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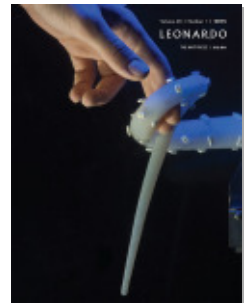
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## **Deciphering and Appeasing the Heavens: The History and Fate of an Ancient Greek Computer**

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*νῦν σωζόμενα, ἅπαντα,*

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PHILOSOPHI AC GEOMETRÆ EX-

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# Deciphering and Appeasing the Heavens: The History and Fate of an Ancient Greek Computer

*Evaggelos Vallianatos*

The Greeks incorporated cunning craftsmanship, inventiveness and beauty in everything they made. *Techné*, the term they used to describe this, was the mother of their culture. Aristotle, who shaped the nature of Greek science and invented zoology, admired craftsmen for their useful devices and wisdom [1]. In fact, of all classes in a polis, he considered craftsmen the most essential. No polis could exist without mechanics practicing their arts and crafts. Of those arts and crafts, Aristotle said, some are “absolutely necessary,” while others enrich life [2]. This Greek mechanics gave birth to the Antikythera Mechanism, discussed below.

## THE TREASURE FROM THE SEA

On around Easter Sunday 1900, Greek sponge divers discovered the remnants of an ancient ship in the waters of the Aegean island of Antikythera. The most precious artifact within this treasure trove was a small piece of metal with gears. Archaeologists of the National Museum in Athens categorized it as an astrolabe [3].

The shipwreck probably happened in the mid-1st century BCE. The doomed Roman ship, sailing from Rhodes to Rome, carried looted Greek treasure: more than 100 bronze and marble statues, amphorae and coins. Some of the amphorae came from Rhodes. The silver coins originated in Pergamon, a Greek kingdom in northwestern Asia Minor, and the bronze coins were from Ephesos, a Greek polis about 100 miles south of Pergamon. The bronze coins, which dated from 70 to 60 BCE, helped to date the doomed Antikythera ship. One memorable statue, the Antikythera Youth, is a bronze masterpiece of a male nude from the 4th century BCE.

The mechanism, calcified and covered with seashells, was kept in a crate until May 1902, when an archaeologist, Spyridon Stais, unpacked it and saw a Greek inscription on its surface. Others noticed perfectly cut triangular gear teeth.

In 1905, Konstantinos Rados, a naval historian, declared that the Antikythera device was too complex to be an astrolabe [4]. In 1907, the German philologist Albert Rehm sided

with Rados [5]. Rehm correctly suggested that the Antikythera clockwork resembled the Sphere of Archimedes, which Cicero described in the 1st century BCE. Archimedes was a mathematician and engineer of the 3rd century BCE (Article Frontispiece).

Cicero recounted that the planetarium of Archimedes reproduced the movements of the sun and moon and the planets Venus, Mercury, Mars, Saturn and Jupiter.

The same eclipse of the sun that happened on the globe of Archimedes would actually happen in the sky [6].

Rehm worked on the device for several years; he died prematurely, however, and his work remained unpublished.

In the 1920s, a Greek admiral, J. Theophanides, opined that the ancient mechanism was a navigational device that could tell the position of certain planets [7].

## GEARS FROM THE GREEKS

The next important phase in the decipherment of the Antikythera Mechanism began with Derek de Solla Price, a British physicist and historian of science then teaching at Yale University. In studying the papers of the Greek scientists and those of Rehm, Price came to the understanding that the Antikythera Mechanism was probably the most sophisticated technological artifact of the ancient Greeks and that it remained unrivaled for 1,500 years.

In 1971, Price asked the Greek nuclear physicist Charalambos Karakalos to X-ray the Antikythera fragments. In summer 1972, Karakalos took hundreds of radiographs of all large fragments. Price wanted to know how the gearwheels meshed with each other and how many teeth each wheel had. Only then could he figure out the purpose of the Greek machine. He eventually left us “Gears from the Greeks,” a masterful scientific record of his assessment of the Antikythera Mechanism [8].

Price took 16 years to master the intricacies of the device. He reported that the Antikythera Mechanism, dating from about 150 to 100 BCE, was “one of the most important pieces of evidence for the understanding of ancient Greek science and technology” [9]. He explained why: The complex gearing of the Antikythera Mechanism shows a more precise picture of the level of Greek “mechanical proficiency” than that indicated by the surviving textual evidence. This “singular artifact,” he said of the Antikythera Mechanism,

## ABSTRACT

In 1900, Greek sponge divers discovered an ancient Greek treasure in the waters of the Aegean island of Antikythera: a device with gears dubbed the Antikythera Mechanism. Scientists studied it for almost a century and eventually declared it the most advanced machine preserved from the ancient world. This device predicted solar and lunar eclipses and harmonized the Greeks' sacrifices to their gods with their Panhellenic games and agriculture. This geared computer from the 2nd century BCE is now said to mirror the philosophy of Aristotle and the science of Archimedes. It was the product of an advanced Greek technological infrastructure that early Christians destroyed.

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Article Frontispiece. *Works of Archimedes*, Basel, 1544. (Reproduced by permission of The Huntington Library, San Marino, California.)

the oldest existing relic of scientific technology, and the only complicated mechanical device we have from antiquity, quite changes our ideas about the Greeks and makes visible a more continuous historical evolution of one of the most important main lines that lead to our civilization [10].

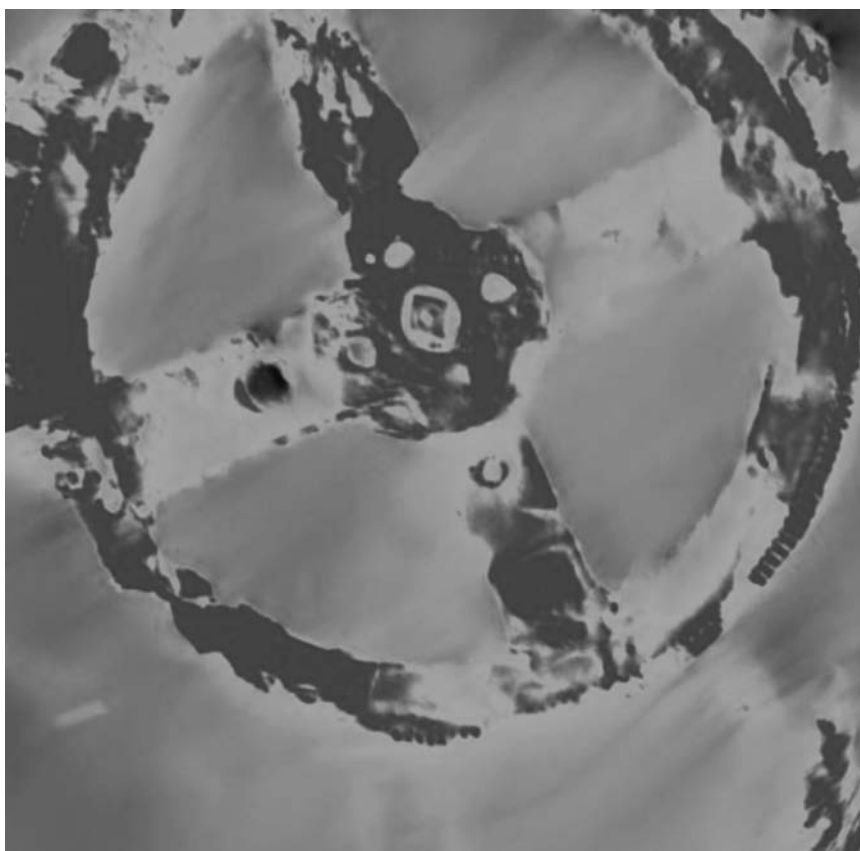
Price described the differential gear of the Antikythera Mechanism as the cornerstone of the computer's technology. The differential gear enabled the Antikythera Mechanism to show the movements of the sun and the moon in "perfect consistency" with the phases of the moon. "It must surely rank," Price said of the differential gear, "as one of the greatest basic mechanical inventions of all time" [11] (Fig. 1).

In fact, in keeping with the near disappearance of the Antikythera Mechanism's technology in late antiquity, the differential gear disappeared for more than a millennium and a half. Price shows that its reinvention eluded Leonardo da Vinci and that it reappeared in 1575 in a clock made by Eberhart Baldewin in Kassel, Germany. This gear and the clockwork culture that developed it advanced the technology of cotton manufacture in the 18th century. Eventually, the differential gear ended up in automobile designs in the late 19th century.

Price complained that the West now judges the Greeks from scraps of building stones, statues, coins, ceramics and a few selected written sources. Yet, when it comes to the heart of their lives and culture, we have practically nothing from the Greek past. We do not have artifacts that show how they carried out agriculture, how they built the perfect Parthenon, what kind of mechanical devices they employed in war, how they used metals or, in general, what the Greeks did in several fields of technology. As Price wrote:

Wheels from carriages and carts survive from deep antiquity, but there is absolutely nothing but the Antikythera fragments that looks anything like a fine gear wheel or small piece of mechanism. Indeed the evidence for scientific instruments and fine mechanical objects is so scant that it is often thought that the Greeks had none [12].

Price was correct, particularly on the value he put on the fragments of the Antikythera device. In this insight, he surpassed his critics and others who maintained that the Greeks had no technology to speak of. (In 1968, the best-selling Swiss writer Erich von Daniken in his book *Chariots of the Gods* advanced the fiction that important technologies in the ancient world were



**Fig. 1. The Antikythera Mechanism: The largest gear, the Wheel of the Sun. (Photo © Xenophon Moussas)**

products of extraterrestrial astronauts or gods.)

This nonsense that the Greeks lacked technology fooled millions for a long time. Finally, in 2005, more than 20 years after Price's death in 1983, a group of international scientists was formed to settle the controversy over the ancient device's scientific significance and functions. Key members included a British mathematician and filmmaker, Tony Freeth; a British professor of astronomy, Mike Edmunds (University of Wales); and two Greek professors of astronomy, J. Seiradakis (University of Thessalonike) and Xenophon Moussas (University of Athens). Freeth, who brought to bear creativity and innovation, convinced two companies, X-Tek of England and Hewlett-Packard of the U.S.A., to volunteer their imaging technologies for study of the Antikythera Mechanism.

In September and October 2005, technicians used a 10-ton machine to take 3D photos and nonlinear computer tomographies of the Antikythera Mechanism. They also exposed the 82 fragments of the 32 known gears of the computer to X-ray bombardment unprecedented in intensity and sophistication. From thousands of X-ray tomographs of the interior and exterior of the ancient ma-

chine, there emerged evidence of the machine's architecture and engineering, and even of a users' manual (Fig. 2). Now it was possible to understand more clearly how the Antikythera computer was constructed.

The fragments bore inscriptions in ancient Greek. Moussas hired physicist Yanis Bitsakis to assist Agamemnon Tselikas, director of the Center for History and Paleography, with the reading of those inscriptions from the computer tomographies. The Greek letters were very small; some were smaller than 2 mm. The first inscription Bitsakis and Tselikas translated was on the back of the Antikythera Mechanism. It read: "The spiral [EAIKI] divided into 235 sections." This meant that one of the back dials was a spiral representing the 19-year Metonic moon and sun calendar of 235 months. Other back dials predicted the eclipses of the sun and the moon. Inscriptions on the front dials, on the other hand, concerned the days of the year; the zodiac ran clockwise around them. These inscriptions allowed one to determine the date based on the rising and setting of constellations. Moreover, the front dials showed the movement and position of the sun, moon and the planets in the zodiac. They also revealed the phases of the





Fig. 2. Part of the users' manual. At center it reads, "So we know four," and below this, "76 years," "19 years," representing the Callippic and Metonic lunisolar periods; "223" [months]; "divided"; and then "ecliptic months." (Photo © Xenophon Moussas)

moon. Indeed, the entire device became a text (Fig. 3). The scientists reported the Antikythera device is "an extremely rare original document that gives us critical information about the astronomy and technology of its era" [13].

The celestial Antikythera device was alternatively like a laptop computer the size of a shoebox, which, according to the scientists, exhibited "longitudes of heavenly bodies on the front dial, eclipse predictions on the lower back display, and a calendrical cycle believed to be strictly in the use of astronomers on the upper back display" [14] (Fig. 4).

### THE GREEKS' ADVANCED TECHNOLOGY

The scientists also concluded that the Antikythera Mechanism was in its time the most sophisticated technology in the Mediterranean and remained so for more than a millennium. They published their reports in the 30 November 2006 and 31 July 2008 issues of *Nature*. Like Price's 1974 report, these two *Nature* articles are fundamental in the decipherment of the Antikythera Mechanism. They complement each other, with the 2006 and 2008 reports building on the technical detail of Price, who had also described the Antikythera Mechanism as a "singular artifact" and an "astronomical or calendrical calculator" that turned out to be "the most enigmatic, most com-

plicated piece of scientific machinery known from antiquity" [15].

Freeth et al. admired the ancient device's "great economy and ingenuity of design." The Antikythera Mechanism, they concluded, "stands as a witness to the extraordinary technological potential of ancient Greece, apparently lost within the Roman Empire" [16].

### CHRISTIANITY OBLITERATED GREEK TECHNOLOGY

The truth is simpler. The Christians destroyed the technological achievements and potential of the Greeks. The technology of the Antikythera Mechanism was not merely lost; the Christians made it obsolete, that is, made it disappear. The Romans were brutal, but it was the Christians, not the Romans of the pagan era, who removed the Greeks' contributions from the landscape.

The apostles directed Christians, "Stay clear of all Greek books" [17]. The church fathers denounced the Greeks, accepting the utility of Greek logic only where Greek philosophy was made a handmaiden of Christian theology. In 391–392, Christians burned the nearly intact Library of Alexandria [18], which possessed most of the books of the Greeks; the Christians brought the Olympics to an end in 393; they imported barbarians to smash the Greek temples in 396.

In 415, Christian monks killed the

Greek philosopher and mathematician Hypatia. Around that time, Augustine, the most important church father of the Latin West, preached that all that a Christian needed was the Bible. In 484, Emperor Zeno defiled the Parthenon, plundering its chryselephantine statue of Athena by Pheidias, one of the foremost Greek sculptors of the 5th century BCE. In 529, Emperor Justinian shut down the Platonic Academy, which had been the greatest university of Greece for about 900 years. These barbaric acts were part and parcel of an extremely effective and sustained Christian attack against Greek culture [19].

The investigators of the Antikythera Mechanism all ignored the effect of Christian actions, which must have almost obliterated Antikythera-like devices and other technology throughout the Greek world. Christian acts against pagan ideas explain the rarity of the Antikythera computer. By means of terror and propaganda, followers of Christianity devalued Greek culture so much that the arts of civilization, including technology and science, fell into a precipitous decline. Also, as a matter of course, the Christians melted down or burned the bronze devices and statues of antiquity.

For example, in the mid-4th century, Firmicus Maternus, a Christian apologist, appealed to the brother emperors Constantius and Constans to "take away . . . the adornments of the temples. Let the fire of the mint or the blaze of the smelters melt them down" [20]. Palladas, a Greek poet of the 5th century, witnessed a smith transforming a statue of Eros into "a frying-pan" [21]. In the early 5th century, the Christian historian Sokrates documented the Christians' recasting of the Greek bronze statues of the Library (Serapeion) of Alexandria into "pots and other convenient utensils for the use of the Alexandrian church" [22].

The fires of the mint and the blazes of the smelters must have consumed Antikythera Mechanism-like devices. In the new Christian society, such devices would have lost all utility and meaning.

Despite such violence, not all Christians hated the Greeks. The Nestorians, for example, became instrumental in the preservation of some Greek texts. They were branded heretics and fled to Persia, carrying with them Greek books. In the 8th century, the caliphs of Islam turned to the Nestorians for the translation of the Greeks' scientific and philosophical works into Arabic. In addition, Greek Christians in medieval Greece copied and protected the key ancient Greek texts that have lasted to our time.

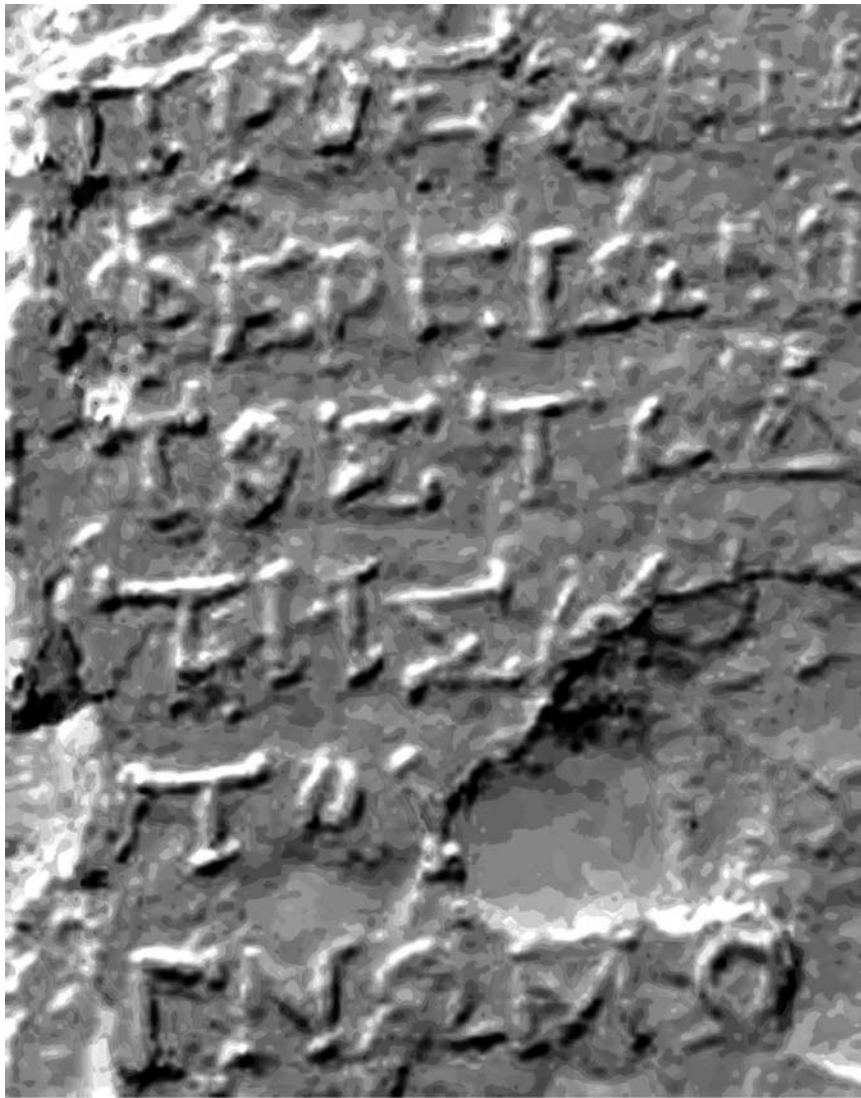


Fig. 3. From the letters of the manual, the archaeologist C. Kritzas estimated the mechanism's date of construction to be between 150 and 100 BCE. (Photo © Xenophon Moussas)

the Antikythera Mechanism. Price would have agreed with this conclusion.

Thus, the considerable scientific and political value of such a small machine would argue for its widespread use and ownership. This suggests dozens of such computers all over the Greek world and more than one place manufacturing them. In contrast to the 14th-century Dondi astronomical clock, set upon a church tower, the Greek computer was not a plaything for the rich. It did not simply vanish.

In 1983, a Lebanese man sold to the Science Museum of London a sundial possibly constructed in Constantinople, in all probability around the early 6th century. This device had 4-toothed wheels and a ratchet carried on 2 small axles. One of the wheels had 59 teeth; this wheel measured the movement of the moon. Like ancient lunar calendars, this sundial represented a 30-day month followed by a 29-day month, the gearwheel turning a tooth a day. This sundial is the oldest surviving Greek clockwork device after the Antikythera device. To find anything resembling this technology, one has to look ahead to the 11th century, when al-Biruni, a Persian scientist, described a geared calendar mechanism.

Price was right that the Greek knowledge of gears was passed on to the Arabs, who made their own clockwork calendars. In addition, the construction of the Constantinople sundial showed that the instrument, clearly descended from the Antikythera model, was not a luxury toy but an everyday calendar.

## HUMAN AND DIVINE ORDER

The Antikythera Mechanism also provided the names and schedule of the Panhellenic games: *OLYMPIA* for the Olympics; *NEMEA* for the Nemean games; *ISTHMA* for the Isthmian games at Korinthos; *PYTHIA* for the Pythian games at Delphi; and *NAA* for games in Dodona in Epiros. Since the Greeks did not need a computer to tell them the times of their Panhellenic games, which for more than a millennium were the most important political, social and religious celebrations in their civilization, the Olympiad dial on the Antikythera device served another purpose.

Freeth et al., in their 2008 report, were right in saying, "It is perhaps not extravagant to see the Mechanism as a microcosm illustrating the temporal harmonization of human and divine order" [23] (Fig. 5). That is exactly the nature of

Fig. 4. The Wheel of the Sun seen from behind. (Photo © Xenophon Moussas)

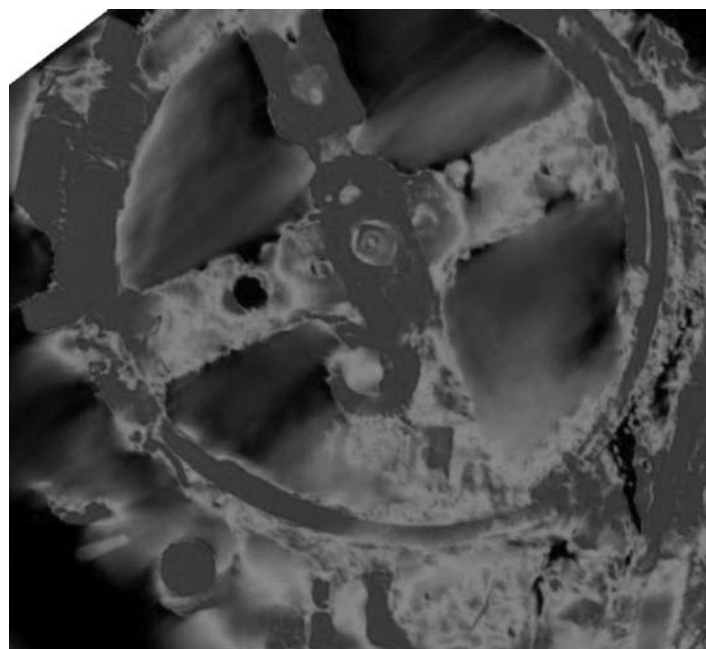






Fig. 5. Antikythera Mechanism fragment: The users' manual with the Wheel of the Sun superimposed. (Photo © Xenophon Moussas)



Fig. 6. A lunar pointer, showing the position and speed of the moon throughout the cycle of the zodiac. (Photo © Xenophon Moussas)

The Arabs copied the Greek geared machine and eventually passed it to Europeans in 13th-century al-Andalus (Muslim Spain). It then became the model for the sophisticated clockwork that underpinned Europe's scientific and technological developments of the 17th century.

### WHERE DID THE GREEKS BUILD THEIR COMPUTERS?

The Antikythera device was probably made in Rhodes or Korinthus or one of the daughter-*poleis* of Korinthus: Kerkyra, Sicily or, most likely, Syracuse.

Rhodes and Syracuse are the most attractive possibilities for the birthplace of Antikythera Mechanism-like devices. It is likely that the Greek computer came from both areas. Ancient Rhodes was a center of Greek science and culture. Here, a *pleiad* of famous scientists and philosophers lived and flourished. Indeed, the work of these people was one of the reasons Rhodes became one of the earliest and most important cultural centers of ancient Greece. According to the Greek physicist Antonios Pinotsis, the first meteorological observations neces-

sary for Greek calendars took place in Rhodes [24].

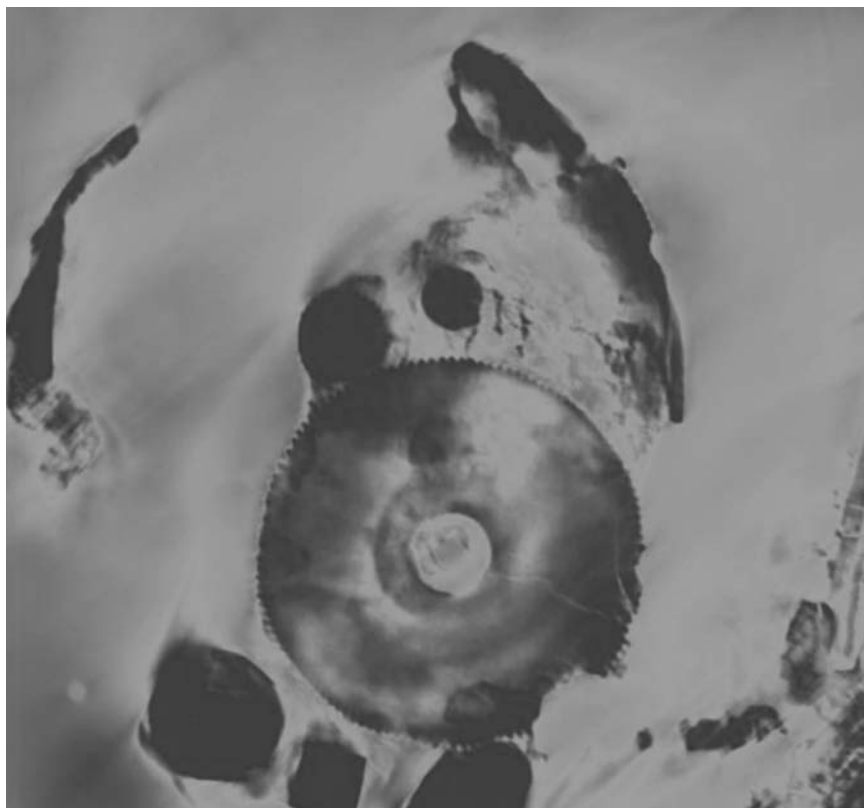
Hipparchos, the greatest Greek astronomer, had his laboratory in Rhodes from 140 to 120 BCE. He, more than other Greek astronomers, made use of the data of Babylonian astronomers. However, like the rest of the Greek astronomers, he employed geometry in the study and understanding of astronomical phenomena. He invented plane trigonometry and made astronomy the predictive mathematical science it is today. He computed eclipses. In addition, he discovered the precession of the equinoxes—that is, he proved that the fixed stars are very slow movers that appear to be stationary [25]. He left a list with all his astronomical observations, including the observations he borrowed from the Babylonian and Greek astronomers. His only surviving book is a commentary on the works of Eudoxos and Aratos. Most of what we know of Hipparchos comes from the *Almagest* of Ptolemy, a great astronomer of the 2nd century of our era.

The connection of Hipparchos to the Antikythera Mechanism is in the front bronze plate of the device, where point-

ers displayed the positions and speed of the sun and the moon throughout the cycle of the zodiac. According to the July 2008 *Nature* report, that technology mirrored work by Hipparchos [26].

Hipparchos knew the moon moved around the earth at varying speeds. When the moon is close to the earth, it moves faster, and it slows down when it is farther from the earth. This is because the moon's orbit is elliptical, not the perfect circular movement the Greeks associated with the stars. Hipparchos resolved this difficulty with his epicyclic lunar theory, which superimposed one circular motion of the moon onto another, the second movement having a different center.

Those who made the Antikythera Mechanism modeled these ideas of Hipparchos, setting one gearwheel sitting on top of another but located on a different axis. A pin-and-slot mechanism then accounts for the non-circular or elliptical orbit of the moon. A pin originating from the bottom wheel enters the slot of the wheel above it. When the bottom wheel turns, it also drives the top gearwheel around. However, the wheels have different centers, and therefore, the pin



**Fig. 7. Gears of the computer, showing their intricacy and the complexity of the machine.** (Photo © Xenophon Moussas)

slides back and forth in the slot, which enables the speed of the top wheel to vary while that of the bottom wheel remains constant.

Poseidonios (c. 135–c. 51 BCE) was also connected with the technology of the Antikythera Mechanism. He succeeded Hipparchos in the school of astronomical studies in Rhodes. Poseidonios became a citizen of Rhodes and served Rhodes in senior political positions. Powerful Romans visited him for his friendship and learning. General Pompey stopped at Rhodes in 66 and 62 BCE to see Poseidonios. Cicero studied under him and reported that Poseidonios constructed a sphere that looked like the planetarium of Archimedes. That globe showed “the movements of the sun and the stars and planets, by day and night, just as they appear in the sky” [27].

Finally, Geminos, probably a student of Poseidonios, was another astronomer who flourished in Rhodes in the 1st century BCE. His book *Introduction to the Phenomena* is a general overview of Greek astronomy, written by a knowledgeable polymath for the general reader [28]. It served as a scientific bridge for 400 years of Greek astronomical thought, connecting Hipparchos (2nd century BCE) and Ptolemy (2nd century of our era). *Introduction to the Phenomena* includes ideas

that resemble the inscriptions on the Antikythera Mechanism regarding the names of the months, which years had 13 months, which month would be repeated in those years, and which months had 30 and which 29 days. After reading its inscriptions, the scientists who studied the Antikythera Mechanism saw the hand of Geminos in the Antikythera device [29].

## RECKONING TIME

According to Geminos, the ancient Greeks reckoned the days and months by the moon and the year by the sun. One revolution of the earth on its axis equals a day. The Greeks and other ancient people had determined that the year had 365 days. However, the duration of the earth’s spinning on her axis 365 times is not exactly the time it takes the earth to circle around the sun, which is 1 year or 365.242199 days. The same kind of rotational deviation governs the month, which turns out to be 29.53059 days. Nevertheless, time-reckoning by the Greeks was not far off the mark.

The crescent moon was seen at the beginning of a month. The time between one crescent and another was never more than 30 days and never less than 29 days. The solar year was vital for marking time, telling the Greeks when to sow and when to harvest; and the moon’s cycles, averaging  $29\frac{1}{2}$  days, reminded the Greeks to join farming to civic life. According to Geminos, the astronomical calculation of the month and the year helped the Greeks to follow the tradition of their ancestors in sacrificing to the gods, allowing “the same sacrifices to the gods to be performed at the same times of the year” [30].

## GREEK TECHNOLOGY

All the cycles in the heavens, especially those of the sun and the moon, were captured in the Antikythera Mechanism, as the lunar pointer shows (Fig. 6). The Greeks used their mathematics, especially geometry, to simulate astronomical

**Fig. 8. The Tower of the Winds. An octagonal planetarium with sundials, a wind vane and a klepsydra or water clock.** (Photo © Evaggelos Vallianatos)





phenomena, creating an accurate model of the universe through the use of gears (Fig. 7).

Could it be that Hipparchos, who explained why the moon changes speed while zooming around the earth, created the first astronomical computer, something like the Antikythera Mechanism? It is quite possible he did. His astronomical models were more advanced than those of Archimedes, and his footprint is in the Antikythera Mechanism. However, he relied on Archimedes, because Archimedes's science and mechanics moved the world in Greek times; he was the model for Hipparchos as much as he was for Galileo Galilei and Isaac Newton.

Price proposed that the creator of the Antikythera Mechanism was Andronikos Kyrrhestes, who built the Tower of Winds in Athens (Fig. 8) [31]. Pinotsis makes a case for Poseidonios being the architect of the Antikythera computer and indeed inventing the differential gear [32]. Archimedes, however, built the prototypical astronomical computer, that is, his planetarium, and Poseidonios must have been indebted to him.

Pinotsis favors Rhodes as a point of origin. Studying the coins of Rhodes, he noticed an interesting evolution in the ray-crowned head of Helios on Rhodian coins, which changed with the advances in the astronomical knowledge on the island. That is a great insight. However, even if that observation is accurate, and in all likelihood it is, science and advanced technology in the Alexandrian era became Panhellenic, spreading rapidly from polis to polis, possibly from Syracuse to Rhodes or from Rhodes to Korinthos.

Some Western scholars and scientists, being preeminent in the modern world, question Greek achievements in science and technology, preferring that Western Europe take special credit for the birth of science and technical knowledge. They know or should know their claims are false.

Above I have mentioned Aristotle and how much he admired craftsmen and artists. A near contemporary to Archimedes, Philon of Byzantium, also wrote about mechanics, including about the construction of weapons. He was emphatic that advancements in technology rely on trial and error as well as theory. His experience came from working in both Alexandria and Rhodes. For example, the catapult was made more effective by changing the size of the hole through which its twisted skeins, the springs of the weapon, moved. Doubling the size of a

catapult required a larger diameter for the hole, which meant solving the interesting and difficult geometrical problem of doubling the cube. Philon tells us that the Ptolemies, the Greek kings of Egypt, funded experiments for "the long-range shooting of missiles which [would] land with vigorous impact" [33].

The mechanics and engineering of Philon, just like those of Archimedes, persisted as late as the 4th century of our era, when the Greek mathematician Pappos of Alexandria divided mechanics into theory and praxis. Theory includes "geometry, arithmetic, astronomy, and physics." Practical mechanics relies on "metal-working, architecture, carpentry" and "painting" [34].

Thus crafts and mechanics among the Greeks, including the technology of the Antikythera Mechanism, were not trivial but comprehensive, scientific and fundamental to their culture and life.

Francois Charette, professor of the history of natural sciences at the Ludwig-Maximilian University in Munich, Germany, studied the Antikythera computer and concluded that "mind-boggling technological sophistication" must have been available to those who made it [35].

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