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A MINOAN ECLIPSE CALCULATOR

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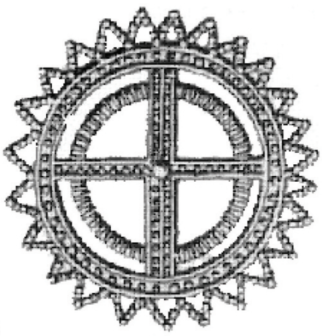
ABSTRACT
A stone die of the Minoan period, discovered near Palaikastro in Crete, Greece, in 1899, was selected for this study as bearer of astronomical significance. Strong evidence is presented in favor of its use (especially of the "ray-bearing" disc on its right-hand side) as a die for the construction of a device that could determine eclipse dates during the Minoan period (*circa* 15th century BC); additionally, two more practical uses for it are examined: as a sundial and as an instrument for the determination of the geographical latitude.

KEYWORDS: Minoan Crete, archaeoastronomy, computing, Palaikastro, Moon, lunar eclipses

1. INTRODUCTION

An observation by the British archaeologist Sir Arthur Evans in his book *The palace of Minos at Knossos* (Ev-ans, 1935) led us to research the three figures he in-cludes in the book of the Palaikastro plate. According to Evans, these carvings were representations of the Moon and the Sun.

However, it must be noted that in this book the illustra-tor did not draw an accurate representation of the stone die, which prevented researchers from deducing its proper function (Fig. 1a). More specifically, only the 47 of the 59 inner carvings of the disc are depicted, and only 51 of the 58 dots of the outer circle. In addition, the depiction of the ray-like triangles is not correct.



a

Figure 1. a. The drawing in the book by A. Evans (1).

The first publication of this plate, including figures, was done by the archaeologist Stephanos Xanthoudides in the difficult-to-find journal *Archeologiki Ephemeris* (Xanthoudides, 1900). The article mentions that the findings were actually two plates, which were discovered together in the same field, 150 m NW of the village Palaikastro of the Siteia province in Crete in 1899. Today they are dated by archae-ologists as originating in the 15th century BC.

Upon examination of the two plates, we concluded that only one of them has an astronomical significance (Fig. 2), and chose

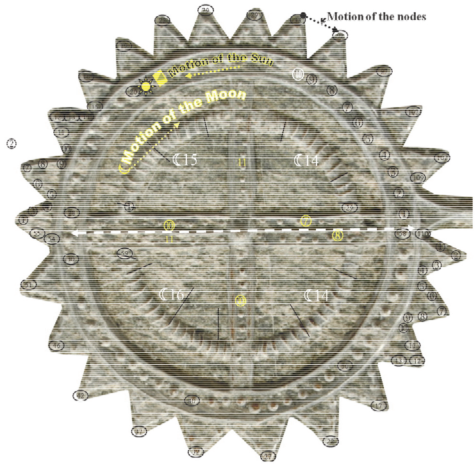


Figure 2. The "ray-bearing" disc on the Palaikastro plate as it was photographed at the Heraklion Archaeological Museum, with the carvings and dots on its surface and with illustrative annotations.

to study this one in detail. The plate was probably used as a die for the production of possibly metallic (copper, silver or golden) copies of its depictions. The symbols and figures carved on the surface of this plate are described below.

The problem in dating the stone dies is that they were not discovered during an excavation, so they can't be dated from pottery and stratigraphy. In the Ph.D. dissertation of the archaeologist Stylianos Alexiou (Alexiou, 1958), a dating of the dies is attempted by relating the figure of the deity that appears at the centre with other idols of the late Mycenaean period III (14th – 12th centu-ries BC). Martin Nilsson (1950) correlates the figure of the goddess holding poppy flowers in the middle of the plate (Fig. 1b) with the sealing ring of Mycenae (16th cent. BC), where the same picture

b

Figure 1b. An im-print of the Palaikastro die, which measures 10 cm × 23 cm × 2 cm.

appears. The issue of dating is still open. However, in our opinion, the most probable dating is that of M. Nilsson or the intermediate one of the 15th century BC.

Our team acquired high-definition photographs of the finding, provided by the Heraklion Archaeological Museum after issuing a permission to study, which could be studied at a magnification of about 5×. By examining the magnified photographs of the plate (Fig. 1c), our team observed that there were various depressions, notches and dots in number ratios that indicated a relationship to astronomical phenomena.

Figure 1c. The Palaikastro plate and a copy of it as it was photographed at the Heraklion Archaeological Museum (No. of permission to publish: A.M.H. L 116/ 192/ 7-2-2011).

By studying the components of the die and correlating these with astronomical phenomena, we were able to explain its intended use. The most obvious interpretation is that of an eclipse calculator, which could be produced by imprinting a copy of this die on a soft solid (e.g., malleable metal or even soft wood). In order to test this interpretation, we constructed a three-dimensional model of the "ray-bearing" disc in its original dimensions: 8.5 cm × 8.5 cm.

2. THE "RAY BEARING" DISK

Observing the right-hand-side carving on the Palaikastro die (Fig. 1b) we see a disc with many carvings and a cross at its centre. From the high-definition image (Fig. 1c), we were able to carefully measure the dots that appear both on the disc itself and on the triangular "rays" on its circumference, and arrived at the following results:

In the disc's circumference appear 25 triangular "rays" or "teeth" (△). Each one of the 20 of them has 5 tiny dots (°) , while other 4 "rays" have three dots each and one ray has no dots at all, just one dash (-), denoting probably some starting point.

The total number of these dots is 112. Knowing that a saros cycle includes 223 lunar months, 112 seemed to be too close to half that number to be mere coincidence. Until now, the earliest record of the saros cycle is by Babylonian astronomers from 750 BC to 1 BC. The saros is a period of 6585.3 days (approximately 18 years and 11 days) during which the relationship of the Sun, Earth and Moon will return to the same configuration as the starting eclipse. Looking at the Palaikastro plate, we found that by moving six nodes every twelve lunar months, then the triangular ray circle can cover one saros cycle. A different way of expressing this is that if 112 is divided by 6, then the number (18.66) approxi-mates the number of years in a saros cycle. Therefore, it seems logical that the nodes shift by 6 positions every 12 lunar months.

Inside the disc there are carved two circles, the outer one, which contains 58 small circular cavities (⦿), and the inner circle, which is a single depression that contains 59 carved short lines and is interrupted in four places by a cross. The two lines of the cross (diameters of the circle) bear dots in rows as follows: The vertical line bears 11 dots in its upper part and 10 dots in its lower part. The horizontal line bears two rows of dots, the upper row of its left-hand part having 10 dots and of its right-hand part having 7. The lower row has 11 dots in its left-hand part and 8 dots in its right-hand part (11 + 8 = 19). The horizontal diameter of the cross divides the disc into two semicircles, each of which has 28 dots.

It can be also observed that, if metallic imprints of this die are produced, then, in addition to the disc, there will be two pins, each 6 cm long, and a flexible tweez-ers-shaped object that probably served as a compass (for drawing circles and measuring distances). Assuming that the disc and its carvings served the stated purpose, then these objects, which correspond to horizontal forms to the right of the ray-bearing disc on the die (Fig. 1c) can be understood as tools for its proper functioning. The two pins could be cut into three parts each, yielding six pins. Six pins are required for the proposed operation of the device.

After our numerical results, it appears that the most probable use of the plate's ray-bearing disc in combination with the pins and the pair of compasses pertains to astronomy (gnomonics).

Considering that gnomonics were known from the earliest antiquity in Egypt, an application in this disc is very probable. With the use of a pin placed at the center of the cross, its solar shadow on the disc's surface could lead to the determination of the following elements:

- The true solar time during daytime (use as a sun-dial)
- The geographical latitude
- The cardinal points on the horizon
- The first day of each of the year's seasons
- The length of the tropical year
- The daily change of the declination of the Sun

In what follows, these probable functions of the "ray-bearing" disc will be presented. For their study we created some drawings (Fig. 2) of the right-hand-side im-age of the plate, which show its functions as a) a sun-dial, b) an instrument for the determination of geographical latitude and c) an analog calculator for eclipse prediction.

3. FUNCTIONS AS A SUNDIAL AND LATITUDE FINDER

The die's imprint can determine the hour and the geo-graphical latitude of a location with the use of the three tools included, i.e. the two pins and the pair of concentric compasses of the die's right-hand side (Fig. 1c).

The "ray-bearing" disc has 25 triangular "teeth" (Fig. 3). If they are enumerated per 0.5-hour intervals and a pin is placed perpendicular to the central cavity, then the pin's solar shadow indicates the point of the disc's circumference that corresponds to the time of the observation when the central cross is aligned in the North-South direction. In this way, this simple device could be used as a portable sundial of 12.5 hours. Its "hour" corresponds to approximately 58 minutes, very close to the modern hour. The triangles ("rays" or "teeth") are not of equal size. This couldprobably be re-lated to the fact that in antiquity the hours were of un-equal length.

With each "tooth" corresponding to approximately 0.5 hour, the five dots on each tooth divide this length of time into 5 smaller time intervals, about 6 minutes each.

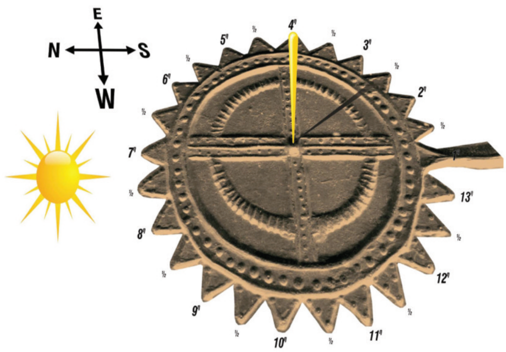


Figure 3. Representation of the function of the "ray-bearing" disc as a sundial.

If the one pin and the pair of compasses are used, with the user marking every 14 or 15 days (half of a lunar month) the edge of the pin's solar shadow at the moment of the true noon (upper culmination of the Sun resulting in the shortest shadow), then in the course of one year an *analemma* would form, a figure similar to the digit 8 (Fig. 4a, 4b, 4c). The shadow's angle at the equinoxes is at the two edges of the cross at Fig. 4c, and it is equal with the geographical latitude, approximately 35°15′ N in the case of Knossos. If a user had drawn the analemma in the area of Knossos, after a year's observations, and then travelled to a location to the North (e.g. latitude 51°), he would be able to find the latitude of the new position within half a month without prior knowledge of the date of the year, by comparing the part of a new analemma he would draw with the old one. Using this method, and marking the pin's shadow (in 15-day intervals) while travelling back to the south, the user would know that he was at the same geographical latitude with Knossos once the shadow produced the same analemma as the initial one. It would be easy for him to then return to Crete by sailing east or west.

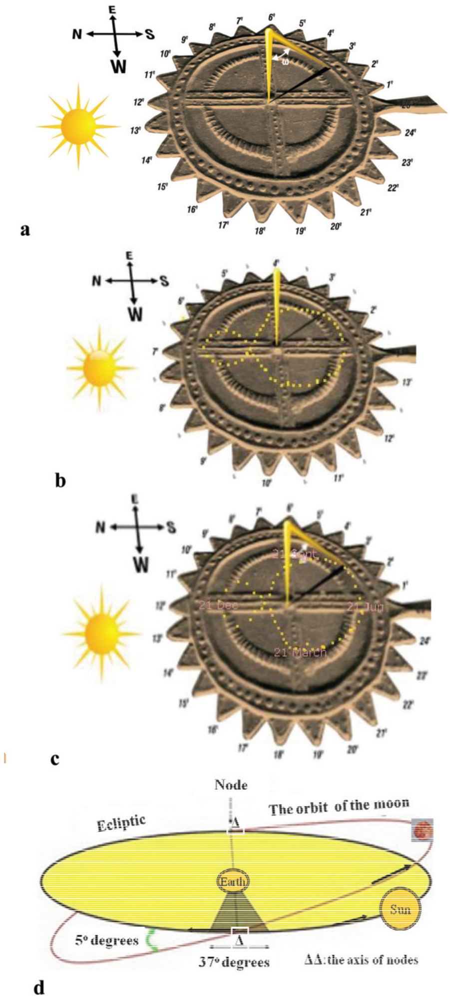


Figure 4. a. Representation of the use of the disc for the determina-tion of the geographical latitude. b. Recording of an analemma in the course of one year for the geographical latitude of Crete with the use of a ruler. c. Recording of an analemma in the course of one year for the geographical latitude of Crete, with the pair of compasses measuring the angle of incidence of the solar rays. This angle equals the geographical latitude at the equinoxes (about 35° in the case of Crete). d. A description of the motions of the Sun, the Moon and the nodes

4. AN ANALOG ECLIPSE CALCULATOR

Beyond this gnomonic use, we will now demonstrate a more complex function of the imprint of this die: as a portable calculator for predicting lunar eclipses. It re-cords every eclipse that occurs per lunar month and year whenever the Sun and the Moon are in conjunction (i.e. either at the full moon or at the new moon phase) near a node of the lunar orbit.

The inner circle (Fig. 5a) is divided horizontally by the double row into two semicircles, the one with 29 carved dots (15 on the left and 14 on the right-hand side) and the other with 30 (16 on the left and 14 on the right-hand side), that is a total of 59 dots. These two in-ner rings, with the 29 and 30 dots, lead to the conclusion that they correspond to two successive lunar "orbits" — apparent orbits since their average is the number of days (29.5) in a lunar or synodic month, that is the average time between two successive full moons. The exact value is 29.53058866 days, a difference of only 44.05 minutes per month. To use the die as an eclipse calcula-tor, six pins are required, corresponding to the following positions:

- ***One*** for the position of the Sun, which moves counterclockwise on the outer circumference with the 58 dots (small cavities on the imprint), one po-sition per approximately 6 days. These dots are numbered in yellow in Fig. 5h.

- ***One*** for the position of the **Moon**, which re-volves on the inner circumference with the 59 short carved lines. These lines are within the green dashed circle in Fig. 5h.
- ***Two*** for the **nodes** of the lunar orbit — the two points where the orbit of the Moon around the Earth intersects the ecliptic (the plane of the Earth's orbit around the Sun), on the triangles or "rays" of the "ray-bearing" disc. These are the 112 dots that run along the edges of the triangles in Fig. 5h.
- and ***two*** on the dots of the cross in order to fol-low the number of the lunar months and years that pass. The months are on the horizontal arm, and the 18 dots for the years are on the vertical arm in Fig. 5h.

With such a device the astronomers of the Minoan period could predict with considerable accuracy and precision the lunar eclipses, as well as some of the solar ones. This function of the device is performed as follows.

First of all, the device needs an initialization, after a lunar eclipse (preferably a total one) at a certain known date, with the following steps:

a) A pin is placed on the inner circle with the 59 dots, on one of the positions of the full moon marked at the end/start of the lower semicircle (because in the lower semicircle there are 30 short carved lines), the po-sitions ◖ immediately under the horizontal diameter.

b) Two pins are placed at the points of the nodes (denoted with Δ in Fig. 5b), on the dots of the two diametrically opposite "rays"–triangles, where the extrapolation of the line of the horizontal diameter intersects the triangles. These dots are inside the 25 triangles.

c) Another pin is placed on the initial position of the Sun ("58" in Fig. 5h). The outer circle, which appears in the disc's circumference next to the triangles, is the circle that corresponds to the motion of the Sun.

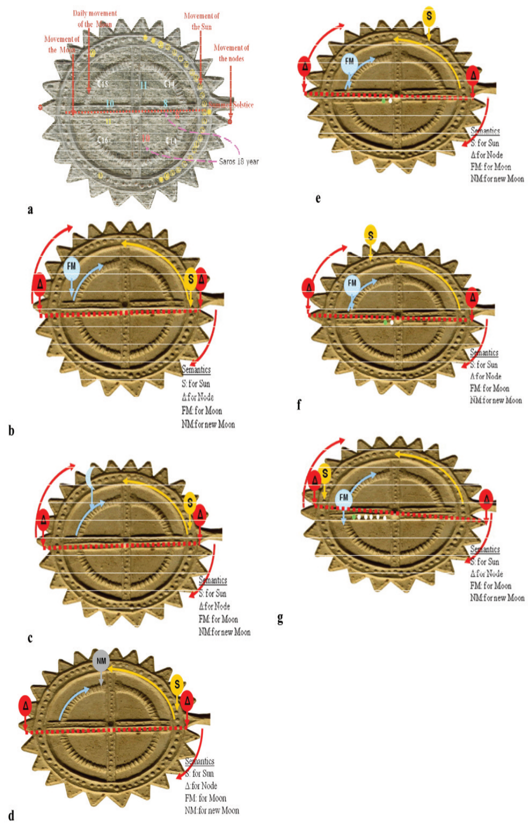


Figure 5. a. The "ray-bearing" disc with a description of the motions of the Sun, the Moon and the nodes. b. The initial conditions when the calculation starts from the December 21, 2010, eclipse; we see the positions on the next day. c. The positions 7 days later. The Moon has moved by 7 positions, while the Sun has moved by 1 position to the opposite direction (counter-clockwise). d. The positions 15 days after the full moon of the initiali-zation. Now the moon is new and the Sun has moved by two positions to the opposite direction. A partial solar eclipse is observed (January 4, 2011). e. The positions of the Moon, the Sun and the nodes two lunar months later, on February 23, 2011(2nd month). f. The positions of the Moon, the Sun and the nodes four lunar months later, on April 24, 2011(4th month). g. The positions of the Moon, the Sun and the nodes six lunar months later, on June 15, 2011, predict the lunar eclipse of that date(6th month)

i. The lunar cycle

Each day corresponds to the advancement of the Moon's pin by one short line, clockwise, along one of the two semicircles of the inner circle. When this pin reaches the position 29 of the inner semicircle, in the next step it jumps to the position "1" of the other semi-circle, which represents the full moon (◖). Then it moves to the next carved line, etc. When it reaches the thirtieth line (position "30" of the semicircle), i.e. at the next full moon, it is transferred to the position "1" of the next semicircle, and so on. Thus, between two succes-sive full moons there are on the average 29.5 days, the length of the lunar or synodic month, which is also the time period between any given phase of the Moon (e.g. first quarter) and the next same phase. When the Moon completes a full lunar month, a pin on the dots of the cross shifts by one position along the horizontal row of the cross, which has 11 dots (left-hand part of the horizontal line of the cross). When it reaches the 12th dot, a lunar year of 354 days has been completed. This event is denoted with the help of another pin, which is placed on the first one of the 18 dots of the lower right part of the horizontal diameter of the cross. This part of the horizontal diameter along with the lower right part of the vertical diameter corresponds to the saros cycle. In this way the current lunar year is recorded.

ii. The nodical cycle – Solar and lunar eclipses

Another motion tracked by the Palaikastro device is the cycle of the nodes. Indeed, we consider that the most logical interpretation of the 112 dots inside the 25 triangles or "rays" of the disc's circumference is that they track the shift of the lunar nodes as time passes. These nodes (Fig. 4d) are the two points where the plane of the orbit of the Moon around the Earth intersects the ecliptic (the average plane of the Earth's orbit around the Sun). These two planes are inclined with respect to each other by 5° 8′ (5.145 °).

The lunar nodes shift in space, so that they complete a whole circle once every 18.61 lunar years, or 18.61 × 12 lunar months. This shift is tracked by moving the pins of the nodes clockwise by 6 dots every 12 lunar months, always keeping them in diametrically opposite positions. Their initial positions are the points, marked with number "56" (Fig. 5h), intersected by the extrapolation of the horizontal line along the double row. The number 6 is the product of the division of the total number of dots in the triangles (112) with 18.61. The discovery of the cycle of the lunar nodes, and not just of their shift, requires several decades of careful ob-servation of the eclipses, which testifies to the astro-nomical tradition behind the civilization that constructed this die.

A total or partial *lunar* eclipse occurs when the moon is full and at the same time the Sun is near one of the lunar nodes, at an angular distance of less than about 14.4°.

When the Sun is very close to the point of the node, a total lunar eclipse occurs, while when it is at an angular distance of up to about 14.4° the eclipse is partial (there are also the penumbral eclipses, but these could go unnoticed by the ancient civilizations). If the Moon is at the new moon phase, then a total, partial or annular *solar* eclipse occurs. This observation has been carried upon the disc in an impressive way: Each triangle on the disc's circumference corresponds to a central angle of 14.4 degrees (= 360°/25). When the Sun is located between two successive triangles *and* the Moon is at the phase of full moon or new moon, then a total or partial eclipse of the Moon or the Sun occurs, respectively. The phenomenon corresponds to the relative positions of the bodies of the Moon-Sun-Earth system during a total or partial lunar eclipse (see Fig. 4d).

iii. The motion of the Sun

The movement of the Sun's pin on the outer circle is closely related to the movement of the Moon's pin on the inner circle. Once every 7 or 6 days, counted by the motion of the pin of the Moon, the Sun's pin moves one place counterclockwise in the circumference with the 58 dots. In other words, the number of days after which the Sun's pin moves by 1 place is the result of the motion of the Moon's pin according to the sequence 7, 6, 6, 7, 6, 6, 7, 6, 6, 7... In this way, the Sun moves by 56 positions in the course of one lunar "year" of 354 days (Every two lunar months the Sun moves by 9 positions and after 177 days or six lunar months the Sun will have moved by 28 positions. After six more lunar months, the Sun will be in the place no. 56 and 354 days will have passed, so the Moon will be at the point of day 47.)

In order to complete the full circle of 58 points, 12 more days are required, as it is shown in Fig. 5d. In this way, the length of the *solar* year is calculated to be 366 days.

iv. Verifying the function of the device

The first step for testing the Palaikastro device is to verify whether it can predict future eclipses with a reasonable accuracy and precision. Following the method described in the previous sections, we now use the device for the calculation of the lunar and solar eclipses of the next few years, starting ("initializing") from the total lunar eclipse of December 21, 2010. On this date the Moon's pin is on the "full moon" position (☾) of the lower right quadrant, as shown in Fig. 5h. The Sun's pin (✱) is on the dot no. 58. The lunar nodes (⬋Δ) are in diametrically opposite positions on the dots no. 56 of the "rays" or triangles of the disc's circumference — 4 pins are placed on all these dots (one for the moon, one for the sun and two for the lunar nodes). One day later, the Moon will have moved by one place (one short line), as in Fig. 5b, while 7 days later it will be in the position shown in Fig. 5e and the Sun's pin will have moved by one place towards the opposite direction.

Fifteen days after the full moon, the date is January 4, 2011. On this date there is a new moon and the Sun's pin has been moved by 2 places towards the direction opposite to the direction of the motion of the Moon's pin; the nodes remain on the same dots. It is observed that the Sun's pin is in the area of the triangle of the node, therefore, since there is a new moon, a partial solar eclipse takes place on January 4, 2011. Two lunar months later, on February 23, 2011, the Moon will be in a full moon phase and the Sun's pin will has been moved by 9 dots, while the nodes will have shifted one dot, as shown in Fig. 5e. The positions of all pins (lunar, solar and nodical) on April 24, 2011, are shown on Fig. 5f.

On June 15, 2011, 176 days (or 6 lunar months) af-ter the first lunar eclipse (December 2010), the position of the Moon corresponds to the full moon phase after it moved clockwise by one short line per day on the inner circle's semicircles of 29 and 30 days. The Sun's pin has been moved in the opposite direction and it is now on dot no. 28. The nodes have been moved clockwise by three positions during these six months, as can be seen in Fig. 5g.

On the left-hand side of Fig. 5h the node's pin is on the dot ③, the Sun is within the opening of the triangle and the moon is full, a coincidence that denotes a total lunar eclipse.

With this Minoan calculator one can further predict the total eclipse of December 10, 2011. This date comes 178 days or six more lunar months after the previous eclipse (178:29.5). Then the Moon's pin will have completed three cycles of two lunar months each and will be on the same full-moon line, while the Sun's pin will have been moved by another 28 dots and it will be placed on dot no. 56 of the outer circle; the nodes in the triangles will have been moved by another three dots and will be at the point ⑥. The fact that one node is ad-jacent to the Sun and the moon is full testifies to the reliability of the device.

In order to avoid probable coincidence

in the cases of the previous predictions, we extended our testing to the future eclipses up to the year 2028 (one saros period), as they are given in the NASA eclipse website (http://eclipse.gsfc.nasa.gov/OH/OH2010.html).

In the first three columns of Table 1 the dates and types of all eclipses that will occur after December 21, 2010, are given. In the 4th column there is the number of days that have passed after this date. In the 5th and 6th columns there are the corresponding numbers of lunar months and lunar years, respectively. In the 7th column the decimal parts of the years are converted into lunar months, while the 8th column gives the movement of the nodes in number of dots. The last two columns show the motion of the Sun's pin: the precise one and rounded to the nearest integer, which gives the number of the dots the pin has been shifted.

The proper eclipse prediction function of the Palaikastro device is shown in Fig. 5h through the positions of the lunar nodes, the Sun and the Moon based on the corresponding numerical elements of each eclipse.

The Palaikastro device predicts, in addition to the lunar eclipses, the partial solar eclipse that will be visible from Greece on March 20, 2015. It should be noted that, in the case of a total eclipse, the positions of the nodes and the Sun are within the same region of the same triangle, while in the case of a partial or penumbral eclipse the position of the Sun is usually on the triangular region adjacent to the one where the node is.

As a final description of the device's predictions let us consider the total lunar eclipse of September 28, 2015. Starting from the eclipse of December 10, 2010, and the positions of the Sun, Moon and nodes that have been mentioned, the number of days between the two eclipses is (365.24×4 + 8×30.5 + 28 + 10) = 1,742. If this number of days is converted into lunar months by dividing by 29.5, the result is 59 lunar months, which correspond to 4.92 lunar years. Thus, the Moon's pin must trace 59 semicircles or 29 full circles of two months plus one more month, and for the date of September 28, 2015, it will be placed on the full moon line opposite to the one it was on the December 2010 date.

During these 1,742 days the Sun's pin will have been moved counterclockwise by 275 places (4×58 + 43) and it will be on dot no. 43 of the outer circle, while the nodes, shifted by 6 places per lunar year, will be ap-proximately on the dot no. 30 (4.92×6 = 30) of the triangles. As it can be discerned in the lower part of Fig. 5b, the position no. 43 of the Sun's pin is exactly opposite to the position no. 30 of the node; and, since the moon is at the full moon phase, there is a total eclipse of the Moon. Additionally, the other two pins that mark the dots of the cross, in the lower right quadrant, are used to record the event of the eclipse, being on the dot no. 11 for the month and no. 4 for the year of the saros.

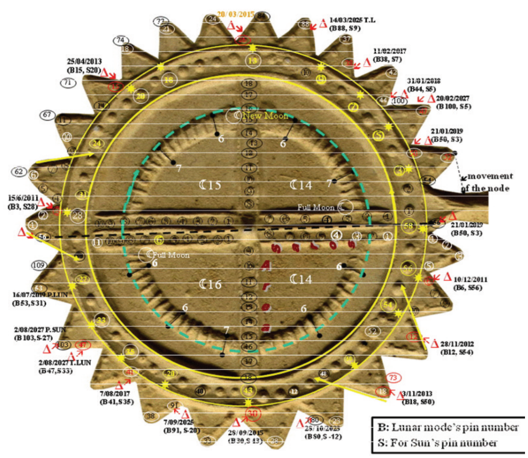


Figure 5. h. The analog calculator of the Palaikastro die with the eclipses of the years 2010 to 2028 recorded on it

Following the same algorithm, all 32 eclipses of Table 1 are shown in Fig. 5h upon the disc of the Palaikastro calculator.

v. The algorithm of the Palaikastro calculator positions

By studying a number of eclipses (Table

Table 1. The prediction of modern eclipses by the Palaikastro die. T = Total (or annular in the case of solar eclipses), P = Partial, N = Penumbral. The explanations for the columns 4 to 10 are given in the text.

#	Eclipse date	Eclipse type	[4]	[5]	[6]	[7]	[8]	[9]	[10]
0.	21/12/2010	T. Lunar	0	0	0	0	**0**	58	**58**
1.	04/01/2011	P. Solar	15	0.5	0.042	0.5	**0**	**2.37**	**2**
2.	15/06/2011	T. Lunar	176	6	0.5	6	**3**	27.82	**28**
3.	10/12/2011	T. Lunar	354	12	1	0	**6**	55.94	**56**
4.	28/11/2012	N. Lunar	709	24	2	0	**12**	-3.96	**-4**
5.	25/04/2013	P. Lunar	857	29	2.42	5	**15**	19.58	**20**
6.	18/10/2013	N. Lunar	1034	35	2.93	11.06	**18**	47.56	**48**
7.	03/11/2013	P. Solar	1047	35.5	2.96	11.47	**18**	50.01	**50**
8.	20/03/2015	P. Solar	1550	52.5	4.38	4.49	**26**	13.34	**13**
9.	**28/09/2015**	**T. Lunar**	**1742**	**59**	**4.92**	**11.02**	**30**	**43.44**	**43**
10.	16/09/2016	N. Lunar	2097	71	5.92	11.01	**36**	41.42	**41**
11.	11/02/2017	N. Lunar	2243	76	6.34	3.97	**38**	6.53	**7**
12.	07/08/2017	P. Lunar	2420	82	6.84	9.98	**41**	34.58	**35**
13.	31/01/2018	T. Lunar	2597	88	7.33	3.97	**44**	4.52	**5**
14.	27/07/2018	T. Lunar	2775	94	7.83	10	**47**	32.65	**33**
15.	21/01/2019	T. Lunar	2953	100	8.34	4	**50**	2.65	**3**
16.	16/07/2019	P. Lunar	3130	106	8.84	10	**53**	30.63	**31**
17.	10/01/2020	N. Lunar	3307	112	9.33	4	**56**	0.64	**1**
18.	***05/06/2020***	***N. Lunar***	***3455***	***117***	***9.75***	***9***	***59***	***24.02***	***24***
19.	21/06/2020	P. Solar	3471	117.6	9.80	9.56	**59**	26.63	**27**
20.	16/05/2022	T. Lunar	4164	141	11.75	9.03	**71**	20.14	**20**
21.	***25/10/2022***	***P. Solar***	***4326***	***146.5***	***12.21***	***2.5***	***73***	***-12.33***	***-12***
22.	05/05/2023	N. Lunar	4519	153	12.75	9.03	**77**	18.13	**18**
23.	28/10/2023	P. Lunar	4695	159	13.25	3	**80**	-11.98	**-12**
24.	18/09/2024	P. Lunar	5019	170	14.16	1.97	**85**	-18.82	**-19**
25.	14/03/2025	T. Lunar	5194	176	14.66	7.9	**88**	8.87	**9**
26.	07/09/2025	T. Lunar	5376	182	15.17	2.06	**91**	-20.36	**-20**
27.	28/08/2026	P. Lunar	5730	194	16.17	2.04	**97**	-22.47	**-22**
28.	20/02/2027	N. Lunar	5904	200	16.66	7.96	**100**	5.15	**5**
29.	02/08/2027	P. Solar	6069	205.5	17.13	1.52	**103**	-26.9	**-27**
30.	12/01/2028	P. Lunar	6231	211	17.58	7	**106**	-1.29	**-1**
31.	06/07/2028	P. Lunar	6407	217	18.08	0.97	**109**	-31.32	**-31**
32.	31/12/2028	T. Lunar	6585	223	18.6	7	**112**	-3.27	**-3**

1) and the positions occupied by the Sun, the Moon and the node pins, it was discovered that these positions can be determined by the following formula. The extraction of the described algorithm is based on the number of days that have passed from the date of an initial eclipse until the date of a future eclipse. If H is this number, then the position of the Sun's pin on the outer circle of the disc is the value of the integer function ΘH:

$$\Theta H = \mathrm{INT}[-2\times\mathrm{INT}(H/354) + (H/354 - \mathrm{INT}(H/354))\times 56 + 0.5] \quad (1)$$

Moreover, the position of the lunar nodes is the value of the integer function:

$$B\Delta = \mathrm{INT}[(H/354)\times 6 + 0.5] \quad (2)$$

In order to check the correct positions the outer circle of the disc, where the Sun moves, the dots on this circle have been enumerated from 1 to 58. The negative position numbers, for example -2, -4 or -12, correspond to the dots no. 56, 54 and 46, respectively, and so on. The circle of the 25 "rays" or triangles has been as-signed dot numbers in a symmetrical way (upper and lower part), from 1 to 56. (see Fig. 5h).

vi. Accuracy of the predictions of the Palaikastro calculator

From the 33 eclipses of Table 1 only two are not predicted: The one is the penumbral lunar eclipse of June 5, 2020, with node position 59 and Sun position 24 (it is the eclipse #18 of Table 1). It can be shown that, if the Sun's pin were one position forward, i.e. on dot no. 25, then this penumbral eclipse would be predicted.

The second case of an unpredicted eclipse is the event of October 25, 2022, which is #21 of Table 1. For this date the node's pin is on dot no. 73, and the Sun's pin is on dot. -12 or 46. This position is at least two places away from the red line that defines the boundary around a node within which the Sun must be to have an eclipse.

4. CONCLUSIONS

As a conclusion it can be said that the device generated by the die of Palaikastro can be used as a competent lunar and solar eclipse calculator even to this day: In a total number of 33 eclipses only two are not predicted, giving a percentage of error of 6 percent, while 94 percent of the predictions are accurate in the course of one full saros period of 223 lunar (synodic) months. However, a solar eclipse may well pass unnoticed for a civilization not possessing the proper equipment (partial or annular eclipse, or even no eclipse at all visible from the Mediterranean if the path is on the other hemisphere). Therefore, the device would probably have been used primarily as a lunar eclipse predicting device in addition to its simpler uses as a sundial and a geographical latitude finder.

The Palaikastro die can be regarded as an integral part of the astronomical knowledge of the Minoans as it is evidenced by the astronomical orientations of palaces and peak sanctuaries that have been determined by archaeoastronomical research (Henriksson and Blomberg 2011, Shaw 1977).

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