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ON THE ORIENTATION OF OLD KINGDOM EGYPTIAN PYRAMIDS

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1. *Introduction*

Although a matter of general interest, the question of how the ancient Egyptian pyramids were oriented with high precision in the cardinal directions has been dormant for some time in scientific discussions. However, the recent publication by the British Egyptologist Kate Spence of a new and revolutionary theory has re-opened the debate.[1]

Not all the pyramids of Egypt are accurately oriented; in fact, for only a handful of the sixty known pyramids do we have accurate measurements of their orientation.[2] The pyramids of the Fourth Dynasty pharaohs at Giza, near Cairo, are the finest exceptions in both senses since they are accurately oriented to better than $\frac{1}{4}^\circ$ and we know their orientation to within an error of less than 0.2 arc minutes.[3] However, it is worth mentioning than the resolving power of the average human eye is about 3′ and only a trained observer with the most accurate pre-telescopic instruments can reach a precision of one arc minute.[4] Consequently, in the following discussion we shall consider an average error in the alignments of at least ±2′, independently of the quality of the measurements. All the relevant information is summarized in Table 1.

For over a century, ever since the Giza monuments were accurately measured for the first time, by Petrie,[5] pyramid orientation has been the subject of frequent discussion. Various methods, employing astronomical observations, have been proposed in order to determine accurately the meridian line. Most of them have taken either the sun or a particular star to be the observing target. The following are among the most plausible:

(i) Observe the "pole" star of the epoch of the construction of the pyramid. This was the method suggested by Piazzi Smyth in the nineteenth century when the age of the pyramids was not known, and later followed by Proctor and Brugsch.[6] Thuban (α Dra) reached its nearest position to the Pole in 2787 B.C. when it was a mere 2′ away. However, most scholars have proposed much later dates (by at least two centuries) for the Great Pyramid, the only known monument oriented with such precision.

(ii) Observe the meridian transit of a circumpolar star. First proposed by Romieu at the beginning of the twentieth century and later followed by Pogo in the 1930s, this theory does not permit the required accuracy because it is extremely difficult to determine when a certain star is crossing the meridian even if we know, as Pogo suggested, which star we should observe.

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TABLE 1. Pyramid alignment to the culmination of the pair Phecda-Megrez.

King	Regnal Years	High[a] Chronology	Low[b] Chronology	Pyramid	Error	Astronomical Alignment Dates	Dates New Proposal[i]
Huni	24	2637–2613	2600–2575	*Meidum*[c]	−18′±2′	2611 to 2605[g]	Sometime between 2649 and 2601
Snofru	24 to 48 30[d]	2613–2589	2575–2551	*Meidum*[c]	−18′±2′	2611 to 2605[g]	2601–2577
				Shining South	−12′±2′	2595 to 2589[g]	*If 30: 2607–2577*
				Shining (Red)	−9′±2′	2585 to 2579[g]	*If 48: 2625–2577*
Khufu (Cheops)	23	2589–2566	2551–2528	Horizon's	−3′±2′	2571 to 2565[g]	2577–2554
Djedefre	8	2566–2558	2528–2520	Sehedu Star	?[e]		2554–2547
Khafre (Chephren)	25	2558–2532	2520–2494	Great	−6′±2′	2547 to 2541[h]	2547–2522
Menkaure (Micerinus)	18 (28[f])	2532–2514 (2532–2504)[f]	2494–2477 (2494–2467)[f]	Divine	+14′±2′	2527 to 2521[g]	2522–2504
Sahure	14	2501–2487 (2491–2477)[f]	2458–2446 (2448–2236)[f]	Rising Spirit's	−23′±10′	2513 to 2487[h]	2491–2477
Neferirkare	10	2487–2477 (2477–2467)[f]	2446–2436 (2436–2226)[f]	Spirit's	+30′±10′	2495 to 2469[g]	2477–2467

(a) According to Malek, *op. cit.* (ref. 30).
(b) According to Baines and Malek, *op. cit.* (ref. 30).
(c) The same pyramid, of unknown name. According to some scholars, it was started by Huni and continued by Snofru.
(d) According to Krauss, *op. cit.* (ref. 35).
(e) No accurate data. This would be a good test of the Error *v.* Time theory.
(f) Dates according to a reign of Menkaure of 28 years.
(g) Pyramid alignment with Phecda and Megrez at Upper Culmination.
(h) Pyramid alignment with Phecda and Megrez at Lower Culmination.
(i) With an estimated error of ±3 years (±13 years for the reigns of Sahure and Nefeirkare).

(iii) Observe the shortest shadow produced by a gnomon. Proposed by Zinner in 1931 and revived by Chatley in 1948, this method could hardly yield a precision of 3′ to 6′ such as we have in the largest pyramids.[7]

(iv) Observe the rising and setting position of the sun at a certain date (especially the summer solstice) and bisect the angle formed by both positions to determine the meridian line. This idea has recently been defended by Gallo.[8] However, it has been demonstrated that, for a latitude of 30°, it is extremely difficult to determine the rising position of the sun with a precision better than half a degree (nearly a solar diameter).[9] Consequently, this method could not provide the required accuracy.

(v) Observe the rising position of a star at due east or its setting at due west. In the 1980s, Haack[10] discovered the very important fact that the errors in the orientation of the pyramids of the Fourth Dynasty and of some of the Third and Fifth (see Table 1) seemed to follow a temporal correlation. This trend was such that the earlier pyramids had a greater error, the error then diminishing to reach a precision

culminating with the pyramid of Khufu; it then increased in the ensuing monuments at a rate of about 20′ per year. There might be just one objective reason for such a behaviour and that is precession. Despite the importance of this finding, its impact was diminished because Haack decided that this trend could be explained by the gradual displacement in azimuth of the rising position of a particular star over time. He selected α Arietis and proposed a date near 2640 B.C. for the beginning of the Fourth Dynasty. However, we know that it is extremely difficult to observe a bright star rising on the horizon with a precision better than about $\frac{1}{2}°$, the situation becoming even worse when the star is fainter. So, once more, the method does not permit the required accuracy.

(vi) Because of the limitations of the methods described above, the one that has gained most support in Egyptological literature is that proposed by Edwards, the pyramid specialist, in 1947.[11] According to this method, one should establish an artificial horizon to avoid the problems of extinction and refraction near the horizon, select a circumpolar star, observe and mark in the artificial horizon its rising and setting positions, and then bisect the angle between those positions, thereby finding the meridian line with high precision. The supposed accuracy of this method has won backing for the theory down to the present time, although it took no account of the error *v.* time trend discovered by Haack.

This was the situation at the end of the twentieth century when Spence rediscovered this relation between error and time and proposed a new and revolutionary theory that included the best of the earlier proposals.[12] She proposed selecting a pair of stars, on opposite sides of the pole, and determining the moment at which one is at upper culmination and the other at lower culmination simultaneously. At that exact moment, a line passing through both stars would coincide with the local meridian and its projection on the horizon would determine due north with high accuracy. Of course, this would be the case only around the epoch when both stars had exactly a 12-hour difference in right ascension, and there would be a deviation in the alignment both before and after that time, exactly as the existing orientation data would require. After many trials, Spence selected the pair formed by Mizar (ζ UMa) and Kochab (β UMi). Granted this, the orientations of the pyramids implied that most of them would have been aligned with Mizar at lower culmination, but the pyramids of Khafre and Sahure would have been aligned with Kochab at lower culmination. The highest precision would have been reached in 2467 B.C., giving for the alignment of the pyramid of Khufu either a value of 2478 B.C. (preferred by Spence on grounds of internal coherence) or 2456 B.C., for Mizar at lower or upper culmination, respectively.

Consequently, one important and potentially revolutionary inference from Spence's proposal is that the Great Pyramid would be nearly 80 years younger than the latest date hitherto assigned to it (see Table 1). But why these stars? Spence considered the only pair of brilliant stars around the Pole that gave her dates near those expected by the Egyptologists (with a margin of ±200 years). Very different dates might have been reached if she had chosen another pair. For example, if

the stars selected had been the handles of the two celestial adzes, mentioned in the Pyramid Texts (see below), Alkaid (η UMa) and Polaris (α UMi), the date of maximum accuracy would have been about 2150 B.C. and the dates of the Fourth Dynasty would have been 'reduced' by four centuries.[13] On the other hand, if the stars selected had been Alkaid and Kochab, dates around 2950 B.C. would have been obtained, in open contradiction, however, with radiocarbon dates that locate the First Dynasty around this time.[14]

2. *What Did The Egyptians Do?*

This point having now been reached, it might be interesting to explore what we actually know from the original sources represented by the texts and the works of art of the ancient Egyptians. Unfortunately, the pyramids of the Fourth Dynasty and all but one of those of the Fifth Dynasty are mute. The hieroglyphic texts in the tombs of the nobles and workmen offer little information about the pyramids themselves, about how they were built, or about the corpus of beliefs surrounding their construction. However, in the burial chamber of the last king of the Fifth Dynasty, Wenis (*c*. 2350 B.C.), a very important corpus of mythological and cosmological texts was inscribed for the first time. It is in these "Pyramid Texts"[15] that we have the first mention of certain stars and "constellations" that were important for the Egyptians of the Old Kingdom. Let us study some of them:

> Sah is encircled by the Duat
> Pure and living in the horizon
> Sepedet is encircled by the Duat
> Pure and living in the horizon.
> I (the king) am encircled by the Duat
> Pure and living in the horizon.
>
> (PT216, 151)

Here we learned about *Sah* (*sꜣḥ*) and *Sepedet* [*spdt*], two extremely important asterisms in ancient Egypt, which correspond to the southern part of the constellations of Orion and the northern sector of Canis Major (the star *Sepedet* would be Sirius), respectively.[16] The king is encircled by the Duat — the Egyptian Netherworld, although perhaps originally the dawn glare of the sun — because he has been converted into a star that travels in the sky with *Sah* and *Sepedet*:

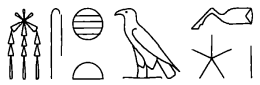
> O King, you are this great star, the companion of Sah, who traverses the sky with Sah, who navigates the Duat with Osiris; you ascend from the east of the sky, being renewed at your due season and rejuvenated at your due time.
>
> (PT446, 882)

> Your sister is Sepedet, your offspring is the Morning Star, and you shall sit between them on the great throne which is in the presence of the Two Enneads.
>
> (PT609, 1707)

Both *Sah* and *Sepedet* are 'southern constellations'. However, there are also utterances where a very important 'northern' constellation is mentioned:

> The sky is clear, Sepedet lives, because I am a living one, the son of Sepedet, and the Two Enneads have cleansed themselves for me in Meshketiu, the imperishable.
>
> (PT302, 458)

This *Meskhetiu* [*msḫtyw*] is often represented in Egyptian art as a Bull's Thigh or Foreleg, which is often used, together with a star, as the determinative on its name:



It was also normally associated with the north while the *Sah* constellation was associated with the south.[17] Of course we are talking about the asterism of the Plough or the Big Dipper, in the constellation of the Big Bear. *Meskhetiu* is qualified as "imperishable". The Imperishable Stars were a group of stars in the north of the sky, inhabitants of the Field of Offerings, and one of the objectives of the dead king was to be among them:

> You shall set me to be a magistrate among the spirits (lit. *3ḫw*), the Imperishable stars in the north of the sky, [etc.]
>
> (PT519, 1220)

> I have gone to the great island in the midst of the Field of Offerings on which the swallow-gods alight; the swallows are the Imperishable Stars.
>
> (PT519, 1216)

> I will cross to that side on which are the Imperishable Stars, that I may be among them.
>
> (PT520, 1222)

The Imperishable Stars are normally linked to the group of the circumpolar stars, although, in recent times, the opinion that they should be identified with those stars visible every night, despite their either rising or setting during the night, is winning ground.[18] Among the Imperishable Stars, there might be other 'constellations' which are mentioned side by side, namely the Mooring Post:

> The doors of the sky are opened for you, the doors of the firmament are thrown open for you, even those which keep out the plebs. The Mooring Post [*mnit*] cries to you, the sun-folk call to you, the Imperishable Stars wait on you.
>
> (PT463, 876)

and the Two Adzes:

> May you stand at the head of the Imperishable Stars, may you sit on your iron throne from which the dead are far removed, your adzes having hacked up

> the mansion of your sky of water.
>
> (PT666, 1926)

> ... and the king spends day and night propitiating the Two Adzes in Unu.
>
> (PT259, 312)

We do not know exactly what should be interpreted as the Mooring Post but it is sometimes identified with the Pole Star of that epoch, Thuban.[19] However, later representations of the same constellation suggest that it should be located somewhere to the southwest of the Plough or even in the Plough itself.[20] As to the Two Adzes, it is accepted that they refer to the distinct asterisms, of similar form, of the Big and Small Dippers. These adzes would be identical to that used by the priests in the Opening of the Mouth ceremonies.[21] Bearing in mind all that has been said, it becomes obvious that the Plough would have been a very important constellation at the age of the pyramids, perhaps, together with *Sah* and the star Sirius, the most important of all.

To conclude this discussion of the Pyramid Texts, we shall mention an important utterance in which no star is mentioned but where we learn that one of the objectives of the king is to reside at the Pole of the Heavens, if this is the correct interpretation of the text and the hieroglyphic for 'pole':

> ... and you will give satiety to me at the Pole, at that which is the foremost of its flagstaffs.
>
> (PT519, 1218)

The Pyramid Texts are funereal and cosmological in character and do not include, at least in a direct way, any information about how the pharaoh actually reached his celestial destinies. It has usually been argued that the pyramids themselves were a sort of stair for that purpose. Consequently, the pyramids should reflect in their design (including the orientation) some clues to support this hypothesis.

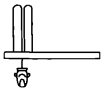
In fact, we have no information from the Old Kingdom about how the pyramids were oriented. However, we do have some important texts of the Helleno-Roman period about how the foundations of a temple were established. In particular, the temple axis was laid out by stretching a rope between two stakes, poles or flagstaffs in a ceremony known as the "Stretching of the Cord", which is frequently depicted on temple walls:

where the pharaoh and the goddess Seshat, with her hieroglyphic sign  over her head, are represented holding up the two poles. But let us listen to the king himself:

> I have grasped the stake along with the handle of the mallet. I take the measuring cord in the company of Seshat. I observe the progressive movement

> of the stars. My eye is now fixed upon Meskhet(iu). The god of time-keeping stands by me, in front of his *merkhet*. Then, I have established the four corners of the temple.

This text is written on the walls of the temple of Horus in Edfu, whose foundations were laid in 237 B.C.[22] Two important facts can be gained from this paragraph. On the one hand, we learn of the additional use of an instrument called *merkhet* [*mrḫt*] and represented in these texts by:



A version of this instrument is known to have been used by the Hour Priests (the *Imy Unut*, normally translated as 'astronomer') to observe the transit of stars across the meridian during the New Kingdom (*c.* 1500 B.C.) and after. On the other hand, the astronomical target observed in order to lay out the temple axis is of course the constellation of the Bull's Foreleg, the Plough. In this sense, some additional information can be obtained from another text associated with the Stretching of the Cord; on this occasion at the temple of Dendera, a further 150km to the north of Edfu:

> The king stretches the rope in joy. With his glance toward the *3ḫ* of the Thigh, he establishes the temple of the Lady of Dendera, as took place there before.

Here the text mentions the *3ḫ* of the Plough. The term *3ḫ*, plural *akhu* [*3ḫw*], is mentioned in the Pyramid Text and has been translated as "spirit", "brilliant" or "blessed".[23] Hence, we might translate it as "the brilliant (star) of the Plough". However, bearing in mind that the seven stars of the Plough are almost of the same brightness (only Megrez, δ UMa, is slightly fainter), we could consider, as Krupp has already suggested,[24] that *3ḫ* "most likely refers to a particular position and orientation of the Plough in its circular course around the Pole". This idea will be relevant in what follows.

As demonstrated in Figure 1, the Stretching of the Cord inscriptions surely reflect a very ancient tradition that can be followed across the New Kingdom to the beginning of the Old Kingdom, the moment when we find a relief in the sun temple of Abu Gurab, between Giza and Saqqara, where the Pharaoh Niuserre, sixth king of the Fifth Dynasty (*c.* 2425 B.C.), is seen together with Seshat almost in the standardized image of later epochs, or when later traditions (the so called Book of the Foundations) attributed the "invention" of the ceremony to the sage Imhotep, architect, and perhaps "astronomer", of the Third Dynasty King Djeser.[25]

However, the earliest notice of a Stretching of the Cord ceremony is to be found in the Palermo Stone (Figure 2), and it refers to a period earlier than that of Djeser and probably to the reign of an unknown king of the First Dynasty (*c.* 3000 B.C.). There, the sign of Seshat is written in a way more similar to that of the Old and

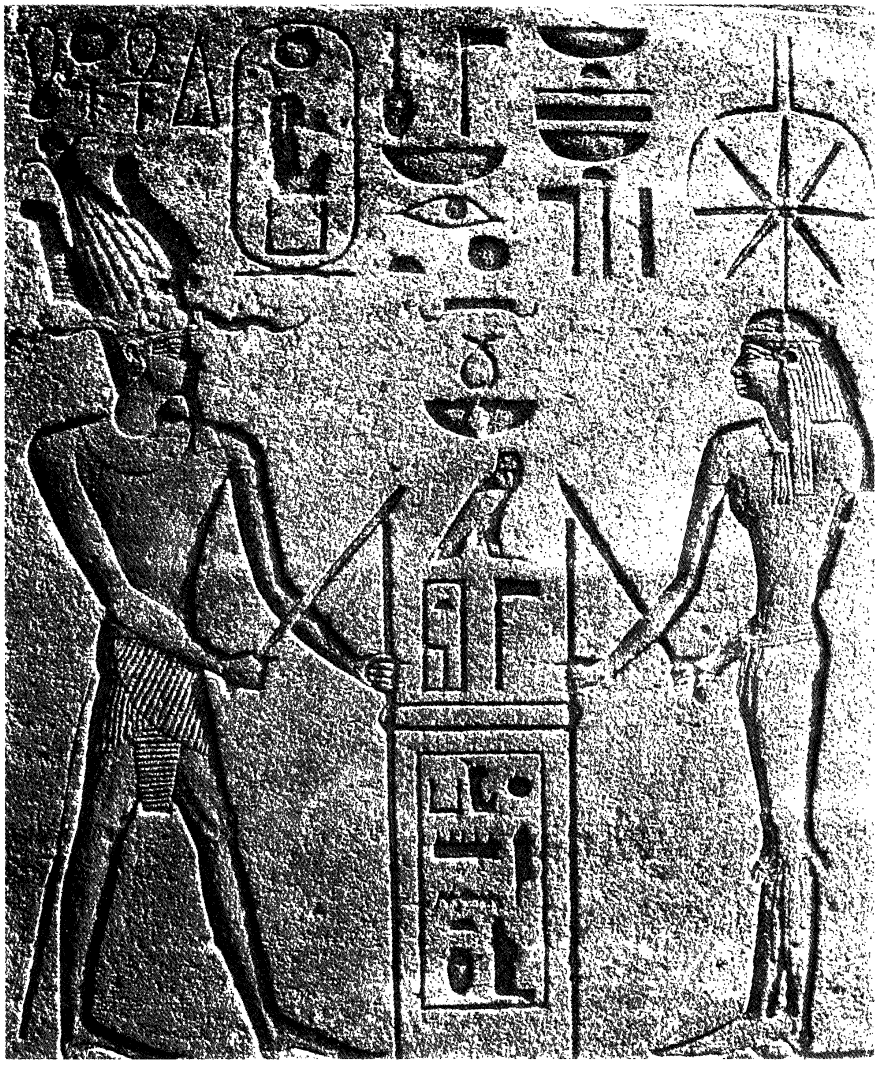


FIG. 1. The Stretching of the Cord ceremony represented on one of the talatat of the reconstructed chapel of Queen Hatshepsut at Karnak. The Queen, to the left, stretches a rope between two poles with the help of the Goddess Seshat, to lay the axis of a temple. Note the hieroglyphic sign of Seshat over her head.

early New Kingdom depictions (e.g. at the pyramid temple of Sahure or in Figure 1) than to those of the Helleno-Roman period:

i.e.  instead of 

Consequently, we might take the Stretching of the Cord ceremony to be older than the pyramids, and imagine that it was very probably used to establish their main axis prior to starting the actual building of the monument. Again, this hypothesis will be relevant in the following discussion.

Unfortunately, neither the Palermo Stone nor the reliefs of the sun temple of

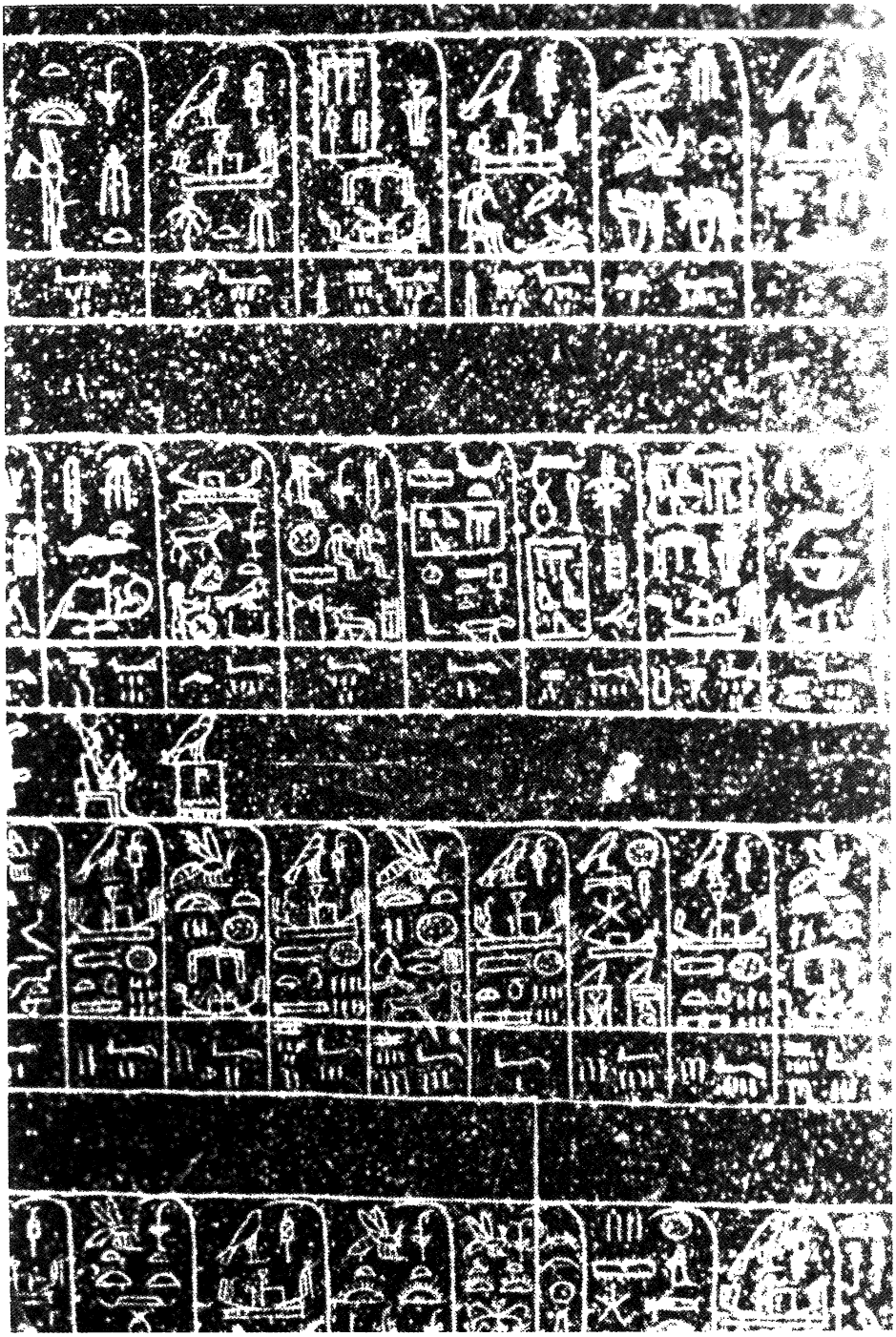


FIG. 2. Close-up of the annals of the first Egyptian dynasties assembled in the Fifth Dynasty, as presented in the basalt slab known as the Palermo Stone. In the third year entry of the second register, a Stretching of the Cord ceremony, celebrated during the reign of one of the later kings of the First Dynasty (*c.* 3000 B.C.), is mentioned. Note the 'isolated' hieroglyphic sign of Seshat. (Photograph by the author, courtesy of the Archaeological Museum of the city of Palermo.)

Niuserre mention the name of the star or asterism viewed in the ceremony, so we will have to make the best guess we can on the information provided by the Pyramid Texts and the later tradition, which, as we have seen, mentions only the constellation of the Thigh. Apart from the rope and poles, the same can be said for the instruments used in the Old Kingdom, especially in the case of the *merkhet*.

3. *Discussion*

Spence has suggested that the device needed to make her hypothesis operational would be similar to a sort of gigantic *merkhet*, with a plumb-bob on a long string. This is because a standard *merkhet* is an small instrument, appropriate for small angular distances, but incapable (as we ourselves have tested) of laying out with high accuracy a line of sight for an angular distance of some 40°, the angular height from either Mizar and Kochab at upper culmination to due north at the horizon. In fact, despite the ingenuity of her theory, this seems a weak point, for we have no proof that such a large device was ever developed or used by the ancient Egyptians, although the existence of plumb-lines is attested for that period.

The second weakness has already been mentioned: why Mizar and Kochab and not some other pair of stars? It is worth remarking that only Mizar belongs to *Meskhetiu*. However, Kochab belongs to the Small Dipper and consequently, to the smaller of the Two Adzes, Mizar belonging to the larger one. Thus we have a possible mythological justification for the importance of these two stars as members of a pair of relevant celestial 'instruments'.

Another relevant consideration relates to the controversy surrounding the so-called 'airshafts' of the pyramid of Khufu. As stated in Table 2, two shafts leave the King's Chamber, heading for the north and south faces of the pyramid at a certain inclination. Another two shafts leave the Queen's Chamber in a similar way, at a different inclination, but these do not reach the surface of the pyramid.

Old measurements by Petrie were used by Badawy and Trimble in the 1960s to interpret the airshafts of the King's chamber as stellar channels for the soul of the dead Pharaoh, who could reach the Imperishable Stars through the northern and *Sah* (in fact, the Belt of Orion) through the southern.[26] Recently, more accurate measurements of the inclination achieved by use of a small robot (called *Upuaut*, The Opener of Ways) were obtained by Gatenbrick,[27] of the shafts not only of the King's Chamber but also of the Queen's, and these are shown in Table 2.

The new data confirm earlier speculations that the shafts of the King's Chamber were oriented to the upper culmination of Thuban and to the meridian transit of Orion's Belt; they also offer attractive alternatives for the orientations of the shafts of the Queen's Chamber, such as the upper culmination of Mizar, one of the stars selected by Spence (Kochab gives 3000 B.C., too early an epoch), or the meridian transit of Sirius (*Sepedet*), or of the Orion Nebula (M42) and neighbouring stars, an important part of the *Sah* asterism.[28] All these stars form, or belong, to asterisms mentioned in the Pyramid Texts.

TABLE 2. Astral destination of the airshafts of the pyramid of Khufu.

"Airshaft"	Inclination[a]	Dec.	Star	Asterism[b]	Epoch[c]
King's Chamber North	32°28′	87°34′	Thuban	*mnit?*	2425 B.C.
Queen's Chamber North	41°28′	78°34′	Mizar	*mshtyw*	2525 B.C.
King's Chamber South	45°14′	−14°48′	Mintaka	*s3ḥ*	2600 B.C.
			Alnilam	*s3ḥ*	2500 B.C.
			Alnitak	*s3ḥ*	2430 B.C.
Queen's Chamber South	39°30′	−20°32′	Sirius	*spdt*	2350 B.C.
			M42	*s3ḥ*	2650 B.C.

(a) Average values, according to Gatenbrick.[27]
(b) Mentioned in the Pyramid Texts.
(c) Estimated error of ±125 years, corresponding to ≈½°.

With the exception of the Orion Nebula, the dates obtained fit Spence's 80-year lowering of the chronology, but, if we bear in mind the low precision one can assume for those devices, the standard dates (*c.* 2575 B.C., see Table 1) would also be valid.

This was the situation when I realized that there was one alternative that, to my knowledge, had not been tested. Today, when one wants to find the Pole Star, Polaris, what one normally does is to extend fivefold, in the northern direction, the line connecting Merak (β UMa) and Dubhe (α UMa). To my surprise, I saw that a similar situation was produced almost 5000 years ago when another pair of stars of the Plough, Phecda (γ UMa) and Megrez (δ UMa) would have been pointing to the Pole Star of that epoch, Thuban, in identical fashion. I therefore supposed that this pair of stars could have been used to determine the Pole in the Pyramid Age, only to discover that this idea had been already proposed by the astronomer B. Polák in the early 1950s.[29] However, Polák never made accurate calculations, nor did he imagine that due north could have been found with extremely high precision by a variant of this method. This variant is simply a copy of Spence's hypothesis, but applied to a pair of stars that culminate on the same side of the Pole.

Figure 3 shows how the meridian transit, at lower culmination, of Phecda and Megrez could have been used to establish due north, with an error limited only by human capacity, in the year 2562 B.C. Figure 4 shows the same but with these two stars in upper culmination at an angular height of ≈45°. Column 7 of Table 1 presents the results of the astronomical modelling as intervals in which the axis of the subsequent pyramids might have been laid out, confirming the accuracy of the vertical alignment, which varies owing to precession, at a rate of ≈24″ per year. Most of them, with the probable exceptions of those of Khafre and Sahure, would have been aligned with the pair of stars at upper culmination.

According to my proposal, the pyramid of Khufu would have been aligned between 2571 and 2565 B.C., at a time when Phecda and Megrez were at upper culmination, since, as we shall see below, with the pair of stars at lower culmination, the dates (2559 to 2553 B.C.) do not fit the chronological pattern accurately. If we assume, following Spence, that the alignment was carried out in the first years of

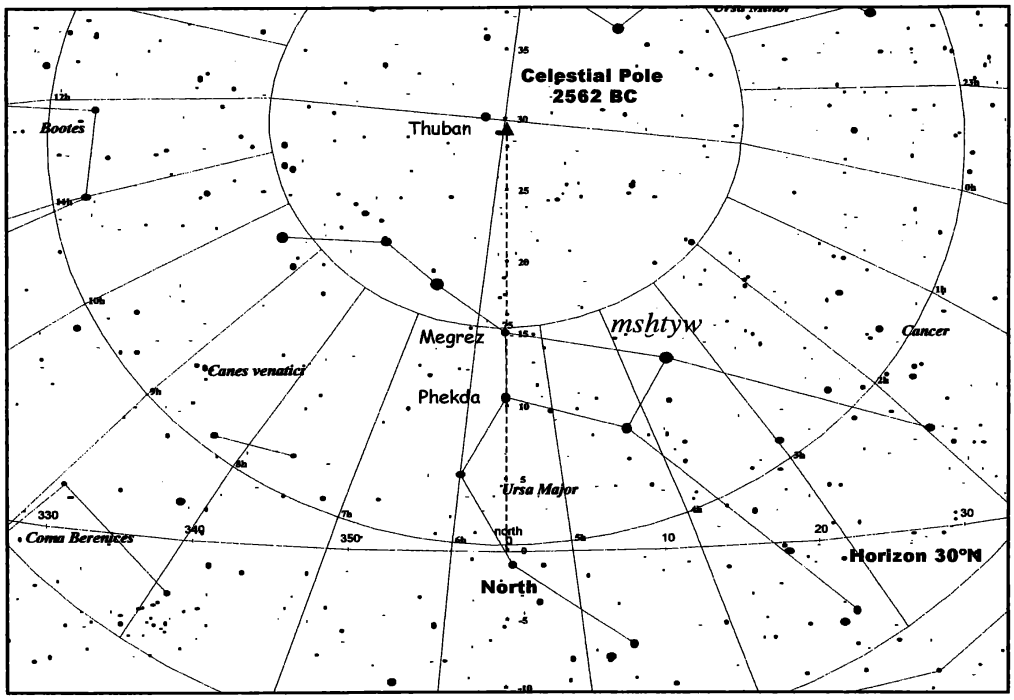


FIG. 3. The Bull's Thigh constellation [*mshtyw*] at lower culmination in the year 2562 B.C., when the line connecting the stars Phecda (γ UMa) and Megrez (δ UMa) accurately marked the position of the Pole in one direction and, in the opposite sense, the location of due north over the horizon.

the king's reign, we obtain dates for Khufu's ascension to the throne that are just in the middle of the highest and lowest chronologies accepted today by Egyptologists (see Table 1, columns 3 and 4).[30] This hypothesis, then, has the advantage that our current knowledge of Egyptian chronology in the Old Kingdom need not be subject to major alteration. Some historical implications will be discussed below, but perhaps, to be fair, I should now submit my proposal to the same trials that I have proposed for other hypotheses.

First, why these two stars? Here, all sources support the idea that *Meskhetiu* was an extremely important constellation in the northern Egyptian sky. It was "imperishable" and, certainly in later epochs and perhaps during the Old Kingdom, it was used to align monuments astronomically.

Second, what instrument could have been used to obtain the required accuracy? In Figure 5, I try to give an answer to this difficult question. Let us assume that the Stretching of the Cord ceremony took place (it was known in the Old Kingdom and even before). In the case of lower culmination, we need to make a simple assumption, that the *merkhet* was also known. As demonstrated in Figure 5(a), Megrez would have been at a height of only 15° and the moment of the vertical alignment of the two stars could have been easily observed with a *merkhet*; a plumb line suspended from the instrument would have yielded due north with the required

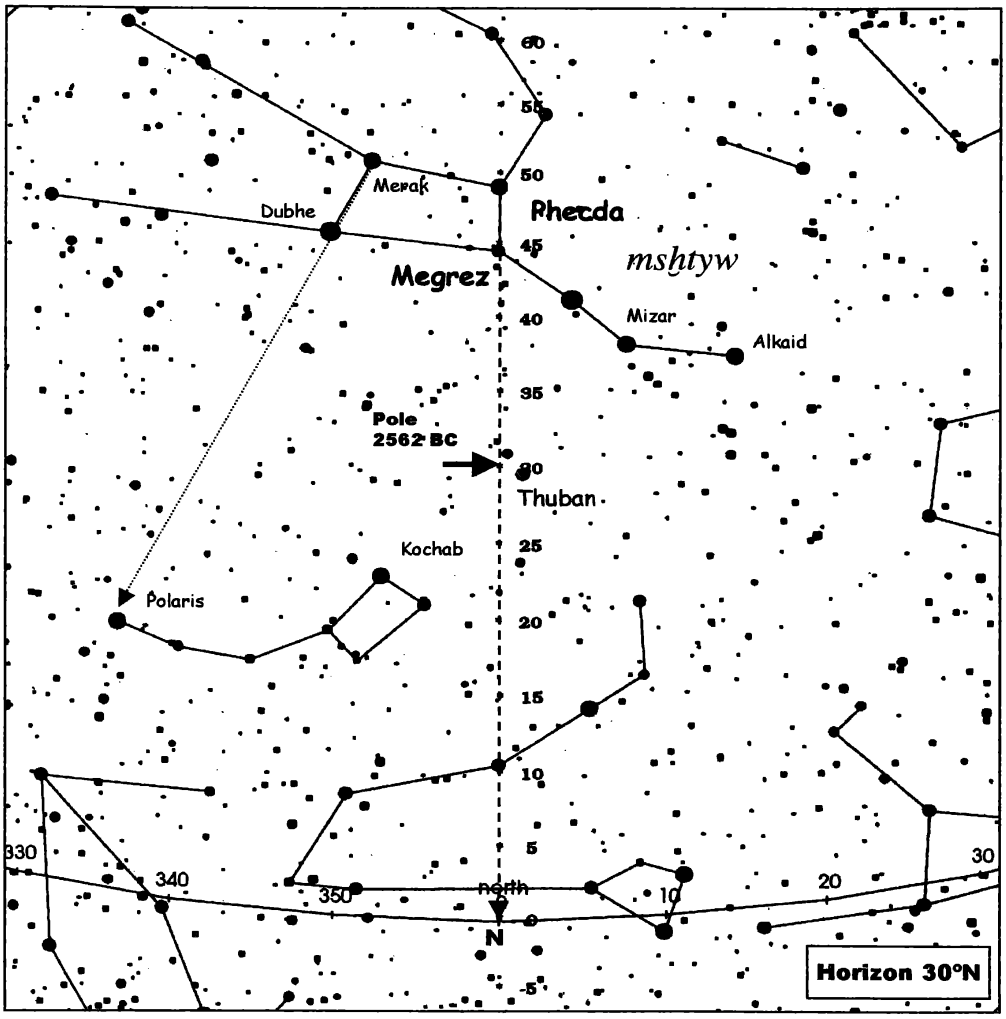


FIG. 4. The same as Figure 3 but with Phecda and Megrez at upper culmination. This configuration could have been used by the Old Kingdom Egyptians to lay the axes of the majority of their pyramids. The current method to find the present pole star, Polaris, by the "Pointers", Dubhe and Merak, is also indicated.

precision. This method might have been used to align the pyramids that are best orientated, that of Khafre and perhaps that of Khufu.

However, as mentioned earlier, most of the pyramids (perhaps including that of Khufu for chronological reasons, see below) should have been aligned with the pair of stars in upper culmination and, in that case, with Phecda at 50° and Megrez at 45°, the *merkhet* is useless. We could consider the possibility that the two poles used in the Stretching of the Cord ceremony were large (like the one represented in some reliefs of the pyramid complex of Pepi II, a king of the Sixth Dynasty) since a height of several metres would have been needed to obtain sufficient precision;

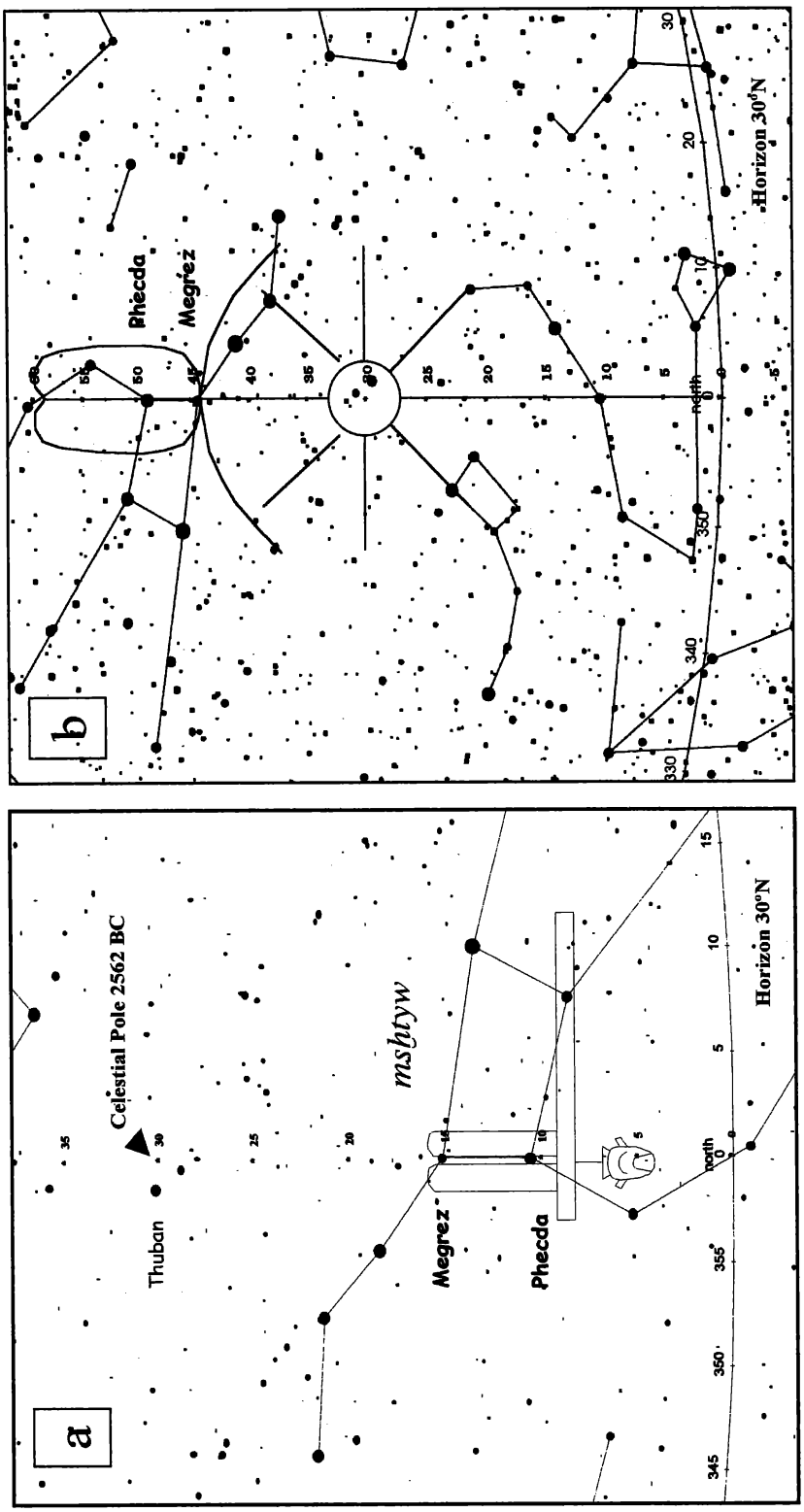


FIG. 5. Two possible methods to observe the simultaneous meridian (or vertical) transit of Merak and Phecda: (a) in lower culmination using the *merkhet*; (b) in upper culmination using a hypothetical device similar to that represented by the Seshat hieroglyphic sign. See text for further discussion.

or, perhaps better, we could speculate about a large device with a purpose similar to that proposed by Spence (although here we will make use of additional information coming from the Egyptian way of representing the World).

As real objects were often represented as if they were hieroglyphics,[31] it is accepted that some hieroglyphics of difficult interpretation could be representations of actual objects of which no original has survived. Our hypothesis, following this line of argument, is that the hieroglyphic of Seshat,

actually represented something that the Pharaoh was seeing in front of him when laying out the axis of the monument during the ceremony.

Figure 5(b) shows the Seshat sign overlapping the northern horizon, with its base lying due north, at the moment of upper culmination of Phecda and Megrez. Surprisingly, there are two interesting coincidences. On the one side, the Pole is exactly at the middle of the so called seven-point star[32] (or seven-petal flower). On the other, the line connecting Phecda and Megrez lies exactly where the two "horns" of the bull (or any other interpretation of this part of the symbol, see also Figure 1) become straight and parallel to the local meridian.

Bearing these 'coincidences' in mind, I speculate that, originally, the Seshat sign might in fact have been a device (a high pole or flagstaff, similar to those put in front of the temples and chapels, with a pair of parallel stakes on top) to observe the upper meridian culmination of stars near the Pole, whose exact position would be indicated by the seven-point star. If the 'instrument' came into use in the First Dynasty, when we have the first known representation of it, then Thuban would have been a mere 20′ from that location and, for 2787 B.C., only 2′ (our estimated error). Besides, if the 'instrument' was erected and dismounted on every occasion, and built with wood, this could be the reason why no original has survived.[33]

4. *Conclusions*

Whatever the truth of this, in any case, if we accept that the simultaneous vertical culmination of Megrez and Phecda was used to align the pyramids of the Fourth and early Fifth Dynasties, we can attempt to build a chronology for the period. Column 2 of Table 1 gives the best estimates for the number of regnal years of the relevant pharaohs, which have been compared with original sources and with the Turin Canon.[34] Column 8 offers a new proposal, with the alignment of the pyramid of Khufu based on Phecda and Megrez at upper culmination, in order to allot enough room for the 23- and 8-year reigns of Khufu and Djedefre respectively. The proposed dates fit the pyramid alignments, in a correct chronological sequence, to within a margin of 3 years (13 years in the Fifth Dynasty). They have been chosen to give a period of nearly 25 years between the Great and the Divine pyramids, taking as a starting point the reign of Khafre (see Table 1). The only marginal 'discrepancy'

would be the alignment of Horizon of Khufu later in his reign.

There are interesting implications of our proposal. For instance, a long reign of 28 years for Menkaure is excluded by our results. As to the reign of Snefru, if a 24-year reign is accepted, then the pyramid of Meidum would have been aligned in the reign of Huni; but if we accept the 30 years of Krauss[35] or the maximum 48 years of Stadelman,[36] all three pyramids (that of Meidum and the two of Dashur — the Shining and the Shining of the South or Bent pyramid) could have been designed, aligned and built in the reign of Snofru. On the other hand, the Red pyramid at Dashur (The Shining one) would have been built during a period of 10 years at most, in agreement with Krauss's estimate of 10.6 years, an estimate that is related to a reign of 30 years for this pharaoh.[37]

The pyramid of Wenis (c. 2375–2345 B.C., according to this new chronology; see Table 1), which has also been measured with good accuracy, has a deviation of only $17\frac{1}{2}'$ east of north and obviously does not follow the pattern established by the proposed simultaneous culmination theories. However, it is worth noting that this was the first pyramid to have Pyramid Texts inscribed on the walls of the burial chamber and this might be a clue to a very ancient enigma of Egyptology. Why did the Pyramid Texts appeared suddenly at the end of the Fifth Dynasty?

By the year 2375 B.C., the theory based on the cumulative trend of the simultaneous vertical transit of Phecda and Merak would yield an error of $\approx 1\frac{1}{4}°$ in the laying down of the axis of the pyramid of Wenis. This is more than two lunar diameters and perhaps it was considered unacceptable for the celestial travel of the king to the Imperishable Stars. It is possible that as a result, the earlier method of aligning monuments, which had already been in use for a quarter of a millennium, was abandoned for a different one,[38] and to ensure the king's eternal life, further instructions were inscribed in the burial chambers of the successive kings (and some queens), down to the end of the Old Kingdom two centuries later.

The simultaneous culmination theories (both that of Spence and the one proposed here) could be easily tested by obtaining high quality data of the orientation of other pyramids of the Old Kingdom. Accurate measurements of the Khaba pyramid at Zawiyet el Aryan could tell us if the method was already in use for the last step pyramids of the Third Dynasty.[39] Good alignment data on the known pyramids of the other kings of the Fifth Dynasty (Niuserre, Neferefre or Isesi) might enable us to test the continuation of the method in the successive reigns. Finally, a careful measure of the orientation of the pyramid of Djedefre at Abu Roash,[40] which has a name involving astronomy (see Table 1), would be the strongest test of the theories, since an error of only $\approx 3 \pm 2'$ would be expected.

The orientation of ancient Egyptian monuments has been a topic of debate since the end of the nineteenth century, when the pioneering work of Lockyer began a controversy that lasted for decades.[41] Fortunately, however, the situation has changed in recent years[42] and we may hope that archaeoastronomy will start to play its due part in the study of the culture of pharaonic Egypt.

Acknowledgements

Discussions with the lecturer in Egyptology at La Laguna University, Miguel Angel Molinero, and the study of the work of Kate Spence opened my mind to some of the ideas reflected in this paper, ideas that had been in circulation for many years. Some of my colleagues at the IAC, notably Fernando Pérez, Antonio Aparicio, Juan Bethencourt and César Esteban, helped me to understand the problem of the simultaneous vertical transit of a pair of stars. I also thank Hugh Thurston together with Edwin Krupp, editor of the *Griffith observer*, for allowing access to Thurston's paper prior to publication; Amanda-Alice Maravelia for her most interesting comments and the correction of errors in Egyptian spelling, and for allowing the quotation of her paper prior to publication; and Kate Spence for drawing my attention to certain errors. I am greatly indebted to them. This work is part of the IAC project P07/93 "Arqueoastronomía".

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1. K. Spence, "Ancient Egyptian chronology and the astronomical orientation of pyramids", *Nature*, vol. 408 (2000), 320–4. Spence's work has proved highly controversial, with serious debates between scholars, and her proposals have been severely questioned. See for example H. Thurston, "Aligning Giza: Astronomical orientation of the Great Pyramid", *Griffith observer*, Sept. 2001, in press; Alice-Amanda Maravelia, "L'horizon astral de Khéops: Archéoastronomie, Égyptologie ... et quelques scénarios de science-fiction", *Tôzai*, v (2000 [2001]), 1ff; and C. Lamberti, "Mizar, Kochab et la piramide di Cheope", *L'astronomie*, ccxvii (2001), 32–38.
2. See e.g. W. M. F. Petrie, *The pyramids and temples of Gizeh* (London, 1883), or Z. Zaba, *L'orientation astronomique dans l'ancienne Egypte et la précession de l'axe du monde* (Prague, 1953). Apart from those of the Fourth Dynasty, which are entirely built of stone, most of the pyramids are in very bad condition and it will never be easy to obtain accurate measurements of their orientation. A good alternative would be to measure the mortuary temples that adjoin most of the pyramids.
3. For the most accurate measurements, see J. Dorner, "Die Absteckung und astronomische Orientierung ägyptisher Pyramiden", Ph.D. thesis, University of Innsbruck, 1981, or Spence, *op. cit.* (ref. 1), Table 1.
4. Only Tycho Brahe, in the sixteenth century, with the sophisticated instruments he built in Uraniborg, is reputed to have obtained a 1′ precision for stellar position measurement prior to the use of the telescope in astronomical observations. I believe, on the basis of my own experience, that it would have been extremely difficult for an Egyptian 'astronomer' to obtain a precision better than two or three arc minutes.
5. See Petrie, *op. cit.* (ref. 2).
6. See Charles Piazzi Smyth, *Our inheritance in the Great Pyramid* (London, 1890), and R. A. Proctor, *Myths and marvels of astronomy* (New York, 1889).
7. For a good review of the different proposals see C. Gallo, *L'astronomia egizia* (Padua, 1998). See also M. Isler, "An ancient method of finding and extending direction", *Journal of the American Research Center in Egypt*, xxvi (1989), 191–206, and A. Pogo, "The astronomical ceiling decoration in the tomb of Senmut", *Isis*, xviii (1932), 301–25. Pogo proposed Mizar (ζ UMa) as the star observed at culmination. Romieu proposed Alkaid (η UMa).
8. See Gallo, *op. cit.* (ref. 7), 77–90.
9. See J. A. Belmonte, *Las leyes del cielo* (Madrid, 1999), 275.
10. S. C. Haack, "The astronomical orientation of the Egyptian pyramids", *Archaeoastronomy*,

no. 7 (1984), S119–25.

11. I. E. S. Edwards, *The pyramids of Egypt*, 3rd edn (Harmondsworth, 1993). See also Maravelia, *op. cit.* (ref. 1): "Discrepancies and diminishing precision in the orientation of pyramids ... are explained as due to random and systematic errors during the observations of ancient Egyptian priest-astronomers" and not as a systematic trend.
12. See Spence, *op. cit.* (ref. 1), or G. Schilling, "The star-pyramid connection", *Mercury*, xxx (2001), 28–31. Spence's calculations have been questioned by Dennis Rawlins and Keith Pickering who have argued about a small discrepancy between the difference of azimuth at the horizon — the actual astronomical datum — and the angle of the cord connecting the simultaneous vertical crossing of the stars and the Pole as calculated by a colleague on behalf of Spence, see Thurston, *op. cit.* (ref. 1). It is also worth mentioning that Robert Bauval claimed that he had already published this idea without having this recognized by Spence (R. Bauval and A. Gilbert, *El misterio de Orión* (Spanish transl. of *The Orion mystery*, Madrid, 1995), Fig. 15a). However, this figure shows the meridian connecting Kochab and Mizar across the Pole merely by chance, and no direct claim that this was involved in the actual method of orienting the pyramids is to be found in the corresponding text. In fact the figure related to the orientation of one of the airshafts of the Queen's chamber of the pyramid of Khufu.
13. These dates are too late for any compromise with the vast majority of Egyptologists. See e.g. J. von Beckerath, *Cronologie des pharonischen Ägypten* (Mainz, 1997). However, James *et al.* might be very happy with such a proposal. See P. James, I. J. Thorpe, N. Kokkinos, R. Morkot and J. Frankish, *Siglos de oscuridad* (Spanish transl. of *Centuries of darkness*, Madrid, 1993), 216–50.
14. The date of the reign of Qa', the last king of the First Dynasty, has been radiocarbon dated at 2925 ± 110 B.C. See M. Hassan, "The Predynastic of Egypt", *Journal of world prehistory*, ii (1988), 135–85. Alternatively, Rawlins and Pickering (see ref. 12) propose, without contextual evidence, to use Thuban and 10 Dra, offering a new chronology centred on 2627 B.C.
15. R. O. Faulkner, *The ancient Egyptian Pyramid Texts* (Oxford, 1969).
16. See J. A. Belmonte, "The decans and the ancient Egyptian skylore: An astronomer's approach", Proceedings of the INSAP III Meeting, Palermo, 31 December 2000 – 6 January 2001, *Memorie della Societa Astronomica Italiana* (in press), and references therein. Other interpretations can be found in R. Böker, "Über Namen und Identifizierung der ägyptischen Dekane", *Centaurus*, xxvii (1984), 189–217, and in the masterpiece: O. Neugebauer and R. A. Parker, *Ancient Egyptian astronomical texts* (3 vols, Providence, 1960–69).
17. H. Brugsch, *Thesaurus inscriptionum aegyptiacarum* (Leipzig, 1883–91). See also R. O. Faulkner, "The king and the star-religion in the Pyramid Texts", *Journal of Near Eastern studies*, xxv (1966), 153–61.
18. I am also of that opinion which locates the Field of Offerings, where the Imperishable Stars alight, either north of the ecliptic (Rolf Krauss, personal communication) or north of the Milky Way. See also V. L. Davis, "Identifying ancient Egyptian constellations", *Archaeoastronomy*, no. 9 (1985), S102–4.
19. See K. Locher, "Probable identification of the ancient Egyptian circumpolar constellations", *Archaeoastronomy*, no. 9 (1985), S152–3.
20. J. A. Belmonte, "The Ramesside star clocks and the ancient Egyptian constellations", in *Proceedings of the SEAC 2001 meeting on symbols, calendars and orientations, Stockholm, 27–30 August* (in press). See also M. Clagett, *Ancient Egyptian science*, ii: *Calendars, clocks and astronomy* (Philadelphia, 1995).
21. E. C. Krupp, *Echoes of the ancient skies* (New York, 1983), 211–13. See also A. M. Roth, "Fingers, stars and the opening of the mouth: The nature and function of the nṯrwi-blades", *Journal of Egyptian archaeology*, lxxix (1993), 57–79.
22. Brugsch, *op. cit.* (ref. 17). See also Krupp, *op. cit.* (ref. 21), 26, and C. Leitz, *Studien zur Ägyptischen Astronomie* (Ägyptologische Abhandlungen, 49; Wiesbaden, 1991).
23. R. O. Faulkner, *A concise dictionary of Middle Egyptian* (Oxford, 1988).

24. Krupp, *op. cit.* (ref. 21), 126.
25. See Gallo, *op. cit.* (ref. 7), 82. Imhotep was "First of the Observers", the title of the high-priest of the sun god Re at Heliopolis.
26. V. Trimble, "Astronomical investigations concerning the so-called air shafts of Cheops' pyramid", *Mitteilungen des Institut für Orientforschung*, x (1964), 183–7.
27. The data obtained by Rudolf Gatenbrick are reported by Bauvall and Gilbert, *op. cit.* (ref. 12).
28. See Belmonte, *op. cit.* (ref. 16) and references therein, including: K. Locher, "New arguments for the celestial location of the decanal belt & the origins of the *s3ḫ* hieroglyph", *Proceedings of the Oxford V Conference on cultural aspects of astronomy* (Sante Fe, 2001, in press).
29. See Gallo, *op. cit.* (ref. 7), 85–86.
30. The most widely accepted chronology for the Old Kingdom, according to Spence (private comm.) is that from von Beckerath, *op. cit.* (ref. 13). However, earlier dates have been proposed, for example by J. Malek, "The Old Kingdom" in *The Oxford history of Egypt*, ed. by I. Shaw (Oxford, 2000), 89–117, and by P. A. Clayton, "Crónica de los Faraones" (Madrid, 1996), 30. The lowest dates in the literature can be found in the outdated "Egipto: Dioses, templos y faraones", *Atlas culturales del mundo*, by J. Baines and J. Malek (Barcelona, 1988), 36.
31. R. Tefnin, "Reflexiones sobre la imagen egipcia antigua: La medida y el juego", *Arte y sociedad del antiguo Egipto*, ed. by M. A. Molinero and D. Sola (Madrid, 2000), 15–36. See also Image 1.9.
32. This seven-point star and the inverted horns of a bull are often assumed to be related in some way to the seven stars of the Bull's Thigh, the Egyptian *Meskhetiu*. See e.g. Krupp, *op. cit.* (ref. 21), 25–26.
33. Despite the hundreds of *merkhet*s that must have existed throughout Egyptian history, taking into account that they were used to measure the hours of the night in every temple, those remaining can be counted on the fingers of one hand. It is perfectly possible, then, that no "Seshat instrument" has survived, especially if they were not used after the Old Kingdom, when the device became simply the ritualized hieroglyphic sign of the goddess.
34. See von Beckerath, *op. cit.* (ref. 13), and A. H. Gardiner, *The royal canon of Turin* (Oxford, 1987).
35. R. Krauss, "The length of Sneferu's reign", *Journal of Egyptian archaeology*, lxxxii (1996), 43–50.
36. R. Stadelman, "Beiträge zur Geschichte des Alten Reisches: Die Länge der Regierung des Snofru", *Mitteilungen des Deutsches Archäologisches Institut, Abteilung Kairo*, xliii (1986), 229–40.
37. Krauss, *op. cit.* (ref. 35).
38. Not only the pyramid of Wenis, but also the pyramids of the Middle Kingdom with known orientation data (see Spence, *op. cit.* (ref. 1) and references therein) must have been aligned either by another method or with another pair of stars. Curiously, the pyramid of Wenis might have been aligned (with its error of $17\frac{1}{2}°$ east of north) on the simultaneous vertical transit of the handles of the Two Adzes, the stars Alkaid (η UMa) and Polaris (α UMi), with the former in lower culmination, in 2400 ± 30 B.C., a date in perfect agreement with the chronology we are dealing with in this paper. It would be interesting to have accurate measurements for the rest of the Fifth, Sixth, Eighth and Twelfth Dynasty pyramids in order to analyse the problem deeply.
39. The step pyramid of Djeser, with an estimated deviation of 3° west of north, was certainly not aligned by our method, which would have yielded a deviation of nearly ½°.
40. A measurement of the substructure of the "Unfinished" Pyramid at Zawiyet el Aryan, often attributed to an unknown transitory king of the Fourth Dynasty because of its structural similarities to the pyramid of Djedefre, would also prove to be a good test.
41. The book by J. N. Lockyer, *The dawn of astronomy* (London, 1894), was critized by the Egyptologists of his time because of the numerous historical errors and mythological

speculation presented in it.

42. A renewal of interest in Egyptian archaeoastronomy was generated by the works of G. S. Hawkins, *Beyond Stonehenge* (New York, 1973) and "Astroarchaeology: The unwritten evidence", *Archaeoastronomy in pre-Columbian America*, ed. by A. Aveni (Austin, 1975), 131–62. For more recent work, see R. A. Wells, "Sothis and the Satet Temple on Elephantine: A direct connection", *SAK*, xii (1985), 255–302; Krupp, *op. cit.* (ref. 21); and Belmonte, *op. cit.* (ref. 9), 136–71. Even Egyptian scholars are now interested in these issues; see the work of the astronomer M. Shaltout, "Sun perpendicularity on Abu Simbel Temple phenomenon" (in press; preprint available at <mamshaltout@frcu.eun.eg>).