The Antikythera Mechanism – Real Progress Through Greek/UK/US Research

M.G.Edmunds for the Antikythera Research Project

M.G. Edmunds & A. Freeth, School of Physics & Astronomy, Cardiff University, Cardiff CF24 3YB, UK; Y. Bitsakis &X. Moussas, University of Athens; J. Seiradakis, Aristotle Uinversity, Thessaloniki; E. Magkou & M. Zafeiropoulou, National Archaeological Museum, Athens; P.Haycock, Keele University, U.K.; P.Hadland & A. Ramsay, X-Tek, Tring, UK; D.Gelb & T. Malzbender, Hewlett-Packard, Palo Alto, USA.

Abstract. We give a brief report on the aims and objectives of a new international research effort to investigate the Antikythera Mechanism. The extraordinary nature and importance of the mechanism is emphasized, and the new techniques employed are outlined. As well as addressing the question of the functions of the mechanism, the project will provide a generally available web-based experimental database.

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INTRODUCTION

""“History with its flickering lamp stumbles along the trail of the past, trying to reconstruct its scenes, to revive its echoes, and kindle with pale gleams the passions of former days”

This quotation, from Sir Winston Churchill – himself an accomplished historian - mirrors our own reaction to the unique Antikythera Mechanism. The Mechanism is a physical artifact of almost tangible power, more complicated than any known mechanism for a millennium after its construction, forcing us to confront its implications for the development of human thought and technology. Past attempts to understand its purpose are by now quite well documented, yet it seems as though its profound implications are still not widely recognised among astronomers, classicists and historians of ideas and technology.

The mechanism was found in 1900 as a single corroded lump, about the size of a shoe box, by sponge divers near the Mediterranean island Antikythera – hence its name – in the sea-floor remains of a shipwreck. Through some of the very first underwater archaeology, the wreck subsequently yielded a fabulous collection of bronze and stone statues, glass and other artifacts, many of which are displayed in the rich collection of the National Archaeological Museum in Athens. (some illustrations can be found at http://www.culture.gr/2/21/214/21405m/e21405m4.html). The shipwreck may have been of a trading or plunder vessel on its way to Rome around 80-60 BC.

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Investigation of the mechanism began with the discovery of gearwheels when the "lump" split open. Once radiography was carried out by Ch. Karakalos and Derek de Solar Price the true extent and complication of the mechanism became apparent – over 30 gear wheels, with multiple display scales of uncertain function. Price published a fine account of his pioneering researches in his book "Gears from the Greeks" in 1975. But one has the impression that he had rather fixed ideas, and it has become apparent since that time that his reconstructions are probably not correct in detail. Much subsequent interesting and imaginative work has been done by Michael Wright and his collaborators. A major problem that faces any new potential investigator is the lack of access to real data. Illustrations in books and journals are often poor, and "image enhancement" on the few published X-rays has tended to mean an ink line drawn around gear teeth! One of the major goals of our new investigation is to provide a web-based data archive which will allow much of future research without the need for direct access to the original mechanism, except of course where radically new techniques may be developed. Our campaign, described below, is designed to gather and make available full surface imaging of the extant fragments of the mechanism, and full 3-dimensional X-ray tomography at sufficient resolution to extract all possible physical information on structure, construction and inscription.
A short basic general illustrated review of the mechanism was given by one of us a few years ago (Edmunds & Morgan 2000), to which the reader is referred for source references where they are not given below.

THE MYSTERY OF THE MECHANISM

To establish a date for the mechanism within a window of 90 years is not too difficult. The shipwreck contained coins dating to 86-60 BC, so the mechanism must be at least as old as this. The epigraphy of inscriptions is characteristic of the beginning of the first century BCE. The use of the older form "ΧΥΛΑΙ" in a zodiac dial suggests an earlier origin than Geminus' *Isagogue* which was written around 55 BC and used a later form. Circumstantial evidence comes from Cicero's account of orrerys existing in Rhodes around 78-44 BC. Taken together, a date within the period 150-60 BC seems appropriate. This is a potentially interesting period, since it falls within a rather "dark age" in our knowledge of advances in Greek astronomy. As Dreyer (1906) put it "From Hipparchus [190-120 BC] we have to pass over two centuries and a half……[to Ptolomy, 85-165 AD]". A brief reading of Ptolomy's Almegeist will convince anyone of the intellectual brilliance of both Hipparchus and Ptolomy. Hipparchus himself was dead by 120 BC, but as realised by Price, Hipparchus had worked in his later years on Rhodes. From that account by Cicero of an orrery on Rhodes, and the evidence we have of Rhodes as a major naval (and hence probably technological) centre, certainly suggests Rhodes as the most likely site for the construction of the Anikythera Mechanism. It would perhaps be wrong to completely rule out other possible sites (Pergamon?) - but a tradition or school of mechanical representations of the Universe originating from Hipparchus on the island of Rhodes is rather attractive. Archimedes, working some one hundred years before Hipparchus is reported to have made mechanical devices to display astronomical phenomena, but his book on the subject,

de Spherae, is unfortunately lost. What seems certain is that the Antikythera Mechanism could *not* have been unique. It is surely inconceivable that so complicated a device was the single example – it must have been the result of considerable development. No similar device is known for a thousand years afterwards, until the coming of the mediaeval cathedral clocks. There is an interesting sundial-calendar from 400-600 A.D. Byzantium (Field & Wright 1985), which suggests some continuation of the geared mechanism tradition, but it is much simpler with only eight gears.

The Antikythera gears are hand-cut or filed from 2mm bronze sheet. We wait for definitive gear teeth counts from our X-ray images, and the unpublished images of other investigations. It is interesting to speculate on the implications of what is so far known, and memory of school geometry with a straight edge and pair of compasses might suggest that powers of two, and three times powers of two, would be easy to lay out. Indeed it seems that many of the gears conform to this pattern. But for astronomical cycle ratios, some more difficult gears are needed – it seems likely, for example, that there are gears with 38 and 127 teeth. Rough numbers may be about 21 easy gears, 9 not difficult, and 2 rather challenging! – but present day metalworkers point out that there are various uncomplicated schemes for setting out *any* number of gear teeth. It is obviously crucial in determining the astronomical function that the teeth counts are known accurately, but this may not be easy where only partial evidence remains, and we are developing simple statistical methods to help understand the confidence limits. Price was greatly impressed that the mechanism appeared to contain a differential gear mechanism – something of which did not appear again until modern times, and not widely known before the 19th century. It will be important to establish whether the gearing actually is a differential – the doubt comes because there appear to be much easier straightforward gearing trains that would carry out the function proposed for the differential by Price. Why go to the complication of a differential when simple gearing would suffice? And if the structure is not a differential gear, then what is it for?

What astronomical cycles should we be looking for? Price's reconstruction and the numbers clearly visible in the inscriptions - 19, 76 and 223 - are already very suggestive. The inscription fragment with these numbers on (in Greek notation of course) can be viewed at the Hewlett-Packard website mentioned below – image AK01a-512. There are scales with zodiac signs and months, and a parapegma inscription – calendrical data. The obvious calendrical cycles are Metonic (*19* years of 235 lunar months) and the Callipic (*76* years of 940 lunar months, and a day less than four Metonic cycles). Hipparchus had formally improved the cycle with 304 years, and a day less than four Callipic cycles, but this period might well be too long for useful representation in a mechanical mechanism. The *223* suggests the Saros eclipse cycle. Another possibility that might be worth looking for is the approximately 19 year cycle of lunar standstills – the times when the moon moves its at furthest North and South of the ecliptic, and a phenomenon which it is believed was followed by megalithic astronomers in Northern Europe (Ruggles 1999). That the device showed lunar phase seems very likely, with both Price and Wright noting that the circular structure on the reverse of Fragment C might well have been associated with a mechanical moon phase display.

Did the mechanism show planetary positions? This is a crucial question. The only real evidence that it might have done is rather circumstantial. The main clue is the single tantalising word "Aphrodite" (Venus) on the inverse inscription on Fragment B, together with rather half-hearted early reports by Price (1959) that he had read the word "stationary" in the inscriptions, implying planetary retrograde motion. Secondary support is the statement by Cicero that devices existed in Rhodes that *did* show movement of the planets. Much enjoyable speculation has been made by ourselves (Edmunds & Morgan 2000, Freeth 2002,) and Wright (2002) in suggesting how simple epicyclic planetary mechanisms might have fitted in to the device. But as yet we have to admit that the evidence is very thin – and will obviously be a major target for our new investigations. If evidence were to be found it might shed some light on the development of planetary theories. By about 55 BC Geminus was supposing that the sun, moon and planets move so that "their circles are eccentric or that they move on epicycles..", but the earlier views of Hipparchus are not known. Ptolomy comments that Hipparchus "being a great lover of truth…did not even make a beginning in establishing theories for the five planets, *not at least in his writings which have come down to us"*. There are hints (A. Jones 2005, private communication) that the inscriptions on the tablet from Keskinto in Rhodes, dated to around 100 BC – and hence perhaps contemporary with the Antikythera Mechanism, and within 20 years of Hipparchus' death – deal with a planetary model rather different from that eventually adopted by Ptolomy.

So back to the obvious question; just what was the mechanism for? Six possibilities suggest themselves, although there could of course be a combination of functions:

1) It was a device for performing calendrical calculations
2) It was a device for performing calendrical and astronomical calculations
3) It was a tellurium – a device for representing (for display or educational purposes) the relation of the Earth, Moon and Sun.
4) It was an orrery – displaying the relation of the Earth, Sun, Moon and planets
5) It was a navigational instrument
6) It was a device for performing astrological calculations

The fifth of these can probably be dismissed straight away. Although it is true that the mechanism was found in a shipwreck, so were many other high status artifacts like the sculptures and glass, and there is no obvious way (at least to a present-day sailor) in which the mechanism could have performed a navigational function. The last suggestion, an astrological purpose, is harder to dismiss. But for horoscopic calculation one would probably have to have a display of planetary positions and one would expect astrological references in the inscriptions – again not yet found. Real evidence in favour of the idea would be the discovery that the mechanism was able to calculate and display the "lot of fortune" – a relatively easy and characteristic calculation off the sun, moon and horoscopic point position, although historically there were some variants in the calculation (Bouche-Leclerc 1899).

Who made the mechanism? The traditional view that Greek philosophers would not stoop to mechanical work might suggest that it had to be a partnership between and able astronomer and a master craftsman. Neither would have the skills or astronomical/mathematical knowledge on their own. If, following Price, Rhodes is indeed the site of construction, then a school perhaps 140 - 60 BC based around Hipparchus and later Posidonius (died 51 BC) seems a reasonable choice. Exactly when this particular mechanism was designed and constructed within that period remains an open question, as does the actual role of these two prominent astronomers.

THE NEW INVESTIGATIONS

Our new investigations will primarily concentrate on the obvious need for better and readily available data on inscriptions, gears, axles, scales, constructional details and overall structure. We also hope that further consideration of the historical, astronomical, economic and technological *context* in which the mechanism was made may help illuminate its purpose and implications. It will also be important to be able to trace the sequence of photographic material showing how the many fragments have originated from the original single find, in order to understand the overall mechanism structure. In direct investigation technique we are using two very powerful new tools, through excellent collaboration with, and support from, industry. The first is to use for surface studies a reflectance imaging technique pioneered by Tom Malzbender at Hewlett- Packard in California (http://www.hpl.hp.com/research/ptm/ri.html). A small lightweight hemispherical dome contains a carefully-spaced array of electronic flashbulbs and a digital camera. From a controlled sequence of exposures, computer images are produced in which the research worker can subsequently greatly alter the lighting conditions and angle – allowing subtle surface detail to be seen, particularly so with image enhancement processing. The technique has already proved very successful in investigating palimpsests and archaeological tablets. The excellent Hewlett-Packard Website explains and illustrates the technique. It may be noted that subsequent to the conference talk in September, the imaging of the fragments of the mechanism in the National Archaeological Museum in Athens was very successful. Examples of the images obtained, which allow image enhancement and variation of lighting are displayed at:
http://www.hpl.hp.com/research/ptm/antikythera_mechanism/index.html

The other technique is X-ray tomography, offering full 3-dimensional internal reconstruction at sub-mm resolution. Here we befitted enormously from the collaboration with X-Tek, a company who make rugged specialist X-ray instrumentation typically used in the detailed examination of components such as turbine blades and printed circuits. We will also undertake some “element specific” tomography to differentiate iron and bronze details. X-Tek’s web site is at: http://www.xtekxray.com/systems.htm. It is very pleasing to report that after the conference we were able to use a new version of their “Bladerunner” machine, which was transported to the Athens museum from the UK especially for the investigation.

We have much data processing to do, with some of the data sets stretching to gigabytes, but we can say that the initial results are very exciting – the technique is beginning to allow us to read inscriptions *inside* the fragments which have not been seen for over two thousand years. We hope that initial publication of the major results will begin in the summer of 2006, and that the detailed database of experimental material will be established by sometime in 2007.

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MGE is very conscious of the honour in being invited to present this progress report to the Helenic Astronomical Society, and thanks them very much.
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We hope that the structure, purpose and significance of the Antikythera Mechanism will soon be available for all to share. The technical achievement represented by this artifact can only cause a sense of increasing wonder at the extraordinary achievements of the ancient Greek world, and engender a resolve and cooperation among us all that "dark ages" should never again be allowed to close in and destroy the beneficial fruits of civilization.

REFERENCES

1. A. Bouche-Leclerc, *L'Astronomie Grecque, Paris* (1899).
2. W.S. Churchill, *Parliamentary tribute to Neville Chamberlain November 12th* (1940).
3. J.L.E. Dreyer, *A History of Astronomy from Thales to Kepler, Cambridge Univ. Press* (1906).
4. M.G. Edmunds & P.Morgan, *The Antikythera Mechanism: still a Mystery of Greek Astronomy? Astronomy & Geophysics* **41**, 6.10 (2000).
5. J.V. Field & M.T. Wright, *Annals of Science* **42**(2): 87-138 (1985): A picture of the sundial is at: http://www.scienceandsociety.co.uk/results.asp?image=10308322&wwwflag=2&imagepos=8
6. A. Freeth, *Mediterranean Arch.* **2**, 21 & 45 (2002).
7. D. de Solar Price, *Scientific American* **200**, 66 (1959).
8. D. de Solar Price, *Gears from the Greeks, Science History Publications, New York* (1975).
9. M.T. Wright, *Horological Journal*, **144**, No. 5, 169-173 (2002); see also Bull.Scientific Instrument Society **85**, and **87,** (2005).
10. C. Ruggles, *Astronomy in Prehistoric Britain and Northern Ireland, Yale University Press,* (1999).