The Inscriptions of the Antikythera Mechanism by Martin Allen, W. Ambrisco, Magdalini Anastatsiou, D. Bate, Yanis Bitsakis, A. Crawley, Mike Edmunds, D. Gelb, R. Hadland, P. Hockley, Alexander Jones, T. Malzbender, Helen Mangou, Xenophon Moussas, Andrew Ramsey, John Seiradakis, John M. Steele, Agamemnon Tselikas, and Mary Zafeiropoulou

Turnhout, BE: Brepols, 2016. Pp. 310. Special edition: Almagest 7.1, Paper €33.00

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In 1900, Greek sponge-divers, on their way back home to Symi in the eastern Aegean from working the sponge-beds off the Libyan coast of Africa, found by chance the wreck of an ancient ship in deep water at the bottom of the sea off the coast of the small island of Antikythera, south of the Greek mainland. The recovery of the contents of the wreck constitutes one of the first concerted underwater excavations and it brought to the surface a significant collection of Greek sculptures in bronze and marble. These remains, some well known, others not so, recently became the focus of their own special exhibition in the National Archaeological Museum in Athens [Kaltsas, Vlachogianni, and Bouyia 2012].

One particular part of the cargo has attracted the interests of historians of science: the remains of a technical instrument, which were recognized soon after discovery. (The details of the recognition in 1902, attributed to Spyridon Staïs, the Minister of Education in the Greek government, are given in the book under review [38–41]; see Kaltsas, Vlachogianni, and Bouyia 2012, 18–31 and 228 for a description of the discovery of all the finds in 1901–1902 and for the recognition of the instrument.)

In 1972, X-rays were taken of the Mechanism by radiographer Charalambos Karakalos for the physicist Derek de Solla Price. These showed that it originally comprised over 30 interlocking, toothed gears and several plates that were interrelated by their capacity to mark time in various ways: an Egyptian calendar; a zodiac-dial; and a star-calendar (*parapegma*). These discoveries led Price to attempt a reconstruction and ultimately to publish his findings in a monograph [de Solla Price 1974]. For him, the instrument was a type of calendar-computer, a loose term nowadays since it was not programmable, but adequate for his time.

Ground-breaking though this research was and fundamentally important for our appreciation of the complexity and sophistication of the Antikythera Mechanism, more intensive techniques and ongoing physical reconstructions have been undertaken and have allowed investigators to refine or correct much of Price's interpretation and model.

In the 1990s, Michael Wright at the Science Museum in London and Allan Bromley at the University of Sydney became collaborators, working initially from the 1970s' X-rays but then developing their own. Since Bromley's untimely death, Wright has continued his research, in the process manufacturing the most detailed physical reconstructions of the Mechanism and explaining its underlying theory in a long series of publications. In its time, Mogi Vicentini's [2009] virtual reconstruction of Wright's model version 2 provided a brilliant opportunity to imagine the device as a whole and yet also to appreciate the extraordinary engineering skill that lies behind its construction. I have had the pleasure of seeing Wright's workshop and tools, which, barring a modern metal-working lathe, have largely adhered to the type of hand-tools available to an ancient craftsman. As I recall, in Wright's own estimation, it would take a single person a year working full-time with ancient techniques to make the Mechanism.

The most recent investigators of the device, and by far the largest group, are the members of the Antikythera Mechanism Research Group (AMRG), some of the fruits of whose work are assembled in the publication under review. Originally led by Tony Freeth and Mike Edmunds, the AMRG has comprised three teams from the UK, Greece, and North America: the academic team (Mike Edmunds, Tony Freeth, John Seiradakis, Xenophon Moussas, Yanis Bitsakis, and Agamemnon Tselikas); the Hewlett-Packard team (Tom Malzbender, Dan Gelb, and Bill Ambrisco); and the museum team (Eleni Mangou and Mary Zafeiropoulou from the National Archaeological Museum in Athens). Notable additions to the team after 2006 have been Alexander Jones, John Steele, and Magdalini Anastasiou. Jones figures as author or co-author of all the chapters in the present publication under review, and Bitsakis of all but one. Freeth withdrew from the AMRG in 2012 and has

proceeded to publish on his own [e.g., Freeth 2014]. Indeed, one of the best introductions to the Mechanism and what it tells us is provided in a virtuosic (not to say epic, at almost two hours' length) lecture that Freeth gave at the Stanford Humanities Center in 2016. This provides, towards the end, a stunning virtual reconstruction of the Mechanism, which has the added advantage of placing the known fragments in their appropriate positions. As a matter of disclosure, I am listed on the AMRG's website as a collaborator with the project [www.antikythera-mechanism.gr/project/team]. This has taken the form of independent publications of my own interpretations of the findings with respect to the Mechanism's calendars, based at times on privileged access to the data, and of discussions with members of the team about various other aspects of the device (notably with Freeth while he was still a leader of the team).

X-ray computed tomography-or CT scanning as we know it in medicine, but here increased in radiation well beyond what a living organism like a human body could endure—as well as Polynomial Texture Mapping, developed by Hewlett Packard, have been particularly useful for the AMRG to provide far more data capable of interpretation than had been visible even under standard X-ray. Not only have these investigations clarified the interconnections of the gearing and enabled increasingly precise reconstructions of the device, they have provided the level of detailed images of the minute inscriptions upon which this book is based. The Mechanism's complex train of more than 30 gears, moving at different speeds, was arranged so as to coordinate otherwise discordant time-scales. It managed to correlate the motions of the Sun and the Moon via the 19-year Metonic Cycle, and probably of the five planets known to antiquity in epicyclic motion through the zodiacal band. The device could also be used to compute eclipses and it had a dial to signal the two- and four-yearly games festivals at Olympia, Isthmia (near Corinth), Delphi, Nemea, Dodona, and possibly Rhodes. A parapegma or star-calendar also coordinated with dials giving the zodiacal year, the Egyptian calendar, and even a civil calendar, which was probably the Epirote variation of the Corinthian calendar [Iversen 2017].

The initial section of the volume under review presents an introduction to the original form and scale of the device itself, known now only through the 82 fragments of very variable size and preservation. Readers are also introduced to the technique of computed tomographic imaging and polynomial textual mapping, by which the inscriptions are now read in greater detail than before.

There follows a useful summary of the history of the discovery of the Mechanism and a discussion of the problems associated with reading and dating the inscriptions by traditional techniques. The remaining four sections of the volume take us through transcriptions and translations of the inscriptions on:

- the front dial and *parapegma* (the zodiacal band and Egyptian calendar-dials, plus the *parapegma*, whose unusual, or even unique, placement clockwise around the central dial deserves attention);
- (2) the back dial and back plate (the Metonic and Saros-dials, along with the small 'Games' dial within the Metonic dial and an exeligmosdial within the Saros-dial), as well as surrounding text relating to the predictions of eclipses (the authors refrain from attempting to date the construction of the Mechanism on the basis of the eclipse-cycles, something that has been attempted in a previous study by Freeth to suggest a date of construction near 205 BC [Freeth 2014]);
- (3) the back cover (preserved only as very small fragments, this plate, or pair of plates, provided a description of the dials, pointers, and other external features of the Mechanism); and
- (4) the front cover (texts give data on synodic cycles for the five planets, and it may be conjectured that lost lines described the behavior of the Sun and Moon).

Overall, the volume may be regarded as the *editio princeps* of the inscriptions of the Antikythera Mechanism in so far as it provides what are regarded as the most plausible readings of the fragmentary inscriptions. But it does more than that by providing historical and cultural interpretations of the readings.

One of the fundamental problems of the Mechanism is that we do not know its precise date. Despite protestations to the contrary presented in the volume by Jones ('we cannot appeal to the letter forms to narrow this interval' between the late third century BC and the date of the shipwreck [58]), at present the best means of dating still seems to be the style of the Greek lettering found on several of the fragments, which is rather ironic given the degree of highly technical analysis that the instrument has been subjected to of late. Perhaps the latest word on this fraught aspect belongs to Iversen, who adumbrates a forthcoming article in which he discusses the paleography of the inscriptions and indicates that he

can show that all the letter forms that they [Kritzas and Crowther] discuss as dating from the end of the 3rd century to the beginning of the 1st can also be found on inscriptions from Rhodes securely dated within 30 years of the Antikythera shipwreck, ca. 70–50 BC. [Iversen 2017, 146n67]

This is a tight chronology indeed in the world of Greek inscriptions which lack a secure dating point such as is provided by political names or events. My own view, expressed in Hannah 2008, 31 and in more substantiating detail at 160n10, is that the letter forms could suit the second half of the second century BC. But I gave the necessary caution that the Mechanism's inscriptions are on bronze and on a very small scale compared with the epigraphical parallels that I offered. These parallels were presented as a result of my own independent study over the years of the forms of the inscription, so I am puzzled that I am said in this volume to have given an 'endorsement of Kritzas' dating' [57n77]. I have had cause to work for 40 years with Hellenistic inscriptions which lack means of secure dating, such as political elements, and margins of error in the range of 50, 100, or 150 years are not unusual. I am happy to run beyond *ca* 100 BC and into the first century BC for the Mechanism's script, if Iversen's argument about local script-forms in Rhodes holds.

Such a relatively late date for the Mechanism would work well with another aspect of the device that is just hinted at in the section on the back dial and plate, namely, the relationship with astrology as evinced by references to the color and size of the Sun at eclipse, which might be linked with astrology:

The correspondences between these predictions and the eclipse phenomena invoked in the astrological literature are surely not accidental. We see it as an indication that the Mechanism was fashioned to represent and simulate a Hellenistic cosmology in which astronomy, meteorology, and astral divination were intertwined. [211]

Elsewhere Jones, while regarding the Mechanism as 'an educational tool', has noted that

Greek astronomy around 100 BCE was undergoing significant transformation through contact with the contemporary, but more mathematically advanced, astronomy of Babylonia and also in response to the demand coming from the relatively new but hugely popular practice of horoscopic astrology for positions of the heavenly bodies calculated for arbitrary dates, on the basis of which astrologers generated their prognostications. [Jones 2017b]

This stands somewhat in contrast to his view in his recent monograph on the Mechanism, where astrology is acknowledged as a potential use for the Mechanism but ultimately dismissed [Jones 2017a, 236]. In the past, I have posited an astrological function for the instrument, as it could have permitted the rapid calculation of the positions of all the major planetary bodies and related phenomena that were essential to ancient astrology. The Antikythera Mechanism could provide a means by which the major astrological positions (which sign, even which degree of which sign, the planets were in) could be ascertained at a certain point of the year over a prolonged period of time, and so could be the type of instrument that an astrologer would find useful in constructing the sorts of tables that we know of from the Imperial Roman period. Otto Neugebauer proposed a combination of observation and calculation to explain the accuracy and discrepancies in these tables [1942], and an instrument like the Antikythera Mechanism could fulfill the need for the calculated positions. The earliest surviving horoscopes are the sculpted one at Nemrud Dağ in Commagene, Turkey, from 62 BC and the slightly earlier literary one of 72 BC preserved by the mid-first century AD astrologer Balbillus [Hannah 2008, 63–64]. If the Mechanism does date to the decades before the shipwreck, then indeed it falls into the period in which horoscopic astrology was making its presence felt in the Greek world.

One last aspect of the volume that I would like to raise concerns the *parapegma*, which features around the front dials. Apart from providing a valuable, up-to-date transcription and translation of the *parapegma* on the Mechanism, Bitsakis and Jones present the background to *parapegmata* in general and devote some time [117–135] to a discussion of the observational astronomy that they believe underlies this and other *parapegmata*. At issue is the question of the accuracy of the observations for any given latitude for which the Mechanism was devised. At this point, I worry that all the care that has been devoted elsewhere in the volume to understanding the cultural context of the Mechanism has been put to one side in favor of a presumption that what we have in the Mechanism's *parapegma*, and indeed in other preserved *parapegmata*, are data derived from direct observation. I have myself aligned with this belief in the past, even in the face of a gentle chiding from Douglas Kidd, the doyen of Aratus-commentators, who once interjected,

when I was talking about observations recorded in the *parapegmata* of Euctemon and Eudoxus, 'if they observed at all'. I assumed then that they did indeed observe. But 20 years on, I have come around to thinking that perhaps the data-sets that have been handed down to us in the *parapegmata* may be, like the astrological data of the tables treated by Neugebauer, a mixture of observation and calculation. In the case of star-positions, the calculation might be based *not* on a star's visibility being a function of its magnitude as we assume nowadays, but rather on a simpler assumption of a set length of time before sunrise or after sunset.

Such a method is actually mentioned by Pliny the Elder at Nat. hist. 18. 218, where he says that the Sun should be 'at least three-quarters of an hour' below the horizon. Le Bonniec and Le Boeuffle suggest that this corresponds to about 12° below the horizon [1972, 264n3]. Matthew Fox has proposed that ancient observations of the stars took the Sun to be at a certain distance below the horizon, apparently regardless of the brightness (magnitude) of the star being observed on the horizon [Fox 2004]. For him, this led to a realization and demonstration that the star-data presented by Ovid in his Fasti, long derided for their apparent inaccuracy, were in fact largely accurate according to the parameters given by Pliny. The few remaining inaccurate data that Fox could not fit into his scheme were later addressed by Anne-Marie Lewis and shown to be accurate too, give or take the occasional textual lapse in the manuscripts that needs correcting [2014]. I have argued elsewhere that some of the data from Euctemon's parapegma fit this method, where the time of the star-observation is, by modern calculation, 40 or so minutes before sunrise or after sunset [Hannah 2018]. Fermor and Steele [2000, 213–214] have discussed inflow waterclocks in Babylonia that could measure in 24-minute units. Much later the Indians, for whom 24 minutes are the fundamental unit of time, had waterclocks that could measure accurately in such units [Sarma 1994, 512–513]. One such instrument comprised a hemispherical bowl with a hole in its bottom, which sat in a bucket of water and slowly sank to the bottom in exactly 24 minutes. 24 minutes are 1/60 of a 24-hour day (a nuchthemeron in Greek), and 48 minutes are simply two such units. which then match well with Pliny's time-lapse of 'at least three-quarters of an hour' for observations, and indeed suit well the sort of temporal gap that can be found for some star-phases in Euctemon's parapegma. An instrument as simple as a bowl or even a clay lamp of appropriate size could have served the purpose of measuring time.

So I wonder now if the Antikythera Mechanism's 'observations' are similarly open to such interpretation, in which case, the search for accuracy based on star-visibility and magnitude, which seems doomed in the present volume, is unnecessary.

These criticisms notwithstanding, there is no doubt that we are deeply indebted to the AMRG for the presentation of all the data in this remarkable volume. The extraordinary *tour-de-force* of engineering that is the Antikythera Mechanism will probably provide more surprises yet, as technology improves to investigate it and scholarship deepens to explain it. Even if its purpose remains a puzzle, it is reasonable to take it as a prestige-item commissioned by (and for?) a wealthy patron, who lived in the Greek world, perhaps in the sphere of influence of scientists of the calibre of Archimedes and Posidonius.

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