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NOESIS
ΚΕΝΤΡΟ ΔΙΑΔΟΣΗΣ ΕΠΙΣΤΗΜΩΝ & ΜΟΥΣΕΙΟ ΤΕΧΝΟΛΟΓΙΑΣ

THE DRACONIC GEARING OF THE ANTIKYTHERA MECHANISM: EVIDENCE FOR ITS OPERATION - THE MECHANICAL BEHAVIOR OF ITS PARTS

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Abstract. One of the Fragments of the Antikythera Mechanism, Fragment D, has not been mechanically correlated with the remaining surviving fragments of the Mechanism, since the day of its discovery. For Fragment D has been suggested that it could be one of the gears that would move the hypothetical Venus planet indicator, but to date the hypothesis of the existence of the planets in the Antikythera Mechanism has not been proven, as no mechanical parts related to the motion of the planets, survive. Our team, The Functional Reconstruction of Antikythera Mechanism – The FRAMe Project, correlated Fragment D with the preserved gears of Fragment A. The mechanical correlation of Fragments D and A shows the existence of the fourth lunar cycle on the Antikythera Mechanism, the Draconic cycle. Until this correlation, the Mechanism of Antikythera presented (through its gears), the three lunar cycles Sidereal, Synodic and Anomalistic, while the fourth lunar cycle, the Draconic, which determines whether an eclipse will occur, was not represented in the Mechanism. By the connection of Fragments D and A, the four lunar cycles, which were known in antiquity, are presented on the Antikythera Mechanism. We found that the correlation of the Synodic with the Draconic cycle of the Mechanism created the sequence of eclipse events, which is engraved on the Saros spiral: The ancient Craftsman took into account the relative positions of the Draconic pointer within the ecliptic limits and the Lunar pointer when aimed towards or opposite the Golden Sphere-Sun. The eclipse events calculation is based entirely on a pure mechanical procedure, without any external/non-related information. A critical observation was also made on this geared device: The inherent mechanical errors present in any gear machine (as also in the Antikythera Mechanism with triangular teeth, non-perfect shape of gear teeth, and the eccentricity errors), lead to some deviations from the ideal position of its pointers, resulting in calculation errors such as the omitted eclipses and the mismatches on the classification procedure. The inherent gearing errors create deviations in the calculations between the bronze gears and the digital/3D representations.

Keywords: Fragment D, Draconic cycle, Gears of Antikythera Mechanism, Draconic pointer, gear mechanical errors.

1 Introduction. Applying a protocol for the reconstruction of functional models of Antikythera Mechanism

Before the reconstruction of our functional models of Antikythera Mechanism, we carefully studied the constructional characteristics of the parts of the ancient prototype, i.e. the style and the way of the parts' assembly, stabilization, the material and the thickness of the parts. This study was based on the AMRP X-ray tomographies, as also the visual photographs of the fragments. In this way we detected the Personal Constructional Characteristics and the style of the ancient Craftsman. Afterwards, we applied a strict protocol of nine parameters in order to reconstruct the Antikythera Mechanism models as much as possible close to the original artifact-research quality:

1. Be based on the CT scans and the visual photographs of the fragments,
2. Without any change of the parts' ordered position,
3. Without making holes where nothing exists on the ancient original prototype,
4. Keeping the *Personal Constructional Characteristics* of the ancient Craftsman,
5. Without any use of modern mechanical parts (such as screws, bolt etc.),
6. Having gears with triangular teeth shape (not with the modern involute shape) constructed from a simple bronze plate, according to the CT-scans,
7. Having gear thickness around 2mm,
8. Using a simple bronze alloy material for the gears, the shafts and the axes (and not special or ferrous alloys), and
9. Using the minimum hypothetical parts adaptation.

Any deviation from these nine parameters can strongly alter the *mechanical status* of the system, leading to different mechanical behavior and to different results. One of the most characteristic examples of the *mechanical status* change after adapting different parts is the almost fatal airplane disaster on 10 June 1990, after the use of wrong-sized bolts (2.5mm shorter than the proper size!) in the pilot's window[1].

2 Input detection on the Antikythera Mechanism

We present the further analysis on the correlation we found between the gear-r1, which is preserved in good condition in Fragment D, and the unknown operation - output of the gear's a1-shaft, which is preserved in Fragment A (Voulgaris et al., 2022). The correlation of the two fragments resulted from the following analysis: Price 1974 hypothesized that the start of the Mechanism's movement - Input should be from the side, where the gear-a1 and its shaft are located. This hypothesis presents serious mechanical problems, such as low torque resulting in a doubtful and non-seamless rotation. Additionally, this hypothesis presents a fast rotation of the Lunar Disc/pointer, which makes it difficult to aim the pointer to any desired position:

[1] https://www.newscientist.com/article/mg13418180-300-wrong-bolts-sent-pilot-into-the-blue/

1) Roumeliotis (2018) presents the analysis of torques assuming Input motion from various gears. The movement from the a-shaft presents limited torque, making the continuous movement of the Mechanism doubtful due to friction. Roumeliotis (2018) mentions that the proper start of movement of the Mechanism is gears-e6/e1, which are connected in 1:1 motion to the Lunar Disc. The e-shaft's torque is ≈5 times larger than the a-shaft's torque.

2) In Voulgaris et al., (2018b) the kinetic energies were calculated starting from the a-shaft and bin-axis. Starting motion from the a-shaft requires 8.2 times more energy than from the bin-axis/Lunar Disc.

3) One full rotation of gear a1 of 48 teeth results in ~2.85 revolutions of the Lunar Disc, or a rotation of the a1-gear by one tooth corresponds to a rotation of the Lunar Disc/pointer by ~21.37°, i.e. the Lunar pointer transits about 21 subdivisions of the Zodiac ring equals to 71% of a 30° Zodiacal Constellation, Figure 1. This rotation is too fast and leads to a complete inability to aim the Lunar Pointer at a desired position by moving the Mechanism from the a-shaft.

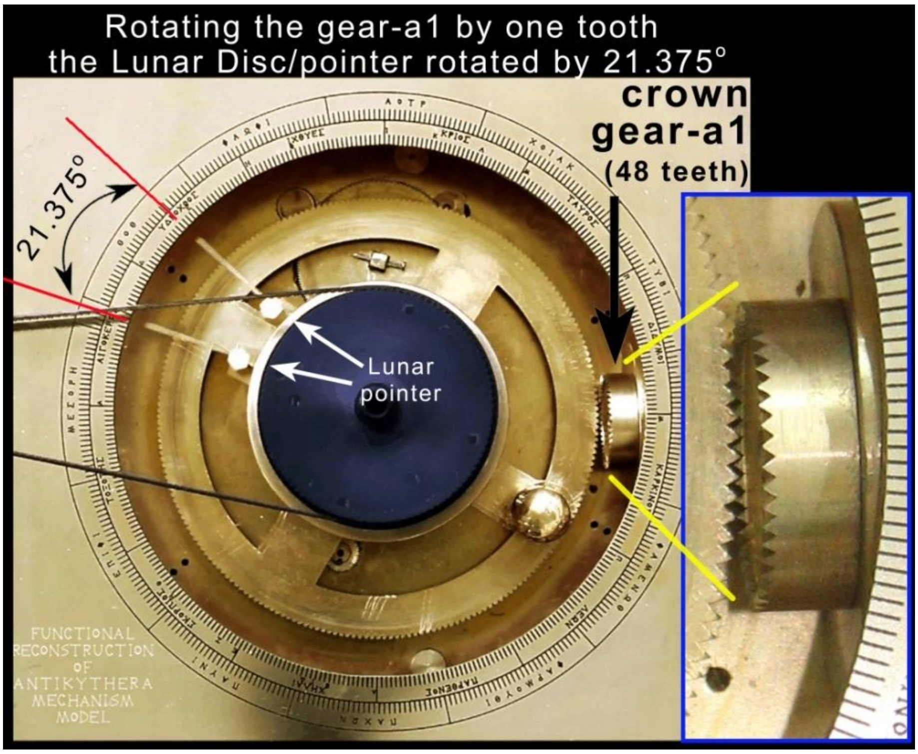

Figure 1. By driving (Input) of the Antikythera Mechanism from gear-a1 the Lunar Disc and its pointer rotate very fast making difficult or impossible the positioning of the Lunar pointer to a desired point (Voulgaris et al., 2018b and 2022). Due to the friction and the small torque, the uncertainty in aiming increases significantly (Roumeliotis 2018). Authors' functional model.

It is questionable if the ancient Craftsman made a machine that started its movement from a shaft with low torque, with doubtful operation in motion and difficulty to control the position of its pointers. As the ancient Greek calendars are based on the Lunar Synodic cycle, the aiming of the Lunar pointer to the Golden sphere-Sun (New Moon, see Bitsakis and Jones 2016b/Back Cover Inscription) and in opposite position (Full Moon), the precise alignment of the pointer is totally necessary.

Any mechanical structure, which takes motion from the Input position, should present ease of movement (whether it is done by hand, or with an electric motor), so that the movement of the following parts is uninterrupted, smooth and overcoming frictions of the system. At the same time, if there are aiming systems, their motion should be easily controllable obeying the theory of Biomechanics and the Theory of the Human Body Motion: E.g. if the path of an electrical dimmer from the 0 position (highest resistance) to the Max position (minimum resistance) is 3°, this dimmer cannot control the electric current by hand with precision and it is completely unusable.

Based on the above three arguments, it follows that the most appropriate and ideal Input of the Antikythera Mechanism is the Lunar Disc/bin-axis rather than the a-shaft, as Price assumed. The Input by the Lunar Disc offers a high torque, perfect control of the pointers and easy aiming of the Lunar pointer to any desired position.

This observation results in the conclusion that a-shaft is an unknown Output of the Antikythera Mechanism.

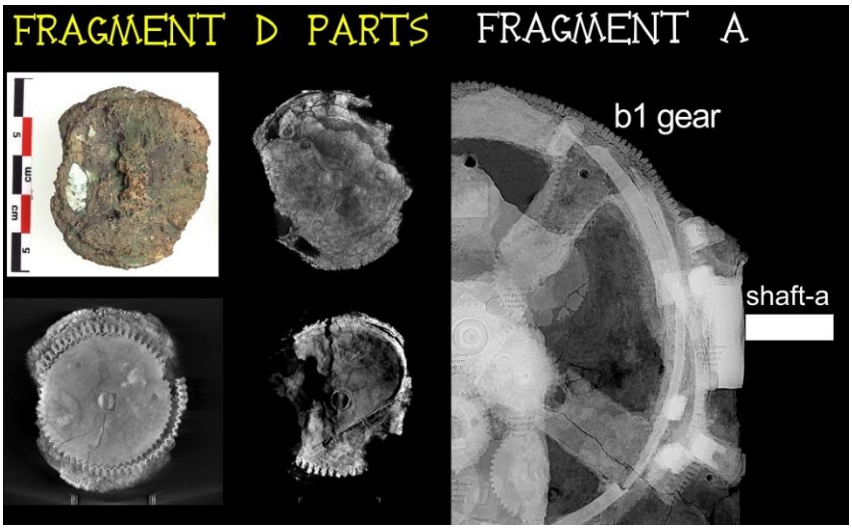

Figure 2. Top-left, photograph of Fragment D (Credits: National Archaeological Museum, Athens, K. Xenikakis, © Hellenic Ministry of Culture & Sports/Archaeological Receipts Fund). The fragment consist three parts (presented in the tomographies of different depth, processed by the authors via Real3D VolViCon software, in three rest panels): the gear is fixed on the Circular base via three pins and a thin Additional plate, which is collapsed on the gear (the original position on this thin plate was not in contact with the gear). The fragment is surrounded by salts-calcites, petrified silt, as also most of the fragments, due to 2000 years under the sea (Voulgaris et al., 2019b). Right panel, AMRP radiography of Fragment A part. The (partially preserved, mostly lost) shaft of gear-a1 is presented in white color. In the shaft, the gear r1/Fragment D is adapted and by adding three hypothetical gears (s1, s2, t1) and the Draconic cycle can be represented on the Antikythera Mechanism. The Draconic gearing output ends in a draconic pointer which is rotated around the Draconic scale[2], see also Figures 4 and 5.

Therefore, for the research on the Antikythera mechanism, these are the following data:

i) an unknown output,

ii) an unplaced part of the Mechanism (Fragment D with its gear) and

iii) a missing procedure on the Antikythera Mechanism.

[2] See authors' Revision for the Draconic Gearing of the Antikythera Mechanism, the Saros spiral eclipse events and their classification (https://arxiv.org/abs/2412.07023).

3 Adapting Fragment D on Fragment A

By correlating the Antikythera Mechanism fragments A and C, the three, out of four, well known in antiquity, lunar cycles are represented on the Antikythera Mechanism procedures: Sidereal (the Moon returns to the same zodiac constellation), Synodic (the Moon returns to the same phase) and Anomalistic (the Moon returns to Apogee or Perigee). The fourth, critical and important lunar cycle, the Draconic cycle, is not represented in the Antikythera Mechanism procedures. The Draconic cycle is the cycle which presents the position of the Moon relative to the Ecliptic plane (named from the Greek word Έκλειψις-Eclipse) and defines if an eclipse will occur or not during New Moon or Full Moon (Voulgaris et al., 2022). When the New Moon or the Full Moon locates on the Ecliptic plane (draconic cycle phase 0 or π phase) then, a Solar or a Lunar eclipse occurs.

The three parts of Fragment D were analyzed, and digitally reconstructed according to the AMRP X-ray tomographies of the fragment. Afterwards, the parts of Fragment D were reconstructed in bronze. The top part of the fragment, the Additional plate, is partially preserved and based on the constructional characteristics resulted by the (well/better) preserved parts, the probable operation of the Additional plate was detected, see Figure 3.

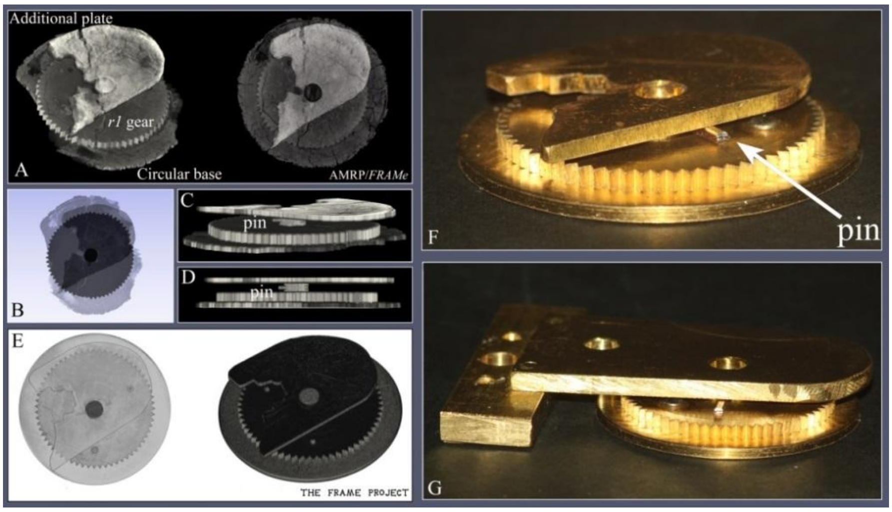

Figure 3. A-E) Digital reconstructions and placements of the three parts of Fragment D. The tomographies of the fragment were separately processed for each part, by the authors using *3D Slicer* software. The fragment consists of three parts: the gear-r1 is fixed on the Circular base via three pins and the thin Additional plate located above the gear. Between gear and Additional plate, a perpendicular to the shaft-r, stabilizing pin is preserved. F) Reconstruction in bronze of the three parts as are today preserved (based on the AMRP tomographies). G) Reconstruction in bronze of the three parts including the completion of the lost area of the Additional plate of Fragment D. Bronze parts and photographs by the authors.

The Additional plate is a thin plate which is applied on the shaft-r of gear-r1 in order to increase the stability of the shaft. The stability of the shaft is critical and necessary during its rotation, in order to avoid the Libration effect. This effect creates problems in the proper rotation of the engaged gears (see Voulgaris et al., 2022).

The unknown output of axis-a, rotates from the annual gear-b1 (one turn/tropical year). Gear-b1 is partially preserved and the estimated number of teeth is around to 226 teeth ±5[3]. Connecting the unplaced gear-r1 (63 teeth) of Fragment D with the unknown operation-Output /shaft-a, and adding three hypothetical gears (s1, s2, t1), the Draconic cycle-the fourth Lunar cycle, appears in the Antikythera Mechanism: one turn of b1-gear corresponds to {(b1/a1)*(r1/s1)*(s2/t1) = (229/48)*(63/57)*(56/22)=} 13.4222 turns of Draconic pointer[4] Figure 2.

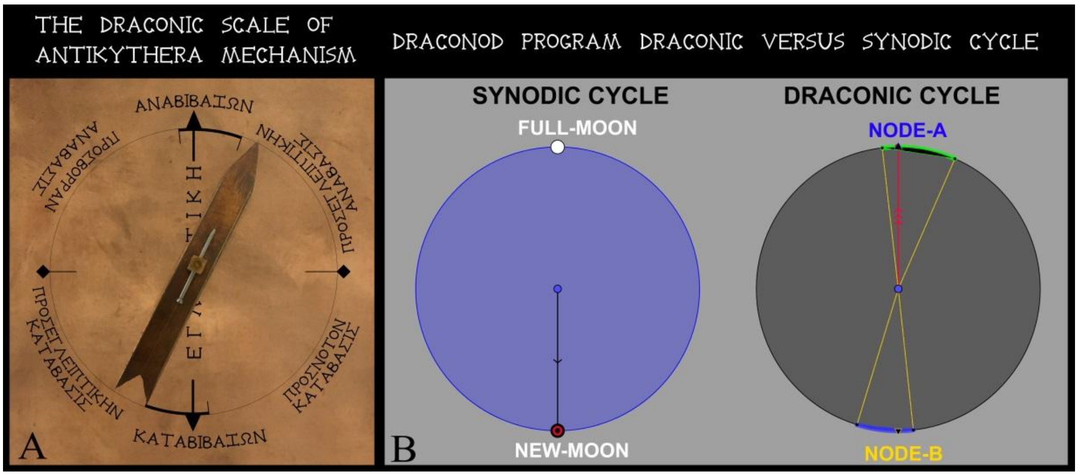

Figure 4. A) One out of two (suggested by the authors) designs for the Draconic scale. The Draconic scale can be adapted on the right side of the Mechanism's wooden case (for the wooden case see Voulgaris et al., 2019b). When the Draconic pointer is located between the blackened ecliptic limits and the Lunar pointer aims to the Golden sphere-Sun or in opposite position, a solar or a lunar eclipse event occurs on the Mechanism. B) *DracoNod* visualization program cadran. The program presents the phase of the three lunar cycles (here two cycles), Synodic, Draconic (Ecliptic latitude) (and Anomalistic, Apogee/Perigee) *versus* New Moon/Full Moon phase. The position of the Moon relative to the Draconic cycle/Ecliptic Zone is presented via the red color radius. When the Draconic pointer is located between the ecliptic limits and during Full Moon or New Moon, an eclipse event (Lunar or Solar eclipse) will occur. When the Draconic pointer is located out of the ecliptic zone (out of the green and the blue arcs) and far away from the ecliptic limits, no eclipse event occurs. If the Draconic pointer is located just right at an ecliptic limit, indeterminacy emerges. By the relative positions of the Synodic and Draconic pointers, the lost eclipse events were calculated and presented on Table 1.

On the Draconic scale should have been engraved points of the two Nodes, Ascending and Descending, as well as the Ecliptic limits, see Figure 4A. When the Draconic pointer located between the Ecliptic limits and the Moon was in the phase of the New Moon (Lunar pointer aims to the Golden sphere-Sun) or the Full Moon (Lunar pointer aims in opposite position to the Golden sphere), there was respectively a solar eclipse or a lunar eclipse, Figure 5 (Green

[3] During the 2000 years under the sea, the bronze material of the Antikythera Mechanism fragments, has been transformed in a new rocky material of Atacamite [$Cu_2(OH)_3Cl$] (Voulgaris et al., 2019b), which has much lower density (3.8 gr/cm^3) and lower absorption in X-Rays (Voulgaris et al., 2018c). When the Mechanism was retracted from the sea bed and exposed to the dry air, this led to its shrinkage, deformation and cracking (Voulgaris et al., 2019b). Today, most of its parts are broken, shrunk, displaced, deformed, worn out and many flattened parts deviate significantly from flatness. The dimension of the original parts of the Mechanism should be a bit larger than the current values.

[4] See authors' Revision for the Draconic Gearing of the Antikythera Mechanism, the Saros spiral eclipse events and their classification (https://arxiv.org/abs/2412.07023).

1985; Smart 1949; Toomer 1984; Neugebauer 1975; Heiberg 1898). The User can be further informed about the specific eclipse event (hour, classification etc.), by reading the information on the corresponding cell of the Saros spiral, in which the Saros pointer aims and also by reading the inscription on the Back plate.

The existence of the Draconic gearing on the Antikythera Mechanism answers the question "with which way the ancient Craftsman found the specific eclipse events sequence and engraved it on the blank cells of Saros spiral". This is a purely mechanical process, without any other non-related information to the Mechanism (Voulgaris et al., 2021 and 2023b).

The hypothesis that the eclipse events of Saros spiral were calculated via a mechanical procedure and directly by the Mechanism is well supported by the results (see Table 1).

In order to calculate the lost eclipse events, we compiled a digital visualization program named *DracoNod*, using GeoGebra software, Figure 4B. *DracoNod* calculates the relative position of the Moon in the three Lunar cycles' phase Synodic, Draconic and Anomalistic versus time. *DracoNod* starts with New Moon at Apogee and at Node-A (Voulgaris et al., 2023a and 2023c). After calibrating the program according to the preserved eclipse events, the lost eclipse events were calculated (see Table 1).

Table 1: Calculation of the lost eclipse events of the Saros spiral using the authors' program *DracoNod* (Voulgaris et al., 2023b). 50 Cells with eclipse events were calculated. The Saros cells are noted in the new numbering according to the correction of Voulgaris et al., 2021. The index symbols of the hooked alpha (ƻ) and the letter cursive Ꙍ are presented on the Back Plate Inscriptions (BPI) of the Mechanism (Freeth 2014 and 2019; Anastasiou et al., 2016; Pakzad 2018; Iversen and Jones 2019). By the results of this table (*DracoNod* calculations), the cursive Ꙍ is not related to the 24th (Index letter omega-1) and 48th (Index letter omega-2) cells with events and it is related to the last cell with solar event Cell-218/ (B3/Ꙍ). The index letter hooked alpha (ƻ) is related to Cell-212/(A3/ƻ). Therefore, the 24th and 48th index letters are Ω1 and Ω2 (omega capital) and the Index letters ƻ and Ꙍ correspond to the 49th and 50th cells with events.

Event #	Event index letter	New cell numbering (*Voulgaris et al., 2021*)	Eclipse events preserved on Saros cells	Reconstructed eclipse events sequence, by *DracoNod* program	Comments/ Moon position relative to the Node/ ecliptic limit
1	[A1]	**Cell-1**		Sun, *Longest duration of the annular eclipse*	**Saros cycle begins. New Moon at *Apogee and at Node-A.***
2, 3	**B1**	**Cell-7**	**Moon, Sun**	**Moon, Sun**	
4	**Γ1**	**Cell-12**	**Sun**	**Sun**	New Moon close to the ecliptic limit
5	Δ1	Cell-13	Non preserved	Moon	
6	**E1**	**Cell-19**	**Moon**	**Moon**	
7	**Z1**	**Cell-24**	**Sun**	**Sun**	
8	**H1**	**Cell-25**	**Moon**	**Moon**	Full Moon at *Node-B*
9	Θ1	Cell-30	Non preserved cells	Sun	
10	I1	Cell-31		Moon	Full Moon close to the ecliptic limit
11	K1	Cell-36		Sun	
12, 13	Λ1	Cell-42		Moon Sun	New Moon close to Node-B
14, 15	M1	Cell-48		Moon Sun	New Moon close to Node-A

16, 17	N1	Cell-54		Moon Sun	New Moon on the ecliptic limit
18	Ξ1	Cell-59		Sun	
19	[O1]	**Cell-60**	**Moon**	**Moon**	
–		Cell-65	Event not exists	(+) Sun Additional event	New Moon just right on ecliptic limit. Indeterminacy or gearing error
20	**Π1**	**Cell-66**	**Moon**	**Moon**	Full Moon close to the ecliptic limit
21	**P1**	**Cell-71**	**Sun**	**Sun**	
22	[Σ1]	**Cell-72**		Moon	Full Moon close to Node-B
23	**T1**	**Cell-77**	**Sun**	**Sun**	
24	**Y1**	**Cell-78**	**Moon**	**Moon**	Full Moon just right on the ecliptic limit
25	[Φ1]	Cell-83		Sun	
26, 27	[X1]	Cell-89		Moon Sun	New Moon close to Node-B
28, 29	[Ψ1]	Cell-95	Non preserved cells	Moon Sun	
30	[Ω1]	Cell-101		Moon	24th Cell with eclipse event (1×24) New Moon is out of the ecliptic limit: No solar eclipse event – no connection to index letter ϹϿ*
31	[A2]	Cell-106		Sun	
32	[B2]	Cell-107		Moon	
33	**Γ2**	**Cell-113 Middle *Saros Cycle*–new Sar period**	**Moon**	**Moon *Total lunar eclipse at shortest duration***	**At the middle of Cell-113, Full Moon at *Perigee* and at *Node-A*.**
34	**Δ2**	**Cell-118**	**Sun**	**Sun**	
35	**E2**	**Cell-119**	**Moon**	**Moon**	
36, 37	**Z2**	**Cell-124**	**Moon, Sun**	**Moon, Sun**	Full Moon on the ecliptic limit
38, 39	**H2**	**Cell-130**	**Moon, Sun**	(–) Missing event Only **Sun**	Full Moon just out of the ecliptic limit. (Gearing errors)
40, 41	**Θ2**	**Cell-136**	**Moon, Sun**	**Moon, Sun**	New Moon at Node-B
42, 43	[I2]	Cell-142		Moon Sun	New Moon close to the ecliptic limit
44	[K2]	Cell-148		Moon	
45	[Λ2]	Cell-153		Sun	
46	[M2]	Cell-154		Moon	
47	[N2]	Cell-159	Non preserved cells	Sun	
48	[Ξ2]	Cell-160		Moon	Full Moon close to Node-A
49	[O2]	Cell-165		Sun	
–		Cell-166	Event non exists	(+) Moon Additional event	Full Moon just on the ecliptic limit. Error of eccentricity or indeterminacy

50, 51	**Π2**	**Cell-171**	**Moon, Sun**	**Moon, Sun**	
52, 53	**P2**	**Cell-177**	**Moon, Sun**	**Moon, Sun**	Full Moon just right at the ecliptic limit. New Moon at Node-A
54, 55	**Σ2**	**Cell-183**	**Moon Sun**	**Moon, Sun**	
56	**T2**	**Cell-189**	**Moon**	**Moon** and (+) Sun (additional event)	New Moon just on the ecliptic limit. Error of eccentricity or indeterminacy
57	[Y2]	Cell-195		Moon	
58	[Φ2]	Cell-200		Sun	
59	[X2]	Cell-201		Moon	Full Moon at Node-B
60	[Ψ2]	Cell-206	Non preserved cells	Sun	
61	Ω2	Cell-207		Moon	48th Cell with eclipse event (2×24)
62	[Ƨ] (A3)	Cell-212		Sun	49th Cell with eclipse event (2×24)+1
63, 64	[Ͻ] (B3)	Cell-218		Moon Sun	50th Cell with eclipse event (2×24)+2

***** Further analysis about the ecliptic limits, events' calculation and results are presented in authors' submitted work entitled "*A Revision for the Draconic Gearing of the Antikythera Mechanism, the Saros spiral eclipse events and their classification*", https://arxiv.org/abs/2412.07023

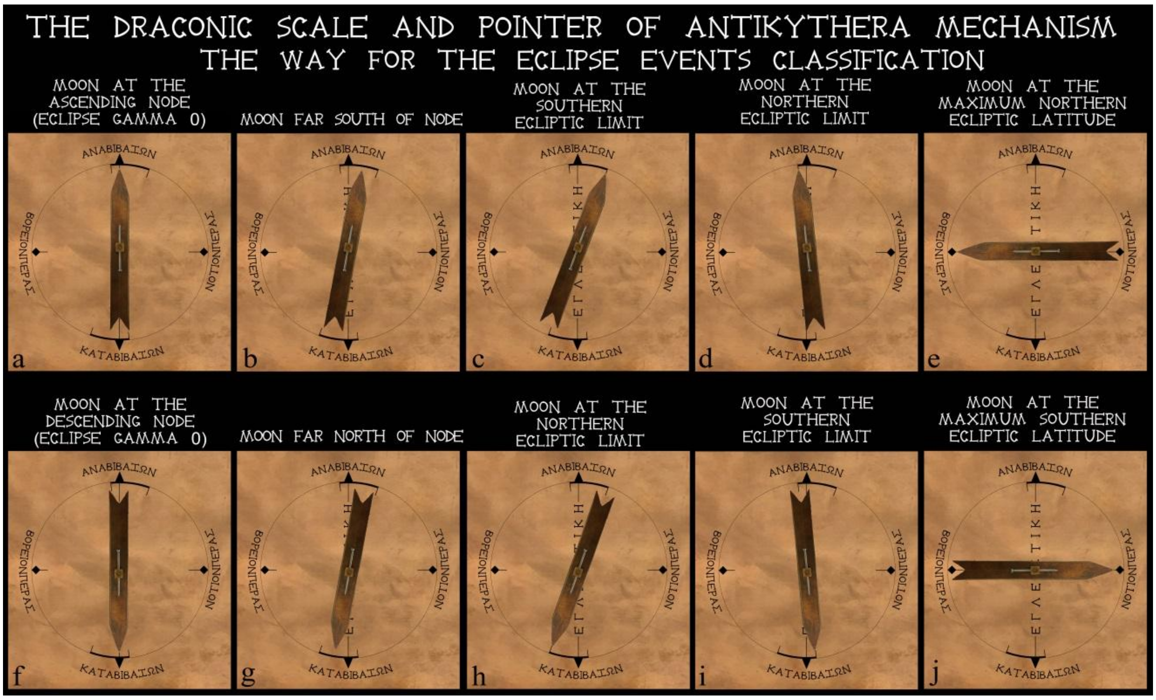

Figure 5. The Draconic pointer position relative to the ecliptic limits which are engraved on the Draconic scale (Voulgaris et al., 2023b). When the pointer aims to a point between the (blackened) ecliptic limits, a solar (during New Moon) or lunar eclipse (during Full Moon) event should be engraved on the Saros spiral. When the Draconic pointer aims to BOPEION or NOTION ΠΕΡΑΣ the Moon is located in greatest Northern or Southern ecliptic latitude (5.15° faraway from the Ecliptic).

DracoNod program calculated with high precision the preserved eclipse events, giving the opportunity to calculate the lost eclipse events. A digital program/software presents results/calculation in a sterilized environment, without mechanical/constructional errors and mismatches. In Reality, all of the geared devices present constructional errors and mismatches, such as eccentricity of the shafts or gears and non-uniformity on the gear teeth shape (Edmunds 2011; Tavner 2008; Muffly 1923, Herrmann 1922; Voulgaris et al., 2023b). The mechanical errors of the geared devices affect the pointers' position resulting in a deviation of the perfect/ideal position. On a calculating mechanical instrument, the instrument itself interferes with the extracted results it presents, by altering the final results. All the mechanical instruments present mechanical (smaller or shorter) errors.

The pointers' deviation by the perfect/ideal position due to the inherent mechanical errors, well justifies the small deviations and the omitted eclipse events (see Anastasiou et al., 2016). Moreover, the deviated position of the Draconic pointer by the perfect/ideal position also affects the eclipse events classification. A wide explanation of the impact on the final results due to the mechanical errors is presented in Voulgaris et al., 2023b.

4 Classification of the eclipse events by the ancient Craftsman

The ancient Craftsman classified the eclipse events according to their specific characteristics. The characteristics of an eclipse (umbra direction, event's duration, also visibility, eclipse magnitude/obscuration, etc.[5]) depend on the relative position of the Moon to the Node (Freeth 2008, 2014 and 2019; Anastasiou et al., 2016; Iversen and Jones 2019; Jones 2020). E.g. when the New Moon is located at the Node, this solar eclipse has a high probability to be visible from the latitudes between ±40°. On the contrary, a solar eclipse with the Moon close to the Northern ecliptic limit would be visible from much higher latitudes around to latitude of +60°. The eclipse events classification is engraved at the free space between the boundary of the Back plate and the outer boundary of the Saros spiral (Freeth 2008, 2014 and 2019; Anastasiou et al., 2016; Iversen and Jones 2019; Jones 2020). Only a part of the events classification is preserved today, regarding the solar eclipses (Figures 5-8).

Due to the mechanical errors of this geared Luni-(solar) time measuring device, some deviations from the perfect/ideal results emerge.

E.g. on the x-lunar cycle, the theoretical position of the Draconic pointer should be just on the ecliptic limit. Due to the mechanical errors of the gears, the Draconic pointer can be located a bit out of the ecliptic limit, i.e. no eclipse event. This effect explains the omitted eclipses. Additionally, if the ideal position of the Draconic pointer was a bit out of an ecliptic limit (no event) due to the errors, the pointer could be just on, or inside the ecliptic limit, presenting an event that would be non-existent if this device had no errors (Figure 8).

The Draconic pointer deviation by the theoretical/ideal position affects the classification of an eclipse event: E.g. if the theoretical position of the Draconic pointer would be just right on the Node, the gearing errors could alter the pointer's position out of the Node and (probably) result in a different classification of this event.

[5] The magnitude of a solar eclipse is the fraction of the Sun's diameter that is covered by the Moon and the magnitude of lunar eclipse is the fraction of the Moon's diameter covered by the Earth's umbra. See an explanatory interactive app in GeoGebra https://www.geogebra.org/m/SnZ7QGTJ. The Eclipse obscuration is the fraction of the Sun's surface area covered by the Moon.

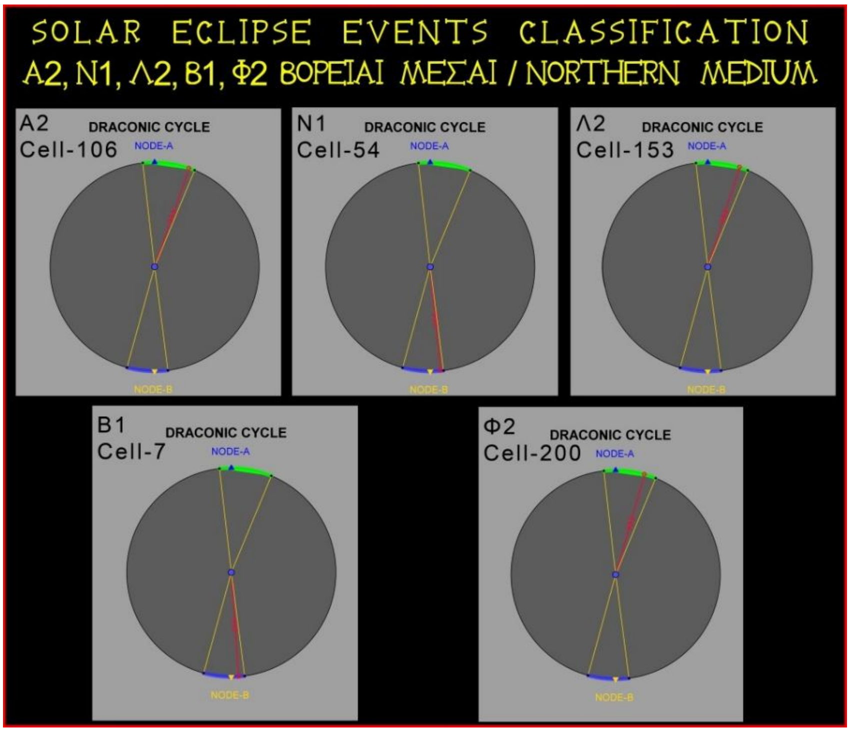

Figure 6. Solar eclipse events classification represented on the Draconic scale according to *DracoNod* program (solar eclipse events A2, N1, Λ2, B1, Φ2, see Freeth 2014 and 2019; Anastasiou et al., 2016; Pakzad 2018; Iversen and Jones 2019). The specific classification corresponds to the Northern Medium eclipse magnitudes/obscuration. The deviations of the Draconic pointer (red radius) by the ideal/correct position is a result of the gearing errors.

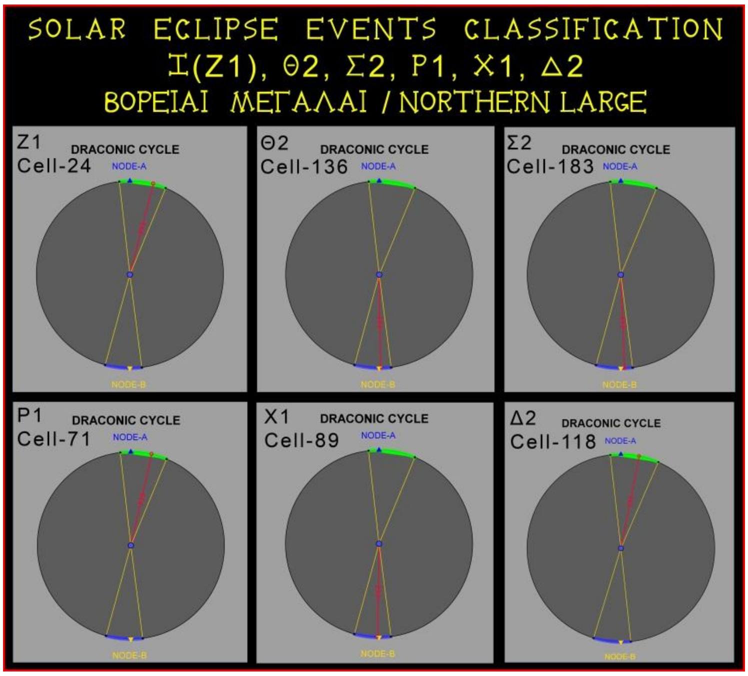

Figure 7. Solar eclipse events classification represented on the Draconic scale according to *DracoNod* program (solar eclipse events Z1, Θ2, Σ2, P1, X1, Δ2, see Freeth 2014 and 2019; Anastasiou et al., 2016; Pakzad 2018; Iversen and Jones 2019),. The specific classification corresponds to the Northern Large eclipse magnitudes/obscuration. The deviations of the Draconic pointer (red radius) by the ideal/correct position is a result of the gearing errors.

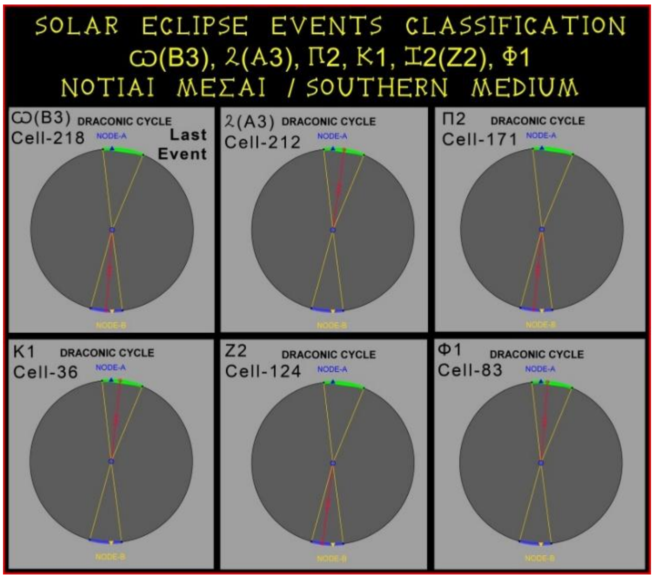

Figure 8. Solar eclipse events classification represented on the Draconic scale according to *DracoNod* program (solar eclipse events Ꙍ(B3), ƻ(A3), Π2, K1, Z2, Φ1, see Freeth 2014 and 2019; Anastasiou et al., 2016; Pakzad 2018; Iversen and Jones 2019). The specific classification corresponds to the Southern Medium eclipse magnitudes/obscuration. The deviations of the Draconic pointer (red radius) by the ideal/correct position is a result of the gearing errors.

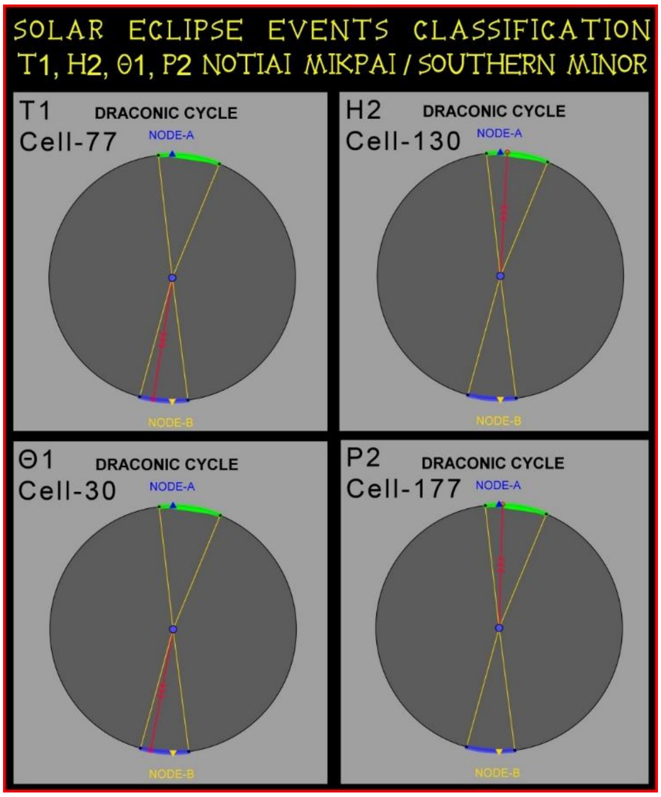

Figure 9. Solar eclipse events classification represented on the Draconic scale according to *DracoNod* program (solar eclipse events T1, H2, Θ1, P2, see Freeth 2014 and 2019; Anastasiou et al., 2016; Pakzad 2018; Iversen and Jones 2019). The specific classification corresponds to the Southern Minor eclipse magnitudes/obscuration. The deviations of the Draconic pointer (red radius) by the ideal/correct position is a result of the gearing errors.

Regarding the controversial solar eclipse event index letters Ꞷ (cursive omega) and the hooked Alpha ƨ (Freeth 2019; Iversen and Jones 2019): According to DracoNod on Cell-101 (event with index letter omega-1) there is no solar eclipse event and the solar eclipse index letter Ꞷ cannot be related to Cell-101. Therefore, the index letter Ꞷ corresponds to a solar eclipse event after 2×24 Cell with event, i.e. >48th Cell with event. DracoNod calculates two eclipse events after the 48th Cell with event (Ω2/Cell-207): Cell-212 (solar) and Cell-218 (lunar and solar). These two cells must have the index letters ƨ(A3) and Ꞷ(B3) (a full analysis is presented in authors' work Revision for the Draconic Gearing of the Antikythera Mechanism, the Saros spiral eclipse events and their classification (https://arxiv.org/abs/2412.07023). Additionally, the index letters omega-1 on Cell-101 and the omega-2 on Cell-207 must be the letter(s) Ω1 and Ω2 (capital).

5. Summarizing

The correlation of Fragment D with Fragment A is resulted by our team - The Functional Reconstruction of Antikythera Mechanism – The FRAMe Project, following a specific Methodology, which obeys the principles of mechanical engineering, the proper operation of the Mechanism, relating to what is missing from the Antikythera Mechanism, applying the least possible assumptions and the least additions of hypothetical parts. The consequences of our hypothesis create results that are well explained/justified based on the experiment and are well matched to the preserved data.

The correlation of Fragment D*(raconic)* with Fragment A presents a large number of arguments for its existence on the Antikythera Mechanism. This correlation removes a number of arguments from the hypothesis of the existence of planet indication gearing in Antikythera Mechanism. Furthermore, upon closer inspection, the text of the Back cover inscription (which is the User's Manual of the Mechanism, Bitsakis and Jones 2016b) where the names of the planets are mentioned does not refer to colored spheres (as is referred for the Sun ΧΡΥΣΟΥΝ ΣΦΑΙΡΙΟΝ Golden sphere), but to the word ΚΥΚΛΟΣ (circle-orbit-relative position of the planet). Moreover, the ancient Craftsman has spent about 3 sentences in order to describe the position, the sphere, its color and its operation of the Golden sphere-Sun and only one sentence (definitely) for each of the outer planets Mars, Jupiter and Saturn.

Based on the aforementioned parameters the rationale of this research follows:

- On the Antikythera Mechanism are represented three out of four lunar cycles, well-known during antiquity, and the fourth lunar cycle, the Draconic, is not represented/missing.
- There exists a shaft, the a-shaft, which is an unknown output on the Mechanism.
- There exists an unplaced gear-r1 with 63 teeth on the Fragment D.

By relating the gear-r1 on the unknown output/shaft-a and engaging the gear-r1 with the hypothetical gear-s1, s2, t1, the Draconic cycle appears on the Antikythera Mechanism (see also authors' work *Revision for the Draconic Gearing of the Antikythera Mechanism, the Saros spiral eclipse events and their classification*, https://arxiv.org/abs/2412.07023.

.The results of this attempt:

- By correlating the two positions: the Lunar pointer to the Golden sphere/Sun (New Moon) or in opposite direction (Full Moon) and the Draconic pointer, the eclipse events engraved on the Saros spiral can be calculated directly by the device and without any external/non-related information. In this way, via a pure mechanical procedure, the eclipse events sequence emerges.

- The results based on our visualization program named *DracoNod* (Draconic pointer position representation vs Synodic month/fortnight) show a good matching to the preserved eclipse events.
- The gears with triangular shaped teeth and the inherent error of eccentricity (in all of the geared devices), affect the final position of the pointers, deviating by the ideal/theoretically calculated position. Any measuring instrument presents errors in the measurements that deviates the results by the ideal/theoretical measurement, changing the Reality and the Originality of the information. Instruments of high quality, present a better proximity/approach to Reality, i.e. the final results are affected in a shorter degree by the instrument.

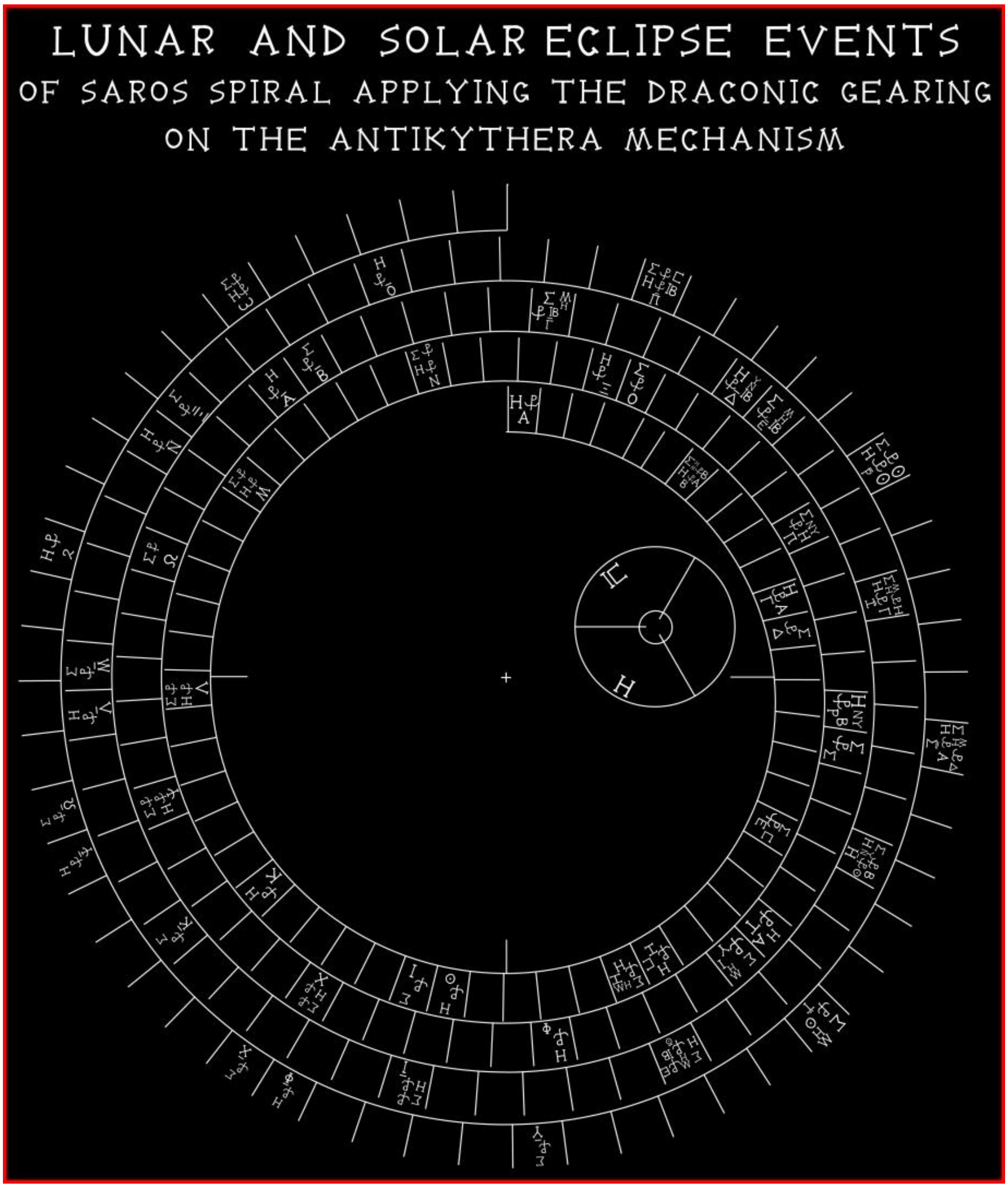

Figure 10. The preserved and the reconstructed (lost) eclipse events applying the Draconic gearing and using the *DracoNod* program, are presented on the Saros cells, according to Table-1. The positioning of the events was based in the new Saros cell numbering according to the observations of Voulgaris et al., 2022, (see also authors' work *Revision for the Draconic Gearing of the Antikythera Mechanism, the Saros spiral eclipse events and their classification*, https://arxiv.org/abs/2412.07023).

- We also found that the omitted eclipses and the events mismatch concern cases that the Draconic pointer locates just on/just out/ just between an ecliptic limit. The missing events (or the calculated but non-engraved events) can be well justified due to the mechanical errors of the gears, axes, shafts of the device.
- The mechanical/gearing errors affect the final calculations/results of the Antikythera Mechanism.
- The reconstructed models of the Antikythera Mechanism cannot present results with perfect identical matching as the digital 3D simulations.

The aforementioned results lead to the conclusion that the ancient Craftsman had no (external) information about the eclipse events dates/hours and he constructed a calculating device in order to calculate these unknown events via a pure mechanical procedure and without using any non-related to the Mechanism information. By starting his device on the unique date of 22/23 December 178 BC, New Moon at Apogee, at Node, Sun entered at 1st Day of Capricorn/Winter Solstice – the New (winter) Metonic cycle – the New (winter) Callippic cycle and the New Saros cycle started, he detected the future eclipse events and the hours of their occurrence (Voulgaris et al., 2023a and 2023c, according to Geminus definition for Exeligmos cycle, see Manitius 1898; Spandagos 2002).

As any measuring instrument influences its measuring results, the mechanical errors of the Antikythera Mechanism resulted in some of the eclipse events' calculations not representative to the Reality.

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The authors' first paper describing the idea for the Draconic gearing existence on the Antikythera Mechanism was initially submitted to a journal on January 14, 2020, and it was eventually published in a different journal (*Mediterranean Archaeology and Archaeometry*) on December 2022.

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ΑΙΓΙΔΑ
ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
Υπουργείο Πολιτισμού

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ΥΠΟΣΤΗΡΙΞΗ
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