Article

JHA

Journal for the History of Astronomy
2017, Vol. 48(3) 312–323

DOI: 10.1177/0021828617721553
journals.sagepub.com/home/jha
SAGE

The Final Date of the Antikythera Mechanism*

Christián C. Carman
Universidad Nacional de Quilmes, Argentina; Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina

Abstract
The Antikythera mechanism is a mechanical astronomical instrument that was discovered in an ancient shipwreck (from about 60 BCE) at the beginning of the twentieth century. A consensus does not exist on the question of whether the mechanism was built shortly before the shipwreck or significantly earlier. Nevertheless, there is an emerging consensus among scholars about the epoch of the back dials of the mechanism: the Saros dial would start at 27 April 205 BCE and the Metonic dial four synodic months earlier, that is, at 25 August of the same year. Using these two starting dates together with the positions that some pointers still show in the extant fragments of the mechanism I calculate the final date of the mechanism (i.e. the date that it showed when it was last cranked, some time before the shipwreck) as approximately 5 March 193 BCE or one anomalistic month earlier.

Keywords
Epoch of the Antikythera mechanism, final date of the Antikythera mechanism, Metonic pointer, pin and slot mechanism, eclipse predictor, lunar anomaly

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 BCE.[1] A consensus does not exist

*This paper is partly based on data processed from the archive of experimental investigations by the Antikythera Mechanism Research Project in collaboration with the National Archaeological Museum of Athens (see Freeth *et al.*, "Decoding" (see note 16)).

Corresponding author:
Christián C. Carman, Universidad Nacional de Quilmes, Roque Sáenz Peña 352, Bernal Buenos Aires, Argentina (B1876BXD).
Email: Carman ccarman@gmail.com

on the question of 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 nevertheless suffice for reconstructing the main structure and functions of the mechanism. It had several pointers, interconnected and driven by toothed gearing, that indicated the positions of the moon and sun (and probably also the planets) in the zodiac, the date according to the Egyptian calendar, the date in a Greek lunisolar calendar, and also the circumstances of upcoming solar and lunar eclipses.[3]

On the back of the mechanism were two large spiral dials with some subsidiary dials inside them. The upper spiral dial (divided to a precision of single months) showed the date according to a lunisolar calendar based on the Metonic cycle, which distributes, in a fixed pattern, 235 synodic months over 19 calendar years (of 12 or 13 months each). The lower spiral was an eclipse predictor based on the Saros cycle of 223 synodic months (equal to 239 anomalistic months or to 242 draconitic months). In 2014, Carman and Evans investigated the possible epoch years for the Saros dial.[4] The key result is that the solar eclipse of month 13 of the eclipse dial almost certainly belongs to solar Saros series 44. It had previously been established[5] that the distribution of eclipses at 6- (or occasionally 5-) month intervals was based on the Babylonian Saros cycle. Carman and Evans assumed this result but also showed that the times of day for the solar and lunar eclipses inscribed on the mechanism were excellently modeled by a scheme in which the departures from mean motion of the sun and moon were treated by Babylonian-style arithmetic methods. (The Babylonian-style methods gave a better fit than did epicycles.) The best agreement between the inscribed times of day for the eclipses and the times of day calculated theoretically from this model occurs if the full moon of month 1 of the Saros dial corresponds to 12 May 205 BCE, with the exeligmos dial set at 0. Solutions are also possible one Saros cycle later with the exeligmos dial set at 8 hours (in which case the full moon of month 1 = 23 May 187 BCE), and two Saros cycles later with the exeligmos dial set at 16 hours (full moon of month 1 = 3 June 169 BCE), although these have somewhat higher errors of fit.[6] For later possible epochs, the fit becomes progressively worse. It is also noteworthy that solar Saros series 44 ended with the eclipse of June 7, 168 BCE.[7] Thus, it is unlikely the eclipse dial was designed more than one or two Saros cycles after 168 BCE. The Babylonian Saros system generally underwent a recalibration after a Saros series ended. Indeed, there was a recalibration between 132 and 110 BCE.[8] Freeth, using a partially independent procedure, obtained similar results for the possible epoch dates.[9] In the following, I shall therefore work with 12 May 205 BCE as the best-fit possibility for the full moon of month one of the eclipse dial (with the exeligmos dial set at 0). The very first day of the eclipse dial in this scenario was 15 days earlier, that is, 27 April 205 BCE. This I refer to as the minimum-error epoch (or starting date) for the Saros dial. However, it should be kept in mind that starting dates one or several Saros cycles later cannot be excluded on the basis of the eclipses.

This date implies that beginnings of the Saros and Metonic dials cannot correspond to the same month, for, as Paul Iversen and John Morgan pointed out to the author in personal communications, there is strong evidence that requires that the beginning of the Metonic dial fell in August or September.[10] Recently, Paul Iversen, using a thorough calendrical analysis, has argued that the first day of the first month of the Metonic dial was (approximately) 25 August of the same year (205 BCE).[11] Thus, the Saros dial started 4 synodic months earlier in the same year than did the Metonic dial.

In this paper, I will use these two starting dates (for the eclipse predictor and the Metonic calendar dial) in 205 BCE together with the positions that some pointers still show in the extant fragments of the mechanism to calculate the final date of the mechanism. By final date, I mean the date that the mechanism showed when it was last cranked, some time before the shipwreck. In order to do so, I have to assume that the extant pointers did not move significantly after the wreck. I will discuss the plausibility of this hypothesis in each case. The final date obtained is (approximately) 5 March 193 BCE or one anomalistic month earlier. The procedure that I will follow is rather simple. There are just two extant pointers in the fragments: those of the Metonic and exeligmos dials. Knowing the starting dates of each dial, we can calculate the dates at which both pointers would point to the position that they are still pointing to now. We will arrive at four candidates, but both historical context and mechanical considerations strongly favor the 193 BCE candidate.

Finding the final date

In fragment B, almost the entire Metonic pointer has survived.[12] Refer to the lower part of Figure 1. A portion of the pointer close to the arbor and part of the bearing device that held the pointer to the arbor are missing. Nevertheless, through a careful analysis of the microfocus X-ray computed tomography (CT) of this fragment, the remains of the bearing device allow us to confirm that it is well aligned with the pointer's tip (Figure 1). Therefore, it is reasonable to assume that the pointer, despite its damaged state, shows pretty nearly the position that it had when it was unbroken.

The pointer tip is well preserved. The guide pin is still in the spiral slot, and the arrow-shaped pin that served as the pointer is in place. It is possible to measure, therefore, the last position that the pointer showed. It is pointing to the first days of month 143, that is, a little more than 142 months after day 1 of the Metonic dial. It is important to recall that the Metonic dial does not afford the precision of reading to a single day, and probably an ancient user was not expected to read off a precise date on the Metonic dial. (He could know the exact day by reading the Egyptian calendar dial on the front of the mechanism). Nevertheless, careful measurements show that it is pointing to day 6 of month 143 (see Figure 2). That is, it indicates a time that is 142 synodic months, 5 days, beyond day 1 of the Metonic cycle.

If we assume Iversen's starting date of 25 August 205 BCE *for the Metonic dial*, then the last position was about 22 February 193 BCE if it had been moved forward in time less than a Metonic cycle. Of course, we cannot assume that the last position is less than a Metonic cycle from the starting date, but what we do know is that the final position is either 22 February 193 BCE or any integer multiple of 19 years before or after that date. I will use 22 February as the paradigmatic date, but the analysis doesn't require such a precise reading of the Metonic pointer. The fact that the pointer is broken and the imperfect alignment between the bearing device and the pointer itself prevent us from assuming a too narrowly defined date. Also, the error due to the construction of the gear teeth should be allowed for. This kind of error has been analyzed already by Edmunds. According to him, in the case of the Metonic pointer, the maximum deviation from a perfectly accurate display in

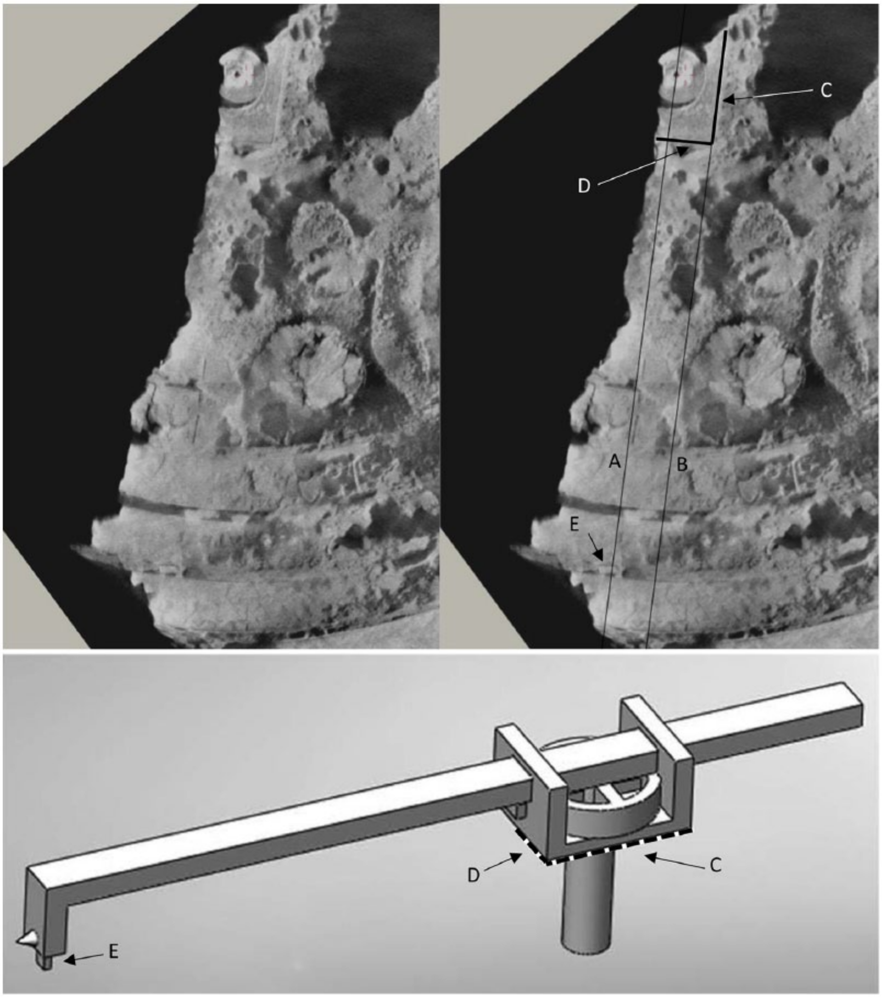

Figure 1. Both sides of the upper figure are the identical CT image, but on the right, I superimpose some lines and references. E is the guiding pin and C and D are lower sides of the pointer bracket. Line B is collinear with border C of the pointer bracket. Line A is parallel to line B but passes though the center of the arbor. Line A passes through the guiding pin E, but not exactly through its center, so the pointer is very well, but not perfectly aligned with the pointer bracket. The lower part of the figure reproduces the reconstruction of the Metonic pointer in Anastasiou et al., "The Antikythera Mechanism" (see Note 12), 453 for comparison. (Copyright of the Antikythera Mechanism Research Project. Image kindly provided by T. Freeth)

the worst-case scenario (taking backlash, uneven division of the teeth, and the imperfect triangular-shaped teeth into account) would be 15 days.[13] In our analysis, I will assume that any date up to one synodic month after or before 22 February is admissible.

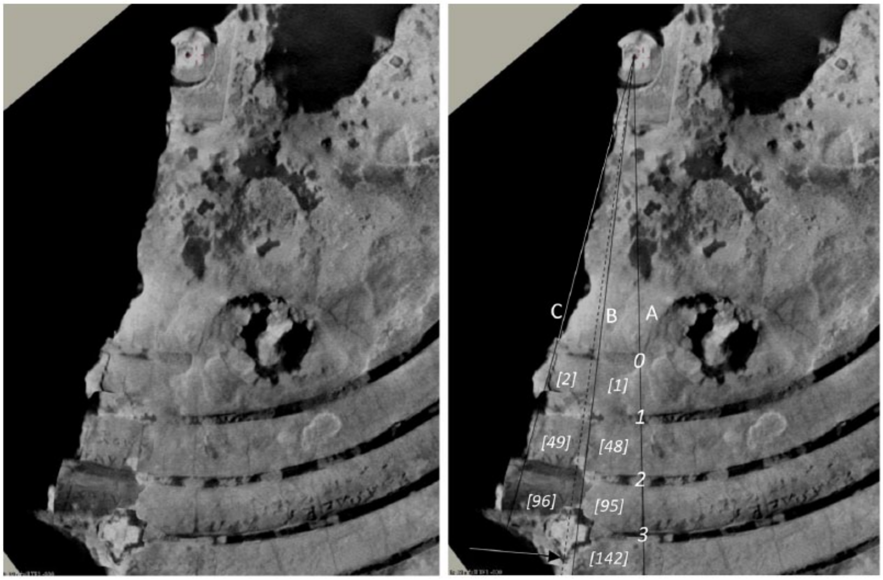

Figure 2. The two sides of the figure are identical CT composites, but on the right, I superimpose some lines. Lines A, B and C pass through the lines that divide the first months of separate turn of the Metonic spiral. Numbers 0 to 3 indicate the turns of the spiral. The dashed line joins the center of the pointer shaft with the middle of the arrow-shaped pin. The numbers in square brackets indicate the month. The pointer is therefore in the second month of the third turn, that is, at month 143, close to the beginning of the month. (Copyright of the Antikythera Mechanism Research Project. Image kindly provided by T. Freeth)

One revolution of the exeligmos dial comprises three Saros cycles, that is, 669 synodic months. In fragment A, there are clear remains of the exeligmos pointer, as Freeth and Jones pointed out.[14] Therefore, our next step is to calculate the position that the exeligmos pointer would have at each Metonic extrapolation from 22 February 193 BCE. We already know that the Saros dial's first turn, and therefore, the exeligmos dial's also, started four months earlier than the first turn of the Metonic dial. This means that when the Metonic pointer indicated the beginning of month 1, the Saros dial was already at the beginning of month 5. After 142 months, when the Metonic dial indicated the beginning of month 143, the Saros dial was at the beginning of month 147. The exeligmos pointer thus pointed at day 6 of month 147 in its first Saros when the Metonic pointer indicated day 6 of month 143, that is, 22 February 193 BCE. When, after 235 months, the Metonic pointer is again at day 6 of month 143, the exeligmos pointer will be pointing at day 6 of month 382 (147+235); after one Metonic cycle more, at day 6 of month 617; and after one more Saros cycle, it will have completed a whole exeligmos and will point at day 6 of month 183 (47 + 235 + 235 + 235 – 669); and so on.

As is evident in Figure 4(a), the exeligmos pointer, though damaged, is clearly pointing in a direction a little clockwise of the middle of the first third (or "zero hours" portion) of the exeligmos dial, so we are interested in candidate dates consistent with this

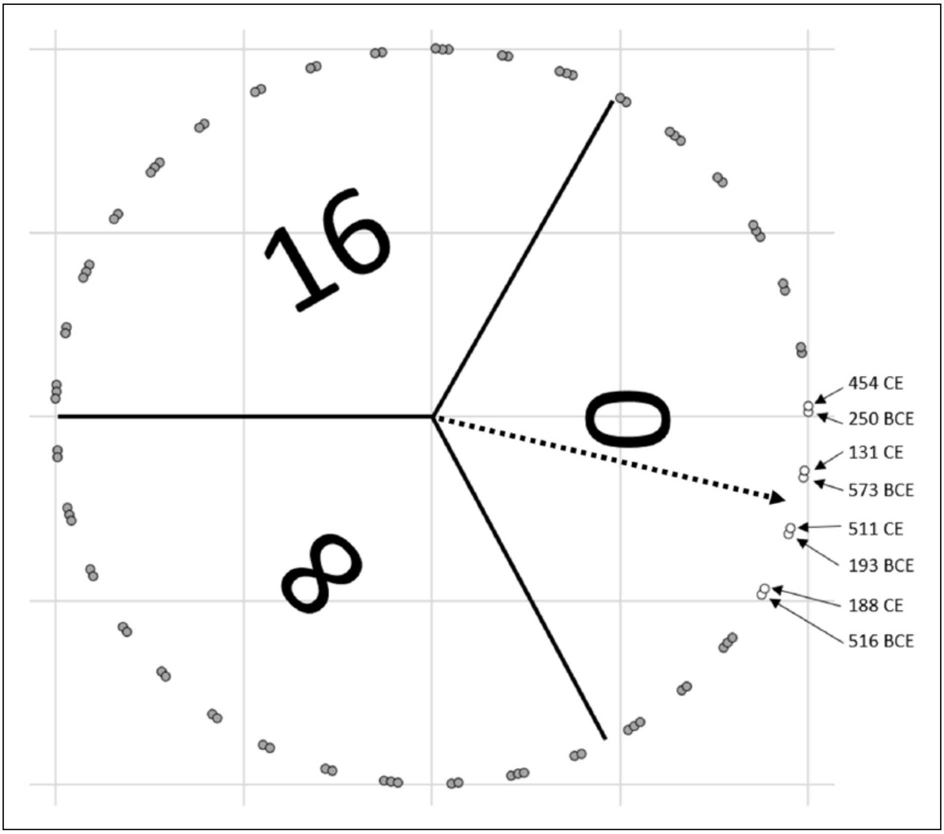

Figure 3. Positions of the exeligmos pointer at the different Metonic extrapolations of 22 February 193 BCE from 858 BCE to 758 CE. The dashed line shows the present orientation of the pointer.

condition. In Figure 3, I have plotted the exeligmos pointer positions for all the Metonic extrapolations within 800 years of the date of the wreck.[15] We can confidently assume that the mechanism would not indicate a date outside this range.

As Figure 3 clearly shows, we should consider only eight candidates, 22 February of the years 573, 516, 250, and 193 BCE, and 131, 188, 454, and 511 CE. But a close analysis shows that the pointer is definitely not pointing toward the pairs at the two extremes. In Figure 4(c) and (d), I superimpose upon the extant position of the pointer, the direction that the outline of the pointer would have if pointing at these candidates. The disagreement is manifest, so we can confidently abandon the four extreme candidates and retain only the four of the middle: 573 BCE, 193 BCE, 131 CE, and 511 CE. The pointer is lodged on its arbor and the driving gears are in place, so unlike in the case of the Metonic pointer, there is no reason to suppose that there could have been any significant deviation of the pointer after the shipwreck. On the other hand, an error of 1 month in position of the Metonic pointer would imply a displacement of just 0.54° of the exeligmos pointer.

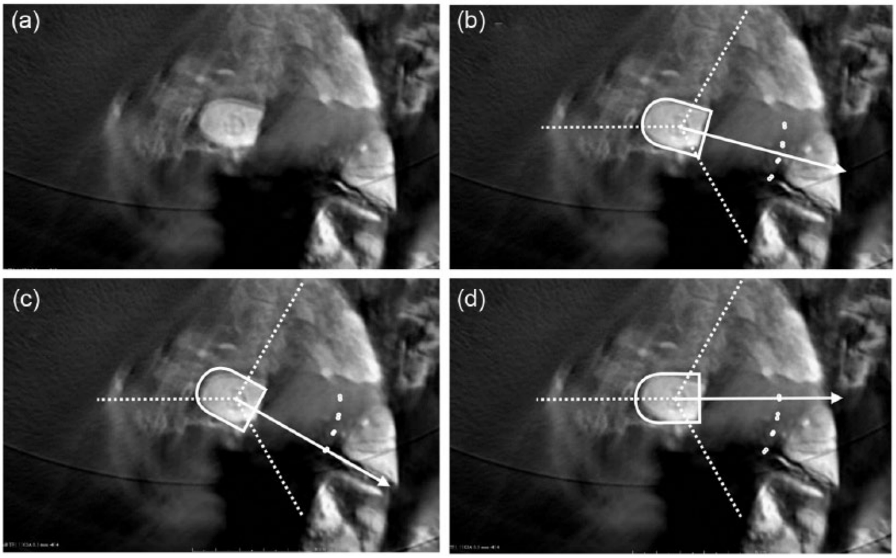

Figure 4. The four CT images are identical. 4A is an unmarked CT of the extant exeligmos pointer. In 4B I superimpose upon the extant pointer a symmetrical shape and extended its line of symmetry in order to find where it is pointing. In Figure 4(c) and (d), I superimpose upon the extant position of the pointer, the direction that the outline of the pointer would have if pointing at the extreme candidates among the Metonic extrapolations. The disagreement is evident in both 4C and 4D. (Copyright of the Antikythera Mechanism Research Project. Image kindly provided by T. Freeth)

Moreover, Edmunds' estimate of the maximum error in angular position (due to imperfections in the gearing mentioned above) in this case could reach around 2.2° (personal communication). Therefore, a total error of 3° is more generous than necessary. We also should allow, say, 5° of uncertainty since we are not sure of the pointer's exact direction, because the pointer itself is incomplete. But the angular distance of the extreme candidates from the line along which the pointer seems to be pointing is around 15°, which means they may be excluded with confidence.

In fragment A, part of the pin and slot device survives.[16] This allows us to calculate the lunar anomaly that the mechanism showed at its final date. As one can see from Figure 5, it is around 211° measured from the apogee. One might be tempted to use this datum to restrict our possibilities still further, but this would require demanding an unreasonably small error in the measured position of the Metonic pointer. The anomalistic month is around 27.55 days. Therefore, in the margin of one synodic month on each side of the Metonic pointer, all the possible anomalies are covered twice. It would not be safe to assume a narrower limit.

But the value of the lunar anomaly can help us to identify with more precision the exact day or days around February 22 that the mechanism showed at the moment of the wreck. The reading of the anomalistic angle in the CT is very precise and all the relevant

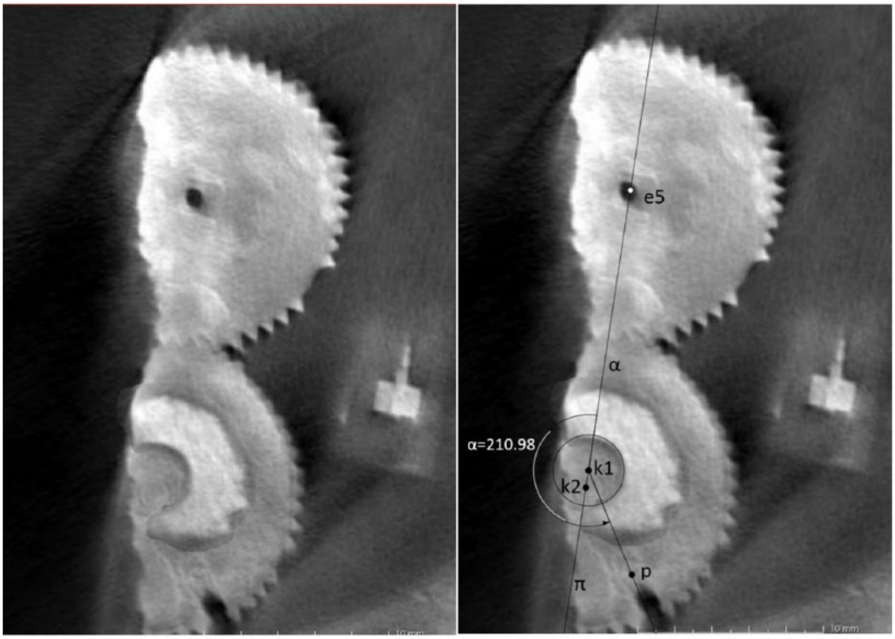

Figure 5. Both sides of the figure are identical. The gear with center k1 (not visible as it is underneath the visible gear) carries the pin P, while the gear centered at k2 has the slot. Both gears rotate counterclockwise. Therefore, the slot turns faster with respect to k2 when it is in the lower part of the figure, closer to k2 and slower when it is further, in the apogee (α). The mean anomaly measured from the apogee is close to 211°. (Copyright of the Antikythera Mechanism Research Project. Image kindly provided by T. Freeth)

parts (arbor, gears, pin, slot, etc.) are in place. However, Mike Edmunds has shown that for this gear the standard deviation in the error in angular position is about ±14° in the anomaly (personal communication). In this case, because I am not using the value for discarding possibilities but for finding the most probable, it is better to use the standard deviation in a reasonable scenario instead of the maximum deviation in the worst scenario. If we also allow an error of another ±4 days in the mechanical setup (because to fix the anomaly at a desired value is not too easy), we should tolerate an error of ±5 days. We know that at the first full moon of the Saros cycle, the lunar anomaly was 0°[17] and, because the Saros (and hence also the exeligmos) cycle involves a complete number of anomalistic months, we are able to calculate the lunar anomaly that the mechanism would show at any possible position of the exeligmos dial. In Table 1, I give the two closest days to each candidate that show the correct lunar anomaly (one before and one after 22 February), and the number of days between these day and 22 February. Of course, the pair of dates for each candidate year will be one anomalistic month apart.

Now, of the four pairs of candidates, the only one that has any reasonable historical plausibility is that of the year 193 BCE. It is hard to imagine a scenario in which some user would choose to turn the crank 1718 times and reset the Saros and Metonic pointers 41

Table 1. Examination of the candidates for the final date of the Antikythera mechanism.

Year	Date	Exeligmos month[18]	Mean Anomaly	Days from Feb 22	Metonic plus Saros re-sets	Crank turns
573 BCE	13 February	129.9	220°	−9	–41	−1718
	11 March	130.8	213°	18		
193 BCE	6 February	146.7	213°	−16	0	55
	5 March	147.6	213°	12		
131 CE	16 February	128	208°	−6	35	1562
	15 March	128.9	213°	22		
511 CE	2 February	144.8	208°	−12	76	3335
	8 March	145.7	213°	16		

times in order to arrive at a date 500 years before the shipwreck, and something similar could be said for the candidates of 131 and 511 CE. Therefore, 193 BCE is the only reasonable candidate. Between both 193 BCE candidates, that of 5 March should be slightly preferred for being closer to 22 February.

I can conclude, therefore, that the last date that the mechanism showed was 5 March 193 BCE (± 5 days) or, less probably, 6 February of the same year (± 5 days).

Concluding remarks

The fact that the only remotely reasonable candidate is less than one Metonic cycle from the starting configuration is intriguing, but it is not obvious what conclusion should be drawn from this fact. There seem to be two main possibilities. (1) It could be the case that the mechanism was simply not used very much and that it was never advanced very far beyond its epoch (starting date). Presumably, the mechanism was set to its epoch date at the time it was made, but during the subsequent time between manufacture and destruction no one cranked it very much. This view of things might be supported by the fact that the Egyptian calendar ring is several months out of position for the date of the wreck, which might imply that, at the time of the wreck, the mechanism was not in the hands of a capable user.[19] Or, (2) in a completely different view of things, perhaps the mechanism was originally set to its epoch date, and during the subsequent time it was sometimes cranked to dates more remote from the epoch, but afterwards was always carefully wound back to near epoch. This would have been a wise procedure because there is no dial that helps to keep track of time on a scale longer than one Callippic period. To keep close to the epoch would have prevented the user from becoming lost in time.

Does the final date displayed by the mechanism have any bearing on the possible date of construction? Not decisively, since possibilities (1) and (2) remain open. But we will observe that a construction date later than one Callippic cycle (76 years) after the 205 BCE epoch favored by Carman and Evans, by Freeth, and by Iversen seems unlikely. This is because, as far as we know, there was no display on the mechanism to disambiguate two dates that were more than 76 years apart (except perhaps the Egyptian calendar ring, which was loose and movable and so, as we have seen, was subject to misplacement).

Thus, if the user cranked past 129 BCE, he risked becoming lost in time. Moreover, as mentioned above, the eclipse calculator ceased to function satisfactorily after the end of solar Saros series 44 (which ended in 168 BCE), though perhaps this was not noticed until the Babylonian recalibration of the Saros that occurred sometime between 132 and 110 BCE. These considerations, together with the fact that the final date displayed by the mechanism is close to the epoch seem to weigh heavily against a construction date close to the date of the shipwreck. The machine was probably old when the ship went down.

However, it is important to highlight that the result that the final date is about 11 1/2 years after the starting date does not depend on the attribution to the dials of absolute dates. That is, if Iversen's starting date for the Metonic dial is not correct, the final date is still only about 11 1/2 years after the starting date. The analysis only requires the periodicities of the exeligmos and Metonic cycles as displayed on the Mechanism. The only exception is the part involving the lunar anomaly, but this has been used to determine with greater precision the candidate dates, not to eliminate any of them. Even here, it is only required to assume that the Metonic cycle started 4 months after the Saros cycle, without assuming any particular pair of dates.

Acknowledgements

I am grateful to Alexander Jones, who generously discussed with me a previous draft of the paper and helped improve the English. Some of the ideas in the paper have been the result of his generous comments. Almost all this research has been done in collaboration with James Evans. He also discussed different drafts of this paper. Parts of this research have been discussed with Tony Freeth, Paul Iversen, John Morgan and Lina Anastasiou. I am in debt to all of them. Mike Edmunds helped a lot by discussing with me the possible position errors of the pointers and by making some calculations ad hoc for this research. I also thank for their comments Gonzalo Recio, Anibal Szapiro and Diego Pelegrin. The Antikythera Mechanism Research Project has, as always, been extremely generous in sharing images and data.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: I would like to express my thanks for the support of Research Project PICT-2014-0775 of the Agencia Nacional de Promoción Científica y Tecnológica of Argentina.

Note on Contributor

Christián C. Carman (ccarman@gmail.com) is Professor and Researcher at the Universidad Nacional de Quilmes, Argentina, and research member of the National Research Council of Argentina (CONICET). He works on topics related to philosophy of science (particularly the scientific realism debate) as well as history of ancient astronomy, mainly related to the Antikythera mechanism and with the calculations of the distances of the sun and moon.

Notes

1. G. Weinberg, V.R. Grace, G. Roger Edwards, H.S. Robinson, P. Throckmorton and E.K. Ralph, "The Antikythera Shipwreck Reconsidered," *Transactions of the American Philosophical Society*, 55(3), 1965, pp. 3–48; A. Cristopoulou, A. Gadolou and P. Bouyia (eds), *The Antikythera Shipwreck: The Technology of the Ship, the Cargo, the Mechanism*

(Athens: National Archaeological Museum, 2012); N. Kaltsas, E. Vlachogianni and P. Bouyia (eds), *The Antikythera Shipwreck: The Ship, the Treasures, the Mechanism* (Athens: National Archaeological Museum, 2012).

2. D. de Solla Price, "Gears from the Greeks: The Antikythera Mechanism – A Calendar Computer from ca. 80 B.C.," *Transactions of the American Philosophical Society*, 66(7), 1975, pp. 1–19, deduced with a probably incorrect argument that the date is in the 1980s BCE; C. Carman and J. Evans, "On the Epoch of the Antikythera Mechanism and Its Eclipse Predictor," *Archive for History of Exact Sciences*, 68, 2014, pp. 693–774, favor a construction date within a few Saros cycles of 205 BCE; T. Freeth, "Eclipse Prediction on the Ancient Greek Astronomical Calculating Machine Known as the Antikythera Mechanism," *PLoS ONE*, 9(7), 2014, p. e103275, 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 Saros dial was designed" (p. 11). P. Iversen, "The Calendar on the Antikythera Mechanism and the Corinthian Family of Calendars," *Hesperia: The Journal of the American School of Classical Studies at Athens*, 86, 2017, pp. 129–203, and A. Jones, *A Portable Cosmos: Revealing the Antikythera Mechanism, Scientific Wonder of the Ancient World* (Oxford: Oxford University Press, 2017), pp. 157–60, argue for a dating closer to the shipwreck.
3. For a systematic introduction to the research on the mechanism as well as an updated bibliography see: Jones, *A Portable Cosmos* (see Note 2).
4. Carman and Evans, "On the Epoch" (see Note 2).
5. T. Freeth, A. Jones, J.M. Steele and Y. Bitsakis, "Calendars with Olympiad Display and Eclipse Prediction on the Antikythera Mechanism," *Nature*, 454, 2008, pp. 614–7.
6. In principle, starting dates one or two Saros cycles *before* the minimum-error starting date would also work.
7. See Fred Espenak's catalog of the eclipses of solar Saros series 44 at <https://eclipsewise.com/solar/SEsaros/SEsaros044.html>
8. Carman and Evans, "On the Epoch" (see Note 2), 702; J. Steele, "Eclipse Prediction in Mesopotamia," *Archive for History of Exact Sciences*, 54, 2000, pp. 421–54 (see pp. 442–3).
9. Freeth, "Eclipse Prediction," (see Note 2). However, Freeth also included several possibilities in which the solar eclipse of month 13 belongs to solar Saros series 50. Carman and Evans, "On the Epoch" (see Note 2), pp. 772–3, showed that these solutions may certainly be excluded. Freeth also used a method in which the distribution of eclipses was not based on the Saros cycle, but on a more complex system of his own devising. However, his solution and the Saros series solution differ only in the months in which two eclipses occur – and these are months that are not preserved on the mechanism. (The Saros scheme described by Carman and Evans has a solar eclipse in month 148, while the non-Saros scheme developed by Freeth puts the same eclipse in month 149. The Saros scheme of Carman and Evans has a lunar eclipse in month 213, while Freeth's scheme puts it in month 214).
10. Carman and Evans, "On the Epoch," (see Note 2), p. 762.
11. Iversen, "The Calendar" (see Note 2).
12. M. Anastasiou, J.H. Seiradakis, C. Carman and K. Efstathiou, "The Antikythera Mechanism: The Construction of the Metonic Pointer and the Back Dial Spirals," *Journal for the History of Astronomy*, 45, 2014, pp. 418–41.
13. M. Edmunds, "An Initial Assessment of the Accuracy of the Gear Trains in the Antikythera Mechanism," *Journal for the History of Astronomy*, 42, 2011, pp. 307–20 (see p. 316).
14. T. Freeth and A. Jones, "The Cosmos in the Antikythera Mechanism," *ISAW Papers*, 4, 2012, <http://dlib.nyu.edu/awdl/isaw/isaw-papers/4/>.
15. As an example, I describe the procedure followed for the value corresponding to 511 CE in Figure 3. We know that on 22 February 193 BCE, when the Metonic pointer indicated day

6 of month 143, the Exeligmos pointer indicated day 6 of month 147. Moving forward in time by 37 Metonic cycles ($37 \times 19 = 703$ years) brings us to 511 CE (= −192 + 703). In 37 Metonic cycles, both dials moved through 8695 synodic months (37×235). The Metonic pointer would obviously again be pointing in the same direction. But the exeligmos pointer turned though $8695/669 = 12.99701$ complete turns, that is, 12 complete turns plus 667 synodic months, which is exactly 2 synodic months less than 13 complete turns. Therefore, the exeligmos pointer will be pointing to a position two months earlier than before, that is, to day 6 of month 145. Thus, the pointer will be 5 days and 144 months beyond the beginning of the "0 hours zone." Because the exeligmos dial turns one revolution every 669 months, each month implies a rotation of the pointer by (360°/669=) 0.538°. Therefore, 144 months and five days correspond to a rotation of 77.58° from the beginning of the 0 hours zone. This is the position plotted on the circle corresponding to 511 CE in Figure 3.

16. See T. Freeth, 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, "Decoding the Ancient Greek Astronomical Calculator Known as the Antikythera Mechanism," *Nature*, 444, 2006, pp. 587–91.
17. M. Anastasiou, Y. Bitsakis, A. Jones, X. Moussas, A. Tselikas and M. Zafeiropoulou, "The Front Cover Inscription," *Amagest*, 7(1), 2016, pp. 250–97 (especially pp. 185–91); Carman and Evans, "On the Epoch" (see Note 2), pp. 722–9.
18. The fraction of the month is expressed in advance, no matter if for arriving at that particular date the knob had to be rotated backward. Therefore, 129.9 means 129 months and 9/10 of the way through month 130.
19. Alexander Jones (personal communication) has suggested that perhaps the Egyptian calendar ring was moved by someone as an aid in measuring the time interval required for the sun to move between two points in the zodiac, and so it should not be considered as necessarily out of place. Of course, one cannot exclude something like this – but moving the calendar ring would not have been necessary for measuring a time interval, since one could simply count months and days on the calendar ring.