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THE ASTRONOMICAL ORIENTATION OF THE EGYPTIAN PYRAMIDS

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Of the many problems involving the design and construction of the Egyptian pyramids, one of the most interesting is that posed by their orientation to the cardinal points. Most of the major pyramids are aligned to within half a degree of true north. Whereas structures aligned to the points of the solsticial sunrises are common in Egypt, as they are throughout the world, accurate alignments to the cardinal points are rare.

It is often proposed that the Egyptians constructed an accurate north–south baseline by sighting the star α Draconis which was close to the celestial pole during the period of pyramid construction. In conjunction with this idea, it is asserted that the descending passage of the Great Pyramid of Cheops was constructed so as to point to α Draconis at its lowest passage. It is, however, very difficult to establish a long, accurate baseline by sighting an object which lies almost 30° over the horizon. Furthermore, the fact that the tangent of the angle of inclination of the descending passage is exactly ½ indicates that the passage was laid out geometrically, the rise over an interval being one-half of the corresponding run. This is consistent with the architecture of all of the pyramids built during the fourth dynasty in that most of their angles can be expressed in terms of ratios of small integers or an integer and π.[1]

The rising Sun on the equinox would present a good target for an east–west base-line, but its high rate of change in declination at this time as well as its size and brightness would lead one to expect a greater error than is actually found in the alignment of the pyramids.

The investigation of possible astronomical procedures which may have been employed in the alignment of the pyramids is hampered by the lack of an absolute chronology covering the period in question. The earliest absolutely-dated event in Egyptian chronology occurs around 2000 B.C. and is established by a record of the date of the heliacal rising of Sirius. Dates prior to this must be reconstructed from often-fragmentary records of the reigns of kings. Thus, estimates for the beginning of the fourth dynasty range from 2720 B.C. to 2600 B.C. The history of the fourth dynasty itself, however, is established fairly reliably, thus allowing us to construct a floating chronology of the period of pyramid construction.

Figure 1 shows the error in alignment for all of the major pyramids for which data are available.[2] It is assumed that in each case the base of the pyramid was laid out within a few years of the beginning of the reign with which it is associated. An exception to this is the pyramid at Meidum which is recorded as being built by Seneferu, the first king of the fourth dynasty. It is almost certain that both of the pyramids at Dahshur were built by Seneferu and, rather than credit him with the construction of three such structures in the course of his twenty-four-year reign, it is often suggested that he may have been responsible for the finishing of the pyramid at Meidum after it had been planned and largely completed by his predecessor Huni. The pyramid at Meidum may,

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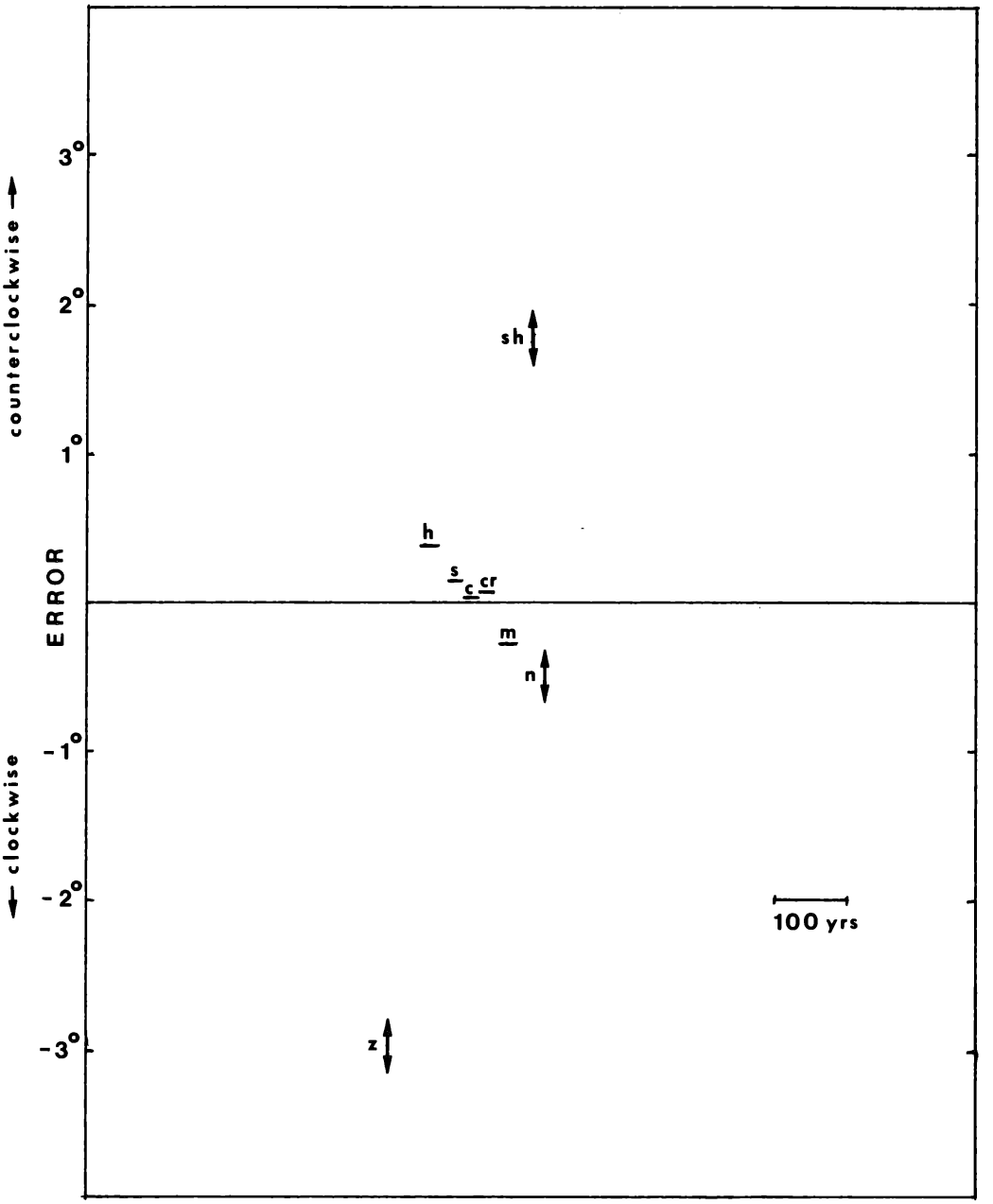

FIG. 1. The deviation from the cardinal points in the alignments of eight pyramids (the abscissa is a scale of relative date and the x-coordinate for each site is taken as the beginning of the reign). Their designations are as follows: *z*, Zoser's step pyramid at Saqqara; *h*, the pyramid at Meidum ascribed to Huni; *s*, Seneferu's Bent Pyramid at Dahshur; *c*, the Great Pyramid of Cheops at Giza; *cr*, the pyramid of Chephren at Giza; *m*, the pyramid of Mycerinus at Giza; *sh*, the pyramid of Sahure at Abu Sir; and *n*, the pyramid of Neferirkare at Abu Sir. The orientations of the pyramids of Zoser, Sahue, and Neferirkare are only approximately known.

therefore, have been laid out some twenty years before the beginning of the fourth dynasty. While the state of preservation of the pyramids of the fourth dynasty allows their alignments to be determined to within a few seconds of

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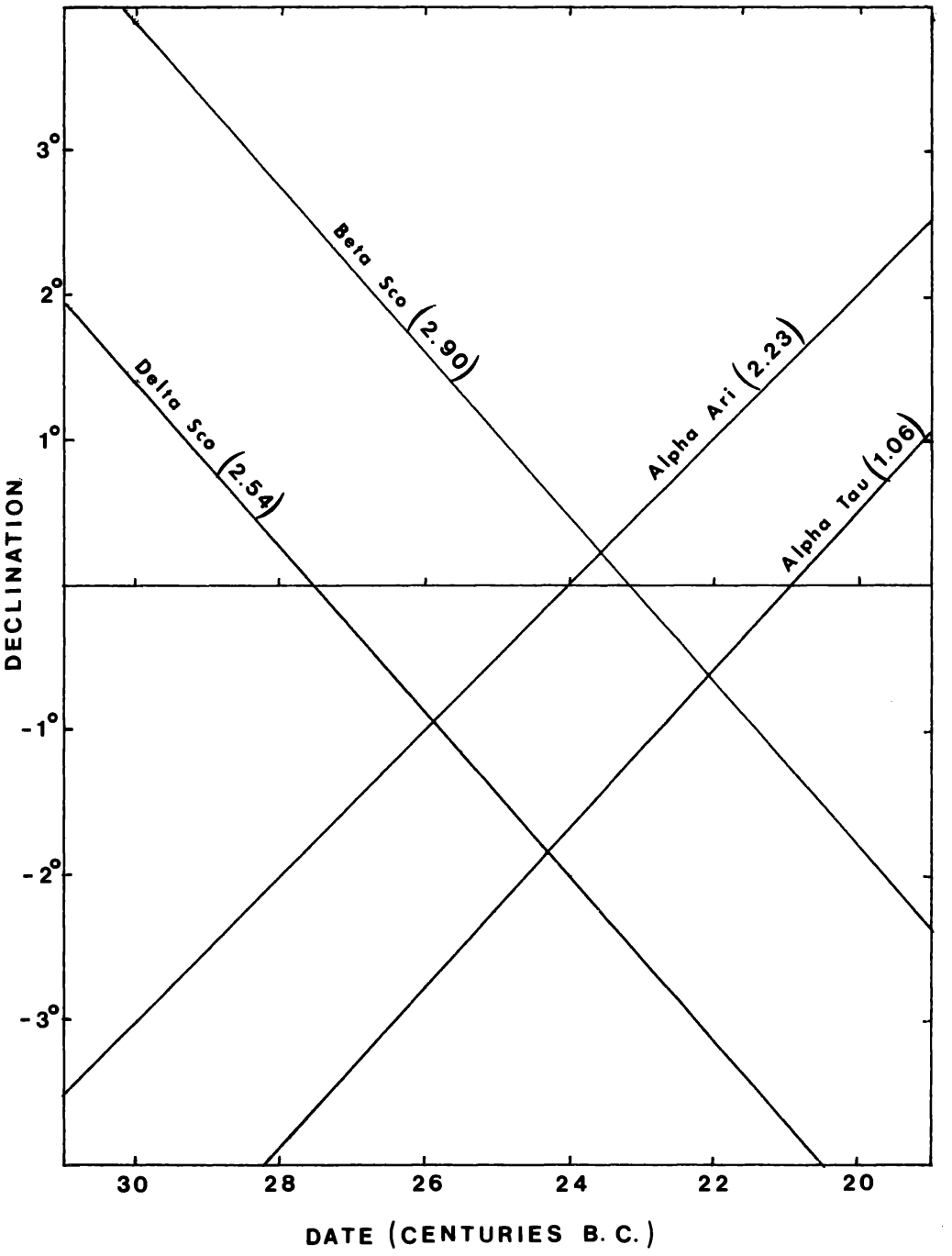

FIG. 2. The declinations between the years 3000 B.C. and 2000 B.C. of the stars brighter than mag. 3 which crossed the celestial equator during the period of pyramid construction. The number in parentheses indicates the apparent visual magnitude of the star.

arc, only a rough measurement of the orientation of Zoser's step pyramid is available. Zoser was the first king of the third dynasty, which lasted between sixty and eighty-six years. The alignments of two fifth-dynasty pyramids at Abu Sir, those of Sahure and Neferirkare, are also known only approximately.

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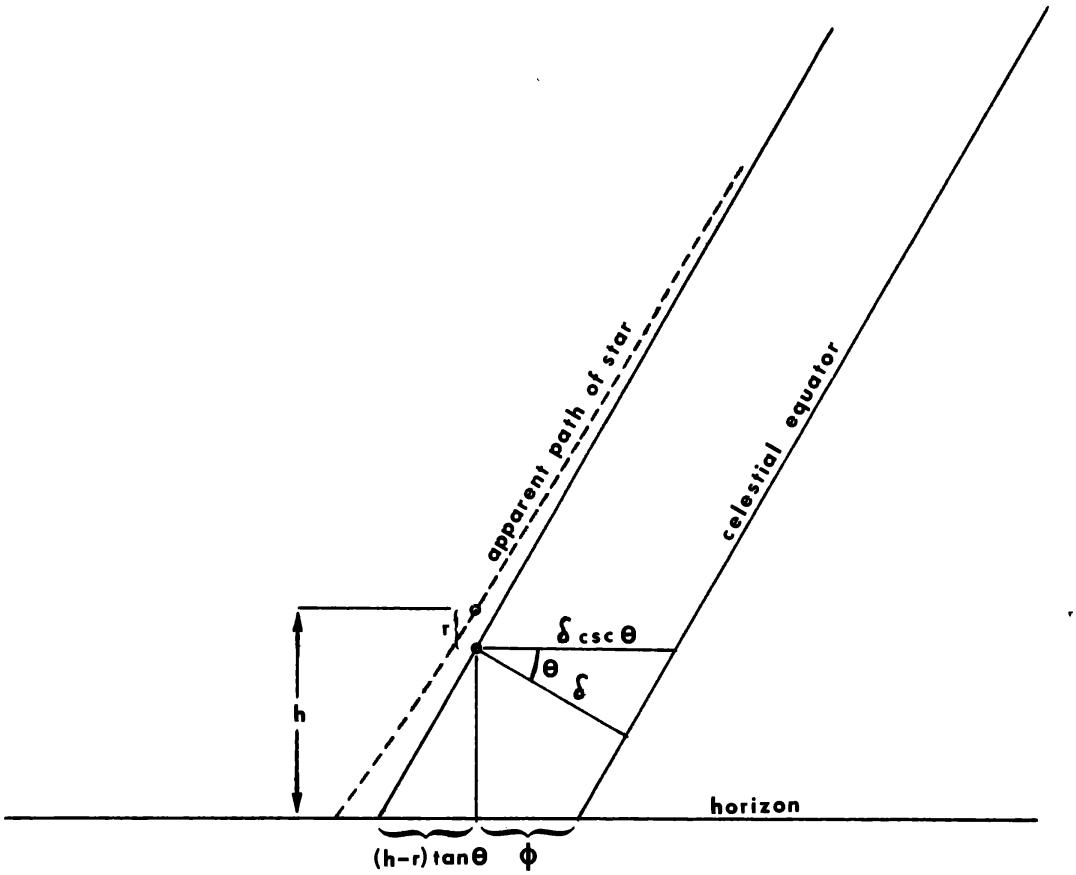

FIG. 3. The azimuthal angle, φ, with respect to due east is a function of the star's altitude (h) and the corresponding refraction (r) as well as its declination (δ) and the latitude of the site (θ). If a baseline is constructed by sighting the star when it first becomes visible, the resulting error will be δ csc θ – (h–r)tan θ in the counter-clockwise direction. Errors resulting from using the same star as it sets in the west will be equal in magnitude and opposite in direction.

A preliminary inspection of Figure 1 suggests the possibility of orientation with regard to some stellar reference point. The pyramids at Meidum and Dahshur, the pyramids of Cheops and Mycerinus, both at Giza, and the pyramid of Neferirkare at Abu Sir all fall on a line which has a slope of about 20 seconds of arc per year. This is, indeed, very close to the maximum rate of change in the declination of a star due to the precession of the equinoxes.

The precision with which the ancient Egyptians understood the structure and motion of the sky is unknown. Like most early civilizations, they showed a great interest in the heavens, populating it with their gods and building a complex mythology around the patterns they perceived the stars to describe. They are known to have used the nocturnal motion of the stars to track time accurately and to have marked the beginning of the year with the heliacal rising of Sirius. It is not unlikely that they had some concept of the celestial equator and, if so, it would have taken but little work to trace its course across the sky. A star known to lie on the celestial equator would then offer an excellent due-east reference point if it could be observed close to the horizon. If the same star was used over a period of time, the resulting baselines would change with

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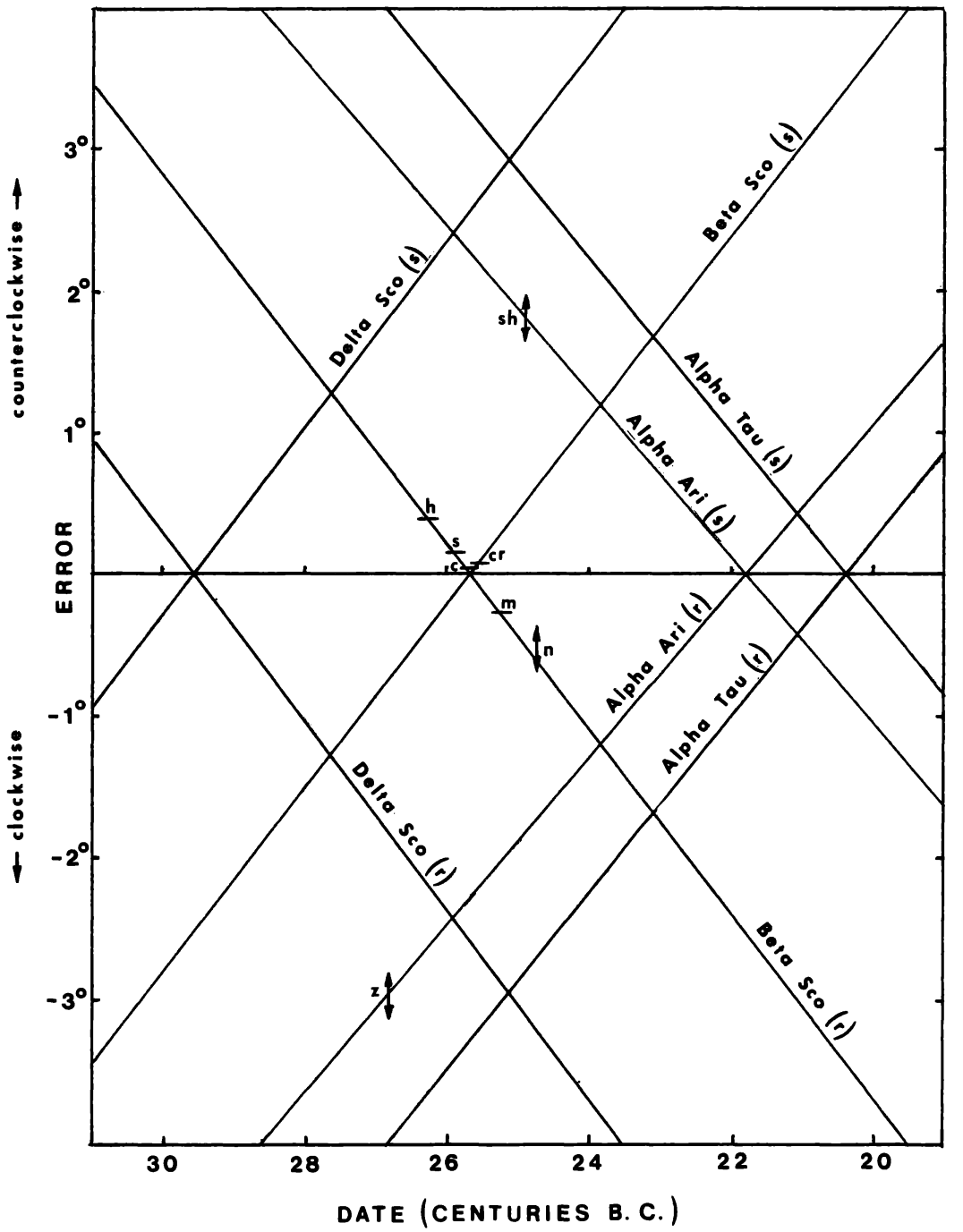

FIG. 4. The diagonal lines give the errors in the baselines constructed by sighting the stars shown in Figure 2 while rising (*r*) and setting (*s*) (the stars are assumed to be first visible when their altitude (in degrees) is equal to their magnitude). We then superimpose the floating chronology of Figure 1, and find a single position for which the baseline of every pyramid is aligned to a bright star on the horizon.

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the star's changing declination.

Figure 2 shows the variation in declination for all stars brighter than mag. 3 which crossed the celestial equator during the period of pyramid construction.[3] The change in declination is due entirely to precession, the effects of nutation and proper motions being negligible. The deviation from a true east–west orientation which will result from sighting one of these stars as it rises will depend not only upon its declination, but also upon extinction and refraction. No star will, of course, be observed to lie directly on the horizon. Even with the clearest of skies, a star's light suffers about five magnitudes of absorption when it is 1° above the horizon. Thom[4] has found British megalithic alignments best explained when it is assumed that the altitude (in degrees) of a star when it first becomes visible is about equal to the magnitude of that star. Coupled with the known clear-sky extinction function, this implies that the star is about mag. 6 when first seen, which is, indeed, near the limit for detection with the naked eye. At the same time, refraction will make the star appear higher above the horizon than it actually is. The amount of refraction is about ½° at the horizon, ¼° at 3° altitude, and diminishes to 0 upon approaching the zenith. Figure 3 shows the effects of these two phenomena upon the azimuth of a baseline constructed by sighting the star when it is first visible. Calculating the azimuths when first visible of the stars shown in Figure 2 (using the extinction suggested by Thom) and bearing in mind that a baseline could also be constructed by sighting the star just before it set in the west, we find that the deviation from true east–west resulting from the above procedure can be plotted for each star as a function of time.

By superimposing the floating chronology of Figure 1 over such a graph and adjusting its position along the abscissa, it is possible to find combinations of rising and setting stars which fit the known alignments of the pyramids (see Figure 4). The only possibility that fits every datum point employs the rising of β Scorpii to align the pyramids at Meidum and Dahshur, the pyramids of Cheops and Mycerinus at Giza, and the pyramid of Neferirkare at Abu Sir, while the setting of β Scorpii is used to align the pyramid of Chephren at Giza. The rising of β Arietis matches the alignment of Zoser's step pyramid and its setting that of the pyramid of Sahure at Abu Sir.

It is unfortunate that the measurements of Zoser's pyramid and those at Abu Sir are not more accurate. Given their state of preservation, it is unlikely that these determinations can be improved upon. Any good measurements of pyramid orientation from the third, fourth, or fifth dynasties would be helpful in confirming or refuting the above choice of stars.

As it stands, the hypothesis of alignment to the rising and setting of equatorial stars does a good job of explaining the available data. Furthermore, it results in a date for the beginning of the fourth dynasty of about 2640 B.C. which is quite consistent with the current range of estimates. This serves as a totally independent date for the events of the early dynasties.

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