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Plato's *Timaeus* and Time

> The Earth he devised to be our nurturer, and, because it curls around the axis that stretches throughout the universe, also to be the marker and guardian of day and night. Of the gods that have come to be within the universe, Earth ranks as the foremost, the one with the greatest seniority. To describe the dancing movements of these gods, their juxtapositions and the back-circlings and advances of their circular courses on themselves […] to tell all this without the visible use of models would be labor spent in vain. (*Timaeus* 40b-d, Zeyl trans.)

The Syracusan Archimedes's planetaria and horological devices are considered to be innovations of the mid- to late-third century BCE, nearly a century after Plato's death in 347 BCE. However, the Roman statesman and orator Cicero (106-43 BCE) makes an explicit connection between Plato's *Timaeus* and Archimedes's invention:

> For when Archimedes fastened on a globe the movements of moon, sun and five wandering stars, he, just like Plato's Demiurge who built the world in the *Timaeus*, made one revolution of the sphere control several movements utterly unlike in slowness and speed. Now if in this world of ours phenomena cannot take place without the act of the divine, neither could Archimedes have reproduced the same movements upon a globe without divine genius.[2]

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[2] Cicero, *Tusculan Disputations*, Book I, Section XXV(63).

While Cicero's association of Plato's literary work with Archimedes's device is not causal, the aim of this paper is to trace the intellectual lineage from Plato's suggestion at *Timaeus* 40c to Archimedes's innovation. Cicero provides additional clues, but establishing a credible link between Plato's cosmology and Archimedes's armillary sphere or planetaria – at this time – requires delving deeper into Plato's mathematical thought and its connections to Pythagorean and Tarentine thinkers. We know from Plato's *Seventh Letter* that he was in contact with these scientists and intellectuals.

The oldest literary accounts we have written in ancient Greek offer explanations for how the world works. These "cosmogonies" attempt to order observable phenomena in such a way as to make sense of the workings of the universe. For Homer and Hesiod, cosmogonies are inseparable from theogonies, that is, stories that explain the origins of the gods and their rise to power. Both poets account for the oldest elements of the universe - earth, air, fire, and water, etc. - and each author anthropomorphizes these elements as deities. The *Timaeus* is Plato's cosmology, his account of how the physical universe came into being, and it represents his synthesis of the mytho-poetic traditions of Homer and Hesiod with the first rationalistic accounts of the universe provided by such early Ionian scientists and thinkers as Thales and Heraclitus. The quote from the *Timaeus* above hints at that dual lineage, since Plato divinizes natural phenomena – the planets are referred to as "gods" – and yet, direct observation, measurement, recording, and analyses of these complex celestial phenomena are critically necessary in order to describe them accurately. The latter sounds rather more like scientific inquiry and a move away from superstitious ignorance, rather than religious devotion. Yet reverence for the Demiurge and divine forces in nature permeate this work, likely ensuring its survival through the Middle Ages in Europe – the only of Plato's works available and read in Latin in the Christian West until the Renaissance.[3]

[3] Cicero's Latin translation of the Greek text of Plato's *Timaeus* was certainly read by early Church fathers, who quote Cicero extensively. The 4th century CE

Plato's *Timaeus* is one of his later works, likely written after the philosopher's first two trips (c. 387 and 366 BCE) to Syracuse recounted in the *Seventh Letter*. Although the conversation at the very beginning of the *Timaeus* takes place at Athens, its intellectual debt to Sicily is evident as Socrates's partners in conversation include two men from Magna Graecia, Hermocrates of Syracuse and Timaeus, from the Southern Italian city of Locri.[4] The fictional title character is perhaps modeled after Archytas of Tarentum, philosopher, statesman, general, and renowned mathematician, the founder of mathematical mechanics, a discipline in which Archimedes would later excel.[5] Archytas was a friend of Plato, whom Plato had introduced to Dionysius II, "apparently in the hope of persuading the Syracusan tyrant to emulate Archytas's just rule."[6] And in 360 BCE, when Plato fell out of favor with Dionysius II, it was Archytas who arranged for Lamiscus to rescue Plato from Syracuse on a Tarentine ship.[7]

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philosopher Chalcidius also translated the first half of the *Timaeus* into Latin. These two Latin translations – those by Cicero and Chalcidius - were essential in the transmission of knowledge of the *Timaeus* in the Frankish kingdoms in the Carolingian era (780s – 900 CE). Rosamund McKitterick, "Knowledge of Plato's 'Timaeus' in the Ninth Century," in *From Athens to Chartres, Neoplatonism and Medieval Thought: Studies in honour of Edouard Jeauneau,* ed. Jeauneau, E., & Westra, H. (Studien und texte zur geistesgeschichte des mittelalters, bd. 35), (Leiden: E.J. Brill, 1992), 86-87. I am grateful to former Gustavus Classics alumnus Andrew Smith for his research on the *Timaeus* manuscript tradition to the 9th century CE as part of his 300-level Plato course work in Spring 2016.

[4] Nails writes that "Timaeus – well-born, rich, an astronomer and philosopher elected to high office in Locri (Epizephyrii) – is unknown outside of the dialogues: the historian of the same name who is a source for some of the 4th c. Sicilian material is about a century later." While other prosopographers "emphasize that Cicero says twice that Plato studied with Timaeus of Locri (*De Fini*. and *Rep*.)," according to Nails, "one cannot rule out the possibility, however, that Cicero inferred the association from the dialogues." Debra Nails, *The People of Plato: A Prosopography of Plato and Other Socratics*, (Indianapolis: Hackett Publishing Company, Inc., 2002), 293.

[5] Diogenes Laertius 8.83. M.F. Burnyeat, "Plato on Why Mathematics is Good For the Soul" in *Proceedings of the British Academy* 103 (2000): 16.

[6] Nails, 2002, 44.

[7] Plato's *Seventh Letter*, 350 a-b. Nails, 2002, 45.

In this work, Timaeus delivers extensive speeches on the foundations of the sciences of astronomy, physics, chemistry, and physiology. His conclusion to a lengthy and complicated description of astronomical phenomena and their role in measuring time is at the heart of this paper, as he points out that a physical model is necessary to illustrate and fully understand the quite complicated movements of heavenly bodies (*Timaeus* 40b-d, quoted above). In the Greco-Roman world, such models – orreries, planetaria, and even the Antikythera mechanism - are typically dated to the later, Hellenistic period (323 – 31 BCE).

Cicero, Archimedes, and Plato

Cicero describes two different devices designed by Archimedes, both of which model the movements of the heavens. While one demonstrates his reception and mastery of the legacy of earlier scientists, the other illustrates Archimedes's own ingenuity. In *De Re Publica*, Cicero relates a discussion that took place in 129 BCE. The interlocutor tells a story of the visit of the Roman consul, Gaius Sulpicius Gallus, to the home of Marcus Marcellus, whose grandfather, the Roman general Marcellus, had sacked Syracuse in 212 BCE. (It was this Roman occupation that led to Archimedes's untimely death, murdered by a Roman soldier, despite Marcellus's instructions to his soldiers to find Archimedes and to bring the Syracusan scientist and inventor to Marcellus unharmed.[8]) According to Cicero's account, the general Marcellus had stolen from Syracuse two devices designed by Archimedes, both of which the victorious general had brought back to Rome. Marcellus dedicated the "more beautiful" of the two, a celestial globe, in the Temple of Virtue, where it was kept publicly on display among the spoils of war. The other he kept for himself and took home (and only this singular object, out of all the abundance of plunder looted from the famously wealthy and beautiful city of Syracuse.) The consul Gallus – nearly a century later - asks his host, the grandson of Marcellus, to bring out this device so Gallus and the other guests can admire it. Gallus is quite knowledgeable about Archimedes's work and

[8] Cicero, *De finibus* 5.50; Cicero, *In Verrem* 2.4.131; Plutarch, *Marcellus* 19.

describes the object dedicated in the Temple of Virtue – the other one - as a solid globe, the scientist's model of an earlier invention constructed by Thales of Miletus (c. 624 – c. 546 BCE) and further elaborated with the constellations and stars in the sky by Eudoxus of Cnidus.[9] The consul Gallus, eager to see this famous device now in the hands of a private collector, one not normally on public display, enthuses about the further development and innovation Archimedes brought to this modeling of the heavens and the solar system that his predecessors had earlier described.

> "But this newer kind of globe," he said, "on which were delineated the motions of the sun and moon and of those five stars which are called wanderers [the five visible planets], or, as we might say, rovers, contained more than could be shown on the solid globe, and the invention of Archimedes deserved special admiration because he had thought out a way to represent accurately by a single device for turning the globe those various and divergent movements with their different rates of speed." And when Gallus moved the globe, it was actually true that the moon was always as many revolutions behind the sun on the bronze contrivance as would agree with the number of days it was behind in the sky. Thus the same eclipse of the sun happened on the globe as would actually happen, and the moon came to the point where the shadow of the earth was at the very time when the sun [was]. . . out of the region.[10]

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[9] Nails describes Eudoxus as a student of Archytas of Tarentum, and possibly also a student of the physician Philistion of Locri Epizephyrii. "Eudoxus was an astronomer and geographer as well as a brilliant mathematician. . . but Eudoxus's most stunning legacy is a geometrical model of the apparent motions of the sun, moon, and planets in homocentric spheres that was able to show retrograde motion and was not overturned before Kepler." And Eudoxus had a school at Cyzicus which is said to have occasionally combined with Plato's Academy. Eudoxus is reported to have been *scholarch* at the Academy in Athens while Plato was away at Sicily in 366 BCE. Nails, *People of Plato,* 147.

[10] Cicero, *De Re Publica*, Book I, Sections 21-22.

What exactly was this device? Illustrations do help to distinguish among the types of this kind of model, but, for the moment, in the absence of such images, a few definitions will suffice. A "celestial globe" is a sphere on which the stars, constellations, and various astronomical orbits are drawn or incised. It is likely that this is the type of globe that Marcellus dedicated in the Temple of Virtue. An "orrery" is a heliocentric model of the solar system in which the planets move about a stationary sun through a clockwork mechanism. A "planetarium" is a geocentric model of the solar system that shows the positions of the sun, moon, and planets as viewed from the earth at various times. An "armillary sphere" is a skeleton made of graduated metal circles linking the poles and representing the equator, the ecliptic, meridians and parallels. Usually a ball representing the Earth or, later, the Sun is placed in its center. It is used to demonstrate the motion of the stars around the Earth. It is unclear from Cicero's descriptions whether the second mechanism, the one kept by Marcellus as his personal possession, was an orrery, planetarium, or armillary sphere, but it does appear to be a working model along the lines of what Plato describes as essential for understanding the complicated movements of the heavens (*Timaeus* 40c).

Eudoxus, Student of Plato(?), Inventor of Celestial Globe

Cicero credits Thales[11] and Eudoxus, the latter said to be a student of Plato, with the invention of the celestial globe. Gregory argues that "while the astronomy of the *Timaeus* is actually quite crude and poor . . . the astronomy and cosmology of the *Timaeus* was

[11] Hahn notes that building the cosmos out of right triangles is a narrative preserved in *Timaeus* 53Cff. "This metaphysical project began with Thales and is taken up by Pythagoras, who is also credited with the 'application of areas' theorem, the construction of all rectilinear figures out of triangles in any angle, and the 'putting together' of the regular solids, later called 'Platonic solids,' that are the molecules, created from right angles out of which all other appearances are constructed." Robert Hahn, *The Metaphysics of the Pythagorean Theorem: Thales, Pythagoras, Engineering, Diagrams, and the Construction of the Cosmos out of Right Triangles*, (Albany: SUNY Press, 2017), xi and 195-212.

of paramount importance to the development of these disciplines in ancient Greece"[12] and he notes how details of the work of Eudoxus and Callippus "show just how immediately fruitful the challenge set by Plato was. They tackle precisely the problems that Plato sets in the *Timaeus* in precisely the way he would like."[13] This description appears to reinforce the impression of Eudoxus as a dutiful student, who took to task Plato's assignment to develop a physical model of the heavens as described in *Timaeus* 40c, and for the successful completion of which Cicero awards credit.

However, Zhmud has argued that "there is no reliable evidence that Eudoxus, Menaechmus, Dinostratus, Theudius, and others, whom many scholars unite into the group of so-called 'Academic mathematicians' ever were [Plato's] pupils or close associates."[14] While it is difficult to determine whether Plato learned from Eudoxus or Eudoxus from Plato,[15] Eudoxan mathematics are evident in the *Timaeus*.[16] The transmission of ideas in antiquity is difficult to trace,

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[12] Andrew Gregory, *Plato's Philosophy of Science*, (London: Duckworth, 2000), 124-58.

[13] Gregory, 2000, 183.

[14] Leonid Zhmud, "Plato as 'Architect of Science'" in *Phronesis* 43:3 (1998), 211.

[15] Wilbur Knorr investigates the claim of Simplicius (early sixth century CE) in his commentary on Aristotle's *De caelo* that it was specifically Plato who inspired Eudoxus in his astronomical study, citing the second-century CE. Aristotelian teacher and commentator, Sosigenes. Knorr concludes, "It thus appears to be only Sosigenes's opinion that Plato played this role; certainly, Simplicius has not transmitted the identities of any special sources that Sosigenes might here have had, if indeed there were such." Wilber Knorr, "Plato and Eudoxus on the Planetary Motions." *JHA* 21 (1990), 318-20. In the end, he concludes that "there can be no doubt that Eudoxus knew Plato's *Republic*, and most likely also the *Timaeus*, before engaging in his own astronomical studies. But he must also have known the technical research on which Plato's astronomical visions are founded, for instance, the work of 'the very few men who are aware of the periods of the other planets', not just of the Sun, Moon and stars known to the many (*Timaeus* 39c), and the work of those who contrive the 'visual representations' that would facilitate serious investigation of intricate planetary phenomena (40c)." Knorr, "Plato and Eudoxus," 323-24.

[16] The Eudoxan mathematics De Groot sees in the *Timaeus* is the scheme of circles of Same and Different. From a cosmic point of view, the Different is the turning in the opposite direction that Eudoxus introduced of the circles of the ecliptic

especially in a far-flung world such as Western Greece, where scholars such as Plato traveled at will from Athens to Syracuse and elsewhere, much in the manner of earlier itinerant philosophers. Discussions were not confined to the Academy *per se*, nor were all conversations documented in ancient sources. Nor are many ancient sources extant. Nevertheless, this bit of Eudoxan mathematics in the *Timaeus* is evidence that there was an intellectual exchange. The text of the *Timaeus* itself no doubt sparked discussion and innovation over the course of space and time. Indeed, the millennia over which it was read in Greek and Latin, together with the works of astronomers, mathematicians, and engineers, yielded time-measuring devices – astronomical clocks and lunar and solar calendars still used today by major world religions. If one thinks about it in metaphysical terms, although time has preceded us and will continue long after our mortal lives are past, humankind has instituted time by means of making a model of the "timemakers" of our world, the heavens.

"Armillary Sphere" in the *Timaeus*

We know that the philosophy of mathematics at Ptolemaic Alexandria was Platonistic, given Hipparchus's reliable testimony about Eratosthenes.[17] They would have taken seriously the model that Plato describes. Generally, scholars make a connection between the armillary sphere ascribed to Eratosthenes in the 3rd century and the *Timaeus*. The mythic account of the Demiurge constructing the Circles of Same and Different and the planetary circles (36 b-d)

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and of the planets (at least we do not know of an earlier astronomer who actually suggests that planets move west to east on their own circles at the same time they participate in the east to west movement of the whole sphere of fixed stars). Plato's speaking of Same and Different as bands with divisions solidifies their cosmic significance. When he speaks of divisions filling up at the space on the bands, proportions leaving over a fraction with a tiny ratio, this suggests the "method of exhaustion" introduced by Eudoxus and used so extensively by Archimedes. These comments from Prof. Jean De Groot, email dated June 14, 2015.

[17] This comment needs more research. I am grateful to Prof. Jean De Groot for this lead.

sounds as though Plato were lending the Demiurge the tools of Hephaestus to forge the heavens, giving it patterns of figures, turning the heavenly bodies on a lathe, and shaping each to its proper form.

According to Cornford, the language describes the construction of a material model of the revolutions of heavenly bodies, an armillary sphere.[18] And, indeed, Cornford assumes that the Academy had such a sphere, and he cites Theon, who quotes *Timaeus* 40c, saying that he (Theon) had himself made a 'sphere' (σφαιροποιία). Plato's *Second Letter*, 312d, mentions a sphere (σφαιρίον) at Syracuse.[19] Cornford speculates that the 'sphere' at the Academy was, like the latter, "a simpler construction than the 'mechanical sphere' of the Syracusan Archimedes, which is said to have reproduced simultaneously all the celestial motions."[20]

Poetry of the Heavens in the *Timaeus*

Plato is one of the Greek philosophers who discuss the problem of time, (a theme raised by earlier thinkers, e.g. Anaximander[21] and Heraclitus). Plato does not define time, but speaks of it in terms of analogies and metaphors, within the context of the entire plan of the universe. The meaning of time can only be understood within this framework, and the significance of time can only be grasped by

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[18] Francis M. Cornford, *Plato's Cosmology*, (New York: The Humanities Press, Inc., 1952), 74.

[19] Cornford, 1952, 73-75.

[20] Cornford, 1952, 75.

[21] The Anaximander fragment, reproduced by the Neoplatonist Simplicius in his c. 530 CE commentary on Theophrastus's Φυσικῶν δόξαι, thus preserving it, is well known in Western continental philosophy. The Greek text was translated by Nietzche in his 1873 lecture, entitled *Philosophy in the Tragic Age of the Greeks*, published posthumously in 1903. Here is Nietzche's translation: "Whence things have their origin, there they must also pass away according to necessity; for they must pay penalty and be judged for their injustice, according to the ordinance of time." Heidegger's chapter, "The Anaximander Fragment" in his work *Early Greek Thinking* is a fairly well known treatment of the fragment and its reflection on time. David Farrell Krell, "Martin Heidegger: the Anaximander Fragment," *Arion: A Journal of Humanities and the Classics* 1:4 (1973): 576-626. http://www.jstor.org/stable/20163348. I am grateful to Tony Leyh for pointing out this specific example of Presocratic thinkers reflecting on time and being long before Plato.

observing its relationship to other beings in the universe. Time is relative - it is measured through motion.

Plato's approach to time is a cosmological one, he is fully aware of the effectiveness of the use of allegory and metaphor, such as we see in the Western Greek poetic tradition, for making sense of the observable phenomena of the workings of the universe. Its order and harmony, mathematics, musical progression, the fundamental harmony in the universe is most evidently, though only partially, manifested in the motions of the heavenly bodies.

In the terms of such poetic language, the sun, moon, and planets were created to distinguish and guard the numbers of time. Their orbits and their duties assist in the fashioning of time. Thus, we have days, months, and years. Time is the wandering and revolution of heavenly bodies and their measurement with numbers. Time and the universe are inseparable and time came into being with the ordering of the universe.

> For before the heavens came to be, there were no days or nights, no months or years. But now, at the same time as [the Demiurge] framed the heavens, he devised their coming to be. These all are the parts of time, and *was* and *will be* are properly said about the becoming that passes in time, for these two are motions. (*Timaeus* 37e)

Plato as Scientist, Innovator, and Teacher

Plato describes astronomical phenomena at length and their role in measuring time. However, he concludes this section of the work with an important observation - he points out that a physical model is necessary to illustrate and fully understand the quite complicated movements of heavenly bodies.

> The Earth he devised to be our nurturer, and, because it curls around the axis that stretches throughout the universe, also to be the marker and guardian of day and night. Of the gods that have come to be within the universe, Earth ranks as the foremost, the one with the greatest seniority. To describe the dancing movements of these gods, their juxtapositions and the back-circlings (Ptolemaic epicycles) and advances of their circular

> courses on themselves . . .to tell all this without the visible use of models[22] would be labor spent in vain. (*Timaeus* 40c)

This passage is extraordinary for a number of reasons. First, it raises questions about general notions of Plato's epistemology, according to which the data provided by sense-perception is not reliable. Second, implicit in this statement is the idea that a (presumably accurate) μίμημα (model) of an εἰκών (likeness) could lead us (or as close as we can get) to knowledge of the παράδειγμα, the divine plan (or Broadie's "recipe"[23]) for the workings of the universe. We are at three (four?) degrees of separation from what is eternal and yet it is seemingly still accessible to us. This doesn't seem to synch up with our general understanding of Plato's theory of knowledge. What gives? What is happening here?

I'll begin with a caveat. The character Timaeus does caution that his entire cosmology is at best an εἰκὼς μῦθος, a "likely story" that must necessarily lack full consistency and accuracy (cf. 29c-d). His astronomical account is presented as a description of the soul of the cosmos, not of the visible system of the heavens. In Plato's ontology, sensible objects are but changing and imperfect copies of the associated Forms, which are perfect and unchanging.[24]

Broadie's argument that Plato in the *Timaeus* is truly concerned to explain the cosmos because the Demiurge was truly concerned to create the best possible world is best set forth in her own brilliant explanation:

> On one of these approaches, the cosmos is the subject-matter for the human scientist, and the paradigm is epistemically subordinate. This is because the scientist reconstructs the paradigm as far as possible just in order to have a well-reasoned theory of the cosmos. What makes it reasonable to hope for such

[22] For those interested in the original Greek translated as "models," it is not παράδειγμα or εἰκών but μίμημα.

[23] Sarah Broadie, *Nature and Divinity in Plato's* Timaeus (Cambridge: Cambridge University Press, 2014) 62.

[24] Wilbur R. Knorr, "Plato and Eudoxus on the Planetary Motions." *JHA* 21 (1990) 318.

a theory is the framework assumption that the cosmos was made in accordance with the paradigm. Moreover, the paradigm in this act of making (or the maker's use of the paradigm) is also subordinate – to the production of the best possible physical world. This world is the maker's primary objective, just as it is the natural scientist's primary object of study. According to the other approach, the intelligible paradigm is the primary object for the Platonic investigator, and the physical cosmos is useful as conveying it by representation. The evidence is strong that the *Timaeus* cosmology is governed by the first approach, even though there are some conspicuous passages whose language suggests the second.[25]

While Plato takes the first approach in the *Timaeus*, we see Broadie's second approach at work in Plato's *Republic*, when Socrates makes a recommendation about the kind of research astronomers ought to engage in:

> By using problems, then, we shall pursue astronomy, just like geometry, but we shall set aside the things in the sky, if we intend to take hold of astronomy in the true sense and so make useful the natural intelligence in the soul (530b).

This new astronomy is "a purely mathematical study of geometrical solids (spheres) in rotation (528a, e), a sort of abstract kinematics; for only a study of *invisible* being will turn a soul's gaze upwards in the sense that interests Socrates (529b)."[26] Now this sounds closer to the Plato we thought we knew. And yet, as Burnyeat points out, "the astronomy section of the *Republic* stands at the origin of the great tradition of Greek mathematical astronomy which culminated in the cosmological system of Claudius Ptolemy."[27] As Knorr comments,

> This remark bears specifically on the kind of study that will suit the purposes of a general liberal education for the state's elite. But, as Bulmer-Thomas has argued, it also embraces a fully

[25] Broadie, 2012, 82-83.
[26] Burnyeat, 2000, 12.
[27] Burnyeat, 2000, 12.

> reasonable program for researchers. By 'setting aside' the visible phenomena, one is not to dismiss altogether the empirical facts, but rather to give priority to the discovery of the underlying geometric regularities, 'the actual swiftness and the actual slowness of the motions in the true number and all the true figures" (529d), through which the phenomena can be accounted for.[28]

In the *Republic*, Socrates says that astronomy should be pursued in the same way as geometry. The visible patterns of motion in the heavens should be studied like the diagrams of geometry, as an aid to thinking about purely abstract mathematical problems (529d-530c). But sense perception again intervenes, as Socrates then describes several distinct types of motion, each with its own proper mode of perception.

> "It is probable," I said, "that as the eyes are framed for astronomy, so the ears are framed for harmonic motion, and these two sciences are sisters of one another, as the Pythagoreans say – and we agree, Glaucon, do we not?"
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> "We do," he said. (*Republic* 530d)

If, then, the observation of astronomical phenomena goes beyond mere perception, including measurement, gathering data on various movements of bodies in the heavens, and recording observations and analyses, representation of this data would necessarily mean creating a model which was similarly movable and changeable but similarly reflecting the realities and inter-workings within the cosmos that its observers documented. Thus, the orreries, armillary spheres, and planetaria were all moving models, capturing the distillation of the measurement of astronomical time which they represented. And, of course, models could get it wrong, just as human observation might prove faulty, never mind hypotheses and theorems. But the plausibility of such an account, a "likely story," at least provides a point of departure, a basis for further investigation and argument.

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[28] Knorr, 1990, 324.

The story does not end there, for making the theoretical visible, in the form of geared devices, would have a significant effect on horological devices, from Hero of Alexandria's water clocks to the astronomical clocks of the Islamic world and late medieval Europe. In the introduction to his *Pneumatica*, Hero of Alexandria (*fl*. 1st cent. CE) explains that this (pneumatic) technology is fundamental to his earlier treatise on water clocks (*hōroskopeia*).[29] His four-volume work on water clocks has not survived, but its mention is revealing.[30] Much of Hero's extant work can be regarded as a kind of palimpsest, both for some of his other works, since lost, and, more importantly, for the works of several Hellenistic scientists, especially Archimedes, Ctesibius, and Philo of Byzantium. Hero was familiar with the technological achievements of earlier scientists and sought to explain, adapt, and improve upon their innovations, although he may not have always fully understood his sources.[31] Hero's surviving documentation of Hellenistic technology is justly famous, especially for the "marvelous engines" which he describes in two of his works, the *Pneumatica* and the *Automata*. These works may have survived precisely because his inventions were entertaining and his descriptions less taxing for the novice reader than the original works of Hellenistic scientists.[32]

The Arabic reception of Hero's works in 9th-century Baghdad led to further research into his sources (which may still have existed in manuscript at that time). Interestingly enough, all of Plato's works, including the *Timaeus*, were available, read, and studied by Arabic scholars in the original Greek and in some Arabic translations

[29] Schmidt, W., ed. 1899-1914, *Heronis Alexandrini opera quae supersunt omnia*, 5 vol., (Leipzig: Teubner, 1899), Vol. I, 2.

[30] A fragment of Hero's treatise on water clocks can be found in Schmidt, ed., *Heronis*, Vol. I, 456.

[31] Lucio Russo, *The Forgotten Revolution: How Science Was Born in 300 BC and Why It Had to Be Reborn.* (Heidelberg and New York: Springer-Verlag, 2004), 141.

[32] Russo, 2004, 137-41.

(prepared in the 9th and 10th centuries) throughout the Middle Ages.[33] Further, enthusiasm for the *Timaeus* led to a split or twofold Arabic transmission of the text, with separate emphases on its philosophy, *Timaeus on Metaphysics*, and on its preservation of earlier Greek scientific and physiological theories, the *Medical Timaeus*.[34]

In turn, Arabic scholars' application of this theoretical knowledge led to a number of important technological innovations within Abbasid culture. Specifically, the development of the astronomical clock provides an excellent case study for the reception of Hellenistic science in Arabic culture, for Arabic scholars' adaptation and development of that technology within their own specific cultural and religious context, and for the subsequent appropriation of this technology, claimed as one of the "re-discoveries" of classical antiquity in the European Renaissance.

Ctesibius had introduced the first real clocks to Alexandria in the first half of the third century BCE, solving all of the problems inherent in the earlier Egyptian water clepsydra and in this way transforming the clepsydra into a reliable and accurate instrument for measuring time.[35] An anonymous work preserved in Arabic describes and attributes to Archimedes a remarkable design for a water clock which is strikingly similar to the Elephant Clock of the famous 12th-century Islamic engineer Ibn Isma'il al-Jazari.[36] Al-Jazari is best known for his *Book of Knowledge of Ingenious Mechanical Devices*, which describes fifty mechanical devices and gives instructions on how to construct them.[37] Such a work is reminiscent of Hero's

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[33] Rüdiger Arnzen, "Plato's *Timaeus* in the Arabic Tradition," in Celia, Francesco, et al. *Il Timeo : Esegesi Greche, Arabe, Latine : Relazioni Introduttive Ai Seminari Della 5. "Settimana Di Formazione" Del Centro Interuniversitario "Incontri Di Culture. La Trasmissione Dei Testi Filosofici E Scientifici Dalla Tarda Antichità Al Medioevo Islamico E Cristiano," Pisa, Santa Croce in Fossabanda, 26-30 Aprile 2010*. (Pisa: Plus-Pisa University Press, 2012), 182.

[34] Arnzen, 2012, 188.

[35] Russo, 2004, 102.

[36] Russo, 2004, 102.

[37] Jim Al-Khalili, *The House of Wisdom: How Arabic Science Saved Ancient Knowledge and Gave Us the Renaissance*, (New York: Penguin, 2011), 277-78.

Automata, and it is likely that familiarity with Hero's work and possibly Hero's source, Philo of Byzantium, led to the development of a guild of automata builders in the Islamic world, which flourished for centuries.[38] Arabic scientists' interest in the Hellenistic technology of automata and geared mechanisms led to the development of the astronomical clock, fully in keeping with their interest in astronomy and astrology, the latter deemed the "mistress of the sciences" in Abbasid culture.[39]

Although not described by Hero in any of his extant works, the astronomical clock has special mechanisms and dials to display astronomical information, such as the relative positions of sun, moon, constellations of the zodiac, and sometimes major planets. It is sensible to assume that such a device existed in Hellenistic technology, thanks to the modern discovery of the Antikythera mechanism, named after the Greek island where the remains of ancient shipwreck dated to the 1st cent. BCE were discovered nearly a century ago. Researchers describe the mechanism as an astronomical calculator with the ability to predict both lunar and solar eclipses, and they confirm that the device has a mechanical display of planetary positions that appears to follow the theories of Hipparchus, who realized that the moon's unusual positions in the sky are caused by its elliptical orbit, a theory demonstrated by the mechanism's complicated planetary alignments.[40]

A similar device, certainly a descendant of the Antikythera mechanism, was described by the Persian scholar al-Biruni around

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[38] Russo, 2004, 332. For the Arabic tradition of building "marvelous mechanisms," which goes back to the eighth century, see Donald R. Hill, "Mathematics and applied science," in *Religion, learning and science in the 'Abbasid period'*, edited by M.J.L. Young, John D. Latham and Robert J. Serjeant. (Cambridge: Cambridge University Press, 1990), 248-73.

[39] Dimitri Gutas, *Greek Thought, Arabic Culture. The Graeco-Arabic Translation Movement in Baghdad and Early 'Abbāsid Society (2nd-4th/8th-10th centuries)*, (London and New York: Routledge, 1998), 108.

[40] Jarrett A. Lobell, "The Antikythera Mechanism" in *Archaeology*, Vol. 60, No. 2 (March/April 2007), 42-45.

1,000 CE.[41] Two early astronomical clocks, Al-Jazari's Castle Clock (1206) and the Three Kings' Clock at Strasbourg Cathedral (1352-54), demonstrate the Arabic reception and development of this particular Hellenistic technology and its subsequent spread across Europe in the thirteenth century.

Conclusion

Plato's *Timaeus* is a complex work, preserving early Greek scientific theories long since considered obsolete by modern Western astronomy and other disciplines. We set ourselves the task at the beginning of this paper to investigate whether Archimedes's device – mentioned by Cicero – may perhaps have been a response to or inspired by the specific assignment or challenge – if indeed it was one – that Plato poses at *Timaeus* 40c, that is, to create a working model that distills a complex knowledge of the patterns of celestial movements, gained through detailed observation, recording, and analyses of that data over time. This investigation reveals another complex, diachronic interplay, that between individual thinkers over space and time and the communication and transmission of ideas and the sparking of inspiration despite barriers of language, religion, and geographic location. The locus, originally, is small. We began with Plato at Syracuse, a visitor from Athens. But that circle rapidly expands, back in time to earlier poets such as Homer and Hesiod and to earlier thinkers such as Thales of Miletus, Anaximander of Miletus (Thales's pupil), Pythagoras of Samos (Anaximander's student), and Heraclitus of Ephesus to Plato's contemporaries in Sicily such as Archytas of Tarentum and Philistion of Locri Epizephyrii, and their students such Eudoxus of Cnidus and Aristotle, and yet another generation of their students at Cyzicus and at the Academy in Athens. The ripples further enlarge and radiate over time to Hellenistic Alexandria, to Archimedes's Syracuse and Rome, to Cicero, Hero of Alexandria, the early Church fathers, Late Antiquity,

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[41] Derek J. de Solla Price, "Gears from the Greeks: the Antikythera mechanism – a calendar computer from ca. 80 B.C.," in *Transactions of the American Philological Society* 64, part 7 (1974), 42-43.

to 9th century Baghdad, medieval and Renaissance Europe, and even to the present day. While this description might seem poetic, even romantic, a vision in the vein of the Renaissance artist Raphael's fresco, *The School of Athens*, the traces of evidence are there, preserved in our texts – though with many lacunae - and in the technology of timekeeping devices themselves, documenting the remarkable human collaborations of scientific study and ingenuity over the course of millennia and around the circumference of the globe. Although Plato's science is now obsolete, there is no question that the *Timaeus* was part of an ongoing conversation inspired by Plato's own engagement with his predecessors and contemporaries, producing a text that motivated its readers to test, respond, and innovate in a process that, while it created the text's own obsolescence, also regenerated itself by inspiring new research, science, and technology.