Correction notice

Calendars with Olympiad display and eclipse prediction on the Antikythera Mechanism

Tony Freeth, Alexander Jones, John M. Steele & Yanis Bitsakis

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In the version of the Supplementary Information originally posted online, there were minor errors in Supplementary Figs 20 and 25. In Supplementary Fig. 20, some glyphs were accidently omitted between months 26 and 67; in Supplementary Fig. 25, seven glyphs in the left-hand semicircle were inscribed one month too early. These have been corrected in the new version of the Supplementary Information; see Supplementary Information Table of Contents for details.

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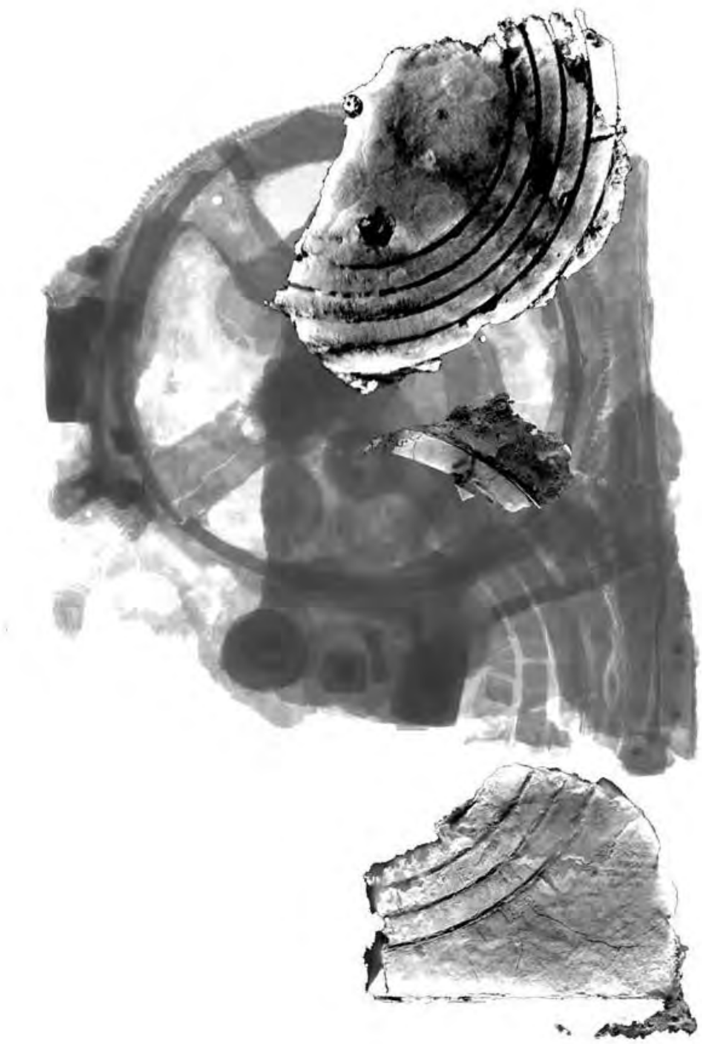
SUPPLEMENTARY NOTES



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1. Overview of the Antikythera Mechanism

1.1 The Fragments

The *Antikythera Mechanism* was recovered in 1901 by Greek sponge divers from a Roman wreck of the first century BC[1]. Initially unrecognized, it was taken to the National Archaeological Museum in Athens amongst a large amount of archaeology from the wreck. It was almost certainly recovered in one piece and was not initially regarded as being anything remarkable. After some months it split apart, revealing some precision gearwheels. This caused considerable excitement, though its true nature was not understood[1]. Current evidence suggests that it dates between the second half of the second century BC and early first century BC[6].

Supplementary Figure 1 | The Fragments of the Antikythera Mechanism. Fragments A-G are in the top half and 1-75 in the bottom half. It is likely, but not definite, that all the fragments belong to the Mechanism.

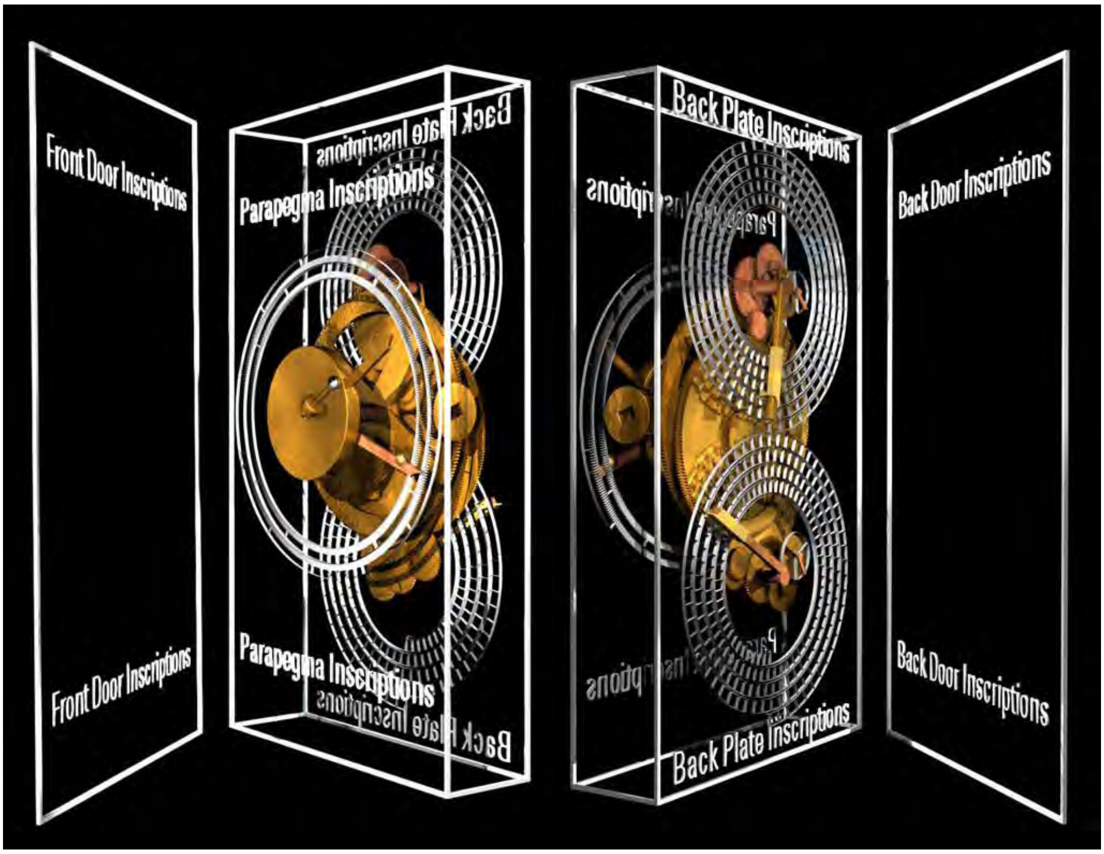
By 1974, it was known to constitute four main fragments (A-D) and about 15 smaller fragments[1]. Fragment E was found at the Museum in 1976. Fragment F together with a large number of minor fragments was found in 2005 in the stores of the Bronze Collection. These were then organized and numbered by the Museum staff so that the current known fragments now consist of seven larger fragments (A-G) and seventy-five smaller fragments (1-75)[6,7].

1.2 The Architecture of the Mechanism

The fragments contain the remnants of thirty bronze gearwheels with teeth about 1.5 mm long, as was confirmed in the first X-ray study[1]. These gearwheels enable the Mechanism to make calculations based on cycles of the Solar System. A recent study showed that all the tooth counts of the surviving gears (with a single exception) can be explained in terms of two cycles of the Solar System, known by both the ancient

Babylonians and the ancient Greeks: the Metonic & Saros cycles (Supplementary Boxes 1 and 2). The basic structure and functions of the gearing were previously described[6]. Here, we publish a revision of this gearing diagram that takes into account the newly discovered *Olympiad Dial*.

The overall architecture of the Mechanism was published in 1974 in a pioneering study[1], though the functions of nearly all of its dials have been radically reassessed since then[6].



Supplementary Figure 2 | Schematic showing the overall architecture of the Mechanism in a 2006 model[6]. The present model revises the Back Dials: the function of the upper subsidiary dial and the geometry of the main lower dial.

The Mechanism consists of a case, which is about 33 cms x 18 cms x 10 cms (with the last measurement being the most uncertain). It has an input on one side, which was probably turned by hand and drives the rest of the gears via a crown gear. On its front and back faces are a number of output dials.

The *Front Dials* consist of two large concentric displays: a Zodiac Dial with the Greek names of the signs of the Zodiac and a Calendar Dial, marked with the months of the Egyptian calendar in Greek[1]. This calendar consisted of 12 30-day months and 5 extra days (*epagomenai*)— making 365 days in the year. Because it lacked the extra quarter day of the solar year, the Egyptian calendar moved relative to the seasons. This was accommodated on the Mechanism with a moveable calendar scale. The scale can be moved by one day every four years, facilitated by a pin on the underside of the scale that engages with a sequence of 365 holes under the calendar scale.

On the Calendar scale, a Date pointer would have shown the date in the Egyptian calendar. In a previous study, this Date pointer also indicated the mean position of the Sun in the Zodiac[1]. However, it is probable that there was a separate pointer that displayed the variable speed of the Sun, according to a solar theory related to that of

Hipparchos[26]. There was also a pointer that showed the position of the Moon in the Zodiac and this is now understood to have incorporated the variable speed of the Moon according to an epicyclic lunar theory related to that of Hipparchos[6]. At the centre of the front dials is an additional mechanism, which uses a semi-silvered ball to display the phase of the Moon[5]. This is calculated from the differential rotations of the Sun and Moon. It might also have shown the age of the Moon in days with an additional scale and this study reinforces this proposal. It seems likely that the Mechanism also displayed some or even all of the five planets known in ancient times[26], but there is considerable debate about this.

The *Back Dials* and their functions are the subject of this study and are described in detail in the Main Text.

2. Data Acquisition & Analysis

2.1 Data Acquisition

In the autumn of 2005, three types of data were gathered on the Antikythera Mechanism under the auspices of the *Antikythera Mechanism Research Project*[6,7].

1. High-resolution still photography on 6 cm x 7 cm film.
2. Digital surface imaging using *Polynomial Texture Mapping* (PTM)[12], gathered by a team from Hewlett-Packard (USA) with specialist equipment.
3. Microfocus X-ray tomography (CT) acquired by a team from X-Tek Systems (UK), now part of Metris (NL), using a prototype high-energy X-ray machine[13].

Supplementary Figure 3 | Fragment A being mounted in X-Tek Systems' *Bladerunner* X-ray machine by Gerasimos Makris, Head Conservator at the National Archaeological Museum in Athens. The fragment was mounted at an angle to minimize the maximum path of the X-ray beam through the sample as it was rotated in front of the X-ray source.

The fragments themselves are in a very delicate state and in danger of decay despite conservation measures. Microfocus X-ray computed tomography (CT) is a completely non-destructive technique, which has enabled the rich store of information hidden inside the fragments to be preserved for all time[6].

The primary data for this study were microfocus CT scans[13]. These were acquired using a specially modified *Bladerunner* X-ray machine, manufactured by X-Tek Systems (UK). Both 450kV and 225kV microfocus X-ray sources were used. These were directed at the sample, which was placed on a rotating turntable while the X-ray image was projected onto a detector. A two-dimensional Perkin Elmer flat panel detector provided all the data for this study. To avoid any mechanical shock to the samples, they were rotated continuously (through just over 360°) while X-ray projections were gathered at regular intervals as 2,048 x 2,048 16-bit TIFF images. The number of images acquired varied between 1,492 and 2,957 for different scans. The resolution of a scan depends on the geometric magnification of the sample onto the detector—with smaller sample yielding higher magnification and hence higher resolution. The resolution varied from 46 microns to 136 microns for different fragments. All the known 82 fragments of the Mechanism were scanned—the larger ones individually and the smaller fragments in batches of up to eight at a time. About 600GB of X-ray data were gathered.

2.2 Data Analysis

The data was processed into viewable X-ray volumes using *Filtered Back Projection* by X-Tek Systems' proprietary software *CT Pro*[13]. These volumes were then viewed with Volume Graphics' *VGStudio Max* software. This software has the ability to isolate single X-ray 'slices' through the fragments and these can be angled to coincide as far as possible with the planes of the Mechanism's plates and gearwheels. The high resolution of microfocus X-ray tomography, together with its ability to isolate a single plane through a sample, are at the heart of the new readings of the inscriptions reported here. As far as we know, the use of this technique on the Antikythera Mechanism[6] is the first time that significant inscriptions have been read inside an archaeological artifact. Analysis of the structure of the Mechanism was carried out both within VGStudio Max and by exporting CT slices into computer-aided design software (Nemetschek's *Vectorworks*), where measurements could be made and 'geometry' superimposed. This was the basis of the analysis of the gearing reported previously[6].

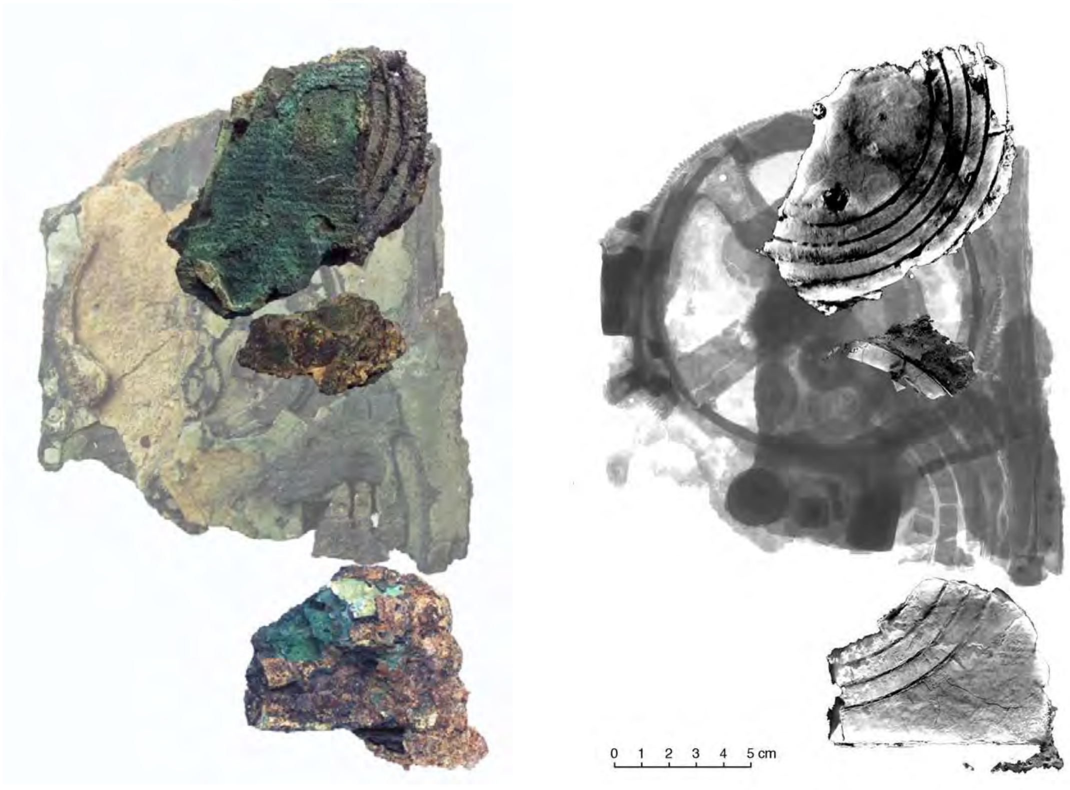
Despite two thousand years under water, fine details in the fragments of the Mechanism have been preserved at sub-millimetre scales. Inscriptions in Greek cover the external plates of the Mechanism, with text varying between 1.2 mm and 5 mm in height. As a text, the Antikythera Mechanism is an extremely rare original document that give us critical information about the astronomy and technology of its era.

Analysis of the text was carried out by viewing slices through the fragments both within VGStudio Max and in image-processing software (Adobe's *Photoshop*). The planes of the bronze plates on which the text is inscribed may not have been completely flat at manufacture and have certainly distorted over time. This means that the whole of an inscription cannot be seen in a single CT slice. Sometimes only a single character can be read in a slice and this character cannot be seen in a parallel slice just 20 microns apart. In order to read as much of the text as possible, multiple slices were exported from VGStudio Max as image stacks into the layers of a Photoshop file, where the text in the different layers could be traced and deciphered.

3. Metonic, Olympiad & Callippic Dials

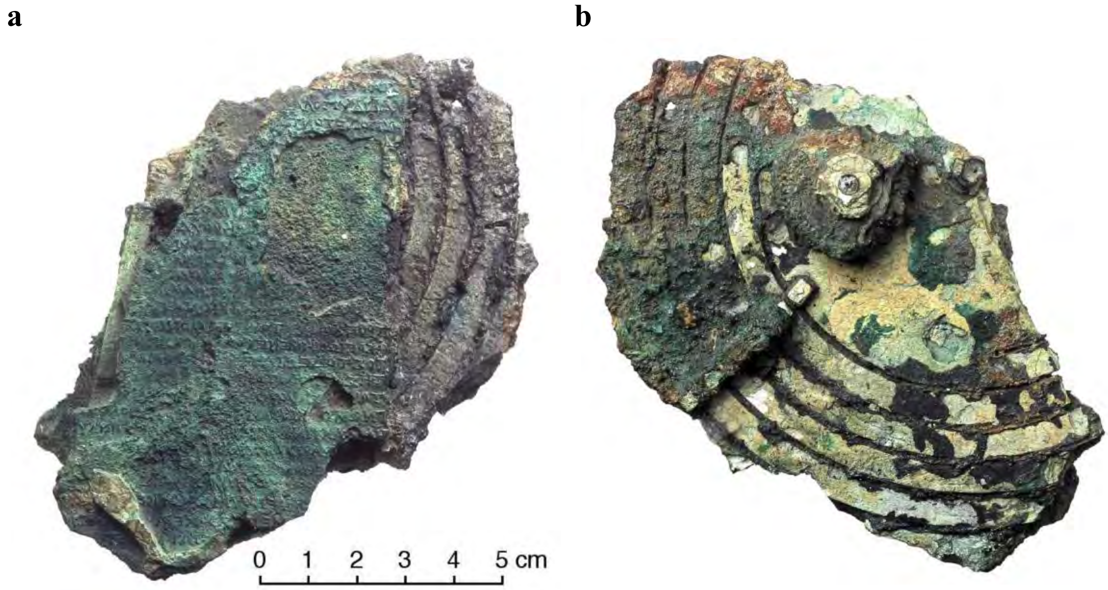
3.1 Fragments that witness the Back Dials

a **b**



Supplementary Figure 4 | Orientation of the main fragments involved in the Back Dials. A, From top to bottom, Fragments B, E and F with Fragment A in the background. B, CT slices of B, E and F with a radiograph of A in the background.

The *Upper Back Dial* system is witnessed by Fragment B, whose orientation relative to the main Fragment A was previously determined by observation of a common axis shared by the two fragments and the horizontal alignment of text imprinted onto the back of the fragment[1]. The *Lower Back Dial* system is witnessed by Fragments A, E and F and their relative orientation was determined previously[6] by CT analysis of the hidden text and scale divisions in these fragments and the understanding that it is a Saros eclipse prediction dial.



Supplementary Figure 5 | Fragment B. a, The external face is covered in a layer of inscriptions in mirror writing that are a cast of text originally on the inner face of the back door. b, The internal face shows the back of the scale rings, held together with a bridging piece. The remains of gear o1 (Supplementary Figure 13) can also be seen on the axis that drives the newly-identified Olympiad Dial.

Fragment B, one of the major surviving fragments, is an amalgam of several separate features from the original device. These include the partial scale rings of the upper back dial system; inscriptions from the Back Door impressed in mirror writing into fine material covering much of the scales; a small part of the Back Door itself (new identification); and a hidden subsidiary dial on the back plate with a single gear underneath.

3.2 The Calendar of the Metonic spiral

Supplementary Box1 | Metonic & Callippic Calendars

From ancient times, astronomers have distinguished a number of different orbital periods of the Moon. The *sidereal month* is the period of the Moon in its passage from a particular star back to the same star (27.32 days); the *synodic (or lunar) month* is the period from one phase of the Moon back to the same phase (29.53 days).

Ancient calendars were based either on the synodic lunar cycle, the solar cycle or both. Twelve lunar months is about 11 days short of a year, so calendars on this basis do not remain synchronized with the seasons. Attempts to rectify this meant finding integer periods of years, which are also integer numbers of lunar months. One of the most accurate of these is the 19-year cycle of 235 lunar months, attributed to Meton of Athens in the 5th Century BC. The *Metonic Cycle* is one of the two basic cycles that underlie nearly all the known gearing of the Antikythera Mechanism.

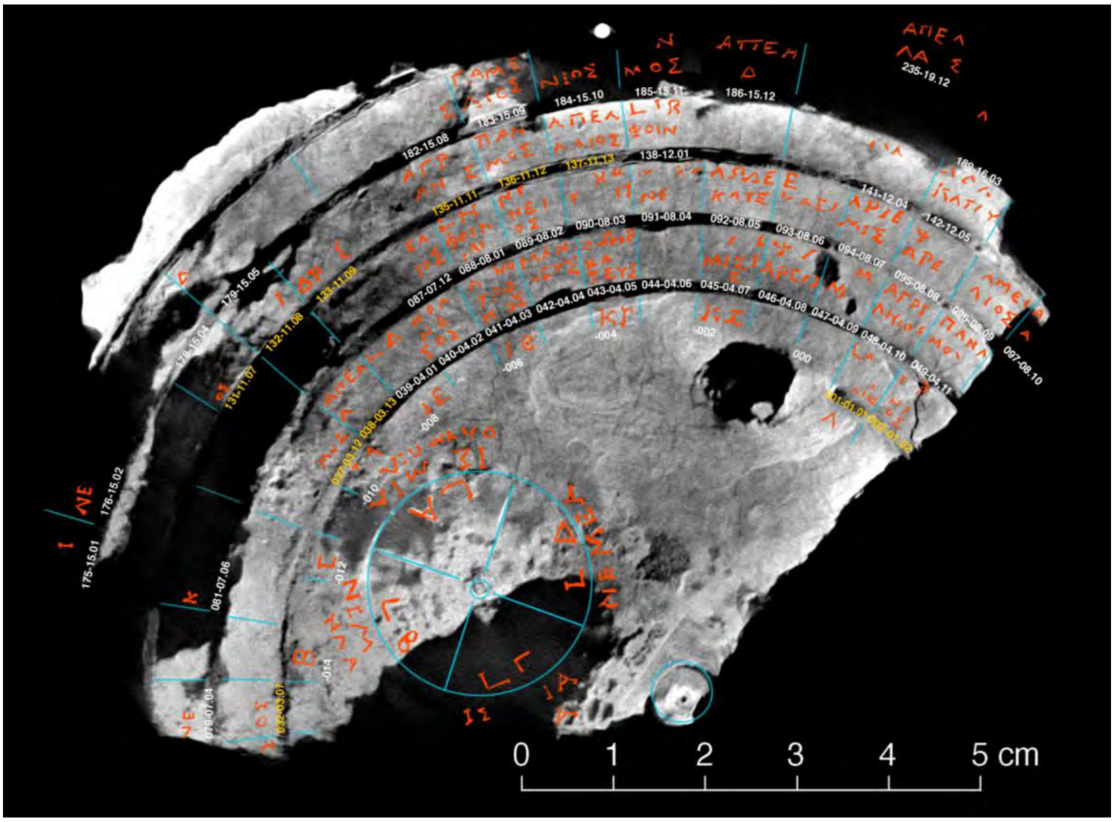
The length of the mean lunar month (29.53 days) can be well approximated in a 235-month calendar by making 125 of these *full* 30-day months and 110 *hollow* 29-day months. 19 12-month years would make 228 months, so 7 years need to contain a thirteenth *intercalary* month in order to make up the 235 months of the 19-year period. Based on these ideas, artificial lunisolar calendars can be devised that as far as possible evenly distribute both the hollow months and the 13-month years over the 19-year period. 125 30-day months and 110 29-day months add up to 6,940 days, which is the period of the Metonic calendar.

In the fourth Century BC, Callippos pointed out that the 6,940 days of the Metonic Calendar implies a year length that is $^{1}/76$ days longer than the length of a year, taken as $365^{1}/4$ days. So he proposed an improvement on the Metonic Calendar, which is based on a 76-year period, consisting of four 19-year Metonic sub-periods minus a day. So the Callippic Calendar has (4 x 6,940) – 1 = 27,759 days.

Supplementary Figure 6 | A CT slice through Fragment B, showing some of the text of the month names.

A proposal that the main upper back dial is a Metonic calendar[1,8] is now well established[6]. The scales of the five-turn Metonic Dial are covered in inscriptions over two or three lines bounded by scale divisions that define each month of the 235-month scale. These inscriptions are identified here for the first time as the months and year starts of the Metonic Calendar and its organization is now understood. It is noteworthy that nearly all the text has been lost where surface material has been removed in the past to reveal the scales.

In order to read as much of the text as possible, sixty CT slices of Fragment B at 70-micron intervals were imported into the layers of a Photoshop file. Where text was hard to decipher, additional 'region-of-interest' image stacks were created at higher resolution and more closely spaced (down to 15 microns). Several hundred CT slices were used for the analysis overall. To help decipher obscure text characters, the CT volumes were also viewed directly in VGStudio Max, where the exact orientation of the slice and its brightness and contrast could be altered to enhance the text.

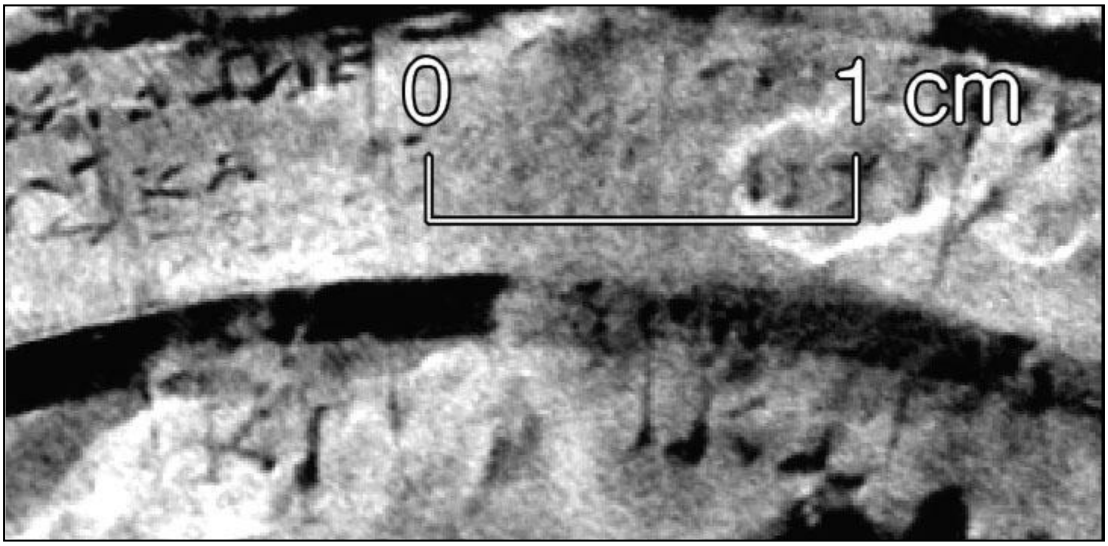


Supplementary Figure 7 | Fragment B X-ray CT with observed text traced in red. The label below each cell indicates its month position in the 235-month scale, followed by its year number and month number within that year. 13-month years have yellow labels.

Very few of the months could be identified from the text deciphered in a single month cell. Knowing the structure of the Metonic calendar enabled the identification of other cells with additional text evidence for the same month. Software improvement by X-Tek Systems in the reconstruction of the X-ray volumes enabled higher resolution and dynamic range. Just enough details of the text characters were finally pieced together to be sure of the identification of all twelve month names.

When complete, the Metonic Spiral had 235 cells, one for each lunar month of a Metonic period, running clockwise and outward from a starting point at the inside bottom of the spiral. We number the cells from 001 through 235. Every cell contained an inscription giving the name of a calendar month, divided over two or three lines. In the cell corresponding to the first month (Phoinikaios) of each of the 19 calendar years, the month name was preceded by the standard L-shaped symbol for *etos* (‘year’) and an alphabetic (‘Ionic’) numeral for the ordinal number of the year, from 1 through 19. Parts of these inscriptions, sometimes complete, sometimes as little as a single letter, have been detected in 49 cells in the surviving portion of the spiral (which is roughly one-third of the whole, centred on the bottom right). Occasionally one of the longer month names appears to have been curtailed by simple omission of the final letters. In our transcription below, which merges the evidence from the various cells, we indicate letters that are visible but not entirely legible in any cell by underdots, and letters that cannot be seen in any of the cells are enclosed in brackets. Question marks designate cells containing traces that are insufficient to guarantee the identity of the month name in that cell.

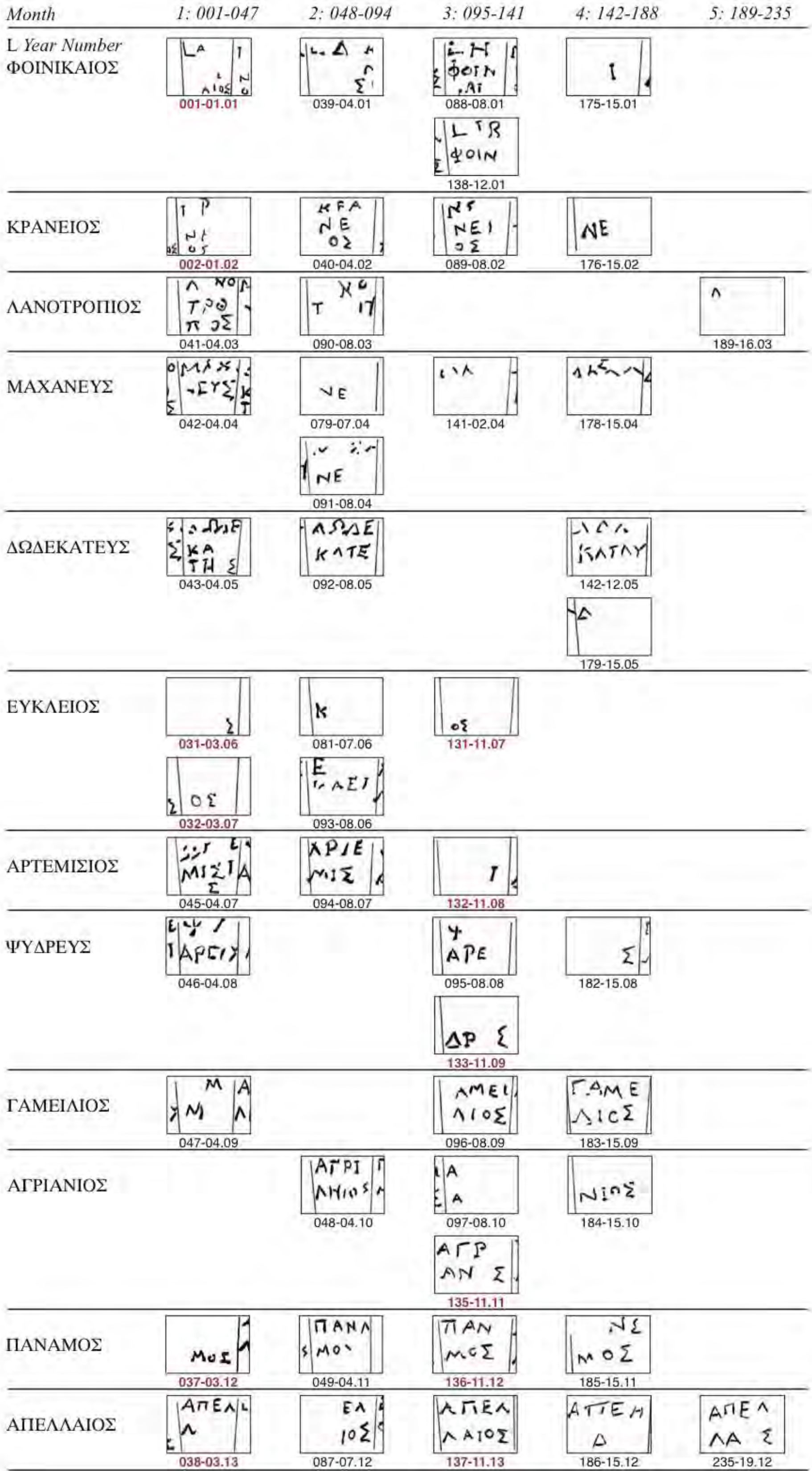
No.	*Transliteration*	*Transcription*	*Surviving Cells*
1.	Phoinikaios	ΦΟΙΝΙ̣Κ̣ΑΙΟΣ	001, 039, 088, 138, 175?
2.	Kraneios	ΚΡΑΝΕΙΟΣ	002, 040, 089, 176
3.	Lanotropios	Λ[Α]ΝΟΤΡΟΠ[Ι]ΟΣ	041, 090, 189?
4.	Machaneus	ΜΑΧΑ̣ΝΕΥΣ	042, 079?, 091, 141, 178
5.	Dodekateus	ΔΩΔΕΚΑΤΕΥ̣Σ	043, 092, 142, 179
6.	Eukleios	Ε[Υ]ΚΛΕΙΟΣ	031?, 032?, 081?, 093, 131?
7.	Artemisios	Α̣ΡΤ̣ΕΜΙΣΙ[Ο]Σ	045, 094, 132?
8.	Psydreus	Ψ[Υ]ΔΡΕΥ̣Σ	046, 095, 133, 182
9.	Gameilios	ΓΑΜΕΙΛΙΟΣ	047, 096, 183
10.	Agrianios	ΑΓΡΙΑΝΙΟΣ	048, 097, 135, 184
11.	Panamos	ΠΑΝΑΜΟΣ	037, 049, 136, 185
12.	Apellaios	ΑΠΕΛΛΑΙΟΣ	038, 087, 137, 186, 235



Supplementary Figure 8 | The numbers ΚΓ (23) and ΚΖ (27) can be seen at the bottom, inscribed inside the spiral scale of the Metonic Calendar. These represent *excluded days*—see 3.3.

Additionally, alphabetic numerals are inscribed below (i.e. inside) some cells of the innermost turn of the spiral: 1 (probably) below cell 1, 2 below cell 33, 6 below cell 35, 11 below cell 37, 15 below cell 39, 19 below cell 41, 23 below cell 43, and 27 below cell 45.

Evidence for the names has been traced from the CT and (in one case) a PTM. The month cells are arranged in five columns for the five turns of the spiral dial. The cell label '088-08.01' means 'Month 088-Year 8.Month 01'. Cell labels in purple are for 13-month years.



Supplementary Figure 9 | The evidence for the names of the months on the Metonic calendar.

3.3 Structure of the Calendar

The study of ancient chronological systems[27,28] and of Greek calendrics in particular[29,16] depends on dispersed literary and archaeological evidence, supplemented by much conjectural reconstruction. The Metonic Spiral is an important new document that illuminates many imperfectly understood aspects of these subjects.

A Metonic cycle specifies which seven of the 19 years have a thirteenth month. In Greek calendars the intercalation was made by repeating one of the twelve regular ones, and the cycle should therefore also determine which of the twelve is repeated in each intercalary year; the intercalated month need not be the last, and could be different in different intercalary years of the cycle. An example of a Metonic cycle of intercalations—in fact the only one from antiquity that is completely known—is the Babylonian calendrical cycle of the last five centuries BC, which had intercalary twelfth months in years 1, 4, 7, 9, 12, and 15, and an intercalary sixth month in year 18[30].

For the calendar of the Mechanism, we can deduce from the inscriptions that two intercalary months fell between cells 2 and 37, one between cells 49 and 87, two between cells 96 and 133, one between cells 142 and 175, and one after cell 189. A good intercalation scheme will spread the intercalary years as evenly as possible, so that the number of years between intercalations will be some rotation of the sequence 2-3-3-2-3-3-3 (as in the Babylonian calendar). Geminos (*Isagoge* 8)[9] expressly states that this kind of distribution was used for Metonic cycles. Since we have found that two intercalations have occurred by the end of year 3, the pattern would have to be either 2-3-3-2-3-3-3 or 2-3-3-3-2-3-3. The latter can be ruled out because it would put the first month of year 12 in cell 137. Hence the intercalations are very likely to have been in years 1, 3, 6, 9, 11, 14, and 17.

Unfortunately, no clear instance of two consecutive cells containing the same month name survives. The intercalary month of year 3 must have been before month 12, and that of year 11 must have been before month 9. A simple hypothesis, among many possible ones, is that the intercalated month was always month 6, in which case cells 31 and 32 would both have contained Eukleios.

In the Babylonian calendar, the length of each month (29 or 30 days) was not determined by its position in the cycle but by direct observation or by an astronomical calculation independent of the cycle[31]. Geminos tells us that the month lengths in Greek Metonic cycles were determined by first assigning each of the 235 months month a nominal thirty days (7,050 days) and then deleting 110 days at intervals of 64 days, resulting in a total of 6,940 days[9] (Supplementary Box 1). (Geminos actually says at intervals of 63 days, because he is not counting the omitted day itself.) Most of these ‘excluded’ (*exairesimoi*) days would fall in the middle of a month, so that for example in one month the day called the ‘9th’ might follow immediately after the ‘7th’, while two months later it would be the ‘13th’ immediately following the ‘11th’. Geminos does not say whether, in a calendar regulated by the Callippic cycle, the deletion of days at 64-day intervals is to run continuously through all 76 years of the cycle or whether it starts afresh with each of the four Metonic cycles making up the Callippic cycle, nor does he explain where an additional day is deleted so that the Callippic cycle will have the requisite 27,759 days instead of the 27,760 that would result from concatenating four Metonic cycles of 6940 days. It has been conjectured[32] that in a Callippic cycle days would have been deleted at uniform 64-day intervals continuously through the 76 years, with one further deletion at the end of the final month of the cycle. Many historians, however, regard Geminos' account of the 'excluded' days as an implausible fiction[15].

Excl.	SPIRAL TURN 1					SPIRAL TURN 2					SPIRAL TURN 3					SPIRAL TURN 4					SPIRAL TURN 5				
	Month	Name	Days	Year	Month	Month	Name	Days	Year	Month	Month	Name	Days	Year	Month	Month	Name	Days	Year	Month	Month	Name	Days	Year	Month
1	001	ΦΟΙΝΙΚΑΙΟΣ	29	01	01	048	ΑΓΡΙΑΝΟΣ	29	04	10	095	ΨΥΔΡΕΥΣ	29	08	08	142	ΔΩΔΕΚΑΤΕΥΣ	29	12	05	189	ΛΑΝΟΤΡΟΠΟΣ	29	16	03
	002	ΚΡΑΝΕΙΟΣ	30	01	02	049	ΠΑΝΑΜΟΣ	30	04	11	096	ΓΑΜΕΙΛΙΟΣ	30	08	09	143	ΕΥΚΛΕΙΟΣ	30	12	06	190	ΜΑΧΑΝΕΥΣ	30	16	04
5	003	ΛΑΝΟΤΡΟΠΙΟΣ	29	01	03	050	ΑΠΕΛΛΑΙΟΣ	29	04	12	097	ΑΓΡΙΑΝΟΣ	29	08	10	144	ΑΡΤΕΜΙΣΙΟΣ	29	12	07	191	ΔΩΔΕΚΑΤΕΥΣ	29	16	05
	004	ΜΑΧΑΝΕΥΣ	30	01	04	051	ΦΟΙΝΙΚΑΙΟΣ	30	05	01	098	ΠΑΝΑΜΟΣ	30	08	11	145	ΨΥΔΡΕΥΣ	30	12	08	192	ΕΥΚΛΕΙΟΣ	30	16	06
9	005	ΔΩΔΕΚΑΤΕΥΣ	29	01	05	052	ΚΡΑΝΕΙΟΣ	29	05	02	099	ΑΠΕΛΛΑΙΟΣ	29	08	12	146	ΓΑΜΕΙΛΙΟΣ	29	12	09	193	ΑΡΤΕΜΙΣΙΟΣ	29	16	07
	006	ΕΥΚΛΕΙΟΣ	30	01	06	053	ΛΑΝΟΤΡΟΠΟΣ	30	05	03	100	ΦΟΙΝΙΚΑΙΟΣ	30	09	01	147	ΑΓΡΙΑΝΟΣ	30	12	10	194	ΨΥΔΡΕΥΣ	30	16	08
13	007	ΕΥΚΛΕΙΟΣ	29	01	07	054	ΜΑΧΑΝΕΥΣ	29	05	04	101	ΚΡΑΝΕΙΟΣ	29	09	02	148	ΠΑΝΑΜΟΣ	29	12	11	195	ΓΑΜΕΙΛΙΟΣ	29	16	09
	008	ΑΡΤΕΜΙΣΙΟΣ	30	01	08	055	ΔΩΔΕΚΑΤΕΥΣ	30	05	05	102	ΛΑΝΟΤΡΟΠΙΟΣ	30	09	03	149	ΑΠΕΛΛΑΙΟΣ	30	12	12	196	ΑΓΡΙΑΝΟΣ	30	16	10
17	009	ΨΥΔΡΕΥΣ	29	01	09	056	ΕΥΚΛΕΙΟΣ	29	05	06	103	ΜΑΧΑΝΕΥΣ	29	09	04	150	ΦΟΙΝΙΚΑΙΟΣ	29	13	01	197	ΠΑΝΑΜΟΣ	29	16	11
	010	ΓΑΜΕΙΛΙΟΣ	30	01	10	057	ΑΡΤΕΜΙΣΙΟΣ	30	05	07	104	ΔΩΔΕΚΑΤΕΥΣ	30	09	05	151	ΚΡΑΝΕΙΟΣ	30	13	02	198	ΑΠΕΛΛΑΙΟΣ	30	16	12
21	011	ΑΓΡΙΑΝΙΟΣ	29	01	11	058	ΨΥΔΡΕΥΣ	29	05	08	105	ΕΥΚΛΕΙΟΣ	29	09	06	152	ΛΑΝΟΤΡΟΠΟΣ	29	13	03	199	ΦΟΙΝΙΚΑΙΟΣ	29	17	01
	012	ΠΑΝΑΜΟΣ	30	01	12	059	ΓΑΜΕΙΛΙΟΣ	30	05	09	106	ΕΥΚΛΕΙΟΣ	30	09	07	153	ΜΑΧΑΝΕΥΣ	30	13	04	200	ΚΡΑΝΕΙΟΣ	30	17	02
26	013	ΑΠΕΛΛΑΙΟΣ	29	01	13	060	ΑΓΡΙΑΝΟΣ	29	05	10	107	ΑΡΤΕΜΙΣΙΟΣ	29	09	08	154	ΔΩΔΕΚΑΤΕΥΣ	29	13	05	201	ΛΑΝΟΤΡΟΠΙΟΣ	29	17	03
	014	ΦΟΙΝΙΚΑΙΟΣ	30	02	01	061	ΠΑΝΑΜΟΣ	30	05	11	108	ΨΥΔΡΕΥΣ	30	09	09	155	ΕΥΚΛΕΙΟΣ	30	13	06	202	ΜΑΧΑΝΕΥΣ	30	17	04
30	015	ΚΡΑΝΕΙΟΣ	29	02	02	062	ΑΠΕΛΛΑΙΟΣ	29	05	12	109	ΓΑΜΕΙΛΙΟΣ	29	09	10	156	ΑΡΤΕΜΙΣΙΟΣ	29	13	07	203	ΔΩΔΕΚΑΤΕΥΣ	29	17	05
	016	ΛΑΝΟΤΡΟΠΟΣ	30	02	03	063	ΦΟΙΝΙΚΑΙΟΣ	30	06	01	110	ΑΓΡΙΑΝΙΟΣ	30	09	11	157	ΨΥΔΡΕΥΣ	30	13	08	204	ΕΥΚΛΕΙΟΣ	30	17	06
	017	ΜΑΧΑΝΕΥΣ	30	02	04	064	ΚΡΑΝΕΙΟΣ	30	06	02	111	ΠΑΝΑΜΟΣ	30	09	12	158	ΓΑΜΕΙΛΙΟΣ	30	13	09	205	ΕΥΚΛΕΙΟΣ	30	17	07
4	018	ΔΩΔΕΚΑΤΕΥΣ	29	02	05	065	ΛΑΝΟΤΡΟΠΙΟΣ	29	06	03	112	ΑΠΕΛΛΑΙΟΣ	29	09	13	159	ΑΓΡΙΑΝΟΣ	29	13	10	206	ΑΡΤΕΜΙΣΙΟΣ	29	17	08
	019	ΕΥΚΛΕΙΟΣ	30	02	06	066	ΜΑΧΑΝΕΥΣ	30	06	04	113	ΦΟΙΝΙΚΑΙΟΣ	30	10	01	160	ΠΑΝΑΜΟΣ	30	13	11	207	ΨΥΔΡΕΥΣ	30	17	09
8	020	ΑΡΤΕΜΙΣΙΟΣ	29	02	07	067	ΔΩΔΕΚΑΤΕΥΣ	29	06	05	114	ΚΡΑΝΕΙΟΣ	29	10	02	161	ΑΠΕΛΛΑΙΟΣ	29	13	12	208	ΓΑΜΕΙΛΙΟΣ	29	17	10
	021	ΨΥΔΡΕΥΣ	30	02	08	068	ΕΥΚΛΕΙΟΣ	30	06	06	115	ΛΑΝΟΤΡΟΠΟΣ	30	10	03	162	ΦΟΙΝΙΚΑΙΟΣ	30	14	01	209	ΑΓΡΙΑΝΙΟΣ	30	17	11
12	022	ΓΑΜΕΙΛΙΟΣ	29	02	09	069	ΕΥΚΛΕΙΟΣ	29	06	07	116	ΜΑΧΑΝΕΥΣ	29	10	04	163	ΚΡΑΝΕΙΟΣ	29	14	02	210	ΠΑΝΑΜΟΣ	29	17	12
	023	ΑΓΡΙΑΝΟΣ	30	02	10	070	ΑΡΤΕΜΙΣΙΟΣ	30	06	08	117	ΔΩΔΕΚΑΤΕΥΣ	30	10	05	164	ΛΑΝΟΤΡΟΠΙΟΣ	30	14	03	211	ΑΠΕΛΛΑΙΟΣ	30	17	13
16	024	ΠΑΝΑΜΟΣ	29	02	11	071	ΨΥΔΡΕΥΣ	29	06	09	118	ΕΥΚΛΕΙΟΣ	29	10	06	165	ΜΑΧΑΝΕΥΣ	29	14	04	212	ΦΟΙΝΙΚΑΙΟΣ	29	18	01
	025	ΑΠΕΛΛΑΙΟΣ	30	02	12	072	ΓΑΜΕΙΛΙΟΣ	30	06	10	119	ΑΡΤΕΜΙΣΙΟΣ	30	10	07	166	ΔΩΔΕΚΑΤΕΥΣ	30	14	05	213	ΚΡΑΝΕΙΟΣ	30	18	02
20	026	ΦΟΙΝΙΚΑΙΟΣ	29	03	01	073	ΑΓΡΙΑΝΙΟΣ	29	06	11	120	ΨΥΔΡΕΥΣ	29	10	08	167	ΕΥΚΛΕΙΟΣ	29	14	06	214	ΛΑΝΟΤΡΟΠΟΣ	29	18	03
	027	ΚΡΑΝΕΙΟΣ	30	03	02	074	ΠΑΝΑΜΟΣ	30	06	12	121	ΓΑΜΕΙΛΙΟΣ	30	10	09	168	ΕΥΚΛΕΙΟΣ	30	14	07	215	ΜΑΧΑΝΕΥΣ	30	18	04
24	028	ΛΑΝΟΤΡΟΠΙΟΣ	29	03	03	075	ΑΠΕΛΛΑΙΟΣ	29	06	13	122	ΑΓΡΙΑΝΟΣ	29	10	10	169	ΑΡΤΕΜΙΣΙΟΣ	29	14	08	216	ΔΩΔΕΚΑΤΕΥΣ	29	18	05
	029	ΜΑΧΑΝΕΥΣ	30	03	04	076	ΦΟΙΝΙΚΑΙΟΣ	30	07	01	123	ΠΑΝΑΜΟΣ	30	10	11	170	ΨΥΔΡΕΥΣ	30	14	09	217	ΕΥΚΛΕΙΟΣ	30	18	06
28	030	ΔΩΔΕΚΑΤΕΥΣ	29	03	05	077	ΚΡΑΝΕΙΟΣ	29	07	02	124	ΑΠΕΛΛΑΙΟΣ	29	10	12	171	ΓΑΜΕΙΛΙΟΣ	29	14	10	218	ΑΡΤΕΜΙΣΙΟΣ	29	18	07
	031	ΕΥΚΛΕΙΟΣ	30	03	06	078	ΛΑΝΟΤΡΟΠΟΣ	30	07	03	125	ΦΟΙΝΙΚΑΙΟΣ	30	11	01	172	ΑΓΡΙΑΝΙΟΣ	30	14	11	219	ΨΥΔΡΕΥΣ	30	18	08
	032	ΕΥΚΛΕΙΟΣ	30	03	07	079	ΜΑΧΑΝΕΥΣ	30	07	04	126	ΚΡΑΝΕΙΟΣ	30	11	02	173	ΠΑΝΑΜΟΣ	30	14	12	220	ΓΑΜΕΙΛΙΟΣ	30	18	09
2	033	ΑΡΤΕΜΙΣΙΟΣ	29	03	08	080	ΔΩΔΕΚΑΤΕΥΣ	29	07	05	127	ΛΑΝΟΤΡΟΠΙΟΣ	29	11	03	174	ΑΠΕΛΛΑΙΟΣ	29	14	13	221	ΑΓΡΙΑΝΟΣ	29	18	10
	034	ΨΥΔΡΕΥΣ	30	03	09	081	ΕΥΚΛΕΙΟΣ	30	07	06	128	ΜΑΧΑΝΕΥΣ	30	11	04	175	ΦΟΙΝΙΚΑΙΟΣ	30	15	01	222	ΠΑΝΑΜΟΣ	30	18	11
6	035	ΓΑΜΕΙΛΙΟΣ	29	03	10	082	ΑΡΤΕΜΙΣΙΟΣ	29	07	07	129	ΔΩΔΕΚΑΤΕΥΣ	29	11	05	176	ΚΡΑΝΕΙΟΣ	29	15	02	223	ΑΠΕΛΛΑΙΟΣ	29	18	12
	036	ΑΓΡΙΑΝΙΟΣ	30	03	11	083	ΨΥΔΡΕΥΣ	30	07	08	130	ΕΥΚΛΕΙΟΣ	30	11	06	177	ΛΑΝΟΤΡΟΠΟΣ	30	15	03	224	ΦΟΙΝΙΚΑΙΟΣ	30	19	01
11	037	ΠΑΝΑΜΟΣ	29	03	12	084	ΓΑΜΕΙΛΙΟΣ	29	07	09	131	ΕΥΚΛΕΙΟΣ	29	11	07	178	ΜΑΧΑΝΕΥΣ	29	15	04	225	ΚΡΑΝΕΙΟΣ	29	19	02
	038	ΑΠΕΛΛΑΙΟΣ	30	03	13	085	ΑΓΡΙΑΝΟΣ	30	07	10	132	ΑΡΤΕΜΙΣΙΟΣ	30	11	08	179	ΔΩΔΕΚΑΤΕΥΣ	30	15	05	226	ΛΑΝΟΤΡΟΠΟΣ	30	19	03
15	039	ΦΟΙΝΙΚΑΙΟΣ	29	04	01	086	ΠΑΝΑΜΟΣ	29	07	11	133	ΨΥΔΡΕΥΣ	29	11	09	180	ΕΥΚΛΕΙΟΣ	29	15	06	227	ΜΑΧΑΝΕΥΣ	29	19	04
	040	ΚΡΑΝΕΙΟΣ	30	04	02	087	ΑΠΕΛΛΑΙΟΣ	30	07	12	134	ΓΑΜΕΙΛΙΟΣ	30	11	10	181	ΑΡΤΕΜΙΣΙΟΣ	30	15	07	228	ΔΩΔΕΚΑΤΕΥΣ	30	19	05
19	041	ΛΑΝΟΤΡΟΠΟΣ	29	04	03	088	ΦΟΙΝΙΚΑΙΟΣ	29	08	01	135	ΑΓΡΙΑΝΙΟΣ	29	11	11	182	ΨΥΔΡΕΥΣ	29	15	08	229	ΕΥΚΛΕΙΟΣ	29	19	06
	042	ΜΑΧΑΝΕΥΣ	30	04	04	089	ΚΡΑΝΕΙΟΣ	30	08	02	136	ΠΑΝΑΜΟΣ	30	11	12	183	ΓΑΜΕΙΛΙΟΣ	30	15	09	230	ΑΡΤΕΜΙΣΙΟΣ	30	19	07
23	043	ΔΩΔΕΚΑΤΕΥΣ	29	04	05	090	ΛΑΝΟΤΡΟΠΟΣ	29	08	03	137	ΑΠΕΛΛΑΙΟΣ	29	11	13	184	ΑΓΡΙΑΝΟΣ	29	15	10	231	ΨΥΔΡΕΥΣ	29	19	08
	044	ΕΥΚΛΕΙΟΣ	30	04	06	091	ΜΑΧΑΝΕΥΣ	30	08	04	138	ΦΟΙΝΙΚΑΙΟΣ	30	12	01	185	ΠΑΝΑΜΟΣ	30	15	11	232	ΓΑΜΕΙΛΙΟΣ	30	19	09
27	045	ΑΡΤΕΜΙΣΙΟΣ	29	04	07	092	ΔΩΔΕΚΑΤΕΥΣ	29	08	05	139	ΚΡΑΝΕΙΟΣ	29	12	02	186	ΑΠΕΛΛΑΙΟΣ	29	15	12	233	ΑΓΡΙΑΝΟΣ	29	19	10
	046	ΨΥΔΡΕΥΣ	30	04	08	093	ΕΥΚΛΕΙΟΣ	30	08	06	140	ΛΑΝΟΤΡΟΠΟΣ	30	12	03	187	ΦΟΙΝΙΚΑΙΟΣ	30	16	01	234	ΠΑΝΑΜΟΣ	30	19	11
	047	ΓΑΜΕΙΛΙΟΣ	30	04	09	094	ΑΡΤΕΜΙΣΙΟΣ	30	08	07	141	ΜΑΧΑΝΕΥΣ	30	12	04	188	ΚΡΑΝΕΙΟΣ	30	16	02	235	ΑΠΕΛΛΑΙΟΣ	30	19	12

Supplementary Figure 10 | Proposed structure of the Metonic Calendar. All months have 30 days, except those with *excluded days*, which have 29 days. On the far left are the *excluded days*, with those in red being observed in Fragment B. The *excluded day* is taken out of each month across all five turns of the spiral—in other words all months on the same horizontal line in the diagram. All the gaps between *excluded days* are 64 days, except those indicated by the blue boxes, which are 65 days. 13-month years are in purple. In the Antikythera Mechanism, chaining successive Metonic periods together maintains the regularity of the *excluded days* scheme, whereas Geminos' scheme is left with an irregular 74-day gap at the boundaries between Metonic periods. This is one possible scheme amongst several with different distributions of the 13-month years and different repetitions of months in these years.

The scheme of the Antikythera Mechanism is designed fundamentally with the Metonic rather than the Callippic cycle in mind, and agrees with Geminos in achieving a distribution of 30-day and 29-day months by skipping over days at different stages in the middle of nominally 30-day months, but not invariably at 64-day intervals. If 110 days are 'excluded' at 64-day intervals, the last omitted day of the cycle will be 74, not 64, days before the first omitted day of the following cycle. On the Mechanism, this discontinuity is smoothed out by lengthening ten of the intervals to 65 days. The Metonic cycle thus naturally divides into five sub-cycles of 47 months, in each of which the 65-day intervals come approximately ¼ and ¾ of the way through the sub-cycle. This accounts for the fact that the Metonic spiral has five turns, each turn representing one 47-month sub-cycle and having the identical distribution of omitted days, which are indicated by numerals written on the inside of the first turn (Figure 1, Supplementary Figure 8). The first omitted day, surprisingly, is the first day of the first month of the sub-cycle. This means that there would be no New Year's Day in this year!

If, as we believe, the calendar displayed on the Mechanism was meant to be regulated in the longer term according to the Callippic cycle, one more day would have to be skipped in every fourth Metonic cycle. This might have been the last day of the last month of the fourth cycle, in which event the day count would have proceeded directly from the 29th of the final month (Apellaios) of the Callippic cycle to the 2nd day of the first month (Phoinikaios) of the next cycle.

It clearly would have been difficult to exclude days in a lunar month if there was no easy means on the Mechanism of counting them—so a display of the days of the lunar month seems essential. It is evident that this cannot be done on the back dials since the pointers rotate too slowly for the inclusion of days on the scales. However a previous suggestion was made that this could be done in conjunction with the Moon Phase mechanism on the Front Dials[5]. In this proposal the differential movement of the Sun and Moon pointers shows the days of the lunar month, which are indicated on a scale of days attached to the Sun pointer—the angle between the Sun and Moon pointers being the elongation of the Moon from the Sun. A modification of this idea is to attach the scale of days to the Moon pointer with the day indicated on the scale by the Sun pointer. This could neatly explain the cylindrical feature of the Moon Phase mechanism, which could easily have been inscribed with a scale, since it appears to be redundant otherwise. However, we have not as yet found any evidence for this in the CT, possibly because the cylinder is covered in corrosion.

3.4 The Calendar's Provenance

The calendars of the Greek cities were always lunisolar, having twelve named months and a calendar year that was kept at a more or less fixed stage of the natural year by means of intercalary months. The actual month names and the alignment of the calendar year with the seasons varied from city to city, though often exhibiting family resemblances that usually reflect a shared ethnic background or a closer historical relationship; for example, cities founded by colonists from another city would normally retain or adapt the calendar of their ancestors. Our knowledge of the calendars of most cities is heavily dependent on dates in inscriptions. It is rare that we know all twelve month names, sometimes just one or two, and direct evidence for the sequence of months and their seasonal alignment is still rarer. Thus we know more details of the calendar of the Mechanism than we do for almost any Greek calendar except that of Athens.

Two month names of the Mechanism's calendar, Artemisios and Panamos, are found, in various orthographical forms, in numerous regional calendars belonging to more than one of the broadest ethnically-based groupings of calendars, especially the Ionian group and the Western Greek (Dorian and northwestern Greek) group. Their chief value for us is that they appear to have had strong seasonal associations, with Artemisios and its variants falling in spring and Panamos and its variants in late spring or summer. This would imply that the beginning of the Mechanism's calendar, six months before Artemisios and ten months before Panamos, was late summer or early autumn.

Others of the Mechanism's months are characteristic of calendars of the Western Greek group and of its Dorian subgroup, though most Dorian calendars shared only a minority of months with the Mechanism. For example, all twelve months of the calendar of Rhodes are known, and the only ones shared with the Mechanism—allowing for orthographical variation—are Karneios (Kraneios), Agrianios, Artamitios (Artemisios), and Panamos. Similar considerations rule out identifying the Mechanism's calendar with other Dorian calendars of the Dodecanese and southwestern Asia Minor, Crete, and the Peloponnese.

Map prepared by M. Anastasiou, Aristotle University of Thessaloniki

Supplementary Figure 11 | Map of distribution of the Antikythera month names.

(a) Blue markers for places with a version of at least one of Artemisios/Artemitios, Apellaios, Panamos but none of (b) and (c).

(b) Green markers for places with at least one of Karneios/Kraneios, Machaneus, Eukleios, Gamilios, Agrianos but none of (c).

(c) Red markers for places with at least one of Phoinikaios, Lanotropios/Lanotros, Dodekateus/Dyodekateus, Psydreus.

A larger typeface has been used for place names with particular relevance to the text.

The division of the months in the three categories is based on the following:

1. Arte/amit/sios, Apellaios and Panamos are very common months among the calendars of the ancient Greek cities, widely spread out also at Ionic regions where they were known as Artemision, Apellaion, Panemos.

2. Karneios/Kraneios, Machaneus/Machaneios, Eukleios, Gamilios, Agrianios/Agrionios are months known only from Dorian and northwestern calendars. Some of them are quite common.

3. Phoinikaios, Lanotropios/Lanotros, Dodekateus/Dyodekateus, Psydreus are four months known only from the calendars of Tauromenion, Corinth, Corinthian colonies and other cities that adopted part or all of the Corinthian calendar.

A Dorian calendar recently reconstructed from inscriptional evidence[33,16] was evidently shared by several cities of southern Illyria, Epirus, and Corcyra (these cities now being within southern Albania, northwestern mainland Greece and Corfu); for brevity we shall refer to this as the *Epirote calendar*. The months of this calendar include ten that are also found on the Mechanism: (in alphabetic order) Agrianios, Apellaios, Artemisios, Gamilios, Eukleios, Kraneios, Machaneus, Panamos, Phoinikaios, and Psydreus. In fact an eleventh match can be found with a month Deudekatos or Dyodekatos attested in two inscriptions (*I.Apollonia* 385 and *IG* IX.1 694) but not previously recognized as a month name. A single month of the Epirote calendar (Alotropios, editorially adjusted to Haliotropios) appears to differ from the Lanotropios of the Mechanism, though the names have obvious graphical resemblance. (Two further months hitherto proposed for the Epirote calendar, Datyios and Heraios, rest on doubtful evidence and probably do not belong.) Matches for eleven of the twelve months, and a near match for the remaining one, with the

Mechanism's calendar confirm the validity of the hypothesis of a common calendar for the cities of this district, as well as establishing the order of the months and probably the beginning of the year, with Phoinikaios in early autumn.

It might also appear that we have identified a provenance of the Mechanism in this district; but such a conclusion would be premature. The cities that shared the Epirote calendar either traced their origins, directly or indirectly, to colonizations from Corinth in the seventh and sixth centuries BC, or were in close cultural contact with the Corinthian colonies. Hence we should consider whether their calendar was the calendar of Corinth. Unfortunately the evidence for the months of the Corinthian calendar is extremely sparse, though so far as it goes it is consistent with the Epirote calendar: an attestation of a month Phoinik[aios] in a Corinthian inscription, and a reference to a Corinthian month Panemos (probably an Ionic representation of Panamos) in a speech of Demosthenes (Speech 18, 157). The Corinthian Phoinikaios is in fact the only attestation of this month name other than in the Epirote calendar and, now, the Mechanism. One further item of information comes from Demosthenes, that Corinthian Panemos was equivalent (in 339 BC) to the Athenian month Boedromion, which normally began with the third new Moon after summer solstice, thus late August or September. If the Panamos of the Mechanism's calendar normally had this position, its year would have begun in mid autumn, somewhat later than our other evidence suggests.

Strong confirmation that the Mechanism's calendar is identical, or nearly so, to the Corinthian calendar comes from the calendar of Tauromenion (modern Taormina) in Sicily[16]. Inscriptions supply us not only with eleven of the twelve month names, but also their sequence, though not which one marked the beginning of the year. In the following comparison, we choose a starting point that brings out the relation to the Mechanism's calendar most clearly:

	Tauromenion	*Mechanism*
1.	Itonios	Phoinikaios
2.	**Karneios**	**Kraneios**
3.	**Lanotr[opios]**	**Lanotropios**
4.	Apollonios	Machaneus
5.	**Dyodekateus**	**Dodekateus**
6.	**Eukleios**	**Eukleios**
7.	**Artem[isios]**	**Artemisios**
8.	Dionysios	Psydreus
9.	(unknown)	Gameilios
10.	Damatrios	Agrianios
11.	**Panamos**	**Panamos**
12.	**Apellaios**	**Apellaios**

The two calendars have a remarkable relationship. Seven of their months match not only in name but also in their relative positions in the sequence, and these include the uncommon Eukleios and the exceedingly rare Lanotropios and Dodekateus. The remaining four known months of the Tauromenian calendar are completely different from their counterparts in the Mechanism's calendar. They can be found in other localities; for example Dionysios and Damatrios are both attested for Locri Epizephyrii (modern Locri, south Italy) and Itonios and Apollonios for Thessaly.

The explanation of this relationship must be situated in the history of Tauromenion, which was originally a settlement of indigenous Sicels but in 392 BC was settled by the tyrant Dionysius of Syracuse with his Greek mercenaries. The Tauromenian calendar is likely to have been adopted at the time of this refoundation. Where Dionysius' mercenaries were from is unknown, but the composition of the calendar suggests a fusion of elements from several distinct regional calendars, with the Corinthian calendar providing the structural framework as well as the majority of the month names. While the possibility cannot be ruled out that this framework is to be ascribed to the presence of soldiers from Corinth or the Corinthian colonies of northwestern Greece (or, less plausibly, to Corinthian influence at the time of the Sicilian campaigns of Timoleon of Corinth in 344-338), the most likely source for it would seem to be Syracuse itself, since Syracuse had been founded as a Corinthian colony in the eighth century and hence is likely to have retained the Corinthian calendar.

The testimony for the Syracusan calendar is regrettably slight; such as it is, it offers obstacles to equating the Syracusan with the Corinthian calendar. First, a month name beginning 'Apo-' appears to be attested in a single inscription; this has been restored conjecturally as Apollonios, a month name found in the Tauromenian calendar but not in the Corinthian. Not much weight can be assigned to this doubtful reading. Secondly, Plutarch (*Nicias* 28) refers to a Syracusan Karneios, which was in the Corinthian calendar. But Plutarch equates this month with the second month of the Athenian calendar and not, as we would expect from the above discussion, with the fourth Athenian month, Pyanopsion. Perhaps Plutarch simply assumed that the Syracusan year began at the same time of year as the Athenian, but the inconsistency is unsettling.

To sum up the argument so far, the calendar of the Mechanism can be identified with certainty as a version of the calendar used in the Corinthian colonies of northwestern Greece, which was very probably the same as the calendar of Corinth itself and, with somewhat diminished probability, the calendar of Syracuse. Unlike the Athenian calendar (or for that matter the Egyptian calendar in its Greek-language adaptation), this calendar was of purely local significance and would almost certainly not have been used as a special 'astronomical' chronological framework. Its presence on the Metonic dial thus connects the Mechanism with one of three districts: Corinth and its immediate vicinity, and the two regions where Corinth founded colonies that were still in existence in the later Hellenistic period, namely northwestern Greece and Sicily. There can be no doubt that the Mechanism was intended to be used in one of these places. It cannot be proved that the Mechanism was actually built there, but the inscriptions, as well as the initial setting of the gearwork and pointers, must have been executed by someone who had very full information about the details of this calendar.

It also is difficult to avoid the conclusion that the way that the calendar is structured on the Mechanism, including the details of the Metonic intercalary cycle and the specification of 'excluded' days, reflects the local practices of the time, since otherwise the information displayed on the Mechanism would have frequently been in conflict with reality. This is a result of considerable importance for our understanding of Greek calendrics, since it provides strong backing for Geminos' claim that the Greek civil calendars of his time were strictly regulated according to cycles that fixed precisely the placement of intercalary months and the pattern of 29-day and 30-day months.

Lastly, we ask whether any considerations favour one or another of the three districts we have identified as candidates for the intended place of use of the Mechanism. For this question, the date of the Mechanism's construction is crucial. The current best estimate, based on the letter forms of the inscriptions, is that the Mechanism was made during the second half of the second century BC, but a slightly earlier or later date cannot be excluded (the Antikythera shipwreck is believed to have occurred during the first half of the first century BC). It is hard to think of likely centres of production in northwestern Greece for a technological and scientific artifact like the Mechanism—or patrons likely to have commissioned one—during the second century, especially after the devastation of the region at the hands of the Romans following the Third Macedonian War (171-168). Corinth, on the other hand, was a prosperous and powerful city through the first half of the century, but was destroyed by the Romans in 146 and only refounded a century later. Hence for most of the period within which the Mechanism appears to have been made, the only place likely to have used the Mechanism's calendar *and* likely to have enjoyed the economic and cultural prosperity that could have given rise to the Mechanism is Syracuse, which at this time was capital of the rich Roman province of Sicily.

A Syracusan provenance for the Mechanism—which, we must stress, is far from certain—might suggest that it was the product of a local tradition of manufacture of astronomical mechanisms originating with the Syracusan mathematician Archimedes in the third century BC. Archimedes was identified long ago in the classic research[1] as the probable initiator of the tradition of gearwork technology for displaying astronomical information of which the Mechanism might be a much later representative—appealing to the descriptions of Archimedes' astronomical 'spheres', and especially the description by Cicero (*De Re Publica* 1.21-22)[17]:

> *… I remember an incident in the life of Gaius Sulpicius Gallus… he happened to be at the house of Marcus Marcellus, his colleague in the consulship (166 BC), he ordered the celestial globe to be brought out which the grandfather of Marcellus had carried off from Syracuse, when that very rich and beautiful city was taken (212 BC), though he took home with him nothing else out of the great store of booty captured… I had heard this globe mentioned quite frequently on account of the fame of Archimedes… I concluded that the famous Sicilian had been endowed with greater genius than one would imagine it possible for a human being to possess… this newer kind of globe, he said, on which were delineated the motions of the Sun and Moon and of those five stars which are called wanderers, or, as we might say, rovers, (i.e., the five planets) contained more than could be shown on the solid globe, and the invention of Archimedes deserved special admiration because he had thought out a way to represent accurately by a single device for turning the globe those various and divergent movements with their different rates of speed. And when Gallus moved the globe, it was actually true that the Moon was always as many revolutions behind the Sun on the bronze contrivance as would agree with the number of days it was behind it in the sky. Thus the same eclipse of the Sun happened on the globe as it would actually happen…*

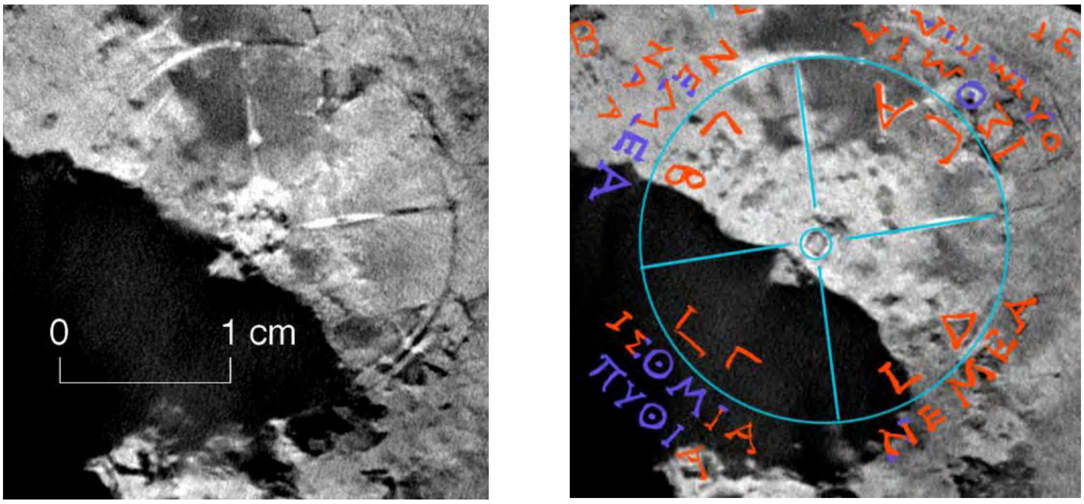
However, the classic research[1] did not propose a more direct geographical link with Archimedes, preferring to locate the Mechanism's place of origin in Rhodes. While

Archimedes had the astronomical, mathematical, and mechanical expertise to design mechanisms reflecting the astronomical theories of his time, his designs would likely have been executed by a workshop, and such a workshop could well have continued to make similar devices after Archimedes' death in 212 BC, revising and augmenting the design in the light of more recent astronomical theory. The basic astronomical principles and period relations of the calendrical and eclipse displays of the Antikythera Mechanism could well have been known to Archimedes and expressed in his 'sphere'. However, models for explaining variation in the apparent speed of the heavenly bodies by epicycles or eccentric circles, such as underlie the lunar anomaly gearwork of the Mechanism, have not been found in Greek astronomy before the second century BC and so were almost certainly later than Archimedes.

3.5 The Olympiad Dial

The Olympiad Dial (formerly identified as a Callippic Period Dial) is divided into four equal quadrants by two perpendicular diameters, which are inclined approximately 8° counter-clockwise from due horizontal and vertical. Inside the circular rim of the dial are year numbers written with the L-shaped symbol for the word *etos* (‘year’) followed by an alphabetic numeral, running from alpha (1) in the lower right quadrant counter-clockwise through delta (4) in the lower left quadrant. This is, so far as we know, the only display on the Mechanism that had a pointer revolving counter-clockwise.

a **b**



Supplementary Figure 12 | a, CT slice showing the Olympiad Dial. b, Inscriptions that have been traced from the CT slices are in red; those that have been reconstructed are in blue. Traces of text below NEMEA in sector LΔ have not yet been deciphered.

Outside the rim, in the same orientation (i.e. with the tops of the letters towards the centre of the dial), each quadrant is labelled in slightly smaller letters with two or three single-word inscriptions. Each word is approximately centred below the year number indication, with the exception of the last line for Year 1, which is constrained to be written to the left of centre by the proximity of the inscriptions for the ‘excluded’ days inside the Metonic Spiral. The Olympiad Dial inscriptions can be transcribed and translated in tabular format as follows (restored readings are in brackets):

L A	L B	L Γ	L Δ
ΙΣ[Θ]ΜΙΑ	ΝΕΜ[ΕΑ]	ΙΣ[ΘΜ]ΙΑ	ΝΕΜΕΑ
ΟΛΥΜΠΙΑ	ΝΑΑ	[ΠΥΘΙ]Α	*traces*
			traces?
Year 1	Year 2	Year 3	Year 4
Isthmians	Nemeans	Isthmians	Nemeans
Olympics	Naa	Pythians	*traces*
			traces?

Leaving aside ‘Naa’ and the so-far unread text for Year 4, the inscriptions are obviously references to the four famous athletic competitions known as ‘panhellenic games’ (because open to all Greeks) or ‘crown games’ (because the prizes for victors were crown wreaths)[20]. These were the Olympic games, held every four years at Olympia; the Pythian games, held every four years at Delphi; the Nemean games, held every two years at Nemea; and the Isthmian games, held every two years at Corinth. The panhellenic games were events of enormous cultural importance for the Greeks. They were associated with religious festivals at important cult sites, and they featured prominently in the diplomatic contacts between cities. Participation and victory in the games enhanced the prestige of wealthy citizens[34].

Since each competition was held regularly at four-year or two-year intervals, it was conventional to refer them to a four-year Olympiad cycle such that Year 1 was the year of the Olympic games, traditionally believed to be the oldest and most venerable of the competitions. Ancient chronologers and historians used the Olympiads as a framework for dating events, counting them from the traditional date of the first Olympic games in 776 BC. For such purposes it was normal practice to coordinate the Olympiads with Athenian calendar years, which began with the first new Moon after the summer solstice. It is clear from the following comparison that the years of the Olympiad Dial had a different starting point, such that games taking place in the spring were counted as being in the same year as the following summer, not the preceding summer:

Athenian year	*Olympiad dial*	*Approximate season*	*Competition*
1	1	late Summer	Olympics
2	2	early Summer	Nemeans
2	3	Spring	Isthmians
3	3	late Summer	Pythians
4	4	early Summer	Nemeans
4	1	Spring	Isthmians

Also apparent is that for each sector of the dial, the inscriptions proceed outwards in the temporal order in which the competitions took place.

In addition to the six panhellenic competitions held in an Olympiad, the Olympiad Dial inscriptions include at least one further competition, the Naa (or Naia) held at Dodona[21]. This was one of a number of competitions that claimed panhellenic status during the Hellenistic period. Hitherto neither the frequency of the Naa nor its position in the Olympiad cycle has been known, although an inscription from Dodona informs us that it took place during the month Apellaios. As we have shown, the calendar of Dodona, like that of the Mechanism's Metonic Spiral, was the Corinthian calendar, and Apellaios was the last month of this calendar's year, normally beginning with the last new Moon before the autumnal equinox. We are now in a position to add that at the time of the Mechanism's manufacture the Naa took place at four-year intervals at the end of summer of the second year of the Olympiad cycle, following the Nemean games.

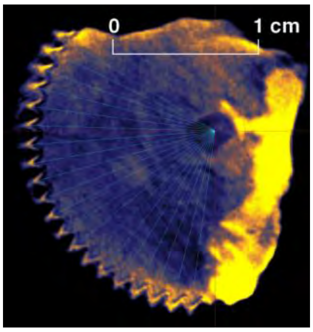
The traces under Year 4 probably belong to the names of one or two as yet unidentified athletic competitions. Their position implies that they took place in the late summer of the fourth cycle year, following the Nemean games. It is tempting to draw a connection between the facts that the one competition so far identified on the dial beyond the universally recognized panhellenic cycle was at Dodona and that Dodona was within the region of northwestern Greece where the Corinthian calendar of the Metonic Spiral was in use. At the least, the Naa would appear most likely to have been an event of importance for Greeks living in the parts of the Mediterranean west of the Aegean Sea.

The 8° tilt of the divisions of the dial (representing a month) can be explained as follows. We propose that the years of the dial were intended to represent the same Corinthian calendar years as were displayed on the Metonic Spiral. However, by its nature the dial could not reflect the variable length of the lunisolar years, but must approximate them as solar years of constant length. We also hypothesize that the Mechanism was initially set up so that when the Metonic Spiral's pointer was at the beginning of year 1 of the Metonic cycle, hence pointing straight down, the Olympiad Dial's pointer was also pointing straight down. Because the Metonic cycle's intercalations were apparently arranged so that Year 1 had the earliest beginning relative to the solar year of any of the 19 years of the Metonic cycle, at the beginning of any other year of the Metonic cycle the Olympiad dial pointer would not be oriented precisely vertical or horizontal, but up to a month's worth of motion further in the counter-clockwise direction, i.e. up to almost 8°. Consequently the date of an athletic festival such as the Naa that took place in the last calendar month would often correspond to a pointer direction a bit counter-clockwise of horizontal or vertical. The offset of the sector divisions of the dial appears to have been intended so that the pointer would never indicate the wrong year during the part of the year when panhellenic competitions took place, roughly the last half of the year (coinciding with the Mediterranean sailing season).

We have recognized that the four-year Olympiad Dial would also have enabled the user to know when to move the Egyptian calendar scale backwards by a day to make leap year adjustments.

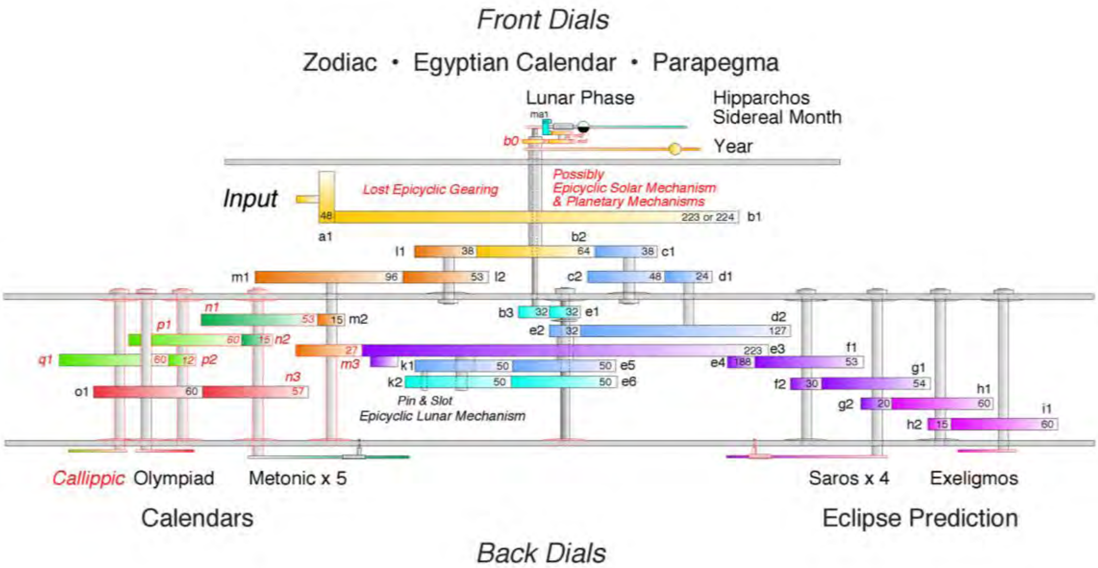
The discovery of a dial displaying cycles of four solar years does not radically alter our understanding of the Mechanism as an artifact of ancient gearwork, but, together with the identification of the Metonic Spiral's calendar, it has deep significance for any interpretation of the Mechanism's purpose. Hitherto it has been possible to see the Mechanism as a device of pure astronomy, exhibiting longitudes of heavenly bodies on the front dial, eclipse predictions on the lower back display, and a calendrical cycle believed to be strictly in the use of astronomers on the upper back display. Now we find that the upper back display was entirely devoted to matters of social, not scientific, interest: a local civil calendar, and a cycle of athletic competitions associated with religious festivals. Since one does not need a piece of high technology to keep track of a simple four-year cycle, the point of the Olympiad Dial is not the specific predictions that it makes, but the correlation of the cycles of human institutions with the celestial cycles on the other parts of the Mechanism. It is perhaps not extravagant to see the Mechanism as a microcosm illustrating the temporal harmonization of human and divine order.

3.6 Gearing for the Olympiad Dial



Supplementary Figure 13 | CT in false colour of Fragment B, showing gear o1, which is now understood to drive the Olympiad pointer. Statistics establish beyond reasonable doubt that it had 60 teeth.

The question of how this dial was driven from the rest of the gearing can now be answered. Underneath the Olympiad Dial, there are the partial remains of gear **o1** with 60 teeth. It has an estimated pitch radius of 12.5 mm.



Supplementary Figure 14 | Revised schematic Gearing Diagram of the Antikythera Mechanism. Elements labelled in black are directly supported by evidence, whereas elements in red are hypothetical. The revisions in this diagram compared with the previously published model[6] are the addition of the 57-tooth gear *n3* to drive the Olympiad Dial and the mirror image of the previously proposed gearing[4] to drive the hypothetical Callippic Dial.

The Metonic pointer rotates on axis **n** at - $^{5}/_{19}$ rotations per year (the minus sign indicating that its rotation is clockwise on the back of the Mechanism). A single additional gear on this axis, ***n3***, which has 57 teeth and engages with **o1,** would turn at a rate of - $^{5}/_{19}$ x - $^{57}/_{60}$ = ¼ rotations per year, which is exactly what we want for the four-year Olympiad Dial. The positive sign means anticlockwise rotation and this explains why the dial sectors are inscribed in an anticlockwise direction—in order to make the gearing of the dial as simple as possible. This is another example of the economy of design of the gearing system of the Antikythera Mechanism. The estimated pitch radius of a gear with 57 teeth and the same tooth pitch as gear **o1** is 11.9 mm. The interaxial distance between axes **n** and **o** is 24.4 mm—exactly the *sum* of the estimated pitch radii of gears **o1** and ***n3*** (though ***n3*** might have been made slightly smaller to avoid binding of the gears). These dimensions add strong support both to the hypothetical gear ***n3*** and to the identification of the Olympiad Dial.

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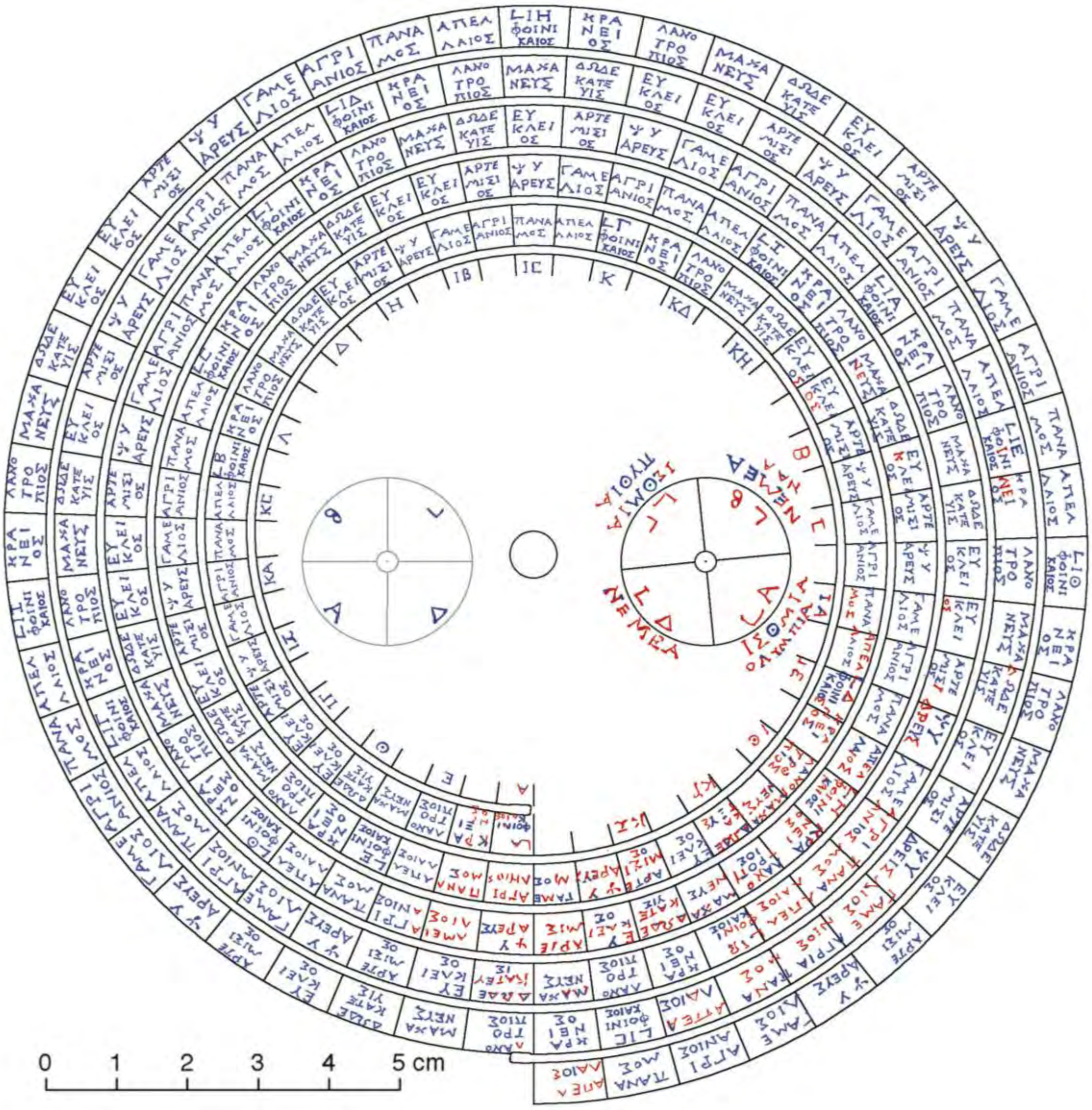
3.7 The Callippic Dial

The Olympiad Dial was previously thought to be a 76-year Callippic Dial[8]. This was considered plausible for a number of reasons. There is an inscription on Fragment 19 (see Main Text, Figure 2), which reads *'…76 years…'*, which is part of a larger inscription that describes the functions of the Back Dials. The dial is divided into four sectors: as a Callippic Dial it would enable the counting of years on the Back Dials beyond those on the Metonic Dial, which only run from 1 to 19. The inclusion of the 54-year Exeligmos Dial clearly signals that the intended use of the Mechanism was for longer time-scales than 19 years. We therefore favour a second subsidiary dial inside the Metonic Dial and placed symmetrically to the Olympiad Dial, driven by the mirror image of the gearing originally proposed for this dial[8] (Supplementary Figure 14).

3.8 Reconstruction of the Upper Back Dials

A reconstruction of the upper back dials can now be made, though there are options for the years with 13 months and which months are doubled in these years. Also the text outside *NEMEA* in sector LΔ of the Olympiad Dial has not yet been resolved.



Supplementary Figure 15 | A reconstruction of the upper back dials of the Antikythera Mechanism. Text in red is traced from the evidence and in blue is reconstructed.

4. Saros & Exeligmos Dials

4.1 The Saros Dial & the Glyphs

Supplementary Box 2 | Saros, Exeligmos and Full Moon Cycles

The Moon's orbit is inclined to the Earth's orbit, so Sun, Moon and Earth do not always line up well enough every month for an eclipse. The two points where the Moon's orbit meets the plane of the Earth's orbit (the ecliptic) are the *lunar nodes*. The passage of the Moon from a node back to the same node is the *draconitic month* (27.21 days). As observed from Earth, the Moon's angular velocity varies through the *anomalistic month* (27.55 days).

The term *syzygy* is a collective noun for *New Moon* and *Full Moon*. Eclipses occur when a syzygy is sufficiently close to a node. Lunar eclipses occur at Full Moon and are visible over almost half the globe, whereas solar eclipses occur at New Moon and have limited geographical visibility. Eclipse prediction cycles rely on the coincidence of an integer number of synodic months with an integer number of draconitic months. Known from at least the 6^{th} Century BC, the *Saros Cycle* is an eclipse prediction cycle of 223 lunar months—just over 18 years—that predicts repeating eclipses over many centuries. The Saros period is also close to an integer number of anomalistic months, which means that repeating eclipses have similar characteristics. In numerical terms the *Saros Cycle* is: *223 synodic months = 242 draconitic months = 239 anomalistic months*. The *Saros Cycle* is the second of the two astronomical cycles that are the basis for nearly all the known gearing in the Mechanism. It is a period of about $6{,}585^1/3$ days. The $^1/3$ day means that the repeat eclipse after 223 lunar months is shifted by about 8 hours in time and, for solar eclipses (where geographical visibility is limited) by about 120° in longitude. The *Exeligmos Cycle* ('Turn of the Wheel') is a *Triple Saros Cycle*, which restores the repeat eclipse to the same time and longitude.

The *Eclipse Year* is the period the Sun takes (as seen from the Earth) to complete an orbit relative to one of the Moon's nodes (11.74 lunar months). It determines when eclipses can occur. It can be seen as the *beat period* of the synodic and draconitic months. The Saros cycle implies that there are 242-223 = 19 *Eclipse Years* per Saros period. *Eclipse seasons* occur twice as frequently since the Moon has two nodes—making 38 eclipse seasons in every Saros period with an average interval of 5.87 months.

Babylonian astronomers produced eclipse prediction schemes with 38 eclipse possibilities in the Saros period with an 8-7-8-7-8-pattern: 8 eclipses with 6-month gaps are followed by a 5-month gap and then 7 eclipses with 6-month gaps and so on. This pattern can be repeated many times to produce a scheme for predicting all eclipse possibilities over a long timescale.

The *Full Moon Cycle* is the cycle of changes in diameter of the Full Moon, which depends on how close the Moon is to the Earth in its elliptic orbit. It is the period the Sun takes (as seen from the Earth) to complete an orbit relative to the Moon's perigee (13.94 lunar months). It can be seen as the *beat period* of the synodic and anomalistic months. The Saros Cycle implies that there are 239 – 223 = 16 *Full Moon Periods* per Saros Period.

The lower back dials can be seen in X-rays of Fragments A, E and F[6,7] (Supplementary Figure 4). This evidence has shown that the main lower back dial is a Saros eclipse prediction dial (Supplementary Box 2), based on a 223 lunar month scale, with eclipse predictions shown as *glyphs* in selected months round the dial[6]. Some of the scale divisions of the Saros Dial and the eclipse prediction glyphs can be seen on the surface of Fragment A but most can only be seen in the CT. The glyphs are labelled according to their month number in the 223-lunar month scale and all 18 known glyphs are illustrated in Supplementary Figure 16. Most of the evidence comes from the CT but two of them here are imaged by PTM. The two newly identified glyphs are Glyphs 67 and 120. The evidence for these is at the limit of the resolution of the CT of Fragment A.

The glyphs not only make predictions of whether there might be a lunar or solar eclipse in a particular month but also what time of day that eclipse possibility would occur. Eclipse times in the glyphs are given on a 12-hour scale using the standard ancient Greek number system with the alphabet standing for numbers and an additional symbol ς for 6.

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1	2	3	4	5	6	7	8	9	10	11	12
Α	Β	Γ	Δ	Ε	ς	Ζ	Η	Θ	Ι	ΙΑ	ΙΒ

The predictions of eclipses in the glyphs are described by the symbols:

Σ: ΣΕΛΗΝΗ (Moon) for lunar eclipses.

Η: ΗΛΙΟΣ (Sun) for solar eclipses.

The times in the eclipses are indicated as follows:

$\omega\backslash^{\rho}$: Abbreviation for ωρα (hour), followed by a text character that indicates time in hours. This is written as a siglum combining ω and ρ.

$H\backslash^{M}$: Abbreviation for ΗΜΕΡΑΣ ('of the day'). This precedes $\omega\backslash^{\rho}$ for a lunar eclipse that occurs during the day, and so cannot be seen.

$N\backslash^{Y}$: Abbreviation for ΝΥΚΤΟΣ ('of the night'). This precedes $\omega\backslash^{\rho}$ for a solar eclipse that occurs during the night, and so cannot be seen (new identification).

In addition, at the bottom of each glyph there are *index letters* and these are in *alphabetical order* (new identification).

Below are listed all the known glyphs and their interpretation. Each glyph is numbered by its month number round the four-turn spiral of the Saros Dial. The label after this denotes the fragment and position of the glyph—for example, F-2.5 means that the glyph was observed in Fragment F on Scale 2 (counting the four turns of the spiral from the inside) and it was the fifth glyph found round this scale. On the far right is the interpretation of the text.

We use the following colour conventions for data interpretation: —

- Observed text, traced from the data
- Text inferred from the data and/or context
- Text of uncertain interpretation

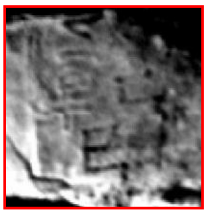
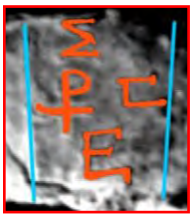
Month Fragment | *Glyph & symbols* | *Symbols* | *Σ/H, Day/Night, Hour, Index*

013 A-1.1

Η
$\omega\backslash^{\rho}$ A or Δ
Γ

020 F-1.1

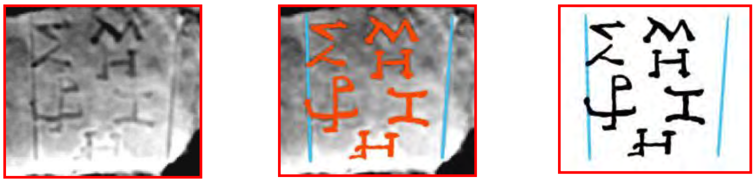
Σ
$\omega\backslash^{\rho}$ ς
Ε

025 F-1.6

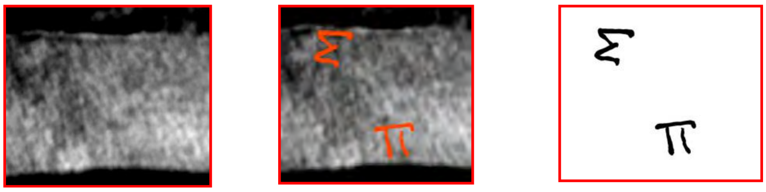
Η
$\omega\backslash^{\rho}$ ς
Ζ

026 F-1.7



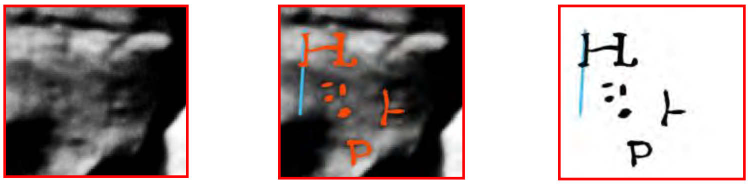
Σ H\M
ω\ρ Z
H

067 A-2.1



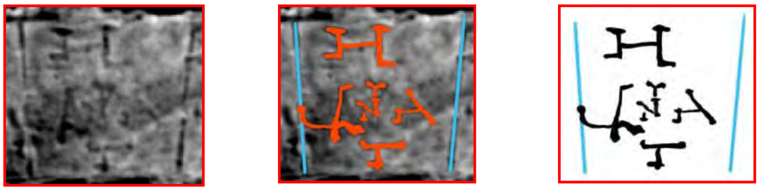
Σ
Π

072 A-2.2



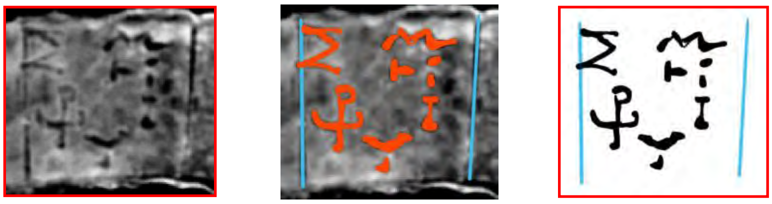
H
H
P

078 F/2.4



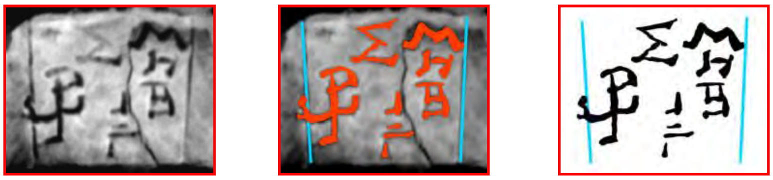
H
ω\ρ N\Y A
T

079 F/2.5



Σ H\M
ω\ρ I
Y

114 E/3.1



Σ H\M
ω\ρ IB
$\overline{\Gamma}$

119 E-3.6

H N\Y
ω\ρ I?
$\overline{\Delta}$

120 A-3.1

Σ H\M
ω\ρ H
$\overline{E}$

125 A-3.2

Σ $_{H}\backslash^{M}$ $_{\omega}\backslash^{\rho}$ H
H $_{\omega}\backslash^{\rho}$ Γ
$\overline{\mathrm{Z}}$

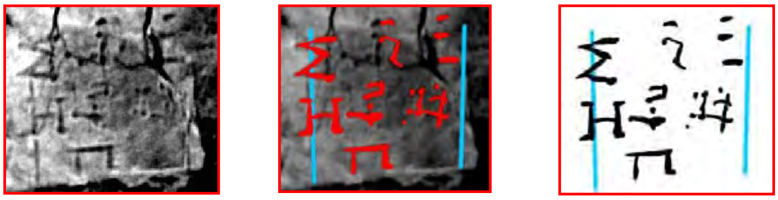
131 F-3.1

Σ $_{\omega}\backslash^{\rho}$ B
H $_{N}\backslash^{Y}$ $_{\omega}\backslash^{\rho}$ Θ
$\overline{\mathrm{H}}$

137 F-3.7

Σ $_{H}\backslash^{M}$ $_{\omega}\backslash^{\rho}$ E
H $_{\omega}\backslash^{\rho}$ IB
$\overline{\Theta}$

172 E-4.2



Σ $_{\omega}\backslash^{\rho}$ E
H $_{\omega}\backslash^{\rho}$ IB
$\overline{\Pi}$

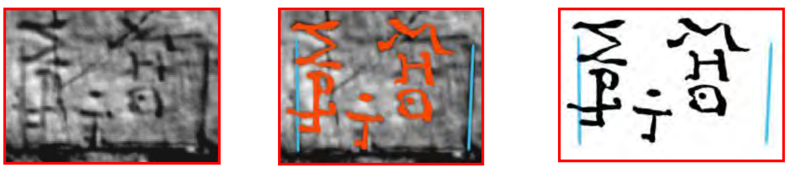
178 A-4.2

Σ $_{\omega}\backslash^{\rho}$ Θ
H $_{\omega}\backslash^{\rho}$ Θ
$\overline{\mathrm{P}}$

184 A-4.8

Σ $_{H}\backslash^{M}$ $_{\omega}\backslash^{\rho}$ Δ
H $_{\omega}\backslash^{\rho}$ A
$\overline{\Sigma}$

190 F-4.5



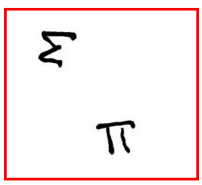
Σ $_{H}\backslash^{M}$
$_{\omega}\backslash^{\rho}$ Θ
$\overline{\mathrm{T}}$

LUNAR GLYPHS

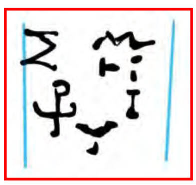
20 F-1.1

26 F-1.7

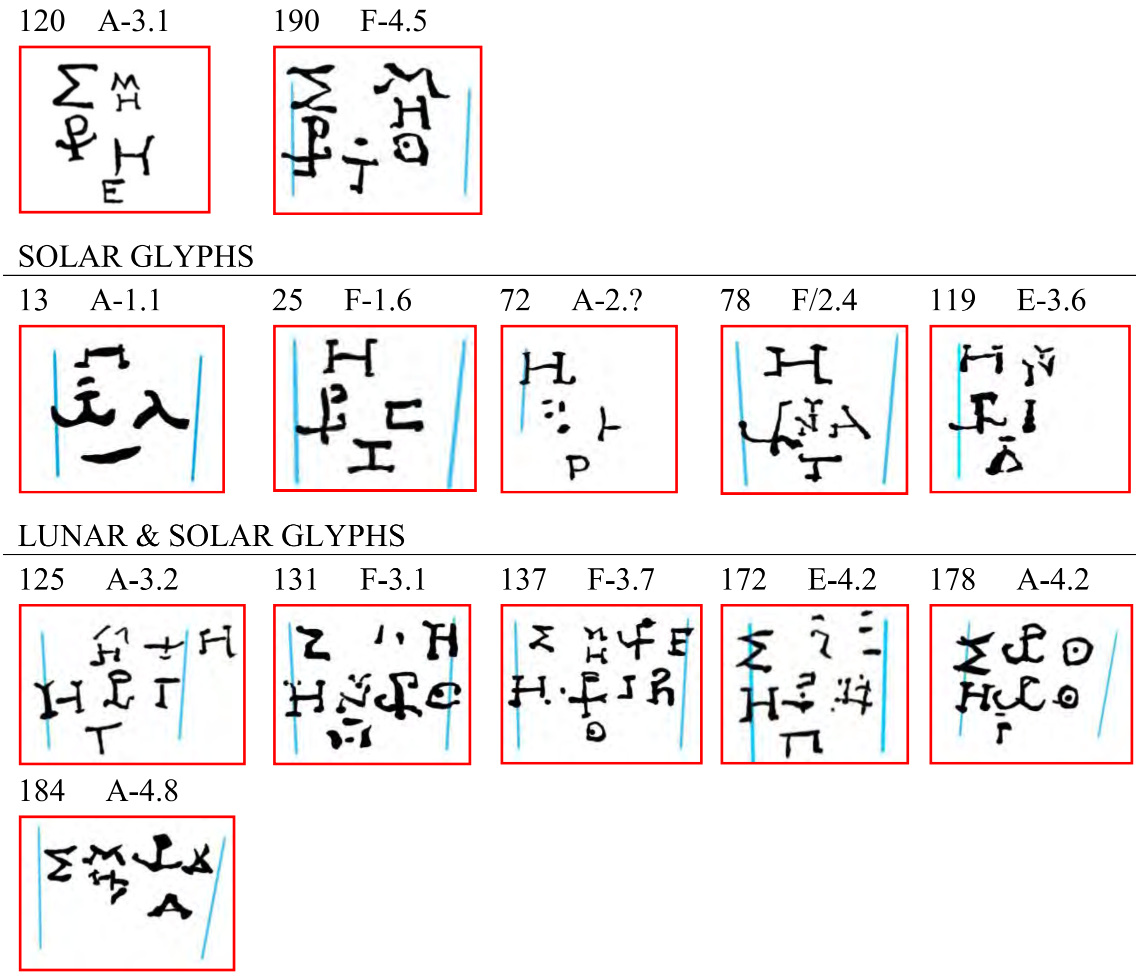
67 A-2.?



79 F/2.5



114 E/3.1



Supplementary Figure 16 | The observed glyphs on the Saros Dial.

In glyphs with both lunar and solar predictions, Σ always precedes H. This strongly suggests that lunar eclipses (that happen at Full Moon) precede solar eclipses (that happen at New Moon). This was confirmed when the glyphs were matched with actual eclipse data, as described below. In a Greek work of technical astronomy lunar months might be treated as beginning with the moment of conjunction, but Greek civil calendars, like the Babylonian calendar, used the directly observable phenomenon of the first crescent Moon to mark the beginning of each month. The months of the Saros Spiral are apparently the same kind as those of the Metonic Spiral, starting at the Moon's first crescent rather than at conjunction, so that solar eclipses occur at the very end of the month, not at the beginning.

The small bar above some of the index letters only occurs in the second alphabet of index letters, though some of these clearly do not have bars. We find bars in Glyphs 114, 119, 131, 178, and 190; and evidence that there were almost certainly no bars in Glyphs 20, 25, 26, 78, 79, 125, 137 and 172. There does not appear to be any obvious pattern and we do not yet know what they mean. A possible observation of Glyph 8 is so uncertain that it has not been included. Glyph 14 should be next to Glyph 13 in Fragment A but we have not been able to find it. It should be on part of the exposed scale in Fragment A. Glyph 13 was previously observed there[1] but is no longer visible on the surface even with PTM and can only be seen in the CT. So, the most likely explanation is that the evidence has now disappeared. Glyph 125 appears to spill over into Month 126. There is an H in the top left of Month 126 that does not make sense as a separate solar glyph. The top line of Glyph 125 within Month 125 seems to read Σ $^{M}/_{H}$ $^{\rho}/_{\omega}$, leaving no room for the glyph time. So we assume that the H (8) in Month 126 is the lunar eclipse time of Glyph 125.

4.2 Matching the Glyphs with Observations

How good is the Antikythera eclipse prediction scheme? One approach to answering this question is to check how well the glyph sequence matches data on actual eclipses. We consider a historical time scale over the last four centuries BC that covers the era when the Mechanism was made. Information about the occurrence of eclipses was obtained from the NASA/GSFC website[22]. The problem of matching the glyph sequence with actual eclipses is akin to matching a short length of DNA with a longer sequence. DNA matching software was initially used for this search and successfully found a match! Subsequently, the historical eclipse records were imported into an Excel spreadsheet and the problem was approached in a 'brute force' way to find all matches, using an Excel macro written in Visual Basic[6]. This checked all the possible matches over the time period and found 100 start dates that were consistent with the glyph sequence—with Σ-glyphs matching lunar eclipses, H-glyphs matching solar eclipses and Σ, H-glyphs matching months with both lunar and solar eclipses. This was clearly a positive result in terms of the effectiveness of the glyphs for eclipse prediction.

	3185 63 -142 Jul-02	3226 104 -139 Oct-25	3267 145 -135 Feb-17	3314 192 -132 Dec-05	3320 198 -131 Jun-01	3355 10 -128 Mar-30	3402 57 -124 Jan-18	3408 63 -124 Jul-12	3449 104 -121 Nov-05	3490 145 -117 Feb-26	3537 192 -114 Dec-17	3543 198 -113 Jun-13	3578 10 -110 Apr-11	3625 57 -107 Jan-28
1														
2	p A	p A*	p T	t A	p T*	p A*	p H*	p A	p H*	p T	t A*	p T*	p A	p H*
3														
4														
5														
6														
7	P				P			P				P		
8	t	t P	p A*	p T*	t	p T	p A	t	t P	p A*	p T*	t	p H*	p A*
9														
10														
11														
12														
13	P	P	P	P	A	P	P	P	P	P	P	P	P	P
14	t P	t P	t P	t	t	t P	t	t P	t P	t P	t	t	t P	t
15														
16														
17														
18														
19	A*	A	P	A	T	P	P	A	A*	P	P	T	P	P
20	p	p	t P	t	p	t	t P	p	t	t P	t	p	t	t P
21														
22														
23														
24														
25	T	H	A	T	n A*	T	A	T	H	A	T	n A	T	A
26	p	p	p	p	n	p	p	p	p	p	p	p	p	p
27														
28														
29														
30														
31	n A*	n H	T	n A*	n T*	A	T	n A	n H*	T	n A	n T	A*	T*
32		n	p	n		p	p		n	p	p		p	p
33														
34														
35														
36														
37	p H	n A	n A	n T*	p A*	n T*	n A	n H	n A*	n A*	n T	p A	n T	n A
38		n	n			n			n	n			n	
39														
40														
41														
42														
43	p A*	p T	n T*	p A*	p T	n A	n H	p H*	p T	n T	p A	p H*	n A	n A
44						n							n	n
45														
46														
47														
48					P							P		
49	t P	p A*	t A	p T	t P	p H*	p H*	t P	p A*	t A*	p H*	t P	p H*	p H*
50														
51														

Supplementary Figure 17 | Part of a large spreadsheet that shows sequences of actual eclipses that exactly match our glyph sequence, both in position and eclipse type. On the left are the month numbers of the Saros period. At the top are the month numbers from the beginning of the sequence starting at Month 1 in -399 (400 BC). In the next row below is this month number (Modulo 223)—so that sequences with the same number in this row start a multiple of a Saros period apart. The third row shows the date of the start of each matching sequence, using the usual convention that -99 is 100 BC. The first column of each matching sequence shows lunar eclipses with n = penumbral, p = partial and t = total. The second column shows solar eclipses with P = Partial, A = Annular, H = Hybrid and T = Total. If A, H or T is marked with a '*' then it was probably visible from some part of the ancient world, as judged by eye from maps of solar eclipse paths. Eclipses in red correspond to the known glyphs on the Antikythera Mechanism. All eclipse data is derived from the NASA/GSFC website[22].

Supplementary Figure 17 shows a small selection of the matching sequences. The eclipses in red are those that correspond to the known glyphs on the Mechanism. It is striking how the other eclipses are arranged in nearly consistent rows by eclipse type.

These correspond to *eclipse seasons* (Supplementary Box 2), which are five or six months apart.

A word of caution: the matches depend on the inclusion of penumbral lunar eclipses in the NASA data and if these are excluded there are no matches. Penumbral eclipses were rarely observed in antiquity and there are at most a couple of recorded observations[39]. However, as discussed below, we believe that the glyphs were designed as predictions of *eclipse possibilities* in the style of Babylonian schemes and not as an extrapolated set of observations. So some matching with penumbral lunar eclipses is to be expected.

4.3 Babylonian Schemes for Eclipse Prediction

The Saros period of 223 lunar months was well known in antiquity as an eclipse cycle. Babylonian astronomers combined the Saros with the knowledge that lunar eclipse possibilities (i.e., syzygies at which a lunar eclipse is possible, as opposed to those where there is no possibility of an eclipse) may be separated by intervals of either six or, less frequently, five months. Simple mathematics ($6a + 5b = 223$ where a and b are the number of eclipse possibilities at six- and five-month intervals respectively, and must be integers with a somewhat greater than b) showed that within one Saros period of 223 months there must be 33 eclipse possibilities with a six-month interval to the next eclipse possibility and 5 eclipse possibilities with a five-month interval to the next eclipse possibility. By distributing the six- and five-month intervals as evenly as possible within the Saros period, Babylonian astronomers were able to identify all lunar eclipse possibilities within a single Saros. Because after one Saros period, eclipses recur with similar characteristics, Babylonian astronomers realized that the distribution of eclipse possibilities within the Saros could be repeated many times to produce a scheme for predicting all lunar eclipse possibilities over a long timescale[24,23]. Identical schemes for predicting solar eclipse possibilities were constructed by analogy. Several cuneiform tablets from Babylon formatted according to these schemes have been preserved[35,36,37]. A Demotic papyri from Abusir al-Malak in Middle Egypt containing predictions of lunar eclipses for 85-74 BC was almost certainly compiled using a similar scheme[38,39].

A theoretical approach to predicting eclipse possibilities is also found in cuneiform and papyrus sources. A sequence of eclipse possibilities similar to that found in the schemes described above can be generated using a simple arithmetical model of nodal elongation at syzygy. A saw-tooth scheme where the nodal elongation increases uniformly month-by-month until reaching 180 degrees (corresponding to the opposite node) at which point 180 degrees is subtracted and the process continues, is found in cuneiform texts and a Demotic papyrus probably dating to the second century AD[25]. The preserved examples of this approach are based upon an eclipse cycle of 135 months, but it is almost certain that similar methods based upon the Saros cycle were also used. By adjusting the maximum nodal elongation at which an eclipse may occur, these saw-tooth functions may be used to generate different distributions of eclipse possibilities within a Saros.

The Babylonian schemes are based on 38 eclipse possibilities in a Saros period in an 8-7-8-7-8-pattern, with 8 eclipses with 6-month gaps (7 gaps in all) are followed by a 5-month gap then 7 eclipses with 6-month gaps (6 gaps in all) and so on. The hyphens indicate the 5-month gaps. This pattern does not however define the starting point for the scheme that might begin, for example, in the middle of one of the ‘8’s. The critical factor in the analysis below is where the 5-month gaps are.

Both Glyphs 120 and 125 are Σ-glyphs and are separated by 5 months. Glyphs 79, 114 are also Σ-glyphs and the number of months between these is 35. In a Babylonian scheme this must consist of 5 6-month gaps and a 5-month gap. Working backwards from Glyph 120, there must be 6 or 7 6-month gaps between Σ-glyphs before this, because there is a 5-month gap after Glyph 120. If there were 7 6-month gaps before Glyph 120, this would take us back to Month 78 as a Σ-prediction. But we know that Glyph 79 is a Σ-glyph, so there can only be 6 6-month gaps before Glyph 120 and the gap after Glyph 79 must be a 5-month gap. Therefore any Babylonian scheme that is consistent with the glyphs must have 5-month gaps between Months 79 and 84 and between Months 120 and 125. This fixes one of the '7's in the 8-7-8-7-8-pattern and it is easy to see that this then fixes the whole Babylonian pattern relative to the glyphs. It is now routine to check that all the Σ-glyphs correspond to the resulting Babylonian scheme for Σ-predictions. Similar (but more complex) arguments show that there are exactly two Babylonian schemes consistent with the H-glyphs. Consequently, if the glyphs are generated by Babylonian schemes for both Σ- and H-glyphs, then there are just two possibilities for the glyph scheme. As we shall see, neither of these is consistent with the *index letters* in the Antikythera glyphs.

4.4 Alphabetical Index Letters

The identification of the index letters has transformed our understanding of the distribution of the glyphs. All the definite index letters in the glyphs are in alphabetical order (13 instances). Where the evidence for an index letter is only partial (4 instances), the text is consistent with alphabetical ordering: for example, it is not possible to be confident of assigning an interpretation to the index letter in Glyph 13 but it is consistent with Γ. So we are confident that the index letters are in alphabetical order. Glyphs 20 and 25 have index letters E, Z. Since these glyphs are separated by five months, there can be no other glyph between them (since eclipse seasons occur at intervals of five or six months). So we know that the alphabetical letters are not supplemented with the number symbol ς, standing for the number 6. The index letters are therefore *letters* rather than *letters standing for numbers*. All the glyphs have index letters. So it is not consistent to assume that the index letters refer to just lunar predictions or just solar predictions: they must index glyphs rather than predictions.

In order to analyse the index letters, we designate the letters of the Greek alphabet by their position in the alphabet as follows:

A	B	Γ	Γ	Δ	E	Z	Θ	H	K	Λ	M	N	Ξ	O	Π	P	Σ	Σ	T	Φ	Y	Φ	X
α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}	α_{17}	α_{18}	α_{19}	α_{20}	α_{21}	α_{22}	α_{23}	α_{24}

The index letters can be observed or inferred in the glyphs as follows. (Designations with the same colour are in consecutive order):

13	20	25	26	67	72	78	79	114	119	120	125	131	137	172	178	184	190
α_3	α_5	α_6	α_7	α_{16}	α_{17}	α_{19}	α_{20}	α_3	α_4	α_5	α_6	α_7	α_8	α_{16}	α_{17}	α_{18}	α_{19}

The glyphs with a Σ-component are as follows:

20	26	67	79	114	120	125	131	137	172	178	184	190
α_5	α_7	α_{16}	α_{20}	α_3	α_5	α_6	α_7	α_8	α_{16}	α_{17}	α_{18}	α_{19}

The glyphs with an H-component are as follows:

13	25	72	78	119	125	131	137	172	178	184
α_3	α_6	α_{17}	α_{19}	α_4	α_6	α_7	α_8	α_{16}	α_{17}	α_{18}

We can now check the consistency of the two Babylonian solar prediction schemes that match the Antikythera glyphs with the index letters. On examining the two consistent Babylonian schemes (not included in these notes), it is immediately clear that in both cases there are too many eclipse predictions in the Babylonian schemes to match the index letters in the glyphs. For example, in both matching schemes the sixth glyph in the sequence matches Glyph 20, which has index letter E—the 5th letter of the alphabet. By Glyph 78, with index letter T (19th letter of the alphabet), there are 21 predictions in one scheme and 22 in the other. By Glyph 190, with index letter 19 of the second alphabet (in other words the 43rd letter), there are 49 predictions in one Babylonian scheme and 52 in the other. The Babylonian schemes generate significantly more predictions than those included on the Antikythera Mechanism.

4.5 Models for generating the Antikythera Glyph Sequence

Eclipses occur when a syzygy is sufficiently close to a node (Supplementary Box 2). The fact that there are fewer predictions in the Antikythera scheme compared with the Babylonian schemes suggests that the glyphs might be generated by a model defined by a tighter criterion for nodal elongation at syzygy. In considering ways that the designer of the instrument might have constructed such a model, the first issue is how the lengths of months were generated. In terms of the knowledge available at the time of construction of the Mechanism two definitions seem likely: lunar months were simply calculated as mean lunar months; or the months were generated including the first lunar anomaly (and possibly also the first solar anomaly). The inclusion of the first lunar anomaly is plausible since it is now known that the Antikythera Mechanism incorporates a device that expresses the Moon's first anomaly[6]. This means that it is very likely that the Mechanism also included an epicyclic realization of the Sun's first anomaly (as previously suggested[26]) since it is much easier to include mechanically than the Moon's first anomaly. In the following, we consider in detail the case where month lengths are simply based on mean months, as calculated in the Antikythera Mechanism using the Metonic cycle and a year length of $365^1/4$ days.

We take a total lunar eclipse (the *calibrating eclipse*) as the starting point for each model. At this time, the syzygy is at a node and both synodic and draconitic months are at the beginning of a cycle. In addition it is a suitable time to calibrate the Mechanism since the ecliptic longitude of the Moon can be observed and that of the Sun can be inferred, because it must be at the opposite point of the Zodiac. At each subsequent syzygy, we calculate the angular difference between the syzygy and the node, assuming that the speeds of motion of the Moon through the synodic and draconitic months are constant. Such models are recorded in antiquity with a set of arithmetic rules for making the calculations[25]. The model could also have been generated using similar technology to that of the Antikythera Mechanism.

All the models considered were developed in an Excel spreadsheet. Excel macros written in Visual Basic were used to test different possibilities. The first model used mean months. For each syzygy after the calibrating eclipse the model calculated the elongation of the syzygy from its closest node. This was then compared with a pre-set criterion of 'closeness', such as 15° for lunar syzygies and 10° for solar syzygies. A prediction was recorded if the elongation was within the criterion selected. These predictions were generated for two Saros periods and for each possible start date within this period the sequence of generated predictions was compared with the glyph sequence to see if there was a match. A match was defined as follows:

1. Every lunar or solar glyph prediction was matched exactly by a generated prediction.
2. The generated sequence of predictions did not produce any predictions where a glyph is observably absent.
3. There were no 'combined errors' in the sense that both a lunar and solar prediction were generated for the same month where the glyph is clearly not a combined lunar and solar glyph.
4. There were no 'index letter errors' in the sense that the number of generated predictions failed to match the index letters (which proscribe the number of glyphs in the gaps between known glyphs).

A generated sequence of predictions that satisfied these conditions for a particular start date after the calibrating eclipse was called a *perfect match*. Systematically checking with an Excel macro for matches with the criteria set at 0.1° intervals over a wide range of criteria produced no perfect matches, though there were some near misses. These near misses generated the sort of sequence that we were expecting with some 11-month gaps as opposed to the 6- or 5-month gaps of Babylonian schemes.

A modification of this scheme was then introduced with a historical justification. In the *Almagest*[11], Ptolemy reports that, because of parallax, the likelihood of a solar eclipse depends not only on how close the New Moon is to a node, but whether it occurs North or South of the ecliptic. He proposed that a solar eclipse will occur if a syzygy North of the node has elongation within 17.7°, but that it must be within 8.4° if the syzygy is South of the node.

Introducing this solar asymmetry into our model produced much better results, with a near-perfect match with only a single index letter error, which we shall call the *best match*. On examination of this match, it could be seen that for lunar eclipses the process generated 39 lunar predictions—one more than the standard Babylonian scheme. Two of these predictions were in adjacent months, which never occurred in Babylonian schemes. In addition, examination of the NASA data[22] on historical eclipses over the last four centuries BC shows that lunar eclipses in adjacent months are always both penumbral—with just two exceptions over the four hundred year period where one of the eclipses was partial. If we discard the second of the adjacent lunar predictions, then we are left with a prediction scheme for lunar eclipses, which is exactly the unique Babylonian scheme that matches the Antikythera glyph sequence. On this basis, we feel justified in discarding the second of the adjacent lunar eclipse predictions.

The situation for the *best match* is different for solar eclipses. It is a *perfect match* for the solar glyphs and it has 27 eclipse possibilities—far fewer than the standard 38 for Babylonian schemes. This then explains the comparative paucity of index letters. The generated scheme is a subset of both solar Babylonian schemes that match the glyph sequence, though it does not appear to be possible to generate the Antikythera scheme by a simple pattern of excisions from one of the Babylonian schemes. The comparative sparseness of the solar predictions on the Mechanism may have reflected a subjective impression that solar eclipses are much rarer than lunar eclipses, which is true for a single location but not true overall. In fact, solar eclipses (viewable from somewhere on Earth) are slightly more frequent than lunar eclipses[22].

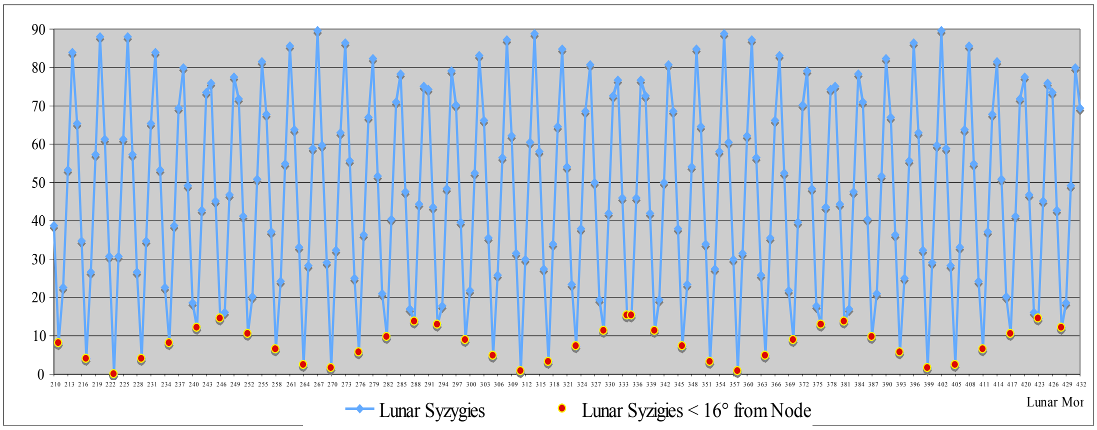
The full reconstruction of predictions generated by our model is given below. The sequence is based on asymmetrical elongation criteria as follows (where any number in the given range will produce the same generated sequence):

Lunar	15.4° - 16.1°	*for example, 16°*
Solar - North	15.4° - 16.1°	*for example, 16°*
Solar - South	5.7° - 6.1°	*for example, 6°*

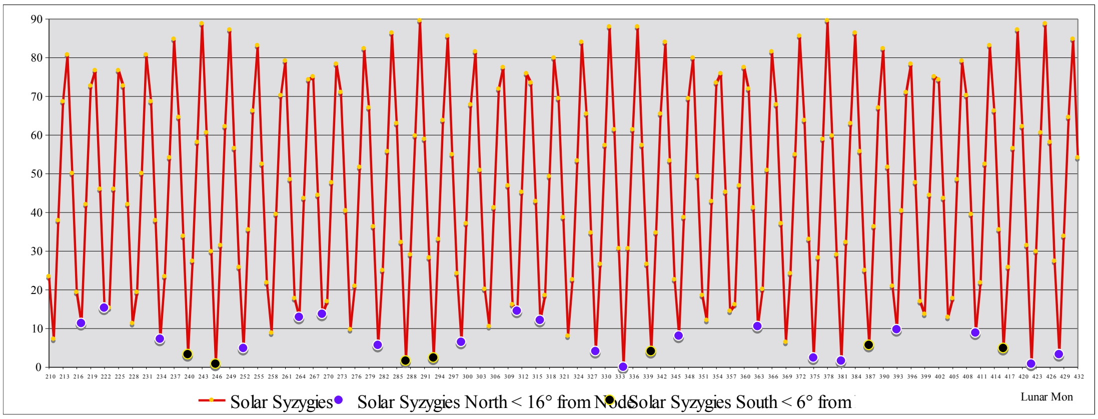
These compare with Ptolemy's figures in the second century AD for estimating eclipse likelihood by syzygy elongations from the closest node:

Lunar	12.2°
Solar - North	17.7°
Solar - South	8.4°

The matching sequence starts 210 lunar months after the calibrating eclipse.



Supplementary Figure 18 | Graph for lunar eclipses, showing degrees of elongation between syzygy and closest node. This shows the regular pattern of a Babylonian prediction scheme with its 8-7-8-7-8-pattern. The peaks of the marked syzygies correspond to the 5-month gaps. The doubled red dot at the third peak along shows lunar eclipse predictions in adjacent months—the second being discarded for our reconstruction.



Supplementary Figure 19 | Graph for solar eclipses, showing degrees of elongation between syzygy and closest node. The model shows the effect of the asymmetrical criteria for syzygies North or South of the ecliptic. The irregular pattern of gaps implied by the index letters appears to apply to the solar predictions only.

Supplementary Figure 18 and Supplementary Figure 19 show the eclipse predictions generated by our model. Putting these together gives our reconstructed glyph sequence. In the list below, elements in red are observed from the glyphs; in blue are inferred from the evidence and the context; and in black are reconstructed by the model. The glyph generated at Month 126 is in italics since it has been discarded as an adjacent lunar glyph.

Month	*Glyph*	*Index*
2	Σ	Α
8	Σ, Η	Β
13	Η	Γ
14	Σ	Δ
20	Σ	Ε
25	Η	Ζ
26	Σ	Η
31	Η	Θ
32	Σ	Ι
37	Σ, Η	Κ
43	Σ, Η	Λ
49	Σ	Μ
55	Σ, Η	Ν
60	Η	Ξ
61	Σ	Ο
67	Σ	Π
72	Η	Ρ
73	Σ	Σ
78	Η	Τ
79	Σ	Υ
84	Σ, Η	Φ
90	Σ, Η	Χ
96	Σ	Ψ
102	Σ, Η	Ω
107	Η	$\overline{\text{Α}}$
108	Σ	$\overline{\text{Β}}$
114	Σ	$\overline{\text{Γ}}$
119	Η	$\overline{\text{Δ}}$
120	Σ	$\overline{\text{Ε}}$
125	Σ, Η	$\overline{\text{Ζ}}$
126	*Σ*	
131	Σ, Η	
137	Σ, Η	$\overline{\text{Θ}}$
143	Σ	$\overline{\text{Ι}}$
149	Σ	$\overline{\text{Κ}}$
154	Η	$\overline{\text{Λ}}$
155	Σ	$\overline{\text{Μ}}$
161	Σ	$\overline{\text{Ν}}$
166	Η	$\overline{\text{Ξ}}$
167	Σ	$\overline{\text{Ο}}$
172	Σ, Η	$\overline{\text{Π}}$
178	Σ, Η	$\overline{\text{Ρ}}$
184	Σ, Η	$\overline{\text{Σ}}$
190	Σ	$\overline{\text{Τ}}$
196	Σ	$\overline{\text{Υ}}$
201	Η	$\overline{\text{Φ}}$
202	Σ	$\overline{\text{Χ}}$
207	Η	$\overline{\text{Ψ}}$
208	Σ	$\overline{\text{Ω}}$
213	Η	$\overline{\overline{\text{Α}}}$
214	Σ	$\overline{\overline{\text{Β}}}$
219	Σ, Η	$\overline{\overline{\text{Γ}}}$

Supplementary Figure 20 | The *best match* generated glyph scheme. It reconstructs not only the glyphs but also the index letters for the whole dial. There are 51 glyphs in the whole scheme, with 38 lunar predictions and 27 solar predictions—a total of 65 eclipse predictions over the Saros period.

A similar analysis can be carried out using months that incorporate the first anomalies of the Sun and Moon—an idea motivated by the knowledge that the lunar anomaly is known to have been incorporated into the Antikythera Mechanism[6] and the solar anomaly is likely to have been included. In this case the sequence is generated from eclipse data for a particular location (in our case Sicily), where the phases of the lunar and solar anomalies at a total lunar eclipse are known. An assumption needs to be made about the magnitude of the lunar and solar eccentricities employed. A number of lunar eccentricities were tried: two values by Hipparchos 0.079 (495/6,245) and 0.104 (983/9432); a value by Ptolemy of 0.0875 (7/80, close to the true value); and two measurements made on the Mechanism itself of 0.112 and 0.125. The solar eccentricity used Ptolemy's value of 0.042 (1/24). The whole analysis is technically more complex but yields a very similar result to that using mean months, though only ippa rchos' too-low value of 0.079 for the lunar eccentricity gave as good a match. For this reason and because the calibrating eclipse for the best match occurs at Jan 5th 196 BC, which is almost certainly too early for the Mechanism, we do not believe that this approach adds much to the analysis.

4.6 The Problem of the Glyph Times

The frame of reference for the eclipse times indicated in the glyphs is not clear. It would seem reasonable to assume that the hours used were *equinoctial* (where the day and night are considered of equal length and both are divided into twelve equal hours), as opposed to *seasonal* hours that divided the intervals between sunrise and sunset into equal parts. Though the newly identified function of the Exeligmos Dial would not really make good sense without equinoctial hours (see below), we have no proof that equinoctial hours were employed. The glyphs contain abbreviations for both Day ($H\backslash^{M}$) and Night ($N\backslash^{Y}$) and we therefore assume that, if equinoctial hours were used, the times were referenced to a nominal sunrise and sunset at 6.00 am and 6.00 pm. All the observed times in the glyphs are numbers between 1 and 12.

The eclipse times probably referred to the time of *syzygy* though *first contact* or *greatest eclipse* times are other possible candidates. For solar eclipses, the time from *first contact* to *greatest eclipse* is almost always less than 1.5 hours and is usually less than an hour. For lunar eclipses, the time from the start of *partial* to *greatest* eclipse is almost always less than two hours and usually of the order of 1.5 hours. So the difference in estimated eclipse time is an hour or two at most. The difference between *syzygy* and *greatest eclipse* is a small fraction of an hour. We shall examine the lunar and solar times separately.

In the following table, $H\backslash^{M} = 0$ if $H\backslash^{M}$ is absent in the glyph; = 1 if it is present. We measure times from nominal sunrise at 6.00 am. If $H\backslash^{M} = 0$, then 12 hours is added to get the *'24-hour Time'*. *'Mean'* is the residue modulo 24 of the glyph month number times the mean synodic month (based on the Metonic cycle) expressed in hours. *'24-hour time'* = *'Time'* if $H\backslash^{M} = 1$; = *'Time + 12'* if $H\backslash^{M} = 0$. *'Less Mean'* = *'Time'* - '*Mean'* (Mod 24).

Both *Mean* and *Less Mean* contain an unknown constant.

Numbers in green are uncertain.

Glyph	*H\\$^{M}$*	*Time*	*24-hour Time*	*Mean*	*Less Mean*	*Comments*
20	0	6	18	14.8	3.2	
26	1	7	7	19.3	11.7	
79	1	10	10	22.5	11.5	
114	1	12	12	12.4	23.6	
120	1	8	8	16.9	15.1	
125	1	8	8	8.6	23.4	*H (8) in Month 126*
131	1	2	2	13.0	13.0	*H\\$^{M}$=1 from text spacing*
137	1	5	5	17.4	11.6	
172	0			7.4		
178	0	9	21	11.8	9.2	
184	1	4	4	16.2	11.8	
190	1	9	9	20.7	12.3	

Supplementary Figure 21 | Analysis of lunar glyph times

If the times were based simply on mean lunar months, then we would expect the times in the *Less Mean* column to be equal. If we ignore the uncertain times, five out of eight times conform well to this model but two of the others certainly do not. A possible resolution to this problem might be that the times include a correction for the first lunar anomaly. If this were the case, then the corrections created by the anomaly should follow a cycle based on the *Full Moon Cycle*. This analysis (not included in detail here) shows that they do not conform to this pattern.

If H\\$^{M}$ = 1, then the eclipse was not observable from the intended location of use of the Mechanism, since it would represent a lunar eclipse during the day. The fact that seven (with two more possible) of the Σ-glyphs include H\\$^{M}$ emphasizes that the glyphs represent predictions of eclipse possibilities, not predictions of observable eclipses.

A comparable analysis can be carried out for solar eclipses. To the previous nomenclature, we add N\\$^{Y}$ = Night and the convention that N\\$^{Y}$ = 0 if N\\$^{Y}$ is absent in the glyph; = 1 if it is present. *'24-hour time'* = *'Time'* if N\\$^{Y}$ = 0; = *'Time'* + *12* if N\\$^{Y}$ = 1.

If N\\$^{Y}$ = 1, then the eclipse was not observable from the intended location of use of the Mechanism, since it would represent a solar eclipse during the night.

Glyph	*N\\$^{Y}$*	*Time*	*24-hour Time*	*Mean*	*Less Mean*	*Comments*
13	0	?		16.0		
25	0	6	6	0.9	5.1	
72	?	?		23.7		
78	1	1	13	4.1	8.9	
119	1	10	22	22.5	23.5	*Time could be 12*
125	0	3	3	2.9	0.1	
131	1	9	21	7.4	13.6	
137	0	12	12	11.8	0.2	
178	0	9	9	6.2	2.8	
184	0	1	1	10.6	14.4	

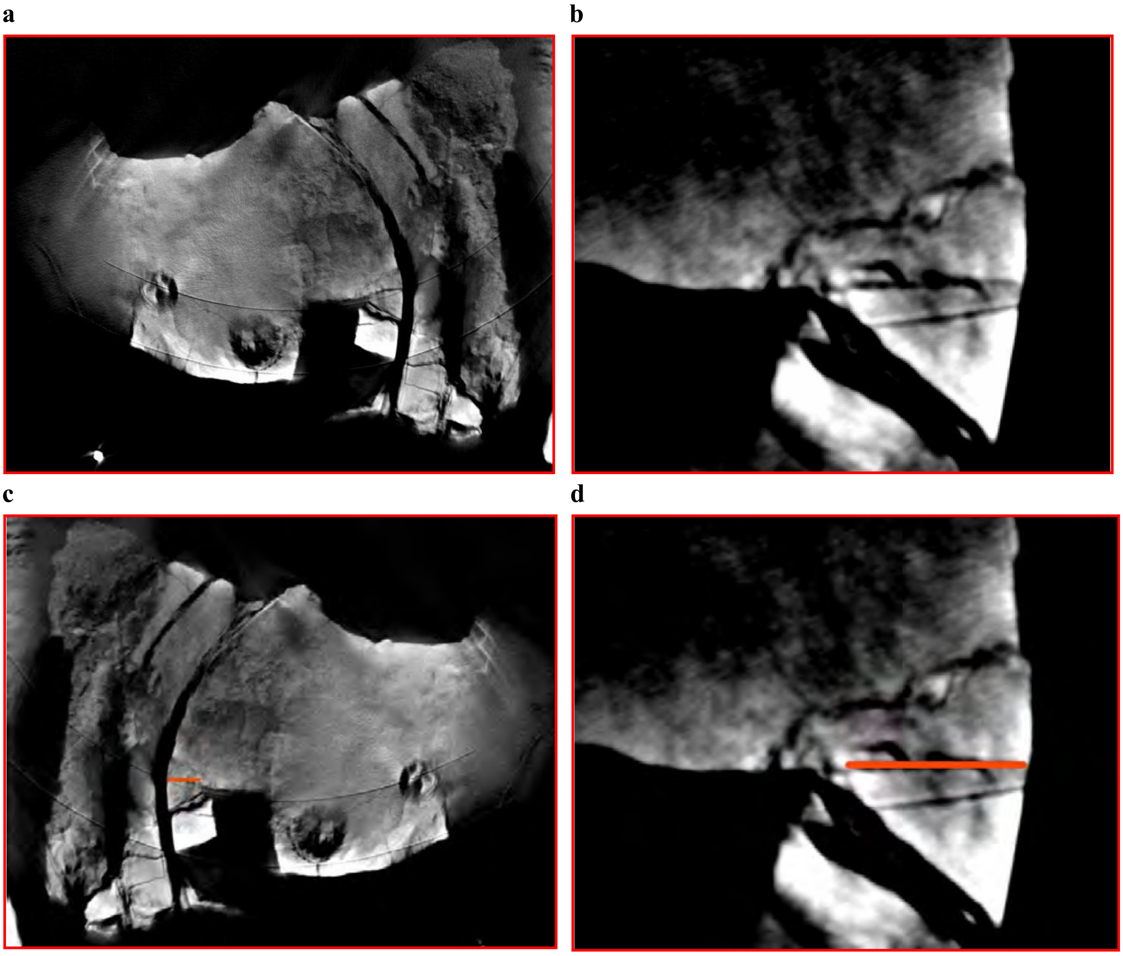
Supplementary Figure 22 | Analysis of solar glyph times

The solar glyph times do not appear to exhibit a derivation from mean lunar months since the figures in the *Less Mean* column vary widely. An analysis of the times in terms of first anomaly corrections also yields contradictory results—though we do not give this argument in detail here. The glyph times were also compared with the actual eclipse times for sequences of eclipse data over the last four centuries BC that exactly match the Antikythera glyph sequence. No persuasive correlations were found.

We have not discovered a rational or plausible basis for the glyph times. We conclude that the generation of the glyph times may not have been well founded and therefore that it may be difficult to discover how it was actually done.

4.7 The Four-Turn Saros Dial

The reason for the five-turns of the Metonic Dial is now clear, but why does the Saros Dial have four turns? The *Full Moon Cycle* (Supplementary Box 2) follows the change in the apparent diameter of the Moon at syzygy. It can be seen as the *beat period* between the synodic and anomalistic months. Since there are 223 lunar months and 239 anomalistic months in a Saros period, there must be 239 – 223 = 16 *Full Moon Cycles* in a Saros period. This means that every quarter turn of the Saros Dial is a Full Moon Cycle and the angle of the Saros pointer within each turn indicates the phase of the cycle. The diameter of the Moon mediates both the length and type of an eclipse—for example, when the Moon's apparent diameter is small a solar eclipse may be annular rather than total. In this way the Mechanism gives additional information about eclipses and we have a rationale for the four turns of the Saros Dial.

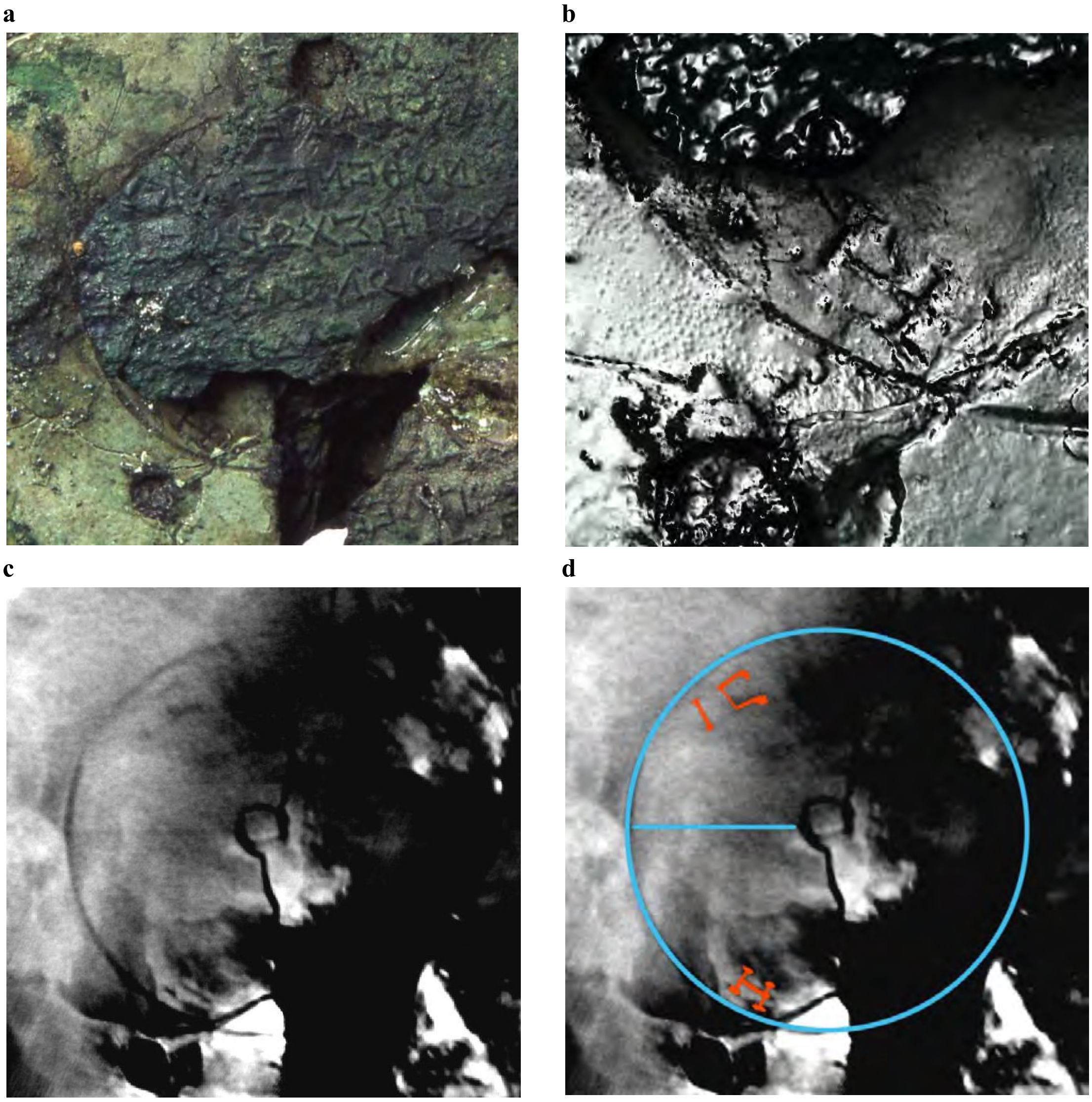


Supplementary Figure 23 | a, CT slice of Fragment A, showing the centre of the Saros Dial, with a possible scale mark in the 3 o'clock position. b, Close-up of the possible scale mark. c & d, The possible mark is highlighted in red. The apparent mark at an angle underneath this is part of a 'ring artefact', created by the X-ray process, and so should be disregarded.

A possible scale mark in exactly the 3 o'clock position on the central plate of the Saros Dial adds support to the idea that there might have been divisions marking the start of each Full Moon Cycle round the dial. It might be expected that there would also be 'intercardinal' divisions at 45° relative to the four main divisions. However we have not been able to find any evidence for these.

4.8 The Exeligmos Dial

The evidence for the Exeligmos Dial comes from Fragment A. Part of it is visible on the surface, including a prominent letter H at the edge of the dial. The rest of the surviving dial can be seen in the CT



Supplementary Figure 24 | The Exeligmos Dial. a, A still photo of part of the back of Fragment A, showing the Exeligmos Dial, mostly overlaid by mirror-image text from the Back Door. b, A PTM showing the letter 'H' that is visible on the surface of Fragment A. c, A CT slice showing the letters 'H' (8) and 'Iς' (16) in the 7 o'clock and 11 o'clock positions. A faint horizontal scale division can also be seen. d, The visible features of the dial are highlighted.

Unlike all other short period eclipse cycles, the 223-month Saros cycle is particularly useful for predicting eclipses because the variation in its length is comparatively small: it exceeds 6,585 days over a range of only 6 to 9 hours. Many ancient authors took the excess to be exactly 8 hours, with a complete cycle of 6,585 $^{1}/_{3}$ days and each

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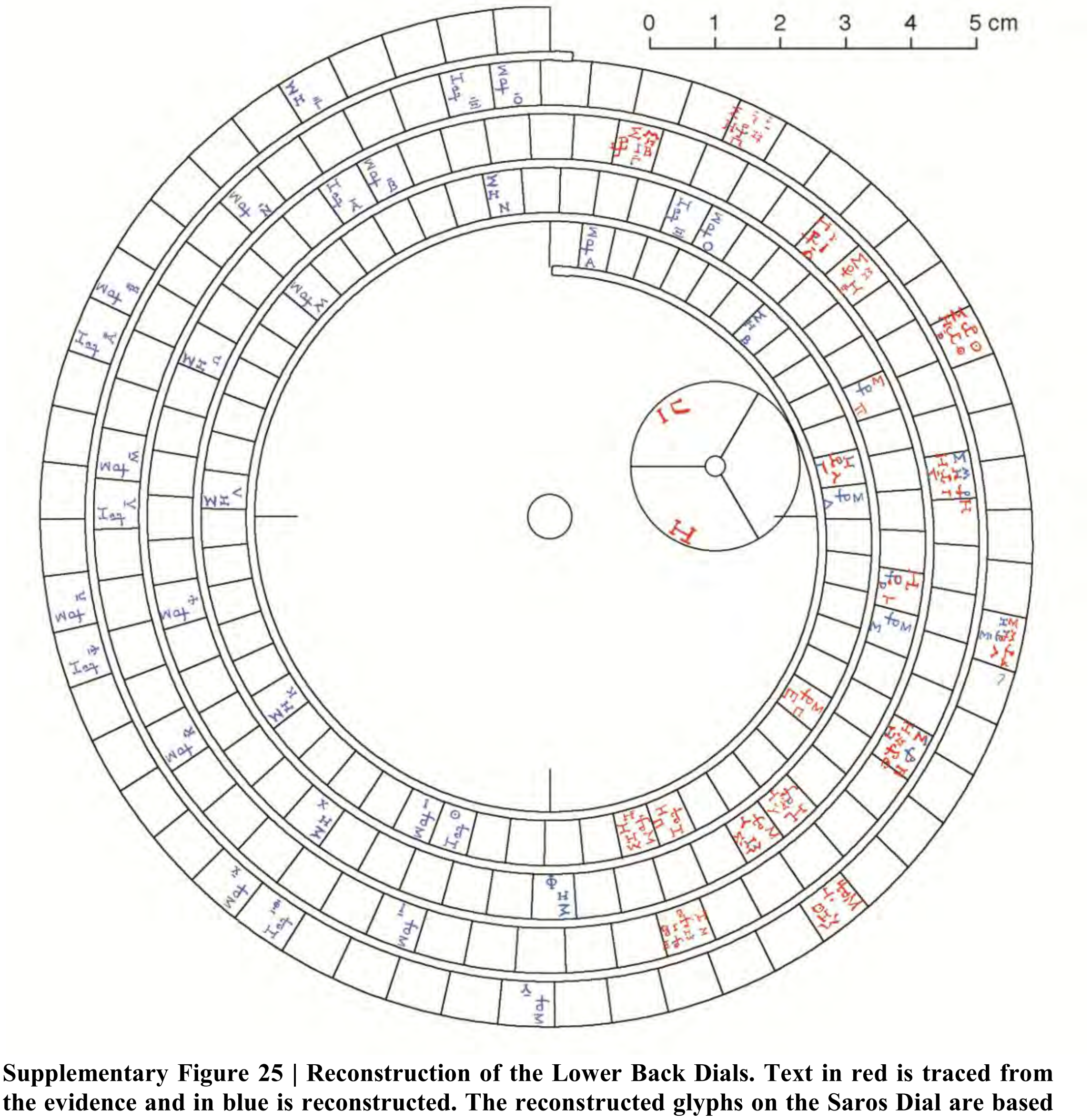
eclipse repeating 8 hours later in the day. On this basis, three Saros Cycles, known in ancient Greece as the *Exeligmos Cycle* ('Turn of the Wheel'), is exactly 19,756 days, after which eclipses repeat at very nearly the same time of day. The Exeligmos Dial is divided into three sectors, with no inscription in one sector and the numbers 8 and 16 in successive sectors. We have now understood the purpose of this dial, which is to tell the user how many hours—0, 8 or 16—to add to the glyph time to get the time of the predicted eclipse.

4.9 Reconstruction of the Lower Back Dials



Supplementary Figure 25 | Reconstruction of the Lower Back Dials. Text in red is traced from the evidence and in blue is reconstructed. The reconstructed glyphs on the Saros Dial are based on a mean month model, using asymmetric criteria for solar glyph generation. The glyph times in the reconstructed glyphs are missing since the process of their generation has not been discovered.

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