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THE HELIACAL RISE OF SIRIUS AND ANCIENT EGYPTIAN CHRONOLOGY

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1. *Introduction*

The heliacal rise of Sirius was an important marker for the ancient Egyptian calendar. As such, a variety of studies have used calculated dates as a basis for deriving an absolute astronomical chronology.

In recent years, the exact date of the heliacal rise from Egypt has become critical in several areas of inquiry. Gurshtein has made a key point in his broad reconstruction of the history of the zodiac based on the dates on which the heliacal rising of Sirius starts its Great Cycle.[1] At the Oxford VI conference in La Laguna, several questioners tried to refute Gurshtein's thesis by arguing that his dates of the heliacal rising of Sirius were wrong since there should also be the effects of precession. Also at that conference, Krauss offered an analysis[2] of the heliacal rise of Sirius based on the Illahun papyri in an effort to improve the absolute chronology in the early second millennium B.C. In addition, various older papers attempt to establish an absolute chronology with the heliacal rise of Sirius as the starting point.[3]

Currently, Egyptologists use dates for the heliacal rise of Sirius derived by the 'arcus visionis' method going back to Ptolemy through the work of Schoch.[4] The latest works[5] have no improvements upon the older work.

Astronomy has made great advances, both observationally and theoretically, since the time of Schoch. In particular, the old rule-of-thumb based on the arcus visionis is now known frequently to lead to large errors that invalidate many old conclusions.[6] More importantly, a reliable theoretical model of the physical and physiological processes has been constructed and verified with extensive observational tests.[7] Also critical, extinction coefficients can be established for ancient Egypt with error bars. With these advances, modern astronomers can calculate the dates of Sirius's heliacal rise to a much greater accuracy than was possible by the old rules-of-thumb.

This paper targets the question of the dates of Sirius's heliacal rise from ancient Egypt with the full power of modern astronomy.

2. *Calculations*

The modern theory of visibility of stars during twilight is based on modelling all relevant physical and physiological processes involved in the transmission of the light through the atmosphere, the production of the twilight sky brightness, and the detection of a point source against a background light. Processes included are

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TABLE 1. Heliacal rise dates for Sirius from Egypt.

Year	DSVE*	Julian Date
3500 B.C.	87.8	July 16.4
3000 B.C.	92.3	July 16.9
2500 B.C.	95.8	July 16.6
2000 B.C.	100.3	July 17.3
1500 B.C.	104.8	July 17.8
1000 B.C.	108.2	July 17.2
500 B.C.	112.9	July 18.2
A.D. 1	117.3	July 18.3
A.D. 500	123.0	July 20.3

*Listed is the number of days since the time of the vernal equinox on which Sirius will heliacally rise from a latitude of 30° north for an extinction coefficient of 0.35 magnitudes per air mass.

the refraction of light, the extinction coefficient (from Rayleigh scattering, Mie scattering, and ozone absorption), the optical path length through the atmosphere, the twilight sky brightness, and the point source thresholds for detectability by the human eye. The author has presented an adequate detailed model with full equations;[8] computer programs incorporating this model are available in printed form[9] or at http://www.skypub.com/resources/software/basic/programs/heliac.bas.

The uncertainties in the model prediction are always dominated only by the uncertainties in the aerosol component of the extinction coefficient. This is because the extinction low on the horizon affects the star's apparent brightness as an exponential of a large number (the air mass) times the extinction coefficient, so that even small uncertainties in the atmospheric haziness will greatly change the visibility. (Only the aerosol component varies significantly in a nonpredictable manner.) By comparison, the normal range of human acuity has relatively small effects and is negligible. Fortunately, the daily changes of a bright star's visibility in twilight are large, so that even the uncertainties related to extinction still allow for heliacal rises to be predicted to within a day or two.

The extinction coefficient for ancient Egypt can be established by three methods. The first method is the quantification of the various aerosol sources as part of a global aerosol model.[10] The second method is the empirical establishment of correlations with altitude, relative humidity, month, temperature, and latitude as derived from year-round extinction measures from more than 300 sites worldwide[11] and then applied to the Nile valley. The third method is to scale from measured extinctions from sites in Egypt (Kottamia, Mount St Catherine, Siwa, Sidi Barrani) and in the Nile Valley (Wad Medani and Bahir Dar) to the conditions at Memphis. The present author has given an example of the simultaneous usage of three methods for the nearby Jerusalem in ancient times.[12] The three methods are consistent and indicate that the visual extinction coefficient is 0.35 ± 0.09 magnitudes per air mass during the summer along the Nile near Memphis in ancient times.

The position of Sirius changes with time due to proper motion and precession. The proper motion of Sirius was taken from Hoffleit.[13] For exact precession, I have adopted the rigorous method of Meeus.[14]

My calculated dates of heliacal rising are presented in Table 1. To be specific about the input, I have taken the visual magnitude of Sirius to be –1.46,[15] used the heliacal rise visibility program of Schaefer,[16] adopted a latitude of 30° north (appropriate for Heliopolis or Memphis), made no adjustment for clouds, and taken an extinction coefficient of 0.35 magnitudes per air mass.

What are the uncertainties in these dates? A variation in the extinction coefficient by one sigma (0.09 magnitudes per air mass) results in a variation in the heliacal rise date of typically 2 days. The year-to-year variation in the optimal longitude will result in variations of up to one day, with the typical value being half a day. Any change in the observer's latitude from 30° north will result in close to 1 day change for every degree of difference in latitude (the heliacal rise date becomes later as the observer moves north). If the Egyptians were basing their calendar on the requirement of first sighting for a single year, then clouds will provide a variable delay which will average perhaps a day or so. On top of these will be observational error, both with false alarms and missed sightings, which is a few percent of the time for similar observational tasks.[17] In all, the observational task of recording the date of the heliacal rise of Sirius has a one-sigma scatter of a few days.

What is the altitude of both Sirius and the Sun at the time of best visibility on the date of the heliacal rising? From Ptolemy to Schoch to Ingham, the situation is idealized with Sirius exactly on the horizon while the Sun is below the horizon by an angle equal to the arcus visionis. For those few researchers who consider the question (such as Aveni[18] and Lockyer[19]), Sirius is always taken to be visible to the horizon at heliacal rise. But this is easily disproven since the extinction (0.35 magnitudes per air mass) at the horizon (with the equivalent of roughly 40 air masses) will dim Sirius by 14 magnitudes. Even one degree above the horizon (with 26 air masses) and a good extinction (0.26 magnitudes per air mass), Sirius will still only be barely visible even under a dark night sky. In general, the altitude of best visibility will be a trade-off between sky brightness and extinction. For the particular case of Sirius, the altitude of Sirius at the heliacal rise will be around 6° while the altitude of the Sun will be around –5°. Although the arcus visionis formulation is flawed (it is nevertheless convenient for historical discussions), the arcus visionis for the heliacal rise of Sirius from Egypt is around 11°.

3. *Discussion*

The heliacal rise dates in Table 1 are substantially the same as those adopted by most Egyptologists.[20] That is, even with the great improvements in methodology, the answer remains much the same. Despite this luck, the dates could well have turned out much different, and so the study reported in this paper is still needed to establish full confidence in the astronomical issues relating to the heliacal rise of Sirius.

The natural variations in the extinction coefficient, clouds, and the phase of the

Earth's rotation all create an apparently random scatter in the observed date of heliacal rise of a few days and in the threshold arcus visionis of a few degrees. This uncertainty must be carried along in all evaluations. Frequently, in the past, differences in arcus visionis or date have formed the basis for significant conclusions, whereas we now know those differences to be insignificant. The moral is that strict mathematical models with no attention to error bars can easily result in wrong answers when the model is pushed too far.

Eddy has claimed[21] that certain spokes of the Amerindian Medicine Wheel on Big Horn Mountain in Wyoming are aligned on the heliacal rise of Sirius. Unfortunately, Sirius was assumed to be first visible at the horizon, which is not the case. For the better extinction at high altitude in the American west, Sirius will be first visible at an altitude of roughly 5°. As Sirius rises at an angle of close to 45° from the horizon, the indicated azimuth of the Medicine Wheel spoke actually points 5° too far north for it to be indicating the heliacal rise of Sirius. Similar errors are made for all other stars with claimed heliacal rises from this and other Medicine Wheels, so we can be confident that the claims are wrong.

In the *Almagest* and *Planetary hypotheses*, Ptolemy gives the arcus visionis for Jupiter (magnitude –2.0) of 10° and 9° and for Mercury (magnitude –1.7) of 10° and 12°. No value is quoted for Sirius. To compare these historical reports with the modern calculations of Sirius, a correction of roughly 1° must be subtracted to allow for the larger typical azimuth of Sirius as compared to sources on the ecliptic, and a correction of roughly 1° in the other direction is required to correct for the magnitudes. So, based on Ptolemy's arcus visionis values, Sirius would have an arcus visionis of 9°–10° or 10°–12°. This is reasonable agreement with the value calculated in the previous section.

The Great Cycle (or Sothic cycle) of the Egyptian civil calendar is the time for the heliacal rise of Sirius to travel completely around the year and return to the date of 1 Thoth. For a civil calendar with a 365.0-day year and a sidereal year of roughly 365.25 days, the length of the cycle is often taken as 365.25/0.25 or 1461 years. Gurshtein[22] made a point that the cycle length should be a comparison of the tropical and civil years, that is, 365.25/0.242199 or 1508 years. At the Oxford VI conference, this result was questioned because it does not allow for the precession of Sirius. However, fortuitously, Sirius's position in the sky is such that the Julian date of the heliacal rise does not change much over the entire range of Egyptian history up until the around the birth of Christ (see Table 1). For a one-day shift in the Julian date (see Table 1), the Great Cycle will be 365.25/0.25068 or 1457 years.[23] From the previous section, observational and meteorological uncertainties amounted to a few days on both ends of the Great Cycle, and each day corresponds to 4 years. So the formal one-sigma error bar on my 1457-year cycle length is roughly 20 years. For a Great Cycle that has one start date in A.D. 139,[24] the previous cycle started in 1319 ± 20 B.C. Gurshtein makes an important point relating to the start of the Great Cycle when he connects this with an anomalous jubilee early in the reign of Akhenaton. The astronomical question is then whether the early part of Akhenaton's reign coincided (within uncertainties) with the start of the Great Cycle? The reign of Akhenaton is variously given as 1375–1358 B.C., 1377–1360 B.C., 1388–1358 B.C., and 1353–1336 B.C.,[25] so a time early in Akhenaton's reign might be expressed as something like 1365 ± 20 B.C. The astronomical question then becomes whether 1319 ± 20 B.C. is coincident with 1365 ± 20 B.C. The difference in date is 46 ± 28 years which is only at the 1.6-sigma confidence level (89%) for assumed normal distribution of uncertainties. This difference is insignificant by all conventional criteria. However, in addition, there are the large political uncertainties, where the astronomy could easily be distorted by a wilful Pharoah to satisfy his political needs. (Prominent examples of such distortions appear in the Chinese dynastic annals as well as the early Christian adoption of the calendar date for the birth of Christ.) In all, the difference between my calculated cycle start date and the canonical reign years of Akhenaton are small enough that this difference cannot be used to reject Gurshtein's claim. Rather, Gurshtein's historical evidence of an anomalous jubilee celebration by Akhenaton is now the critical element in deciding the validity of Gurshtein's claim.

4. *Egyptian Lunar Dates*

I would like to use this article to caution Egyptian chronologists on other astronomical difficulties that are currently unappreciated. Specifically, various workers[26] have tried to establish an absolute chronology for early Egyptian dates based on thin crescent visibility. This enterprise has many deep problems. First, the visibility algorithms used are the old rules-of-thumb which have been discredited with very large data bases of observations.[27] In particular, these are shown to give the incorrect date for the majority of the time. Second, clouds can delay the start of the lunar month by one to many days, and we have no idea of how the ancient Egyptians handled clouds. Did they require an observational detection of the Moon and had to wait for clear skies for starting the month or did they try to guess about the visibility had it been clear? Third, even with the best modern algorithm and perfect knowledge of the Egyptian procedures, the crescent visibility predictions will always be uncertain on ~20% of the dates. This means that in the course of a year, the calculated month lengths will be wrong typically for 2 months out of 12. As such, no set of Egyptian month lengths can ever be matched with calculations. Fourth, the range of possible absolute dates for any specific lunar match is a large part of a century, so that out of the hundreds of strings of lunar month lengths (even assuming perfect calculation) there will always be multiple matches throughout the range. That is, a fifty year period has roughly 600 strings of month lengths with one of two values (29 or 30 days[28]) with various strong long-range correlations, so that the matching of any set of 12 Egyptian month lengths is of low statistical significance. Fifth, the Egyptian definitions for the time of the start of the day and the start of the lunar month are disputed[29] with no sure resolution in sight. Until such resolution is available from Egyptian historical material, any program results based on one set of assumptions can readily be ignored by anyone not liking the result. In summary, sadly, I conclude that the current large uncertainties in predicting lunar visibility and in ancient Egyptian procedures do not allow for any possible astronomical solution of Egyptian absolute chronology with lunar dates.

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