UNLOCKING A SEA SECRET

The Antikythera Mechanism

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A 2200-YEAR OLD COMPUTER WITH MODERN PHILOSOPHY, PACKED WITH A USER MANUAL

The Antikythera Mechanism is a mechanical "computer" programmed to perform predefined calculations. It has two displays, at the front and back sides, much like we can have nowadays a computer connected to two screens. Very briefly, it depicts and predicts the natural motion of objects in the sky, such as the sun, the moon (including its phase) and most probably the 5 visible planets which have not survived but can be inferred. Furthermore, it gives predictions for possible solar and lunar eclipses as well as informs about astronomical events that were important either for agricultural or religious purposes. Finally, the Olympics and other panhellenic games were predicted, bringing a social character to the instrument. All those functions were explained with tiny inscriptions engraved on various parts of the device, similarly to how one nowadays gets a user manual with the purchase of a gadget.

Photo: V. Mathioudakis

DISCOVERED BY SYMIAN SPONGE DIVERS

Sponge divers from Symi chance on the Antikythera shipwreck in 1900, whilst looking for seafood just before Easter. They were on their way to Africa for sponges and made this lucky stop at Antikythera due to bad weather conditions. A year later, on the first major organized underwater archaeological expedition, they discover and retrieve numerous artifacts from the area. This includes **the Antikythera Mechanism, an astronomical calculator of ingenious design and unprecedented accuracy which was to change the history of science and technology** as we knew it. However, this archaeological expedition cost the life of one diver while two others were seriously injured from decompression sickness. Captain Jacques-Yves Cousteau and his crew, make further attempts in 1953 and 1976 to resurrect more ancient items, together with greek divers on board of Calypso. From 2014 onwards, with the latest available piece of technology, the *exosuit*, divers still try… The story of this ancient technological gadget has been full of modern-era technology since its discovery in 1901.

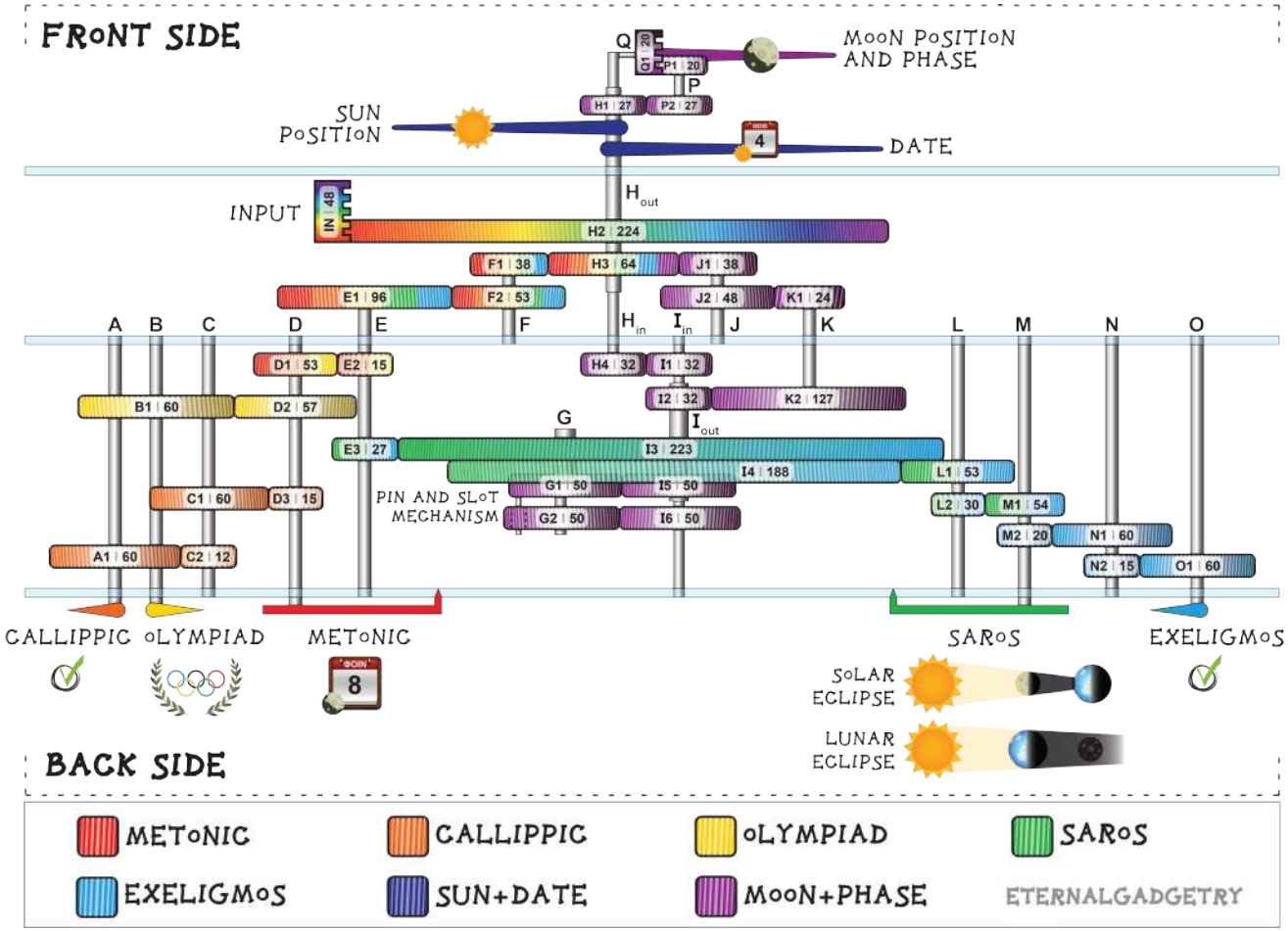
LUNAR AND SOLAR CALENDARS

The Antikythera Mechanism makes extensive use of solar and lunar calendars in order to display its predictions. These two separate calendars differ in their philosophy. For instance, the lunar months shift with respect to seasons throughout years, unlike the months in solar calendars. There are further complications associated with the fact that solar and lunar months don't have equal durations. The Antikythera Mechanism constructor had to deal with, and find solutions to all these problems.

GEARS AND HOW THEY MAKE CALCULATIONS

The Antikythera Mechanism, as we know it today, consists of approximately 40 cooperating gears. Each pair of gears makes a division according to the number of teeth of the meshing gears. This calculation is then fed to the next set until it reaches the final axis, and hence pointer, indicating an event which is read off a dial. It is a modular calculator with its complexity increasing with the number of gears.

As an example, the division 40/60 can be done with a set of gears with 40 and 60 teeth, or more simply with 20 and 30 teeth instead. For calculations involving prime numbers, however, one cannot simplify further and reduce the number of teeth. This is the reason why one finds gears with 53 or 223 teeth on the original mechanism. Scientific findings give the following overall schematic diagram:



Antikythera Mechanism schematic diagram. One can make his own reflections about the complexity of this device which was imagined and created more than two millennia back in time. Visit eternalgadgetry.com for interactive and simplified versions.

Photo: V. Mathioudakis

ABOUT

Dr. Markos Skoulatos is an experimental physicist working in the field of quantum magnetism. Fascinated by natural sciences, experiments and geometry since his childhood, he undertook the challenge of reconstructing the first computer in human history: the Antikythera Mechanism. This hobby project entailed making all the calculations and design from scratch. Whilst staying true to the original design, reflecting ancient wisdom and know-how, Dr. Skoulatos further wanted to expose the full beauty of the Mechanism to today's society.

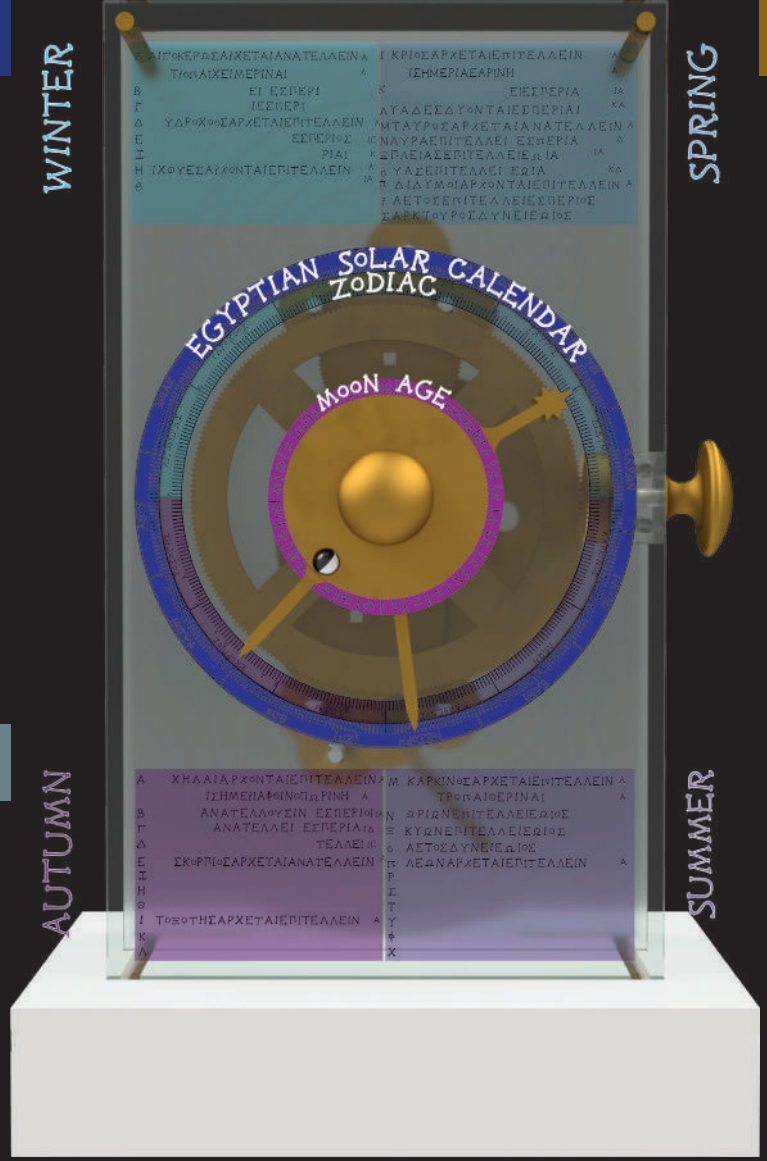
In his view, the Antikythera Mechanism is a timeless testament of civilization, that also constitutes a clever educational gadget. May this raise your interest and enable our children to learn by exploiting technology with an ancient twist.

DIALS

In the front display one can see two large concentric dials. The **external** shows the months of the Egyptian calendar written in Greek, divided in 365 days. This is a solar calendar, much like our January, February etc. In the Egyptian calendar, each of the 12 months has 30 days, with 5 extra days completing the year. This dial can be rotated by 1 division (=1 day) every 4 years, to account for leap years as was known and done in ancient times. A pointer on this dial shows the date. The large **internal** circular dial is the zodiac. The positions of the moon and sun are shown by two extra pointers in this celestial coordinate system of 360°, with twelve 30° divisions. The moon has an ingenious gear sub-system, displaying its phase. The moon age (day of the month according to a lunar calendar) is shown in a smaller concentric dial. Hypothetically, this front display is where the planets could have been depicted as well.

PARAPEGMA

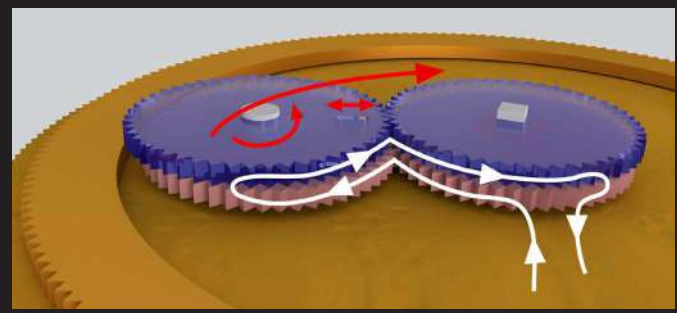
To the top and bottom of the circular dials are inscriptions describing characteristic astronomical events, known as the Parapegma. These events relate to the rising and setting of stars/constellations around the sunrise or sunset. The appearance of such events uniquely and constantly within a year made them important in everyday practicalities such as agriculture, religion, navigation. They are divided in four quadrants, two at the top and two at the bottom, left and right in each case. Each quadrant of the parapegma corresponds to a season of the year, and describes important events taking place within 90° of the zodiac cycle. They are numbered by A, B etc engraved to the left (Greeks used the alphabet also as numbers). A smaller number to the right of each parapegma event, indicates the day of the month when the event will take place. This is then matched by the same number inside the zodiac cycle.



▲ Front display of the Antikythera Mechanism. The solar calendar, zodiac, moon age as well as the star positions throughout the seasons (Parapegma) are shown. The sun, moon and calendar indicators are read off the corresponding dials as the user operates the machine.

A TRULY INGENIOUS CONSTRUCTION

The orbit of the Moon is distinctly elliptical, with an average eccentricity of 0.0549. The constructor(s) of the mechanism considered it essential to depict in detail this motion through the sky, despite a much simpler circular orbit would still capture most of the truth. But how does the mechanism do this, given that all gears are truly circular? The answer to this is not straightforward, and the particular way it is implemented in the instrument is ingenious. Two gears of similar size are placed on top of each other, and held by the same axle. They are however off-centered by just over a millimeter thanks to the particular design of their axle. One gear has a pin close to its edge, which fits in a rectangular slot on the other gear (straight double-arrow below). As the pin-gear rotates, it drives the slotted gear, but with slightly unequal velocity. This produces a variable motion with an effective phase-shift, approximating an elliptical motion. To make it even more complex, the "pin-and-slot" gear system is mounted within a larger gear, so it rotates epicyclically with it (curved red arrows below). This simulates the lunar apsidal precession! This whole concept is truly one of the highlights of the Antikythera Mechanism.



▲ Computer-generated graphics of the ingenious pin-and-slot mechanism that approximates the truly elliptical lunar motion. The white arrow indicates the mechanical pathway, while the red arrows show the complex motion of the gear system.

METONIC, CALLIPPIC AND OLYMPIAD DIALS

A lunar (or synodic) month corresponds to 29.53059 days, which is the duration it takes for the moon to reach the same phase again (for example full moon to full moon). A year consists of 365.2422 days, taking into account the leap-year day. The lunar and solar calendars are not straightforwardly related, since the ratio 365.24/ 29.53=12.37 isn't an integer. The solution to this was given by Meton in 432 BC, much before the construction of the Antikythera Mechanism. He simply took 19 years (6939.60 days) which correspond extremely close to 235 lunar months (6939.69 days). After a full Metonic cycle, the sun, moon and earth are back in nearly the same relative orientations. The Metonic calendar was used in the Antikythera Mechanism (see top red five-turn spiral). Each tiny division corresponds to a lunar month and is marked by its name. In this Greek lunar calendar, the months were regulated to have 29 or 30 days, in order to give the proper average lunar month duration.

The Callippic dial can be seen to the inside left part of the Meton spiral. It follows a 76-year cycle and provides an additional correction to the Metonic dial. According to the Callippic cycle, one day has to be removed every 4 Metonic cycles, which was believed to improve the overall accuracy. It is clear that the people who devised this instrument didn't cut any corners, but were determined to construct it extremely accurate.

The Olympiad subsidiary dial to the right has a four-year cycle and predicts various panhellenic games, including the well-known Olympics. These games were typically repeating every 4 or 2 years, depending on their type. The social part of life was not underestimated but wisely embedded in the mechanism's gear-work in equal terms with the astronomical events.

Back display of the Antikythera Mechanism. This side is covered by two spirals, the upper Meton dial, which is a lunisolar calendar and the lower Saros one, which predicts eclipses. Within them they contain further smaller circular dials with more details, including the Olympic games prediction.

SAROS AND EXELIGMOS DIALS

The Saros dial predicts possible solar and lunar eclipses (bottom green spiral). If an eclipse occurs at a given time, a very similar one will occur 223 lunar months later. This cycle, known already by the Babylonians, arises from the coincidence of three orbital periods of the moon: (i) same phase, (ii) same lunar crossing of the earth-sun orbital plane and (iii) similar earth-moon distances. In other words, after 223 lunar months, the three celestial bodies sun, moon and earth, are back to very similar positions in the sky. The 223 divisions of the Saros cycle are distributed around the four-turn spiral in the lower back part of the mechanism. Engraved symbols can be seen for those months with possible eclipses. The eclipse type is given by H for solar and Σ for lunar after the Greek words ΗΛΙΟΣ (sun) and ΣΕΛΗΝΗ (moon). The special glyph ⌱, after the two first letters of the word ὡρα (hour), signifies the eclipse time. ☌ and ☾ stand for day and night (ΗΜΕΡΑ and ΝΥΞ respectively).

Each eclipse is assigned an index number. Eclipses with similar characteristics such as direction of obscuration, magnitude, color, time etc. are grouped by their indices. This information is then given in areas outside of the two spirals, such as the one marked "eclipse grouping".

Since 29.53059*223=6585 1/3 is not an integer, eclipses will be displaced by 1/3 of a day (8 hours) between successive Saros cycles. Only every 3 Saros cycles = 54 years one gets true eclipse repeat conditions. This is the so-called Exeligmos cycle incorporated to the inside of the Saros dial of the Antikythera Mechanism. It tells us how many hours to add to the eclipse time in order to get its correct time. The dial is divided in three angular parts of 120° each, with the first one being blank and the other two reading 8 and 16, the hours to be added (H and IC in ancient Greek).