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# THALES'S PREDICTION OF A SOLAR ECLIPSE

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The prediction of a solar eclipse by Thales is one of the most celebrated events in the history of Greek science. It astonished his contemporaries, as it has astonished modern scholars. Unfortunately, we have no ancient account of the method that facilitated Thales's extraordinary achievement,[1] and all modern attempts at the reconstruction of such a method seem to have failed. It has been argued that any reliable prediction of a solar eclipse was impossible before the time of Hipparchus, more than four centuries later. Moreover, the accuracy of the main evidence for the story has been largely discredited: Thales is said to have determined the year of the eclipse (or so Herodotus's account is usually understood), but this is odd, for one would think that if one can predict an eclipse at all, one can predict it to the day.

This situation legitimates the radical doubt expressed by two outstanding scholars, Thomas-Henri Martin in the last century and Otto Neugebauer more recently, that the story of the prediction is nothing but a myth.[2] Yet such scepticism is less legitimate when viewed in the light of procedures used in philology: the evidence for Thales's prediction is too strong to be denied.[3] In the words of Sir Thomas Heath, "it remains to inquire in what sense or form, and on what ground, he made his prediction".[4]

It is not only Herodotus who tells us about the prediction.[5] Diogenes Laertius in his *Lives of eminent philosophers* (1.23) refers to Xenophanes (21 B 19 DK) in addition to Herodotus, as having been amazed by Thales's achievement; and Xenophanes lived in the same century as Thales. Diogenes Laertius also refers to testimonies by Heraclitus (22 B 38 DK) and Democritus (68 B 115 DK). All of Diogenes Laertius's information seems to come from a very good source, Eudemus of Rhodes, who is mentioned in the passage (fr. 144, Wehrli).[6]

It seems never to have been taken into account that Eudemus ought to have thought Thales's ability to predict a solar eclipse as astonishing as we do. Nobody could safely predict a solar eclipse even in Eudemus's own day, towards the end of the fourth century B.C., despite the impressive progress of astronomy in the interval. Thales's achievement apparently remained unique for more than two hundred years (see below). Besides, Eudemus's teacher, Aristotle, regularly shows considerable caution regarding the received information on Thales, and so it is most unlikely that Eudemus in his *History of astronomy* would uncritically credit Thales with the prediction of a solar eclipse. On the contrary, his search for additional confirmation of the story told by Herodotus reflects a critical attitude. Such a confirmation was to be found in the writings of early philosophers such as Xenophanes and Heraclitus, and so Eudemus accepted the story as trustworthy.

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There is much in our sources that supports the tradition indirectly. Thales was universally famous as an astronomer. There is a hint of this fame already in Aristophanes (see the contexts of the *Clouds* 180 and the *Birds* 1009), and an anecdote told by Plato (*Theaetetus*, 174 a) has Thales watching stars. There must have been something, then, in Thales's involvement with celestial phenomena that impressed the Greeks so much. What could it be, if not a prediction?[7]

Furthermore, the question should be asked: who could have invented the legend of the prediction? An explanation in terms of folklore is not appropriate here, for in order to invent a prediction of a solar eclipse, one must first accept that a solar eclipse is a predetermined event rather than one that happens at divine command. Ordinary people of the period would not have invented such a story, nor would they have believed in it unless they were confident that the prediction had actually occurred. Accordingly, the claim that the story of Thales's prediction could have emerged as a legend is problematic.

We have another record of the prediction of a solar eclipse long before Hipparchus. Plutarch, in the *Life of Dion*, 19, ascribes such an achievement to Helicon of Cyzicus, during Plato's visit to Sicily. (The date of this eclipse must be either 12 May 361 or 29 February 357.) It has to be said that, at least in the present state of our knowledge, such an achievement was at the time impossible for Greek science. Yet it is difficult to supply a motive for inventing the story.

The situation with Thales's prediction as it is recorded by Herodotus is similar. It is admittedly true that "the reliability of literary eclipses is poor in general",[8] and it is certainly true that there is an example of a fictional eclipse in the *Histories*, namely Herodotus's story about the solar eclipse that occurred at the beginning of the march of Xerxes's army (7.37). But the difference between the two accounts is evident. In the case of Xerxes's eclipse, the motive is quite clear, "to provide Xerxes with a celestial omen commensurate with his ambitions".[9] But in the case of Thales, there is no such motive at all. The eclipse interrupted the battle between the Lydians and the Medes. Thales has nothing to do with that event: he foretold the eclipse to the *Ionians*.[10]

Perhaps there is something that is beyond our present grasp of ancient astronomy.[11] Perhaps there was a method that, while not permitting secure predictions (for otherwise the successful ones would not be as episodic as they were), did allow reasonable attempts to foretell the phenomena. If so, we should try to account for Thales's prediction without resorting to the simple solution of denouncing it as fictional.

There is wide agreement about the date of Thales's eclipse: 28 May 585 B.C.[12] For a long time there also was wide agreement about the method used by Thales for his prediction. "The proposed solutions of the problem have very often been sought in eclipse cycles, most notably the 'Saros' period of 18 years or, more precisely, 223 lunations (about $6585\frac{1}{3}$ days)." Yet, to continue the quotation, "though there are excellent cycles for lunar eclipses ... there are no such cycles or periodic recurrences of solar eclipses for a given location on Earth".[13]

Because these alleged solutions were regularly associated with Thales's access to Babylonian wisdom, another quotation seems appropriate. "In the early days of classical studies one did not assume that in the sixth century B.C. a Greek philosopher had at his disposal the astronomical and mathematical tools necessary to predict a solar eclipse. But then one could invoke the astronomy of the 'Chaldeans' from whom Thales could have received whatever information was required. This hazy but convenient theory collapsed in view of our present knowledge about the chronology of Babylonian astronomy in general and the lunar theory in particular. It is now evident that even three centuries after Thales no solar eclipse could have been predicted to be visible in Asia Minor — in fact not even for Babylon. There remains another vague hypothesis: the prediction by means of cycles (if need be, again available upon request from Babylon). But unfortunately there exists no historically manageable cycle of solar eclipses visible at a given locality...."[14]

The most popular idea, of associating the prediction based on the Saros with the eclipse of 28 May 585, was especially misleading. The fact is that the solar eclipse of 18 May 603, the predecessor of the alleged 'Thales's eclipse' in the Saros, itself had no predecessor in the Saros that was observable in the Mediterranean or the Near East. Who would have predicted that a solar eclipse must happen 18 years later if there was no eclipse 18 years earlier?

The most sophisticated attempt known to me, to discover which cycle Thales could have used, was undertaken by Willy Hartner.[15] His study is interesting and useful. Yet, on the one hand, Hartner postulates in an arbitrary way the existence of systematic observational data recorded in Miletus for decades before Thales's birth, and credits Thales with too much knowledge about too many cycles; while on the other hand, Hartner's train of thought implies no reason why Thales should have chosen one cycle rather than another. Hartner's Thales would hardly have dared to predict an eclipse.[16] Similarly, the explanation cautiously promoted by B. L. van der Waerden[17] leaves Thales with too little conviction to risk making his prediction public.[18]

Thus the reasons for doubting the plausibility of the prediction appear to be as strong as the evidence for it. It may be that there is the possibility of a satisfactory compromise in developing Martin's train of thought. He suggested that Thales explained to his compatriots that an eclipse occurs when the moon passes in front of the sun and declared that they would probably see this natural event again in a number of years.[19]

I believe that something of this kind did indeed take place. But this could hardly be sufficient to arouse the admiration and astonishment of the Greeks. On the one hand, nobody would have been sure that Thales's explanation of the eclipse was correct. On the other hand, in other epochs a prediction of the future recurrence of eclipses would have made a strong impression, since a significant solar eclipse is usually a rare event in a given area; but astronomical data suggest that several impressive solar eclipses were observable by the Greeks in the middle of the seventh century B.C., and also during Thales's lifetime.[20] Consequently, in this particular epoch it was unlikely that anyone would acquire fame by predicting merely that an eclipse would be seen again in the future. This consideration brings us to the same conclusion as does Herodotus's account: in order to gain wide recognition Thales had to have predicted the date, whatever it may be, of a solar eclipse.

But actually there is no need for a compromise that eliminates a prediction in the strict sense. I think it is possible to provide a concrete explanation of how Thales predicted the solar eclipse.

We should probably start with the circumstances surrounding the prediction. Scholars have displayed no interest in this question, apparently assuming that it was of no relevance. But how can we imagine the context of Thales's extraordinary public statement, and where does it fit into the public life of the Greeks? We have to remember that a sudden statement of the kind we are talking about could make a man look ridiculous or arrogant. So we must look for a situation in which such an initiative would be plausible or urgently necessary.

The general public usually shows no special interest in celestial phenomena. Their interest is aroused when an extraordinary celestial event affects people's emotions. We frequently read in ancient authors about the panic caused by eclipses.[21] The solar eclipse of 28 May 585 was, no doubt, an extraordinary event. The usual reaction of the ancients to such an event was fear that it was a bad omen. The Greeks of Ionia and culturally-related areas were not unduly superstitious in that epoch, but occultations of the sun followed one after another. The eclipse of 29 July 588 must have been quite conspicuous, though probably not very frightening, for it reached maximum occultation (0.836 of the diameter) half an hour before sunset. Seventeen months later, on 14 December 587, came another solar eclipse, also conspicuous (0.835) if the weather was not overcast. And then, after a further eighteen months, there occurred an eclipse that was close to total (0.905 in Miletus, and of greater magnitude everywhere in Ionia, because the path of centrality crossed northern Anatolia, and Miletus was the most southern city of Ionia).[22] If Thales had something to say in order to assuage the fear of the Ionians, that was the time to say it. Suppose, then, that soon after the eclipse of 28 May 585 he declared to the Ionians that there was no reason for fear and anxiety — for a solar eclipse was no omen at all, it was a natural event that happened from time to time, and he even knew when it would occur again.

If Thales predicted an eclipse "to the Ionians", as Herodotus says, it must have taken place at the Pan-Ionian festival (*cf.* Herodotus 1.170). Great festivals in the Greek world were usually celebrated during the summer, once every four years. Now, what we read in Herodotus is that Thales, while predicting a solar eclipse, "set as its limit this year in which the change actually occurred" (οὖρον προθέμενος ἐνιαυτὸν τοῦτον, ἐν τῷ δὴ καὶ ἐγένετο ἡ μεταβολή). According to the standard interpretation, this means that Thales predicted the year of the eclipse. But this interpretation misses an important point. A reference to the "limit" implies the notion "not later than". Thus either the end of the current year was intended (i.e., the year in which prediction was made) or the end of a series of years. The latter is obviously more plausible, because the expression of the former idea would require a more precise formulation.

The number of years specified by Thales was four. What he said was something like this: "You will see a solar eclipse again before our next festival." Perhaps, he added: "or, at least, you will hear about one."

His prediction came true! Towards the end of the term established by Thales a solar eclipse did happen, in fact two. These were the eclipses of 21 September 582 and 16 March 581. The Greek year began in summer, some time after summer solstice, and so both eclipses fell on the same year, 582/581, from the Greek point of view. According to the calendar system that was in use in Athens and therefore was largely accepted among Greek writers, the year 582/581 was the year of the archonship of Damasias. A testimony that goes back to a good source informs us that this year was marked for Thales by a public recognition of his prominence: "he became the first to receive the name of Sage."[23] Now we know why.

So what was Thales's method?

I assume that Thales had indeed some acquaintance with Mesopotamian astronomy and was familiar with the notion of eclipse cycles. We do not hear about any Greek astronomer earlier than Thales. It is more than likely that the originator of astronomy among the Greeks would have received the very notion of such a human enterprise from elsewhere. I do not mean that Thales knew a Mesopotamian expert with astronomical diaries to hand or that he took a graduate course in Babylon. No early source credits Thales with the prediction of lunar eclipses, in which the Assyro-Babylonian contemporaries of the Milesian were skilled. Thales received instead some general information, including the notion that there are a number of typical intervals between eclipses, both lunar and solar, with some examples of such intervals.

Scholars, while discussing the availability to Thales of Mesopotamian astronomical knowledge, underestimate the fact that Thales lived in a very particular epoch. After being under pressure for a long time from the Babylonians and the Medes, the Assyrian kingdom was not merely defeated but virtually ruined (626–609 B.C.). Major cities of Assyria ceased to exist. Many people working for the Assyrian kings lost their means of subsistence. Some of them would surely have chosen to emigrate — either to the cities of Phoenicia and Palestine, where they could find a language and culture similar to their own, or to the court of the pharaoh, the enemy of Babylon, the new super-power.[24] Skilful interpreters of celestial signs given by the gods were everywhere welcome.

On the other hand, an intense power struggle between Egypt and Babylon attracted many Greeks as mercenaries. This was, it seems, the epoch of especially close contacts between the Greeks (the Ionians particularly) and Egypt. As a respectable Greek from the most important Ionian city, Miletus, Thales could easily have met at the court of the Pharaoh Necho (610–595 B.C.) various people from Assyria or Phoenicia. In short, Thales lived in an epoch that was especially

TABLE 1. Major solar eclipses observable at Nineveh, 689–635 B.C., with their predecessors in the *exeligmos*.

| No. | Date | Magn. | Time | Date | Magn. | Time |
|---|---|---|---|---|---|---|
| 1 | 689 Jan 11 | 0.83 | 12.22 | 744 Dec 9 | 0.80 | 11.58 |
| 2 | 679 Jun 17 | 0.68 | 07.41 | 733 May 15 | 0.22 | 13.12 |
| 3 | 662 Jan 12 | 0.97 | 16.81 | 717 Dec 10 | 0.56 | 16.10# |
| 4 | 661 Jun 27 | 0.93 | 16.75 | — | — | — |
| 5 | 657 Apr 15 | 0.84 | 11.09 | 711 Mar 14 | 0.66 | 11.78 |
| 6 | 651 Jun 7 | 0.72 | 12.50 | 705 May 5 | 0.46 | 18.76 |
| 7 | 650 Feb 21 | 0.93 | 16.07 | 704 Oct 19 | 0.86 | 13.54 |
| 8 | 648 Apr 6 | 0.77 | 11.33 | 702 Mar 5 | 0.68* | 11.66 |
| 9 | 641 Nov 11 | 0.86 | 10.53 | 695 Oct 10 | 0.36 | 09.07 |
| 10 | 637 Aug 29 | 0.61 | 18.18 | 691 Jul 28 | 0.53 | 18.35 |
| 11 | 636 Aug 19 | 0.67 | 08.68 | 690 Jul 18 | 0.29 | 09.38 |
| 12 | 635 Feb 12 | 0.88 | 11.38 | 689 Jan 11 | 0.83 | 12.22 |

# Sunset at 16.87; magnitude for Babylon was 0.64.
* 0.78 in Babylon.

conducive to the spread of astronomical knowledge from Mesopotamia to Ionia.

I also assume that Thales carried out his own observations of celestial phenomena, for we have evidence from many sources, including the best, that Thales dealt with the course of the sun, the solstices, the seasons, and the calendar, none of which was likely to be the subject of legends.

Now I assert that two different sets of facts, which could have been available to him, would have allowed Thales to venture a prediction of a solar eclipse for the year 582/581 B.C.

A solar eclipse could have been predicted for the year 582/581 on the basis of the *exeligmos*, i.e. the eclipse period of 669 lunations or 54 Julian years and 1 month, which is "by far the best of all periods of less than ca. 100 years".[25]

The fact is that the eclipse of 16 March 581 had three consecutive predecessors in the *exeligmos*, all within the period of regular records carried on in Mesopotamia: 12 February 635 (magnitude 0.88 in Nineveh); 11 January 689 (0.83 in Nineveh); and 9 December 744 (0.80 in Nineveh, 0.75 in Babylon).[26] According to Ptolemy (*Almagest*, IV.2, p. 269 Heiberg), the *exeligmos* was known since quite an early epoch, though he does not specify this epoch more precisely and mentions the *exeligmos* as a lunar period, in a larger context than that confined to the prediction of eclipses (similarly Geminus, *Isagoge*, 18). There is no reason to assume that the *exeligmos* was discovered before 635 B.C., but it is very possible that the eclipse of 12 February 635 would have led an astronomer to notice the double repetition of an interval of 54 years. This eclipse was the last of four consecutive eclipses observable in Mesopotamia within less than six years and it was followed by what was, for the epoch in question, an unusually large gap: no significant solar eclipse took place for more than twenty-five years. Such a situation could have suggested a search for periods of larger scale. It is possible that a period of 27 years was first noticed, as illustrated by the following series:

TABLE 2. Solar eclipses observable in Miletus, 610–581 B.C.[31]

| No. | Date | Lunations elapsed since last eclipse | Maximum phase in digits | Hour of max. phase, true time, Miletus |
|---|---|---|---|---|
| 1 | 610 Sep 30 | 317 | 7.6 | 11.20 |
| 2 | 608 Feb 13 | 17 | 8.8 | 15.32 |
| 3 | 607 Jul 30 | 18 | 7.4 | 09.44 |
| 4 | 603 May 18 | 47 | 5.8 | 08.00 |
| 5 | 597 Jul 9 | 76 | 8.4 | 05.12 |
| 6 | 596 Jun 28 | 12 | 4.2 | 10.48 |
| 7 | 596 Dec 23 | 6 | 8.3 | 16.12 |
| 8 | 594 May 9 | 23 | 5.4 | 08.28 |
| 9 | 588 Jul 29 | 77 | 10.0 | 18.40* |
| 10 | 587 Dec14 | 17 | 10.0 | 10.11 |
| 11 | 585 May 28 | 18 | 10.9 | 18.13• |
| 12 | 584 May 18 | 12 | 4.8 | 06.44 |
| 13 | 583 Oct 1 | 17 | 8.5 | 17.52# |
| 14 | 582 Sep 21 | 12 | 10.2 | 07.41 |
| 15 | 581 Mar 16 | 6 | 6.6 | 07.16 |

* sunset at 19.14.
• sunset at 19.00.
\# sunset at 17.55; the part eclipsed was setting at the moment of maximum occultation.

9 Dec. 744
10 Dec. 717
11 Jan. 689
12 Jan. 662
2 Feb. 635

A large gap after the eclipse of 2 February 635 might have suggested considering a period of 54 (twice 27) years as safer than the previous one of 27 years.[27]

The astronomer who noted that the eclipse of 2 February 635 had had two predecessors in the 54-years interval, would naturally have searched for other eclipses separated by the same interval. Unfortunately, it is difficult to say how many examples he would have found because we do not know precisely what data were available to him and because there is no definite answer to the question as to what magnitude a solar eclipse must have in order to be noticed. It seems there is general agreement that 0.75 is enough when the sun is high and that 0.5 or even less will suffice for the sun close to the horizon.[28] Table 1 lists the major solar eclipses observable in Nineveh in the seventh century B.C. with their predecessors in the *exeligmos*.[29]

Nos. 1 and 12 having already been mentioned, the table reveals only one further clear case: no. 7. But even this would have been enough to make the regularity of 54 years worth further testing. On the basis of no. 7, a solar eclipse should have been expected in 596 B.C. This crucial test would probably have disappointed an observer in Egypt or Phoenicia, and almost certainly those in Babylon, but not an observer in Miletus. The eclipse of 23 December 596 began there about 15.00 and reached its maximum at 16.12 (sunset at 16.50). Provided that the altitude of the sun during eclipse was low, the magnitude of this eclipse, 0.69, was quite enough to attract attention.[30] The eclipse was even more conspicuous for the Greeks living in Athens or in Milesian colonies on the Black Sea coast.

Suppose Thales's teacher knew of other examples of the recurrence of solar eclipses in the *exeligmos* (see Table 1), so that certain other eclipses would also have been expected. A table of solar eclipses observable in Miletus (see Table 2) suggests that in no case would such expectations would remained unfulfilled!

It can be seen that, by a remarkable coincidence, prior to the summer of 585 B.C., all possible expectations of a solar eclipse based on the recurrence of eclipses in the *exeligmos* (Table 1, nos. 3, 5, 6, 8 and 9, plus no. 7 already discussed) would have been fulfilled (Table 2, nos. 2, 4, 5, 8, 10 and 7, respectively). If such expectations were confined to no. 7 alone, the repetition of the interval of 54 years between solar eclipses of his own time and those that had happened half-a-century earlier should still have impressed Thales.[32] The 27-year cycle could have been noted for nos. 1 and 2 (*cf.* nos. 10 and 12 in Table 2). Moreover, the eclipse of 13 February 608 might have suggested the reliability of the particular 27-year cycle: 744–717 (Dec.)–689 (Jan.)–662–635–608.

The conclusions that Thales would have drawn from the occurrence of solar eclipses in his own time, between 30 September 610 and 28 May 585, might have been as follows:

(1) if there is a solar eclipse in a given year, it is likely that another will happen 54 years later; the recurrence of an eclipse in 27 years is also likely;

(2) if there is a solar eclipse in a given year and there was also a solar eclipse 54 years earlier, there should be another one 54 years later;

(3) some solar eclipses have no predecessors 54 or 27 years earlier (this was true, in particular, of the most conspicuous eclipses of the period, nos. 9 and 11).

It followed that a solar eclipse should have happened in the year 582/581 as a continuation of the series: 744/743 – 690/689 – 636/635; a long series of eclipses separated by 27-year intervals suggested the same date (probably, and more precisely, March 581). But there was also a possibility of another solar eclipse (or even eclipses) before this date. This means that, when making his prediction of a forthcoming eclipse soon after May 585, Thales should have defined the interval exactly in the manner stated by Herodotus: no later than the year indicated.

Why did Thales indicate the year and not the exact date? First of all, it is uncertain whether an exact or only an approximate value of the *exeligmos* (669 lunations and 54 years respectively) has been discovered by that time. The calendar year in Mesopotamia was composed of lunar months.

> Since the lunar year was about eleven days shorter than the solar year, it was necessary at intervals to intercalate a thirteenth month, either a second Ululu (the sixth month) or a second Addaru (the twelfth month) in order that New Year's Day, Nisanu should not fall much before the spring of the year (late March and early April). It may have been in the reign of Nabonassar, 747 B.C. that Babylonian astronomers began to recognize ... that seven lunar months

> must be intercalated over each nineteen-year period. The specific years in which the intercalations were to be made, however, and whether they should be second Addarus or second Ululus remained to be determined empirically — a process which lasted some centuries.[33]

This means that a Mesopotamian astronomer of the seventh century B.C. was unable to establish with certainty the number of lunations between two events separated by many years, unless he had the enthusiasm and the opportunity to undertake an archive research in order to determine which years were those with additional months.

Yet whether Thales knew the approximate or the exact value of the *exeligmos*, he would have expressed his prediction in terms of years in both cases. For it is not necessary that he had an exact date for the eclipse of 12 February 635. If he had it, the difficulty remained that the Greek calendar also employed intercalatory months and it would not have been easy to establish how many months had been intercalated since 635. And even if Thales had managed to calculate all that, he would still have been unable to name the exact date of an event expected in a number of years, for it remained uncertain which years would have an intercalatory month: this was after all in the hands of the authorities. Moreover, the two consecutive eclipses, those of 19 August 636 and 12 February 635, fell in the same year in terms of either the Greek or the Mesopotamian calendar.[34] Could Thales be certain which of the two had predecessors in the *exeligmos*? So it was only natural, not to say inevitable, for Thales to formulate his prediction in terms of years. The very detail of Herodotus's account that arose suspicion shows in fact the reliability of what he says.[35]

Thales therefore could venture a prediction on the basis of the recurrence of solar eclipses at 54-year intervals; such a prediction must have been made for the year 582/581 B.C., which perfectly fits Herodotus's testimony as well as independent data for the year of Thales's public recognition.

Yet there was in fact another possible method of prediction. It too implies that Thales managed to learn, ultimately from a Mesopotamian source, that eclipses occur after certain intervals of time. However, these intervals vary (6, 41, 47, 223 lunations, etc.), and it is difficult to discover a clear pattern. For a person like Thales, this might have been enough to cause him to pay attention to the intervals between eclipses. What he would have found can be seen from the data presented in Table 2. It follows that the eclipse of 28 May 585 was separated from the two previous eclipses by intervals of 18 and 17 lunations respectively. But this sequence had taken place once before! The eclipse of 30 July 607 was also separated by intervals of 18 and 17 lunations from the two preceding eclipses (*cf.* nos. 1–3 and 9–11 in Table 2). Thales therefore could have discovered that not only one interval previously encountered had been repeated, but a series of two intervals between consecutive eclipses. Such a 'regularity' might have allowed him to venture a prediction. There were 47 lunations between the earlier sequence and the subsequent eclipse (no. 4). Thales might have concluded that there apparently would be the same number of lunations between the later sequence and the forthcoming eclipse.[36]

If so, a solar eclipse foreseen by Thales was that of 16 March 581. Because of the difficulty of naming the exact date (related to the peculiarity of the calendar explained above), and because he could see that there are several cycles in the occurrence of eclipses, so that some other cycle may intervene to cause a 'premature' eclipse, Thales may well have given a broad formulation of the term, something like "not later than within four years" or "not later than the fourth year". An impressive solar eclipse that happened six months earlier than the expected one, that of 21 September 582, fell in the same year, which made Thales's prediction seem more exact than it actually was.[37]

We see that both possible methods of prediction point to the same two eclipses. It may be that both methods were actually used by Thales.

Which of the two eclipses was it that brought fame to Thales? Though it is wrong to assert that 16 March is ruled out because of the season[38] (military campaigns happened occasionally at any time, and certainly in March[39]), the eclipse of 21 September 582 is clearly the preferable of the two, both from this point of view and because it was of greater magnitude and was the first to occur in the year in question. It is not impossible that the solar eclipse predicted by Thales and the eclipse battle happened on different days, and were later linked to make a better story. But this would be an arbitrary assumption. Moreover, it is very likely that Greeks participated in the battle as mercenaries or as Lydian allies,[40] enabling some of them to hear of Thales's prediction. This being so, the eclipse battle should now be associated with the date of 21 September 582.[41] As to the year 585, this was most likely the year of the prediction,[42] but not the year predicted: no way of predicting a solar eclipse for 28 May 585 has been discovered so far.

It is easy to see why, for centuries, an achievement such as Thales's remained rare (or even unique). The coincidence of two series of lunations between consecutive eclipses was exceptional, as was the success of a prediction based on such a coincidence. As to prediction on the basis of the *exeligmos*, even if Thales revealed his secret to his disciples, further observations would have shown that the method was far from satisfactory. Most expectations based on it must have been disappointed, either absolutely or (more usually) in the sense that the anticipated eclipses were of too small a magnitude to be appropriate for a prediction addressed to the general public.[43] Thales had the advantage (fully recognized by him, as it seems) that at least two eclipses were likely for the period he was indicating. Two were expected for the year 582/581 on the basis of both 54-year intervals and a particular series of 27-year intervals, but a third was likely for the autumn of 583 as following the eclipses of 29 August 637 and 30 September 610 in a 27-year cycle. All this reduced the risk and made it likely that at least one of the following eclipses would be sufficiently impressive.

The interpretation I suggest therefore seems to harmonize the astronomical data and the historical evidence. It explains at once several facts such as

Herodotus's mode of expression and the public recognition of Thales's wisdom in the archonship of Damasias (582/581 B.C.). It depends only on the extent of Thales's acquaintance with Eastern astronomy, the plausibility of which is undeniable. It also makes clear why Thales's prediction of a solar eclipse remained unique for a long time.

This interpretation makes peace between classical philology and history of science: both were correct. The evidence for Thales's prediction is sound, and now the historicity of the story is strongly confirmed. Moreover, Thales achievement was not merely a chance prediction. And yet it still called for good luck.

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REFERENCES

1. The only detailed information is given by Herodotus (*Histories* 1.74): "In the sixth year of the war, which they [Medes and Lydians] had carried on with equal fortunes, an engagement took place in which it turned out that when the battle was in progress the day suddenly became night. This alteration of the day Thales the Milesian foretold to the Ionians, setting as its limit this year in which the change actually occurred." I use G. S. Kirk's translation: G. S. Kirk, J. E. Raven and M. Schofield, *The Presocratic philosophers*, 2nd edn (Cambridge, 1983), 81–82.
2. Thomas-Henri Martin, "Sur quelques prédictions d'éclipses mentionnées par des auteurs anciens", *Revue archéologique*, n.s., ix (1864), 170–99; Otto Neugebauer, *The exact sciences in Antiquity* (Princeton, 1952), 142f. In fact, Martin's judgement was less severe.
3. Such was the reply to Martin's argument made by Paul Tannery, "Thalès et ses emprunts à l'Egypte", *Revue philosophique*, March 1880, 303; *idem*, *Pour l'histoire de la science hellène* (Paris, 1887), 56.
4. Sir Thomas Heath, *Aristarchus of Samos: The ancient Copernicus* (Oxford, 1913), 15.
5. See ref. 1. For the ancient sources on Thales see *Die Fragmente der Vorsokratiker, griechisch und deutsch*, ed. by Hermann Diels, 6th edn, ed. by Walter Kranz (Berlin, 1951; hereafter DK), i, 67–81, no. 11.
6. *Die Schule des Aristoteles: Texte und Kommentar*, ed. by Fritz Wehrli, 2nd edn (Basel, 1967), H.8.
7. Some scholars believe that Thales was originally known as one of the Seven Sages, and only became a philosopher and scientist in the imagination of later authors. But the lack of direct evidence for such a conclusion is striking, whereas the evidence for early recognition of Thales as a philosopher and scientist is abundant. See Dmitri Panchenko, "Thales and the origin of theoretical reasoning", *Configurations*, i (1993), 387–414, esp. p. 399, n. 30.
8. Alden A. Mosshammer, "Thales' eclipse", *Transactions of the American Philological Association*, cxi (1981), 145–55, p. 151.
9. *Ibid.*, 153. *Cf.* Alexander Demandt, *Verformungstendenzen in der Ueberlieferung antiker Sonnen- und Mondfinsternisse* (Akademie der Wissenschaften und der Literatur, Mainz; Abhandlungen der Geistes- und sozialwissenschaftlichen Klasse, 1970, no. 7).

10. This lack of involvement also distinguishes our case from such fictional predictions as the one ascribed to Anaximander: we are told (Pliny, *Natural History*, 2.191) that Anaximander foretold an earthquake, thus providing scholars with another reason for rejecting the tradition about Thales's prediction: Martin, *op. cit.* (ref. 2), 186ff.; J. L. E. Dreyer, *A history of astronomy from Thales to Kepler*, 2nd edn (New York, 1953), 12f. Yet we are told that Anaximander convinced the Lacedaimonians to leave their homes because of the coming earthquake (Cicero, *On divination*, 1.50.112). This is the story of a sage who is capable of using his mind to penetrate hidden things; by means of this secret wisdom he is able to save the entire city. Nothing of this kind is present in Herodotus's account of Thales's prediction. The only real parallel is with Anaxagoras's prediction of the fall of the meteorite at Aegospotami (Pliny, *Natural history*, 2.149; Diogenes Laertius, 2.10; Ammianus Marcellinus, 22.16.22, *cf.* 22.8.5; Philostratus, *The life of Apollonius of Thyana*, 1.2; and *cf.* Plutarch, *Life of Lysander*, 12, and Diogenes Laertius, 2.11–12). Yet the story of Anaxagoras's prediction lacks concrete detail. We are never told to whom he predicted the event, whereas Herodotus's account implies that Thales made his prediction publicly: he addressed it to the Ionians (the comparison with Herodotus 1.170 gives the impression that it was made at the Pan-Ionian meeting). Thales's real prediction could easily have provided a pattern for a number of fictional prediction stories.
11. *Cf.* Asger Aaboe, "Remarks on the theoretical treatment of eclipses in Antiquity", *Journal for the history of astronomy*, iii (1972), 105–18.
12. The ancients give various dates though within narrow limits, ranging from the fourth year of Olympiad 48 = 585/584 (28 May 585 would belong instead to the previous year) to Olympiad 50 = 580/579–577/576 (an indiscriminate reference to a given Olympiad may also mean a reference to the first year of this Olympiad). Some scholars assume that *c.* 50 Ol was the Eudemian date, while a new date was introduced by Apollodorus (active in the latter half of the second century B.C.): Mosshammer, *op. cit.* (ref. 8), 146, n. 2; *cf.* Lenis Blanche, "L'éclipse de Thalès et ses problèmes", *Revue philosophique*, clviii (1968), 184. The uncertainty occurs because both dates appear in sources ultimately dependent on Apollodorus. If a new date for Thales's eclipse was introduced by Apollodorus, it is not impossible that he received it from Hipparchus (see Pliny, *Natural history*, 2.53: the passage was convincingly explained by Otto Neugebauer, *A history of ancient mathematical astronomy* (Berlin, 1975), i, 319–21; *cf.* Tannery, *Pour l'histoire de la science hellène* (ref. 3), 38). Later sources (another of Apollodorus's novelties? — *cf.* Moshammer, *op. cit.* (ref. 8), 150f) change the name of the Median king and link the eclipse battle with Astyages, son of Kyaxares: see the texts of Hieronimus and Cicero in 11 A 5 DK and also P Oxy 2506 fr. 98 (*The Oxyrynchus Papyri*, Part 29, ed. by Denys Page (London, 1963), 21; Page's commentary, 45, n.1 is misleading, see George Huxley, "A war between Astyages and Alyattes", *Greek, Roman and Byzantine studies*, vi (1965), 201–6). The chronology of Kyaxares and Astyages remains a controversial issue; *cf.* Victor Parker, "Zur griechischen und vorderasiatischen Chronologie des sechsten Jahrhunderts v. Chr.", *Historia*, xlii (1993), 385ff, esp. pp. 390ff.
13. Aaboe, *op. cit.* (ref. 11), 105. This truth immediately becomes obvious if one looks at the maps of solar eclipses, which can be found in: Th. von Oppolzer, *Canon der Finsternisse* (Vienna, 1887; English transl. by Owen Gingerich, New York, 1962); F. K. Ginzel, *Spezieller Kanon der Sonnen- und Mondfinsternisse* (Berlin, 1899); Hermann Mucke and Jean Meeus, *Canon of solar eclipses –2003 to +2526* (Vienna, 1983).
14. Neugebauer, *op. cit.* (ref. 12), ii, 604.
15. Willy Hartner, "Eclipse periods and Thales' prediction of a solar eclipse", *Centaurus*, xiv (1969), 60–71.
16. Hartner's conclusion is that Thales intended the eclipse of 18 May 584, while "the unexpected 'Eclipse of Thales' came as a surprise to the Sage exactly 12 months earlier".
17. B. L. van der Waerden, *Science awakening II: The birth of astronomy* (Leiden, 1974), 120ff.
18. *Cf.* Hartner's criticism of van der Waerden (*op. cit.* (ref. 15), 71, n. 14): "The circumstance that a solar eclipse *may* follow a lunar eclipse after 23½ lunations does not of course suffice to make a prediction."
19. Martin, *op. cit.* (ref. 2), 192.

20. See Hartner, *op. cit.* (ref. 15), 65–67, and Table 2 of the present paper.
21. The best attested case is the panic among Athenians during the Sicilian campaign (Thucydides, 7.50; *cf.* Plutarch, *Life of Nicias*, 23).
22. Calculations by Marina V. Lukasheva, Institute of Theoretical Astronomy, Russian Academy of Sciences (St Petersburg).
23. Diogenes Laertius, 1.22, with reference to Demetrius of Phalerum.
24. In 609/608 B.C. the Assyrian and Egyptian troops fought together against the Babylonian army of Nabopalassar. This effort to save the Assyrian kingdom was in vain, the allies having to retreat. But what happened to Ashur-uballit, the last Assyrian king, and the people around him? A natural supposition is that they took refuge in Egypt. See *Chronicles of Chaldean kings in the British Museum*, ed. by D. J. Wiseman (London, 1956), 19 and 63 (B.M. 21901, 66ff).
25. Hartner, *op. cit.* (ref. 15), 60f.
26. The data are based on Manfred Kudlek and Erich H. Mickler, *Solar and lunar eclipses of the ancient Near East from 3000 B.C. to 0 with maps* (Neukirchen, 1971).
27. As we know from their letters to the Assyrian kings, Mesopotamian observers of the seventh century B.C. were careful about various peculiarities of observed celestial phenomena, allegedly so as to be able to draw lessons as to what this or that particular feature signified as an omen. The eclipse of 11 January 689 was likely to be studied especially carefully because it occurred shortly before the destruction of Babylon by the Assyrian king Sennacherib, and this eclipse is a member of both the 27- and the 54-year series.
28. Ginzel, *op. cit.* (ref. 13), 14; Demandt, *op. cit.* (ref. 9), 6f; Hartner, *op. cit.* (ref. 15), 71, n. 17.
29. Based on work by Kudlek and Mickler; the time indicated for the maximum occultation is true local time in hours and fractional parts thereof.
30. Calculated by Marina V. Lukasheva, Institute of Theoretical Astronomy, Russian Academy of Sciences, St Petersburg.
31. The table is based mostly on the analogous table in Hartner's article. However, in Hartner's table nos. 7 and 13 are missing, and the data for nos. 9–15 have been replaced in accordance with calculations by Marina V. Lukasheva and Liana I. Rum'anzeva of the Institute of Theoretical Astronomy. The value for $\Delta t$ assumed in these calculations is based on F. R. Stephenson and L. V. Morrison, "Long-term changes in the rotation of the Earth: 700 B.C. to A.D. 1980", *Philosophical transactions of the Royal Society of London*, ser. A, cccxiii (1984), 47–70.
32. If there had been datable records of solar eclipses observable in Egypt and if Thales had had someone to provide him with the necessary information, he would have established that both major recent eclipses, 30 July 607 (0.86 in Memphis) and 18 May 603 (0.69 at 08.21), had two consecutive predecessors in the *exeligmos*: 27 June 661 (0.74 at 15.94), 5 May 705 (0.71 at 18.15), and 15 April 657 (0.95), 14 March 711 (0.76), respectively. (Data from Kudlek and Mickler.)
33. Richard A. Parker and Waldo H. Dubberstein, *Babylonian chronology 626 B.C.–A.D. 75* (Providence, 1956), 1.
34. According to Hartner's calculations for Miletus, the magnitude of the eclipses of 19 August 636 and 12 February 635 reached 7.6 digits (at 07.22) and 10.6 digits (at 10.04) respectively.
35. This is not surprising from the point of view of source criticism. Herodotus's information on the prediction is concrete, not vague. He gives the addressee of Thales's prediction (the Ionians) as well as the manner in which Thales defined the term for the predicted event. It seems that what we have in Herodotus goes back to an even more detailed account, which could be found in one of the Ionian writers, such as Dionysius of Miletus.
36. Is it possible that Thales could have taken into consideration all the eclipses referred to in Table 2, including those of small magnitude? The answer is affirmative. First of all, the Milesian could have received information from Milesian colonies spread over a wide area, and from other places in touch with Miletus (for instance, the eclipses of 30 September 610 and 13 February 607 must have been very impressive in the Black Sea area). He also was in position to observe all these eclipses himself if the weather was not overcast. He would have had to know, however, that solar eclipses can occur only at the time of the new moon (it is impossible to watch for an

eclipse every day!), but this knowledge is testified for Thales by Aristarchus of Samos (P Oxy 3710, col. II 34–43; *The Oxyrynchus papyri*, liii, ed. by M. Haslam (London, 1986), 97). Now the method of observation of solar eclipses adopted by the Greeks and apparently already by Thales was to watch the reflection of the sun in water (Plato, *Phaedo*, 99d; Diogenes Laertius, 7.146; see also Franz Boll, "Finsternisse", *Realencyclopaedie der classischen Altertumswissenschaft*, vi (Stuttgart, 1909), cols 2329–65, esp. col. 2349). This method would allow an observer anticipating a solar eclipse to detect one of very small magnitude (as I anticipated, and confirmed during the solar eclipse of 10 May 1994 in North America).

37. The eclipse of 1 October 583 would not, of course, have been regarded as a fulfilment of Thales's prediction. This eclipse was too far from the area of Greek settlements to give rise to rumours (the remote city of Cyrena on the Libyan coast was the only significant Greek settlement where this eclipse could have been impressive enough for this). If the partial occultation of the solar disk before setting was observable in Ionia, it is not necessarily the case that the ordinary people would have considered this phenomenon as similar to a sudden darkness during daytime.
38. So Karl Julius Beloch, *Griechische Geschichte*, 2nd impression, i/2 (Berlin, 1926), 354.
39. According to the Babylonian chronicles, there were attacks by the Assyrian and Babylonian armies on each other in March 615 (B.M. 21901, 11); Jerusalem was seized by Nebuchadrezzar on 16 March 597 (B.M. 21946, Rev. 12); Neriglissar returned to Babylon in the month of Addaru (February–March 556) after a campaign in Western Cilicia, on the border of Lydia (B.M. 25124, Rev. 26). See Wiseman, *Chronicles* (ref. 24), 55, 73, 77.
40. It seems to follow from P Oxy 2506 fr.98 (*cf.* ref. 12) that either Alcaeus or his brother Antimenidas participated in the war between Astyages and Alyattes. (We are told, by the way, that Alcaeus praised Thales in one of his poems — 11 A 11 a DK.)
41. According to the calculations by Marina V. Lukasheva, the maximum magnitude of this eclipse was 0.75 at 08.18 for 39°N, 35°E (in the vicinity of ancient Hattusa). Such an eclipse, given the low altitude of the sun in the morning, must have been quite impressive, at least as an omen. However, Herodotus's account of the war between the Lydians and the Medes suggests that the battle took place somewhere to the south or southeast of Hattusa, because we are told that the war was carried on with equal fortune on both sides and that the kings of Babylonia and Cilicia mediated in making peace. The magnitude of the eclipse for a plausible place of the battle must then have been *c.* 0.80; the brightest planets, and even stars, could be seen. In any case, one should not give undue weight to the Herodotean expression, "the day suddenly became night". In contrast to his account of the prediction, Herodotus gives no real detail about the phenomenon (or about the battle). The artistic image he uses fits, strictly speaking, no reality at all; it is just a topical expression (*cf.* Demandt, *op. cit.* (ref. 9), 10ff) repeated almost word for word when Herodotus refers to the fictional eclipse at the beginning of Xerxes's army's march (7.37). Moreover a characteristic indication that is present in the latter case, that "the sun disappeared", is lacking in the former. It is worth noting, indeed, that Herodotus makes Thales predict "the alteration of the day" and not "the disappearance of the sun" (which is the original meaning of what became later a technical term, ἔκλειψις). It seems that Thales consciously avoided limiting his prediction to a total eclipse.
42. One should consider the possibility that Pliny's testimony, usually understood as referring to the date of the eclipse, could in fact record the date of the prediction. Pliny, *Natural history*, 2.53: "apud Graecos investigavit primum omnium Thales Milesius olympiadis XLVIII anno quarto praedicto solis defectu qui Alyatte rege factus est urbis conditae CLXX."
43. See the data in Ginzel's *Spezieller Kanon* (ref. 13). I give just two examples. The eclipse of 21 September 582 had a successor in the *exeligmos*, but its magnitude was 4.2 digits in Athens (Ginzel), with the sun quite high above the horizon; 0.10 in Hattusa (Kudleck and Mickler). The eclipse that happened on 18 April 527, the successor in the *exeligmos* of that of 16 March 581, was central in southern Indian and China and of negligible magnitude, if any, in Ionia (0.16 in Hattusa). As to Helicon's prediction, if he predicted the eclipse of 29 February 357 (which fits perfectly the existing evidence) and not that of 12 May 361 (which is now generally assumed without any real support from the evidence), then his prediction could be based on the recurrences of solar eclipses in the *exeligmos*. A note on this is in preparation.