From Babylonian records to pin and slot: A possible path

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The Antikythera Mechanism is a mechanical astronomical instrument that was discovered in an ancient shipwreck at the beginning of the twentieth century, made about the second century B.C. It had several pointers showing the positions of the moon and sun in the zodiac, the approximate date according to a lunisolar calendar, several subsidiary dials showing calendrical phenomena, and also predictions of eclipses. Scholars agree that it probably also showed the position of the planets in the zodiac. In 2012 Carman and Evans on the one hand, and Freeth and Jones on the other, independently published very similar proposals for the planets based on the pin and slot device, already deciphered for the Moon by Freeth et al. in 2008. One year later, Evans and Carman suggested that the epicycle and deferent system could have been originated using the pin and slot device as an inspiration, and not the other way around. According to that proposal, pin and slot devices were conceived as a mechanical solution for producing anomalistic motions in geared mechanisms and only afterwards, considering the device, some geometer proposed the epicycle and deferent model. We did not propose, however, any particular way in which the pin and slot model could have been designed starting only with astronomical data, being unaware of the epicycle and deferent model. In this talk I will offer a possible path that the maker of the mechanism could have followed.

Introduction

The Antikythera Mechanism is a mechanical astronomical instrument that was discovered in an ancient shipwreck at the beginning of the twentieth century. The shipwreck has been dated to the decades around 60 B.C.E.[1] There is no consensus on whether the Mechanism was built shortly before the shipwreck or significantly earlier.[2] After twenty centuries under water, it is incomplete, and broken into numerous fragments. The extant fragments, however, are sufficient for reconstructing the mechanism's main structure and functions. The mechanism had several interconnected pointers, driven by toothed gearing system that indicated the positions of the moon and the sun in the zodiac, the date according to the Egyptian calendar, the date in a Greek lunisolar calendar, in addition to the circumstances of upcoming solar and lunar eclipses.[3]

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[1] Weinberg et al. 1965, Price 1974, Cristopoulou et al. 2012, Kaltsas et al. 2012.

[2] Price 1974:19 deduced with a probably wrong argument that the date is in the 80s BCE; Carman & Evans 2014 favor a construction date within a few Saros cycles of 205 BCE; Freeth 2014 suggests the same starting date, but says that "it should not necessarily be inferred that the date of the Antikythera Mechanism is the same as the date from which the Sarod Dial was designed" (2014:11); Iversen 2017 and Jones 2017:157-160 argued for a dating closer to the shipwreck.

[3] Price 1974, Wright et al. 1995, Wright 2002, 2003a, 2003b, 2005a, 2005b, 2005c, 2006, Freeth et al. 2006, Freeth et al. 2008, Evans et al. 2010, Edmunds 2011, Carman et al. 2012, Freeth & Jones 2012, Wright 2012,

Less than a decade after the discovery of the fragments, scholars were already arguing whether the Mechanism had some sort of planetary display (see Anastasiou *et al*. 2016b: 286), and since then, researchers offered many different interpretations of the extant fragments in this regard. Even if some of them seem more plausible than others, all remain highly speculative because there are no remains of this supposed planetary device (no pointers, dials, or gears) among the fragments of the Mechanism. Hence some have put the very existence of the planetary display into question. Nevertheless, the recent publication of a new, more complete and more accurate, transcription and translation of the Mechanism's Front Cover Inscription (Anastasiou *et al*. 2016b), mentioning all five planets, together with their main synodic phenomena and the time between them expressed in days, removes all doubt: the Mechanism showed some astronomical information about the planets. The question is which and how.

Scholar have suggested three main different kinds of proposal:[4] (a) Michael Wright among others[5] proposed a model that essentially reproduced the epicycle and deferent model mechanically: a big gear rotates like a deferent for each planet, carrying the axis of another gear that works as the epicycle. A pointer is fixed from the center of the deferent to a pin in the epicycle gear that, therefore, moves like the planet according to this model. (b) James Evans, Alan Thorndike and myself have suggested in 2010 (Evans et al. 2010) that the Mechanism could have had five subsidiary dials, one per planet, with pointers rotating one turn per synodic period showing the synodic phenomena (stations, oppositions, first visibilities, etc.) of each planet. Finally, (c) both Evans and myself on the one hand (Carman & Evans 2012) and Freeth and Jones on the other (Freeth & Jones 2012), almost simultaneously though independently offered models that apply to the planets the pin and slot device's principles for showing the anomaly of the moon.

Scholars usually assumed that the maker of the mechanism somehow translated into gears either the existing geometrical model of epicycles and deferents, or the pin and slot variant (probably more related to the eccentric model), but Evans and myself (Evans and Carman 2014) suggested that the epicycle and deferent model could have originated using a pin and slot device as an inspiration. According to this proposal, pin and slot devices were conceived as a mechanical solution for producing anomalistic motions in geared mechanisms and then, with these devices in mind, a geometer could have suggested the epicycle and deferent system. Our main argument in 2014 was to show that the appearance of gears in Greece is earlier than (or at least contemporary to) the proposal of the geometrical model of epicycles and deferents, but we did not offer any particular way in which the pin and slot model could have been designed considering only astronomical data, without knowing the epicycle and deferent model. I will offer today a possible path that the maker of the mechanism could have followed for this task.

Anastasiou et al. 2013, Anastasiou et al. 2014, Carman & Evans 2014, Freeth 2014, Carman & Di Cocco 2016, Bitsakis & Jones 2016a, 2016b, Jones 2016, Anastasiou, Bitsakis, Jones, Steele and Zafeiropoulou 2016, Anastasiou, Bitsakis, Jones, Moussas, Tselikas and Zafeiropoulou 2016, Allen et al. 2016, Jones 2017.

[4] There is a forth, actually, suggested by Rhem and probably by Price, according to which the display only showed the mean longitude of the planets, but, at least for the inner planets, it would not have made sense. See Anastasiou et al 2016b, 286.

[5] Theofanidis 1934, Edmunds & Morgan 2000, Wright 2002.

I will show that it is possible to arrive in three steps at the pin and slot model for the outer (Carman and Evans 2012) and inner (Evans and Carman 2014) planets. Each step can be understood as a version of a mechanism simpler than the Antikythera Mechanism, or simply as a logical step without assuming that this earlier version of the mechanism actually existed. Nevertheless, it is not at all implausible that these models have actually been built, for the complexity and economy of the Antikythera Mechanism indicates that it is not the first attempt but, rather, the mature outcome of a long tradition (it is certainly unlikely for one to introduce a pin and slot device for producing non-uniform motion for the moon pointer in the very first model that one makes!).

First step: the synodic phenomena

If someone wanted to show with a mechanism astronomical information related to the planets being unaware of the epicycle and deferent model (or of any other geometrical model for representing the motion of the planets, like that of Eudoxus), then he would almost certainly have liked to show the synodic phenomena of the planets, at the time of their occurrence, for this is what Babylonians did. Their arithmetical methods weren't designed to obtain the planet's motion around the zodiac, but to calculate directly some important synodic phenomena (see Evans 1988: 320-321). Therefore, the maker of the mechanism would have liked to have a pointer showing when a planet reached conjunction or opposition, first and last visibility, first and second station, etc. This suggestion is not only consistent with Babylonian practice, but also with the extant text of the Antikythera Mechanism's Front Cover Inscription, which attests the description of the synodic phenomena of each planet, together with the interval in days between them (Anastasiou et al. 2016b). I will call this pointer the synodic phenomenon pointer or, better, the *synodic pointer*.

The maker should have designed a gear train that obtained the synodic period of each planet for making these displays: for example, in the case of Mercury, the synodic pointer should rotate one turn in around 116 days; in the case of Venus, 1.6 years; 2.14, 1.09, and 1.035 years for Mars, Jupiter, and Saturn respectively. The situation for the inner planets is almost trivial for their synodic period is exactly one year. Then, in the display for each planet, a mark for each synodic phenomenon would have been placed in such a way that the synodic pointer would have pointed to this particular mark when the planet was showing these particular synodic phenomena. It would be sufficient to know the times between the synodic phenomena for locating these marks, just like those present in the Front Cover Inscription, and transforming them into angles. For example, in the case of Mars one could infer from the extant text of the Front Cover Inscription that the time from conjunction to the start of the first stationary point is 349 days. After that, Mars would remain 8 days without motion and then it would start moving backward. After 33 days, Mars would reach opposition to the Sun, continuing with retrograde motion for another 33 days, resting 8 days afterwards, to start forward motion once more reaching again conjunction after 349 days. Mars' complete cycle is, then, of 780 days. It isn't difficult to represent these days-intervals in angles, simply multiplying the days by $360°/780^d$. With the intervals expressed in degrees, the dial can be built as shown in figure 1, where C represents the conjunction; O, the opposition; and the short arcs S1 and S2, the time the planet remains at rest during stations. I have added to figure 1 two other synodic phenomena that do not seem to appear in the Front Cover Inscription, but could certainly be present in an earlier version: the first and last visibility and the *nonagenarii*. When Mars is close to conjunction, it is invisible due to the glare of the Sun for around 25 days or 11,5° at each side of conjunction (Toomer 1984: 639). The first and last visibility are indicated with V1 and V2. Finally, at least for Mars, there is evidence that some Greco-Roman astronomical and astrological texts mention another synodic phenomenon: the *nonagenarii* or nintieths. Around 90 days after and before opposition, Mars's elongation is 90° (Neugebauer 1975: 792 and Jones 2004: 380). N1 and N2 indicate the *nonagenarii* in figure 1. The reason for including them is simply didactic and I will make it clear in the next step. In figure 1, the synodic pointer is showing that the planet is stationary, just before starting its retrograde motion.

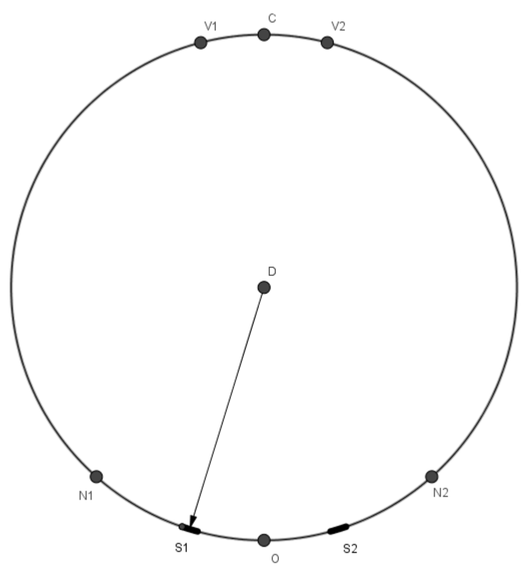

Figure 1: Synodic dial for Mars according to step 1. D is the center around which the synodic pointer (the arrow) rotates. The different letters around the synodic dial represent different synodic phenomena. C represents the conjunction; O, the opposition, N1 and N2 the nonagenarii, V1 and V2 the first and last visibility; finally, the short arches S1 and S2 represent the time the planet remains at rest during stations.

A similar display could be designed for the inner planets, with a dial adapted to their synodic phenomena (maximum elongation, inferior and superior conjunction, etc.). See for example, figure 2, in which SC indicates the superior conjunction; IC the inferior one; E1 and E2 are the maximum elongations; and S1 and S2 the stationary points. The synodic pointer in figure 2 shows Venus reaching its maximum elongation as an evening star.

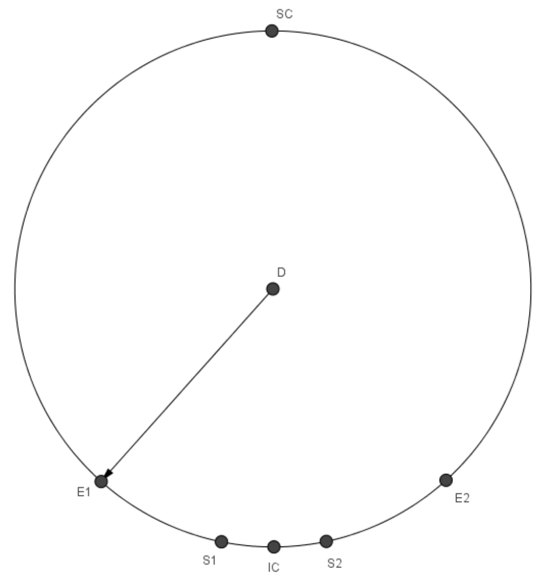

Figure 2: Synodic dial for Venus according to step 1. D is the center around which the synodic pointer (the arrow) rotates. The different letters around the synodic dial represent different synodic phenomena. SC represents the superior conjunction; IC, the inferior conjunction; E1 and E2 the maximum elongations; and S1 and S2 the stationary points. Therefore, Venus is retrograding when the pointer is between S1 and S2.

More synodic phenomena could be displayed, such as first and last visibility at upper and lower conjunction. It is also possible that the dial have had a day-scale, so that it displayed, for example, how many days were left for the planet to arrive to the next synodic phenomena. In any case, this is the first step. Essentially, it is the same proposal Evans *et al.* 2010 made: 5 dials showing the main synodic phenomena of each planet. I'll move now to my second step.

Second step: the elongation of the planet

I have already mentioned that the dials could have had day-scales. Suppose that the maker of a second, improved, version of the mechanism wanted to include the elongation from the Sun of each planet. Since all synodic phenomena depend on the relative position of the planet from the Sun, then, it is reasonable to think that a new version would have been designed to indicate the elongation of the planet at which each synodic phenomenon takes place. Alan Bowen (2002: 157-158) insisted on the fact that pre-Ptolemaic astronomers were not particularly interested in using the fixed stars for describing the main phenomena of the planets. Instead they used to do it only in relation to the other planets, especially the Sun. This is particularly true for the inner planets. Therefore, it is plausible to assume that, besides the isolated indication of the synodic phenomena, an improved version could have included an elongation-scale.

There seems to be two options to include this scale. A) First, one could label the dial of each planet with the degrees corresponding to the elongation. The main difficulty with this approach is that it would imply a non-uniform division of the ring – and a very odd division in the case of the inner planets, in which there would be two 0, one at each conjunction –. Or B) one could look for the center from which the elongation would look uniformly divided. I will explore this second option, since it appears less odd and simpler than the first one.

By "the center from which the elongation would look uniformly divided" I mean the center from which a pointer sweeps out an angle, going from one synodic phenomenon to the next, equal to the angle representing the change in elongation during this period. I will call this point the *elongation center*. So, for example, if the elongation at the first visibility of Mars is 11.5°, the angle from conjunction mark to first visibility mark must be 11.5° when measured from the elongation center.

The reasoning for finding the elongation center for the outer planets is simple and does not imply anything like the epicycle and deferent model (see figure 3). From conjunction to opposition the elongation changes 180°, therefore, the elongation center must be in line CO, somewhere between C and O, so that the angle between them be 180°. I will call line CO the *line of symmetry*, because the synodic phenomena are symmetrically spaced at both its sides. We also know that in the case of Mars, at *nonagenarii* points, the elongation is 90°. Thus, from one *nonagenarius* point to the next, the elongation of the planet also changes 180°. Therefore, the elongation center must also be in the line N1-N2, somewhere between both points. The only point that fulfills both constraints is the intersection between the line of symmetry (CO) and N1-N2: B in figure 3.

The reason for including the *nonagenarii* points is now clear, for they make it easier to find the elongation center. Nevertheless, they are not necessary. To find the elongation center, one has to know the elongation of one synodic phenomenon (in addition to conjunction and opposition) and find the point in the line of symmetry from which the angle between this point and conjunction is equal to that particular elongation.

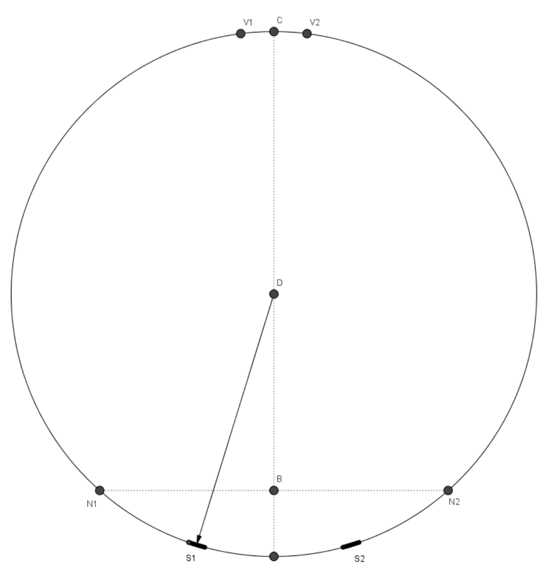

Figure 3: Synodic dial for Mars. For references see caption of figure 1. B is the intersection between the line of symmetry (line CDO) and the line that joins the nonagenarii points (N1 and N2). From B the elongation is uniformly divided.

Thus one finds the elongation center (see figure 4). The following step is to draw a dial, centered at the elongation center, with 360 uniform divisions. After that, we have to add a new pointer centered at the center of elongation and attached to the extreme of the synodic pointer.[6] I will call this new pointer the *elongation pointer*. This pointer, thus, refers to the correct elongation of the planet in the uniformly divided circle centered at the elongation center. In figure 4, while the synodic pointer is showing that Mars is in the first stationary point, the elongation pointer shows that this happens at an elongation of around 125°.

[6] Mechanically, this system would imply attaching a pin at the extreme of the synodic pointer that would move inside a slot in the elongation pointer, so that the uniform motion of the pin measured from D produces de non-uniform motion of the elongation pointer. It is not necessary that the pin is attached to the extreme of the synodic pointer. But if not, then the *nonagenarii* line would not pass through the nonagenarii marks, but through the positions of the pin when the synodic pointer is pointing to the *nonagenarii* marks.

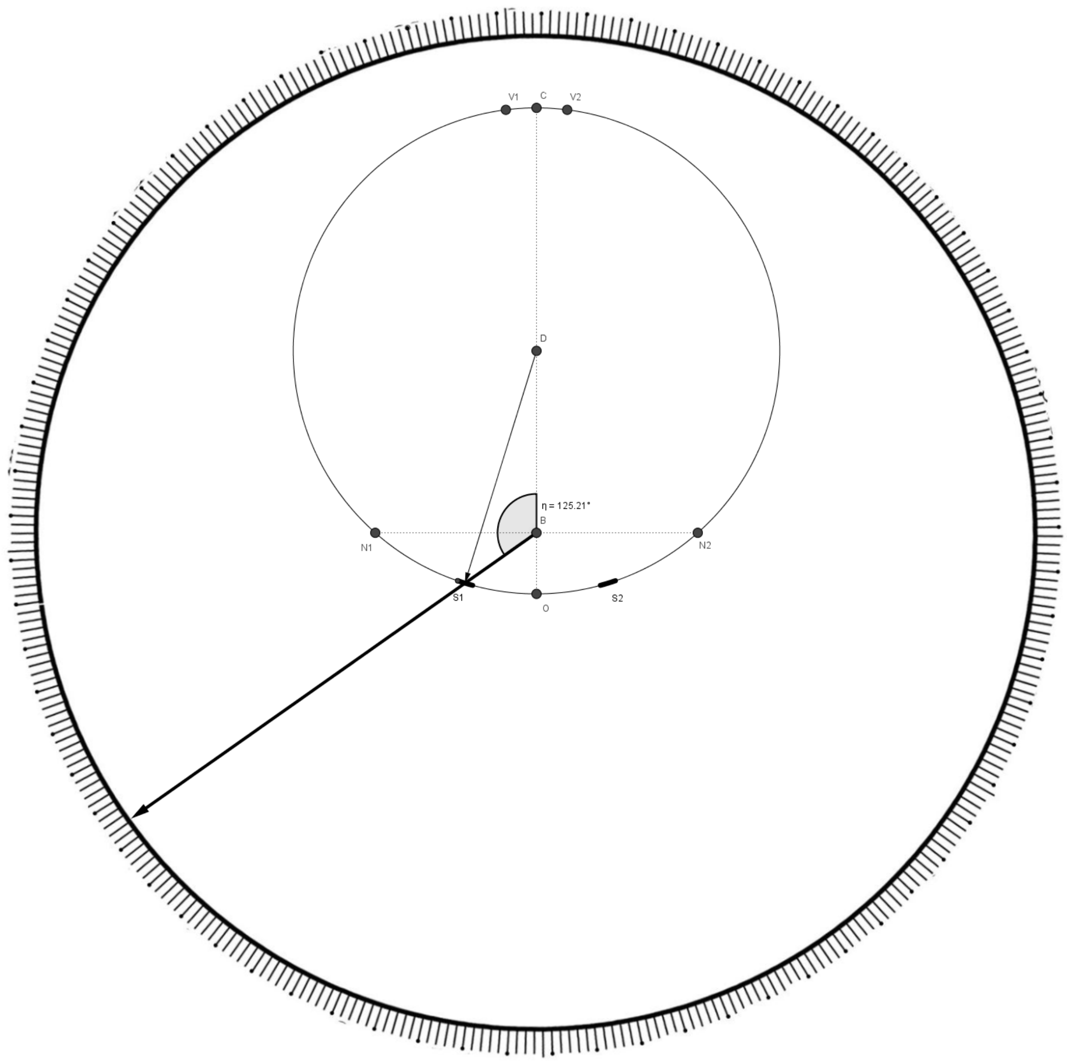

Figure 4: Synodic dial for Mars according to step 2. The references are the same as in figures 1 and 3. The arrow with center at B represents the elongation pointer and shows Mars' elongation in the big scale centered at B. The tip of the synodic arrow moves the elongation arrow. In this case, the synodic arrow is showing that Mars is at the first station and its elongation at that moment is around 125°.

The reasoning is analogous for the inner planets (see figure 5, left). The elongation of the planet is 0 twice per synodic period: at the superior conjunction (SC) and at the inferior one (IC). Therefore, the center of elongation must also be located in line SC-IC (also called line of symmetry). In this case, however, the angle between points SC and IC from the elongation center would not be 180° but 0°. Thus, one must locate the center of elongation above SC or below IC, but not between them. That is, the center of elongation is not located inside the synodic dial, but outside.

In order to find the exact point of the center of elongation, one needs to find another constraint. Again, it would suffice to know the elongation of some synodic phenomenon and look for the point in the line of symmetry (outside the dial) that produces this angle between the line of symmetry and the mark of the synodic phenomenon. For example, if one knows that the elongation of Venus at the stationary point is 29° (i.e., the retrogradation arc is 58°), then one can find the point from which the angle between S1 and the line of symmetry is 29° (figure 5, left).

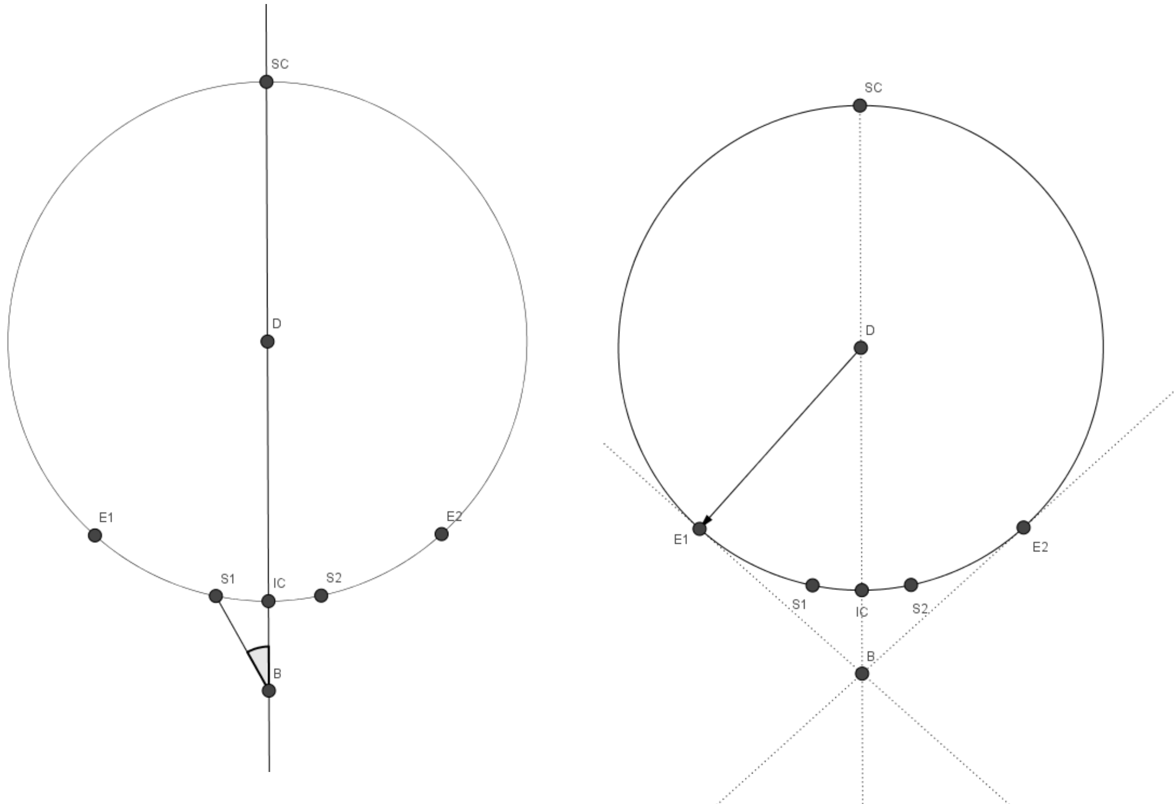

Figure 5: Synodic dial for Venus. For references, see caption of figure 2. B is the intersection between the two tangents of the dial circle at the maximum elongation points (E1 and E2). Both tangents intersect at the symmetry line. From B the elongation is uniformly divided.

There is, however, another way, more economical and more mechanical, to arrive at point B. The fact that inner planets have limited elongations can serve for locating the center of elongation. In figure 6, D is the center of synodic phenomena, and B the center of elongation. The arrows centered at D represent 3 different possible positions of the synodic pointer, while the arrows centered at B represent the three corresponding positions of the elongation pointer. Figure 6 shows that the elongation arrow would reach its maximum elongation (i.e., when the angle between DB and the arrow is maximum) when the two arrows are perpendicular (angle C is 90°). Any other configuration will produce a smaller elongation, as exemplified with A and E. Therefore, a method to find B is to draw a perpendicular to the synodic arrow when the arrow is pointing at the maximum elongation mark in the synodic dial.

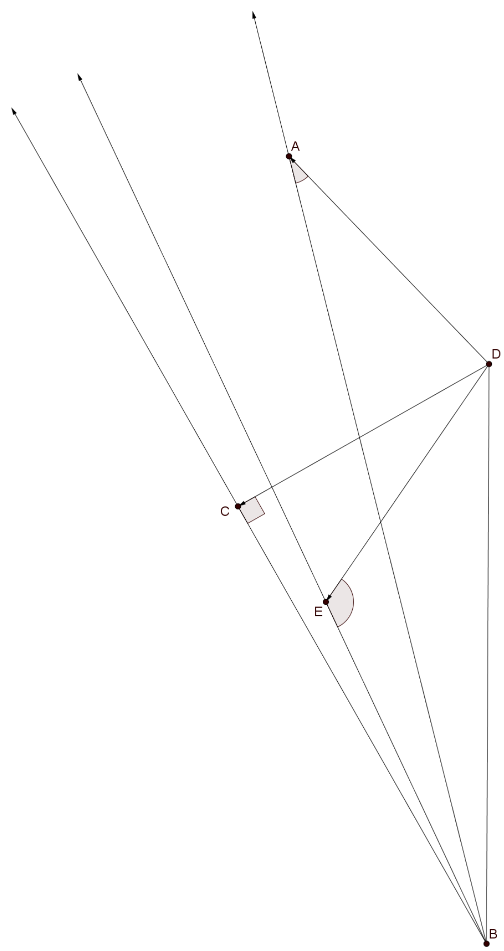

Figure 6: Three different positions of the synodic and elongation dials. D is the synodic center, B is the elongation center, when both dials are perpendicular, the elongation is maximum. This situation is represented at pointers joining at C.

This method will guarantee that the elongation arrow reaches its maximum angular distance from the line of symmetry when the synodic arrow is showing the maximum elongation, as shown in figure 7, in which, as a way of confirmation, one can see that at the point of maximum elongation, the elongation of Venus is 48° measured from B, exactly as was assumed when building the synodic dial.

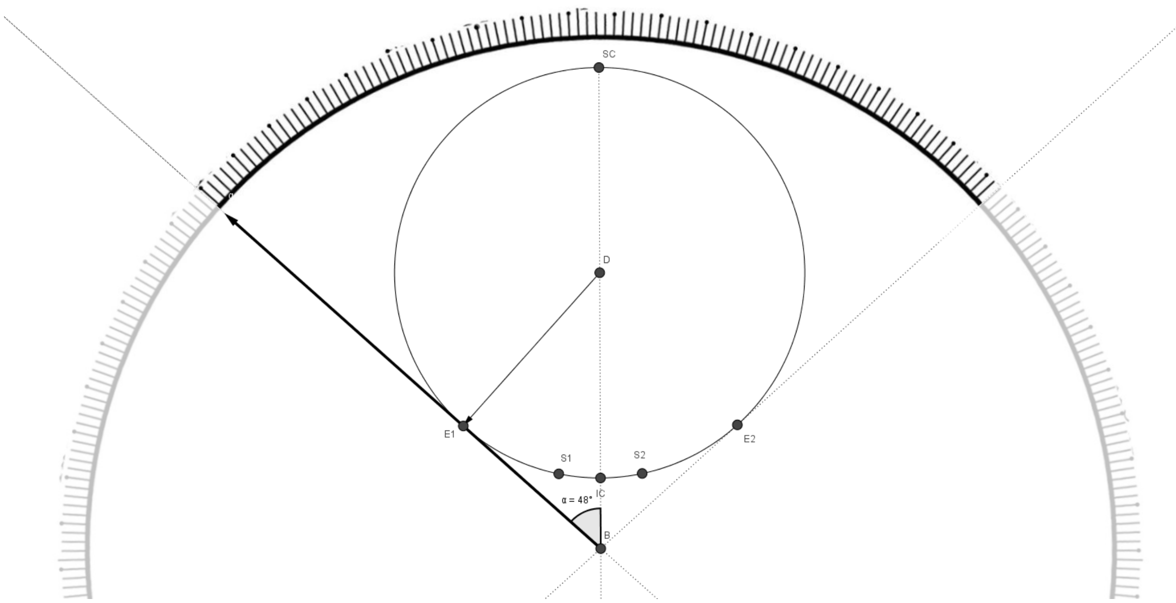

Figure 7: Synodic dial for Venus according to step 2. The references are the same as figures 2 and 4. The arrow with center at B represents the elongation pointer and shows the elongation of Venus in the partial big scale centered at B. The tip of the synodic arrow moves the elongation arrow. In this case, the synodic arrow shows that Venus is at one maximum elongation and that at that moment the elongation is 48°.

In summary, in version 2, in addition to the synodic pointer, the mechanism would include an elongation pointer indicating the elongation of the planet from the Sun at any moment. Certainly, if the marks of the synodic dial are projected to the marks of the elongation dial, the synodic dial will be unnecessary. The synodic pointer, however, will still be mechanically necessary for moving the elongation pointer through its pin.

Third step: the longitude of the planet

The final step consists on producing a model that shows not only the elongations, but also the longitude of the planets, as Evans and myself (2102) suggested on the one hand, and Freeth et Jones (2012) on the other. The necessary modification is fairly simple. Version 2 of the mechanism specifies the elongation of the planet. Knowledge of the longitude of the Sun permits to obtain the longitude of the planet by adding or subtracting the elongation from the longitude of the Sun.

Mechanically, there are two main options. The first option requires replacing the elongation dial with a rotating zodiac that rotates one turn per year (see figure 8). The vertical line (the line of symmetry) at the conjunction tip will show on the moving zodiac the longitude of the Sun (I will call it the (fixed) solar pointer), while the elongation pointer will show the longitude of the planet (and so I will call it the longitude pointer). Like in the Antikythera Mechanism, a calendar dial could also be added so that it displays the day of the year using the fixed solar pointer. The zodiac ring should move in the opposite direction of the signs, so that the fixed solar pointer “advances” on the direction of the signs. See figure 8 representing the outer planet – it is not necessary to duplicate the figure for the inner planet because, in this case, there is no difference. In this particular configuration, the zodiac dial should rotate counter-clockwise.

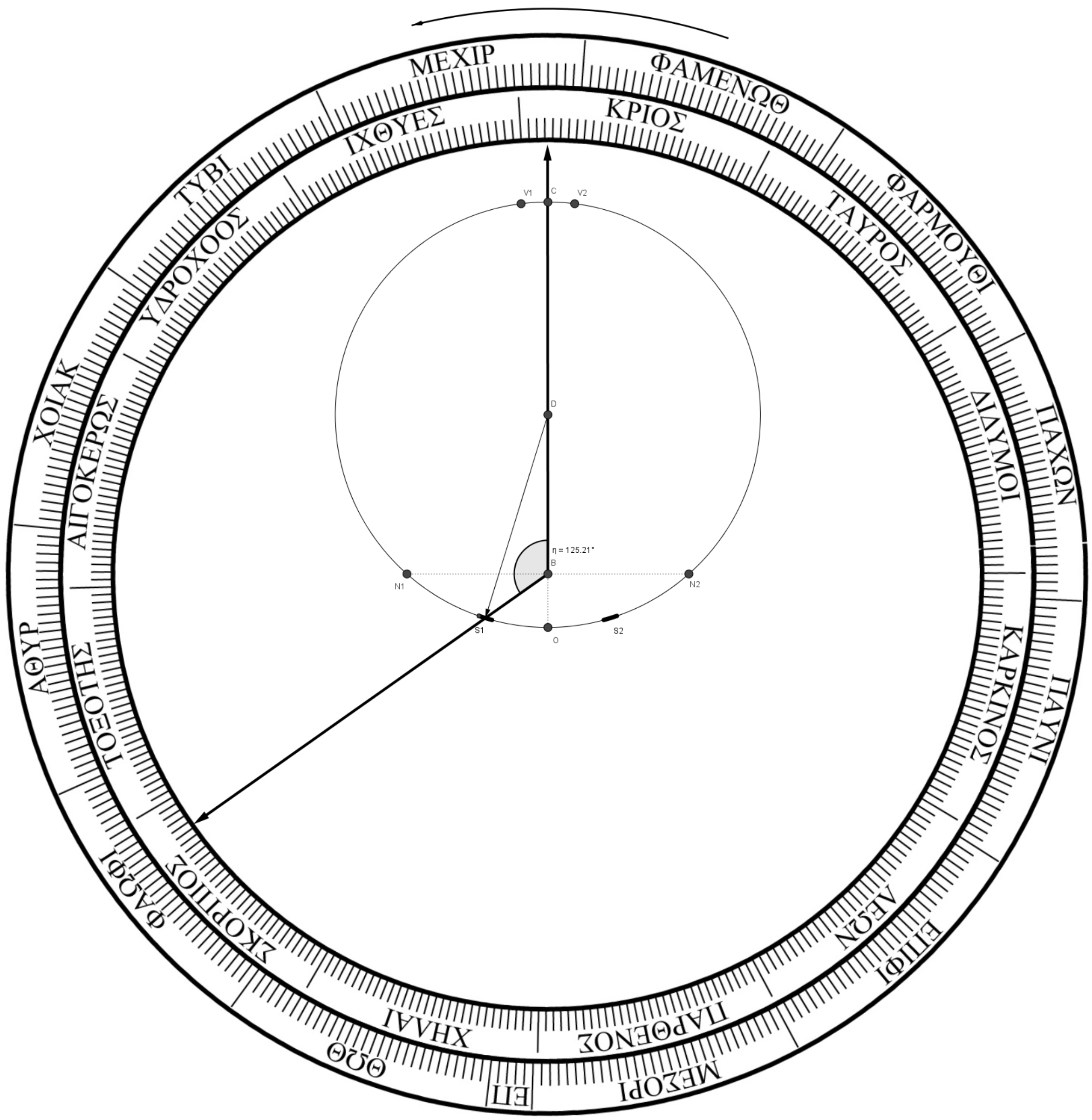

Figure 8: The third model for Mars with a rotating zodiac. References are the same as in figures 1, 3, and 5. A moving zodiac in addition to a calendar ring has replaced the big elongation dial. The rings rotate one turn per year, counterclockwise. The vertical arrow pointing up shows the solar longitude, the elongation arrow is now the longitude arrow and shows the longitude of Mars.

The second option consists on introducing a fixed zodiac and setting the whole device in motion clockwise, rotating one turn per year, as it appears in figure 9:

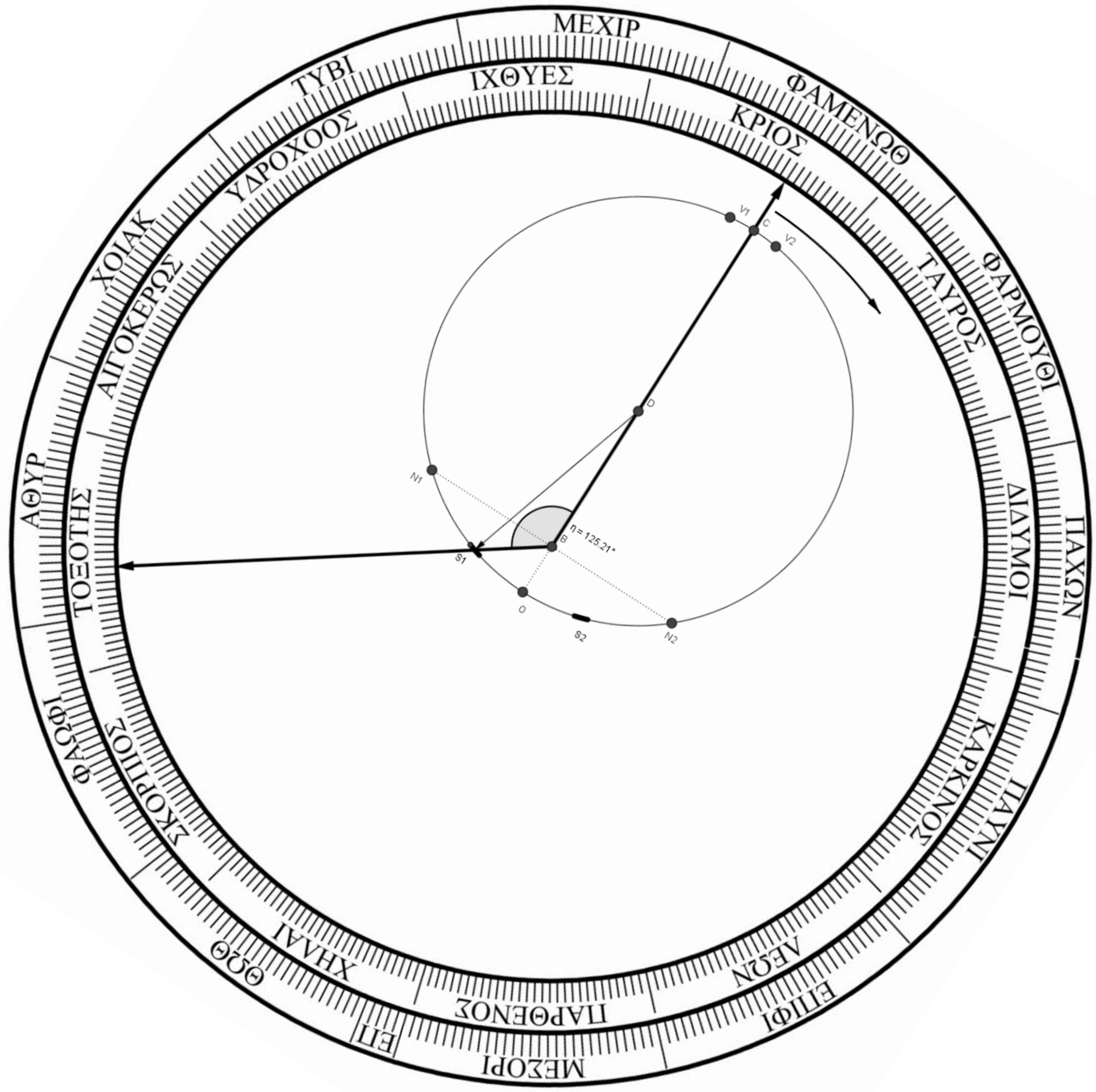

Figure 9: The third model for Mars with a fixed zodiac. References are the same as in figures 1, 3, 5 and 8. The zodiac ring is now fixed and the whole device (the synodic dials with their pointers) rotates clockwise one turn per year. The arrow pointing at 1 o'clock represents the solar longitude pointer and shows the solar longitude, while the arrow pointing at 9 o'clock represents the longitude pointer of Mars and shows the longitude of Mars.

Longitude pointers (previously called elongation pointers) of all five planets could be placed in one and the same zodiac ring, by making point B of each planet to be at the center of zodiac dial, scaling the synodic dials. Figure 10, for example, presents the scaled synodic dial of Mars and Venus so that both fit in the same distance BD. (Strictly speaking, it is only necessary that all pointers have the same center, B, but not for synodic dials to have the same center, D; I will soon show the advantage of introducing this additional constraint).

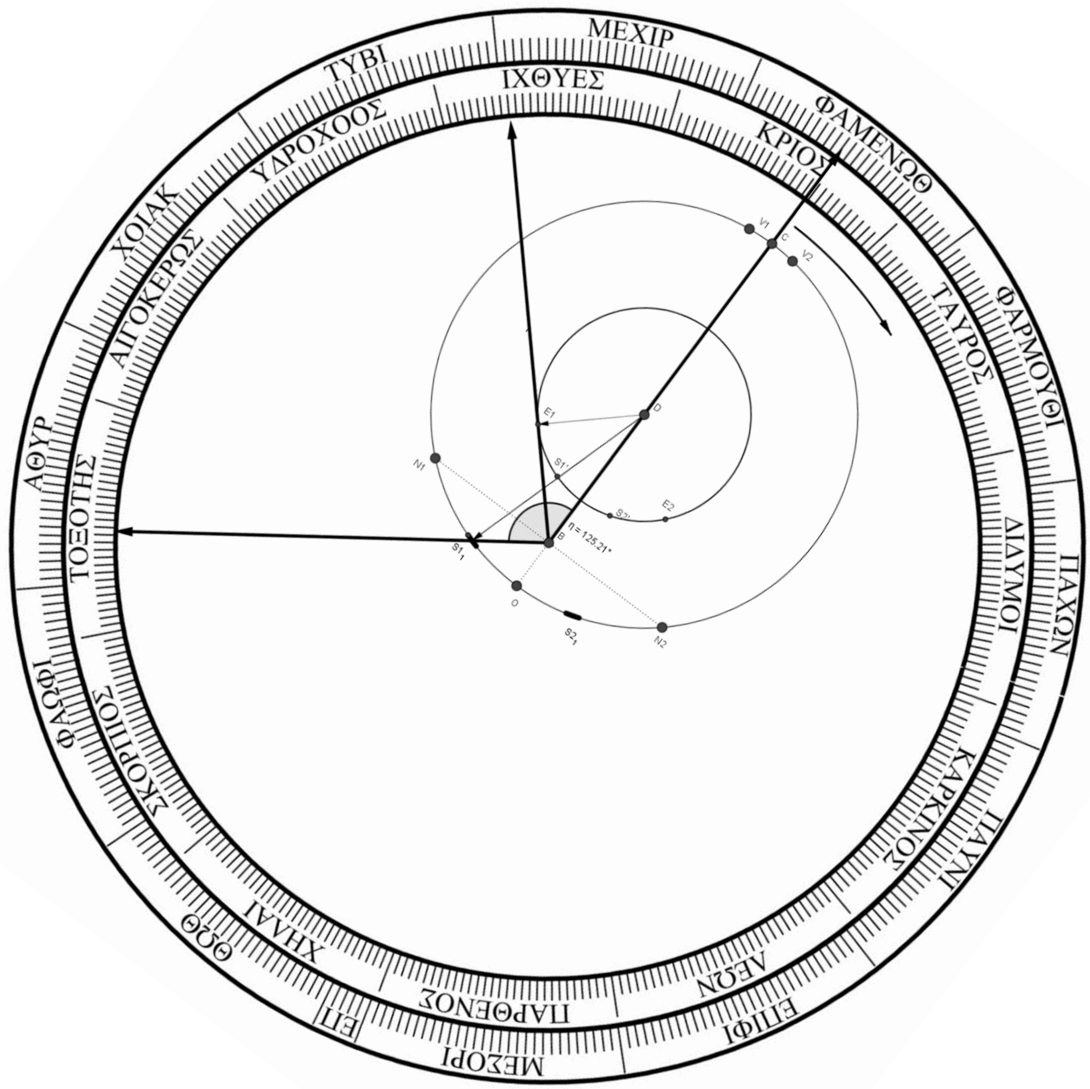

Figure 10: a third model combing one outer planet (Mars) and one inner planet (Venus). References are the same as in previous figures. The smaller circle centered at D represents the synodic dial of Venus, while the bigger one that of Mars. The zodiac ring is now fixed and the whole device (the synodic dials with their pointers) rotates clockwise one turn per year. The arrow pointing at 1 o'clock represents the solar longitude pointer and shows the solar longitude, while the arrow pointing at 9 o'clock represents Mars' longitude pointer and shows the longitude of Mars at one first station; finally, the arrow pointing at 12 o'clock represents Venus' longitude pointer and shows the longitude of Venus at its maximum elongation.

This proposal is exactly the same as Evans and myself (2012) as well as Freeth and Jones (2012) suggested. We all agree that gear B1 rotates one turn per year carrying with it the solar pointer and the pin and slot mechanism for each planet.

Conclusion

I have shown how starting only with the days between the synodic phenomena of each planet, not being aware of anything regarding the epicycle and deferent model, and with three simple steps, one can arrive to the pin and slot models for the planets, as Evans and myself, as well as Freeth and Jones suggested in 2012. It is true that I cannot affirm with certainty that these intermediate steps have been made or even that the maker of the Antikythera Mechanism, or his ancestors, has followed these logical steps. I can be certain, however, that there is a reasonably simple way to arrive to the proposed planetary model without reference to the epicycle and deferent model. Moreover, the small astronomical data necessary to produce these models is impressive: one only needs to know 1) the synodic period in days of the planet, 2) the interval in days between two synodic phenomena,[7] and 3) the elongation of the planet from the Sun at one of these synodic phenomena (the particular value of the elongation or that it is the maximum one, without knowing the angle). So, for example, knowing that the synodic period of Venus is 594 days and that it arrives at its maximum elongation 224 days after conjunction, it would be plausible to build the complete pin and slot model for Venus. In the case of Mars, it is enough to know that its period is of 780 days and that the *nonagenarii* (when the planet is at quadrature with respect to the Sun), are 90 days after and before the opposition.

There is much more to say about this particular way to arrive at the pin and slot device of the Antikythera Mechanism. For example, in following these steps we have arrived at the adequate proportion of epicycle and deferent radii of the planets and also to their adequate periods (see figure 10). The proportion between distance BD and the radius of the synodic dial of Venus is exactly the proportion between the radius of its deferent and that of its epicycle. In the case of Mars, BD represents the radius of the epicycle, while the radius of the synodic dial is the radius of the deferent. Moreover, because BD needed to be the same for both planets, we have virtually arrived to a Tychonic model: the Earth is at B, the Sun at D, and Venus and Mars rotate around their synodic dials, centered at D, the Sun. D, the Sun, rotates around B, the Earth, one turn per year, carrying with it the orbits of Venus and Mars. However, to argue that the pin and slot device of the Antikythera Mechanism reflects a Tychonic system is beyond the aims of this contribution.

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[7] The interval between opposition and conjunction for the outer planets –or between both conjunctions for the inner planets– would not work because it is exactly half a period, and, so, it defines the line of symmetry. To find B along the line of symmetry it is necessary to know the interval between an opposition or a conjunction and another synodic phenomenon.

References

Allen, M., W. Ambrisco, M. Anastatsiou, D. Bate, Y. Bitsakis, A. Crawley, M. Edmunds, D. Gelb, R. Hadland, P. Hockley, et al. (2016), "General Preface to the Publication of the Inscriptions", *Almagest*, 7(1): 1-35.

Anastasiou M., J.H. Seiradakis, J. Evans, S. Drougou, K. Efstathiou (2013), The Astronomical Events of the Parapegma of the Antikythera Mechanism. *Journal for the History of Astronomy* xliv: 173-A10.

Anastasiou, M, J.H. Seiradakis, C. Carman y K. Efstathiou (2014), The Antikythera Mechanism: the construction of the metonic pointer and the back dial spirals. *Journal for the History of Astronomy* 45(4): 418-441.

Anastatsiou, M., Y. Bitsakis , A. Jones , J. M. Steele and M. Zafeiropoulou (2016a), "The Back Dial and Back Plate Inscriptions", *Almagest*, 7(1): 138-215.

Anastatsiou, M., Y. Bitsakis , A. Jones, X. Moussas, A. Tselikas and M. Zafeiropoulou, (2016b), "The Front Cover Inscription", *Almagest*, 7(1): 250-297.

Bitsakis, Y. and A. Jones (2016a), "The Back Cover Inscription", *Almagest*, 7(1): 216-249.

Bitsakis, Y. and A. Jones (2016b), "The Front Dial and Parapegma Inscriptions", *Almagest*, 7(1): 68-137.

Bowen, A. C. (2002), "Simplicius and the early history of Greek planetary theory", *Perspectives on Science*, X(2): 155-167.

Carman, C. and M. Di Cocco, "The moon phase anomaly in the Antikythera Mechanism" *ISAW Papers*, 11. available at http://dlib.nyu.edu/awdl/isaw/isaw-papers/11/

Carman, C. C. and J. Evans (2014), "On the Epoch of the Antikythera Mechanism and Its eclipse predictor"), *Archive for History of Exact Sciences* Volume 68, Issue 6: 693-774.

Carman, C.C., A. S. Thorndike and J. Evans (2012), "On the pin-and-slot device of the Antikythera mechanism, with a new application to the superior planets", *Journal for the history of astronomy,* xliii: 93–116.

Cristopoulou, A, A. Gadolou & P. Bouyia (2012), "The Antikythera Shipwreck: The technology of the ship, the cargo, the mechanism", National Archeological Museum, Athens.

Edmunds, M. (2011), "An Initial Assessment of the Accuracy of the Gear Trains in the Antikythera Mechanism", *Journal for the History of Astronomy,* 42-3(148): 307-320.

Edmunds, M., Morgan, P. (2000), "The Antikythera Mechanism: Still a Mystery of Greek Astronomy?", *Astronomy & Geophysics* 41: 10-17.

Evans, J. and C. C. Carman (2014) "Mechanical Astronomy: A Route to the Ancient Discovery of Epicycles and Eccentrics" in N. Sidoli and G. Van Brummelen (eds.), *From Alexandria, Through Baghdad: Surveys and Studies in the Ancient Greek and Medieval Islamic Mathematical Sciences in Honor of J.L. Berggren*, (Springer 2014).

Evans, J., C. C. Carman and A. S. Thorndike (2010),"Solar anomaly and planetary displays in the Antikythera mechanism", *Journal for the history of astronomy,* xli: 1–39.

Freeth T (2014) Eclipse Prediction on the Ancient Greek Astronomical Calculating Machine Known as the Antikythera Mechanism. PLoS ONE 9(7): e103275. doi:10.1371/journal.pone.0103275

Freeth, T. and A. Jones (2012) "The cosmos in the Antikythera Mechanism". *ISAW Papers* 4, available at http://dlib.nyu.edu/awdl/isaw/isaw-papers/4/

Freeth, T., A. Jones, J.M. Steele and Y. Bitsakis (2008), "Calendars with Olympiad display and eclipse prediction on the Antikythera mechanism", *Nature*, cdliv: 614–17. Supplementary Notes (amended June 2, 2011) available at: http://www.nature.com/nature/journal/v454/n7204/extref/nature07130-s1.pdf

Freeth, T., Y. Bitsakis, X. Moussas, J. H. Seiradakis, A. Tselikas, H. Mangou, M. Zafeiropolou, R. Hadland, D. Bate, A. Ramsey, M. Allen, A. Crawley, P. Hockley, T. Malzbender, D. Gelb, W. Ambrisco, and M. G. Edmunds (2006), "Decoding the ancient Greek astronomical calculator known as the Antikythera mechanism", *Nature*, cdxliv: 587–91. Supplementary Notes available at: http://www.nature.com/nature/journal/v444/n7119/extref/nature05357-s1.pdf

Iversen, P. A. (2017), "The Calendar on the Antikythera Mechanism and the Corinthian Family of Calendars", *Hesperia: The Journal of the American School of Classical Studies at Athens*, Volume 86: 129-203.

Jones, A. (2016), "Historical Background and General Observations", *Almagest*, 7(1): 36-67.

Jones, A. (2017), *A Portable Cosmos: Revealing the Antikythera Mechanism, Scientific Wonder of the Ancient World*, Oxford University Press: Oxford.

Jones, A. (2012) "The Antikythera Mechanism and the Public Face of Greek Science." *Proceedings of Science* PoS(Antikythera & SKA)038, http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=17

Jones, A. (2004), "A route to the discovery of non-uniform planetary motion*", Journal for the history of astronomy*, xxxv, 375-386.

Kaltsas, N., E Vlachogianni, P. Bouyia (2012), "The Antikythera Shipwreck: the ship, the treasures, the mechanism", National Archeological Museum, Athens.

Neugebauer, O. (1975), *A History of Ancient Mathematical Astronomy*. 3 vols. Berlin.

Price, D. de Solla (1974), *Gears from the Greeks: The Antikythera mechanism – A calendar computer from ca. 80 B.C., Transactions of the American Philosophical Society, new series, lxiv/7.*

Theofanidis, I. (1934), "Sur l'instrument en cuivre dont les fragments se trouvent au Musée Archéologique d'Athènes et qui fut retiré du fond de la mer d'Anticythère en 1902", *Πρακτικὰ τῆς Ἀκαδημίας Ἀθηνῶν* 9: 140-149.

Toomer, G.J. (1984), *Ptolemy's Almagest*. London.

Weinberg, G. et al. (1965). *The Antikythera Shipwreck Reconsidered*. American Philosophical Society, Transactions N.S. 55.3. Philadelphia.

Wright, M. T. (2002), “A planetarium display for the Antikythera mechanism”, *Horological Journal*, cxliv: 169–73 and 193.

Wright, M. T. (2003a), “Epicyclic gearing and the Antikythera mechanism, Part I”, *Antiquarian Horology*, xxvii, issue of March, 270–9.

Wright, M. T. (2003b), “In the steps of the master mechanic”, *Ancient Greece and the Modern World* (Patras, 2003), conference paper version available at http://fsoso.free.fr/antikythera/DOCS/AG&MW Olympia2002text tables notes.pdf

Wright, M. T. (2005a), “Counting months and years: The upper back dial of the Antikythera mechanism”, *Bulletin of the Scientific Instrument Society*, lxxxvii, issue of December: 8–13.

Wright, M. T. (2005b), “Epicyclic gearing and the Antikythera mechanism, Part II”, *Antiquarian Horology*, xxix, issue of September: 51–63.

Wright, M. T. (2005c), “The Antikythera mechanism: A new gearing scheme”, *Bulletin of the Scientific Instrument Society*, lxxxv: 2–7.

Wright, M. T. (2006), “The Antikythera mechanism and the early history of the moon phase display”, *Antiquarian Horology*, xxix: 319–29.

Wright, M. T. (2012), “The Front Dial of the Antikythera Mechanism”, *Explorations in the History of Machines and Mechanisms, Proceedings of HMM2012*, Number 15: 279-292.

Wright, M. T., A. G. Bromley, and E. Magkou (1995) “Simple x-ray tomography and the Antikythera mechanism”, *PACT*, xlv: 531–43.