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Solar Eclipse Events in the New Kingdom Part 2 – Astronomical Analysis

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Abstract

The sun played a central role in the religion and culture of Ancient Egypt. It is therefore surprising that there seems to be no unambiguous mention of solar eclipses in Ancient Egyptian texts. Eclipses would certainly have been experienced by the Ancient Egyptians and records of them would be expected to occur in the religious corpus.

Part 1 of this paper looked at the source texts and reliefs. Part 2 now sets out the astronomical background and predicts the solar eclipse events that would have occurred during the New Kingdom. These are then correlated with the New Kingdom texts and funerary material to test the hypothesis that these might record actual eclipse events.

Introduction

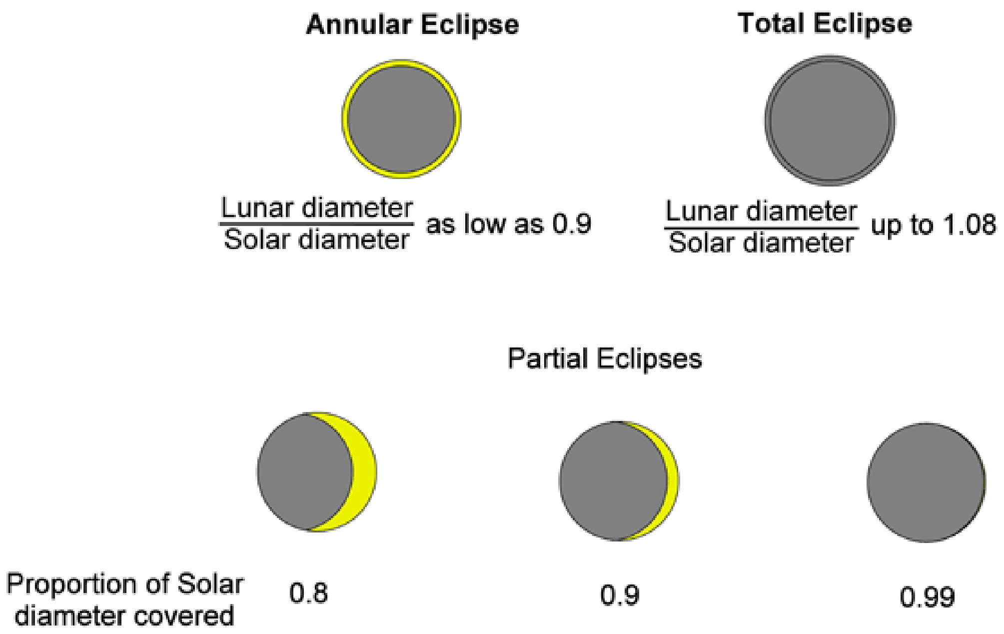

Figure 1: Eclipses

In Part 1 of this paper the apparent lack of any unambiguous reference to solar eclipse events amongst Ancient Egyptian records was noted and possible reasons for this suggested. A number of texts and images for which traditional explanations do not seem wholly convincing or consistent have been considered. The link between Book of the Dead Spell 135 and earlier Coffin Texts has been discussed, particularly in relation to some unusual hieroglyphs, and an alternative explanation suggested for their meaning.

Part 2 of this paper aims to investigate and test the hypothesis that these artefacts could record solar eclipse events, albeit obliquely, in terms that use metaphorical and sometimes spiritual concepts to describe such unusual and disturbing phenomena. The geometry of solar eclipses will be examined and state-of-the art computational techniques used to assess their historical occurrence and the likelihood that these could have been experienced during the lifetimes of the individuals and their families, to whom these artefacts are attributed.

The Significance of the Degree of Darkness

Although between two and five solar eclipses of various types occur each year, there are only about seventy completely total solar eclipses visible on earth during each century and at any given location these will only recur on average once about every 360 years and thus are normally extremely rare events. However, this figure is only an average and there can be a wide variation in the actual interval at any particular place. The number of eclipses in the particular New Kingdom periods discussed in this paper has been surprisingly large. Research has suggested that eclipses at a particular place tend to occur in clusters especially if they occur at sunrise or sunset. Such eclipses, as will be seen later, may allow the obscuration of the solar disk to be much more obvious and therefore more likely than normal to have been noticed. Brewer (1991, p.70) illustrates the flavour of the apparently random nature of the recurrence interval by quoting a table of examples ranging from 837 years for London (from 29 Oct 878 AD to 22 Apr 1715 AD) to 1½ years in Southern New Guinea (from 11 Jun 1983 AD to 22 Nov 1984 AD), listing two for places in Egypt – 312 years for Giza (1 Apr 2471 BC to 29 June 2159 BC) and 9 years for Thebes (31 May 957 BC to 22 May 948 BC).

Although total eclipses are rare, near total eclipses are more common but can be almost as dramatic. The precise degree of darkness achieved during a solar eclipse will depend on many factors, including the time of day, weather conditions and the cloudiness of the sky, but the major factor in determining this will be how much of the solar disk is covered by the moon. Astronomers call this the magnitude of the eclipse, measured simply by the linear fraction of the solar disk obscured by the moon as shown in the figure below. In practice this magnitude (μ) can range from 0, when the moon's disk is about to touch the sun's disk, up to 1.08, when the moon's disk appears slightly larger than the sun.

Absolute light levels are routinely measured during solar eclipses but no subjective scale of the darkness occurring has been proposed, largely because this will obviously depend very much on weather conditions, visual acuity, etc.. However in the normally very clear skies of Upper Egypt, drawing on Können and Hinz (2008), as well as other general works, a tentative scale can be constructed purely to give some flavour to the events being considered:

Magnitude (μ)	**Subjective Degree of Darkness (etc)**
0.0	Normal daylight
0.20 – 0.40	Duller
0.60	A chilling feeling is usually felt by this time
0.70	The temperature begins to fall more rapidly. (By totality the temperature drop may reach several degrees Centigrade.)
0.80	The light levels begin to fall faster
0.90	The rapid drop in light levels becomes very noticeable (as at twilight) and planets and stars may begin to be visible
0.99	“Bailey’s beads” may be seen from up to 15 seconds before and until totality when they will disappear
1.00 and above	Almost as dark as a moonlit night. The solar corona may be seen.

The factors that determine whether a solar eclipse might be noticed are quite complex. Clearly if there is heavy cloud or the sky is significantly obscured then this will considerably reduce its visibility, while on the other hand very thin cloud can paradoxically make it easier to see. This is because at magnitudes less than 1.0 it is not possible to look directly at the solar disk without incurring or risking severe retinal damage. Thin cloud can act as a filter allowing the solar disk to be directly observed during the partial phase. Eclipses can also be safely witnessed via their reflections, for example off the surface of water, or by diffraction, for example through the leaves of trees.

In Middle and Upper Egypt cloud cover will by no means be as significant a problem as it is in the higher latitudes, although mist and fog may occur around dawn. Reliable climate data for the New Kingdom period in Egypt does not exist as such but there is some evidence that the climate there would have been largely the same as it is at present. Areas of the Sahara desert were cultivated and possibly even swampy around 6,000 years ago, but desiccated around 4500 years ago (Kuper and Kröpelin 2006, p.806). Rain was obviously an exceptional event in Thebes in the New Kingdom just as it is today – McDowell (1999, p.64) discusses three graffiti recording the rare event of rainfall.

Current data (see table below) show that cloud cover in Luxor ranges from 1% in the summer period to a maximum of 8% in December. With such low levels of cloud cover there would always be a significant change in the light level during deep eclipse, even in the event that the solar disk itself was not actually visible for various reasons.

Cloud Cover at Luxor

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cloud Cover (total = 8)	0.7	0.6	0.7	0.7	0.6	0.1	0.1	0.1	0.1	0.4	0.5	0.8

Source: “http://www.traditionalegypt.co.uk/practical/weather.php” visited 17th May 2012

The chilling effect before and during an eclipse has not been considered in traditional studies, but Können and Hinz (2008, p. H15) believe that almost everyone experiences a chilling feeling around magnitude 0.6. In Upper Egypt where the ambient temperature during the daytime is high compared with locations at higher latitudes this is therefore likely to be an important factor. If the light level also drops significantly at the same time it would be very likely to cause an ordinary person outside to look up at the sky and to notice the presence of stars and planets. In a culture as focussed on solar issues as that of Ancient Egypt any significant level of chilling and darkness during daytime in the absence of clouds would be unlikely to have gone unnoticed.

Unless a person views an eclipse via its reflection off water or diffracted, for example through the leaves of trees, or if the sun is low in the sky, he or she may well not be aware of the actual degree of lunar obstruction of the solar disk. Muller and Stephenson (1975) have conducted a study to try to assess the reliability of the discernment of the magnitude of historical eclipses, the purpose of which is to be able to give more weight to those eclipses that are extremely reliable in terms of the statistical analysis used to estimate changes in the rotation of the earth. (This subject is discussed further below.) Their main criterion was the reliability with which the observer can estimate the degree of totality based upon their ability to distinguish between a total eclipse and a partial one, aiming to exclude any historic data which cannot be unequivocally substantiated. They argue on this basis that even eclipses of magnitude as high as 0.99 can be overlooked by professional astronomers, but they also conclude that there is adequate evidence to support the contention that untrained observers can distinguish between totality and partiality.

More recently Stephenson (1997, pp. 382-383) discusses what he considers to be six reliable examples of medieval European records where one or more stars were said to be visible and calculates the likely maximum magnitude of the eclipse. He concludes that these do provide strong evidence that even inexperienced observers could discern stars at an eclipse which falls far short of totality. In two of the six cases he examined, the magnitude calculated at the point of observation was as low as 0.84, although the central maximum magnitude of the eclipses were 0.92 and 0.94.

Ginzel published a canon of solar eclipses between 900 and 600 AD and suggests that an unpredicted solar eclipse is likely to be noticed when a magnitude of 0.75 is reached if the sun is high in the sky or when a magnitude of 0.5 is reached if the sun stands close to the horizon (Ginzel 1887, p. 119).

In considering what level of eclipse magnitude is significant for the purposes of this paper, the references to darkness in the texts and the depiction of stars in the vignettes will be used as the main criteria. This is not to say that account should be taken of the precise number of stars in a specific vignette – the fact that observers' apparently precise accounts are often somewhat flawed is well known (Demandt, A., 1971). Visual acuity will of course also vary between people. Such accounts record what an observer may believe they saw and this may also subsequently be subject to later amendment.

It is also worth noting that studies of eclipse events often regard most of the examples used as being the results of historical professional astronomical observations which were then deliberately recorded as part of their duties. In the case of the artefacts being considered here and the argument being put forward in this paper the situation is quite different. We are considering that records represent the accidental observation of eclipses by a small number of inexperienced observers. Most of the population of Egypt is located along the Nile and the associated irrigation channels of the delta and fertile strip and hence many ordinary people will be close to a source of water on which the reflection of the sun may be seen. However small the likelihood of an individual inexperienced observer noticing the eclipse, for whatever reason, given the large number of potential observers in the population the likelihood of a few of these doing so is extremely high.

For the purposes of this paper a figure of 0.9 will be assumed for the minimum level of the magnitude for us to be completely confident that an eclipse or its effects, for reasons of darkening, chilling and for stars and planets to have been potentially visible, would have been likely to have been experienced. Because it is likely that the effects of lesser eclipses of predicted magnitude between 0.7 and 0.9 would have probably been noticed in many cases because of the chilling effect and some darkening of the sky these have also been included in the following tables for purely illustrative purposes.

The following table based on data published by Gautschy (2011) and by NASA (2009) lists how many solar eclipses were visible at magnitudes of 0.5 and above at Thebes during the New Kingdom (assumed to be 1550 BC-1069 BC, based upon Shaw (2000)). From this table it can be seen that an eclipse of magnitude of 0.7 and above would have occurred on average about every 9 years at Thebes, which means that it would probably not have been uncommon for many people there to have experienced an eclipse of at least that magnitude several times during their lifetime, while the average for eclipses of magnitude 0.9 and above is about 28 years.

	Numbers Visible above specific magnitudes at Thebes in the New Kingdom (from Gautschy (2011))					
All Solar Eclipses from NASA (2011)	0.5	0.6	0.7	0.8	0.9	1.0
1148	84	69	53	32	17	2

Traditionally studies of historical eclipse events have used only the estimated magnitude of historical eclipses but these estimates can be subject to a wide range of statistical error and this point will be addressed later.

Classifying and Dating the Evidence

The texts, scenes and artefacts considered in this paper fall into two distinct groups:

- Several relate to specific individuals who were known to have been resident at the village of Deir el-Medina at specific times. The prosopographic study of this community by Davies (1999) has been especially valuable in this respect.
- The remaining items are more disparate but individually have attributes which still make them useful in relation to the examination of the hypothesis that they were originally related to a deep solar eclipse.

To apply modern astronomical knowledge to these groups we first describe the items in some detail, attempting in each case to establish a credible dating. We then attempt to correlate each record with the astronomical evidence.

Group 1: Evidence from Deir el-Medina

The evidence in this group comes from texts on stelae and from tombs and other artefacts showing Spell 135. Frequently evidence from more than one source can be attributed to a single individual.

Stela Bankes No. 6 and TT 1: TT1 was the tomb of Sennedjem, the wife of Iy-neferti. This stela was dedicated to Iy-neferti, a “servant at the place of truth” at Deir el-Medina, where the stela probably originated. It shows Iy-neferti adoring the sun and moon, shown above the inscription. Ĉerný (1958) remarks that the same expression is found on several stelae of the same type and from the same place, translating this as

> [B]e merciful, for you have caused me to see darkness by day because of those women’s talk…..

The vignette of Spell 135 is shown on the ceiling in the burial chamber of TT1 which is known to belong to Sennedjem.

Sennedjem and Iy-neferti lived during the reign of Seti I and Ramesses II and Sennedjem himself had probably died earlier in this period. The couple and several of their sons were buried in the same tomb and it is quite possible that decoration of the tomb continued after Sennedjem himself had died and that Spell 135 was added by his widow, bearing in mind that it was her who commissioned the Stela. Mahmoud (1999, p. 317) believed that Iy-neferti was over 75 years old when she died, which would mean that she probably lived until the middle of the reign of Ramesses II.

Stela BM 374 and TT 218: The stela, from Deir el-Medina, shows Amennakht, scribe of Set-Ma'at, kneeling before the Goddess Meretseger, Mistress of the West. Gunn (1916, p. 87) translated this inscription as *"[T]hou causest me to see darkness by day,"* and concludes that this man was blind – indeed both images on the stela seem to be missing their eyes – although he notes also that Amennakht is a very common name and does not suggest an attribution. The stela is often attributed to Amenakht(e), son of Ipuy, who lived in the 20th Dynasty, based on the fact that on the stela the person was a "Scribe" and he is the only one of that name. Davies (1999, p. 149), however, citing the example of Ipu(y), is of the opinion that the term "scribe" was often used more loosely and sometimes meant "draftsman". In fact, the Stela text reads "Scribe of Set-Ma'at", which is not the same as "Scribe of the Tomb", so for these reasons the owner is unlikely to be Amenakhte, son of Ipuy.

The ownership of the stela cannot therefore be identified with absolute certainty. On the basis of the use of the expression "darkness by day" as used by Neferabu and Iy-neferti, it might seem plausible that it belonged to Amennakht, the son of Nebenmaat, who lived at about the same time. However, records from Deir el-Medina are far from complete and so we must also consider the possibility that it belonged to another, as yet undocumented, Amennakht, possibly a scribe or draftsman, living in the 20th Dynasty. Both datings will therefore be examined later.

Both the vignette and text of Spell 135 are shown on the ceiling in the burial chamber of TT218. Davies (1999, p. 236) clearly identifies the owner of TT218 as the workman Amennakht, the son of Nebenmaat, and dates it to the first half of the reign of Ramesses II.

Stelae BM 589, Turin 50058 (also referred to as No: 102) and TT5: Stela BM 589 shows Neferabu, a worker, probably a painter, at Deir el-Medina. Neferabu erected a number of stelae in his tomb (TT5). TT5 is also discussed by Vandier (1935) who suggested that BM 589 did not come from his tomb but from a private shrine in Western Thebes. Gunn (1916, p. 88) translated the text as

> "[I] am a man who swore falsely by Ptah, Lord of Truth;
>
> And he caused me to behold darkness by day."

Stela Turin 50058 is also attributed to Neferabou. Tosi and Rocatti (1972, p. 95) note that the text of this stela suffers from numerous mistakes, aberrant spellings and omissions. It was dedicated to Meretseger, to whom Neferabou also made a false vow. Gunn (1916, p. 86) translated the text as

> [I] was in her hand by night as by day.

This particular inscription also contains a further clue suggesting that the phenomenon being observed was a solar eclipse. Almost immediately after the sentence above, Gunn (1916, pp. 86-87) reported that the inscription shortly after continues *"[I] called upon the wind, and it came to me not"* and, later:

> "[I] called upon my Mistress:

I found that she came to me with sweet airs".

He acknowledges that both Erman and Maspero took this reference as probably indicating a disease in which the subject suffers from lack of breath, but he suggested that it may only be a poetic figure. This inscription may be an example of the phenomenon known as the '*eclipse wind'* – during a total eclipse local changes in wind speed and / or direction as totality approaches are often reported. The reference to sweet airs might be a reference to cooling.

Part of the vignette of Spell 135 is shown on the ceiling in the burial chamber of TT5, but it is badly damaged and the part showing the gods and stars is missing.

A necropolis workman of the name of Neferabu was mentioned on Ostracon BM 5634 dated to a regnal year of 40+, when he was burying his brother-in-law, so he may be placed with some certainty in the reign of Ramesses II (Ĉerný 1929). Neferabu may have commissioned both stelae urgently at the same time by different stone cutters to record the placation of both gods. Both stelae and tomb can therefore also be dated with some certainty to the early to middle part of the reign of Ramesses II.

Stela Turin 50046 (also referred to as No: 318), pNeferrenpet and Coffin Fragment: This stela was discussed by Gunn and shows the sculptor Neferrenpet with his wife (or sister) and daughter worshipping Thoth who wears a head-dress depicting a crescent and moon and is, himself, being worshipped by a dog-headed ape. Gunn (1916, p. 92) translated the text as *"[T]hou causest me to see a darkness of thy making;"* The decoration in Neferrentpet's tomb (TT336) is damaged and incomplete and if Spell 135 originally appeared in it then it has been lost.

Several individuals of this name are known to have lived at the village during the 19th and 20th Dynasties. Tosi and Roccati (1972, p. 81) tentatively accredited this stela to the worker Neferrenpet, son of Nebre and Pashedet, although they acknowledge the existence of two other people of the same name also at Deir el-Medina. However, the stela specifically stated that he was a sculptor and the only one of this name documented by Davies (1999, p. 183) is Neferrenpet, son of Piay, and brother of the Royal Scribe Huy. They were contemporary with (and probably slightly younger than) the scribe Ramose. Huy and Ramose were serving together under Ramesses II until year 39 of his reign. Milde (1991, p.27) confirms that the ownership of pNeferrenpet as this same person. This stela, the papyrus and coffin fragment therefore all date from the first half of the reign of Ramesses II.

Stela Turin 50050: This stela was dedicated to Ahmose-Nefertari by Heria, a name rarely mentioned on behalf of the Lady of the House Eie. Tosi and Roccati (1972, p. 85) translate the text as

[[G]rant] that I may see the darkness you create;

The name Heria is mentioned in the year 6 of Seti II on Ostracon Nash 1, recording the case of a woman charged with the theft of a copper utensil (Ĉerný and Gardiner 1957 p. 46,2). Because there are several instances of the name Eie, including one who was a daughter of Neferabu (see above), Tosi and Roccati (1972, p. 85) argued that it is not possible to be sure of the precise individual Eie, but document the stela in the period from the end of Dynasty 18 and the beginning of Dynasty 19.

A date as early as the end of the 18th Dynasty seems unlikely if one accepts that the Heria mentioned was the same person as the one accused of theft. It therefore seems more likely that this stela was produced during the first half of the reign of Ramesses II, especially if one accepts that the Eie mentioned was indeed the daughter of Neferabu. No tomb copy of Spell 135 has so far been attributed to the owner of this stela.

Stela Turin 50051 (also referred to as No: 279) and TT290:

Gunn (1916, p. 92) describes this stela as showing Irynefer, a servant at Deir el-Medina, kneeling in front of Thoth, apparently asking for his second wife, Nebtnuhet, shown kneeling below, to be healed. He translates the text spoken by Irynefer as

> [T]hou causest me to see a darkness of thy making;

Irynefer is known to be the owner of tomb TT290 and both the vignette and text of Spell 135 are shown on the ceiling in its burial chamber.

Davies (1999 p. 263) remarks that Irynefer's brother was attested until at least year 40 of the reign of Ramesses II, but there seems to be an inference from this stela that Irynefer has died, leaving a younger widow to mourn him, so it probably dates from somewhat earlier. The tomb and stela probably date from around the first half and middle of the reign of Ramesses II.

Stela Turin 50052: Gunn (1926, p. 90) discussed this stela. It shows the draughtsman scribe Pai, worshiping Khonsu, and is dedicated to the honour of his mother Wadjetronpet, wife of Ipuy. He translated the text as

> [L]o, thou causest me to see a darkness of thy making,

The draughtsman Pai's name occurs in graffito number 817 in apposition to the cartouches of Horemheb, Ramesses I and Seti I (Spiegelberg 1921, p. 66). Pai is known to have been working during the early years of Ramesses II (Ĉerný 1954). Given that Pai's mother was by this time dead, it seems likely that the stela probably dates to the first half of the reign of Ramesses II. No tomb copy of Spell 135 has so far been attributed to the owner of this stela.

TT 265: This tomb belonged to Amenemopet, a scribe at Deir el-Medina, whose chapel (TT215) also exists. The badly damaged text and part of the vignette of Spell 135 is shown on the ceiling in the burial chamber of TT290.

Davies (1999, p. 77) reported that Amenemopet named his closest colleague, Huy in this tomb chapel and that they were both in office in the early years of Ramesses II, although he may have been succeeded by Ramose in year 5. Whether he died then or simply "retired" is not known, but it seems likely that this tomb dates to the first half of the reign of Ramesses II and decoration in it may have been continued after his death by his family. No stela bearing an inscription of the form discussed earlier has so far been attributed to the owner of this tomb.

TT 356: This tomb belonged to Amenmuwia, a worker at Deir el-Medina about whom we know very little. What is certain is that Amenmuwia was active during the first half of the reign of Ramesses II, and he and his stonemason grandson Qenhirkhopshef were both active by the middle of the reign of Ramesses II (Davies 1999, p. 207). No stela bearing an inscription of the form discussed earlier has so far been attributed to the owner of this tomb.

Correlating Dates with Deep Solar Eclipses

To perform a useful correlation it is necessary to establish the location of each artefact, its date and the dates of possible eclipses. Stelae and the graffito, which bear the name of an individual may well have been created in direct response to an eclipse event. On the other hand, tomb decoration and funerary materials may have been added by any of the individuals in the family of the tomb owner and although prompted by an eclipse event such decoration would most probably have been intended as protection against the recurrence of the event and may have taken longer to complete. In either case a broad dating is still possible by the relationship of the event to specific named individuals who were known, from other references, to have been present in a particular place at particular regnal dates.

Even then, linking these regnal dates to an absolute date is still subject to error since it is generally accepted that the chronology remains uncertain before about 664 BC (Shaw 2000). Traditionally absolute dating of the New Kingdom period has been based upon two main correlations, the accession dates for Thutmose III and Ramesses II, which are associated with specific astronomical lunar and Sothic events (Kitchen 1987). More recent research has, however, questioned the chronology of Dynasty 18 and the early part of Dynasty 19 and there has been much speculation in particular on the length of Horemheb's reign. The chronology of the Amarna period is also extremely tentative.

Huber (2011) has recently examined the astronomical base of the chronology during this period and its relationship with the surrounding countries and concludes that the dating of the New Kingdom is at best ambiguous. Two possible chronologies based upon Huber's work will therefore be considered in this paper as follows:

Chronology 1 (BC)	Chronology 2 (BC)	Notes
(Long Horemheb reign)	(Short Horemheb reign)	
Tuthmose III 1479	Tuthmose III 1479	
Amenophis II 1426	Amenophis II 1426	
Thutmose IV 1400	Thutmose IV 1400	
Akhenaten 1353	Akhenaten 1353	Possible co-regency?
Smenkhkare 1335	Smenkhkare 1335	Possible co-regency?

Tutankhamun 1332	Tutankhamun 1332	
Ay 1321	Ay 1321	
		Suppiluliuma’s death 1318
Horemheb 1317	Horemheb 1317	
		Mursillis II 10^{th} year 1308
	Ramesses I 1303	
	Sety I 1301	
Ramesses I 1292		
Sety I 1290	Ramesses II 1290	
Ramesses II 1279		

Although the mathematics of solar eclipse prediction is now well known, one parameter in the calculation introduces an element of uncertainty into the precise path of the solar eclipse across the globe. This parameter is the changing rate of the earth’s rotation over the centuries, due mainly to the drag of tidal friction caused by the moon upon the earth. Currently, this parameter amounts to an increase of about 1.7 milliseconds per century in the length of the day, but during the period between 1900 AD and about 2000 and 1900 AD, the length of the day was actually declining. Work by Stephenson and others (Stephenson and Holden 1986; Stephenson 1997) showed that the accumulated change in the earth’s rotational position at the precise timing of an eclipse for dates in the period covered by this study is significant. For example, for eclipses occurring around 1500 BC, this parameter, known as ΔT, amounts to about 9½ hours, compared with the position the earth would be in if the rotation had been constant over the entire period or a distance at the equator of about 0.46 km for each second. Morrison and Stephenson (2004) have developed the following formula to estimate ΔT (in seconds) for eclipses before 1000 BC

$$\Delta T = -20 + 32*[(\text{BC year}-1820)/100]^2$$

For example, for the year 1500BC (i.e. year -1499) this calculation yields

$$-20+32*((-1499-1820)/100)^2 \text{ or } 35230 \text{ seconds.}$$

In the light of the publication by NASA of the DE406 ephemeris (NASA 2007) which takes into account a slightly improved estimate of the moon’s secular acceleration this formula has to be corrected and becomes:

$$\Delta T \text{ (corrected)} = \Delta T-0.91072*(-25.858 + 26.0)*t^2 \qquad \text{(X)}$$

$$\text{where: } t = (\text{BC year}-1955)/100$$

i.e. for the same year, 15000BC this yields…

$$35230 – 0.91072*(-25.858 + 26.0)*((-1499-1955)/100)^2, \text{ or about } 35041 \text{ secs.}$$

Although this absolute time difference is significant in calculating precisely where an eclipse will be visible, what is of more importance is the error in the estimate of ΔT. Even a small amount of error in this estimate can sometimes significantly affect the calculated path of an eclipse and make the difference between a total or very deep eclipse and a less significant partial one at a given location.

Morrison and Stephenson (2004) have estimated from historical data the standard error of the estimate of ΔT in seconds as:

$$SE(\Delta T)= 0.8*[(\text{BC year} - 1820)/100]^2$$

which for the example above would give the result

$$0.8*((-1499-1820)/100)^2 \text{ or } 881 \text{ seconds.}$$

but they have been reluctant to publish estimates for ΔT and its standard errors back beyond 1000 because of the lack of empirical evidence. Huber (2006) addresses this problem and using a refined statistical analysis of Morrison and Stephenson's data has for the standard error estimate for the period beyond 1000BC. He calculated this using modern data over a 2,500 year extrapolation period working from a baseline of 500BC up until 2000AD and has suggested the following formula for its use to produce a better estimate the error as far back as 3000BC:

$$SE(\Delta T)=0.36525*N*\sqrt{(0.056N/3)*(1+(N/2500))} \quad \text{(Y)}$$

$$\text{where } N=ABS(\text{BC year}+500)$$

which gives the result

$$0.36525*(-1499+500)*\sqrt{(0.056*(-1499+500)/3)*(1+((-1499+500)/2500))}$$

or 1864 seconds, more than twice that from applying Morrison and Stephenson's formula.

Although Huber's formula was published prior to the publication of DE406 Gautschy (private communication) has confirmed by comparing the calculated results that this difference does not significantly affect the calculation.

Modern canons of historical solar eclipses have been published by NASA (2009) and a slightly improved version has been published more recently by Gautschy (2011). The latter only covers eclipses with a predicted magnitude exceeding 0.5 somewhere in the eastern Mediterranean area defined by the rectangle (20°N, 5°E), (20°N, 50°E), (50°N, 5°E) and (50°N, 50°E), which includes many of the capitals of ancient civilisations. These canons can be used to identify precisely when relevant historical eclipses took place, where they were likely to be visible and with what predicted magnitude. The eclipse calculation software, EmapWin 1.21 (Takesako, 2000) has then been used along with the latest estimates of ΔT to examine these predictions and their sensitivity to errors in the estimate of ΔT.

Notes accompanying EmapWin 1.21 confirm it uses DE 406 despite the date on the web site, but in earlier versions the author chose to incorporate his own slight modification to the formula for estimating ΔT and this has been carried forward into later versions. It is therefore necessary to use the built-in facility to modify the program's calculated ΔT so as to produce the correct path forecast and predicted maximum magnitude. This does not actually affect the calculations on magnitude and probabilities carried out below. Essentially, EMapWin is being used only as a visualisation facility to observe the change in eclipse magnitude with variation in ΔT. Figures for magnitude calculated in this way are extremely close to those published by Gautschy (2011), differing only occasionally in the second decimal place so the technique is robust even though quite different computer programs have been used for the two sets of calculations.

The sifting and calculation process proceeds in three stages. Firstly all eclipses potentially visible at the site being considered will be identified and those with a predicted magnitude exceeding 0.7 taken from Gautschy's 2011 canon have been listed for closer consideration. (It is, incidentally, worth noting that some of the eclipses of lower predicted magnification than 0.5 excluded from Gautschy's canon and also those of predicted magnitudes between 0.5 and 0.7, which have also been excluded here, may also have had slightly larger magnitudes for values of ΔT away from the central estimate. Any of these might potentially have been noticed, of course, but would be less likely to have reached the level 0.9 which has been set in this paper as the baseline for the purposes of this investigation.)

Because the error margin in the estimation of ΔT is large for the historical period being considered and the tracks of the region of totality and near totality of an eclipse are relatively narrow there could be some uncertainty in whether an eclipse exceeding a particular magnitude would actually have occurred at a particular place and time. This is where traditional studies using only the predicted magnitude of an eclipse for a specific time and date and for the predicted value of ΔT are potentially flawed. In this study this weakness is remedied by assessing how robust the magnitude of the eclipse is to variations in ΔT.

By way of illustration of why this is important, one should note that the tracks of solar eclipses across the surface of the earth exhibit a very chaotic appearance due to the complexity of the geometry involved in the movement of the sun, earth and moon. When the track of an eclipse crosses very obliquely across the path along which the observer's location moves as the earth rotates, even a small error in the prediction of the ΔT value can mean the difference between a total eclipse and a lesser one. On the other hand, if these paths match closely, the magnitude is relatively insensitive to this error. It is important, therefore, in quoting estimates of the magnitude of historical eclipses to assess how robust these estimates are if they are to be used with any degree of confidence.

Secondly, therefore, those eclipses of predicted magnitude exceeding 0.9 (i.e. those meeting the criteria outlined earlier) have been subjected to a sensitivity analysis. This has been carried out by incrementally varying the adjustment to ΔT within EMapWin to identify the range of values within which a particular magnitude is exceeded. The value of ΔT and its associated error estimate are then used together with this range to calculate a probability figure – a Gaussian (normal) distribution of errors in the estimation of ΔT has been assumed here. In the analysis presented here this probability figure is essentially, therefore, being used as a proxy measure of how robust the results are.

The data for the major eclipses of magnitude exceeding 0.9 at Thebes, which will be considered below, are illustrated in the following chart, showing why the calculated probabilities are very high, particularly for the eclipses of 1337 BC, 1262 BC and 1257 BC, which have paths that would yield very large magnitudes for any reasonable estimate of ΔT. For this reason these would not be very helpful to anyone attempting to use a record of their occurrence as a data point to estimate the historical value of ΔT, but they are especially useful in this research in confirming that we can be very confident that a deep eclipse could have been experienced irrespective of major errors in the estimate of ΔT. On the other hand, the eclipse of 1522 BC, which occurred so close to sunset that it could only be experienced for a very narrow range of ΔT, if the dating of the associated artefact could be established with confidence (which is clearly not the case for Ostracon Cairo 12202) would be an excellent data point for use in studies aimed at refining the empirical prediction of ΔT over the historic period.

Eclipses Relating to the Material from Group 1

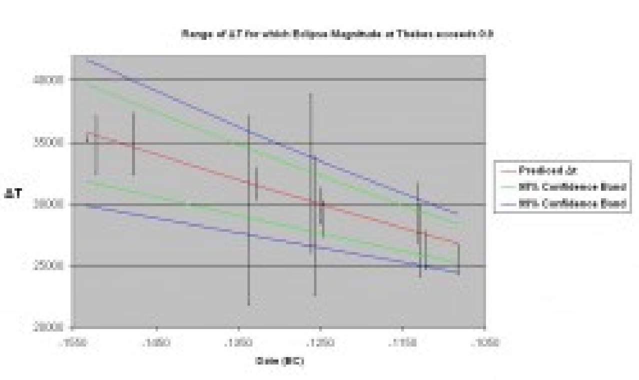

Figure 2: Range of ΔT for which Eclipses Magnitude Exceeds 0.9 at Thebes

All the evidence in this group, except Stela BM374 attributed to Amennakht, comes from workers and their families at Deir el-Medina who can be shown to have lived probably during the reign of Seti I and certainly during the early to late middle period of the reign of Ramesses II. Stela BM374 has been attributed by the British Museum to the 20th Dynasty. The reigns of Seti I and Ramesses II and the dates of Dynasty 20 vary between the two chronologies being considered.

To allow for the differing chronologies the following table shows the eclipses with predicted magnitude exceeding 0.7 at Thebes during the period 1303 BC to 1213 BC corresponding to the reigns of Seti I and Ramesses II. During this period there were nine eclipses which would have exceeded a predicted magnitude of 0.7. Only one of these fell in the reign of Seti, whereas the remaining eight fell throughout the long reign of Ramesses II. Of these, two eclipses of predicted magnitudes exceeding 0.7 and 0.8 respectively, three eclipses exceeding a magnitude of 0.9 and a total eclipse with a predicted magnitude exceeding 1.0 fell in the short period during the period 1262 BC to 1247 BC corresponding to the first half of his reign. Four of these eclipses fell in a period of four years, two being in the same year in 1262 BC. However, of the latter two, one occurred at dawn while the other occurred as the sun was setting. The eclipse of 1261 BC also occurred in the late afternoon. These three eclipses may have been partially obscured at Deir el Medina by the surrounding hills but occurring at such a low altitude, if visible, would have been very likely to have been noticed. Allowing for the range of possible estimation errors in ΔT for the other eclipses in the table it is highly likely that most, if not all, of these nine eclipses could have been experienced at Deir el-Medina but for the purposes of this investigation the sensitivity analysis will focus only on the four eclipses with predicted magnitude exceeding 0.9 occurring from 1262 BC to 1247 BC.

Date (BC)	Max Magn at Thebes	Probability Magn > 1.0	Probability Magn > 0.99	Probability Magn > 0.9	Probability Magn > 0.8
1281/4/14	0.70				
1274/11/19	0.77				
1262/4/14	0.95			>0.999	>0.9999
1262/10/9	0.83				
1261/9/27	0.74				
1258/7/27	1.01	0.83	0.90	>0.999	>0.9999
1251/9/7	0.96			0.77	>0.99
1247/12/20	0.91			0.69	0.97
1223/3/5	0.73				

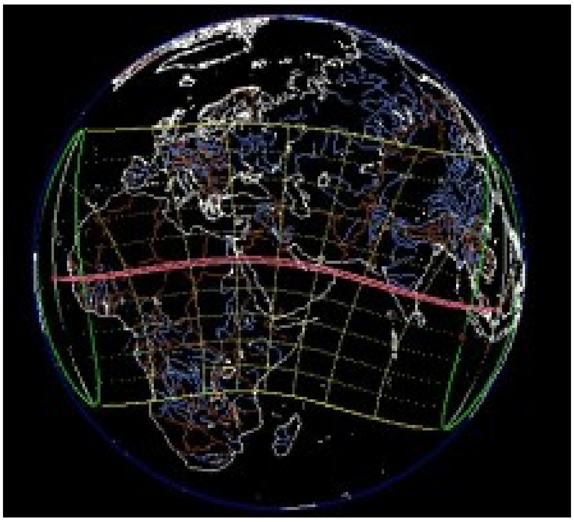

Figure 3: Image showing the path of the eclipse of 1258 BC.

The total eclipse of 1258 BC occurred at 10:37 am on Jul 27th corresponding to year 22nd or 43rd year of the 66 year reign of Ramesses II according to which chronology is used. Totality would have lasted about three minutes and the time from first to last contact would have exceeded 3 hours. The path of this eclipse is roughly parallel to the equator and errors in ΔT have very little effect on its magnitude. Analysis of the sensitivity of this result to errors in ΔT shows that the probability that this total eclipse would have been visible with a magnitude exceeding 0.9 is virtually 1.00. The track of this eclipse, shown below illustrates particularly well why it is so robust to errors in ΔT. For all practical purposes, this means that the eclipse would definitely have caused darkness possibly revealing the planets Venus and Jupiter and several stars including Sirius, Arcturus and Canopus. Occurring in July it is unlikely that there would have been any significant cloud cover so the chilling effect and significant darkening effect would have been unusual at this time of year.

With regard to Stela BM374, the data in the following table shows the nineteen eclipses with predicted magnitude exceeding 0.7 at Thebes during the dates suggested by the two chronologies for the 20th Dynasty, i.e. one or more in every decade except one, although none of these would have been as spectacular as the eclipse of 1258 BC during Ramesses II's reign. Four of these were of magnitude greater than 0.9. Three deep eclipses of predicted magnitudes 0.91, 0.86 and 0.93 occurred in the years 1132 BC, 1131 BC and 1129 BC respectively and a further deep eclipse of predicted magnitude 0.95 occurred a few years later in 1124 BC. Two of the early eclipses occurred while the sun was setting and may have been partially obscured at Deir el Medina by the surrounding hills, but of the rest it is highly likely that many, if not all, could have been experienced in some way at Deir el-Medina. However, for the purposes of this investigation we will focus the sensitivity analysis only on the four major eclipses with maximum predicted magnitudes exceeding 0.9.

Date (BC)	**Magn at Thebes**	**Probability Magn > 0.9**	**Probability Magn > 0.8**
1207/10/30	0.86		
1197/10/9	0.86		
1192/1/21	0.80		
1186/3/16	0.72		
1183/1/12	0.86		
1175/2/12	0.83		
1164/7/8	0.74		
1157/8/19	0.83		
1143/11/11	0.81		
1138/2/23	0.73		
1132/4/17	0.91	0.70	>0.999
1131/9/30	0.86		
1129/2/14	0.93	>0.99	>0.999
1124/5/18	0.95	0.74	0.98
1103/9/21	0.76		

1091/8/9	0.82		
1090/12/25	0.74		
1084/3/27	0.93	0.64	0.97
1078/5/20	0.80		

All of these four eclipses and their effects would probably have been experienced at Deir el-Medina. Occurring early in the year there would have been a chance of a little cloud cover (up to 6-7% of the sky) but even if this obscured the sun (when it may indeed have made the effect on the solar disk more obvious) and rendered the chilling effect less obvious it would still have become unusually dark. The annular eclipse of 1129 BC on 14th February at 9:45 am local time would have been deep enough for Mercury and Venus to have been possible to see during the 45 second period of maximum magnitude. The time from first to last contact would have been almost three hours.

In summary, there are deep eclipses which would have been likely to have been experienced during the period in which the articles in Group 1 were produced, irrespective of which chronology is accepted.

Group 2: Records from Elsewhere during the New Kingdom and Eclipses Relating to this Material

Three other texts and a tomb inscription from different times and places in the New Kingdom period contain evidence relevant to this study. Each one will be examined individually for possible association with known eclipses.

Grafitto Pawah: This graffito was also written in hieratic by the brother of Pawah, a "wab" priest and scribe of the divine offerings of Amun. It was found in the tomb chapel of Pere (TT139) at Thebes and can be dated more precisely than the other texts discussed in this paper because it specifically mentions a precise date. Gardiner (1928, pp. 10-11) translates the beginning of the graffito

> "[Y]ear 3, 3rd month of inundation, day 10. The king of Upper and Lower Egypt, Lord of the Two Lands, Ankhkheprure – beloved of [Neferkheperure??], the Son of Re Nefernefruaten – beloved of Wanr[e?].

Interpreting the determinative used in line 21 of the graffito as a slight variant of N46b, he translated this section as

> [T]hou causest me to see a darkness of thy giving. Illume for me, that I(?) may see thee (?). As thy soul endureth, and as thy beautiful, beloved face endureth, though shalt come from afar, granting that this servant, the scribe Wah, may see thee. Give to him "Enduring is Re, enduring is Re!"

Assmann (1994, p. 16) believes that this text may also be referring metaphorically to the absence of the king – there is a very similar text on the stela belonging to Huy (see below). Indeed these were very troubled and uncertain times. However, such concerns would surely have been exacerbated by witnessing the darkness during an eclipse and it would be entirely understandable if the experience were interpreted in spiritual terms.

The following table shows eclipses of predicted magnitude exceeding 0.7 at Akhetaten during the Amarna period, which, according to both chronologies being considered is 1353 BC to 1332 BC. It is interesting to note that there were four eclipses visible there with predicted magnitude exceeding 0.7, two of which exceed 0.8. The first of these in 1352 BC was before Akhenaten had decided to build the city and he would probably still have been at Thebes at that time – the predicted magnitude of this eclipse was in fact slightly larger than 0.80 and it is interesting to speculate what effect this might have had on him if he had experienced it, occurring in his first year as king according to the chronologies being considered.

Date (BC)	**Magn at Akhetaton**	**Probability Magn > 1.0**	**Probability Magn > 0.99**	**Probability Magn > 0.9**
1352/8/15	0.77			
1340/1/8	0.83			
1338/5/14	1.01	0.99	>0.99	>0.9999
1332/12/30	0.72			

The total eclipse on May 14th 1338 BC occurred at about 2:12 pm local time and would have been quite spectacular. Occurring in May there is a chance that there may have been a small amount of cloud cover (up to 6% of the sky) but even if this had obscured the sun (so possibly revealing the lunar obscuration of the solar disk) with such a deep eclipse there would have been a chilling effect and it would still have become unusually dark. Totality would have lasted nearly five minutes and the time from first to last contact would have been over 2½ hours. The sensitivity analysis is therefore restricted to this total eclipse. The path of this eclipse is so insensitive to errors in ΔT that it is 99% certain that it occurred with a magnitude of 1.00 or more and that the planets Mercury, Venus and Mars and the stars Sirius, Canopus and possibly Aldebaran would have been visible. It would have been dramatic and seen at Akhetaten by most people there. Even at Thebes it would have been experienced as a deep partial eclipse exceeding a magnitude of 0.94 and planets and some stars would have been visible there as well.

The particular date given in Graffito Pawah, is III Akhet 10 of the 3rd year of the reign of the Pharaoh. It refers to Ankhkheprure / Nefernefruaten, which is normally assumed to be Smenkhare (Allen 1991, pp. 74-85) although (Dodson 2006) has questioned whether this may actually have been Nefertiti, ruling jointly with Akhenaten, but residing at Thebes during the last few years of her life. There is much speculation about the precise dating of the reigns of the various Pharaohs, especially as to who actually reigned, for what period and whether there were co-regencies. The evidence for the overall length of the period is also speculative. One possibility worth considering is that Dodson is correct in his suggestion but

Akhenaten had a co-regency with his father of a few years and that Nefertiti under the name of Ankhkheprure / Nefernefruaten later reigned jointly with him up to the point when Smenkhkare became a coregent with Akhenaten.

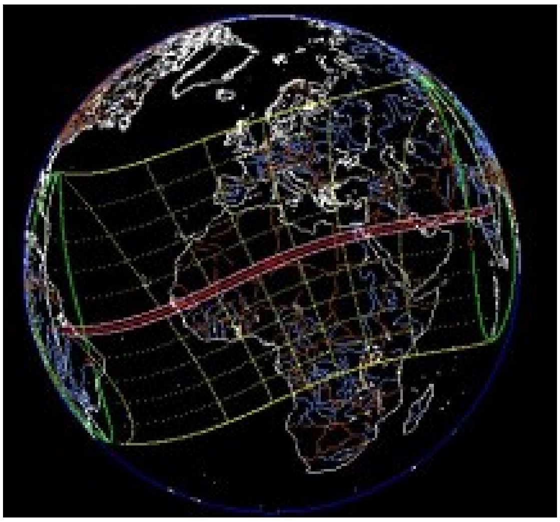

Figure 4: Image showing the path of the eclipse of 1338 BC

Under this hypothetical scenario, 1338 BC could correspond to the third year of Nefertiti's reign but there is a period of five months between the eclipse and the subsequent graffito written on 1st October, which needs to be explained. There would almost certainly have been communication difficulties and delays between Akhetaten and Thebes – the total eclipse at Akhetaten would surely have caused considerable consternation in Akhenaten's court and some form of "communications blackout" would not have been surprising. A suitable opportunity would also need to have arisen for Pawah's brother to have access to a site of appropriate significance in which to place the prayer even after he received the news. Given that the plea to see again is made twice and reference is also made to the enduring nature of Re, another plausible explanation is that Pawah's eyesight had been damaged when he tried to view the eclipse and this had been affecting his ability to carry on his job. When his eyesight had not returned to normal after an extended period he may be facing redundancy.

It is easy to speculate about the possible chronology and the reasons for the delay, but the essential point is that a significant eclipse event occurred during the Amarna period and thus the hypothesis that it is associated with the Graffito cannot be categorically rejected until the dating for this period can be more accurately established.

Stela Museum Cairo JE 37463 and TT40: This stela belonged to Huy, Viceroy of Nubia under Tutankhamun and was found in the Karnak cachette. Its poor quality suggests that it may have been created elsewhere, perhaps while Huy was in Nubia. The text on this stela does not contain the hieroglyph N46b which may have simply been omitted by the sculptor for reasons of space. Rowe (1940, p. 48) translated the text as

> Come back in peace [oh] lord, Nebkheperure, [for] I see the day-time

darkness thou has made. Illume me that I may see thee.

Because of the absence of the hieroglyph N46b from the stela the argument that these artefacts should be considered part of the group is not quite as strong (except that it was Rowe (1940, p.49), who likened the description to an eclipse), but it is highly likely that Huy would also have experienced the earlier eclipse of 1338 BC. This Stela can be fairly accurately dated to the reign of Tutankhamun. Huy might have been based at Karnak or in Nubia, possibly at the provincial capital, Aniba and so could have been travelling between the two around the time of an eclipse.

On the ceiling in Huy's tomb (TT40), there is another reference to darkness, using an older variant of the determinative hieroglyph N46b, which de Garis Davies and Gardiner (1926, p. 33) translated as

[M]ay thy sight be clear in the way of darkness.

Traditionally, the darkness has been assumed to refer to the afterlife itself, but in the context in which it is used, amongst prayers for health, food etc. in the afterlife it might also be being used in a precautionary way.

In his role as Viceroy of Nubia for Tutankhamun Huy would probably have been based at the provincial capital, Aniba, but have periodically visited Thebes. The data in the following table for Thebes and Aniba shows the main eclipses during the reign of Tutankhamun, which is from 1332 BC to 1322 BC. It can be seen that during this period there were two eclipses exceeding a predicted magnitude of 0.7 at either place. The predicted magnitude of the second of these exceeded 0.9 at both places and the sensitivity analysis is therefore restricted to this particular eclipse.

Date (BC)	**Magn at Thebes**	**Probability Magn > 0.9**	**Probability Magn > 0.8**	**Magn at Aniba**	**Probability Magn > 0.9**	**Probability Magn > 0.8**
1332/12/30	0.75			0.83		
1328/10/17	0.95	0.64	0.98	0.96	0.68	0.96

The very deep partial eclipse on October 17th 1328 occurred at about 2:08 pm local time, and reached a predicted magnitude of about 0.96 at Aniba. Even at Thebes the predicted magnitude would probably have been about 0.95 about five minutes earlier than at Aniba, so even if Huy was travelling between the two he would also have had an opportunity to experience it. Occuring in October there is a chance that there may have been a small amount of cloud cover (up to 4% of the sky) but even if this obscured the sun (possibly revealing the effect on the solar disk) there would have undoubtedly have been a chilling effect and it would still have become very dark, both very unusual in this area of Upper Egypt and Nubia. This eclipse would have lasted nearly 3 hours from first to last contact and since the duration of maximum magnitude was about 3½ minutes it would scarcely have gone unnoticed, with the possibility that Venus, Jupiter, Mercury and Mars may have been visible.

Ostracon Cairo 12202: This originated from Sheikh 'Abd el-Qurna, at Thebes. It is written in hieratic and the determinative hieroglyph used on the reverse was interpreted by Posener as the equivalent of N46b when he translated this text as "*you made me see the day like the night*".

He suggested for this, and a number of other similar ostraca which he examined at the same time, an approximate dating of around the middle of the 18th Dynasty (Posener 1975, p. 195 – 210). This conclusion was based on the use of some rather unusual syntactic forms, the one appearing on this ostracon had been in current use as far back as the Middle Kingdom but had disappeared from use during the reign of Tuthmosis III. A provisional dating for this ostracon to the period from the beginning of the New Kingdom up until the end of the reign of Tuthmosis III would therefore not be unreasonable. Shaw (2000) considers 1550 BC as the date of the start of the 18th Dynasty while the chronologies being considered in this paper both date the end of this period as 1427 BC.

The data in the following table shows eclipses with predicted magnitude exceeding 0.7 at Thebes during this period. The table shows that there were eleven such eclipses, nine of which had predicted magnitudes over 0.8 and three with predicted magnitudes of 0.9 or more. One of the latter, occurring early in the reign, was of predicted magnitude 1.02 and would have been quite spectacular. The eclipses of 1536 BC and 1462 BC occurred at dawn whilst the deep eclipse of 1533 BC occurred while the sun was setting and may have been partially obscured at Deir el Medina by the surrounding hills. During this long period, according to Gautschy's canon, there were many other eclipses of predicted magnitude under 0.7 which have been excluded from the table, some of which would almost certainly have been experienced in some way or another. The eclipse of 1533 BC would also have been very noticeable if the local hills did not obscure it as it occurred low down in the Western sky, but at values of ΔT on either side of the central estimate the sun had sunk below the horizon during its maximum phase, hence the low probability. The focus of the sensitivity analysis will therefore be restricted to the two eclipses of 1523 BC (Amenhotep I) and 1478 BC (Tuthmosis III). The first of these occurred in April when there might have been a small amount of cloud cover (up to 6% of the sky), whereas the second eclipse occurred in June when the chance of any cloud cover would have been much less. In both cases, even if the sun was obscured, possibly revealing the effect on the solar disk, the chilling effect and the level of darkness would still have been unusual.

Date (BC)	Magn at Thebes	Probability Magn > 1.0	Probability Magn > 0.9	Probability Magn > 0.8
1547/ 2/15	0.72			
1536/ 7/11	0.86			
1533/ 5/10	0.90		0.08	0.25
1523/ 4/20	0.98	0.20	0.75	0.98
1508/ 7/ 1	0.77			
1478/6/1	1.02	0.24	0.82	0.98
1462/12/28	0.86			

1453/1/28	0.87
1436/8/13	0.80
1432/6/ 2	0.83
1429/3/31	0.83

During the period when this ostracon was probably produced there would therefore have been numerous occasions when eclipses might have been experienced (an average of about one every ten years). Two of these, both very deep eclipses, would most probably have produced a level of darkness when Mercury, Jupiter, Venus, Aldebaran (in 1523 BC) and Mercury and Venus (in 1478 BC) might have been seen.

The Eclipse of Mursilis

Huber has also researched this phenomenon and dates he associates with it have been included in the chronologies above; he notes in his earlier research (Huber 2001) that a prayer by Mursilis year discussing intrigues by his stepmother, the widow of Suppiliuliuma, mentions an "omen of the sun". This corresponds to his 9th or 10th year just as he was about to launch a campaign. It has been generally accepted that this refers to a solar eclipse. This event is important from the point of view of Egyptian chronology since an Hittite record exists of a letter being sent to Suppiliuliuma while he was besieging Carchemish by the widow of an Egyptian Pharaoh. It is generally believed that this Pharaoh was Tutankhamun and because Suppiliuliuma died soon after and was succeeded by Mursilis II this event is important in helping to establish a specific date for Tutankhamun's death.

The eclipses of predicted magnitude which might have been experienced by Mursillis during the period 1330BC – 1300BC using Ginzel's criteria are shown in the table below. Allowing for the range of error in the prediction process, only one, that of June 24th 1312 BC, would have reached a sufficient magnitude for it to have reached the criterion used in this paper, i.e. a magnitude exceeding 0.9. The sensitivity analysis calculation shows that occurrence of this eclipse is not sensitive to errors in ΔT so this is clearly a strong candidate.

Date	Predicted Magn	Probability Magn > 1.0	Probability Magn > 0.9	Probability Magn > 0.8	Time of Max Eclipse
17th Oct 1328 BC	0.75				13:55
26th Aug 1315 BC	0.70				16:38
24th June 1312 BC	0.99	0.98	>0.99	>0.99	13:28
13th Apr 1308 BC	0.65				05:25

17th Nov 1301 BC	0.75		09:22

Huber includes a specific date of 1308 BC for Mursilli’s 10th year in his work on chronologies (Huber 2011). In selecting this date he presumably draws upon his earlier research (Huber 2001, p. 644) where he lists plausible candidates which include all of those listed in the above table except that of 1301 BC. From his analysis of the context in which the intrigues related in the prayer occur he dismisses the very deep eclipse of 1312 BC on the grounds that it occurs too late in the year. The eclipse of April 1308 BC, although only partial, fits precisely with his argument – it would have occurred after sunrise, when the sun was low in the sky and if there was dust or light cloud in the air the obscuration of the solar disk would have been noticeable.

Conclusions

This paper began with two proposals:

- records of eclipses exist, but have been overlooked or misinterpreted; and
- why eclipses are not more prominently featured in texts and on other material may be explained;

During the reign or Ramesses II when most of the Group 1 material was produced, irrespective of which chronology is used to date this period, there were eclipses of magnitude such that they could have been experienced and in some cases planets and stars might have been seen. In the case of Stela BM374, thought to have been produced in Dynasty 20, there are also eclipses of sufficient magnitude during that period such that they could have been experienced and in some cases planets and stars might also have been seen. For these artefacts there is therefore clear evidence that the hypothesis put forward in this paper, namely that these texts and spells were produced in response to solar eclipses, even if couched in religious terms, cannot be discounted.

One might argue, however, that the dating of Stela BM374 should be challenged and that instead it belonged to the owner of TT218, Amennakht, the son of Nebenmaat, who lived at about the same time as Neferabu and Iy-neferti who both had stelae and tombs, discussed in this paper, associated with them.

The dating of artefacts in Group 2 does not depend on which of the two chronologies set out earlier in this paper is used, but it does depend on the detailed chronology of the Amarna period, which is itself highly contentious.

Graffito Pawah was produced some time in the reign of Akhenaten probably during the reign of Smenkhare or Nefertiti. In this paper it is suggested that if Akhenaten shared a co-regency with his father, and that both Smenkhkare and Nefertiti were at some time co-regents with Akhenaten, then it is possible to construct a plausible chronology which would allow Nefertiti under the name of Ankhkheprure /

Nefernefruaten to celebrate her third year as co-regent with Akhenaten in 1328 BC, so matching the deep eclipse of that year. However, there is a period of five months between the eclipse and the subsequent graffito which needs to be explained and some possible reasons for this delay have been suggested but unless further evidence is discovered about this turbulent period one can only speculate.

In the case of Stela Museum Cairo JE 37463 and TT40 the solar eclipse of 1328 BC, although not as deep as some of the others discussed earlier, would have been likely to have caused noticeable chilling and was probably of sufficient depth for stars potentially to have been seen. Huy could have experienced this whether he was at Aniba or Thebes; in addition he would probably have had the opportunity to experience the earlier more spectacular total eclipse of 1338 BC as well. If Huy had commissioned the Stela while in Aniba, this might explain its poor quality and the fact that the eclipse was such that the light level would not have dropped as far as for a very deep eclipse is a plausible reason for the omission of the specific hieroglyph depicting “twilight”. Since Huy would have then experienced two such disturbing events it would not be surprising for him to choose to include reference to the phenomenon in his tomb as a precautionary measure.

The dating of Ostracon Cairo 12202 is of course much less accurate than for the other cases examined. Nevertheless during the reign of Tuthmosis III, which was the most likely period of its production, whichever of the chronologies one is using, there were two deep eclipses, possibly total, during which stars might have been visible at Thebes, as well as a number of other eclipses of lesser magnitude which could also have been experienced.

Turning now to the Eclipse of Mursillis, that of 1308 BC, although only partial, is the strongest candidate matching the chronology of the period proposed by Huber (2011). Although it is not of direct relevance to the discussion in this paper of records relating to darkness or the visibility of stars and planets, this reference demonstrates very well the point that eclipses of magnitude well below the strict criterion of 0.9 set in this paper could have been experienced.

The scientific evidence for deep solar eclipses, visible in New Kingdom Egypt, is convincing. Lack of reference to them would, indeed, be a remarkable omission. The evidence of the coincidence of “loss of light” and of their distinctive hieroglyphic representation, with known eclipses, is also compelling. In fact the large number of deep eclipses which have been noted in this paper has been rather surprising, suggesting that the New Kingdom period as a whole may have enjoyed an above average frequency. Only certain dates related to the artefacts being considered have been examined in this paper so it would be particularly interesting to see if a comprehensive statistical study would confirm this pattern occurred over the New Kingdom period has a whole.

This leaves the question of why these texts have been consistently misinterpreted, and what researchers are to make of the alternative explanations put forward in the scholarly literature. In this context it is relevant that, in addition to the sources we have quoted, there is a substantial body of German scholarship centred on the metaphorical interpretation of “loss of sight.” The different interpretations which are found in the literature provide three alternatives. Each text records either:

- actual blindness, permanent or temporary;
- metaphorical blindness of the spirit, or
- actual observation of astronomical phenomena.

Of these, metaphorical blindness and actual observation seem to be entirely consistent – the event and the response to it being part of the same occurrence. It is the religious and psychological impact of eclipses which makes their supposed absence from the record so remarkable. The conclusion is simply that the majority of the texts considered probably record real astronomical events interpreted religiously.

Something similar is true for the second question proposed. Either the lack of prominence within the surviving Egyptian corpus is due to deliberate cloaking of the reference, in a society where startling and fearsome events sit ill in a universe presided over by *Maat* and in which writing something down can make it happen, or the conflation of the report of an event with the response of the observer creates difficulties for scholarly interpretation.

The alternatives are actually consistent and the best explanation is achieved by taking them together as evidence that most if not all the texts and spells considered in this paper were produced in response to solar eclipses, even if couched in religious terms.

The proposals put forward here can be tested by further discoveries. If generally accepted, this research can also be helpful in dating material containing the appropriate references. Its acceptance would make Egyptian material available to scientists attempting to improve our knowledge of eclipses anywhere before 1000 BC.

Finally, the calculation of probabilities for the magnitude of historical eclipses provides a much more robust way of testing hypotheses relating these to known events than merely using the central estimate for ΔT given its wide uncertainty range. However, using software designed solely to predict eclipses makes the task of calculating these probabilities both time consuming and tedious, with scope for accidental human error given the complexities of eclipse paths. Given the increasing interest in the field of archaeoastronomy there is therefore clearly scope for the development of tools to facilitate this task either integrated into the existing eclipse prediction software or as a specialist stand-alone suite.

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