Astronomy and the Great Pyramid

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Pyramidology! The very word produces groans and upturned eyes in an audience of scientists, along with sighs of "here we go again." As well it might. The rubbish written about pyramids generally, and the Great Pyramid of Khufu (or Cheops) in particular, is overwhelming. Bizarre theories about its construction and supposed metaphysical properties have only multiplied over the centuries. The Internet is filled with this nonsense.

Figure 1. The Great Pyramid of Egypt has attracted commensurate attention over the centuries. Most of it has been speculative, even fanciful, but some studies of this grand tomb have been quite rigorous-as befits the early astronomers who situated this and other monuments according to precise celestial observations. Thus, pyramids point to the heavens in metaphorical as well as literal terms. Corbis

Yet these age–old monuments are a marvel, and they do tether our modern civilization to its origins. So there is a danger that the baby of rigorous scholarship can all too easily be thrown out with the bathwater of mystical blather, particularly by those scientists or educators who are plied with questions from well–meaning New Age disciples. But in fact, there are, and long have been, serious scientists applying careful methods to the study of ancient pyramids. Henry Petroski penned a thoughtful analysis of the engineering challenges of pyramid construction in a recent issue of *American Scientist* (May–June). Here I look at some studies that examine the astronomy of the pyramid builders.

Anatomy of a Pyramid

Whatever the excesses of its advocates, the Great Pyramid is one of the most remarkable structures ever made, if only in terms of sheer workmanship: The fact that it is the only standing remnant of the seven ancient wonders speaks for itself. Built roughly 4,500 years ago, it towers over the Giza plain some 16 kilometers west of Cairo amid several smaller pyramids, 60 or more of which stretch down the western bank of the Nile. The base of the Great Pyramid covers 13 acres, or about seven midtown blocks in Manhattan. It rises in 201 stepped tiers comprised of more than two million pieces of limestone and granite, averaging two or three tons apiece (with some a good deal more), to the height of a modern 40–story building. It was the tallest construction in the world until the Eiffel Tower was erected in the 19th century.

For the first 3,000 years or so of its history, the Great Pyramid was encased in brilliant polished limestone—about 22 acres of it. The slabs were up to 2.5 meters thick and were fitted together with joints so fine they could scarcely be seen, according to Herodotus, who visited in 440 B.C. This must have been a dazzling sight in the Egyptian sun! Unfortunately, the covering was stripped in medieval times to build palaces and mosques in Cairo, and now we can only see the rough building blocks.

Under this shining canopy lay the interior structure. Strabo, after a visit in 24 B.C., described an entrance on the north face of the pyramid made of a hinged stone that could be raised but was otherwise indistinguishable from the stones around it. So indistinguishable, in fact, that its location was lost during a period of neglect in early Christian times. Much later, in the early 9th century, an Arab potentate named Al–Mamun, following rumors of vast, hidden wealth, forced a new entrance near the base of the north side. So impregnable was the structure that his engineers could proceed only by building fires against each huge stone in their path and, having heated it to a high temperature, dousing it with cold vinegar to shatter it. The residue was cleared, and they repeated the process on the next stone. Inching forward in this way for some 30 meters, and almost at the point of giving up, they broke through into a pre–existing tunnel, later termed the Descending Passage because it started high on the north face and sloped smoothly into the pyramid's depths below ground level. Unlike the ragged tunnel gouged by Al–Mamun's men, the Descending Passage, about a meter square, was astonishingly straight. It was so exact that in 1881, Flinders Petrie, an experienced, professional surveyor and skeptic, using the best equipment then available, found that the average departure from a perfect line over the full length of some 100 meters was less than 7 millimeters.

Of less interest was the discovery of another tunnel, the so–called Ascending Passage, which led off of the Descending Passage and headed up to what the potentate's henchmen called the King's Chamber because it had a flat ceiling, which was an Arab custom for male deceased. An offshoot of the Ascending Passage led to the Queen's Chamber, so called for its gabled ceiling. The dimensions of these rooms, along with the overall dimensions of the pyramid itself, provoked endless discussion among luminaries such as Isaac Newton and John Herschel, who speculated that the measurements might hold the key to converting biblical units to their modern equivalents. Although this numerical Rosetta Stone never emerged, Newton did conclude that the builders must have employed more than one unit of length.

Pointing at the Heavens

The first modern European astronomer on the scene was probably John Greaves, a professor of geometry at Gresham College. In 1637, Greaves suddenly abandoned the academy in order to undertake measurements of the Great Pyramid. His work was thorough and extensive, and Newton and others scrutinized the published results for data to develop their theories. Upon his return to England in 1640, Greaves's reputation won him the Savilian Professorship of Astronomy at Oxford. Unfortunately, he fell from this lofty position after being fired for misappropriation of funds!

Some two centuries later, a much more famous astronomer named Charles Piazzi Smyth, Astronomer Royal for Scotland, turned his attention to the Pyramid. A curious figure, Smyth produced some first–rate science in other fields, but he lost almost all rationality when it came to this subject. For example, he attributed great significance to the fact that the slope of the Pyramid is near the ratio 10:9, and that its height of 484.9 feet (or 0.09184 mile) multiplied by 10^9 equaled 91,840,000 miles. Coincidentally, that number is close to the actual distance between the Earth and the Sun. Smyth believed that the coincidence meant that the Pyramid builders must have also known this distance. There was much more along these lines, with liberal doses of religious and prophetic conclusions. He published a three–volume, 1,600–page opus about his findings, which, needless to say, was a great hit among the like–minded, but which was dismissed by one reviewer as containing "more extraordinary hallucinations than has appeared in any other three volumes of the past century." Nevertheless, Smyth was not entirely without redemption. Like a previous investigator, he was intrigued by the extraordinary straightness of the Descending Passage and took care to measure carefully its angle of descent, noting that a person within the passage looking out through the surface opening would see a patch of sky close to the celestial north pole. However, Polaris, the current pole star, would not have been visible to the builders because precession (the slow wobble of the earth's axis of spin) would have placed the pole much farther from Polaris than it is now. A possible (though not very likely) pole star for people of that era is the magnitude 3.7 star Thuban (Alpha Draconis), which, Smyth calculated, would have been visible in the opening at lower culmination (the time of its lowest point in the sky) around the years 2123 and 3440 B.C. He suggested that the Pyramid might have been built near either of those dates, which despite the flimsiness of his argument is not entirely ridiculous when compared to the modern estimate at about 2500 B.C.

A long–standing problem relating not only to the Great Pyramid but also its smaller cousins is the question of how the builders managed to orient such colossal structures to the cardinal points with surprisingly high accuracy. The eastern side of the Great Pyramid, for example, points only three arcminutes away from a true north–south line, and other pyramids in the group are not much worse. This makes it virtually certain that some astronomical method was used to establish the local meridian. At first thought this does not seem too difficult a problem, even without a bright star close to the north celestial pole during the millennia of interest. (Even today, Polaris is some 43 arcminutes from the pole, and during this time it was about 25 degrees away.)

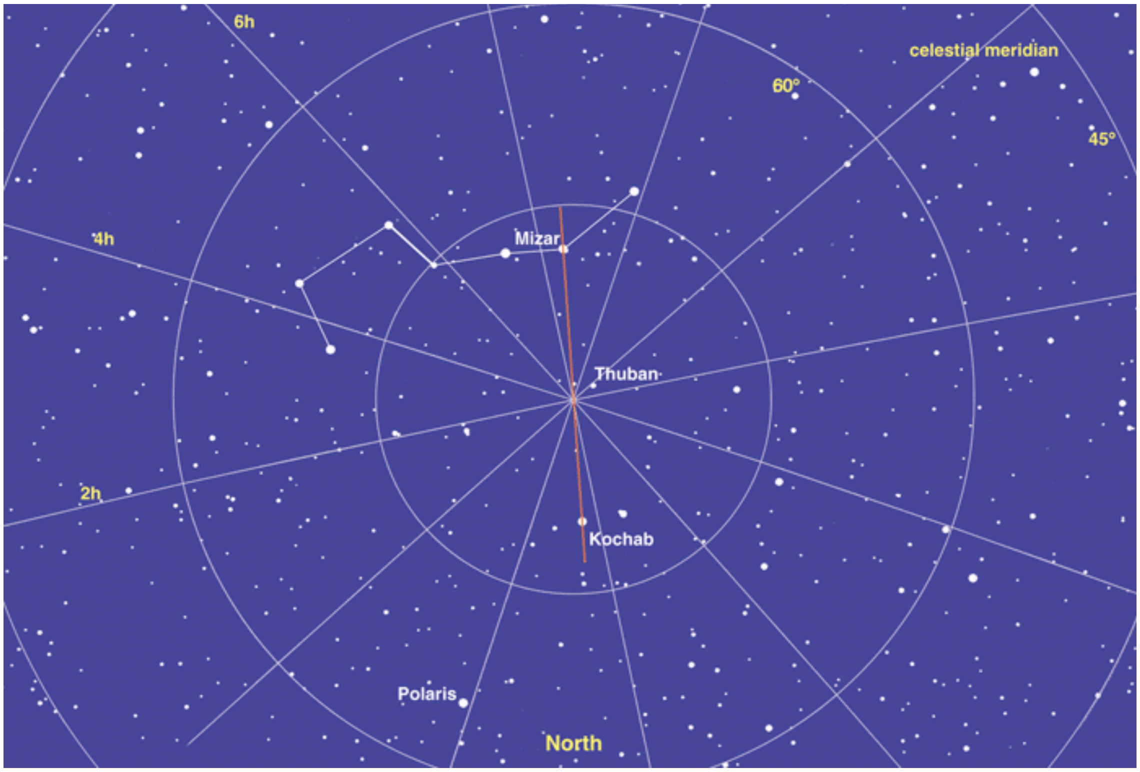

Figure 2. The apparent movements of the stars were different in ancient Egypt, as seen in this reconstruction of the 9 o'clock sky in Cairo on April 25, 2467 B.C. Then, Polaris was quite distant from the north celestial pole, for which dim Thuban might have been the closest marker. Yet the pyramids point north with such accuracy that a more rigorous method must have been used. A recent analysis shows that a line drawn between the circumpolar stars Mizar and Kochab would very nearly cross the pole, and that the pyramids themselves exhibit the slight deviations that would result from using these stars to determine true north. Chris Brodie

Still, other possibilities spring to mind. An obvious method would be to note the directions of sunrise and sunset on a given day and bisect the angle between the two—the result marks the meridian. But this, and other seemingly straightforward methods, while fine in principle, turn out to be unsatisfactory in practice, at least when accuracies of a small fraction of a degree are called for. For instance, in this case the rising and setting sun must be seen over an absolutely flat horizon, which Giza lacks. Then there is refraction in the earth's atmosphere: When one sees the lower edge of the setting sun just touching the horizon it has in fact already set. The light rays are bent to produce an image above the horizon, thereby shifting the direction in which the sun appears to set. And since the amount of refraction depends on air temperature, pressure and other factors, all of which can differ between morning and evening, the effect may not be consistent between rising and setting. Furthermore, the sun's celestial coordinates will change during the course of the day, spoiling the symmetry of the method. All in all, these practical hurdles have stymied modern astronomers who tried to figure out just how the early Egyptians managed to orient their pyramids as precisely as they did.

An Answer Written in the Stars

That an astronomical method was used to orient the pyramids received strong, if unexpected, support in the 1980s when historians discovered that among most of the Giza pyramids, the departure of a pyramid's eastern edge from a true north–south line correlated strongly with the accession date of the king for whom each was constructed. Which is to say that the direction of north as determined by the Egyptian method varied systematically as the centuries went by. The ready explanation for this is once again precession of the equinoxes: The early Egyptians must have applied some method of using the stars to find the north celestial pole without realizing that the pole is not fixed, but rather drifts slowly through the heavens.

In November 2000, Kate Spence, an Egyptologist at the University of Cambridge, published a seminal paper in *Nature* in which she suggested a method by which the pyramid builders determined what they thought was north. She also showed that the resulting orientation errors varied as a function of time—just as predicted by precession. Moreover, by fitting the time–linked precession errors to the slight deviations of each pyramid, she revised their building dates. Instead of 2554 B.C., her data suggest the Great Pyramid was constructed between 2485 and 2475 B.C.

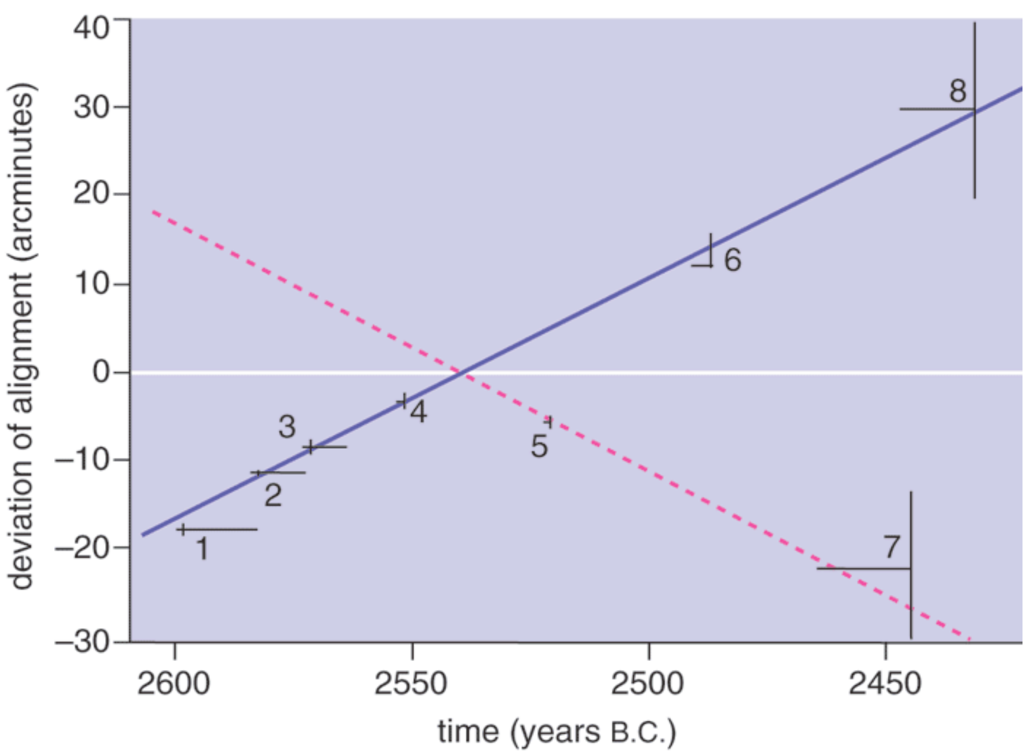

Figure 3. Slight deviations in the orientations of pyramids match the errors that would have been introduced if Mizar and Kochab had been used to identify the celestial pole. The Earth's precession causes these errors to add up over time, which allows modern astronomers to make accurate guesses about the building date of each pyramid. This pattern holds regardless of whether the monuments were oriented when Kochab was directly above Mizar (*solid diagonal*), or six months later when Mizar topped Kochab (*dotted line*). The eight pyramids are 1, Meidum; 2, Bent Pyramid; 3, Red Pyramid; 4, Khufu; 5, Khafre; 6, Menkaure; 7, Sahure; 8, Neferirkare. Graph appears courtesy of Kate Spence and Nature Publishing Group.

The method proposed by Spence involved two stars on opposite sides of the celestial pole. She had to choose them by trial and error, since the pole drifts into different star fields as millennia pass. For the period of interest, Spence found that the stars named Mizar (Zeta Ursa Majoris) and Kochab (Beta Ursa Minoris) would have appeared to revolve around the pole on almost (but not exactly) opposite sides, so that a line joining them would always pass very nearly through the pole. When these two were aligned vertically, the pyramid builders might have hoisted a long plumb line and fixed it at the moment when the two stars both lay on the line. The point where the vertical line touched the ground would indicate north.

One idiosyncrasy of this method was that because these two stars were circumpolar (they never set), they could be seen from Egypt year–round. Thus, at some date during the year Kochab would have appeared above Mizar at meridian transit (when they would have been vertically aligned), but six months later Mizar would have topped Kochab. Early in the pyramid era, the pole was really slightly west (or east, depending on which star was uppermost at the time) of the line. Because of precession, the opposite was true late in the era. Support for Spence's theory came from two pyramids whose deviation from true north was of the expected magnitude but opposite sign. The explanation was that all the pyramids except these two had been set during the time of year when Kochab was above Mizar—these two must have been set six months later (or earlier), when Mizar surmounted Kochab.

Like many groundbreaking papers, this one quickly became the center of arguments and proposed improvements. Spence accepted a small but significant correction by extending the pole displacement to an azimuthal displacement, but she seems not to have been enthused by other proposals to use different stars in a different way. The method still has some practical problems. For one, the plumb line would have to be very long to reach high enough to be seen against the upper star, especially because the observer would need to be far away from the line to achieve sufficient accuracy. And it would have been difficult to see the line at all against a dark sky. Nevertheless, the explanation for the two pyramids with errors of reversed sign supports the basic idea. As centuries went by and the errors grew, later builders may have realized the problem and abandoned the method or used different stars. Thus, the failure of Spence's scheme among later pyramids is not necessarily a valid critique. My own inexpert view is that whether she is proved right or wrong, Spence's basic idea marks a major breakthrough in dating these pyramids.

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