# McGraw-Hill Yearbook of Science & Technology

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1985

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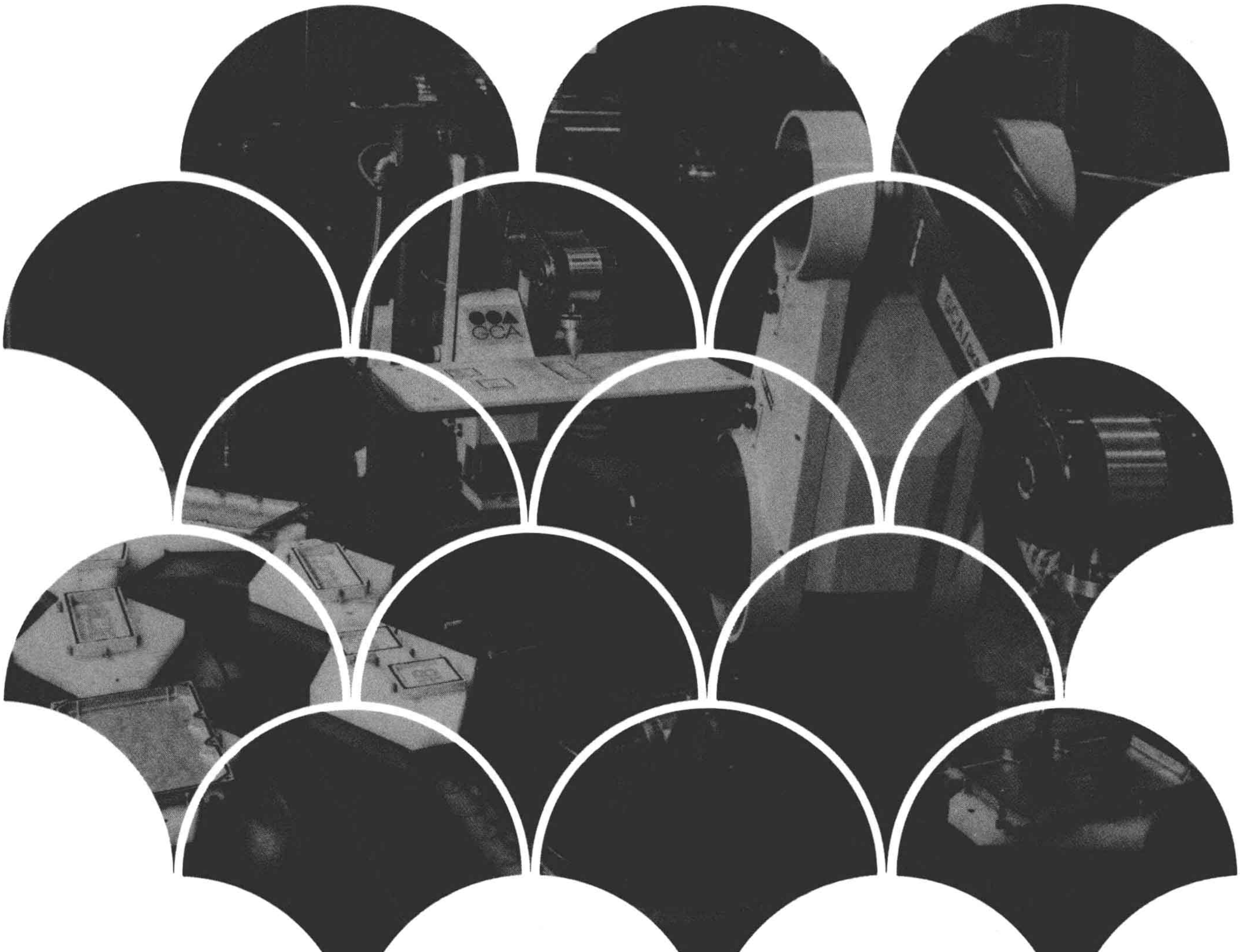
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# Preface

The 1985 *McGraw-Hill Yearbook of Science and Technology*, continuing in the tradition of its 22 predecessors, presents the outstanding recent achievements in science and technology. Thus it serves as an annual review and also as a supplement to the *McGraw-Hill Encyclopedia of Science and Technology*, updating the basic information in the fifth edition (1982) of the Encyclopedia.

The Yearbook contains articles reporting on those topics that were judged by the consulting editors and the editorial staff as being among the most significant recent developments. Each article is written by one or more authorities who are actively pursuing research or are specialists on the subject being discussed.

The Yearbook is organized in two independent sections. The first section includes five feature articles, providing comprehensive, expanded coverage of subjects that have broad current interest and possible future significance. The second section comprises 159 alphabetically arranged articles.

The *McGraw-Hill Yearbook of Science and Technology* provides librarians, students, teachers, the scientific community, and the general public with information needed to keep pace with scientific and technological progress throughout the world. The Yearbook has successfully served this need for the past 23 years through the ideas and efforts of the consulting editors and the contributions of eminent international specialists.

SYBIL P. PARKER
EDITOR IN CHIEF

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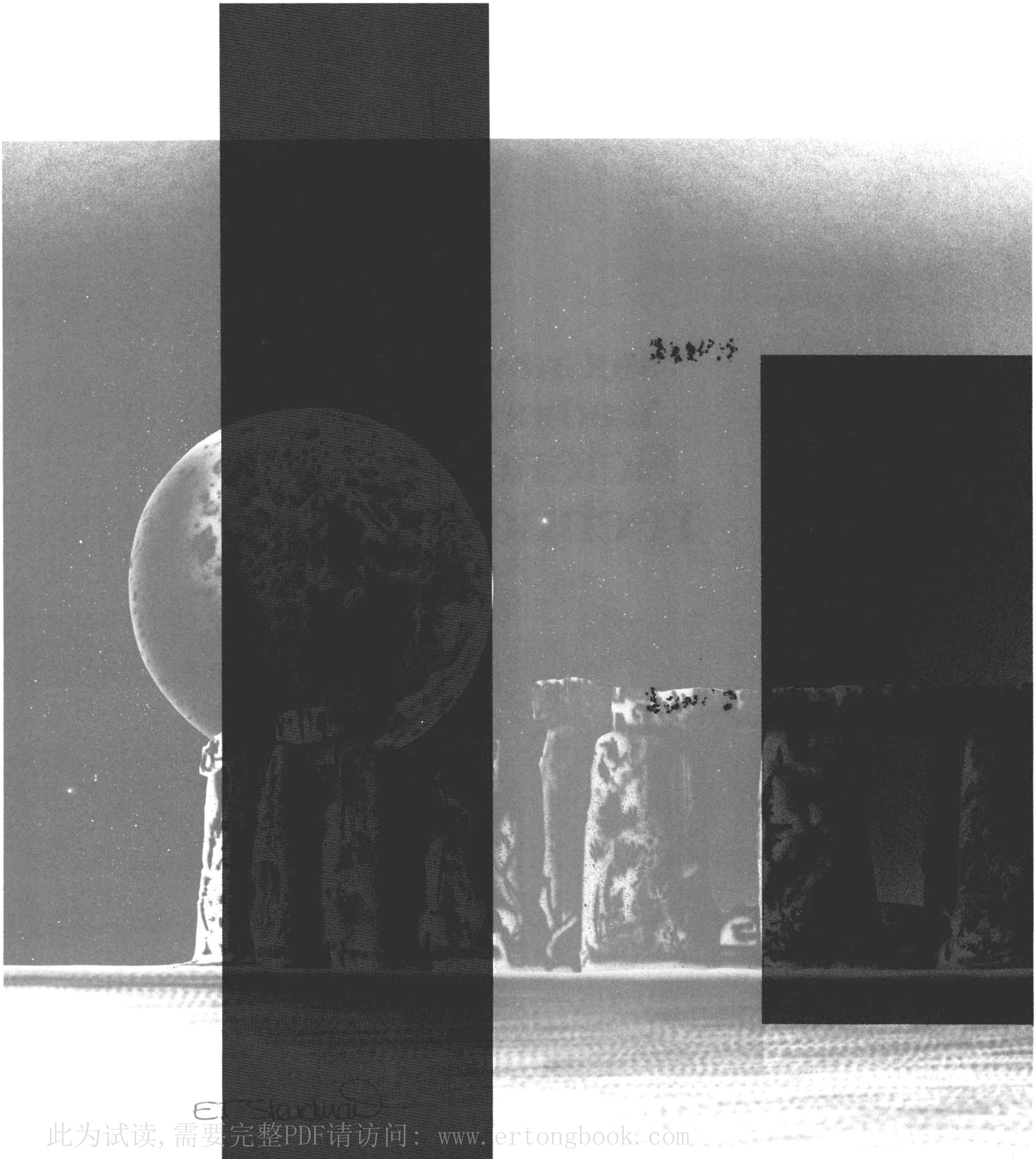
# Archeoastronomy



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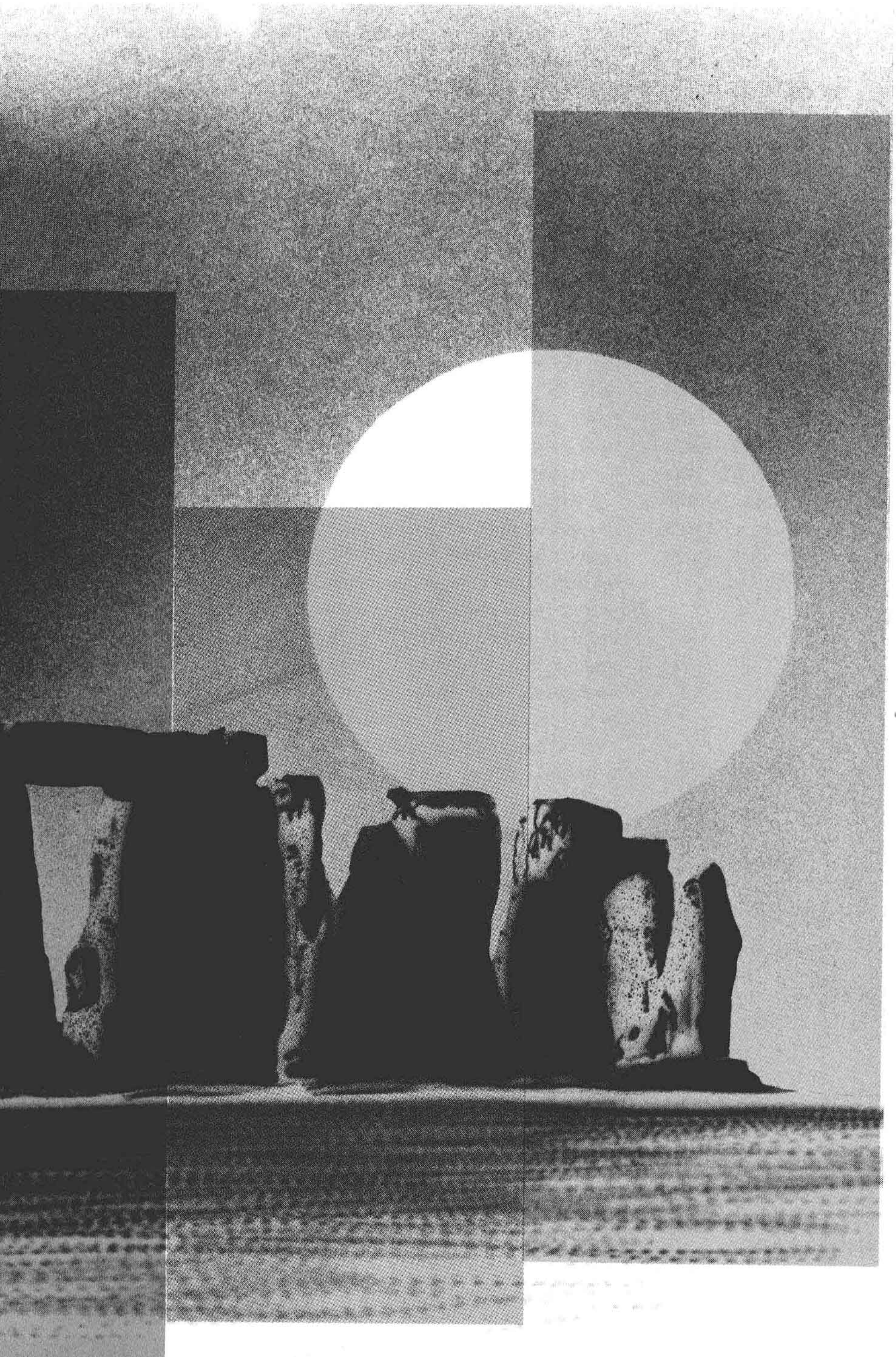
**MICHAEL ZEILIK**

*Michael Zeilik is an associate professor of astronomy at the University of New Mexico. He serves as a member of the Education Board of the American Astronomical Society and the Editorial Board of the "Journal of College Science Teaching." His research interests center on star birth, binary systems with solar-type stars, and archeoastronomy in the Southwest. Recipient of a doctorate in astronomy from Harvard Unversity, he is the author of two books.*



Archeoastronomy is a young scientific field that attempts to determine how much astronomy prehistoric people knew and how it influenced their lives. It involves the work of many disciplines—astronomy to chart the heavens, archeology to probe the cultural context, engineering to survey sites, and ethnology to provide clues to the cultural past. Born in the controversy over Stonehenge, modern archeoastronomy has yet to reach maturity. At its best, it amalgamates the talents of diverse experts; at its worst, it degenerates into controversies over intellectual turf. Despite these problems, archeoastronomy has prompted valuable insights into the astronomy of the past—even to revolutionizing some of the models of prehistoric cultures.

This article highlights some fruitful work in archeoastronomy. It touches on the Old World and New World, especially the southwestern part of North America. This restricted focus does not imply that archeoastronomers do not work throughout the world. Researchers in Africa, for instance, have just started to put together the astronomical past of that continent. Any prehistoric or preliterate people has their story to discover.

Of course, it can never be known for certain if archeoastronomers' ideas about the past are right. That is the ultimate weakness of all archeology. But researchers stand on firmer ground if ethnographic information is available to bolster the archeology. That is where the New World has a distinct advantage over the Old: here still live the descendants of people who were observing the sky before the arrival of Europeans. Their culture, although suffering from pressures to change, serves as a caution and guide to interpreting the past. Clearly, to gain a real understanding of ancient people, one needs to know their cultural heirs.

### NAKED-EYE ASTRONOMY

Before plunging into the astronomy of the past, one must review briefly the kinds of observations of celestial cycles that can be made without a telescope—the same as were made by ancient people. For the purposes of this article, only the Sun and the Moon will be considered.

**Sun.** The Sun will be discussed first, since it is the easier of the two. Most people are aware that the height of the Sun in the sky at noon changes with the seasons: highest in the summer, lowest in the winter, and in between during spring and fall. The Sun reaches its highest noon point on the summer solstice (around June 22); drops to its lowest on the winter solstice (December 22); and is at the middle at the equinoxes (March 21 and September 23).

There is, however, less familiarity with the Sun's seasonal motion along the horizon. On the day of the summer solstice, for example, the Sun rises the farthest north of east that it will get for the year (Fig. 1). On the equinoxes, it rises due east. And on the winter solstice, it reaches its farthest point south of east. (The same occurs, mirror-reflected, at sunset.)

Thus, from summer to winter, the sunrise point moves to the south; from winter to summer, to the north. The rate at which the sunrise point moves on a day-to-day basis varies during the year. At the solstices, the sunrise points do not noticeably move for a few days. The Sun appears to "stand still" (the meaning of the word solstice). In contrast, at the equinoxes, the sunrise points move at their fastest rate—by almost the Sun's own diameter in a day at midlatitudes.

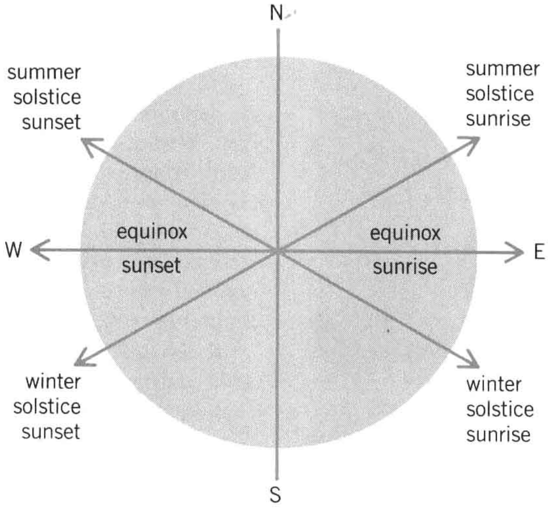



Fig. 1. Angular swing of the Sun along the horizon at rising and setting from solstice to solstice. The angle is for a latitude of 36°, that of the United States' Southwest.

This seasonal voyage of the Sun along the horizon differs with latitude with respect to the size of the solstice-to-solstice swing along the horizon. At 36°—the latitude of the Southwest—the swing amounts to 60°, one-sixth of the total horizon circle (Fig. 1). Farther north, the arc is greater; at the latitude of Stonehenge, it is about 80°. At more southerly latitudes, the arc is less; at 20° (middle of Mexico), it varies a total of 50°. So the Sun's seasonal dance appears most dramatically at far-northern latitudes.

**Moon.** The Moon's most obvious change is that of its phases, referring to how much the side turned to the Earth is illuminated. At new moon, that side is dark. At first and last quarter, half the side is illuminated. At full moon, the entire side is bathed in sunlight. The month of phases (synodic month) is simply the time from one phase of the Moon to the repetition of that phase, say from full moon to full again. It averages 29.5 days.

Suppose the point of moonrise is observed for a month. It would be seen that the moonrise point varies from a point farthest south to one farthest north during the month. In other words, the moonrise motion mimics the sunrise motion but occurs at a much faster rate, about 12 times as fast. Depending on when the observations are made, the moonrise arc may be larger than, the same as, or smaller than the sunrise arc. This is because the Moon's path in the sky with respect to the stars is not the same as the Sun's, but is inclined at about 5°, crossing the Sun's path at two points. Thus, the Moon can appear as much as 5° below the Sun's path, 5° above it, or right on it.

**Complication.** The matter is complicated in that the two points where the Sun's and Moon's paths cross (the nodes) move with respect to the stars, taking 18.6 years to circle the sky once. The result is that when the Moon's path reaches its highest point above the Sun's, the Moon's horizon swing is greater than the Sun's. When the two line up, the swings are the same. When the Moon's path falls below the Sun's, the total arc is less.

How much greater or less can be considerable. At a latitude of 36°, the Moon moves through a maximum arc of 70° and a minimum arc of 45° during the 18.6-year cycle (Fig. 2). In analogy to the Sun standing still at the solstices, the two extremes of the Moon's positions are also called standstills: major standstill for the maximum angle and minor standstill for the minimum, with 9.8 years between. Again in analogy to the Sun, these angular changes are more pronounced at more northern latitudes.

Much of the time while the Moon moves from minor to major standstill, the Sun's arc encompasses that of the Moon's. During this time, any alignment that works for the sun will work for the Moon as well. So the best way to ascertain that an alignment tracks the Moon is to see if it works when the Moon's swing lies outside the angle of the Sun. Then the alignment can relate to the Moon but not the Sun, while the Moon is near major standstill.

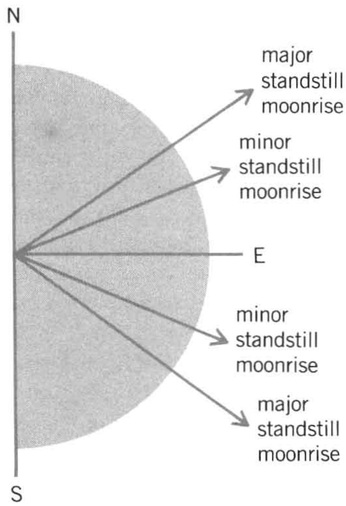



Fig. 2. Monthly angular swing of the Moon along the horizon at moonrise, for times of maximum angle (major standstill) and minimum angle (minor standstill). The latitude is 36°.

**Horizon-marking system.** It can now be seen how a simple horizon-marking system is set up. One must first find a spot to stand with a clear view of the horizon, which should have at least a few prominent features over the angular range of the sunrise (or sunset). Then it is necessary to return to this spot daily and note the rising positions of the Sun throughout the year at significant times: the solstices, when the Sun does not move, the equinoxes (halfway between the solsticial points), and, perhaps, important times to plant crops. One then has a basic solar calendar. Since the Sun's positions at various dates along the arc remain fixed for a long time, once established the calendar will be good for many years.

With this basic solar and lunar astronomy in mind, the relics of the past that may have had astronomical uses can be examined.

### THE OLD WORLD: STONEHENGE AND OTHER MEGALITHIC SITES

In a direct sense, Stonehenge created the interest in archeoastronomy—revealing its inventive strengths, highlighting its weaknesses, and starting a confrontation between astronomers and archeologists that has only recently settled into a creative interaction. Stonehenge exemplifies the problems and potential of the archeoastronomical enterprise.

When one hears of Stonehenge, the massive upright stones that form a central horseshoe and circle (some 65 ft or 25 m in diameter) in the center of the site are envisioned (Fig. 3). Such large stones are commonly called megaliths in Great Britain; this term has come to be applied to all sites where stones, even fairly small ones, are arranged in some pattern. The horseshoe opens out on the main axis of Stonehenge, called the Avenue. Some 260 ft (80 m) from the center, within but not in the center of the Avenue, sits the tilted Heel Stone. This main axis of Stonehenge aligns roughly with the summer solstice sunrise, a fact noted more than 200 years ago. "Roughly" is emphasized because the Sun rises somewhat to the left of the Heel Stone as seen by an observer at the center of the structure.

Despite earlier interpretations of the astronomical

Fig. 3. The inner great trilithons of Stonehenge. (*Courtesy of O. Gingerich*)

use of Stonehenge, the modern controversy developed in the 1960s. Gerald Hawkins, an astronomer, applied the brute-force calculational power of a then-novel electronic computer to search for astronomical alignments to the Sun, Moon, stars, and planets for the main features of the site. He found them for the Sun and the Moon, including moonrise and moonset during major and minor standstills. Later, he proposed that the site could even have been used to warn of the times of possible eclipses. That assertion contradicated the rather confident claims of archeologists concerning the primitive nature of the society of the times.

Radiocarbon dates indicate that Stonehenge was built over a span from 3100 to 1000 B.C. in three separate stages. These cover the Neolithic era to the Bronze Age. The muddle over the astronomical use of Stonehenge comes, in large part, from the fact that it is a mosaic of structures, most likely built by different people, perhaps for different reasons. The great stones were erected between 2000 and 1500 B.C.; it is not clear what their cultural connection was to the earlier structure.

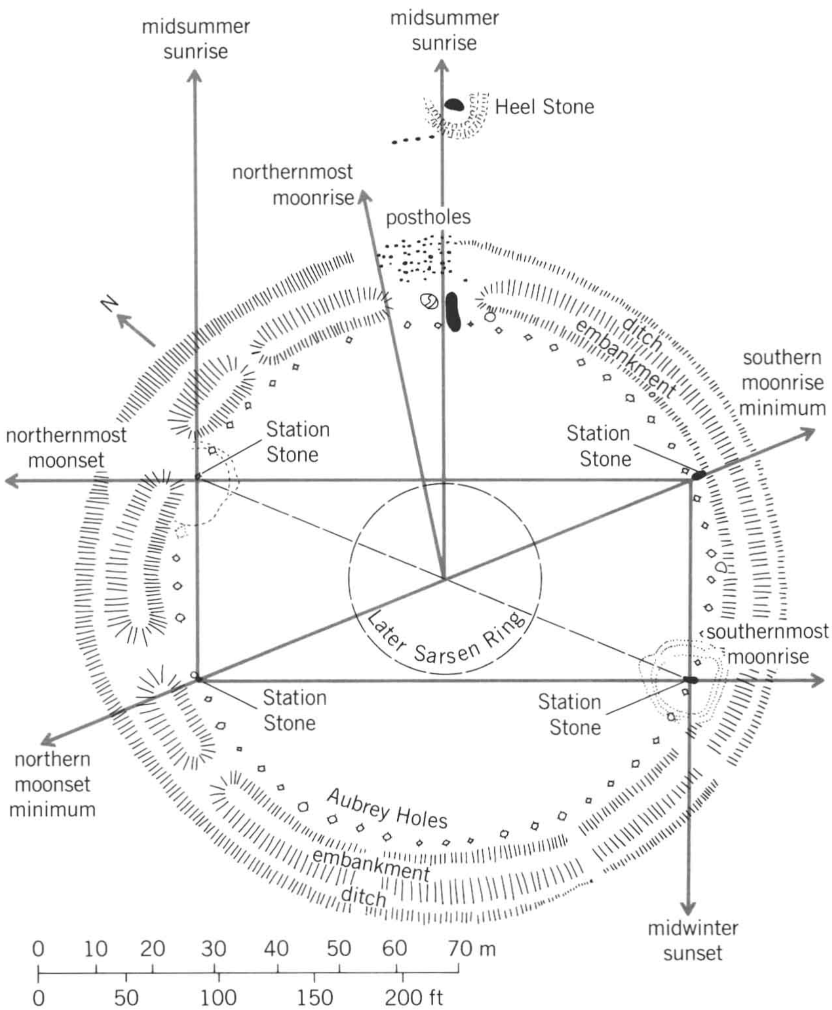



Fig. 4. Diagram of the major features of Stonehenge that may have been used astronomically. (*After O. Gingerich, in K. Brecher and M. Feirtag, eds., Astronomy of the Ancients, MIT Press, 1979*)

It is the earliest parts of Stonehenge, constructed between 3100 and 2100 B.C., that have the most astronomical promise (Fig. 4). These comprise the outer earthwork ring and ditch (about 330 ft or 100 m in diameter and 7 ft or 2 m high) broken only in the direction of the Heel Stone; a ring of 56 holes (the Aubrey Holes) that were dug and then quickly filled with chalk; an array of postholes near the opening to the Heel Stone; and the four Station Stones that lie along the circle of the Aubrey Holes.

Now with just these elements, lunar and solar observing can been done (Fig. 4). The four Station Stones form a fairly good rectangle. From its center, the summer solstice Sun rises along the opening to the Heel Stone. The short sides of the rectangle are parallel to this line, so they point to the summer solstice sunrise and winter solstice sunset. The long sides of the rectangle and its diagonals line up the moonrises and moonsets at the major and minor standstills.

Hawkins also contended that the inner megaliths of the horseshoe sighting outward through the ring around them also aligned to important settings and risings of the Sun and Moon. Hawkins then argued that the Aubrey Holes were used to indicate "danger seasons" when eclipses might occur. One lunar eclipse cycle (it is not the only one) takes 56 years (three times the 18.6-year standstill cycle). In this picture, the Aubrey Holes were used as a counter to keep track of the years within these cycles.

Does this all work out? Yes and no; both astronomical and archeological criticism can be applied. First, Stonehenge can be criticized as a lunar eclipse anticipator. A 56-year cycle does exist, but once worked out, it fails to apply after a few cycles. Also, to work out the cycle in the first place requires hundreds of years of careful observing and a preserved record (probably oral) from which to infer the cycle. Given problems with bad weather hiding eclipses and the difficulty of preserving a nonwritten record for such a long time, the establishment seems highly impractical. Second, the purported alignments with the inner megaliths are also questionable; the gaps are rather wide and, depending on where one stands, can cover a large angle on the horizon. Their crudeness suggests that alignments attributed to them are probably accidents of the layout.

The inner rectangle seems much better astronomically; because of its fairly large size (112 by 260 ft or 34 by 79 m), it results in fairly accurate sightlines. These also contain nice symmetries, which increase their appeal. However, the archeologist R. J. C. Atkinson notes that only two of the four stones actually survive; of these two (91 and 93), one has fallen and one seems to be a later replacement. So the original positioning of the stones is not known with accuracy.

All told, the older parts of Stonehenge make a reasonable solar and lunar observatory. The sloppiness (of about a degree of arc) should not be considered offensive, for the modern fetish with accuracy may be a cultural trait that was absent among Neolithic cultures. The extensive symmetries are very appealing and more important than the accuracies of the sightlines. Finally, even archeologists admit that the summer solstice alignment, more than any other, appears as an intention of the original construction.

The basic problem in all of this is that even if the astronomy works, one cannot be sure of the cultural context. Horizon watching can be used simply to tell the time of year or more forcefully to set a ritual calendar. Since megalithic societies have left few clues about their thinking—it can only be inferred from their material remains—the only hope of guessing about the importance of astronomy is to look at other sites along with Stonehenge.

That has been done for some hundreds of sites (in Great Britain and France) by Alexander Thom, an engineer. Long before the Stonehenge controversy, Thom started very carefully surveying prehistoric sites in the British Isles. He first found indications of alignments for the solstices and equinoxes, then for the lunar standstills. More recently, he has promoted the idea that megalithic astronomers made extremely accurate observations of the Moon (using very distant foresights, tens of kilometers long) so as to pick out very small, long-term variations of the Moon's motions.

The pervasiveness of the sightlines to astronomically important observations implies that megalithic cultures knew about the astronomy and deemed it important enough to construct numerous observing stations. More so than Hawkins's efforts, Thom's work forced archeologists to account for the astronomy in these cultures. The validity of precise lunar observations remains to be shown. They have been questioned, and different analyses lead to the other conclusion: the Moon was observed, but not with the precision inferred by Thom. From the view of cultural necessity, it is unclear how such precision would benefit megalithic people in terms of simple survival value. Even anticipating eclipses has dubious value—at most, a device to enhance the predictive dimension of priestly power.

Still, despite disputes over fine points, the archeoastronomers have forced a reexamination of the standard picture of megalithic life. That certainly marks one of the positive aspects of the field. Certainly astronomy was important, even if it is not known exactly how or why. Before the 1960s, such a concept was ignored for the most part by archeologists.

### SKYWATCHING IN THE NEW WORLD

Compared to the Old World, the New World archeoastronomer has the advantage of the survival of remnants of the cultures from pre-Columbian times. Even the great destruction wielded by the Spanish in Mesoamerica—especially their burning of Mayan books that contained much astronomy—could not wipe out completely the astronomy inherent in that culture.

Turning northward, the Spanish marched on a fruitless search for the fantastic Seven Cities of Cíbola, said to be made of gold. They found none. But they did encounter the adobe villages, which they called *pueblos*, of the native peoples who had lived in them at least a thousand years prior to the arrival of the Spanish. Many of these pueblos disappeared in historic times (from 1540 onward); those that survived are the cultural connection to the people called the Anasazi, who occupied a vast area in the Southwest, centered on the Four Corners area (where New Mexico, Arizona, Utah, and Colorado now meet). Here stand ruins deserted from A.D. 1000 to 1400, stone and adobe constructions that provide some insight into the life of the Anasazi.

The Hopi pueblos (in Arizona) and Zuñi (in New Mexico) provide the best clues to the past because these villages were touched only lightly by the Spanish (in contrast to the submission demanded of the pueblos along the Rio Grande). Ethnographers worked here at the turn of the century and gathered cultural information before the severe pressures on the part of Anglos occurred. It is inferred that the Hopi and Zuñi are cultural descendants of the Anasazi (although it is not known from which specific Anasazi sites). So these pueblos preserve a remarkable cultural continuity with prehistory.

At Hopi and Zuñi, astronomy plays a central role in the agricultural and ceremonial life. The seasonal cycle of the Sun sets the ritual calendar and determines the times of specific crop plantings and harvestings. The dry Southwest demands an observant farming, for raising crops is a marginal activity; in the past, failed crops could mean death. So solar astronomy carries a practical weight as well as a religious one. The counting of months by lunar phases plays a secondary role in tracking the ritual calendar.

The observing is invested in a religious office, usually called the Sun Chief. He watches daily from a special spot within the pueblo or not far outside of it. The Sun Chief carefully observes sunrise (or set) relative to the horizon features. He knows from past experience what points mark the summer and winter solstice and the times to plant crops. These he announces within the pueblo, usually ahead of time so that ritual preparations can be carried out. The winter solstice—called Soyal at Hopi and Itiwanna at Zuñi—marks the heart of the ritual year. For the Hopi, each month was named, and the passing of a month sometimes was used to set the time for a ceremony.

Along with horizon features, the Zuñi Sun Watcher, called Pekwin, used a natural pillar to chart the seasons. When the shadow cast by the pillar lined up in a special fashion, Pekwin knew that the summer solstice would soon occur. Also, within the pueblo, special windows and portholes allowed sunlight to hit special plates or markings on the walls at significant times of the year. So light and