PROCEEDINGS OF SCIENCE

The Antikythera Mechanism and the Public Face of Greek Science

Alexander Jones[1]
Institute for the Study of the Ancient World, New York University
15 East 84th Street, New York, NY 10028, USA
E-mail: alexander.jones@nyu.edu

From the outset two questions have dominated the study of the Antikythera Mechanism: what did it do? and what was it for? The first question, essentially the problem of reconstructing the Mechanism as the integral, functioning object that it was when it was manufactured, has largely been solved. The second question remains open to dispute. I attempt in the present paper to show how our present knowledge of the Mechanism's functions and the texts that were inscribed on its exterior point to its having been constructed primarily as a didactic device through which the complexity and unity of Hellenistic astronomy and cosmology could be made comprehensible to a lay audience.

From Antikythera to the Square Kilometre Array: Lessons from the Ancients,
Kerastari, Greece
12-15 June 2012

[1] Speaker

PoS(Antikythera & SKA)038

1. Introduction.

The remnants of the Hellenistic device known as the Antikythera Mechanism were salvaged in 1900-1901 from the site of a shipwreck dated to approximately 70-50 BC, near the coast of the island of Antikythera.[1] They lay unnoticed in the National Archeological Museum in Athens among miscellaneous bronze fragments of statuary recovered from the wreck site until May 1902, when Spyridon Stais, the former Minister of Education who had commissioned the salvage operations on the part of the Greek government, visited the museum and chanced to observe fragments of corroded metal bearing gears and inscribed texts on some of their surfaces. Since 1902 there have been three periods of active research on the Mechanism: 1902-1910 (many archeologists and other scholars), late 1920s-early 1930s (Ioannis Theofanidis), and 1953-present (Derek de Solla Price, Allan Bromley, M. T. Wright, the Antikythera Mechanism Research Project, and others).

From the outset two questions have dominated the study of the Mechanism: what did it do? and what was it for? The first question is essentially the problem of reconstructing the Mechanism as the integral, functioning object that it was when it was manufactured, and perhaps as it still was when it was taken on board the ill-fated vessel. The principal obstacle to such a reconstruction is the incomplete, damaged, and corroded state of the existing fragments. The Mechanism may well have suffered from impacts at the time of the wreck, for example from the rolling about of marble statuary and other heavy objects that formed part of the ship's cargo. But even if it escaped immediate damage, one could scarcely expect it to have held together after two thousand years of lying at the sea bottom. Its mechanical parts and front and back faces were thin metal plate, while the casing was wooden. The wood was gradually bored away by teredo worms, leaving only bits adjacent to the metal, so that there was no framework left to hold the pieces in place. Meanwhile the bronze corroded almost completely into brittle minerals. Shifting objects on the sea bed and the actions of marine life such as octopus (a notorious disturber of undersea archeological sites) would have broken and dispersed the Mechanism's parts, likely crushing some of them into grit and dust. Further breakage may have occurred between when the divers brought the remains to the surface—we do not know whether they brought the Mechanism up in one piece or several—and when they were noticed about a year later in the museum. That we have something like a quarter of the original object, including a substantial and largely coherent part of the gearwork, is a tremendous stroke of luck. A half-century of detailed observation, progress in techniques of photography and x-ray scanning, and ingenious interpretation of the evidence, has brought us to the point where we can describe with a high degree of confidence most of the functions and much of the appearance of the Mechanism. We know about three-quarters of what happened when someone turned the knob (or crank) on its side, and we can make a pretty good guess about the rest.

[1] A detailed account by the present author of the discovery of the fragments and their vicissitudes during the 20th century will be given in the introductory paper of a forthcoming series of papers on the inscriptions of the Antikythera Mechanism, under the supervisory editorship of M. G. Edmunds.

The second question, what was the Mechanism for, remains open to dispute: purpose turns out to be more elusive than function. The question can be approached at more than one level, drawing on different categories of evidence. Imagine a situation in which we could study (or could reliably reconstruct) the interior mechanical components and their interconnections, while having no knowledge of the exterior whatsoever. From this kind of evidence alone, taken together with certain scientific facts—or still better, with information about ancient scientific theories—we would be able to establish the meaning of the Mechanism's functions in terms of astronomy and chronology. For example, a gear train that exactly translates nineteen revolutions of one gear into 254 revolutions of another would, all by itself, be compelling evidence that the first gear represents the Sun's longitudinal revolution while the second represents the Moon's longitudinal revolution, because the equation of nineteen years with 235 lunar months and 254 lunar revolutions is an accurate period relation that was well known in antiquity. On the other hand, one would need to see part of the exterior, in particular the scale of the dial on which the Sun's revolution was displayed, to establish that the Sun's position was expressed in terms of zodiacal signs and degrees or that certain solar longitudes were associated with the dates of first and last visibility of stars and constellations. Even a complete and perfectly preserved Antikythera Mechanism probably would not tell us explicitly who would have *wanted* a machine that displayed this astronomical information and why. For such questions, we need to look at context: the archeological context of the find, but also the cultural and intellectual context of the Greco-Roman civilization that produced the Mechanism. And the remains of that civilization, whether we speak of written sources or archeological sites and artifacts, are a far tinier and less representative fraction of what once existed than the fragments of the Mechanism are of *its* original state.

Having sounded this note of caution, I will attempt in the present paper to show how our present knowledge of the Mechanism's functions and the texts that were inscribed on its exterior point to its having been constructed primarily as a didactic device through which the complexity and unity of Hellenistic astronomy and cosmology could be made comprehensible to a lay audience.

2. A hundred and ten years of thinking about the Mechanism.

2.1 Ship's gear or cargo? Early conservation and conjectures.

The remains of the Mechanism that were the subject of vigorous debate during the early years of the twentieth century did not look as they do now. For one thing, there were initially only three known fragments (and a fourth that had come to light by early 1903); now we have 82. Two of the present fragments, designated E and F, were probably in the same assemblage of unidentified pieces of corroded bronze among which Stais made his discoveries, but they ended up somewhere else in the museum's store and were recognized as belonging to the Mechanism only in 1976 and 2005 respectively. Most of the others—perhaps all—are small bits of metal plate that were formerly parts of the original three fragments (designated A, B, and C) but became separate either intentionally in the process of conservation work or through accidental breakage. Moreover, chemical cleaning has done away with some of the material on the surface of the fragments, and some bits that broke off before the 1950s can no longer be found.

Fragments A, B, and C were photographed within a few days of their discovery. The first published photograph, showing the side of B known as B-1 (which bears traces of an inscription), was published in the leading Greek archeological journal later in 1902 [1]. Photographs of both faces of Fragments A, B, C, and D were published in 1903 [2] [3]. It is not known whether any of these published photographs came from the set made in May, 1902, but in any event they show the fragments as they were before they underwent their first chemical cleaning and in a condition that cannot have been much changed since they first came to notice. What strikes one, especially when one is familiar with Fragments A, B, and C as they are now, is how little detail could be made out at that time. A thick layer of coarse-textured patina all but concealed the gears on the rear face of A (A-2), while only the leftmost letters were legible in each line of the mirror-imaged inscription on B-1, the impressions left in hardened accretion matter by a lost inscribed plate. Meager as they were, the readings from this inscription seemed to offer some significant vocabulary: part of a word meaning "pointer" (ΓΝΩΜΩ), three letters that might be the beginning of the name of the planet Venus (ΑΦΡ), and two more or less complete words meaning "Sun's ray" (ΗΛΙΟΥ ΑΚΤΙΝ). By contrast, no one was able to deduce much from the visible gears.

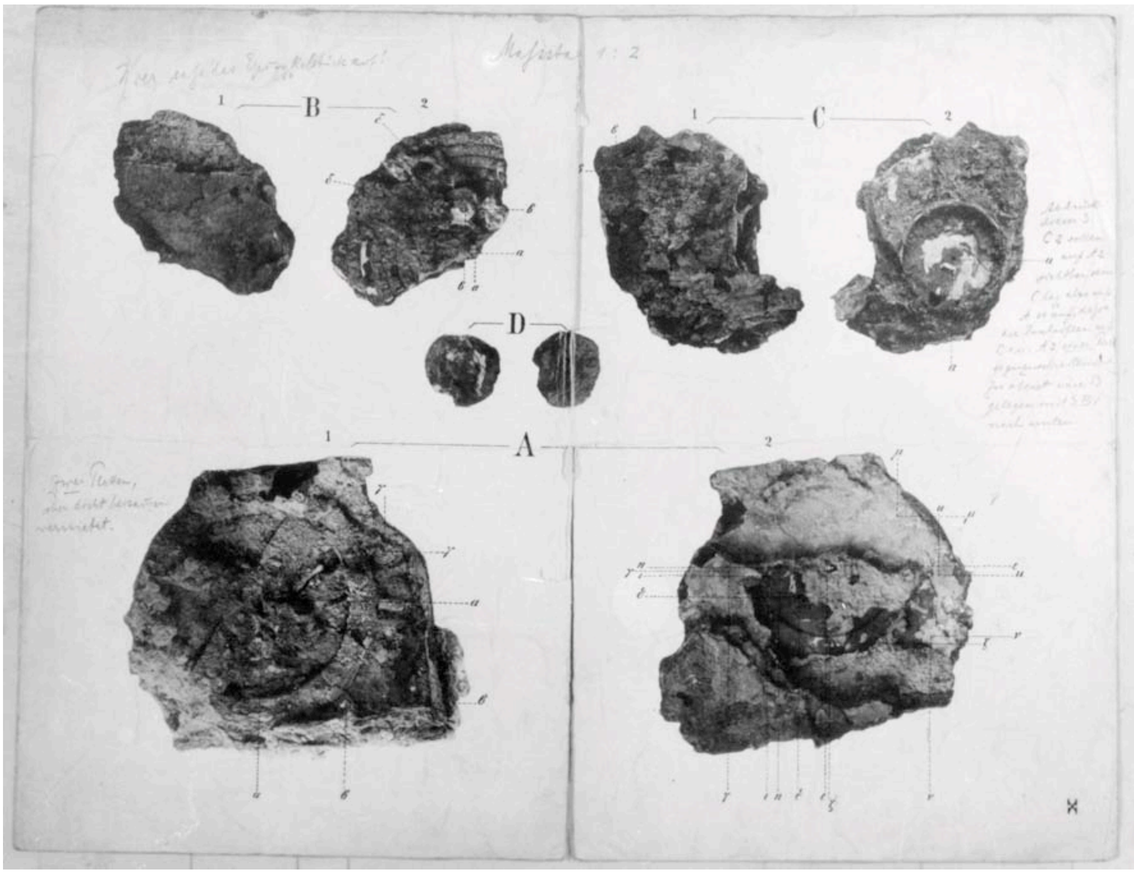

Fig. 1. Plate 10 from [2], showing Fragments A-D before conservation. The pencilled notes are by Albert Rehm. (Courtesy Adler Planetarium, Chicago.)

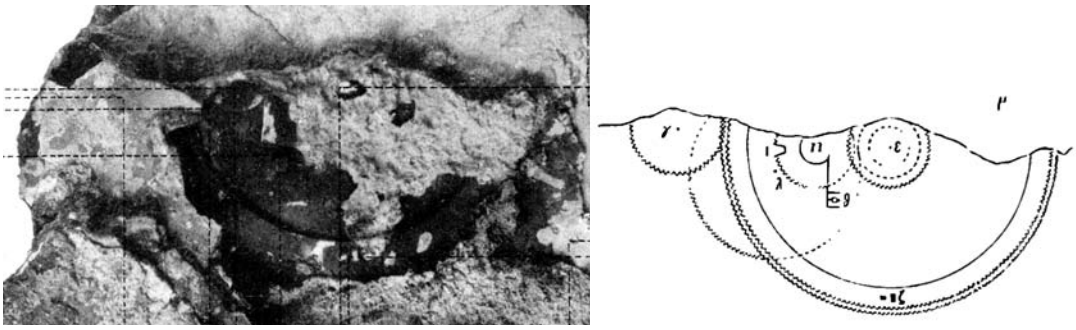

Fig. 2. (a) Detail of Plate 10 from [2], showing remains of gears on A-2. (b) Rediadis's drawing of the gears on A-2, from [2].

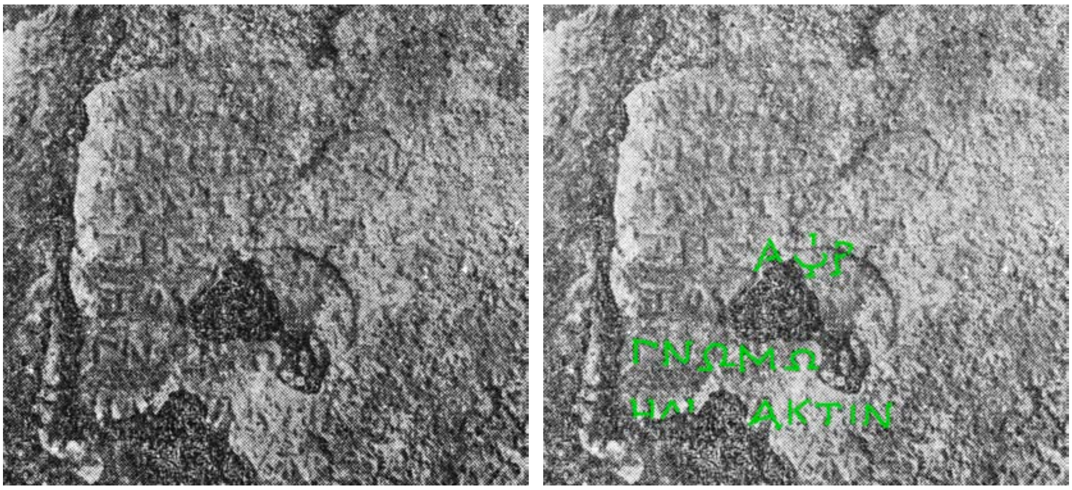

Fig. 3. (a) Detail of Fig. 14 from [1], mirror-reversed, showing letters on Fragment B-1 offset from a lost inscribed plate. (b) Tracings show word fragments read in 1902 and barely visible in the printed photograph, suggesting astronomical content.

The conservation of the fragments was entrusted to Othon Rousopoulos, a chemist (and the son of a notable archeologist); but Rousopoulos had other pressing tasks in the museum, including dealing with an outbreak of so-called "bronze disease" that was disfiguring objects in the collection of Egyptian antiquities, and cleaning and stabilizing the bronze statuary from the Antikythera wreck. It was only in 1904 or 1905, apparently, that he began what he described as the "delicate task" of conserving the Mechanism's fragments [4]. His work involved removing the patina by means of potassium cyanide, carefully separating layers of plate that had become stuck together, and preserving the newly exposed and cleaned surfaces with Zapon, a cellulose nitrate varnish. The results of his work can be seen by comparing sets of photographs dating from 1905 and 1918 with the earlier published ones. The changes are most conspicuous on A-2 and C-1, from both of which he removed pieces of inscribed plates that now exist as separate fragments: most notably G, which was reassembled from many pieces removed from C-1, and 19, removed from A-2. The most significant immediate consequences of the separation of these fragments were that the text on Fragment 19, which had faced inwards when it was attached to A, was now accessible, and that a new inscribed plate as well as a bit of an inscribed dial scale were now exposed on C-1.

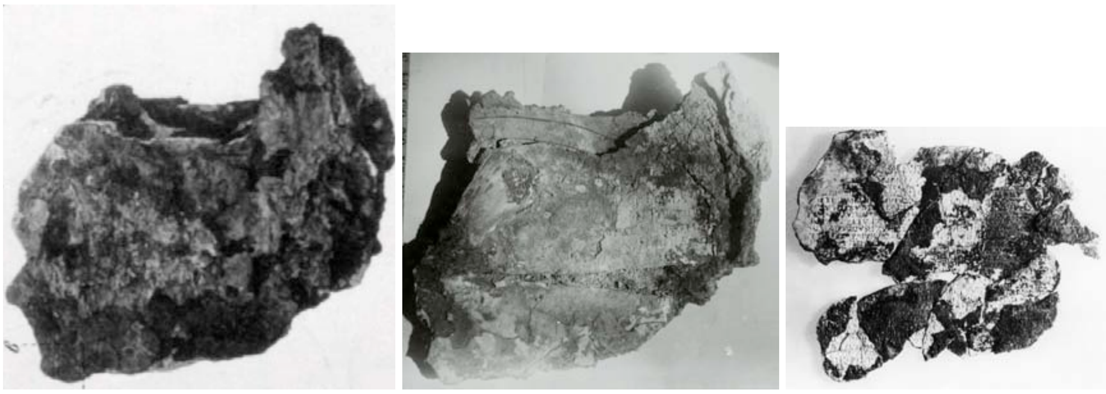

Fig. 4. (a) Fragment C-1 before conservation, from [2]. (b) C-1 in 1905, after removal of accretion layer and inscribed plate. (Courtesy Adler Planetarium.) (c) Fragment G in 1958, reassembled from pieces of the plate removed from C-1. (Courtesy Adler Planetarium.)

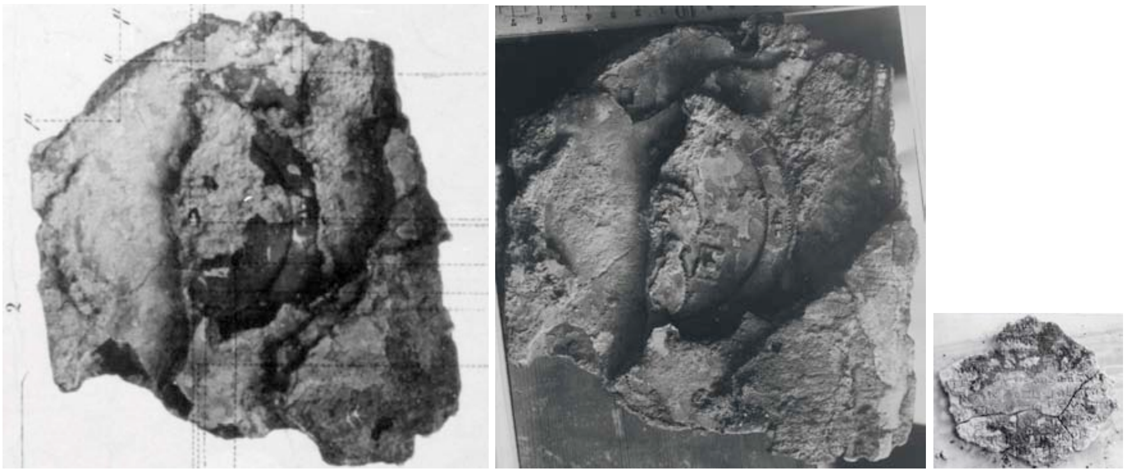

Fig. 5. (a) Fragment A-2 before conservation, from [2]. (b) A-2 in 1918, after removal of accretion layer and inscribed plate. (Courtesy Adler Planetarium.) (c) Fragment 19 in 1905, removed from lower right of A-2. (Courtesy Adler Planetarium.)

During the first month after Spyridon Stais—a politician and former schoolteacher trained in the physical sciences and possessing a layman's interest but no special expertise in antiquities—noticed the Mechanism's fragments, they were inspected by a succession of archeologists (including Gavriel Vyzantinos, Panagios Kastriotis, and Valerios Stais, the director of the museum whose identity has frequently been mixed up with that of his relation Spyridon), an epigrapher (August Wilhelm of the Austrian Institute in Athens), a numismatist (Ioannis Svoronos), a naval historian (Konstantinos Rados), and a naval officer (Periklis Rediadis). In all the disputes that arose among them, which can be followed day by day in reports and correspondence published in the Athens newspapers as well as in a handful of scholarly and popular publications over the next few years, there was complete agreement on one point: having been found in a shipwreck, the Mechanism must have been part of the vessel's equipment, evidently something to do with navigation. An initial guess (Vyzantinos's?) reported in the newspapers that it might be a compass seems to have been quickly abandoned. The reading by Wilhelm and Svoronos of apparent allusions to the Sun and Venus in the mirror inscription on B-1 turned people's imaginations towards astronomy. Svoronos, who was already engaged in a vocal dispute with practically the whole Greek archeological community over whether the Antikythera shipwreck dated to the last centuries BC or (as Svoronos stoutly maintained in the face of abundant archeological evidence to the contrary) the late Roman Empire, insisted that the Mechanism was a kind of astrolabe with a component for observing the altitudes of heavenly bodies, and he quickly won Rediadis's support for this view. Rados, on the other hand, insisted that it was *not* an astrolabe, and conjectured that it could have been a marine odometer that used gearwork to keep a count of the revolutions of a paddle wheel. There is a neat symmetry here: the Svoronos-Rediadis theory, being based more or less entirely on the vocabulary of the bits of inscription that had so far been read, was unable to account for the gears, while Rados's theory, inspired by the gears, disregarded the astronomical references in the inscription.

In 1905 and 1906 the young philologist Albert Rehm examined the fragments during two or three short stays in Athens. Rehm had the advantage over the earlier investigators that more physical details and considerably more inscribed text could be made out now following Rousopoulos's conservation. But Rehm was also peculiarly well suited to study the Mechanism. His training had given him a broad familiarity with Classical texts, both Greek and Latin, with particular expertise in the less technical part of the ancient astronomical literature. During the years in question he was acquiring practical experience in Greek inscriptions through service as an epigraphical assistant at the German excavations in Asia Minor—his annual excursions from Munich to the excavations and back were in fact the occasion of his sojourns in Athens. And he was deeply interested in the material culture of ancient astronomy.

Although Rehm was to develop and refine his ideas about the Mechanism over the following year, the dozen or so manuscript pages that he hastily wrote up in late 1905 as part of a book (never published) on ancient meteorology already present his fundamentally new view of the Mechanism's nature and purpose [5]. It was a planetarium, displaying the Sun, Moon, and planets simultaneously revolving at their varying rates of motion around the Earth through gearwork driven by a single rotary input, a kind of instrument that could be likened to the planetaria of Archimedes and Posidonios described by Cicero. And what was it doing on a ship?

> Of course the delicate and complicated mechanical work of art was not intended to be handled by mariners; it is one of those articles of commerce with which the culturally superior Hellas impressed its Roman lords.

In short, it was part of the cargo, and its purpose was not practical. It was an object to confer prestige both on its destined Roman owner and on the Greek culture whose theoretical and practical wisdom it embodied.

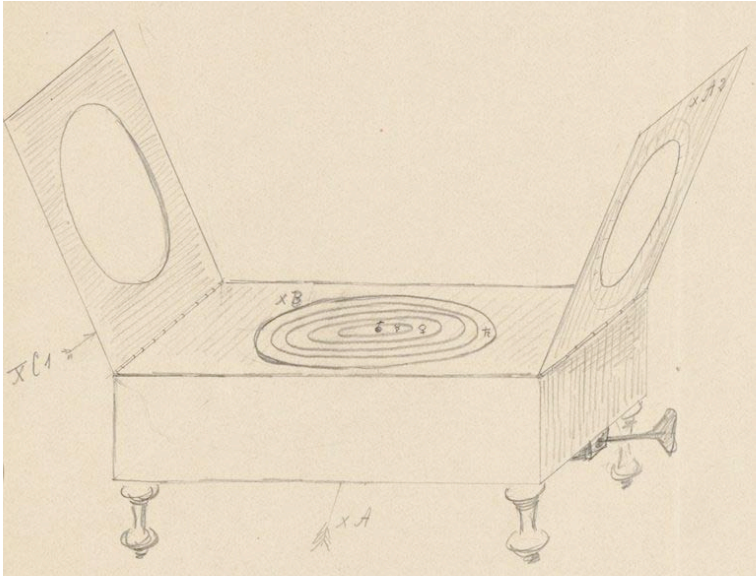

Fig. 6. Rehm's 1905 sketch of his reconstruction of the Antikythera Mechanism [5]. The planetarium, center top, consists of concentric mobile rings representing the "spheres" of the Sun, Moon, and planets in a geocentric cosmology; either of two perforated plates could be swung down over the planetarium to provide different scales. The motion is imparted by turning the key at lower right. (Courtesy Bayerische Staatsbibliothek and heirs of Albert Rehm.)

Rehm never published his investigations of the Antikythera Mechanism, but he did allow his friend Georg Karo to report the substance of his 1906 draft paper [6] (which he referred to as his "Athens lecture" or "my planetarium-manuscript") as part of a lecture on the Antikythera Wreck delivered at the German Archeological Institute in Athens on December 19, 1906. Karo's presentation must have been fairly detailed, and as a result Rehm's conclusions about the Mechanism were much better known among Greek scholars than abroad. Rados, who published a short monograph on the Mechanism reviewing the various interpretations that had been offered so far, was entirely convinced by Rehm's planetarium: "the professor from Munich has expressed the right opinion." [7] Rediadis was not; he adhered to the astrolabe theory, making the important qualification that the device in question did not resemble any known astrolabe but must have used its gearwork to perform the astronomical computations that in a conventional plane astrolabe would be carried out by manual setting of the rete and rule [8]. Rehm's "Athens lecture" had not explicitly raised the general issue of whether the Mechanism was a navigational instrument or cargo, nor was it brought up by Rados, but Rediadis does make the claim that it was part of the ship's equipment as part of his argument for its being an astrolabe.

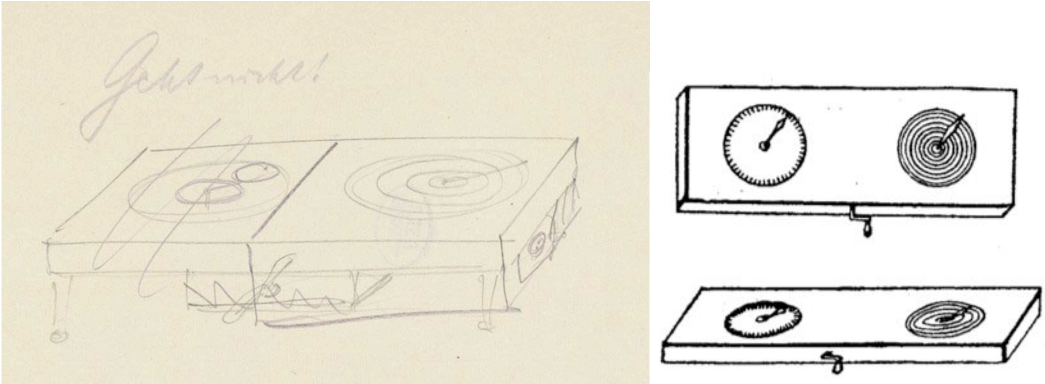

Fig. 7. (a) Rehm's 1906 sketch of a reconstructed Mechanism as a "cooking stove" (his expression) with two dial faces [6]. The dial on the left displayed the Moon's motion according to an epicyclic model, while that on the right was the planetarium. It was almost certainly after 1906 that Rehm crossed out the lunar dial with the comment, "Won't work!" (Courtesy Bayerische Staatsbibliothek and heirs of Albert Rehm.) (b) Rados's drawing of Rehm's reconstruction [7]. Rados must have seen a version of Rehm's drawing, probably at Georg Karo's lecture, but he seems not to have grasped Rehm's notion of a lunar epicyclic model.

A gap of about a decade and a half elapsed between these last publications of the period of initial research on the Mechanism and the studies made by Ioannis Theofanidis in the late 1920s and early 1930s, and Theofanidis's work was to be followed by another two decades of inactivity. Theofanidis reconstructed the Mechanism (through a physical working model accompanied by a paper [9]) as a navigational computing device that combined features of a planetarium (using gearwork to represent the motions of the Sun, Moon, and planets) and of an astrolabe (conversion of celestial longitudes to an equatorial frame of reference by means of stereographic projection), in other words, a fusion of Rehm's conception, which he knew through Rados's monograph, and Rediadis's. He entertained no doubt that the Mechanism was a navigational tool, and in fact his first publication concerning it was—rather incongruously—a long section of an encyclopedia article on the voyages of St. Paul [10].

2.2 Computer or planetarium? Price and after.

Derek de Solla Price began to take an interest in the Mechanism as early as 1951, but it was his personal inspection of the fragments in Athens in 1958, and the resulting nontechnical article in the June, 1959 issue of *Scientific American*, that constituted the pivotal stage at which intelligent speculation gave way to progressive understanding of the Mechanism's structure [11]. In terms of specific conjectures about what the Mechanism displayed, Price is much more circumspect in the *Scientific American* article than either Rehm or Theofanidis had been; and there is no attempt to explain the structure of the gearwork. But he had established something outweighing in significance all the clever guesses of his predecessors, namely the original spatial relationships of the principal fragments (A, B, and C) and the exterior layout of the original Mechanism. His reconstruction for the first time attributed two faces to the Mechanism: a front face bearing a single dial that displayed the Sun's motion through the zodiac and the date according to the Egyptian calendar, and a back face bearing an upper and lower dial, and inside each a small subsidiary dial, the meaning of none of which Price was able to identify with confidence. All subsequent reconstructions have sought to flesh out the basic framework of Price's 1959 article.

Fig. 8. Price at the National Archeological Museum in 1958. Since 1918 Fragments A and C had experienced some breakage, probably due to wartime storage, and all the fragments were subjected to a new round of conservation and cleaning in 1953. In 1958 Price had access to the majority of the fragments known today, including all the major ones except D, E, and F. (Courtesy de Solla Price family.)

The title of Price's article is "An Ancient Greek Computer," and in it he suggested that the Mechanism "might have been held in the hand and turned by a wheel at the side so that it would operate as a computer, possibly for astrological use." But he goes on to say that "it is more likely that it was permanently mounted, perhaps set in a statue, and displayed as an exhibition piece." In other words, he was wavering between seeing the Mechanism as a tool for yielding certain categories of predicted data required for some application such as astrology—navigation seems to have been out of the question—or as a "wondrous device" intended merely to make a general impression.

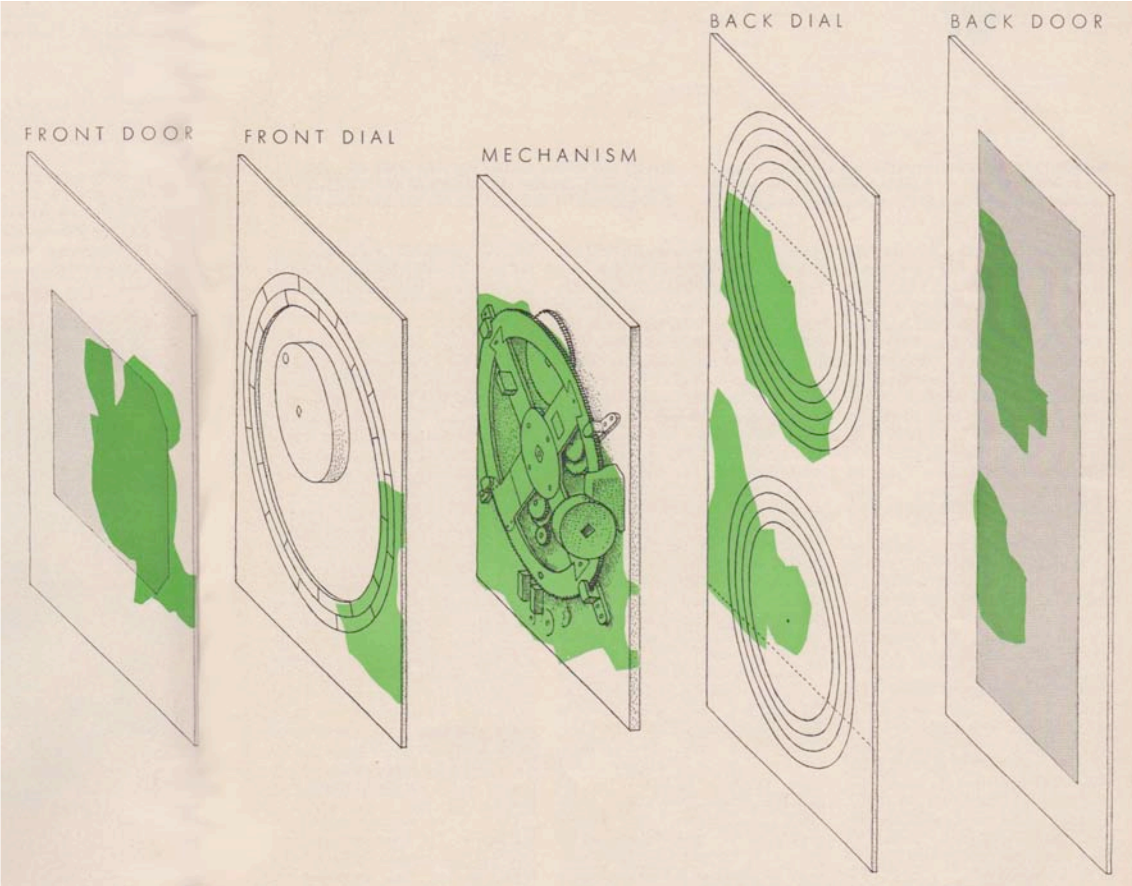

Fig. 9. Price's 1959 diagram showing the positions he had deduced for fragments G, C, A, and B in relation to the original Mechanism [11]. The dark shape in the leftmost layer is G, then C; A comprises the middle layer and the lower parts of the two right layers, while B comprises the upper parts of the right layers. Price subsequently came to believe (probably rightly) that the correct orientations of G and C were 90° clockwise of the orientations shown in this diagram.

Price's 1974 *Gears from the Greeks* offered a partial reconstruction of the gearwork based on radiographs of the principal fragments [12]. His matured conception of the layout and functions of the Mechanism only comes out piecemeal and with frequent hedgings in *Gears from the Greeks*, but he provided a clear summing up in a separate paper that came out in the following year [13]:

> The front dial of the instrument showed the circle of the zodiac, and on a slip ring around it there was the normal Greco-Egyptian calendar…. Within this dial there is a pointer or a little model to indicate the place of the Sun and another to indicate that of the moon. Possibly the Moon is shown in its phases, and though no trace of such a mechanism exists there could also have been a unit geared to show the mean motions of the five planets. Along the zodiac scale there are also placed at irregular intervals the 26 [*sic*] letters of the Greek alphabet, and an accompanying inscription tells letter by letter, as it is reached by the Sun pointer, the various heliacal risings and settings of major bright stars and constellations….

> The back plate of the instrument contains an upper and lower dial of which only the latter can be elucidated. Its main pointer rotates in exactly one synodic month over a series of scales which each contain 59 divisions, each of which therefore corresponds to a half-day…. A subsidiary small dial, set like a seconds dial on a modern watch, records numbers of synodic months in cycles of twelve such months which constitute a lunar year. The upper back dial also has a main dial and a small subsidiary, but at this point the gear trains are incomplete right at the end and one can only guess that a longer cycle of perhaps a Metonic cycle of exactly 19 years, or an eclipse cycle of a little more than 18 years may be involved together with some multiple or submultiple of this.

The same paper is also more explicit than the monograph about the reason that the Mechanism was found in a shipwreck:

> … it was lost at sea with a cargo of other art objects that were in process of being shipped from the region of Rhodes to Rome. I like to think it possible that it was Cicero himself who lost his baggage in the Antikythera Channel.

Price remained ambivalent about the Mechanism's fundamental purpose. The word "computer" appears once more in the subtitle of *Gears from the Greeks*: "The Antikythera Mechanism—A Calendar Computer from *ca*. 80 B.C." But when he finally comes to consider how the Mechanism might have been displayed and used (pp. 59-60), he writes:

> Since we do not know for certain whether the Antikythera mechanism was driven automatically by water power or turned by hand, it is perhaps unfair to call it a "calculator." If automatic, it is more properly an exhibition device, an elaborate clock-dial assembly; if manual it is still primarily an elegant demonstration or simulation of the heavens, more like an astrolabe perhaps than a direct ancestor of the calculating machines of Pascal and Leibniz.

Yet, he continues, the precision and abstract character of displays consisting of pointers on graduated dials seems to make the Mechanism an arithmetical predicter of discrete phenomena rather than a representation of geometrical modelling, so that "it is more in the spirit of Babylonian astronomy and the modern digital computer than in that of Greek geometrical models and the automated sphere of Archimedes." Price could write this because the parts of his reconstruction that he felt most sure of were revolving pointers representing the zodiacal revolutions of the Sun and Moon as uniform motions and chronological units such as the lunar month as constant intervals of time; he mentions the possibility that the Mechanism had a planetarium display only in passing, and, as the above quotation from his 1975 paper reveals, he supposed that such a display, if it existed, would also have been limited to uniform rates of

PoS(Antikythera & SKA)038

revolution.[2] He has nothing to say about how the data yielded by the Mechanism might have been applied.

The situation after Price, and particularly following the entry of Allan Bromley and M. T. Wright (since about 1990) and the Antikythera Mechanism Research Project team (since 2005) into the field, is too complex to discuss here except in the most general terms.[3] The most important developments with respect to the present understanding of what the Antikythera Mechanism *was* can be summarized as follows:

> (1) A strong evidence-based consensus now exists about most aspects of the Mechanism's gearwork and displays relating to the Sun, Moon, calendars, and eclipses, through the researches of Wright and the AMRP. The upper back dial displayed uniform passage of time through the 235 lunar months composing a nineteen-year cycle, with scale inscriptions relating the cycle to a specific Greek regional calendar (the Corinthian calendar as known primarily from inscriptions in Epirus, Illyria, and Corcyra). Its extant subsidiary dial displayed a four-year cycle, with inscriptions relating it to several Greek athletic competitions held at 2-year and 4-year intervals; a second subsidiary dial is conjectured displaying a 76-year calendrical cycle. The lower back dial displayed uniform passage of time through the 223 lunar months of a so-called Saros eclipse cycle, with scale inscriptions marking the months in which lunar and solar eclipses might occur; its subsidiary dial displayed a triple-Saros or Exeligmos eclipse cycle. The front dial had pointers representing the apparent positions of the Sun and Moon, with a fixed scale representing the signs and degrees of the zodiac and a movable scale representing the Egyptian calendar. In addition to a pointer, the Moon was represented by a revolving particolored ball showing the current lunar phase.
>
> (2) The lunar gearwork is now known to have incorporated a pin-and-slot coupling that introduces a nonuniformity in the Moon's rate of longitudinal motion, conforming to the behavior of a simple epicyclic or eccentric model with a shifting lunar apogee such as is familiar from the theoretical work of Hipparchos and Ptolemy.
>
> (3) The theory that the Mechanism's front had some kind of planetary display has won wide acceptance, and there is increasing support for the supposition (strongly urged by Wright since the early 2000s) that this took the form of pointers on the front dial representing the longitudinal motions of all five planets known in antiquity according to epicyclic or eccentric models, making the front dial a planetarium. Despite the absence of any surviving gearwork that can definitely be assigned to a planetary mechanism (only one extant gear, isolated in Fragment D, remains unaccounted for after the reconstruction of the lunisolar system), physical remains on A-1 indicate that a substantial part of the

[2] It was this assumption that the Mechanism would have displayed only the mean motions of the planets that led Neugebauer to make his notorious dismissive remarks applying not only to the Mechanism but also to the lost planetaria of Archimedes and Posidonius [14]: "such an apparatus… can be taken at best only as evidence for mechanical skill but not for any planetary theory reaching beyond the basic facts." (p. 652)

[3] The present consensus is essentially the reconstruction presented in [15] with a minor modification concerning the upper back subsidiary dial [16]. The former paper gives references to many papers, especially by Wright, that have contributed to the reconstruction.

> mechanism has been lost, and progress in reading the inscriptions on Fragments B and G has revealed detailed references to planetary pointers and planetary nonuniform motion.

The new picture we have of the Antikythera Mechanism is more complex than Price's, and his expression "calendar computer" clearly will no longer serve. On the other hand, we cannot follow Rehm in simply calling it a "planetarium." We would have to invent a new word to describe a device that simultaneously displays time cycles on one face and celestial motions on the other: perhaps a "cosmochronicon"? But the uncertainty remains whether the Mechanism existed for the sake of illustrating or calculating the phenomena of time and the heavens; thus Wright entertains both options [17]:

> The ancient literary accounts assembled by Price suggest use for philosophical study, educational demonstration, intellectual entertainment, and the prediction of notable astronomical events such as eclipses. Another use is suggested by the rise in interest in personal horoscopy during the first century BC…. In any case, the evident enthusiasm of a variety of present-day spectators to whom I have demonstrated my model, echoing that of Cicero in the first century BC, shows that the instrument's value as an intellectual entertainment alone probably provided a sufficient incentive for its design and construction.

The present author has heard well-informed colleagues over the last few years advocating various forms of the "illustrating" interpretation (most frequently either as a didactic instrument or a "rich man's toy") as well as various forms of the "calculating" interpretation (especially for the sake of horoscopic astrology, but other applications are suggested including geography and, yes, navigation).

3. Seeking the use and the user.

3.1 Applications of the data?

There can be no disputing that the information displayed by the Antikythera Mechanism was regarded as useful for various aspects of life in the Greco-Roman world. The difficulty with seeing the Mechanism as a "computer" built for the sake of the data it generates is not to identify possible applications for each single dial, but to identify a plausible type of owner or user for whom *all* the dials would have some practical relevance.

	agriculture	navigation	medicine	civil life and religion	astronomical research	geography	astrology
Longitudes of Sun, Moon, Planets					X		X
Lunar phases	X	X	X		X		
Solstices and equinoxes	X	X	X		X		
Stellar risings and settings	X	X	X		X		
Egyptian calendar					X		X
Lunisolar calendar	X	X	X	X	X	X	X
4-year cycle				X			
Solar and lunar eclipses					X	X	X

Fig. 10. Fields in which the kinds of data displayed on the Mechanism might have been applied in the Hellenistic period. It is presumed that one would require the lunisolar calendar of the upper back dial to set the date for any application.

The principal annually repeating solar and stellar phenomena (solstices, equinoxes, risings and settings of conspicuous asterisms) were of traditional importance as markers for stages of the natural year and weather signs, so the farmer, the seaman, and the physician could be expected to pay attention to them. Similarly the phases of the Moon, aside from determining how well one could see at night, were widely believed to influence or at least correlate with patterns of life and growth in plants, animals, and people. Civic life and cult were structured around the local lunisolar calendars, and if we may include involvement in the Panhellenic and other prominent athletic festivals under this head, the four year cycle also mattered. Planets, however, and precise zodiacal longitudes did not, and the Egyptian calendar would have been irrelevant for these contexts anywhere where the Corinthian calendar was in use and *vice versa*. To the extent that the Antikythera Mechanism would have provided useful data for these aspects of ancient life, it would surely have seemed an extravagant means to fairly simple ends—one hardly imagines a farmer using high technology to decide when to prune the beanstalks, or an athlete to determine whether the Nemean games were going to be held this summer or next.

The sciences (other than medicine) that made significant use of astronomical data were geography and astrology. A geographer could have made little use of the Mechanism's displays. Terrestrial latitude was determined by gnomon ratios, observed altitudes of the Sun and stars, or estimates of maximum and minimum day length, none of which were featured on the Mechanism. Relative longitude was at least notionally measurable by comparing the times of observed lunar eclipses with eclipse times predicted for a reference meridian, but the predicted times on the Saros dial (it has not been established whether they refer to the beginning or mid-eclipse) are stated only to the hour, corresponding to an uncertainty of ±7.5° of longitude even if the times were accurately computed, which they are not.

Horoscopic astrology depended on the availability of precise longitudes of the Sun, Moon, and planets for any given date and time, using the scale of zodiacal signs and degrees as on the Mechanism's front dial. Eclipses were the most prominent astronomical phenomena whose prognostic significance was interpreted in "general" astrology, the part of the science dealing with forecasts for regions and peoples. And the Egyptian calendar finds a role here as a standard chronological framework for astronomical predictions, as we know from astronomical tables from the first century AD and later. Though numerical tables were, in fact, the usual means by which astrologers got their astronomical data [18], and static "zodiac boards" were a common means of displaying them [19], one might suppose that a very prosperous astrologer might find use for a mechanism either to save labor or to impress his clients. [4] However, he would have had scarce need for lunar phases, the annual solistellar phenomena, or the Panhellenic games.

One could also imagine a mechanism as a computing device for research in astronomy in its own right, as a representation or simulation of various theories for the sake of testing against observation or facilitating the kind of computation that Ptolemy, say, would have performed using trigonometry and tables. In this case, one could justify the presence of most of the dials, but it is hard to see the point of the four-year dial with its athletic festivals. There would also be a glaring defect in the lack of a direct means of setting the Mechanism to a specific year and date according to the Egyptian calendar, which was the standard chronological system for astronomy as well as astrology at this time. An astronomer, moreover, could hardly have failed to be aware of the large and unavoidable inaccuracies in the predicted data arising from imperfections in the gears; the error would have been especially pronounced in the lunar longitudes and phases [20].

To sum up: there does not seem to be any specific field of practical application that explains all the functions of the Antikythera Mechanism. Moreover, if one was only interested in the data it generated, there was always a less expensive or more accurate alternative.

3.2 The Mechanism and Geminos: didactic representations of astronomy.

Of all the remains of intellectual life from classical antiquity, none has more points of contact with the functions of the Antikythera Mechanism than Geminos's book, *Introduction to the Phenomena* [21]. This work, composed during the first century BC and thus roughly contemporary with the Antikythera wreck, consists of eighteen chapters explaining various topics in astronomy for the benefit of nonspecialist readers. The subject matter is not limited to "pure" astronomy but takes in geography, astrology, astral weather prediction, and calendrics. Some chapters, for example those dealing with the celestial sphere and its principal circles, the system of constellations, the varying length of day, and geography, have little connection with the Mechanism. On the other hand, very nearly everything about the Mechanism corresponds to something in Geminos:

[4] The poet Nonnos (c. AD 400) pictures Astraios, god of prophecy, casting a horoscope using a mechanical *sphaira* (*Dionysiaca* 6.58-88); one may however suspect that this is just a poetic conceit rather than a reflection of real-world astrological practice.

Feature on Mechanism	*Related chapters in Geminos*
Zodiac	1. On the circle of the zodiacal signs.
Motion of Sun, Moon, planets	1. On the circle of the zodiacal signs (discussion of solar longitudinal motion and anomaly). 12. That the planets make a movement contrary to that of the cosmos (longitudinal motion of Sun, Moon, and planets and stations and retrogradations of planets). 18. On the exeligmos (lunar motion in longitude and anomaly).
Moon's phases	9. On phases of the Moon.
First and last visibilities of stars	13. On risings and settings. 17. On weather-signs from the stars.
Egyptian calendar	8. On months (discussion of Egyptian calendar and its shifting relative to the seasons).
Metonic and Callippic dials	8. On months (discussion of Greek calendars, intercalation cycles, 29-day and 30-day months).
Four-year dial with games	*No correspondence.*
Saros and exeligmos dials	10. On the eclipse of the Sun. 11. On the eclipse of the Moon. 18. On the exeligmos.

As noted in our tabulation, Geminos has no discussion related to the four-year dial and the cycle of Panhellenic games, but his treatment of calendars relates calendar structures to the conventions of the societies that used them, so that it would not have been foreign to his conception of his subject to include other chronological cycles that appear more social than astronomical.

We can thus characterize the Mechanism as an illustration of the part of astronomy—understanding the science's scope more or less as Geminos does—that dealt with time on a scale of days, months, and years (but not fractions of a day), the chronological cycles of Greek society, the motions and phenomena of the Sun, Moon, and planets, and the visibility phenomena of the fixed stars. It could have served the same didactic role as Geminos's book, by explaining these topics in a form that an intelligent layman could grasp without recourse to technicalities and mathematics. And to a greater degree than Geminos, the Mechanism would have represented all the periodic motions and cycles that it displays in a way that emphasizes their unity as functions of time.

3.3 Astronomy in the public eye.

Geminos's book was a manifestation of the popularizing and didactic tendency in Greco-Roman astronomy. The Greek astronomical tradition differed from those of Mesopotamia and early China in that there never seems to have been an establishment employing astronomers in large numbers and providing them with a livelihood in exchange for the performance of professional duties, comparable to the teams of scholars employed by the Neo-Assyrian court in

Nineveh and by the temples of Uruk and Babylon, or the Chinese imperial astronomical bureau. Like mathematics, astronomy was an avocation, and had no formal schools, only a dispersed network of independent practitioners linked by personal acquaintance, correspondence, and the open distribution of their work. The productions of Greek astronomers, even when they took the form of communications ostensibly addressed to fellow specialists, were usually accessible to interested outsiders. There was no clear-cut distinction between an astronomical text written for fellow specialists and one intended for a broader readership.

During the Hellenistic and Roman periods, utilitarian and decorative objects in both public and private spaces were visible emblems of astronomy. Sundials were ubiquitous, with the common spherical bowl variety standing as an inverted image of the celestial sphere. Mechanized anaphoric clocks correlated astronomical time, as represented for example by a revolving dial on which the constellations of the night sky were inscribed, with time as measured by controlled mundane physical processes. Parapegma inscriptions erected in public view gave daily predictions of astronomical and meteorological phenomena by means of a movable peg marking the current date. Star globes and Aratos's verses propagated the system of constellations originally set out by Eudoxos. The sundial and armillary sphere were familiar enough to have become conventional artistic motifs, emblems of time and cosmos, wisdom, and mortality.

Specialists also made efforts to expose a wider audience to some of the more technical aspects of their science. Archimedes's *Sand Reckoner*, a popularizing work addressed to the crown prince of Syracuse (his "serious" mathematical writings were addressed to fellow mathematicians), addresses the light-hearted task of naming a number greater than that of the grains of sand that would fill the cosmos, but along the way he summarizes recent astronomical research on cosmic dimensions and discusses at some length the problem of instrumentally measuring the apparent diameter of the Sun. Hipparchos's critique of Eudoxos and Aratos was aimed at a literary rather than scientific readership but is full of quantitative data and arguments. The Hellenistic astronomical inscription from Keskintos (*IG* XII,1 913) and Ptolemy's *Canobic Inscription* were publicly posted monuments tabulating the precise numerical parameters defining the planetary system.

Some of the most successful efforts to make astronomy accessible to a broad readership were composed by well-informed nonspecialists. We have already discussed Geminos's *Introduction to the Phenomena*; Geminos is known to have written other works on meteorology and on philosophical and foundational issues in mathematics, and he clearly had the competence to write accurately at least on the more elementary aspects of mathematical astronomy, but there is no reason to suppose that he was a researching astronomer. Later authors of somewhat less sure-footed introductions to astronomy, Theon of Smyrna and Kleomedes, were respectively Platonist and Stoic philosophers. An outstanding late specimen of the genre is the Neoplatonist philosopher Proklos's *Outline of the Astronomical Models*, a largely nontechnical treatment of planetary theory based on Ptolemy's *Almagest*.

PoS(Antikythera & SKA)038

3.4 Who owned the Mechanism?

Two facts about the Antikythera Mechanism have to be reconciled if we want to form a plausible hypothesis about its owner's time and place. First, it was on board a commercial vessel laden with a cargo of statuary, glass, and ceramics, mostly of recent manufacture, as well as some agricultural products (not, as sometimes suggested, a Roman ship carrying booty from a looted Greek city), and the ship was clearly heading from the Aegean Sea into the central part of the Mediterranean [22]. Secondly, its calendar dial is inscribed with the months of the Corinthian calendar, which was the calendar of Corinth itself and of many localities in Epirus, Illyria, and Corcyra, but nowhere east of Antikythera.[5] Although of course one can invent all sorts of contrived stories accounting for how a rare object made for someone in a western Greek locality managed to end up in Asia Minor or the Aegean islands and thereafter on a ship heading back westwards, the most probable explanation, in the absence of compelling evidence that the Mechanism was much older than the wreck, is that it had recently been manufactured in the east and was being transported to the person who commissioned it when it was lost in the shipwreck.

Since the fragments were discovered, several estimates have been offered of the date of the Mechanism based on the letter forms of its inscriptions. Those by competent epigraphers (August Wilhelm, Albert Rehm, Vasileios Leonardos, B. D. Meritt, and H. Kritzas) have consistently placed the inscriptions within the last two centuries BC. Kritzas's judgment that "dates around 150 BC to 100 BC are a plausible range" has frequently been cited, sometimes as if dates before 150 or after 100 can be excluded, which was certainly not Kritzas's meaning [14]. It is widely conceded by epigraphers that dating of Greek inscriptions by their letter forms is extremely unreliable, and when the provenance is uncertain, an inscription may actually turn out to be from as much as a century before or after the date suggested by paleography [24] [25].[6] In the present instance, moreover, the uncommon medium (bronze rather than stone) and the exceptionally small letter size might have affected letter forms.

If the Mechanism was made around 70-50 BC, it was roughly contemporary with the only comparable device from antiquity of which we have a reliable, probably eyewitness, account, the *sphaera* of Posidonios. Cicero wrote his philosophical dialogue *De Natura Deorum* in 45 BC, setting the imagined conversations, with his younger self present though almost mute, about 77-76 BC, soon after Cicero returned to Italy from his travels in Greece in 79-77 during which he had made the acquaintance of Posidonios in Rhodes. In Book 2, section 88 he has Balbus, his advocate of the Stoic school, say:

> What if someone took to Scythia or Britannia that *sphaera* that our friend Posidonios has recently made, in which single turnings have the same effect for the Sun and Moon and the five planets as occurs in single days and nights? Who in that barbarous land would doubt that this *sphaera* was accomplished by reason?

---

[5] In [15] it was suggested that Syracuse also used the Corinthian calendar. Inscriptional evidence proves, however, that the Syracusan calendar had some months not found on the Mechanism, and was likely identical with the better preserved calendar of Tauromenion [23].

[6] Inscriptions from Rhodes with letter forms very similar to those on the Mechanism can be found with dates through the entire first century BC and even into the first century AD [23]

Cicero's recollection of Posidonios's planetarium probably gave shape to his descriptions of the *sphaera* of Archimedes in two other dialogues, the *De Re Publica* (begun in 54 and completed by 51 BC) and the *Tusculan Disputations* (written 45 BC, just before *De Natura Deorum*). The circumstantial account that Lucius Furius Philus is made to give in *De Re Publica* (the dialogue is set in 129 BC) of a visit in 166 BC to the house of Marcus Marcellus where he saw a demonstration of Archimedes's bronze *sphaera*—supposedly still in working order half a century after it was retrieved by Marcellus's grandfather from the sack of Syracuse in 212 BC—is surely a fiction designed to serve Cicero's philosophical agenda.[7] Philus makes the same observations about Archimedes's device as Balbus does concerning Posidonios's, that a single turning brings about the diverse motions of the Sun, Moon, and five planets, and that single turnings corresponded to single simulated days of motion. Philus adds that the Archimedean *sphaera* showed the Sun, Earth, and Moon in the correct configuration for a solar or lunar eclipse on the appropriate dates; the wording is ambiguous but seems to suggest some kind of graphical representation of the eclipses.

Fig. 11. The frontispiece of Angelo Mai's *editio princeps* of Cicero's *De Re Publica* (Rome, 1822). The characters of the dialogue converse, with Archimedes's *sphaera*, conceived as a kind of armillary, on the ground at the lower left—a conflation of the fictitious colloquy set in 129 BC and the probably equally fictitious one of 166 BC when the *sphaera* was demonstrated.

We recall how Rehm wrote of the Mechanism as "one of those articles of commerce with which the culturally superior Hellas impressed its Roman lords," that is, as an object intended to confer prestige on its Roman aristocratic owner as well as on the Greek artisan and his science.

[7] At one stage Cicero intended to set *De Re Publica* in his own time, as a conversation between himself and his brother; he settled on the much earlier dramatic date to avoid references to contemporary events that might cause offence (*Epistulae ad Quintum Fratrum* 3.5.2).

Rehm was doubtless thinking of that occasion in 166 BC at Marcellus's house when Sulpicius Gallus explained and demonstrated Archimedes's contraption, leading Philus to praise Archimedes for exhibiting "more ingenuity than one would suppose that human nature can hold." But if we take the tale at face value, the Roman lords were merely the accidental possessors of Archimedes's planetarium. It is rather Posidonios to whom we should turn for a model of the type of person who would commission an Antikythera Mechanism: a prosperous philosopher and teacher, deeply interested in the physical world though not necessarily in the technicalities of mathematical astronomy. Our Mechanism may well have come from the same workshop as Posidonios's—there can hardly have been more than one or two manufacturers of sophisticated *sphaerae* at any one time—and we should probably be seeking a pupil or associate of Posidonios who lived in or about Epirus.

References

[1] [Anonymous], *Τὰ εὑρήματα τοῦ ναυαγίου τῶν Ἀντικυθήρων*, *Ἐφημερὶς Ἀρχαιολογική* 1902 146-172.

[2] I. Svoronos, *Ὁ θησαυρὸς τῶν Ἀντικυθήρων*, Beck & Barth, Athens 1903.

[3] J. Svoronos [I. Svoronos], *Die Funde von Antikythera*, Beck & Barth, Athens 1903.

[4] O. Rousopoulos, *Über die Reinigung und Conservierung der Antiquitäten*, *Comptes rendus du congrès international d'archéologie, 1re session, Athènes 1905*, Hestia, Athens 1905.

[5] A. Rehm, *Meteorologische Instrumente der Alten*, unpublished manuscript dated 1905, Bayerische Staatsbibliothek (Munich), Rehmiana III/7.

[6] A. Rehm, Untitled manuscript dated 1906 ("Athener Vortrag"), Bayerische Staatsbibliothek (Munich), Rehmiana III/9.

[7] K. Rados, *Ναυτικαὶ καὶ ἀρχαιολογικαὶ σελίδες. Περὶ τὸν θησαυρὸν τῶν Ἀντικυθήρων.* Τύποις «Πανελληνίου Κράτους», Athens 1910.

[8] P. Rediadis, *Τὸ ἐξ Ἀντικυθήρων ἀστρολάβος*, *Ἐφημερὶς Ἀρχαιολογική* 1910 157-172.

[9] J. Théofanidis [I. Theofanidis], *Sur l'instrument en cuivre dont des fragments se trouvent au Musée Archéologique d'Athènes et qui fut retiré du fond de la mer d'Anticythère en 1902*, *Πρακτικὰ τῆς Ἀκαδημίας Ἀθηνῶν* 9 (1934) 140-149.

[10] I. Theofanidis, *Ἁγίου Παύλου (πλοῦς), Μεγάλη στρατιωτικὴ καὶ ναυτικὴ ἐγκυκλοπαίδεια*, Athens n.d. [1929-1930], 1 83-96 [89-96 misprinted as 97-104].

[11] D. J. de Solla Price, *An Ancient Greek Computer*, *Scientific American* June 1959, 60-67.

[12] D. J. de Solla Price, *Gears from the Greeks*, *Transactions of the American Philosophical Society* n.s. 64.7, 1974.

[13] D. J. de Solla Price, *Clockwork Before the Clock and Timekeepers before Timekeeping*, *Proceedings of the Second World Conference of the International Society for the Study of Time*, Springer, New York 1975, 367-380.

[14] O. Neugebauer, *A History of Ancient Mathematical Astronomy*. Springer, Berlin 1975.

[15] T. Freeth *et al. Decoding the Ancient Greek Astronomical Calculator Known as the Antikythera Mechanism*, *Nature* 444 (2006) 587-591.

[16] T. Freeth, A. Jones, J. Steele, and Y. Bitsakis, *Calendars with Olympiad and Eclipse Prediction on the Antikythera Mechanism*, *Nature* 454 (2008) 614-617.

[17] M. T. Wright, *The Antikythera Mechanism Reconsidered*, *Interdisciplinary Science Reviews* 32 (2007) 27-43.

[18] A. Jones, *The Place of Astronomy in Roman Egypt*, in T. D. Barnes, ed., *The Sciences in Greco-Roman Society*, Academic Printing and Publishing, Edmonton 1994, 25-51.

[19] J. Evans, *The Astrologer's Apparatus*, *Journal for the History of Astronomy* 35 (2004) 1-44.

[20] M. G. Edmunds, *An Initial Assessment of the Accuracy of the Gear Trains in the Antikythera Mechanism*, *Journal for the History of Astronomy* 42 (2011) 307-320.

[21] J. Evans and J. L. Berggren, *Geminos's Introduction to the Phenomena*, Princeton University Press, Princeton 2006.

[22] N. Kaltsas, E. Vlachogianni, and P. Bougia, eds., *The Shipwreck of Antikythera: The Ship, the Treasure, the Mechanism*, Hellenic Ministry of Culture, Athens 2012.

[23] P. Iversen, personal communication.

[24] S. V. Tracy, *Dating by Lettering in Greek Epigraphy*, in A. M. Fernández, ed., *Estudios de epigrafía griega*, Servicio de Publicaciones, Universidad de la Laguna, La Laguna 2009, 105-112.

[25] B. Mclean, *An Introduction to Greek Epigraphy of the Hellenistic and Roman Periods from Alexander the Great down to the Reign of Constantine (323 B.C. - A.D. 337)*, University of Michigan Press, Ann Arbor 2002.