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INDIANA JONES and the Astronomers of Yore

by Louis Winkler, Pennsylvania State University

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Edwin C. Krupp at the Saqqara pyramids near Cairo, Egypt. Krupp has poked around nearly 600 archaeological sites throughout the world. He is director of Griffith Observatory in Los Angeles and author of several books, including In Search of Ancient Astronomies and Echoes of Ancient Skies: The Astronomy of Lost Civilizations. Photo by Robin Rector Krupp.

Archaeoastronomy, like the study of dinosaurs, reconstructs things and circumstances of the deep past. There's the intrigue of the megaliths of Stonehenge, the ancient pyramids of Egypt, the earthen figures of Britain and Peru, and the bloody rituals of the Maya. The earliest societies of the British Isles, Egypt, China, Peru, and North America all paid close attention to the skies (see figure 1). The ancient Maya, Romans, Christians, Jews, and Muslims all devised calendars. To make sense of these great structures and sophisticated concepts, archaeologists and astronomers have pooled their talents. They work together to understand ethnic groups over six millennia of world history.

As a science, archaeoastronomy is unusual in the amount of subjectivity that it involves. Although based on astronomy and spherical geometry, interpretations of sites can vary wildly. For teachers, this is a blessing. High-school students can get involved in real problems. They can perform activities either in the classroom or field, and if funds are available, they can visit actual archaeological sites. Some of the material requires little or no mathematical manipulation; the most difficult involves simple trigonometry.

Starting Lineup

One of the fundamental objectives of archaeoastronomy is to find an *alignment* at a site. Archaeoastronomers look for pairs of stones or architectural features, located at some distance from each other. When they find a pair, they stand at one and look toward the other. Does it lie in the direction of a particular celestial body, such as the Sun, the Moon, a star, or a planet? If so, it suggests that the celestial body was carefully observed by that society. If the alignment is backed up with a relevant calendar, mythology, or early writing, it helps us to understand and appreciate the culture.

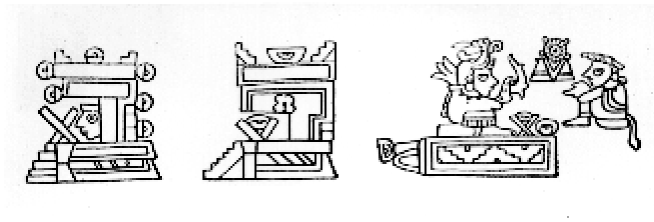

Figure 1
Astronomers as depicted by the ancient Maya. The Maya thought highly of their astronomers, who developed a sophisticated calendar and techniques to predict eclipses. These representations come from three Mayan books, called the Nuttall Codex (left), Selden Codex (center), and Bodleian Codex (right). Courtesy of G. Kohlmann and L. Blanco, CIEA del Instituto Politecnico Nacional, Mexico.

We can even tell *how* carefully the society observed the body. If the distance between the two sighting points is short, the alignment was just a rough guide, probably used to point in the general direction of the celestial object when a particular ceremony was performed. Longer separations, however, result in higher precision alignments. People could use these alignments to synchronize their calendars or track the exact path of a celestial object.

Precision sightings were some of the earliest known scientific efforts of humanity. In ancient Egypt, precision alignments oriented Cheops' pyramid. In the classical Maya period, precision alignments determined the *synodic period* of the planet Venus, the length of time for the planet to undergo a cycle of brightness variation (see figure 2). And in the early Bronze Age of the British Isles, precision alignments told people the length of the year, from which they predicted the coming of the seasons.

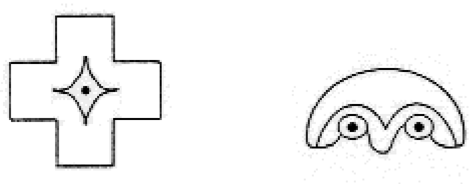

Figure 2
Maya glyphs of Venus. Figures courtesy of Louis Winkler unless otherwise indicated.

The amount of attention people paid to the stars varied from society to society. Most cultures grouped stars into constellations and gave them names. The modern constellations have Mesopotamian and European origins. The Chinese utilized many more, but smaller, constellations; Native Americans used fewer, but much larger, constellations. The mythologies of stars and constellations are sketchy, since stories of the stars were transmitted orally. People seem to have devised mythologies for the purpose of preserving history relevant to their culture, as well as helping them to remember the complex appearance of the night sky. When certain stars appeared near the horizon simultaneously with the Sun, people could reckon what time of year it was.

Ancient observers paid close attention to the positions of the Sun or Moon near the horizon, particularly when they were at their most northerly or southerly positions. In their most northerly position, the Sun and Moon rose highest in the sky and so attained their greatest astrological significance. (In the tropics, this extreme was in the zenith, or directly overhead, twice a year.) At their most southerly position, the Sun and Moon were at the end of one cycle and the beginning of another. To the ancients, this affected not only the celestial body, but also dead people, who were presumed to have gone on to an afterlife associated with the heavens.

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First You Must Measure...

With a little geometry, students can study alignments. Archaeoastronomers measure four important angles (see figure 3 and figure 4):

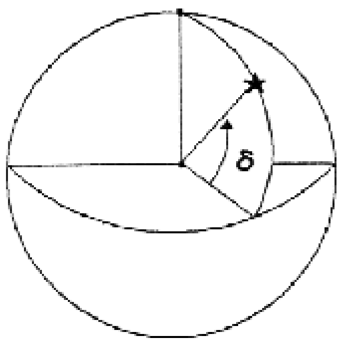

Figure 3
Definition of declination. Declination is the angle between a star and the celestial equator, an imaginary line across the sky that runs parallel to the Earth's equator. To find the celestial equator, hold your arms in an `L' shape and point one arm at the North Star; the other arm will point at the celestial equator.

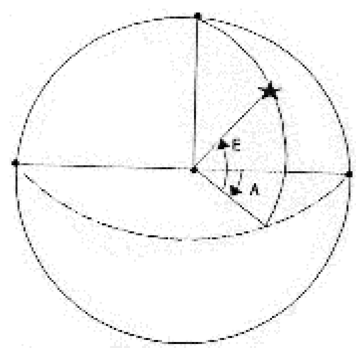

Figure 4
Definition of azimuth and elevation. Azimuth is the compass direction, measured clockwise, between a star and the north. Elevation is the angle between a star and the horizon.

- Geographic *latitude,* the angle between the horizon and the North Star, Polaris. This indicates your position on the Earth, as measured from the equator. You can look up the latitude on a map or, if you visit the site, measure it with a surveyor's transit.
- *Declination,* the angle between Earth's equator and a particular star (angle *delta* in figure 3). Because this angle does not change as the Earth rotates, astronomers use it to describe the positions of stars. You can look up declinations in a catalog of celestial objects.
- *Elevation* (or *altitude*), the angle between the observer's horizon and the star (angle *E* in figure 4). Straight up is 90 degrees, the horizon is 0 degrees. For the North Star, the elevation equals the geographic latitude. For all other stars, the elevation angle changes as the Earth rotates. Elevations can be measured with a protractor on a sketch of the site or with a surveyor's transit.

- *Azimuth,* the angle between north and the star (angle *A* in figure 4), measured along the observer's horizon. North is 0 degrees, east is 90 degrees, south is 180 degrees, and west is 270 degrees. As in the case of elevation, azimuth can be measured from a site sketch or with a transit.

Astronomers are always using these angles to determine where to find a particular star at a particular time of year. They look up the star's declination and convert it to elevation and azimuth. The conversion requires a bit of trigonometry; students who feel comfortable with the subject can find the equation in books such as the *Observer's Handbook,* which the ASP catalog sells, and *Practical Astronomy With Your Calculator* by Peter Duffett-Smith.

The geometry determines which objects are visible from a given site and how the Earth's rotation affects their motion. Stars fall into different categories:

- *Circumpolar* stars are always above the horizon, never rising or setting. From North America, the Little Dipper never sets; it just appears to rotate about a point in the sky called the north celestial pole, marked by the location of the North Star. The north celestial pole is the apparent center of the heavens and the place where, according to many cultures, the soul of the deceased went.
- *Seasonal* stars rise and set, and stay up all night for part of the year. For example, from North America, the constellation Orion is up all night in the winter, and Cygnus in spring. The seasonal stars are the ones that can be used in connection with the Sun to determine approximate times of the year.
- *Perpetually obscure* stars are always below the horizon. From North America, we never see the constellation Centaurus, for example.

Using their knowledge of these angles, archaeoastronomers have analyzed the great pyramid of the pharaoh Cheops (see figure 5). Two air shafts leading to the king's chamber relate to an afterlife, a strong theme found in Egyptian hieroglyphics. The shaft on the north side leads directly to the north celestial pole, which in Cheops' time corresponded to the star Thuban in the constellation Draco. The shaft on the south side is associated with the constellation Orion, which in Cheops' time passed directly through the line of the shaft every day. Orion was a multipurpose god associated with the hereafter.

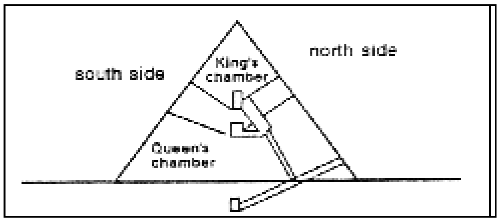

Figure 5
Shafts to King's chamber of Cheops' pyramid. The pyramids, built nearly 5,000 years ago, incorporated the astronomical knowledge of the ancient Egyptians. The sides of the base line up with north, south, east, and west. Two air shafts slope upwards from the main burial chamber. These shafts are aligned with two stars of religious importance: Thuban (the North Star at the time) and Alnilam (the center star in Orion's belt).

...And Then You Can Understand

Geometry also sheds light on the great raised earthworks of the Hopewell. The Hopewell were Native Americans who lived in southern Ohio between the second century B.C. and sixth century A.D. Only a few of their earthworks have survived the farmers' plows and developers' bulldozers. Fortunately, surveys of several dozen monuments by George Squier and E.H. Davis in the mid-1800s preserve the knowledge of the Hopewell (see figure 6). These surveys give the azimuths and the latitude of the sites, so that archaeoastronomers can calculate the declinations of the alignments. Nearly all correspond to noteworthy positions of the Sun or Moon on the horizon.

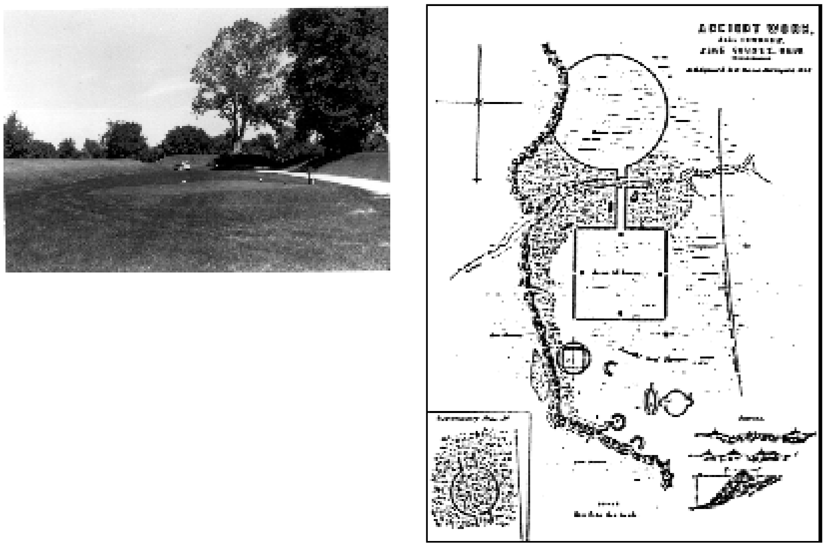

Figure 6
Hopewell earthworks. Right, a diagram of the earthworks at Seal in southern Ohio. Left, the circle and octagon mounds at Newark, Ohio, now a municipal golf course. This photograph looks northeast along what some archaeoastronomers think is a moonrise alignment. Other earthworks have been leveled to build shopping malls. Photo courtesy of E.C. Krupp, Griffith Observatory.

Many of the largest earthworks have squares or octagons associated with circles. The squares and octagons have several openings in their perimeter, but the circles do not. This suggests that ceremonial participants entered the earthworks through the square or octagon openings and proceeded to the center of the circle. Which ceremonies were conducted here, we don't know. Yet nearly all the azimuths defined by the direction of the ceremonial procession are associated with a life hereafter. During the ceremonies, spectators could stand on the surrounding earthworks to view the activities.

Geometry also accounts for the well-known alignment at Stonehenge in England. There, the Sun rises over the Heelstone, as viewed from the center of the site, at the summer solstice. Students can easily verify this for themselves, using figure 7, a protractor, and the equation: sin *delta* = cos *phi* cos *A*.

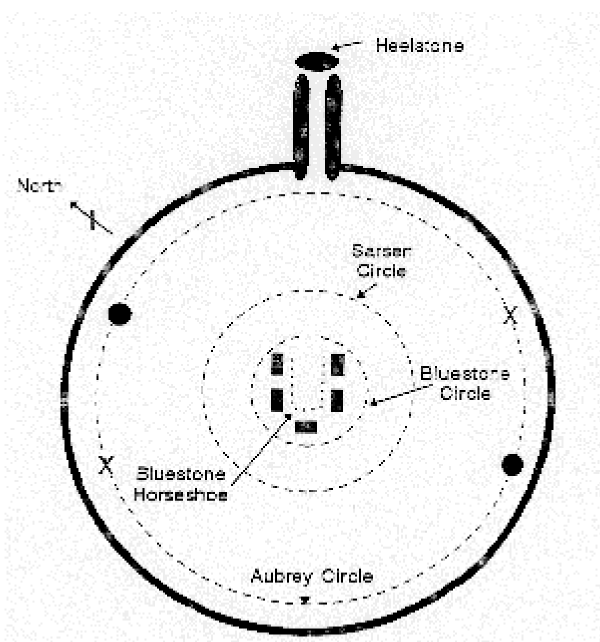

Figure 7
Layout of Stonehenge in Wiltshire, England. Stonehenge is the most famous of ancient astronomical sites. If you stand in the center of the site and look northeast through the stone arches, you see the Heelstone, which points to the place where the Sun rises in midsummer. Stonehenge was built and rebuilt beginning 5,000 years ago.

With the protractor, measure the azimuth of the Heelstone as seen from the center of the Aubrey Circle. It should be about *A* = 50 degrees. The direction of geographic north is indicated on the figure. Then, on a map of England, look up the latitude of Stonehenge, near the town of Salisbury. It should be about *phi* = 51.2 degrees. By substituting *A* and *phi* into the equation, find the declination. It should be *delta* = 23.7 degrees, which is close to 23.9 degrees, the declination of the summer solstice position at the time Stonehenge was built.

The same mathematical expressions demonstrate that this sighting cannot determine the exact *time* of the solstice. The sighting is of low precision. Because the Sun's path moves slowly at this time of year, there are dozens of days when the positions of the Sun are indistinguishable. From this we conclude that Stonehenge was a great ceremonial center, but not an observatory.

Although naked-eye observations cannot determine the precise time of the solstice, they can determine the precise time of the *equinox*. At this time of year, the Sun's path changes considerably from day to day, so that the positions on successive days are quite discernible. The length of time it takes the Sun to return to the same equinox is the year. If a long enough baseline in time is used, the year can be determined with precision.

By dividing the year into quarters, ancient peoples predicted the time of the solstices. Whether these predictions agree exactly with our modern calculations does not matter. Generally people don't mind if they get the date of their holidays wrong, as long as everyone agrees to celebrate on the same day. For example, it is unlikely that Christ was born on December 25. If Christians meant to celebrate Christmas on the winter solstice, they are a few days off. But they don't care, since they have *agreed* to celebrate Christmas on December 25 (in North America and Western Europe).

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Changes in the Sky

The appearance of the night sky has remained roughly the same for millennia, but has changed in subtle ways. Different stars appear behind the Sun because of a phenomenon known as *precession*[see "To Every Season There Is a Reason,'' *The Universe in the Classroom,* Winter/Spring 1995]. The positions of the planets also change continuously.

Simulating the current night sky is easy to do with a star chart or planisphere, which accounts for the time, date, and geographic latitude. But these charts don't work for ancient cultures, because of precession. To go back in time, archaeoastronomers and teachers can turn to personal computers and any of a number of software packages. The shareware *Skyglobe* operates on IBM-compatible computers; the ASP sells *Dance of the Planets* (IBM) and *Voyager II* (Mac) through its catalog. Such simulations can be used to study ethnic groups of the past. For example:

- The simultaneous appearance of the Sun and star Sirius on the horizon, in the middle of the third millennium B.C. as seen from Giza, Egypt. When Sirius, in the constellation of Canis Major, appeared on the horizon at the same time as the Sun, the Egyptians knew it was the summer solstice. This marked the time when the Nile flooded. The silt deposited by the overflowing Nile was important to Egyptian agriculture.
- The merger of the images of the planets Venus and Jupiter on June 16, 2 B.C., as seen from Bethlehem, Palestine. This merger is a possible interpretation of the Star of Bethlehem.
- The appearance of the Crab supernova during July 1054, as seen from Beijing, China, just before sunrise, with the crescent Moon and the planet Mercury nearby. The supernova was considerably brighter than Venus, but probably not as bright as the full Moon.
- The simultaneous appearance of the Sun and the Pleiades near the horizon as seen from Teotihuacan, Mexico, about two millennia ago. The Pleiades is a small cluster of stars in the constellation of Taurus, and the date corresponds to one of the times the Sun passed through the zenith.

It takes some trial-and-error to find the date of these events, but the exact position and time are not needed; the events could be seen from many places and at various times of night.

Messages on a Hillside

People did not just watch the sky; they evidently tried to communicate to it. The large earthen figures of the British Isles and Peru are huge and difficult to recognize from the ground; perhaps they were constructed for viewing by the gods. Examples include the Long Man of Wilmington, England and the Owl Man of Peru (see figure 8 and figure 9). Although the true intentions of the people who constructed the figures is still a mystery, students can make informed guesses by comparing the figures to images intended by modern scientists for extraterrestrial civilizations.

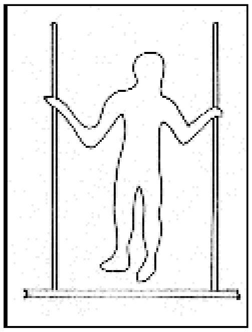

Figure 8
Long Man of
Wilmington, England.

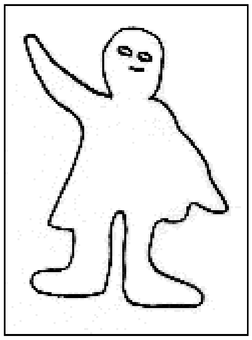

Figure 9
Owl Man of Peru.

Examples of modern messages include:

- Radio signals beamed toward the globular star cluster M13 in the constellation of Hercules, with the large radio dish at Arecibo, Puerto Rico [see "The Search for Extraterrestrial Intelligence," *The Universe in the Classroom,* Spring 1992].
- The plaque fixed to the *Pioneer* spaceprobe (see figure 10).
- Encapsulated photographs placed in the interplanetary vehicle *Voyager* (now available on the CD-ROM *Murmurs of Earth*).

Students can tabulate and analyze the striking similarities that exist among the modern and ancient images. They could also construct an original pictorial message for extraterrestrial civilizations, explaining why they chose particular symbols. If a nearby football field is nearby, students can map their picture on graph paper and lay it out on the ground.

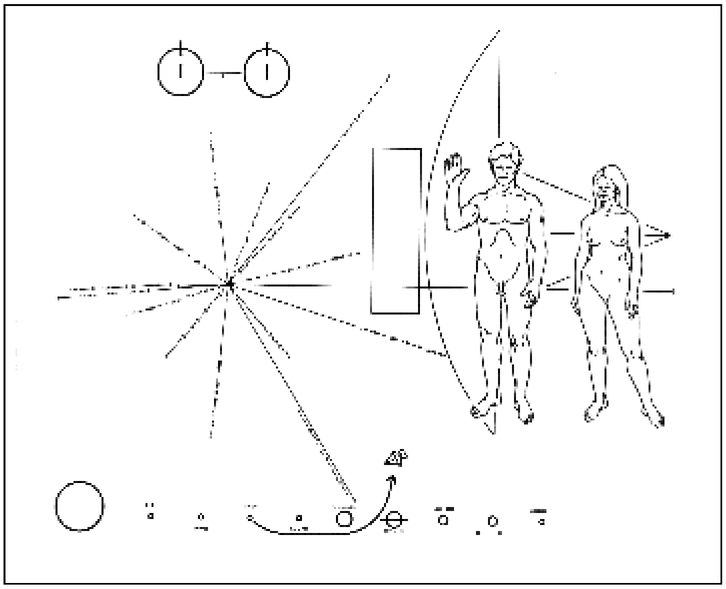

Figure 10
The Pioneer plaque, designed as a message to extraterrestrial beings. The plaque shows where Pioneer came from and who sent it. The barbell at top left represents the hydrogen atom; the radial pattern at left center shows the position of the Earth with respect to pulsing stars. Photo courtesy of NASA.

Deciphering the unique number system of the Maya is another archaeoastronomy topic that involves a minimum of math. Unlike our modern Arabic system -- 10 digits, strung out horizontally, representing powers of 10 -- the Maya used digits, stacked vertically, representing powers of 20 (see figure 11). Several collections of early writing of the Maya survive; numbers from them can be read and in some cases interpreted (see figure 12). One document, for example, shows the 584-day synodic period of Venus and the associated Maya god, Kukulcan [see "Ancient Astronomy in Mexico and Central America,'' *Mercury,* January/February 1975, p. 24; "Emissaries to the Stars: The Astronomers of Ancient Maya,'' *Mercury,* January/February 1995, p. 15]. The synodic period of revolution of a planet is the length of time it takes to return to the same position relative to the Sun, as seen from Earth.

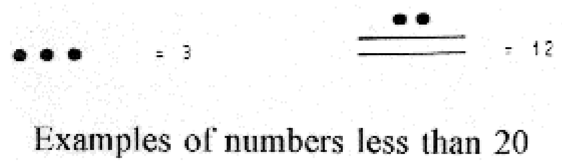

Figure 11
Mayan numerals. A dot means 1, a horizontal bar means 5. These symbols are an abstraction of hand-counting gestures from pre- literate times. The Mayas used base-20 notation, as opposed to our base-10 notation; each Mayan numeral represents a number from 1 to 19. The numerals can be written either horizontally or vertically; the dots appear above or to the left of the bars. The Maya often decorated their numerals and adopted special glyphs for important numbers.

As archaeoastronomers study the calendar of the Maya, they find ceremonial intervals of time that can be related to the year and the synodic period of Venus. These cycles are represented by large, whole numbers; when multiplied by other cosmologically significant whole numbers, they result in a single, very large, sacred number, 37,960.

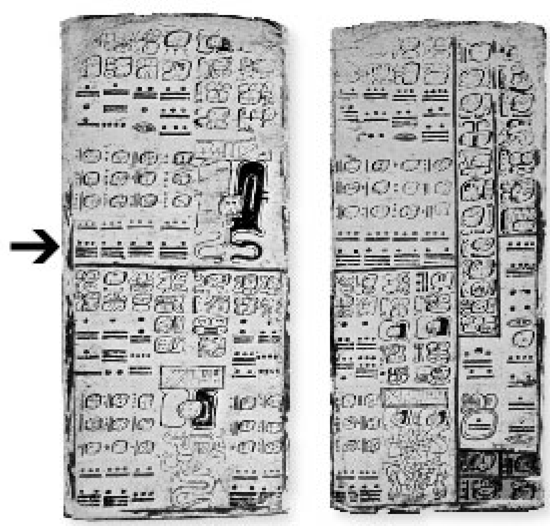

Figure 12
The Maya Eclipse Table, from the Dresden Codex. There are plenty of numbers to decipher! For example, the arrow points to a number that consists of two numerals. The top numeral, three dots and a bar, equals 8. The bottom numeral, two dots and three bars, equals 17. Since the Mayas used base-20 notation, this number is 8 x 20 + 17 = 177. The number 177 was important in eclipse predictions. Photo courtesy of G. Kohlmann and L. Blanco, CIEA del Instituto Politecnico Nacional, Mexico.

The archaeoastronomy of numerous societies over the millennia shows remarkable similarities and differences in the interpretation of the appearance and motions of the celestial bodies. Worldwide similarities are mostly in timekeeping and the association of a hereafter life with the heavens. The differences are mostly in the ways and times that particular holidays were determined.

In spite of the ancient origin of the diverse ethnic topics of archaeoastronomy, the subject is quite contemporary in character. As the world shrinks with advances in technology of communications and travel, the more we are required to understand the global community and its ethnic diversity.

LOUIS WINKLER teaches astronomy to nonscience students at Pennsylvania State University in University Park. His instruction includes large lectures with numerous computer demonstrations, small laboratories with students operating computers in many activities, and a mathematically founded course in archaeoastronomy.

Archaeoastronomy Resources

The educational materials listed below relate to all the topics covered here, as well as many more. All publications are by the author, and prices include postage and packaging. Direct orders and inquires to Louis Winkler, 636 Belmont Circle, State College, PA 16803.

- *Archaeoastronomy / A Science Module for High School and Conscience College Students / Text and Activities.* Includes Harvard Graphics and a teacher's manual, 51 pages, $39.95.
- *Skyglobe Activities.* Detailed instructions for simulating skies for different times and latitudes, 6 pages, $9.95.
- *Popular Archaeoastronomy.* Used in a college level course, hand drawn sketches, 220 pages, $34.95.