηκός: 149.15); cf. the development of this thesis by Alexander of Aphrodisias in his *Quest.* II.21 65.17–71.2 Bruns, and [Alex. Aphr.] *Mant.* 22, 171.8–14 Bruns. It eventually evolved into a full-blown doctrine of the providential arrangement of the universe: see Merlan (1969), pp. 86–89, Sharples (1982), pp. 204–5.

32 The phrasing here is reminiscent of Plato's *Laws*, X 898A8–9. It has to be noted that this at-out and Plato is credited with making a very substantial contribution to it by his system of spheres, axes, spindles and whorls described in the final myth of the *Republic*. Theon grasps the opportunity to declare that the "Platonic" *sphairopoiia* contrived by himself had shown that the movement of the planets "is not variegated and irregular, but well-regulated (εὔτακτος) … for their seemingly haphazard and multifarious motion is caused by a double movement" combining the sidereal motion of the firmament carrying the fixed stars with the particular motions of each individual planet (151.4–13). Moreover, the latter motions can be further analyzed as combining the movements pertaining to the system of cycles and epicycles on which each of them is attached. After examining the option of eccentric (ἔκκεντροι) spheres as a possible alternative,[33] Theon focuses on his preferred theory of epicycles (ἐπίκυκλοι), which he considers as the most appropriate to provide an explanation that will "save the appearances" (158.11 ff.).

Most of the details of his theory need not concern us here.[34] One passage, though, is of paramount significance. While discussing Callippus' postulation of intermediary spheres in order to account for the motions of the sun and the moon, Theon proceeds with his exposition as follows:

> Since they [sc. the astronomers at the time of Callippus] believed that it is in accordance with nature that everything should move in the same direction (ἐπὶ τὸ αὐτό), but saw the wandering stars (τὰ πλανώμενα) progressing in the opposite direction, they assumed (ὑπέλαβον) that there must be some other solid spheres between the ones carrying [them] which through their motion would unwind (ἀνελίξουσι)[35] the carrying ones in the opposite direction by being in contact with them: in exactly the same way as the so-called gears (τυμπάνια) in the mechanical planetaries (ἐν ταῖς μηχανοσφαιροποιίαις) move according to their proper movement around their center and, by engaging their teeth (τῇ παρεμπλοκῇ τῶν ὀδόντων), they set in motion and unwind in the opposite direction the ones below and attached to them (180.13–22).

tribution is characterized by Burkert (1972), p. 325, as "one of the most horrendous examples of anachronism in the construction of a science for Pythagoras."

33 In fact he endorses Adrastus' postulate, following a suggestion by Hipparchus, that the theory of eccentric spheres is *per accidens* reducible to that of epicycles, and argues effectively that the converse is also true: see 166.4–172.14; cf. Ptol. *Alm*. XII.1 (450.8–452.4 Heiberg), and Neugebauer (1959), pp. 5–18. On the import of this, see Lloyd (1978), pp. 217–19.

34 For a brief account see Neugebauer (1948), pp. 1016–20, and (1969), pp. 122–26; See also Freeth – Jones (2012), § 3.2. A further advantage was that it could explain "the annual approach and retreat of some planets in relation to the earth"; see Sorabji (2007), pp. 576–77. For an authoritative presentation of Theon's views, see Jones (2015).

35 As Prof. Jones has reminded me, this is Theon's reinterpretation of Aristotle's "unwinding spheres", in *Meta*. Λ.8 1074^{a}2–11.

This description is undoubtedly meant to remind us of the previous references to the instrument constructed by Theon in order to explain the way the Platonic system of celestial "whorls" is supposed to work. But here the contrivance is transposed from the model to the physical reality it is supposed to depict:[36] there are indeed real (aethereal?) spheres that govern and determine the movements of the actual bodies circling in the sky,[37] and, therefore, are subject to the basic physical laws, such as the one postulating uniform motion as the only one properly conforming to nature.[38] The outcome is that "the stars residing [in the spheres], while moving according to their own simple and regular motion, appear *per accidens* to follow complex, irregular and variegated courses" (181.4–7).

Theon proceeds to draw a diagram (ἀναγκαῖον εἰς τὰς σφαιροποιίας διάγραμμα) illustrating the function of these spheres and supplements it with an extensive commentary. Again, an analysis of all the details of their operation would require a separate study, but it becomes immediately evident that this has an effect both on the positions occupied by the planets at different parts of their orbit, and on their apparent velocities: see esp. 184.24–185.11. The author concludes that "Plato adhered to the theory of epicycles maintaining that the carriers of the planets are circles, not spheres; this is indicated by the fact that at the end of the *Republic* [616D3–E3] he speaks cryptically (αἰνίσσεται) of whorls (σφόνδυλοι) being attached to each other" (188.25–189.4).[39]

Theon's engagement with the making of a mechanical model of the cosmos certainly points back to a tradition of constructing similar instruments, some of which were said to have been the work of that ingenious paragon of mechanical

36 On this point see Evans and Carman (2014), p. 154, who use it, along with other evidence, in order to plead for the more general claim that "early Greek mechanics may have contributed in a significant way to the development of Greek theoretical astronomy" (op. cit. p. 171).
37 Cf. Sorabji (2007), pp. 581–82.
38 It is not entirely clear what reasons Theon has for regarding uniform circular motion as "according to nature (κατὰ φύσιν)" in the case of the stars (see the relevant discussion in Petrucci 2015, pp. 167–78). He mentions Aristotle's postulation of a "fifth body" in order to account for it (178.19–22, 189.7–9), but we happen to know that already the Peripatetic Xenarchus (1st cent. BC) had maintained that, by being a simple body and after it has reached its proper place, even fire must by its own nature move in a circle; see Falcon (2012), pp. 32–34. Cf. also the explanation given by Philoponus *De aet. mund.* XIII.6, 492.16–493.24 Rabe. Anyway, Lloyd (1978), p. 218, is surely right in counting Theon among the "realists", who regarded astronomy as being founded on physics.
39 On this point see Sorabji (2007), pp. 584–86. The last remark possibly alludes to a debate surrounding both the text and the interpretation of the passage from the *Republic* recorded by Proclus, but already known to Theon as has been plausibly suggested by Tarrant (1993), pp. 82–84; cf. Procl. *in R.* II 218.1–222.5 Kroll, and the analysis in Adam (1902), vol. 2, pp. 475–79.

achievement, Archimedes (3rd cent. BC). The most striking report is the one by Cicero in his *De re publica* I.21–22, regarding two *sphaerae* that the conqueror of Syracuse, Marcus C. Marcellus, had brought home from that city and were attributed to the art of Archimedes.[40] One of them was publicly exhibited at the temple of Virtue in Rome, while the other was kept in his private villa, where his namesake grandson is said to have displayed it on various occasions to his guests. The latter is described by the witness adduced by a speaker in Cicero's dialogue, reporting an event that supposedly had taken place at about 166 BC, as having on it "delineated the motions of the sun and the moon and of those five stars which are called wanderers." It is further said to have been equipped with a contraption making it able to represent all the "various and divergent movements with their different rates of speed" by means of a single turn (*una conuersio*) of its handle.[41] It thus indicated the relative positions of the celestial bodies such as the sun and the moon on a marked bronze display (*in aere illo*), as well as the occurrence of lunar eclipses by revealing where the shadow of the earth would fall at any given moment.[42]

It has to be noted here that, although most translators render the term *sphaera* used by Cicero's speaker Lucius F. Philus as "globe" or "sphere",[43] this is by no means necessary. The word can as easily be employed to indicate, by metonymy, any device suitable to *represent* the motions of the celestial sphere, as indeed seems to be the case in Cicero's own account of a similar *sphaera* "recently constructed by our friend Posidonius, which at each revolution reproduces the

40 Cf. the account of Archimedes' death given in Plutarch's *Marc*. 19.6. That the name of Archimedes was associated with the construction of a σφαιροποιία was a commonplace in late antiquity, sometimes producing reports of a markedly paradoxographical outlook. See, e.g., Pappus VIII 3, 1026.2–12 Hultsch, and Claudian's *In sphaeram Archimedis* LI (LXVIII), vol. 2, pp 278–80 Platnauer. Cf. Dijksterhuis (1987), pp. 23–25, Berryman (2009), pp. 150–53. Keyser (1998), pp. 247–49, remains sceptical concerning the attribution of such geared devices to Archimedes; see, however, the evidence adduced by Tassios (2012), pp. 251–53.

41 This handle would correspond to the "knob or crank handle" used as input drive in the Antikythera Mechanism; see Freeth et al. (2012), p. 260. See further Gigon (1973), p. 149, on its possible significance as indicating the unitary nature of the origin of all cosmic movement. Cf. Pseudo-Arist. *Mu*. 6 398b13–27.

42 At this point the text of our only manuscript has a long lacuna, thus depriving us of any further details about the instrument in question. Some authorities have expressed doubts as to whether Cicero's description actually relates to the device constructed by Archimedes or is simply to be attributed to his literary flair: see e.g. Goldstein and Bowen (1991), p. 106. However, it is hard to believe that Cicero would grossly misrepresent such a well-known and publicly displayed exhibit.

43 See, e.g., C. W. Keyes (in the Loeb edition) and Freeth – Jones (2012), § 2.2.

same motions of the sun, the moon and the five planets that take place in the heavens every twenty-four hours" (*ND* II.88) and rendered by H. Rackham as an "orrery".[44] What strikes Cicero's speaker in the former passage as a significant innovation on the part of Archimedes with respect to similar previous constructions, such as those by Thales of Miletus and Eudoxus of Cnidus, is that, whereas these had been "solid and contained no hollow space (*solidae atque plenae*)" and thus had "the constellations and stars fixed in the sky", his device allowed for the independent movements of the celestial bodies, since it was implemented, as Lactantius later formulated it in his *Inst. diu.* II 5.18, "in hollow bronze (*in concauo aere*)", that is having inside it room for an encased mechanism.[45]

Nonetheless, the most striking instance of such a device we know today is one that has almost miraculously come down to us thanks to a series of lucky coincidences and represents one of the most fascinating and intriguing archeological discoveries of the last century. Near the end of the year 1900, a group of professional sponge-divers from the island of Syme was driven by a storm to find refuge near the inhospitable shores of a remote island in the western Aegean called Antikythera. While trying to pursue their fishing in this area, they happened upon the remains of an ancient shipwreck carrying an astonishingly rich cargo of various artifacts, including remarkable sculptures, high-quality glassware and pottery, as well as the usual array of amphorae used as containers for carrying commodities such as olive oil and wine. Among the findings retrieved from the site during the next year were the remains of a rather inconspicuous metallic construction that seemed hardly discernible among the surrounding rocks. It took some time before these corroded vestiges attracted the attention of the archeologists who were called to examine the findings, however it quickly became apparent that they belonged to one of the most bizarre objects ever

44 Cf. Heath (1921), vol. 1, p. 18 (Gigon 1973, p. 147, however, chooses to translate it even in this instance as "Globus". Perhaps a better description would be "a planetarium", a term that is more appropriate for a geocentric arrangement, provided, of course, that one is prepared to regard the Sun and the Moon as "planets"). The same can be said about the term σφαῖρα used by Greek authors in order to refer to Archimedes' device. See S. E. *M.* IX.115 (with R. G. Bury's note), and cf. Procl. *in Euc.* 41.16–18 Friedlein, who however uses the cognate term σφαιροποιία. Notice that when Cicero comes to speak of the same instrument again at *Tusc.* I 63, in the course of an argument from design in favor of divine Providence, he is careful to remark that "Archimedes fastened (*illigauit*) on his *sphaera* the *movements* of the moon, of the sun and of the five wandering stars", thus suggesting that what was indicated was the motion and the relative positions of the stars and not the celestial bodies themselves. Cf. also Firmicus Maternus *Mathesis,* Prooemium 5, 2.15–19 Kroll – Skutsch.

45 Cf. Tassios (2012), p. 254.

encountered in any archeological operation. It appeared to consist of a complex arrangement of bronze gears intricately intertwined and compactly encased in some kind of container. A series of spectacular developments in modern methods of analyzing and imaging over the last hundred years have provided researchers with new tools of unprecedented incisiveness and accuracy for the scrutiny of these rusty remains. Such analyses have shed more intense light on the device's construction and purported operation and, consequently, have provoked new, albeit sometimes controversial, insights regarding the purpose of the so-called Antikythera Mechanism.[46] The consensus prevailing today maintains that, to all appearances, it must have been designed and constructed during the second half of the second century BC or, at any rate, some time before the fateful shipwreck off the shore of Antikythera (most probably in the 60s BC), in some major center of contemporary scientific research, such as either Syracuse in Sicily[47] or some other city possibly located near the cost of Asia Minor, such as Ephesus or Rhodes.[48]

According to the most recent assessment of the evidence, the Mechanism combined two main functions "as an analogue computer, permitting quantitative read-off of the longitudinal positions and motions of the heavenly bodies, and as an educational wonder-working device, portraying the cosmos and its constituent parts in their hierarchical structure and intricate movements."[49] It is now established that it comprised three main dial systems, one on its front and two

46 After being neglected for some time because of its badly preserved condition, the Mechanism eventually attracted the attention of a variety of scholars, starting with the publications by the numismatologist I. N. Svoronos in 1902 and 1903, who compared it with the astrolabe described by John Philoponus in a special work entitled *On the Use of the Astrolabe and its Construction*, edited by H. Hase, Bonn 1839 and reprinted with French translation by A. P. Segonds, Paris 1981. There is an English translation by H. W. Greene in Gunther (1932), vol. 1, pp. 61–81. For useful recent accounts of contemporary research on the Mechanism see Magou (2012), Freeth et al. (2012) and Jones (2012), pp. 3–14. See further the official website of The Antikythera Mechanism Research Project (AMRP) at http://antikythera-mechanism.gr and the introductory account given in Allen et. al. (2016), pp. 8–32.

47 See Freeth et al. (2008), pp. 17–18 (§ 3.4), on the merits of this option. Prof. Jones informs me that it now appears less likely, in view of the fact that, most probably, the calendar employed in Syracuse was different from the one used on the Mechanism.

48 See Cabanes (2011), pp. 258–60, Magou (2012), p. 236, Freeth et al. (2012), p. 271. A recent examination of the *parapēgma* framing the frontal display of the Mechanism has led to the conclusion that the data contained in it conform better to a date around 150 BC. See Zapheiropoulou (2012), p. 246. On the other hand, Evans and Carman (2014), pp. 155–157, provide arguments based on a fiducial mark discernible on Fragment C of the Mechanism in favor of an earlier date, near the end of the third century BC.

49 See Freeth – Jones (2012), § 2.3.2. Cf. also ibid. § 3.12.

on its back side, along with several subsidiary dials and pointers, all of them governed by the same complex system of intertwined gears and put in motion by means of a single knob or crank handle like the one we saw earlier used in Archimedes' planetary.[50] To be sure, many uncertainties still remain concerning the various aspects of its operation, its precise aim and its relation to its contemporary astronomical theory and practice, but there can be little doubt concerning its innovative character and that its construction apparently marked a significant breakthrough in the technology of the time.[51] This, along with the astounding degree of ingenuity and sophistication involved in its design, and also the technical precision of its execution, has made some modern researchers to relate not only its inception, but also its construction with some of the most prominent scientific figures of the period, such as Archimedes (who, however, died in Syracuse in 212 BC), Apollonius of Perge (probably fl. around 200 BC), Hipparchus (who died in Rhodes ca. 126 BC) and Posidonius (ca. 135 to ca. 50 BC, also active in Rhodes). At the same time, there are several remarkable correspondences that relate it to the device we saw earlier referred to by Theon of Smyrna:

1. The most obvious and, perhaps, the most important of these is that the function of both mechanisms relied on a complex system of gears intertwined, in the words of Theon, by "the engagement of their teeth". Indeed, the word τυμπάνιον used by Theon in order to designate the gears in his device appears also on an inscription on Fragment E of the Antikythera Mechanism, deciphered in 2005 by members of the AMRP team.[52]

2. As we have seen, the system of epicycles constitutes the theoretical foundation upon which Theon builds his account of the motion of the planets. It is said to provide an adequate explanation of the irregularities observed in their courses by reducing them to the regular, uniformly circular movements of the underlying spheres. On the other hand, epicyclic gearing is most prominent in the

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50 Parts of no less than thirty gears have been identified so far on the remaining fragments, but the complete Mechanism is estimated to have included several others, possibly reaching a total of forty or more.

51 See Keyser (1998), pp. 245–46, and Evans and Carman (2014), pp. 146–49, on the development of gearing technology before the time of the Mechanism. Sedley (1976), p. 38, had already estimated that it might have gone back to the school of Eudoxus at Cyzicus. For a comprehensive account covering the history of the construction of such "cosmic devices", see Berryman (2009), pp. 81–87. See further Aujac (1970), pp. 93–107.

52 The text of the inscription is now published in Bitsakis – Jones (2016), p. 235, where the term seems to occur at least twice (fr. E II 5 and 9). For its meaning as a gear bearing "teeth" (ὠδοντωμένον) cf. Heron of Alexandria *Dioptra* 3 and 34 (190.30–194.19, 294.21–296.22 Schöne), and idem *Pneumatica* I.16 (94.6 Schmidt).

construction of the Antikythera Mechanism, while the pin-and-slot contraption observed on the gear apparatus governing the lunar motion,[53] and now considered by Freeth – Jones 2012, §§ 2.4.3 and § 3.7, as "providing the essential model, both mechanically and conceptually" regulating the movements of all the superior "planets", is estimated to have produced results precisely equivalent to the ones reached by the system of epicycles.[54]

3. The "accidental" motions resulting from the combined function of the spheres governing the orbit of any particular planet are described by Theon (186.10–12) as "whirls" or "spirals" (ἕλικες). This seems to pick up an idea presented in Plato's *Timaeus* (39A5–B2), where the irregularities in the movement of the planets are explained by means of the combination of the motions of the Same and the Different which give it the form of a "helix".[55] Remarkably, the word ἕλικι (in the dative) appears also in the aforementioned inscription on Fragment E of the Mechanism, mentioning further its subdivision into "235 sections" (τμήματα σλε′).[56] It is thereby taken to refer to the spiral-formed upper dial on its back side, where the celestial motions displayed on the front are related to the division of each four-year cycle into 47 lunar months and thus to the so-called Metonic calendar (see Freeth et al. 2012, p. 266). Accordingly, the mention of spirals on the part of Theon might possibly reflect an analogous attempt to explain the way celestial motions are related to the established calendar systems used for terrestrial events (cf. Procl. *in R.* II 233.24–234.14 Kroll).[57]

4. The term μηχανοσφαιροποιία (a *hapax*) used by Theon for his device is, in my view, most appropriate in order to describe a mechanism such as the one found in Antikythera. That the world as a whole may be conceived as a mechanism was by no means a novel idea. Already Lucan *Pharsalia* I.80, could speak of a *machina mundi* (cf. also Vitr. X.1.4), while a few centuries later Proclus *De Prou.* I.2.22–24 Isaac, describes the deterministic view of his addressee, the "mechanic"

53 It is now presumed that this device is mentioned in the inscriptions of the Mechanism by the terms στημάτια ('bearings') and τρήματα ('perforations') (fr. E II 5–7, 11). See Bitsakis – Jones (2016), p. 245.

54 See Freeth et al. (2012), pp. 264–65. This is now formally established by Evans and Carman (2014), pp. 157–61. See further on this Wright (2003) and (2005), passim.

55 Cf. also [Pl.] *Epin.* 978D1.

56 See Bitsakis – Jones (2016), p. 235.

57 Theon quotes extensively from Adrastus' account of the relations connecting the heavenly circuits with terrestrial events such as variations of climate, seasonal changes and related meteorological occurrences (129.10 ff.). One may be reminded here that the Antikythera Mechanism comprises information concerning meteorological phenomena, such as winds, some of the names of which appear on Fragments A2, E2 and F; see Zapheiropoulou (2012), p. 247.

Theodorus, as postulating a mechanical universe with the spheres composing it operating like "gears engaged with each other (*tympanis implicatis*)".[58] Moreover, in his *in Ti.* III.56.21–31 Diehl, Proclus castigates the "moderns" (νεώτεροι) who advocate a purely mechanical explanation of heavenly motions.

5. Both the ordering and the names and designations given for the planets by Theon are identical to the ones contained in the inscription on the inside face of the back cover of the Antikythera Mechanism,[59] known as Fragment B, obviously meant to refer to its front dial. It is most likely that at the time the Antikythera Mechanism was constructed these features were considered, to some extent, as a novelty, possibly introduced by Stoic theorists influenced by Babylonian lore. Cicero, in his famous *Somnium Scipionis* (*De re publ.* VI.17, possibly drawing on some Stoic source: see Boyancé 1936, pp. 97–104) had also followed the "Chaldean" system. Geminus, *Introd.* 24–30, and Cleomedes, *Meteora* I.2 22–37 Todd, offer the same ordering and nomenclature for the planets, while Achilles, in his *Introductio in Aratum* 17 43.15–29 Maass records the existing disagreement (διαφωνία) on this issue.

One should add here a detail in the construction of the Mechanism which, although it finds no parallel in Theon's description, bears a remarkable corre-

58 See Berryman (2003), p. 362, and Berryman (2009), pp. 226–27.

59 I reproduce here the text of fr. B I 15–26 published by Bitsakis – Jones (2016), pp. 232–33, adding my own supplements and translation:

...]cθ̣ε ... τὸ σφαιρίον φέρε[ται	... the little sphere is carried ...
προέχον αὐτοῦ γνωμόνιον c[... περι-	a little pointer projecting from it ...
φερειῶν, ἡ μὲν ἐχομένη τῷ τῆc[... Στίλβον-	rings, the adjacent ... of Stilbôn,
τοc, τὸ δὲ δι᾽ αὐτοῦ φερόμεν[ον cφαιρίον	and [the little sphere] moving through it
τῆc Ἀφροδίτη⟨c⟩ Φωcφόρου ...[ὑπὲρ δὲ τὴν	of Aphrodite Phôsphoros ... [above
τοῦ [Φω]cφόρου περιφέρειαν.[	the ring of Phôsphoros ...
γνώμω[νι] κεῖται χρυcοῦν cφαιρίον ...[	on the pointer lies a golden little sphere ...
Ἡλ̣ί[ο]υ̣ ἀκτίν, ὑπὲρ δὲ τὸν Ἥλιόν ἐcτιν κύ[κλοc	ray of the Sun. And above the Sun is the circle ...
... το]ῦ Ἄρεω̣c Πυρόεντοc, τὸ δὲ διαπορευόμενον	of Ares Pyroeis, and the [little sphere] moving through ...
Διὸc Φα]έθοντ̣οc, τὸ δὲ διαπορευόμενο̣ν [cφαιρίον	[of Zeus] Phaethôn, and the little sphere moving through ...
Κρόνου Φα]ί̣νοντ̣οc κύκλοc, τὸ δὲ cφαιρίον φλ̣	the circle of Kronos Phainôn, and the little sphere ...
c. 7 litt.]ε̣ρὰ δ̣ὲ τοῦ κόcμου κεῖται ̣c[...	... of the Cosmos lies ....

Freeth – Jones (2012), § 2.3.2, mention the parallel list in Geminus (see his *Introduction to the Phaenomena* I.24–30) who, as it happens, also mentions the Pythagoreans in the same context (ibid. I.19). See also Aujac (1975), pp. 124–25.

spondence with Plato's own account in the myth of Er: the dial indicating the motion of the sun in the front display of the Mechanism is described on the aforementioned Fragment B as being equipped with a "little golden sphere (χρυσοῦν σφαιρίον)", while it has been surmised that other (presumably differently coloured) such *sphairia*, now lost, represented the other planets (see Freeth – Jones 2012, § 2.3.2 and cf. § 3.11). This naturally brings to mind Plato's attribution of different colors to the various whorls, where, among others, the sun's "whorl" is described as being "the brightest" (λευκότατον) and the one carrying Mars as "almost red" (ὑπέρυθρον) (*Rep*. X, 616E9–617A4).[60] It thereby provides a possible further indication that the Mechanism was designed to conform more or less accurately to the features of the heavenly bodies as described by Plato in the *Republic*.

Both Theon and the creator of the Antikythera Mechanism appear, therefore, to adhere to the same basic guidelines Plato had offered to those willing to engage in what he termed as "true astronomy". By constructing "visible models" depicting the combination of regular motions responsible for the varied motions of the stars, as suggested in the *Timaeus*, they believed they could provide a reasoned account which converted the apparent irregularities observed in the workings of the cosmos into their orderly and mathematically analyzable components and thus could make them understandable in terms of their underlying conformity to the basic principles governing the behaviour of the divine beings inhabiting the celestial regions of the universe. It thus becomes evident that both the treatise of Theon and the Antikythera Mechanism, although separated by a gap of perhaps more than two and a half centuries, represent different but complementary facets of one and the same project, aptly epitomized by the formula "to save the appearances". It is reflected in a strikingly straightforward manner through the arrangement of the various parts of the Mechanism itself: its front dial is designed to display as accurately as possible the celestial *phaenomena*, namely the observable motions and the relative positions of the heavenly bodies, as well as the occurrence of various other astronomical incidents such as the ones mentioned in the *parapēgma* which frames it by being inscribed on its upper and lower margins.[61] On the other hand, the complex system of dials in the back depicts the *per acci-*

60 Various reasons have been adduced for these attributions, ranging from observational data going back to Babylonian astronomy (see Bidez 1945, Appendice I) to purely theoretical considerations pertaining to the balance between the volumes and the densities of the celestial spheres (see Brumbaugh 1951, pp. 174–75).
61 As Evans (1999), pp. 256, says, "*parapēgmata* served as vital complements of the Greek civil calendars."

dens impact of the aforementioned occurrences on the terrestrial domain along with their repercussions on human social institutions, such as the Panhellenic games. Finally, the geared mechanism inside represents the causal concatenation of the regular movements of the celestial spheres thus offering an account of the mathematical relations underlying the events exhibited on the various displays and combining them into a unified *cosmos*.

The project of "saving the appearances" would thus comprise a theoretical, but also a distinctly practical component, namely the construction of visible models capable of exhibiting the way in which the celestial bodies perform their orbits, under the assumption that the constituent parts of the structures on which they reside perform regular (viz. circular) and orderly (viz. involving no variations of speed) motions. Such constructs would not just represent, but would actually implement the very same principles governing the movements of the heavenly spheres, forming precise analogues of the celestial mechanism determining the positions of the planets and their relative placement with respect to each other, the zodiac cycle and even the sublunary world. These two courses of pursuing the project undoubtedly differ in laying emphasis, the former on the literary aspect of the issue and the latter on its more technical side. However, as the references to the mechanical *sphairopoiia* in the first and the literary allusions embedded in the inscriptions of the second indicate, there is a considerable amount of overlap and cross-influence in their approach connecting both as parts of a comprehensive and strictly theoretical enterprise which attempts to offer a deeper understanding regarding the motions of the heavens by reducing them to a system of simple, regular and uniform rotations.[62]

I believe that the Antikythera Mechanism can be seen as belonging precisely to this tradition of constructing operating models of the cosmos. This would further explain the puzzlement discernible in most modern researchers concern-

62 As Posidonius, fr. 18.25–39 E.–K., has remarked, this does not amount to a full causal explanation of planetary motions but merely "resembles (ἐοικέναι) the enquiry into cause by means of the 'possible' (κατὰ τὸν ἐνδεχόμενον τρόπον) method." See Kidd (1978), p. 11. Cf. also the remark attributed to a certain Diodorus of Alexandria by Eudorus, apud Achilles *Introd*. 2 30.20–28 Maass, according to which "mathematics differs from *physiologia* because, while mathematics examines the consequences (τὰ παρεπόμενα) of substance (οὐσία) ..., *physiologia* investigates substance, what is the nature (φύσις) of the sun etc." We may quote here from a recent assessment concerning the general character of the Mechanism: "Many aspects of the design of the Antikythera Mechanism suggest that it was essentially a mathematician's instrument. The design has the purity of conception and the economy that is based on arithmetic cycles and the geometric theories current in the astronomy of its time." (Freeth – Jones 2012, § 2.4.2) ing its actual use.[63] For there is no conceivable practical application that might seem to justify the tremendous amount of intellectual effort and technical expertise invested in this almost incredibly sophisticated artifact.

Such lack of practical applicability may also offer an answer to another of the great puzzles that surround the Mechanism, namely, why, as far as we know, it has left no discernible legacy. There seems to have been no real continuation in the evolution of the technological achievement it represents and, unless a group of stray sponge divers had accidentally been diverted by a storm from their customary fishing grounds into an area close to the rocky shores of an obscure and inhospitable small island in the Aegean,[64] it would have been completely beyond us today even to imagine that such a feat of technological acumen had been possible during the Hellenistic age.[65] Such devices, however, appeared to have no real reason to continue to be produced, once the scientific project laid out by Eudoxus and his colleagues had begun to fade. In the meantime, other instruments, designed to serve much more practical and pressing needs began to make their appearance, and the newfangled plane astrolabe was perfectly suited to address the demands of the expanding and multifarious world of late antiquity. Due to its multiple uses, encompassing land surveying, time reckoning, mathematical calculation, navigation and astronomical (and astrological) observation, so eerily reminding us of our modern laptops and tablets, it quickly dominated the field and became a favorite gadget suitable both for avid entrepre-

63 See, e.g., Magou (2012), pp. 239–240, and Zapheiropoulou (2012), p. 247, who advances the somewhat illogical suggestion that such a complex and sophisticated device was used in order to predict the occurrence of the great Panhellenic games, indicated by one of the subsidiary dials on the back of the Mechanism, a task almost any schoolboy or -girl can perform by using nothing more than the fingers of his or her one hand. In my view, the indications on this dial served to establish the precise year in which a certain astronomical event would take place, since no other universally accepted chronological system was available at the time, apart from the one based on the years of the Olympic games. Cf. Freeth et al. (2008), p. 21 (§ 3.5). Note that Theon, 177.9–23, speaks disparagingly of the Babylonian, Chaldean and Egyptian astronomers of old, because they concerned themselves with mere predictions without properly understanding the natural causes underlying the celestial phenomena (ἄνευ φυσιολογίας ἀτελεῖς ποιούμενοι τὰς μεθόδους).

64 Another piece of good fortune has to do with the insightfulness of the young naval officer Pericles Rediadis who prevented a member of his crew from hurling the remains of the Mechanism back into the sea, taking them for a useless piece of rock. See Proskynitopoulou (2012), p. 231, note 1.

65 "The Antikythera Mechanism shows that Greek gear technology was far in advance of the level we should infer from the written record." (Freeth – Jones 2012, § 3.12) neurs and for refined intellectuals.[66] However, such a change of attitude inevitably precipitated the extinction of devices that by then had begun to look far too complicated and too abstruse even for the subtlest minds.[67] In this way the ingenuity and technical skill required for the development of *sphairopoiia* was eventually diverted towards the more urgent and profitable serviceability of the astrolabe, and from the exercise of elevated scientific research to that of everyday and mostly mundane technological application.[68]

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66 An instance of the latter variety can be found in Synesius of Cyrene who, in his short epistolary essay *On the Gift to Paeonius*, offers a description of the silver plane astrolabe he had constructed according to the guidance of his teacher Hypatia (who, in turn, was obviously adhering to the specifications given by her father, Theon of Alexandria, in his own special treatise on the subject) and serving as a guidance for engaging with natural philosophy by being "a most beautiful effigy of the extension of the universe" (4 138.9–13 and 5 140.4–5 Terzaghi). See Neugebauer (1949), pp. 242–43 and 248–51. Evans (1999), pp. 268–70, mentions other similar portable devices that emerged in late antiquity.

67 Another, perhaps more sophisticated, explanation might involve the switch from a strictly "realist" or "causal" understanding of the project of "saving the appearances" towards a more "instrumentalist" approach, represented by theorists such as Posidonius, Ptolemy, Proclus and Simplicius, as suggested by Duhem (1982), pp. 19–25, 31. According to this analysis, the latter view postulated that astronomical theories were devices or fictions put forward purely for the sake of calculations with no claims to correspond with physical reality. Thereby, one might surmise that it discouraged attempts to construct mechanical instruments purporting to illustrate the actual function of the celestial spheres. However, Duhem's theory has been effectively debunked by Lloyd (1978), pp. 202–21.

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