This paper refers to the investigation of the Zodiac scale and the Egyptian calendar ring of the Antikythera Mechanism front plate, based on the known surviving fragments of the Mechanism, mainly of Fragment C (National Archaeological Museum, Athens, inventory number X.15087). Fragment C is the preserved part of the front plate of the Antikythera Mechanism, located in front and above the large gear b1. Until now, only a portion and other isolated smaller fragments of the front plate survive.

The front plate dial was the cadran of the Annual and the Astronomical - calendar of the Mechanism. The manufacturer engraved on the front plate the information about the recurring events of every year on the Egyptian calendar ring and the Zodiac scale. During its revolution (1 turn/year), the pointer of the Golden Sphere - Sun (Gnomonion) pointed on the Egyptian Calendar ring, traversing the 12 months with 365 subdivisions and simultaneously the 12 zodiac constellations, engraved in arcs with subdivisions around the inside ring, just next to the Egyptian ring. The pointer - Gnomonion of the Sun - Golden Sphere (a bronze sphere with a pointer, which was possibly placed close to the perimeter of the annual gear b1) (Voulgaris et al 2018), as it traversed the two rings, informed the user about the position of the Sun on the sky, (on Zodiac Constellation), during the corresponding Egyptian month and day.

Ophthalmoscopic examination of Fragment C shows that the front plate had a large hole in the center (Bitsakis and Jones 2016). Two plates with engraved inscriptions of the parapema were on the top and on the bottom of the front plate of the Mechanism (Anastasiou et al 2013; Freeth and Jones 2016; Bitsakis and Jones 2016). In Fragment C, an
almost well preserved part of the parapegma inscriptions, is situated fossilized in front of the surviving dial rings and the Lunar Disc (Ptolemy; Wright 2012 notes; Carman and Di Cocco 2016). On the back side of Fragment C, lies the Lunar Disc, also fossilized (Fig.1), which was at the center of the mechanism before the ancient artifact was destroyed. By hand rotating the Lunar Disk (Voulgaris et al 2018), the user was also informed about the phases of the Moon, looking at the Moon Phases Sphere.

DATA MINING
Critical and determinant for our investigation, was the design and construction by A. Voulgaris of an optomechanical device with a modified camera lens, mounted on a micro moving x-y-z axes for tilting and aiming of the lens. This setup is capable to capture images of the fragments with extremely different position angles up to 83˚, eliminating the defocusing problem arising from the limited depth of field, which is strongly detected in conventional-non modified camera lenses (Fig. 1, 4, 5).

We also captured high resolution - “isogeometrical” images of the front and rear faces of Fragment C. We named our images “isogeometrical” because the capturing was done with the same optical system, in almost the same distance and perpendicularity from the well detected center of the fragment, so the parallax is the same and totally minimized on all of the images. So the images of the front and the rear faces are all of about the same scale and orientation. After the digitally processing (mirror invert in y axis) by the one the two images, we adding together and we constructed the Master Isogeometrical, Multilayered - high resolution - (visual) Image (Fig. 1,5). Then we added some of the corresponding AMRP X-ray tomographies (Figures 3,7). The very accurate-precise aligning of the set of these images was achieved by aligning on some distinctive - sharp areas of the boundaries of the fragment and especially the side to side mechanical (perpendicular on the plate) holes and other formations, avoiding aligning on the random cracks of the material or deformed areas. Therefore the Master Isogeometrical Multilayer Image offers the simultaneous selective observations of the front and rear areas of Fragment C.

After the digital processing, some very important new data about the design, the construction of the astronomical dial of the front plate, the handling and the using of the Mechanism were detected. Also some crucial differences from the published bibliography about the design and the role of the front plate dial have resulted.

THE DESIGN OF THE ANTIKYTHERA MECHANISM FRONT PLATE DIAL
The information about the annual astronomical events was engraved in the front plate of the Antikythera Mechanism (parapegma) and also in the two concentric rings: the Egyptian months ring and the Zodiac Constellations ring. The front plate of the Antikythera Mechanism was divided into three separate sections: the two Rectangular Sections, where the star events of the parapegma were inscribed.
Fig. 4 - Extreme "depth of field" image, shows the two rings which are located in the same level with the Middle Section of the front plate. Credits: National Archaeological Museum, Athens, A. Voulgaris. Copyright © Hellenic Ministry of Culture & Sports/Archaeological Receipts Fund.

Fig. 5 - On the top left: the Fragment C image with extreme depth field of view. The equal level of the two dial rings is shown and the rear stopper with a central hole. On the right: AMRP X-ray tomography in sideways direction. Bottom left: the stopper position compared to the boundaries of the two dial rings. Credits: National Archaeological Museum, Athens, A. Voulgaris. Copyright © Hellenic Ministry of Culture & Sports/Archaeological Receipts Fund and ©AMRP.
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(Anastasiou et al. 2013; Freeth and Jones 2016; Bitsakis and Jones 2016) and the almost square Middle Section, with the central hole (Bitsakis and Jones 2016; Wright 2012). Around the central hole of the Middle Section, the Egyptian calendar and the Zodiac Constellations were engraved in circular distribution. As shown in Fig. 2, from the Master Isogeometrical Multilayer Image of Fragment C, three totally independent rings surround the central hole of the Middle Section:

a) The Bearing-Base ring (Wright shows this as not independent from the Middle Section and present this as a sink dug on the Middle Section, (Video presentation at 50:55' and 50:58'').
b) The inlaid Egyptian calendar ring
c) The Zodiac Constellations ring (totally independent), (Wright shows in https://www.youtube.com/watch?v=cSh551cdeY at 50:55'' and 50:58'' and also Bitsakis and Jones (2016) and Jones (2017) refer to this, as a not independent part from the Middle Section, i.e. a "solid body" with the Middle Section).

The detection from CTs that the Zodiac Constellations Ring and the Bearing Base ring is an independent ring, it is not easy, because of strong fossilization, which transformed the rings as "one body" with the Middle Section. The Bearing-Base ring is stabilized to the almost square Middle Section by staples, from which only one from the four survives (Fig. 2). As detected from the Master Isogeometrical Multilayer Image and the composition of the corresponding CT by the AMRP, this staple is the rear edge of (one of the four, preserved and detected in CTs (Bitsakis and Jones 2016) peripheral stabilizers of the Egyptian calendar ring Fig. 3. These stabilizers prevent the Egyptian Calendar ring from falling outside.

In X-ray CT scans, out of a possible total of 365 holes, 87...
have been detected on the **Bearing-Base ring** with diameter 0.7mm - 0.8mm (Wright 2012; Evans et al 2010). These holes well drilled by the manufacturer in a circular allocation on the **Bearing-Base ring** with excellent accuracy (Fig.7).

Some of these holes were also detected in our visual photographs of Fragment C, with the help of the X-ray images. From our photographs with extremely sideways capture angle, it is evident that the **Zodiac Constellation and the Egyptian calendar rings** are on the same level with the **Middle Section** of the front plate Fig.4 (Wright video presentation; Bitsakis and Jones 2016; Jones 2017). About half of the width of the Egyptian calendar ring is positioned on the half of the width of the **Bearing-Base ring** Fig.7, while the **Zodiac Constellations ring** does not have any contact with the **Bearing-Base ring**. It is of course mandatory that the **Zodiac Constellations ring** is somehow supported. In Fig.5 behind the two rings, just at their contact boundaries, a formation is detected, which seems it could well be one of four (or three) rear stops. This elongated formation-stopper has a cylindrical perforated cross section and it is curved following the circular boundaries between the contacts of the two rings. This formation could be stuck (soldered?) on the rear face of the **Zodiac Constellations ring** (or on the Egyptian calendar ring, but it is not easily evident from the tomographies), preventing this ring from falling outside (or inside). We also assume that of 3 or 4 stops acting also as little pointers (needles), stuck on the front side of the **Zodiac Constellations ring** (or on Egyptian calendar ring) were necessary to prevent this ring from falling inside (outside). These totally necessary front and back stops placed the **Zodiac Constellations ring** on the same level with the Egyptian calendar ring and allowed its free rotation.

The free - independent rotation of the **Zodiac Constellations ring**, offers the ability of the very precisely aiming and calibration of the ring, in relation to the positions of the **Golden Sphere- Sun pointer** and the **Lunar Disc pointer** (see chap…..). It also offers the ability of correction of the Callippic calendar which requires the subtraction of one day every four Metonic cycles (Theodosiou and Danezis 1995; Freeth et al 2008): after four Metonic cycles, the user can rotate the independent **Zodiac Constellation Ring** CCW by one subdivision (one day). A similar ability can be detected on the clocks cadran: after the assembling of a clock, it is possible that the pointer of the seconds does not coincide exactly with the clock’s cadran subdivisions (usually 1 subdivision/5 sec-min) (Fig.6). The clock maker must calibrate the clock: he can rotate the clock cadran CW or CCW to achieve the absolute coincidence of the pointer of seconds with the subdivisions of the cadran.

The three rings of the front plate of the Mechanism, had engraved measuring scales with subdivisions or holes, so it is logical to assume that they were sequentially made by dividing, engraving, drilling machines (Voulgaris et al 2017; Irby 2016). According to our precise measurements about the drilling process of these holes, the dividing error must be ≤ 0.3˚ to avoid overlapping of the holes. Even today the dividing and drilling of 365 holes with a diameter of 0.8mm with mechanical conventional tools, is an arduous work and requires extreme accuracy and attention. The **FRAME Project** team designed and constructed the conventional cutting-dividing-drilling machine for the **Bearing-Base ring** and studied the procedure and the duration of the drilling on the **Bearing Base ring**.

The central section of the front plate was secured with four sliding caches (Wright 2012; Bitsakis and Jones 2016), of which only one is preserved. The sliding pin was secured on the rear face of the two rectangular parts of the parapegma (upper and bottom). In Rehm’s photograph of Fragment A, taken on 1904/5 (Rehm 1906), some preserved wooden linear formations, in vertical and horizontal positions (a part of wooden outline there is Fragment F via radiography of AMRP) (Fig.8) (Wright 2012). Based on the preserved Fragment C photographs and CTs, we digitally reconstructed the possible view of the Middle Section of the ancient prototype Fig.8. In this digital reconstruction, we also added Rehm’s reconstructed photograph of Fragment A. In Figure 8 it seems that the vertical fossilized wood acts as a bearing spacer between the Front Middle Section and the Medium plate. The lower boundaries of the Middle Section plate are not matching with the wooden horizontal outline formation. The horizontal wooden outline formation acted as a bearing spacer of the lower Rectangular Section (parapegma).

By measuring the dimensions of the preserved deformed, distorted and incomplete parts of the Mechanism, the possible true dimensions of the Front Plate of the Mechanism (including the partially preserved wooden outline, as detected from the radiographies of the Fragment B) were at least 200mm X 330mm. In our functional models we chose the ratio of the sides equal to the golden ratio φ=1.618, which was used by ancient designers, sculptors, mathematicians and applied in a lot of constructions in ancient Greece (Hambidge 1924; Euclid).

**THE EGYPTIAN CALENDAR RING**

The inlaid freely rotating ring represented the Egyptian months ΘΑΘ (Theta, ΦΑΘΟΙ (Phaophi), ΑΘΥΡ (Athyr), ΧΟΙΑΚ (Hoiak), ΤΥΒΙ (Tybi), ΜΕΧΙΡ (Mechir), ΦΑΜΕΝΟΘ (Phamenoth), ΠΑΧΩΝ (Pachon), ΠΑΥΝΙ (Payni), ΕΠΙΦΙ (Epiph), ΜΕΣΟΙ (Mesori) of 30 subdivisions each) and 5 induced (epagomenai) days. According Figure 2 the Egyptian calendar ring was adapted onto the **Bearing Base ring** (see the previous chapter).
and was held in place by four peripheral stabilizers (Bitsakis and Jones 2016). Setting the disc in a given position, the fixation was probably done by inserting one (or two) pins, applied in one (or two opposing) of the 365 peripheral holes of the Bearing-Base ring (Wright 2012). The user removed the pins every four years or 53.4 full rotations of the Lunar Disc (sidereal months), rotated the Egyptian calendar ring anticlockwise by one hole and placed the pins back, thus accounting for the slide of the Egyptian calendar ring relative to the solar year.

The Egyptian calendar had 365 days per year and did not account for a correction over the actual duration of 365.25 days. This meant that it preceded the actual year by one day, every four years or 6 months in 720 years and essentially the seasons and the risings and settings of the stars did not occur in the same Egyptian date overtime. Every 1460 years, namely during a Sothic Cycle (Theodosiou and Danezis 1995) or Calendar Period (Murray 1828), the Egyptian calendar would return to its original starting position. The Sothic Cycle began with 1\(^{\text{st}}\) Thoth (the first month of the Egyptian calendar) at the first day of the morning rising of Sirius. Censorinus and Theon of Alexandria report that the Egyptian calendar at the first day of the morning rising of Sirius, 150 BC should point at the third subdivision of the month ‘‘Χηλαι’’ (Libra). By examining the surviving fossilized Egyptian calendar ring and the Zodiac Constellations scale ring of the Fragment C, 1\(^{\text{st}}\) Payni points to 18\(^{\text{th}}\) subdivision (day, see next chapter 2.3) of Libra and this correlation happened on 569 BC (see also Price 1974).

The Egyptian Calendar ring does not affect and is not related with the measurement system of the Mechanism, the pointers or with the gears. Its role is “more passive” and its position depended entirely from the other scales-calendars.

As described above, the Mechanism was constructed so it could be readily used at any given date and year and it is possible that it was set to this specific date by the user and the Egyptian calendar ring position followed the position of the rest rings and pointers.

**THE ZODIAC MONTHS SCALE - RING**

Concentric to the Egyptian Calendar ring, was the smaller inlaid and freely rotating Zodiac Constellations ring. On this ring were engraved the zodiacal constellations Libra (XHAAL), Scorpio, Sagittarius, Capricorn, Aquarius, Pisces, Aries, Taurus, Gemini, Cancer, Leo and Virgo. Of the 12 zodiacal constellations, Libra (by naked eye) and Scorpio (by CTs) are completely preserved in Fragment C, with 30 subdivisions each and also parts of Virgo and Sagittarius survive (Bitsakis and Jones 2016). Because of the existence of the subdivisions, this ring was also a measuring scale.

According to Price 1974, the Zodiac scale was probably divided into 12 equal arcs, with 30 subdivisions each, therefore was divided into 360 subdivisions i.e. degrees (Wright 2002b). If the Zodiac scale was divided into 360 equal subdivisions, then the solar anomaly could not be represented (Evans et al 2010). We will argue that the Zodiac ring was divided into 365 (equal) subdivisions (or less possibly in 364 divisions + 1.25, a more extended one) i.e. days (and not degrees), with 12 zodiac (unequal arcs) months, with an uneven number of days, depending on the duration of each zodiac month, for the following reasons:

1) The fact that the rotation of the Lunar Disc and the revolution of the Golden Sphere-Sun with its pointer, traced the 365 subdivisions-days of the Egyptian calendar ring, indicates that the Mechanism acted as an astronomical calendar-time measuring device. Thus, in the front plate, the quantum unit of the front dial measuring system was one day (time unit) and in the back plate was one synodic lunar month.

The Egyptian Calendar ring and the Zodiac Constellations ring seem to be concentric and both of these have engraved subdivisions. The pointer of the Golden Sphere traced simultaneously the subdivisions of the two scales during its revolution.

A characteristic paradigm of a measuring machine - device with two concentric scales with a common central pointer is the old analog voltage-current multimeter. The two scales are related with a constant ratio or they have the same units.

Because the Zodiac Scale and the Egyptian calendar ring of the Mechanism are circular and concentric with a common pointer (pointer-Golden Sphere), the ratio of their measuring units (subdivisions) must be a constant number. If the measuring unit of the Egyptian month dial ring is days \(t_{\text{days}}\) and the zodiac scale units is \(x\), the ratio \(t_{\text{days}}/x = a\) (4) must be a constant number. If we assume that the zodiac scale had 360 subdivisions i.e. angle degrees, the equation (4)
is written in an analog function: $\alpha(t^{\text{days}}) = a \cdot t^{\text{days}}$ (5). The time ($t^{\text{days}}$) that the Sun takes to cross an angular distance of $d^\circ$ in the zodiac circle in the sky, is given by the equation $t^{\text{days}} = d^\circ / v_{\text{sun}}$ (6). Because of the solar anomaly, Sun’s velocity $v_{\text{sun}}$ is not constant, so the equations 6 and 5 cannot be constant. Therefore, the hypothesis that the zodiac scale had 360 equal subdivisions of degrees is not correct.

2) The parapegma of the Mechanism (Anastasiou et al 2013) referred to observations on specific dates (i.e. days) when the risings/settings occurred. The manufacturer engraved the numbering of the risings/settings of the stars of the parapegma, on some of the subdivisions of the zodiac scale with index letters (in Fragment C, 12 index letters are preserved on some zodiac scale subdivisions) (Bitsakis and Jones 2016). The user read the index letters on the zodiac subdivisions and simultaneously these letters were engraved on the beginning of each parapegma corresponding sentence of the star event.

We do not think that the manufacturer converted the dates of the star events (days) in the corresponding degrees and then engraved the letters on the subdivisions of the zodiac scale, using a different scale unit than days. The ratio $365 \text{ days} / 360^\circ = 1.01388888 \text{ days/degree}$ and this conversion creates periodically errors during the dividing-engraving of the subdivisions, because of the rounding error, which downgrades the accuracy: in the beginning of the two scales (Egyptian-days and Zodiac-“degrees”), the subdivisions are coincident, but as the subdivisions proceed the two scales
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3) Taking into consideration the constructional techniques at that time, it would be more precise and easy to simultaneously divide and engrave two concentric rings, attached to a common center. The probable divisional machine of the manufacturer was already calibrated in 365 subdivisions for engraving the ring of the Egyptian months and for drilling the 365 holes on the Bearing Base ring. If the zodiac scale had 360 subdivisions, then he would need to recalibrate the dividing machine tool for 360 divisions. This task at that time was quite painful and slow.

4) If the Zodiac scale had 360 subdivisions in degrees, then to account for the solar anomaly, it would require 360 unevenly distributed subdivisions (closer spaced at the months that the Sun’s velocity is faster). We consider this hypothesis unlikely, because we must assume more hypotheses and more structural-constructional modifications of the front plate (Evans et al 2010). This contradicts the principle (philosophy) of the fewest assumptions, as first stated by pythagoreans philosophers and later known as the Occam’s razor (https://plato.stanford.edu/entries/logical-construction).

Therefore, the hypothesis that since both the two surviving constellations, Libra and Scorpio, were divided in 30 subdivisions, then all of the remaining constellations would also be divided in 30 subdivisions (degrees) is neither necessary, nor mandatory for the proper functioning of the Mechanism. Instead it hinders the functionality of the Mechanism. There is no reason to divide the zodiac scale in 360 subdivisions, since the dividing into 365 subdivisions is simplest, easier,

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Era 432 BC Days</th>
<th>Era 330 BC Days</th>
<th>Era 130 BC Days</th>
<th>Era 80 BC Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn Season</td>
<td>28/9-25/12 (perihelion 29th Noe)</td>
<td>92</td>
<td>27/9 - 24/12 (perihelion 30th Noe)</td>
<td>92</td>
</tr>
<tr>
<td>Winter Season</td>
<td>26/12-25/3</td>
<td>90</td>
<td>25/12 - 24/3</td>
<td>90</td>
</tr>
<tr>
<td>Spring Season</td>
<td>26/3-27/6 (aphelion 29th May)</td>
<td>94</td>
<td>25/3 - 26/6 (aphelion 30th May)</td>
<td>94</td>
</tr>
<tr>
<td>Summer Season</td>
<td>28/6-27/9</td>
<td>92</td>
<td>27/6 - 26/9</td>
<td>92</td>
</tr>
</tbody>
</table>

Tab. 1 - The dates of the Solstices and Equinoxes and the duration of the seasons for different Eras.

<table>
<thead>
<tr>
<th>ZODIAC CONSTELLATION</th>
<th>Date on 130 BC</th>
<th>Equinoxes and Solstices</th>
<th>Duration of the Zodiac Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Libra</td>
<td>27 September-26 October</td>
<td>Autumnal equinox</td>
<td>30 (Fragment C)</td>
</tr>
<tr>
<td>Scorpio</td>
<td>27 October -25 November</td>
<td></td>
<td>30 (Fragment C)</td>
</tr>
<tr>
<td>Sagittarius</td>
<td>26 November-24 December (perihelion on 1st December)</td>
<td></td>
<td>29</td>
</tr>
</tbody>
</table>

**autumn season duration** 89 days duration

| Capricorn | 25 December - 22 January | Winter Solstice | 29 |
| Aquarius | 23 January -21 February | | 30 |
| Pisces | 22 February -24 March | | 30 |

**winter season duration** 89 days duration

| Aries | 25 March-24 April | Vernal equinox | 31 |
| Taurus | 25 April-26 May | | 31 |
| Gemini | 27 May-26 June (aphelion on 31st May) | | 32 |

**vernal season duration** 94 days duration

| Cancer | 27 June-27 July | Summer Solstice | 31 |
| Leo | 28 July-27 August | | 31 |
| Virgo | 28 August-27 September | (parapegma inscriptions) | |

**summer season duration** 93 days duration

Tab. 2 - The duration of the Zodiac Months.
without errors and fully functional. So we believe that the Antikythera Mechanism was a time measuring machine and not a machine like a sextant (for angles measuring).

THE ANCIENT MEASUREMENTS OF A SEASONAL DURATION

The unequal duration of the seasons and also the different duration of each zodiac month were known in ancient Greece, from observations of Meton and his partner, Euktemon (Pavel 2006; Jones 2017). The calculation of the dates of the solstices and the equinoxes, was done from the hill of Pnyka in Athens, using their invention, the Heliotropion or Helioscopion. Meton identified the repetition of the positions of the Sun and Moon in relation to the sky (stars) in the era of about 432 BC, known as the 19 years Metonic cycle (Freeth et al 2008; Theodosiou and Danezis 1995). About one hundred years after Meton, around the era of 330 BC, Callippus continued the observations and improved the accuracy of the calculation of the dates of the seasons and the dates of the Solstices and Equinoxes.

One possible setup of the Helioscopion and a method for calculating the dates of the solstices and equinoxes in ancient time, could be based on the use of an East-West aligned oblong container, filled with mercury, which acted like a permanent leveled mirror reflecting the sun’s light Fig.5 (mercury as cinnabar was in use in ancient Greece and Egypt for the separation of gold ore) (Theophrastus). The observer secured the container to a fixed place on the ground in some distance from a wall several meters high (e.g. The Horologion of Kyritos - Οχρολόγιον του Κυρρητος, known also as the “Tower of the Winds” in Pnyka of Athens, was 12m high) (Noble and Price 1968). By making observations for a few consecutive days and recording the maximum daily height of the reflection of the sun rays on the wall, he could determine a point of the “reflected” local meridian. Next, by using a plumb line cord (“Σταφυλίς – Staphylis”) (Orlandos 1955), he drew the local meridian on the wall, as a vertical line. The reflected sunrays from an oblong mirror have also oblong form, thus making the measurements easier and more accurate. The lowest height of the solar reflection was during the date of the Winter Solstice (Sun’s Declination -23.4˚) and the highest during the date of the Summer Solstice (Sun’s Declination +23.4˚). Using trigonometry (calculations on the Meridian Wall or using the local latitude), the observer could calculate the point on the Meridian Wall at the dates of the equinoxes (Sun’s Declination 0˚). He could also design-mark other useful information of the celestial sphere e.g. the projection of the Ecliptic in different dates. If the distance between the two solstices on the wall was about 5m (i.e. the distance of the mirror from the wall was about 2.5m), the scale on the Meridian Wall, would be about 0.1˚/1 cm. This scale offers a resolution of about 4 arc min, enough for precise calculations. In this manner, also some nighttime lunar observations could be performed. A second idea of how Helioscopion could be implemented is the pinhole camera (camera obscura). The pinhole camera was known in Ancient Greece since Aristotle (Gatton 2016; Aristotle; Euclidis; http://paleo-camera.com/) . In a dark room with a small hole on the wall, located towards the meridian, the Sun’s image was projected on the floor and the projection of the solstices was inverted: the Summer Solstice closest to the wall with the hole and the Winter Solstice farthest (Sutter 1964, https://www.youtube.com/watch?v=MnnntOVHw4Y) . The distance of 2.5m between of the hole and the floor offers the same resolution with the...
Moreover, if the distance between the pinhole and the projected image on the floor is large enough, then it is even possible to measure the diameter of the solar image (as a pinhole camera solar projection). For example for a hole-floor distance of 10m, the projected solar image has a diameter about of 93.5 mm on perihelion or about 90.5 mm on aphelion i.e. sufficient enough for someone to realize and measure the change of the apparent solar diameter from perihelion to aphelion.

We consider unlikely the possibility that the Heliotropion, designed-constructed and used by the excellent geometer-engineer Meton, could be only a high pillar, because the projected shadow on the ground is of too much low contrast with very extensive and blurred limits.

**THE ZODIAC MONTHS RING RECONSTRUCTION**

The division of the Zodiac scale ring into 365 equal subdivisions (days) converts it to a Zodiac Months ring. Each Zodiac Month begins when the Sun transits (projected on) the Zodiac Sign of the corresponding Zodiac Constellation and its duration is measured in days. The 12 arcs of zodiac months are not equal, because they have a different number of days, due to the solar anomaly. Of course we don’t know which data, astronomical map, zodiac signs, observations and calculations about the duration of each zodiac month the manufacturer used.

We assume that on the ancient astronomical map used by the manufacturer, the Ecliptic was divided in 12 equal arcs of 30˚ each. Each of the 12 zodiac constellations began with its zodiac sign, as usually inscribed on most ancient astronomical/astrological maps of Babylon, ancient Greece and even on most recent maps until today (Theodosiou and Danezis 1995; Rogers 1998; Powel 2006).

For the calculation of the duration of each zodiac month in era of 130 BC (the possible era of the Mechanism’s construction) (Freeth et al 2006), we firstly calculate the duration of each seasonal period.

Each seasonal period of three months, started with the date of the corresponding solstice or equinox. According to the ancient Greek calendar (Theodosiou and Danezis 1995), the beginning of every day was the time of the sunrise and for our calculations we used the exact time of sunrise (about 6 a.m. ±1 hour, depending on the season). Using the recalibrated astronomical planetarium software Starry Night
In the era close to 130 BC, the autumn season duration was 89 days. The two zodiac months Libra and Scorpio fully preserved on Fragment C, each have 30 subdivisions-days (Bitsakis and Jones 2016). So the duration of Sagittarius (the third zodiac month of the autumn season) must be 29 days. In this way the zodiac month of Sagittarius, has the smallest duration in days, which is in correlation with the fact that it includes the date of perihelion i.e. the date when the Sun’s velocity is in its highest value (so the duration of this zodiac month must be shorter).

The duration of the winter season is also 89 days. The duration of the three missing zodiac months of the winter season, were chosen to be of 29, 30 and 30 days respectively. These numbers were chosen because of the gradual decrease of the sun’s velocity after the date of perihelion. As a result, the duration of each month of the winter season is in mirror - axial symmetry to the corresponding months of autumn season.

The spring season has duration of 94 days and the summer season of 93 days. In the same manner, we keep the pattern of the axial mirror symmetry of the duration of months with respect to the line of apsides (and also close to the Solstices). The month with 32 days (to account for the extra day of the spring season) was chosen to be the zodiac month of Gemini, because this month includes the date of aphelion, when the Sun’s velocity is in its lowest value. The rest two months of spring season were chosen to be of 31 days each. Also for the summer season duration of 93 days we chose the duration of each month to be 31 days so that the axial mirror symmetry of the duration of months with respect to the line of apsides continues to apply.

Another proof of the above calculations is the crucial observation from the Front Dial inscriptions (Bitsakis and Jones 2016). In the preserved part of Fragment C of the constellation of Virgo, Bitsakis-Jones report the detection of two subdivision letters (index letters), Ψ on the 19th subdivision engraving and Ω on the 21st. The part of Virgo constellation arc with engraved subdivisions 1-14 is missing and the numbering of the index letters Ψ and Ω was calculated from the existing end of the month, counterclockwise, assuming the presence of 30 subdivisions (for Ψ, 30-12=19th sub. and for Ω, 30-10=21st sub.).

On the preserved Fragment 28, detected individual letters may be associated with the constellation of Virgo. Parts of words and two (date) numerals [IC and K[A,B,...]] are preserved on fragment 28 (Bitsakis and Jones 2016):

**Line 1:** [Zodiacal constellation begins rising] [A]
**Line 2:** ...... (male attribute) [rises/set in the even]ing IC (i.e. in 16th subdivision of the zodiac month scale)
**Line 3:** ...... (female attribute) [rises/set in the even]ing IC [A,B,...]
**Line 4:** Rising .......... E...[K+1, KA+1, KB+1,...]

Bitsakis and Jones suggest the following star events associated with Fragment 28:

**Line 1:** Virgo begins to rise [A]
**Line 2:** ...... (male attribute) [rises/set in the even]ing IC (i.e. in 16th subdivision of the zodiac month scale)

**Line 3:** Capella (Âιαταια) rises in the evening K or [K[A,B,...] (20th or 21th, 22nd ..... subdivision of the zodiac month scale) for "Ψ" index letter

**Line 4:** Arcturus rises in the morning [Kα or K[B,Γ1,...]] (21th or 22nd or 23rd or 24th,...) for "Ω" index letter

The correlation between Fragment 28 and the preserved index letters of Virgo in Fragment C, leads us to the conclusion that the index letters Ψ and Ω must be at the 20th (K) (Line 3) and the 22nd (KΩ) (Line 4) respectively engraved subdivisions and not at 19th and 21st subdivision. So in the Zodiac Month scale, the arc sector of Virgo, must have 31 subdivisions i.e. 31 days (Fig.13).

If the zodiac month of Virgo has a duration of 31 days, then the two previous months should also have at least 31 days each (see below) (because they are closer to the date of aphelion). As a result, the summer season had a duration ≥ 93 days. The 93 days of the summer season is valid for 130 BC, but not for 432, 330 and 80 BC (see Table 1) and also not for the era of 150 BC (according to Starry Night program). So the astronomical data used for the construction of the Zodiac Month scale by the manufacturer, must originate from observations made at about 130 BC (or a few years later) (Hipparcos age c. 190-c. 120 BC). At that time the access to astronomical information was slow and delayed for a few years, since the publication of the observations was time consuming and expensive. So we believe that the date of the construction of the mechanism was between 125 and 100 BC.

According to Table 2, we reconstructed the Zodiac Months ring. The division of the Zodiac Months ring scale into 12 zodiac unequal months and 365 equal subdivisions creates unequal arcs of the zodiac months, depending on the number of days in each zodiac month. Therefore with this design, the calculation of the solar anomaly is included in the Antikythera Mechanism mechanical model, without any other assumptions. Figure 14 shows the possible representation of the Zodiac Months ring of the front plate with 365 subdivisions of the 12 unequal zodiac months.

Because the Zodiac Months Ring was free to rotate, it is obvious that the position of the four seasonal columns of the parapegma does not correlate with the preserved position of the Zodiac Months Ring (Price 1974; Freeth and Jones 2016; Bitsakis and Jones 2016). So it is possible that on the top left position of the parapegma, the summer season star events were engraved (Cancer, Leo, Virgo) and not the winter season star events, because the Callippic Cycle started at the Summer Solstice (Theodosiou and Danezis 1995, Evans 1998).

**ANTIKYTHERA MECHANISM AS A TIMELESS COMPUTER**

As we mentioned above, the Zodiac Months Ring was also independent and free to rotate. Although the manufacturer could engrave the zodiac months around the perimeter of the central hole in a fixed position, he did not do so.

The mechanical system of the engaged gears that moved the Moon and the Sun was fixed (“closed” system), therefore it was impossible to accurately rotate the Golden Sphere independently to the Lunar Disc-Moon Sphere to any position (date), without disengaging some of the gears. It is obvious that the manufacturer designed the Zodiac Month-Sky, as an independent ring, so that he could quickly set the front plate dial to a specific date (by turning “the sky” of the Mechanism) starting the mechanism in any desired date, as a perpetual computational calendar mechanism with very extensive time limits. With this process, it seems that the mechanism had the ability of fast recalibration and of necessary minor adjustments, to account for mismatches...
between the actual calendar date and front plate dial indications caused by mechanical errors (Edmunds 2011; Jones 2017) and also the subtraction of the one day in every Callippic cycle (Freeth et al 2008). Moreover, to move forward in Time, the Mechanism should be rotated clockwise from the Lunar Disc. For the past dates, the user needed to rotate the Lunar Disc counter clockwise. This change in the direction of the rotation introduced some mechanical problems between the teeth of the gears, a lot of “backlash effects” and aiming errors of the pointers (especially in “slower” pointers) (Edmunds 2011). All of these errors disappear, if the Lunar Disc was continuously rotated (only) clockwise, as the Time moves forward: for a desired date of the Past, the user rotated the Zodiac Months ring (just on the desired date) and then continued the clockwise rotation of the Lunar Disc.

For example the ancient user could start the Mechanism from the date of the total solar eclipse on 19th August of 310 BC (i.e. during the 20th year of the first Callippic cycle, the first day of the third synodic month of the ancient Greek calendar, in the corresponding 18th day of Zodiac Month of Leo, for 310 BC), known as the eclipse of Agathocles (https://eclipse.gsfc.nasa.gov/SEsearch/SEsearchmap.php?Ecl=-03090815 ; www.mreclipse.com ; Stephenson 1997). Firstly the ancient user, via clockwise rotation set the pointer of the Lunar Disc, aiming to the Sun-Golden Sphere (New moon). Then he rotated the independent Zodiac Months ring up to the pointer of the Golden Sphere aiming to the 18th zodiac day of Leo. After this calibration, he started the back dial plate calibration (Voulgaris et al under writing). Finally he rotated the Egyptian calendar ring to the corresponding date. After the calibration of the Egyptian calendar ring, the user knew the dates of the equinoxes /solstices on the corresponding Egyptian dates.

The Mechanism was a “time measuring machine computer” (Fig. 15), designed and constructed so as to minimize all the mechanical and calendrical errors. Because of the engraved days on the Zodiac Months Ring and its freedom to rotate, we argue that the tropical year was known and in use (as a measured part of the 1/19 of the Metonic Cycle) in Ancient Greece, but the synodic month was more usable in that era. We strongly believe that the Mechanism was constructed for some governmental or administrative authority of that era. This hypothesis is enhanced by the presence of the Stephanites Games, engraved at the back plate of the Mechanism (Freeth et al 2008): several synodic months before the starting date of the Olympic Games, the “spondophoroi messengers” (Σπονδοφόροι Αγγελιοφόροι) traveled to the Greek cities to announce the starting date of the Olympic Games on the 2nd full moon after the Summer Solstice (Perrotet 2004).

The new findings of the front astronomical dial, shows us that the Mechanism could calculate the positions of the Sun, the Moon and also the Moon Phases and that it entailed all of the astronomical knowledge known in antiquity (Moussas 2009), like a “bronze astronomical book”, equipped with all the parameters required to perform astronomical calculations, thus making it a real astronomical calendar-time computer.

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ABSTRACT

The present study aims to investigate the astronomical calendar-dial display of the Antikythera Mechanism Front Plate. The design, position and role of the Zodiac ring, are investigated and discussed. Special photographs taken from the ancient prototype, give us new information about the design and operation of the front dial. From these new findings about the Zodiac ring, we conclude that the user of the mechanism was able to easily perform astronomical calculations at any selected time - of past or future date. Based on the new findings during “The Functional Reconstruction of Antikythera Mechanism Project” (FRAME), we reconstructed the new bronze front plate and we placed it in our functional model of the Antikythera Mechanism.

KEYWORDS

Antikythera Mechanism; Front Plate; Zodiac Month; Zodiac Ring Front Dial; Egyptian calendar ring

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