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'Greek' Astronomy

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Abstract:

The author has read through three Greek history books '**The Persian War**' (8th century BC – 479 BC) by Herodotus, '**The Peloponnesian War**' (431 BC – 411 BC) by Thucydides, and '**Greek History**' (411 BC – 362 BC) by Xenophon. There are no dates in 'The Persian War' nor in 'Greek History', whereas there are two pairs of dates in 'The Peloponnesian War'. The author's tentative conclusion is that there was no observational astronomy in Greece before 362 BC, contrary to the general belief that there was.

Contents

1 Introduction

1.1 Motivation

In the study of the long-term variations of the rotation of the Earth, the author has been interested in the records of solar eclipses in the ancient Greece. We have made a list of records of deep solar eclipses (see Table I; see also [1]).

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Table 1: A list of deep solar eclipses recorded in the ancient Greece. .
(Reproduction of Table VII in [1])

Opp.#	Y	M	d	place	recorder	date	event
1328	−647	4	6	Paros or Thasos	Archilochus(Poet)	No	
1489	−584	5	28	Pteria	Herodotus(Historian)	No	War
1795	−462	4	30	Thebes	Pindaros(Poet)	No	
1873	−430	8	3	Athens	Thucydides(Historian)	No	War
1959	−393	8	14	Chaeroneia	Xenophon(Historian)	No	War
2149	−309	8	15	Sicily	Diodoros(Historian)	No	War
2566	−128	11	20	Hellespont	Hipparchus	No	

For the identification of eclipses, see [2].

The author notes the following characters of records in Table I.

(a) No dates of the eclipses;
(b) No names of astronomers before 300 BC;
(c) Unusual historical events happened together.
(d) Recorders were not necessarily the observers.

Item (a) shows the very different characters of Greek records from those of the ancient China. In the Chinese history books, the records start generally with dates. In particular, records of solar and lunar eclipses always start with dates. Otherwise, the records are useless for astronomy. Item (b) needs explanation. In the Chinese books, there are no names of astronomers. However, there were royal astronomers since (at the latest) the Chunqiu period (770 BC - 403 BC). Thus, astronomical phenomena were surely observed by astronomers. Of course the author admits that Item (b) does not imply the non-existence of astronomers in the ancient Greece before BC 300. Item (c) is indirect evidence of the non-existence of observational astronomers. The author believes that deep solar eclipses were remembered if unusual historical events co-happened in the region where there were no observational astronomers. In Item (d), the eclipse on May 28, −584 are not observed by Herodotus. He obtained information from someone else because Herodotus was a historian in the fifth century BC. Hipparchus was not the observer of the eclipse on Nov. 20, −128 since he was not in Hellespont on that day.

Now, the author is quite suspicious of the existence of observational astronomers in the ancient Greece. In the Chinese case, history books are the target to confirm the existence. In Greek case, the author decided to do the same trial.

1.2 Definition of astronomy

The author feels necessity to define the term 'astronomy'. The meaning of astronomy may be different between the present-day astronomers and the present-day historians of ancient Greece. Modern historians may say that the meaning of astronomy be different for ancient and modern people.

There are various kinds of heavenly phenomena which are recorded in the Chinese history books. The author mainly affected by reading Chinese history book. Additionally, the textbook [2] can be used as a sourse for European records. The book lists more than 100 Babylonian timed observations of lunar eclipses in the BC period starting at 721 BC. The author is sure that the meaning of astronomy was the same in China and in Babylonia.

Now, our definition goes like this: We adopt the definition close to the ancient situations.

Definition: In the ancient civilizations, astronomy is the study of the motions of the sun, moon, and five visible planets among constellations (the referene frame).

In the naked eyes, the bodies which are not fixed to the heaven are the sun, moon and five planets. The moon can evidently be used for counting the days because it changes form everyday in a cycle of around 29.5 days. The motion of the sun surely soon turned out to be related to seasons for ancient people from the fact that the length of daytime changes according to the height of the sun. Thus, the moon and sun should have been the most interesting objects in the heaven. The brightest stars in the heaven are, of course, Venus, Jupiter, and Mars. The existence of the morning star and evening star are remarkable. We notice that these stars change positions and brightness day by day. Jupiter conitnues to be seen for a long time, but it changes position slowly. These stars plus Mercury and Saturn should have attracted the attention of ancient people. They noticed the periodicity of the motions of heavenly bodies, and noticed their relations to various phenomena in our world. This recognition is considered to be the beginning of astronomy.

The precise definition of astronomy is given in Table 2. This definition is valid only in the present work. Of course, the author has tried to be as general as possible. The readers who are not satisfied by the definition may be recommended to do their own. Astronomy is classified into, of course, observation and theory.

Table 2: Contents of ancient astronomy

Observation:		
	Positions of the sun and moon in the constellations	
	Positions of five planets in the constellations	
	Relative positions of fixed stars (i.e., Star Catalogue)	
Theory:		
	Calendar	⇐ Motion of the sun and moon (Four civilizations)
	Cosmology	⇐ Motion of the sun (China: 蓋天説)
		⇐ Motion of five planets (Babylonia[1], (Egypt), Greece[2])

[1]vaguely referred to in "Almagest" [3], [2]see [4]

1.3 Purpose of this report

Our purpose in this report is to confirm the existence or non-existence of observational astronomy in the ancient Greece. Observations of the sun and moon is basic in the observational astronomy. Observations of positions in the heaven of planets are in the advanced astronomy. The motion of five planets are considered with reference to the equator (”red road” in Chinese term) and ecliptic (”yellow road” in Chinese term). Here the ecliptic is the path of the sun in the heaven. The path of the moon (”white road” in Chinese term) is close to the ecliptic. Observations of five planets base their reason d’etre on the observations of the motion of the sun and moon. Observations of the relative positions of fixed stars are more advanced. The precise determination of the positions of the sun and moon depends on the accuracy of the relative positions of fixed stars.

Thus, our purpose is to confirm whether observations of the sun and moon were done or not in the ancient Greece. We do not have records of the motions of the sun and moon in the ancient Greece. These records may have existed but lost, or are yet to be found. In short, we cannot directly attain our purpose. So we appeal to an indirect way. Our way is to look for the calendar system in the ancient Greece. If the astronomy of Greece is independent of astronomy of other regions such as Egypt or Babylonia, there should have been Greek astronomical calendars. So, our job is to check the character of the Greek Calendar.

Now, our job is simple. To read Greek history books and to understand the calendar system from the dates of the events written in the books. We want to know the first day of the year, the first day of the month, and the lengths of a year and a month. If there are enough number of year-month-day data, we can determine whether the calendar system is astronomical or not, and choose from the lunar, solar, or luni-solar calendars.

There is some danger in this indirect way. To make the own astronomical calendar, there is needed an accumulation of data. At least, say, 50 years of observations are necessary. We need to take into account this uncertainty of the start of the calendar system.

The list of our history books are as follows:

History (The Persian War) by Herodotus translated by A.D. Godley[5]
History (The Peloponnesian War) by Thucydides translated by Thomas Hobbes[6]
Greek History by Xenophon translated by Carleton L. Brownson[7]

We sometimes refer to the original Greek texts.

2 Information on Calendars in Greek History Books

The author is relatively familiar with Chinese history books. The descriptions of the events in the Chinese history start in the dates. Almost always the dates first. Observations of the sun and moon were done to revise the existing luni-solar calendar. According to Qu anjing [8] , the theoretical Chinese calendar system goes back to the Warring States period (403 BC – 221 BC). The oldest calendar is known to exist in the ’Spring and Autumn’ period (BC 722 - BC 403). As is well known, the first day of the month should be the new moon, or in the first day of the month, there should be the instant for which the moon is invisible due to the coincidence of the longitude with the sun.

In the ancient civilizations such as the Egyptian, Mesopotamian, Indian, and Chinese, the calendar systems were constructed from the observations of the sun and moon. These civilizations have their own characterisctic observations. As an example, Babylonians preferred lunar eclipses, whereas Chinese preferred solar eclipses.

So, our concrete jobs are to read the history books and to find dates and to get information on calendar systems of Greece or the Greek world.

2.1 Herodotus: The Persian War [5]

"The Persian War" is consisted of nine Books. Book I is consisted of 216 chapters, Book II 182 chapters, Book III 160 chapters, and so on. We show this structure in Table 3. The descriptions of the war between Persia and mainland Greece start only at the last part of Book VI. Descriptions before that part are for the behavior of the Last King of Lydia, Croesus, and then of Persian Kings before the war.

Table 3: Books and Chapters of "The Persian War"

Book	Chapters	Book	Chapters	Book	Chapters
I	216	IV	205	VII	239
II	182	V	126	VIII	144
III	160	VI	140	IX	122

2.1.1 Dates

Among other characteristics of "The Persian War", the most remarkable is the non-existence of dates (year, month, and day) for the described events. In order to interpret this characteristics, let us classify the stories of "The Persian War" into three categories:

(1). Stories coming from indirect information of interviewed persons by Herodotus;
(2). Stories coming from direct observations due to persons interviewed by Herodotus; and
(3). Stories coming from direct observations of Herodotus or the direct information from his contemporaries.

Stories in the first Category may have happened few decades or hundred years prior to the periods of Herodotus. So, exact dates are naturally not expected. Stories in the second category may have been transmitted to Herodotus with exact dates. Stories of the third category should have exact dates if the society in which Hereodotus lived has a calendar. The author is sure that the contemporary Greek world had a calendar system or calendar systems. Without a calendar, the society would be a mess.

Then, why Herodotus did not wrote down the dates of important events? The reason will be clear after reading "The Peloponnesian war" of Thucydides. The reason is that there were no common calendar system in the Greek world. The respective polises used the respectvie calendar whose dates are different from polis to polis. We will see this in section 2.2.

2.1.2 A calendar

There was a calendar system in Greece prior to Herodotus and possibly in his period. This can be confirmed in two places of "The Persian War". The calendar is non-solar nor non-luni-solar, that is, it was a solar calendar with intercalary months.

In Book one, Chapter 32, Solon (639? BC - 559? BC) counted the total days of human life of 70 years in front of the king Croesus of Lydia. He explained the contemporary calendar.

> For I set the limit of man's life at seventy years; in these seventy are days twenty-five thousand and two hundred, if we count no intercalary month. But if every second year be lengthened by a month so that the seasons and the calendar may rightly accord, then the intercalary months are five and thirty, over and above the seventy years: and the days of these months are one thousand and fifty; so then all the days together of the seventy years are seen to be twenty-six thousand two hundred and fifty; and one may well say that no one of all these days is like another in that which it brings. (Book one, Chapter 32)

That seventy years without intercalary months are equal to 25,200 days means one year is equal to 360 days. Then Solon adds an intercalary month of thirty days every two years. From this fact, we understane that one ordinary year is equal to 360 days, and that one year comprises twelve months of thirty days. We can say that basically the calendar is solar since the length of one year is not 354 days, hence the phase of the moon is neglected. Hoewever, the notion of intercalary month comes from the luni-solar calendar. Solon may have introduced the part of solar calendar from Egypt, and the part of luni-solar calendar from Babylonia. As a result, one year is too long. 'the seasons and the calendar may rightly accord' was not realized.

The above episode was at around the middle sixth century. So it might be that Solon's calendar were not used in the periods of Herodotus. However, the following descriptions of Book two, chapter 4 suggest that the calendar was used even in the days of Herodotus:

> It seems to me that the Egyptians monthly system is cleverer than Greek one; the progress of the seasons forces the Greeks to insert an intercalary month evey other year, whereas because the Egyptians have twelve months of thirty days and add five extra days on to every year, the seasonal cycle comes round to the same point in their calendar each time. (Book two, Chapter 4)

Thus, according to Herodotus, the Greek calendar was a mixture of solar and luni-solar calendars. Since the average length of a year is 375 days, contrary to the expectation of Herodotus, 'the seasons and the calendar may rightly accord' was not realized.

In Book six, Chapter 57, section 2, Herodotus talks about new moons in Sparta:

> At each new moon and each seventh day of the first part of the month, a full-grown victim for Apollo's temple, a bushel of barley-meal, and a Laconian quart of wine are given to each from the public store, and chief seats are set apart for them at the games. (Book six, Chapter 57, section 2)

Some may interpret these phrases as showing that the lunar calendar was used in Greece. However, the present author does not agree with this idea. First, if the lunar calendar was used, then Herodotus would have said 'at each first day' instead of 'at each new moon'. Second, as we already pointed out, the Athenian date and Spartan date did not coincide. This means either or both of Athenian and Spartan first day of the month are not the new moon day. In both cities as well as other cities, the principle of calendar systems may have been similar, that is, there did not happen that one city adopts a lunar calendar, while a neighboring city adopts a luni-solar calendar, while yet another neighboring city a solar calendar, and yet another city adopts a non-astronomical calendar. Then, it is highly propbale that Spartan and Athenian did not adopt a lunar nor luni-solar calendars.

2.2 Thucydides: The Peloponnesian War [6]

"The Peloponnesian War" is consisted of eight Books. Book I is consisted of 146 chapters, Book II 103 chapters, Book III 116 chapters, and so on. We show this structure in Table 4. The descriptions of the war between the Athenian ally and Spartan ally start at Book II. Book I concerns the pre-history of the war including the Troy and Persian wars. Thucydides did not finish his descriptions of the war. In fact, the main interval that the book covers is from 431 BC to 411 BC though the peloponnesian war continued until 404 BC.

We do not assume that the calendar system of Solon was used in the period of "The Peloponnesian War". We simply do not know what calendar systems were used in that period.

Table 4: Books and Chapters of "The Peloponnesian War"

Book	Chapters	Book	Chapters	Book	Chapters
I	146	IV	135	VII	87
II	103	V	116	VIII	109
III	116	VI	105		

2.2.1 Information on Dates

There are two pairs of dates in "The Peloponnesian Wars". A "pair" means that dates are different for different polises even though the dates point to the same day.

First evidence:

In Book four, chapter 118, there appears a particular date in Athenian calendar of the conclusion of a suspension of arms. The date is the fourteenth of the month Elaphebolion.

> ‘ The people decreed it. Acamantis was president of the assembly. Phaenippus the scribe. Niciades overseer, and Laches pronounced these words: ’With good fortune to the people of Athens, a suspension of arms is concluded, according as the Lacedaemonians and their confederates have agreed.’ And they consented before the people that the suspension should continue for a year, beginning that same day, being the fourteenth of the month Elaphebolion, (Book four, chapter 118)

In Book four, Chapter 119, the same day is written in the Spartan calendar. The date is the twelfth day of the month Gerastion.

> The same articles the Lacedaemonians propounded and the confederates agreed unto with the Athenians and their confederates in Lacedaemon on the twelfth day of the month Gerastion. (Book four, Chapter 119)

From chapters 118 and 119, we see that the fourteenth day of the month Elaphebolion in Athen is equal to the twelfth day of the Spartan month Gerastius. We note two points. The names of month are different, and the days of the month are different by two. We will discuss implications of these facts in the calendar systems in the following subsection.

Second evidence:

In Book five, Chapter 19, Thucydides talks about the conclusion of the treaty between Athens and Sparta.

> This peace shall take beginning from the 24th of the month Artemisium, Pleistolas being ephore at Sparta, and the 5th of Elaphebolium, after the account of Athens, Alcaeus being archon. (Thomas Hobbes; Book five, Chapter 19)

> The treaty begins from the Ephoralty of Pleistolas in Lacedaemon, on the 27th day of the month of Artemisium, and from the Archonship of Alcaeus at Athens, on the 25th day of the month of Elaphebolion. (J. M. Dent, New York, E. P. Dutton. 1910; Book five, Chapter 19)

> The treaty shall take effect from the following date: in Sparta, in the ephorate of Pleistolas, the fourth day before the end of the month Artemisium; in Athens, in the archonship of Alcaeus, the sixth day before the end of the month Elaphebolion. (Martin Hammond, Oxford World’s Classics, 2009)

The first two English transaltions contradict each other on the day of the conclusion of the treaty. In order to compare the third translation with the former two, we need an interpretation of the length of a month.

The Greek version goes like this:

> *αρχει δε των σπονδων ⟨εν μεν Λακεδαιμονι⟩ εφορος Πλειστολας Αρτεμισιον μηνος τεταρτη φθινοντος εν δε Αθηναις αρχων Αλκαιος Ελαφηβολιωνος μηνος εκτη φθινοντος. ωμνυον δε οιδε και εσπενδοντο.* (Thucydides. Historiae in two volumes. Oxford, Oxford University Press. 1942, Book five, Chapter 19) (The present author have neglected the accents and breath notatiions)

The third English translation is close to the original Greek version. If the length of the month is thirty days, and the ancient Greek counts the ordinal number including the starting number, then fourth day before the end of the month is 27th and sixth day before the end of the month is 25th. So, the translation of J.M. Dent is consistent with that of Martin Hammond and with the Greek version under the assumption that the length of the month is thirty.

Third evidence:

In Book eight, Chapter 58, a convention was concluded between Sparta and Persian representatives (translation by Thomas Hobbes). The author wonders why Thucydides did not write the date of the treaty (convention) between Persia and Sparta. The Persians should have used the astronomical calendar. The author guesses that the Persian astronomical date and Spartan date were so different that Thucydides did not want to show the difference.

> In the thirteenth year of the reign of Darius, Alexippidas being ephor in Lacedaemon, agreement was made in the plain of Maeander between the Lacedaemonians and their confederates on one part and Tissaphernes and Hieramenes and the sons of Pharnaces on the other part concerning the affairs of the king and of the Lacedaemonians and their confederates. (Book eight, Chapter 58)

2.2.2 Calendars

One of our conclusions looking at the first and second evidence in section 2.2.1 is that either or both of the Athenian and Spartan calendars are not lunar nor luni-solar based on their own observations. Two days difference for the same day shows that in either one or both of the calendars, days are not counted by the phase of the moon. Actually, in the one extreme, the longitude distance of the sun and moon is 12 degrees, while in the other extreme, the distance is 36 degrees in two days. On a simple average, the distance of the sun and moon is 24 degrees. Then the moon is 24 degrees (along its orbit) above the horizon when the sun is just below the horizon. Thus, we clearly see the moon two days before (in the morning) or two days after (in the evening) the new moon. So, if the Spartan calendar is lunar or luni-solar, the Athenian is not. Similarly, if the Athenian is lunar or luni-solar, the Spartan is not. And Both can be non-lunar and non-luni-solar. The latter is highly probable since both cities might have adopted the same principle of the calendar system.

Another conclusion is that either or both of the Athenian and Spartan calendars are not solar based on their own observations. In any calendar system, the beginning of the year should be determined by some method. We raise several methods of observations for the determination of the first day of the year.

1. The sunrise or sunset at the winter or summer solstice.
2. The sunrise or sunset at spring or autumnal equinox.
3. The shadow length of gnomon at the noontime of the winter/summer solstice.
4. The heliacal rising[9] of a particular star.

The time of winter solstice or summer solstice can be determined rather poorly. Let us consider the case of the winter solstice. Suppose that the west horizon is covered by low mountains. Observe the sunset near the winter solstice. The setting point on horizon gradually goes to the south as the days go toward the winter sostice. In the winter solstice, the setting point becomes southmost. After the winter solstice, the setting point gradually goes to the north. We want to measure stably the instant of winter solstice. Then we move until the setting point at the day of winter solstice just fits the minimal highest place, i.e., the mountain pass. This adjustment takes, may be, decades of years.

There are three sources of errors. The first one is the error coming from naked eye observations. The second one is the uncertainty of the instant of winter solstice. Tne time of sunset is not necessarily the time of winter solstice. Thus, year by year the setting point may differ. This error can be reduced if one observe the sunrise on the day of winter solstice with a similar procedure (the place of observation may not be the same). The maximum error of the timing is 7 hours, i.e., the timing difference between sunrise/sunset and midnight, at Latitude 40°. The third error is more serious. The rising or setting positions of the sun at horizon moves little at around the day of solstices.

To avoid the third error, we can use the sunrise or sunset at equinox. The angular motion of the sun at the horizon is quick at equinoxes, say, thirty minutes (the diameter of the sun) per day. In this sense, equinoxes are better to observe. In any case, the positional determination with naked eyes becomes reliable if the observations are repeated for many years. In ancient China, the winter solstice has been used as a standard to fix the beginning of the year though the measurement might be done at equinoxes.

In conclusion, if Greek cities respectively determine the beginning of the year from observations, two-day difference of the calendar means that either of Athenian or spartan is not solar from their observations. Both calendars may have been not solar from their observations. Let us summarize our observations.

(1) Ancient Greek polises did not have a common calendar system;

(2) Each polis had its own calendar;

(3) Calendars were (should be) non-astronomical.

2.2.3 An easy calendar of Thucydides

Thucydides noted the above three characters of the whole Greek calendars. In order to avoid the confusion in describing the history of the Greek world, he decided

1. Not to use the year name such as used in Athens and Sparta where years are counted by the names of chief officers [10];
2. Not to use the month name because the names of the months are different from polis to polis;
3. Not to use the day number because the day numbers are different from polis to polis.

Instead, he proposes a very simple counting of the years. Starting from a certain fixed year (say, the beginning year of the Peloponnesian War), he counts the years as the first year, second year, third year, and so on. Inside a year, he discerns summer and winter. This is all. As a calendar system, this is extremely crude.

As evidence, Thucydides states in Book five, Chapter 20, that

> ... But now for the certainty hereof, let a man consider the times themselves and not trust to the account of the names of such as in the several places bare chief offices or for some honour to themselves had their names ascribed for marks to the actions foregoing. For it is not exactly known who was in the beginning of his office, or who in the midst, or how he was, when anything fell out. But if one reckon the same by summers and winters, according as they are written, he shall find by the two half years which make the whole, that this first war was of ten summers and as many winters continuance. (Book five, chapter 20)

Also in Book two, Chapter 1 ([6],Thomas Hobbes), Thucydides says

> The war between the Athenians and the Peloponnesians beginneth now from the time they had no longer commerce one with another without a herald, and that having once begun it they warred without intermission. And it is written in order by summers and winters according as from time to time the several matters came to pass. (Book two, chapter 1)

2.2.4 Eclipses

It seems that Thucydides knows about the lunar or luni-solar calendar. However, his knowledge is not precise. This is clear from his statement 'it **seems** only possible' in the following solar eclipse record. The two descriptions of eclipses again verify that the Greek calendars are not lunar nor luni-solar. Thucydides knew that a lunar eclipse takes place at full moon. Of course, this is an elementary knowledge.

In Book two, Chapter 28, Thucydides reported the occurrence of partial but deep solar eclipse.

> Also the same summer, on the first day of the month (Tanikawa: Aug. 3, 431 BC) according to the moon (at which time it seems only possible), in the afternoon happened an eclipse of the sun. The which, after it had appeared in the form of a crescent and withal some stars had been discerned, came afterwards again to the former brightness. (Book two, Chapter 28)

In Book four, Chapter 52, Thucydides again reported the solar eclipse.

> The next summer, in the very beginning (Tanikawa: March 21, 424 BC), at a change in the moon the sun was eclipsed in part; and in the beginning of the same month happened an earthquake. (Book four, Chapter 52)

In Book seven, Chapter 50, Thucydides reported the occurrence of a lunar eclipse.

> All was prepared and they were on the pint of sailing away when there was an eclipse of the moon, just then at the full. At this most of Athenians felt misgivings and called on the genea;s to postpone the operation: and Nicias (who was rather too much inclined to divination and the like) refused even to discuss any earlier move until they had waited for the thrice nine days prescribed by the soothsayers So, with this the reason for their sudden delay, the Athenians had stayed on. (Book seven, Chapter 50) (translation by Martin Hammond)

2.3 Xenophon: Greek History [7]

”Greek History” is consisted of eight Books. Book I is consisted of 146 chapters, Book II 103 chapters, Book III 116 chapters, and so on. We show this structure in Table 5. The span that the book covers is from 411 BC to 362 BC. The Peloponnesian war continued until 404 BC. So Thucydides did not finish his descriptions of the war. Xenophon without any introduction starts the continuation of Thucydides.

2.3.1 Calendars

As in the case of the Persian War, Greek History of Xenophon has no dates in the descriptions. He divides a year into summer and winter following Thucydides. The battle between Athenian and Spartan Allies were fought mainly in summer. Xenophon does not say when the year starts, but he usually begins his decriptions of events in a year by naming the year. Thus for example in Book one, Chapter 2, he begins like this:

Table 5: Books and Chapters of "Greek History"

Book	Chap.	No. sects.	Book	Chap.	No. sects.	Book	Chap.	No. sects.
I	1	37	III	3	11	V	3	27
	2	19		4	29		4	66
	3	22		5	25	VI	1	19
	4	23	IV	1	41		2	39
	5	21		2	23		3	20
	6	38		3	23		4	37
	7	35		4	19		5	52
II	1	32		5	19	VII	1	46
	2	24		6	14		2	23
	3	56		7	7		3	12
	4	43		8	39		4	40
III	1	28	V	1	36		5	27
	2	31		2	43			

> In the next year, in which was celebrated the ninety-third Olympiad, when the newly added two-horse race was won by Euagoras of Elis and the stadium by Eubotas of Cyrene, Euarchippus being now ephor at Sparta and Euctemon archon at Athens, the Athenians fortified Thoricus; and Thrasyllus took the ships which had been voted him, equipped five thousand of his sailors so that he might employ them as peltasts also, and set sail at the beginning of the summer for Samos. (Book one, Chapter 2, Section 1)

The year can be identified by the phrase 'Euarchippus being now ephor at Sparta and Euctemon archon at Athens'. Here 'ephor' or 'archon' is the executive officer(s) in each polis. However, ephorship in Sparta and archonship in Athens for particular persons are not long, say two years, so that the counting of years in Greek world is not easy for modern historians. This can be observed in Book two, Chapter 4, Sections 9 and 10 where Xenophon raises 29 names of the eponymous ephors (i.e., chief officers) in Sparta for 28 years and six months. This means one eponymous ephor for one year. This way of counting the year is valueless as a calendar.

2.3.2 Eclipses

Xenophon recorded two solar eclipses in Book two, Chapter three, Section 4 and Book four, Chapter three, Section 10:

> It was near this date, and at about the time of an eclipse of the sun, that Lycophron of Pherae, who wanted to make himself ruler of all Thessaly, defeated in battle those among the Thessalians who opposed him, namely the Larisaeans and others, and slew many of them. (Book two, Chapter three, Section 4)
>
> When he was at the entrance to Boeotia, the sun seemed to appear crescent-shaped, and word was brought to him that the Lacedaemonians had been defeated in the naval battle and the admiral, Peisander, had been killed. It was also stated in what way the battle had been fought. (Book four, Chapter three, Section 10)

According to the wording of Xenophon. it seems that he is not so much interested in solar eclipses, which in turn may imply that he is not interested in lunar or luni-solar calendar.

3 Conclusion

Our conclusion in this report is that in the ancient Greek world or at least in the main land of Greece before 362 BC, there were no observational astronomy in our sense defined in section 1.2.

In the preceding sections in all three history books of the ancient Greece, we have seen the Greek calendar systems are not astronomical. These seem to be not lunar nor luni-solar as well as not solar based on their own observations. Solon's calendar is a mixture of solar and luni-solar calendars, hence it was not astronomical.

In Book five, chapter 20 of "the Peloponnesian war", Thucydides proposed a simple calendar system common to the Greek world in which a year is divided into summer and winter, and the years are counted by the number of summers or winters. This was motivated to avoid the mess of calendar systems of Polises which adopt different calendar systems of their own.

In order to make a lunar calendar, one needs to know the instant of full moon or the instant of new moon for the determination of the beginning of the synodic month. In order to make a luni-solar calendar, one needs in addition, to measure solstices and/or equinoxes to determine the beginning of the month and year. In order to make a solar calendar, one needs to know the instant of solstices and/or equinoxes and to determine the beginning of a year and the length of a year. As suggested by the three history books of the ancient Greece, Greek people did not measure neither of these.

4 Discussions

There is a popular science book "The Beginnings of Western Science"([11], p.89) in which the author states that 'Early Greek astronomy appears to have been concerned primarily with observation and mapping of stars, with the calendar, and with the solar and lunar motions that had to be plotted before a satisfactory calendar could be constructed." It seems to the present author that the above idea is common to European audience.

Lindberg adds "These calendric efforts culminated in the Metonic cycle, proposed by Meton (fl. 425 BC), based on the understanding that a very close approximation nineteen years contain 235 months." So, in Lindberg sense, "Early" contains 425 BC and is before the Hellenistc period. Then, the interval of years overlap with our periods before 362 BC. Lindberg further adds, "It seems that Meton intended this as an astronomical rather than a civil calendar; and it was put to astronomical use for several centuries."

The argument of Lindberg is self-contradicting. His argument proceeds like this:

1) Early Greek astronomy appears to have been concerned primarily with observation and mapping of stars, with the calendar, and with the solar and lunar motions that had to be plotted before a satisfactory calendar could be constructed;

2) These calendric efforts culminated in the Metonic cycle, proposed by Meton (fl. 425 BC);

3) It seems that Meton intended this as an astronomical rather than a civil calendar; and it was put to astronomical use for several centuries.

In short, early Greeks wanted to make good calendars, and their effort calminated in the Metonic cycle in 425 BC, but the luni-solar calendar implied by the cycle was not used for centuries. We now know that the Greek calendars in those days were non-astronomical.

It seems that the entire argument of Lindberg is based on the Metonic cycle. There is no evidence for issue 1), that is, Lindberg does not provide any evidence for this. The present author will be convinced if Lindberg provides the records of solar or lunar eclipses. Issue 1) seems to be added by Lindberg to explain the existence the Metonic cycle. Also, Issue 3) is unnatural. The Metonic cycle is not private. Lindberg talks about Meton's private intention to keep calendar as astronomical rather than civil. However, if there are calendar astronomers, they do make a civil calendar against Meton's will. This is natural.

The non-existence of a civil luni-solar calendar for centuries after Meton implies that there were no observational astronomy during the centuries. To ascertain the existence of the Metonic cycle, high precision determination of a synodic month and a tropical year is necessary. There is a possibility that Meton introduced this idea from Mesopotamia. In that case, Lindberg's argument loses basis. We know that in Babylonia, the observation records of lunar eclipses exist already in the eighth century BC [2]. So Babylonian astronomers knew the lengths of a synodic month and a tropical year by the fifth century BC. The trial to make a good calendar lead to the discovery of an approximate ratio of the month to the year.

O. Neugebauer does not assert that there was observational astronomy in the Greek world before 300 BC. He admits that Greek astronomy is mathematical. He says (Chapter 1, section 11 of [4]) that

> 'This period, from about 300 B.C., to the beginning of our era, has furnished us with a great number of astronomical texts of a most remarkable **mathematical character,** fully comparable to the astronomy of Almagest.'

As for the Meton cycle, Neugebauer admits that the cycle is not the discovery of

Meton. Neugebauer writes ([12], p.622) that

> The 19-year cycle assumes
>
> $$19\text{years} = 19 \cdot 12 + 7 = 235 \text{ syn. months} \qquad (1)$$
>
> A corresponding intercalation pattern, using six times a month XII_2 and once a month VI_2, is well-known not only from Babylonian ephemereides but also as the regulating principle of the Babylonian civil calendar. Its use is attested from 490 B.C. (except one disturbance in -384/3) into the first century of our era.

It seems that Greek astronomers obtained Babylonian astronomical data, learned the Babylonian theory of the motion of the sun and moon, and developed their theory. The present author understands that this is the meaning of the 'Greek mathematical astrnomy'.

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[9] The 'heliacal rising' may needs explanation. It is the phenomenon that a (bright) star rises just before the sunrise, that is, the star can be seen at sunrise. Take the brightest star Sirius. The sun moves from west to east in the constellations. Before the heliacal rising, Sirius can be seen in the evening sky in the west. If the longitudes of the sun and Sirius coincides, then Sirius cannot be seen. After this, the sun is to the west of Sirius. So the Sirius rises before sunrise. If the sun is too close to sirius, we cannot see it. The brightness of Sirius is constant, so the separation of the sun and Sirius for which Sirius can be seen just at sunrise is almost fixed. Thus the heliacal rising of a star can be used as a start of a (sidereal) year.

[10] In Book two, Chapter 2, Thucydides says

> The peace, which after the winning of Euboea was concluded for thirty years, lasted fourteen years. But in the fifteenth year, being the forty-eighth of the priesthood of Chrysis in Argos, Aenesias being then ephor at Sparta and Pythadorus, archon of Athens, having then two months of his government to come, ... (Book two, chapter 2)

[11] Lindberg, D.C.: 1992, The Beginnings of Western Science, The University of Chicago Press.

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