Heliacal rising of Sirius and flooding of the Nile

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Abstract. In this paper the question of prediction of the Nile flood based on the first morning visibility of Sirius is considered. It is shown that the only text that describes this event is formulated very vaguely. It makes impossible to derive a reliable astronomical dating. Modern interpretations of this text are based on the free interpretation of the original source, and often do not match. According to historical evidence of Greek authors and later Egyptian texts, flooding of the Nile based on heliacal rising of Sirius could be predicted at the beginning of I millennium AD. This fact is confirmed by astronomical calculations.
Key words: archeoastronomy of Ancient Egypt, heliacal rising of Sirius

1 Introduction

Among historians of astronomy it is widely believed that in Egypt the astronomical observations were carried out as early as the Early Kingdom (3120 to 2649 BC). This view is based on the interpretation of the text, dating from I Dynasty. According to this text the first morning visibility (heliacal sunrise) of the star Sirius (α Canis Major) coincides with the flood of the Nile River. If the information was translated and interpreted correctly, it is possible to date the time period when the phenomenon could be observed.

There is only one document which describes the connection of the first morning visibility of Sirius with the flooding of the Nile. It was written on an ivory plate and was found in a tomb at Abydos (Waerden, 1974) which is located near the modern town of Arabet El Madfuna about 100 km to the north of Dendera. B. van der Vanden, a historian of astronomy, provided the following information on this issue:

"The ancient Egyptians worshipped Sothis, that is Sirius, as 'herald of the new year and of the flood'. (Klaus Baer (Chicago) informs me that the reading 'Sothis, herald of the new year and the flood' is not certain.)"

"This event [flooding of the Nile] is heralded some weeks beforehand by a striking event in the firmament, namely the first visibility of Sirius in the morning sky."

"Thus we learn from our text, if the reading given above is correct, first that the morning rising of Sirius heralds the flooding of the Nile, and second, that the New Year also begins about this time."

Van der Vanden immediately provides that translation "Sothis (= Sirius) is a forerunner of the New Year, and floods" is not reliable enough. Unfortunately, he does not specify whether it is only Baer's opinion or the opinion of the whole expert group, however, the reliability and quality of translation are very important factors. In case the translation is unreliable and the text has no relation to the astronomical event any attempt of dating is meaningless. On the other hand, if the text describes some relationship between the events

of heliacal rising of Sirius and flood of the Nile, an accurate translation is required to solve an astronomical task.

Let's consider the interpretations of the text, which exist in historical and astronomical literature. In fundamental edition of World History, edited by the Academy of Science of USSR, at first glance, the same information is formulated with a different meaning (Frantsev, 1956):

"The need to predict the periods of the Nile flooding created Egyptian astronomy. Year is calculated on the star Sirius, which morning appearing after period of temporary invisibility coincided with the annual onset of flooding."

In the excerpt from Van der Vanden the appearance of Sirius is a harbinger of flood, but according to the last quotation the appearance of Sirius coincides with the onset of flooding. A little difference between the interpretations of the text leads to a completely different dating of the event. Let's see what is written by other authors about the heliacal rising of Sirius. Neugebauer (1968) mentions Sirius as a harbinger of the flood, but he does not date this event:

"Tracing back centuries of Egyptian history of the "deans", we find the interaction of two main components of Egyptian time reckoning: rising of Sirius as a precursor of floods and a simple scheme of the civil year consisting of 12 months three decades each." [Back translation from Russian.]

Pannekoek, a historian of astronomy, argues (Pannekoeuk, 2009) that the flood of the Nile was accompanied by the first appearance of Sirius, what differs in meaning from Neugebauer's text.

"In ancient times, the Egyptians drew attention to the fact that at the very moment when the water of Nile started coming over in nation's capital of Memphis the brightest of the fixed stars - Sirius appeared for the first time at dawn at the horizon." [Back translation from Russian.]

According to Neugebauer Sirius is a harbinger of floods, and Pannekoek's opinion the flood of the Nile and rising of Sirius are simultaneous events. In principle, both points of view can exist together in case if we will understand Neugebauer's words "the appearance of Sirius is a harbinger of severe flooding, which will happen after a while," and Pannekoek's text means "the rising of Sirius coincides with a small flooding of the Nile." Indeed, in this case we can reconcile the views of the authors. (The sense can be interpreted in different ways but the most essential point is the fact that two different interpretations come from one and the same origin.)

A curious point of view is presented by Seleshnikov (1972). On the one hand, he asserts about "approximate" coincidence of heliacal rising of Sirius and the beginning of the Nile flood, though the term "approximate" is rather blurred. If we take as the standard unit the interval from the beginning to the end of the Nile flood, which is more than 100 days, the word "approximate" can mean the time interval of ± 15 days. However, this error makes pointless attempts to astronomical dating of the text.

"The centuries-old, and even thousands of years of observations have made it possible to establish that the heliacal rising of Sirius roughly coincide with the beginning of the Nile flood, when the ancient Egyptians began the new economic year."

On the other hand, the author suggests the coincidence of the moments of summer solstice, heliacal rising of Sirius and flood of the Nile, which was not

mentioned in the original text submitted by Van der Vanden. Probably, he makes this statement of the fact of the inscription dating the 3^{rd} Millennium BC.

"A striking impression on the ancient Egyptians produced a coincidence of the three great natural phenomena: offensive solstice, the first appearance of Sothis and the beginning of Nile flood. For this reason, it is not surprising that in the inscriptions belonging to the era of the Old Kingdom (3^{rd} millennium BC)the majestic Sothis is mentioned. "

Idelson (1975) also suggests the coincidence of three great natural phenomena: the solstice, the first morning visibility of Sirius and flooding of the Nile. As a result, the author gets dating around 3000 BC. But this date was obtained on the basis of erroneous assumption:

"Indeed, in present flooding of Nile occurs in the time of the summer solstice."

At the conclusion of the review, we note the most radical view of predicting the Nile flood on the first morning visibility of Sirius suggested by Klimishin (1990). Unfortunately, the author neither conducts any calculations and nor refers to other investigations. Therefore it is unknown which source is the basis for this assertion.

"Egyptian priests have learned to associate the beginning of Nile flood with a view the star sky. For about 4000 *years BC they found that just before flooding, the star Sirius(Sothis) appears in the morning sky after a* 70*-day period of invisibility."*

Let's consider the original content of the tablet which is given in Parker's study (1950), Fig. 1.

The text of the tablet is a very laconic phrase which is typical of protodynastic inscriptions. It contains two characters, one of which is the image of a lying cow. It is believed that this character means "Sirius." The sign between the horns of the cow is understood as "opening (i.e., the beginning) of the year ". Apparently, the second sign means "ahet" (season spills). So, if we read the title literally, we get the phrase "Sirius, opening the year: the season of the spill". There is no indication about relation between the appearance of Sirius and the beginning of the season of flood. It is possible to assume that Sirius is a harbinger of a spill, appears after the beginning of the spill, finishes the season of the spill. Given that the season spill lasts four months, and the specified label, unfortunately, has no analogues or parallels in close to its time epochs, it is hardly possible to use this text as a reliable source for the dating of the rising of Sirius.

To sum up, we suggest the following conclusion. All mentioned above studies use different interpretations of the same single source. Van der Vanden and Neugebauer consider Sirius a harbinger of flooding, according to Pannekoek, Seleshnikov and Idelson the heliacal rising of Sirius coincides with the flood. Furthermore, Idelson for unknown reason believes that in modern time (and in the past) flooding of the Nile falls on the summer solstice. All the arguments and datings are based on a free interpretation of an uncertain text. Among all the researchers only van der Vanden provides reference to the original source but the other authors just retell it.

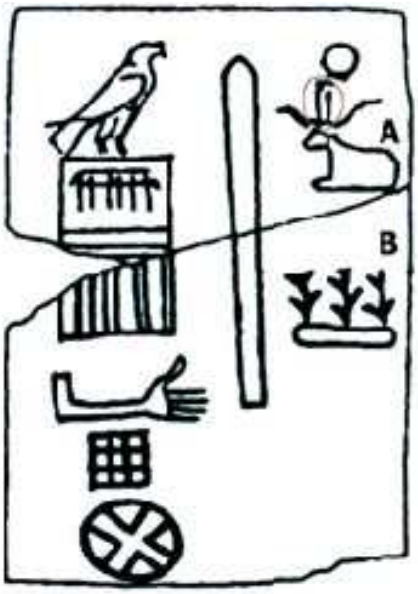

Fig. 1. Plate which states the relationship between the first morning visibility of Sirius and the flooding of the Nile. It is believed that the sign between the form of a cow, which is noted by the letter "A", means "the star Sirius". The circled inscription between the horns of the cow is read as "the beginning of the year". Character designated under the letter "B" means "the season of the spill".

2 When does the flooding of the Nile occur?

To study the time period of the Nile flood we used the data from 1870 to 1952 when the Aswan Dam, located upstream was not yet built (Britannica, 1958). Figure 2 shows the averaged flow of the Nile River at the level of city of Wadi Halfa (22^0 N).

The figure shows that in the early 20^{th} century the flooding of the Nile accounted for the end of July or early August. During this time the derivative of the water flow takes its maximum value (the tangent to the graph has a maximum slope), and the function passes through an inflection point. The inflection point is placed in the range of dates roughly from July 25 until August 1, when about 6 weeks have passed from the time of the summer solstice to the inflection point. Then, the beginning of a major flood occurs a month after the solstice. The maximum value of the spill occurs from mid-August to late September and lasts, so about six months. In our time, beginning August 15, within two weeks the National Holiday of Egypt is celebrated which is dedicated to the Nile flood. A marked drop in the flow of water occurs in early October, after the autumnal equinox, when about 100 days have passed after the solstice. Flooding of the Nile is described in the book V, and the book XVIII Natural History of Pliny (Pliny 2), (Pliny 3) and reflects the situation at 1 century AD.

"The Nile begins to increase at the next new moon after the summer solstice, and rises slowly and gradually as the sun passes through the sign of Cancer; it is at its greatest height while the sun is passing through Leo, and it falls as slowly and gradually as it arose while he is passing through the sign of Virgo. [Book V]"

"In that country [Egypt], performing the duties of the husbandman, the Nile begins to overflow, as already stated, immediately after the summer solstice or the new moon, gradually at first, but afterwards with increased impetuosity, as long as the sun remains in the sign of Leo. When the sun has passed into Virgo, the impetuosity of the overflow begins to slacken, and when he has entered Libra the river subsides." [Book XVIII]

In Pliny's text the most valuable is the fact that all the events are described relatively to solstice, that enables you to make a direct comparison with the modern data. According to Pliny, the floods started after the first new moon after the solstice. This method of description is not very accurate, since formally a full Moon could occur on the first day after the summer solstice, or on the last day of lunar month after solstice. In this case, the date of flooding is located within interval of 28 days. However, it is unlikely that Pliny chose this way to describe the beginning or the end of the month, because it could be done easier. The most likely, he meant that the Nile begins to overflow somewhere in the middle of this range, that is about a couple of weeks after the solstice.

Pliny notices the beginning of the slow spill, when the Sun is in the sign of Cancer, and he further states that in the future the spill accelerates. The maximum water level in the river reaches in the sign of Leo, in the sign of Virgo spill slows down, and in the sign of Libra it is on the wane. Pliny tells that the summer solstice falls on the 8^{th} degree of Cancer, therefore, the autumnal equinox should be in the 8^{th} degree of Libra. This means that the decline of water level occurs after the autumnal equinox, and about a month before it, when the sun comes in the sign of Virgo, the water level in the Nile is stabilized. Note that, according to modern data, the level of water in the Nile begins to subside just after the autumnal equinox. According to Pliny, slow spill (and the achievement of the maximum water level) is in Virgo, a month before the equinox, which corresponds to the end of August and the beginning of the maximum flow of water, Fig. 2.

The Greek geographer Strabo (1964) provides very useful information, where he mentions the flood of the Nile:

In summer the water level is held for more than 40 *days, and then it starts to gradually decrease, in the same way as it was coming; during* 60 *days plain is naking and it begins to dry up and as the more it rapidly drying up, then the sooner man begin plowing and sowing; and drying occurs in the parts, where the heat is stronger.*

Although Strabo does not report any start dates of flooding, the maximum duration of the flood and the fall of the water level are useful to overall assessment of the dynamics of flooding. According to our assessment of modern data, the maximum duration of the spill makes one and a half month that corresponds to Strabo's statement very well. In this case, the maximum spill occurs from mid-August to September, further, in October and November, the water level decreases and reaches approximately baseline by December.

This also corresponds to the duration of falling of the water level, which is reported by Strabo. Finally, Pliny's and Strabo's data could be complemented by Herodotus' words which Pliny refers to, (Pliny 1; 2).

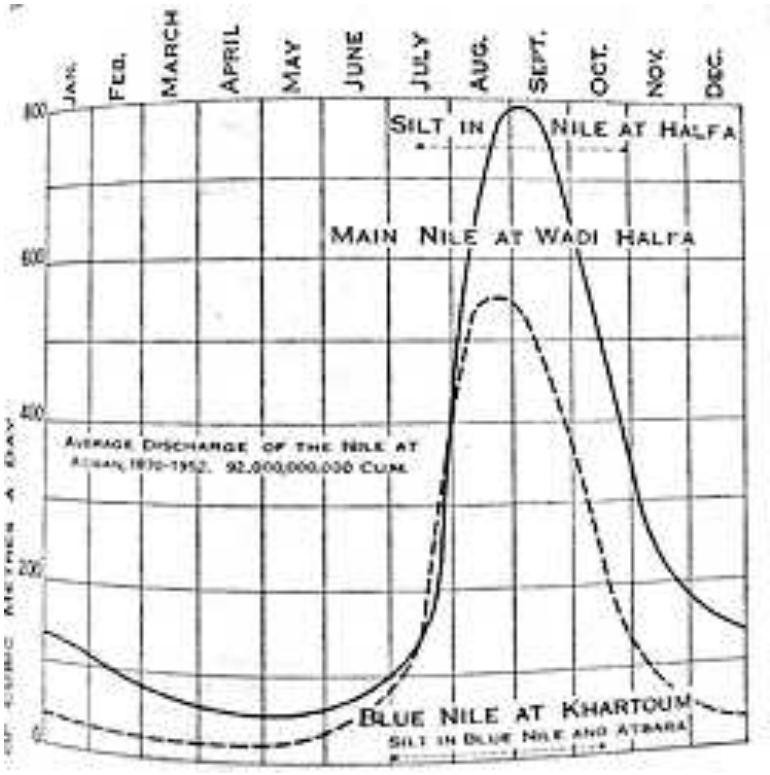

Fig. 2. The average flow of water flowing is registered at the level of Wadi Halfa in the period from 1870 to 1952 according to Encyclopedia Britannica.

"It [Nile] has totally subsided between its banks, as we learn from Herodotus, on the hundredth day, when the sun has entered Libra." [Book V]

From this quotation, we learn that the Nile returns to its banks about 100 days after the spill. Thus, if we synchronize all these events to the summer solstice and the autumnal equinox, then the flooding of the Nile occurred about the same period in the days of Herodotus, Strabo, Pliny and in the early 20^{th} century. Small flooding of the Nile began in two weeks after the solstice, as it follows from Pliny's description, and a strong spill occurred 6 weeks later after the solstice, as it follows from the modern data. Therefore, we can apply this model of the Nile flooding for more ancient times, if we do not take into consideration the influence of significant climate changes.

We note one more important point. Pliny described the flooding of Nile for Lower Egypt, that is the Nile Delta. These data of late 19 - early 20 centuries describe the average flow of water at Wadi Halfa, on the border of Upper Egypt, which is at 8 degrees south of the Nile Delta. However, we found no

significant differences in the characteristics of the flood. This means that the availability of irrigation system has no significant effect on the rise of water in Lower Egypt, although it may slightly shift the flood in Upper Egypt at a later date. Therefore, our estimates would be fair, including the time when there was no irrigation system in Egypt.

3 The dating of the rising of Sirius based on the flooding of the Nile

In columns (3)-(6) the dates of heliacal rising of Sirius for four values of atmospheric extinction coefficient k at different times are presented (Table 1). Calculations are made based on the model [Belokrylov, 2011].

The similar calculation for $k = 0.35$ was performed by Schaefer [2000]. Comparison with our result for this value of the extinction coeficient indicates that the date of sunrise coincides up to one day. However, we believe that he used overestimates assessment of the extinction coefficient for the summer, which corresponds to the rising of Sirius. To support this assertion, we present Ptolemy's statement [Toomer, 1998], who conducted observations near the Tropic of Cancer while calculating the arcs of visibility for planets, "because at this time the air is clear and transparent, and the slope of the Zodiac is symmetric [in the east and in the west]." In addition, our estimates show that the arc of visibility of Ptolemy corresponds to the extinction coefficient in the range $k = 0.20 - 0.25$. Probably Ptolemy knew about the variation of atmospheric transparency from day to day, and therefore he selected the most successful observations. To estimate the average value of the extinction coefficient it is safer to use the value of $k = 0.25$.

Columns $7 - 10$ show the difference between the dates of heliacal rising of Sirius and the time of the summer solstice. Calculations show that the date of the heliacal rising has a weakly dependent on the extinction coefficient. Therefore, if we take the assessment of extinction coefficient $k = 0.25 - 0.30$, the transparency of the atmosphere can slightly differ from this value, and the error will be negligible.

To check our results, we use another testimony of Pliny.

On the sixteenth before the calends of August, Procyon rises to the people of Assyria, and, the day but one after, of nearly all other countries as well, indicating a crisis that is universally known among all nations, and which by us is called the rising of the Dog-star; the sun at this period entering the first degree of Leo. The Dog-star rises on the twenty-third day after the summer solstice. [Book XVIII, Pliny 2]

On the sixteenth before the calends of August, Procyon rises in Assyria, and three days later, the almost everywhere known huge star rises, which we call the generation of the Dog; the Sun at this time comes into the first degree of the Lion. This happens at the twenty-third day after the solstice. [Book XVIII, Pliny 3]

Sirius (Dog-star) rises on the 23^{th} day after the solstice. Since Pliny believed that the solstice occurs in the 8^{th} degrees Cancer, then taking a uniform motion of the Sun, we can calculate that within 23 days it passes 23 degrees. Adding this value to the longitude of the Sun at the time of the solstice, we

Table 1. Legend: *Sum.Sol.* - the date of summer solstice; the columns (3)-(6) - the calculated dates of the first appearances of Sirius in the morning depending on the extinction coefficient; the coefficient of extinction k - the value of fading star magnitude by the atmosphere during the passage of one air mass; Δ_i - the difference in time between the date heliacal rising of Sirius and the date of the summer solstice for the i^{th} variant.

Year	**Date**	**Var.1**	**Var.2**	**Var.3**	**Var.4**	Δ_1	Δ_2	Δ_3	Δ_4
	Sum. Sol.	k=0.20	k=0.25	k=0.30	k=0.35				
-3000	19 July	13.07	15.07	16.07	17.07	-6	-4	-3	-2
-2500	14 July	14.07	15.07	16.07	17.07	0	1	2	3
-2000	11 July	14.07	15.07	16.07	17.07	3	4	5	6
-1500	06 July	14.07	15.07	17.07	17.07	8	9	11	11
-1000	03 July	15.07	16.07	17.07	18.07	12	13	14	15
-500	29 June	15.07	16.07	18.07	18.07	16	17	19	19
1	25 June	16.07	17.07	18.07	19.07	21	22	23	24
500	20 June	16.07	17.07	19.07	19.07	26	27	29	29
1000	16 June	17.07	18.07	19.07	20.07	31	32	33	34
1500	12 June	18.07	19.07	20.07	21.07	36	37	38	39

get 31^{st} degree of Cancer, or the 1st degree of sign Leo. Thus, Pliny's data agree with each other. Furthermore, his assertion that the first morning visibility of Sirius occurs on the 23^{th} day after the summer solstice, confirms our calculation, Table 2. If 1 AD is taken as the period of observation, then with an accuracy of $\pm$ 2 days any value of the extinction coefficient will suit. If we take an assessment $k = 0.25 - 0.30$, we get an exact match between Pliny's description and our calculations.

Let's consider another excerpt from Pliny, who tells us about a hypothesis of mathematics Timey about the reason of the Nile flood, (Pliny 1), (Pliny 2).

Timaeus the mathematician has alleged a reason of an occult nature: he says that the source of the river is known by the name of Phiala, and that the stream buries itself in channels underground, where it sends forth vapours generated by the heat among the steaming rocks amid which it conceals itself; but that, during the days of the inundation, in consequence of the sun approaching nearer to the earth, the waters are drawn forth by the influence of his heat, and on being thus exposed to the air, overflow; after which, in order that it may not be utterly dried up, the stream hides itself once more. He says that this takes place at the rising of the Dog-Star, when the sun enters the sign of Leo, and stands in a vertical position over the source of the river, at which time at that spot there is no shadow thrown. Most authors, however, are of opinion, on the contrary, that the river flows in greater volume when the sun takes his departure for the north, which he does when he enters the signs of Cancer and Leo, because its waters then are not dried up to so great an extent; while on the other hand, when he returns towards the south pole

and re-enters Capricorn, its waters are absorbed by the heat, and consequently flow in less abundance. [Book V]

In the words of the Timaeus, flooding of the Nile occurs at the moment of heliacal rising of Sirius, when the Sun enters the sign of Leo. At the same time, in the previous quotation he argues that heliacal rising of Sirius occurs on the 23^{rd} day after the solstice and it coincides with the entry of the Sun in the first degree of Leo. In this case, according to Pliny, flooding of the Nile begins after the first new moon after the solstice. So, if there exists a difference between Timaeus's and Pliny's statements about the time of flood, it is not great.

But further Pliny argues that most of the authors don't share Timaeus's opinion. They believe that the flood begins when the Sun reaches the maximum of the northern deviation, what occurs when the Sun enters the sign of Cancer and Leo. Obviously, this statement is either wrong or inaccurate. Indeed, the Sun reaches the extreme northerly position in summer solstice, when it has maximum declination. According to Pliny, the summer solstice occurs in the 8th degree of Cancer. Therefore, the statement "this happens when the Sun enters the sign of Cancer and Leo" can refer only to the time of the Nile flood. That is, according to the opinion of unnamed authors, the spill occurs in earlier time than Timaeus assumed. Probably Pliny supports the point of view of unnamed authors, and marks the moment of beginning of the spill uncertain. However, Timaeus's opinion is consistent with our estimates within the error.

It was shown that our calculation coincides with the description of Sirius visibility during Pliny's epoch, so we can use the previously obtained estimates to determine the period of time when the first appearance of Sirius in the rays of dawn accompanied by a flood of the Nile. If we assume that the Nile begins (slowly) to flood two weeks after the summer solstice, we get the dating range from 15^{th} century BC to 5^{th} century BC. If we assume that the report describes the beginning of the major flood of the Nile, which begins in a month after the summer solstice, we'll get the date range from 1^{st} century AD to 10^{th} century AD. The latest estimate corresponds to the time of Pliny. However, two Pliny's quotations allow to understand without any calculation that the appearance of Sirius coincides with flooding of the Nile.

Conclusion. The most significant result is the fact that the time of observation before the 15^{th} century BC does not match dates of any version. The results of dating [Selehnikov, 1972], [Idelson, 1975] should be considered unsatisfactory, as they are all based on the erroneous assumption that the summer solstice and the rising of Sirius coincides with flooding of the Nile. Modern observations of the early 20^{th} century and Pliny's data refute this point of view. The flooding of the Nile could be predicted by heliacal rising of Sirius in the later times.

For example, Idelson [1975] mentions a number of inscriptions, which refer to the Greco-Roman era. They are in the temple of the goddess Hathor at Dendera, the construction of which began under the last Ptolemies and completed during the reign of Tiberius. There is a translation of that text below. Note that the text under the number 2 is presented in studies [Selehnikov,

1972] and [Nikolov, Harlampiev, 1986].

1. Divine Sothis calls the Nile to the beginning of the year.
2. Sothis the Great shines in the sky, and the Nile overflows its banks.
3. Divine Sothis produces flooding of the Nile in its upper reaches.

According to Idelson's opinion these three texts show how deeply Sirius was associated with the minds of Egyptians for thousands of years. We will not argue with the last statement. The whole life of Egyptians was built around the Nile, and it really had a special place in their minds. However, in the light of Pliny's testimony and the results of our estimates, we note that the texts dating under Tiberius, fully correspond to the actual situation with the flooding of the Nile at that time. Mathematician Timaeus says about the coincidence with the beginning of the Nile flood and rising of Sirius. Therefore, we have every reason to believe that all these coincidences are not random. Flooding of the Nile could be predicted on the first morning visibility of Sirius in the early I millennium AD.

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