CHAPTER ONE

A Sky for All Seasons

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For the peoples of antiquity the sky was always overhead. What happened there repeated itself, and these repetitions made it possible to structure time and the world, as they do for us today.

Some of the cycles are simple. Others are complex and difficult to master, and today, when we are removed by city lights and air pollution from a clear view of the sky and are distracted by our daily affairs, most of us are not even aware that the cycles exist.

The sun persists in its daily risings and settings, but through the year the sun's first and last appearances vary in time and place. In consequence, we have seasons. The moon, too, alters its face, waxing and waning through the month. The moon has far subtler motions also, however, and had we time and inclination, we could eventually discover them.

Although the sun and the moon go through their changes, the stars at least seem ever constant. But the stars, too, change, from season to season, and through the long cycle of precession, even their seasons change.

In this chapter the daily and annual motion of the sun is explained and related to the observations the early astronomers made. The moon's monthly pattern of phases, its 18.61-year cycle of regression, and its tiny wiggle of a perturbation are also described and explained, as are eclipses, which depend on these lunar variations. The progress of the stars, too, is explained, and particular attention is given to the phenomenon of heliacal rising.

We have always looked to the heavens for orientation and perspective. It satisfies a need. It may be what our brains require to perceive the world at all. Anything might do the job, but the heavens do it well. They repeat themselves over and over, and no one can tamper with them.

THE SIMPLE SUN

The sun, the brightest object in the sky, exhibits a daily motion. It rises roughly in the east and sets in the west, as do all celestial objects. This apparent motion is due, of course, to the rotation of the earth on its axis, but from the purely observational point of view of the ancient astronomers it also hardly matters. The important thing is the phenomenon itself, and we are looking for evidence of its having been observed.

The cardinal directions—north, south, east, and west—are devices with which we orient the world. They are based upon two fundamental places of reference, the horizon and the zenith. The horizon is where the earth meets sky, and it surrounds the observer. Ideally it is the circular boundary of the sky at ground level for an observer located at the circle's center. Naturally, foreground objects often obscure the true horizon, but it is still possible to imagine it without difficulty. The zenith is the point in the sky directly overhead, directly above the observer. These two concepts, a circle and a point, constitute a very personal reference frame. In this very democratic cosmos everyone has his or her own horizon and zenith. If one moves ever so slightly, the bounds of one's horizon and the direction of one's zenith change.

The cardinal directions are all located on the horizon. It is as if someone had painted or lighted signs out on the horizon to indicate those directions. They would have no meaning were the earth not in rotation. The earth rotates from the direction we call "west" to the direction we call "east." Because we are rotating with the earth and because everything else on the earth is rotating with us, we have no sensation of motion. The sun, moon, and stars all move around, to be sure, but their apparent motion is sufficiently slow to deceive us.

Once east and west are established, say, by the risings and settings of celestial objects, it is a simple matter to go halfway between them and call one direction north and its opposite south. North has a special meaning, though, because we see the earth's rotation reflected in the sky. In the northern hemisphere it looks as though the whole sky is spinning around a single point. The point is called the "north celestial pole," and it is just a direction in space, now roughly toward the star Polaris, toward which the earth's rotational axis points.

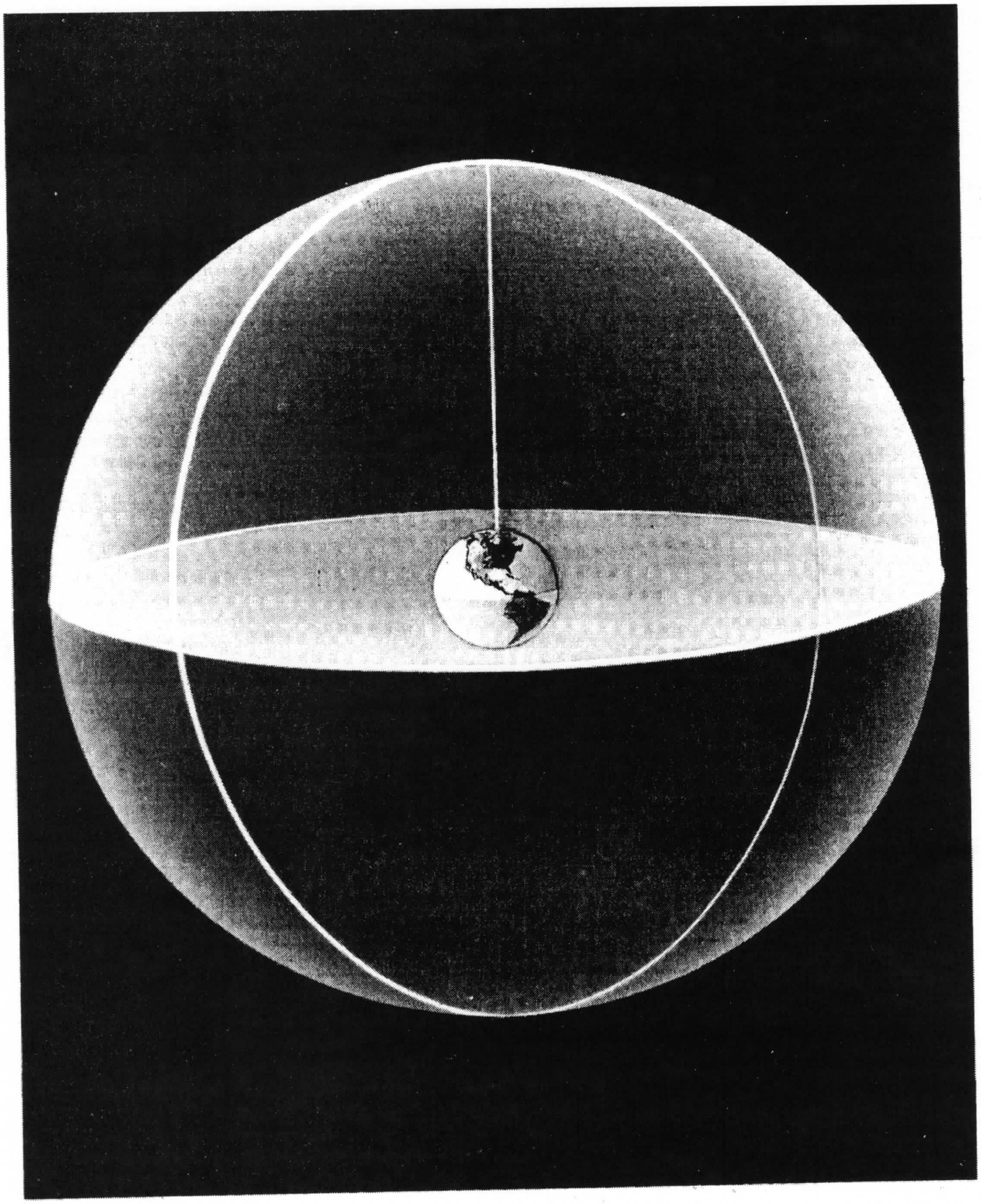
The earth is roughly spherical in shape, and this means that one's movement to the north or south will change the zenith. The observer's view of the heavens is therefore altered by his movement along the earth's surface. In particular, as an observer moves north, the north celestial pole moves higher in the sky. As an observer moves south, it moves closer to the horizon. This makes sense. If one travels far enough north to stand on the earth's north pole, the sky's north pole will be directly overhead. All of the visible stars will appear to circle around the celestial north pole, as the earth rotates, and all visible stars will remain above the horizon.

To all but the most precise instruments of measurement, the rate of the earth's rotation is extremely uniform and constant. This uniformity produces an apparent sequence of repetitive events in the sky—sunrises, for instance—and permits the measurement of time through celestial observations.

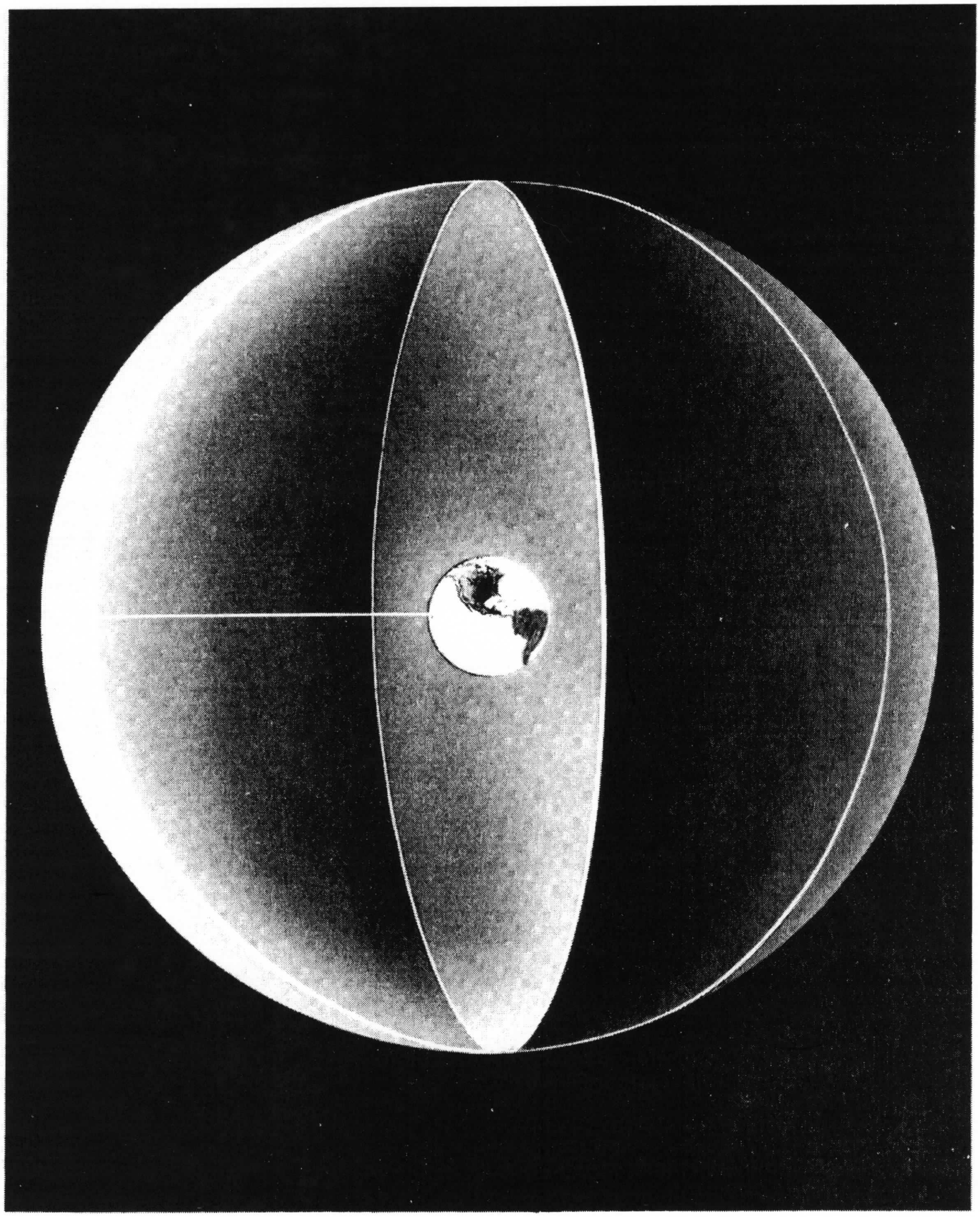
We perceive the sky over our heads as the inside surface of an inverted bowl, or hemisphere, which arcs down in every direction to the horizon. In addition to the horizon, the local celestial meridian is another convenient reference for description of celestial phenomena. Any northern hemisphere observer has a local celestial meridian which is the circular arc that passes from the north point on the horizon through the north celestial pole, through the zenith, and on to the south point on the horizon. All celestial objects appear to cross, or transit, the celestial meridian as the earth turns. As they cross the local celestial meridian, they also reach their highest angles, or altitudes, in the sky. When the sun transits the local celestial meridian, the local apparent solar time is said to be noon, and this usually occurs close to the time our clocks read twelve noon. If we imagine that our sky looks like a hemisphere suspended over our heads, we can also imagine a second, invisible hemisphere that is below the ground and that connects with the visible sky, all around the horizon. This second hemisphere is, at any moment, the unseen part of the sky, and it is unseen, naturally, because the earth is in the way. The earth's rotation eventually brings at least part of the unseen sky above the horizon and into view. The part of the local celestial meridian that extends around the unseen hemisphere of the sky is called the "lower branch" of the meridian, and it passes through the south celestial pole. This lower branch is the local celestial meridian for observers in the opposite hemisphere with this meridian, and when the sun transits the lower branch, for them it is noon. For those in the north, who use its upper branch, it is midnight.

After sunrise but before the sun transits the upper branch of a time zone's standard celestial meridian, the clock time is specified as A.M., or ante-meridiem ("before midday"=before meridian transit). After the sun transits the upper branch of the meridian, the clock time is said to be P.M., or post-meridiem ("after midday"=after meridian transit). These terms are all part of our everyday experience and are in use, of course, simply because the earth rotates on its axis. This daily motion is responsible for the cycle of night and day and for the diurnal rising and setting of each celestial object.

A second apparent motion of the sun provides a second unit of time. The annual solar movement defines the year just as the diurnal motion



The sky can be imagined as a huge, hollow sphere at the center of which is the earth, but it is impossible to draw the earth and this imaginary celestial sphere to the same scale. The earth is very small compared to the distances of stars. If we imagine the earth as just a point in this picture, we can visualize how an observer at the top of the earth, at the north pole, sees his zenith straight overhead on the celestial sphere and also how he sees half of the entire sky. The surface of the earth, upon which he is standing, blocks his view of the bottom half of the sky. The horizontal circle on the celestial sphere therefore corresponds to the limits of the observer's horizon. (Griffith Observatory, John Lubs)



For an observer located on the earth's equator, the zenith is still straight overhead, but from our point of view outside the celestial sphere this direction is to the left. The celestial sphere is again divided into two halves by the observer's horizon, and in this case only the left portion of the celestial sphere is visible to our astronomer at this time. (Griffith Observatory, John Lubs) defines the day. If it were possible to see the sun and the stars in the sky at the same time, the sun would be observed to move slowly across the background stars along a well-defined path. The movement of the sun can be detected indirectly through observation of the slowly changing composition of the nighttime sky. Some patterns of stars, or constellations, are visible in the evening summer sky, but as the year progresses, the sun moves into that region of stars. These same stars then rise and set with the sun and are invisible because the scattered sunlight of the daytime sky is so bright. The constellations are obvious keys to the seasonal cycle, too. Orion, for instance, is prominent through winter nights, but Scorpius dominates the summer nights.

The annual celestial circuit of the sun is due to the motion of the earth in its orbit around the sun. On earth we do not sense this motion. Instead, it appears as if the sun moves in relation to the background of stars. Even though we cannot see the daytime stars, they can be charted, along with the sun's position among them, by timing the sunset and watching for the first stars to appear in the west on successive evenings at the same specified time after sunset. This is a laborious procedure, and some small errors will creep in because the earth's orbit is not exactly circular, but gradually the technique will permit a good understanding of the annual motion of the sun. In a planetarium, by contrast, we can observe the sun and stars simultaneously to see easily that through the course of a year the sun moves completely around a circle in the sky. The circle is called the "ecliptic." The constellations of stars that fall along it are known collectively as the "zodiac," a word which means "ring of animals."

Alert observers would soon notice a pattern in the sun's motion that is related to the earth's orientation in space. During the course of the year the duration of hours of daylight varies from a minimum in winter to a maximum in summer. Autumn and spring occur at times when the hours of daylight and night are roughly equal. Even though most of us are not aware of the day-to-day changes in appearance and position of the sun, moon, planets, and stars, we do still sense the yearly cycle of the changing number of daylight hours. We also sense a special quality in the summer daylight, in which the hot sun is high and bright and the shadows are short. In winter the sun is lower in the sky throughout the day. The air is crisper. The windows on the northerly sides of the house are not so well lit. The sunlight seems diffused, and the shadows are long. To mark these changes in the seasons we might use the cycling height of the sun at noon: maximum in summer, minimum in winter. We would also notice that the sun's points of rising and setting vary through the year. On the longest day of the year, which we call the first day of summer (in Britain, midsummer), the sun rises at a point farthest to the north and sets likewise. On the first day of winter, the time of shortest daylight, the sun rises and sets at points to the farthest south. On the first days of spring and fall, the sun rises and sets due east and west respectively.

The seasonal changes of the sun, indeed, the seasons themselves, result from the earth's orientation in space. The earth's axis of rotation is tipped with respect to the direction of its orbital motion around the sun. We do not know what specific events or processes led to the present orientation of the earth's axis at an angle of 23½ degrees, but that element of primordial history created circumstances to which living creatures, including humans with their seasonal rituals, have been responding ever since.

Vegetation growth cycles are related to the seasons. Agricultural techniques are related, in turn, to the growing cycles. Farming provides food, necessary for life, and recognition of these relationships is expressed by many cultures in rituals. Holidays and their feasts and sacrifices are bound to the seasonal round. They define the calendar's circuit, and the calendar is perfected to establish them.

Some holidays occur at astronomically significant times. Astronomical phenomena are both indicators of the orientation and motion of the earth in space and, in turn, the indicators of the changing seasons. To ancient peoples it might have seemed that the astronomical indicators were simultaneously the cause and symbol of the world's great forces. Observation of the astronomical indicators would allow changes to be charted and anticipated.

One class of astronomical monuments includes alignments that indicate at least one particular direction on the horizon. Significantly, some object, usually the sun or the moon, appears there at a special time. It is really the occurrence of the celestial event, of course, that makes that time of singular interest. This may be the moment of sunrise or sunset on the longest or shortest day of the year. These days, the first days of summer and winter (or "midsummer" and "midwinter," in Britain) astronomically go by the names summer solstice and winter solstice. These same names are applied to the time of their occurrence as well. The summer and winter solstices occur roughly near the 21st of June and December, respectively, and mark extreme positions of the sun. The first days of spring and fall occur midway between the solstices, roughly on the 21st of March and September.

If we only were a little more immersed in the natural environment, we could not miss the solstices, those times when the sun seems to stop in its tracks and double back to where it appeared on the mornings before. Each day approaching the solstice the sun rises a little closer to the extreme position, to the north in summer and to the south in winter.

The amount of movement looks less each day until the sunrise is stopped in its motion along the horizon. For a few days the sun appears to linger at the same extreme at dawn. From this behavior derives the term "solstice," which means "sun still." The date of this occurrence could be marked by putting up a monument to point out the direction of the sun on the horizon on that special day at rising or setting.

Likewise, we would know the equinoxes well. On the equinoxes, the vernal in spring, the autumnal in fall, which mark the halfway points between summer and winter, the duration of daylight is the same as that of night. The meaning of the word "equinox" is, sensibly, "equal night."

The changing position of the sun throughout the year can be charted on the celestial sphere, and it is observed to oscillate above and below the celestial equator. Just as the north celestial pole is an extension of the earth's north geographic pole to the celestial sphere, the celestial equator is the extension of the earth's equator. At the winter solstice the sun is at its greatest angle below the equator. The northern hemisphere receives the sunlight obliquely, the weather is cold, and the sun rises and sets to the south. At the equinoxes the sun crosses the equator, and the weather is in transition. In summer, the sun is as far north of the celestial equator as it gets. The northern hemisphere receives direct sunlight, the weather is hot, and the sun rises and sets to the north.

In the sky these effects are manifested by the angle between the ecliptic, the path to which the sun is constrained, as reflected by the earth's orbital motion, and the celestial equator, whose movement mirrors the earth's rotation. These two circles are set at angle to each other because, again, the earth's axis is tilted, and this tilt of 23½ degrees is called the "obliquity of the ecliptic."

Evidence of solar alignments that are useful observationally comes from locations as widely separated as Wyoming and Scotland. We shall see that the Cahokia Mounds, laid out by Amerindian mound builders near present-day East St. Louis, Illinois, include a device that may have permitted a determination of the date of the solstice. Maya date glyphs imply that this Mesoamerican Indian culture had established the length of the tropical (or solar) year, the time from summer solstice to summer solstice (365.24220 days) with considerable accuracy.

The ancient peoples who committed themselves to ambitious programs of astronomical observation are separated widely by geography and time, but they usually shared at least one attribute: they were settled on land on which they built entire complexes of permanent public structures. Their efforts in earth and stone indicate a high level of social organization, with all the central authority and division of labor that may imply.

It is no coincidence that wealthy, agrarian societies like those in Egypt and the Americas spared no effort to make observations of the sky. Nor is it surprising that observatories were included among their major structures. Without the practical benefits that astronomy supplied, it might not have been possible to have civilization at all.

The rhythm of life is the rhythm of a culture. This rhythm is keyed to the seasonal cycle, as is the yearly agricultural cycle. A calendar is the expression of our sensitivity to these cycles. The calendar is a practical device, and its immediate application to agriculture is obvious. Yet the real power of the calendar goes beyond this. It is the device that permits complex organization of a culture, the device that rules the exchange of goods and services.

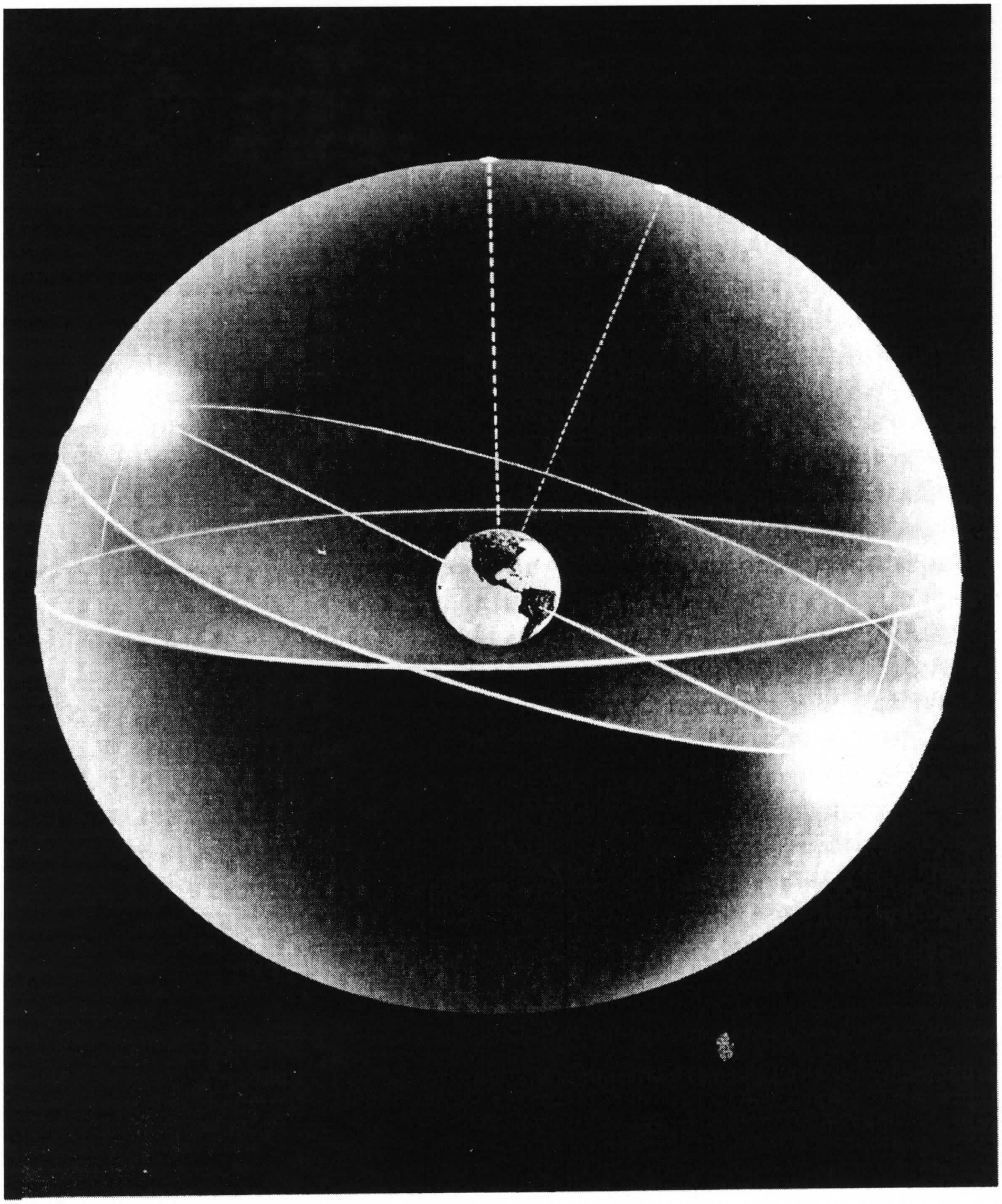
If there are farming surpluses, time becomes available to people for other activities which in turn enhance the society's economy. If full-time farming is not required of all society, division of labor is stimulated. More goods and services become available, and the society grows more complex. The increasing complexity demands a precise calendar. A small farming effort wouldn't require this. Even today, backyard gardeners can rely on natural woodlore and folk traditions to cue them to the appropriate time for planting and harvesting.

Our economy is stitched to the sky. As the scale of our agricultural enterprise increases, it is important that a device as common to us as the calendar be available to maintain smooth operations and the social order. We take it for granted that we can make appointments, schedule vacations, and remember birthdays with such ease. We are removed by technology from an everyday awareness of how and why our calendar works. Most of us do not heed the height of the sun at noon or the azimuth of its rising on any particular day. Nor are we particularly aware of the moon's phase unless we should chance to see it. In the past we were closer to the source of our food than to the all-night market, and we were more aware of celestial phenomena.

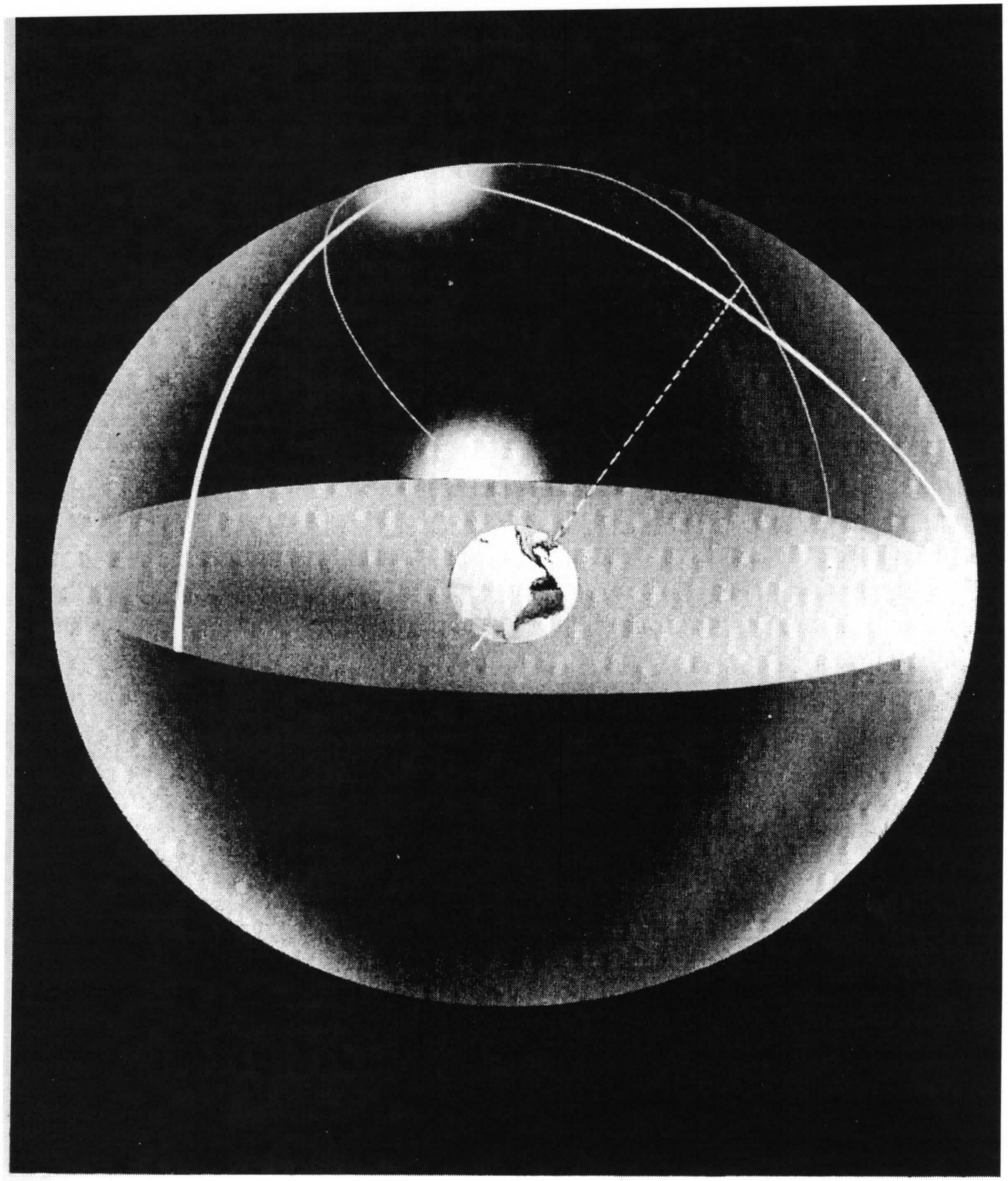
This awareness changed as society grew more complex. Responsibility for the calendar fell to a more-and-more specialized class of astronomer-priests, and ritual overtook in importance the celestial event prompting it.

There are still relics of ancient calendrical traditions in certain holiday customs. The ritualization of obvious astronomical events into holidays and ceremonies oriented the community to its common needs and purposes. Even today it is no coincidence that Christmas falls so near the winter solstice. There is still a bit of the vegetation myth in Yule celebrations.

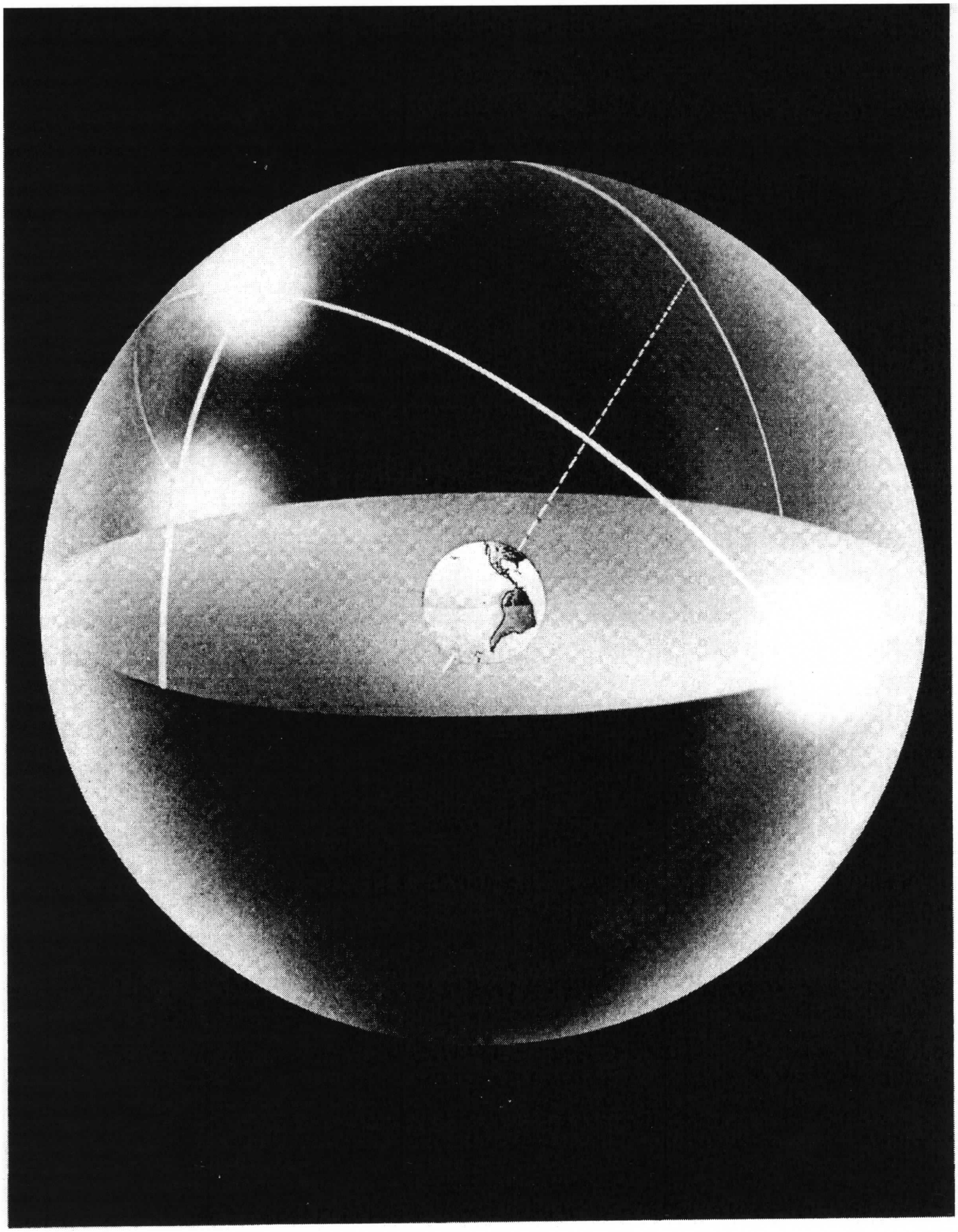
A reliable calendar can be obtained by observing the rising (or setting) points of the sun. The solstices mark the two extremes between



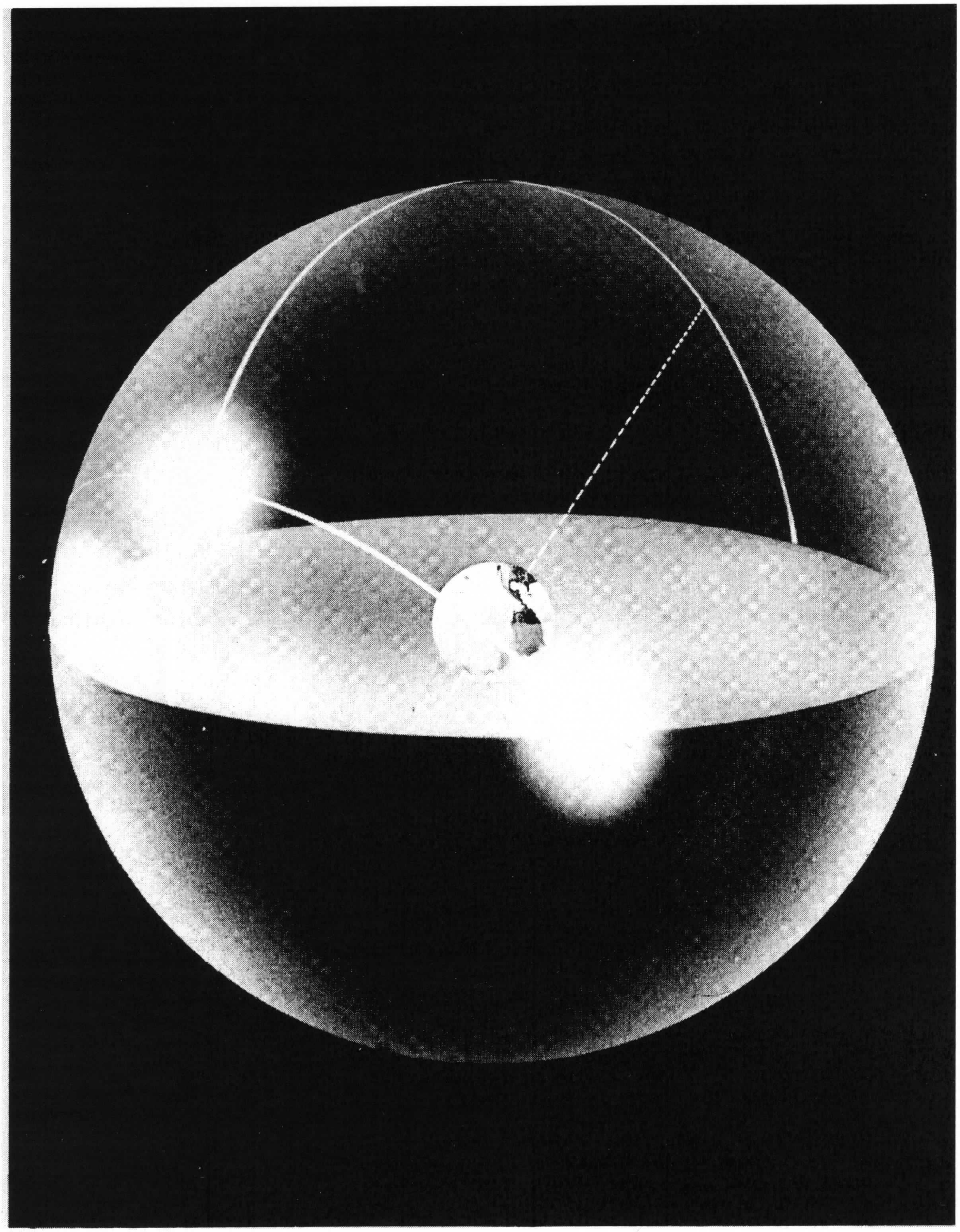
Two other circles centered on the earth and traced out on the celestial sphere are important. One of these is the celestial equator and the other is the ecliptic. In this case, the celestial equator is drawn horizontally, and the north celestial pole is straight overhead, above the north terrestrial pole. Summer solstice occurs when the sun is at its highest point above the celestial equator. The winter solstice takes place when the sun is at its lowest point below. The equinoxes occur at the two intersections of the celestial equator and the ecliptic. (Griffith Observatory, John Lubs)



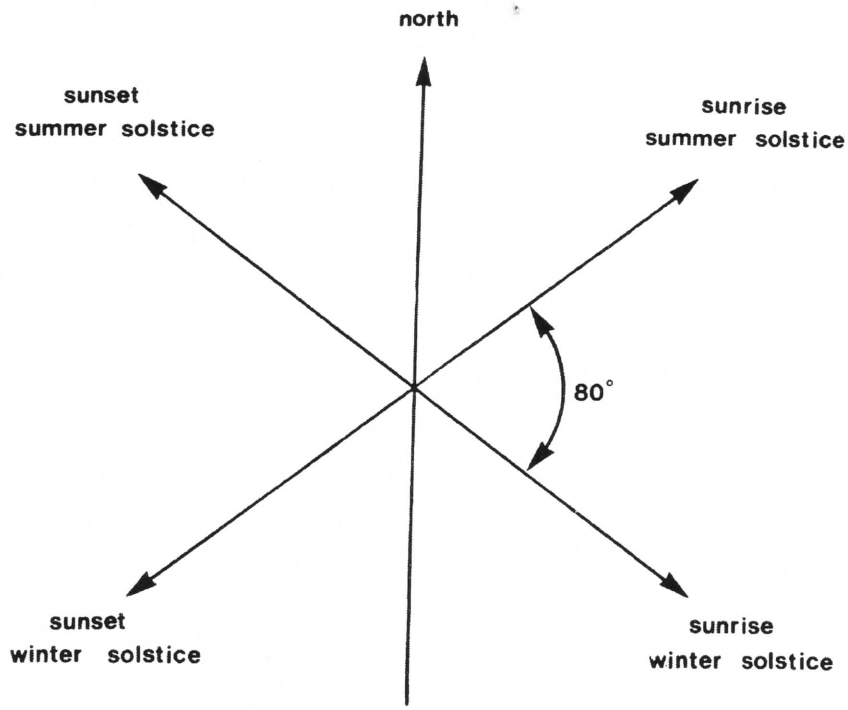
At the summer solstice, in the northern hemisphere, the sun rises as far to the northeast as it ever will. During the day, at noon, it transits as high above the horizon as it is ever seen. Finally, the sun sets as far to the northwest as it ever does, on this, the longest, day of the year. (Griffith Observatory, John Lubs)



When either equinox arrives, the sun rises due east, arcs across the sky at a height midway between those at the solstices, and sets due west. (Griffith Observatory, John Lubs)



About six months after the summer solstice, the winter solstice takes place. Now the sun rises, as seen from the northern latitudes, in the southeast. It transits at its lowest altitude of the entire year, and it sets at its extreme position to the southwest. (Griffith Observatory, John Lubs)

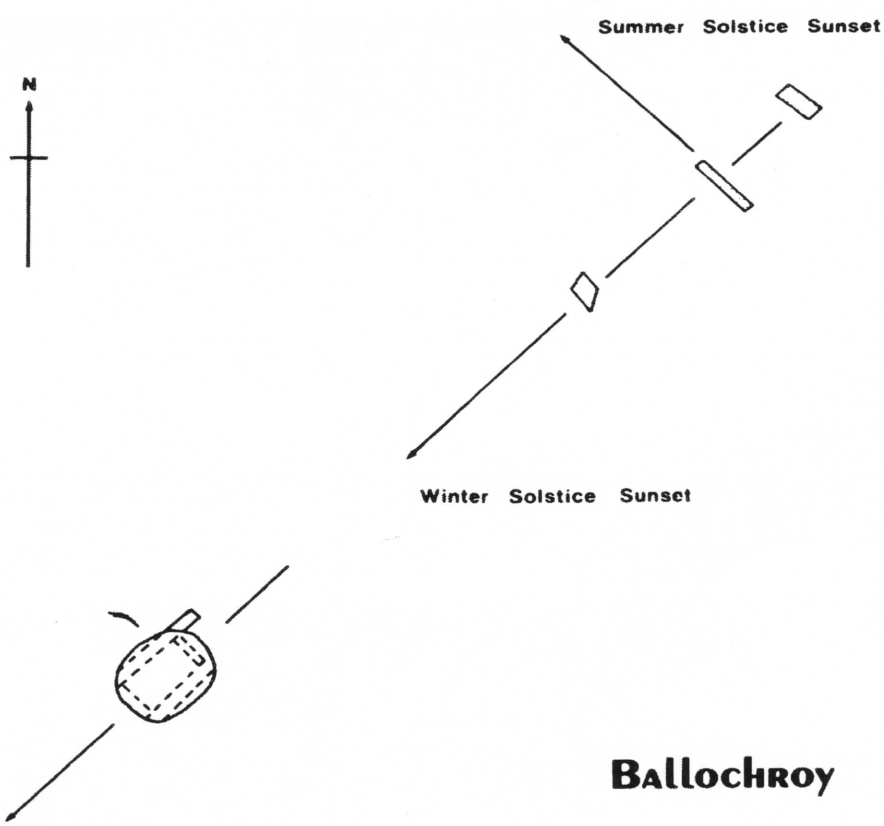


Extreme Azimuths Of The Sun At Stonehenge

At the latitude of Stonehenge, in Wiltshire, England, 51 degrees north, six months shift the rising and setting points of the sun at the summer solstice 80 degrees north of what they had been at the winter solstice. This shift is obvious and easily observed throughout the cycle of the year. (Griffith Observatory)

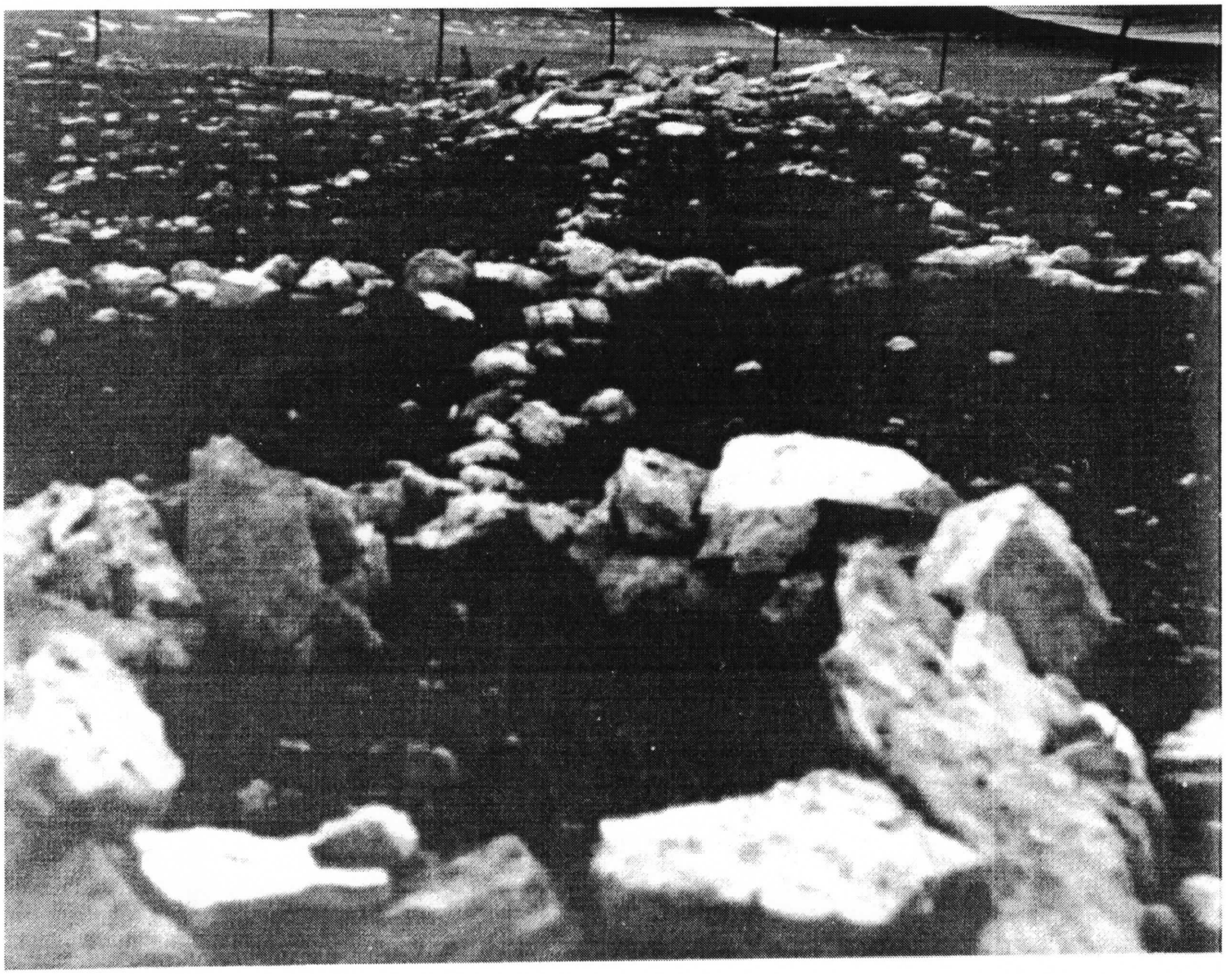
which the sunrise oscillates. Midway between is equinox sunrise. For convenience, additional sunrises, midway between each solstice and the subsequent equinox, might be noted. Alexander Thom has found alignments of British megaliths marking these solar declinations and offers further evidence for division of the year into sixteen intervals. Professor Thom has carefully measured, mapped, and analyzed over three hundred Megalithic sites in Britain and France. Almost singlehandedly he has established the standards for archaeoastronomical fieldwork and interpretation, and his amazing results have stirred controversy during the last three decades. According to Thom, a position near the equinox, and not precisely on it, was used to counteract the effect of the ellipticity of the earth's orbit on the calendar.

Stonehenge, it has long been said, includes an alignment, from the



Ballochroy, on Scotland's Kintyre peninsula, is an alignment of three stones and a kist, or stone chamber. The line to the southwest points to a feature on the small island of Cara and the point of winter solstice sunset. The center stone appears to indicate the foresight to the northwest for the summer solstice sunset. (Griffith Observatory, after Alexander Thom)

monument's center to the tip of the Heel Stone, directed toward the summer solstice sunrise. Many precise solstice alignments have been found among the megaliths of Britain and France by Thom. One of the best of these is at Ballochroy, on Scotland's Kintyre peninsula, overlooking the Sound of Jura. Kintraw, in Argyllshire and about forty miles, by road, north of Ballochroy, is another well-substantiated solstice indicator. Sir Norman Lockyer claimed that the Great Temple of Amen-Ra at Karnak, Egypt, was aligned on the summer solstice sunset. In recent years, Gerald Hawkins has supported a solstitial interpretation of this temple, but he has turned it around 180 degrees to the winter solstice sunrise. Dr. John Eddy examined the Big Horn Medicine Wheel in Wyoming and demonstrated its solstitial character. At Uaxactún in Guatemala, the Maya may have constructed a set of solstice oriented platforms.



Sunrise on the summer solstice at the Big Horn Medicine Wheel, in Wyoming, appears over the central cairn when viewed from the outlying cairn southwest of the wheel's rim. (John A. Eddy)

THE MYSTERIOUS MOON

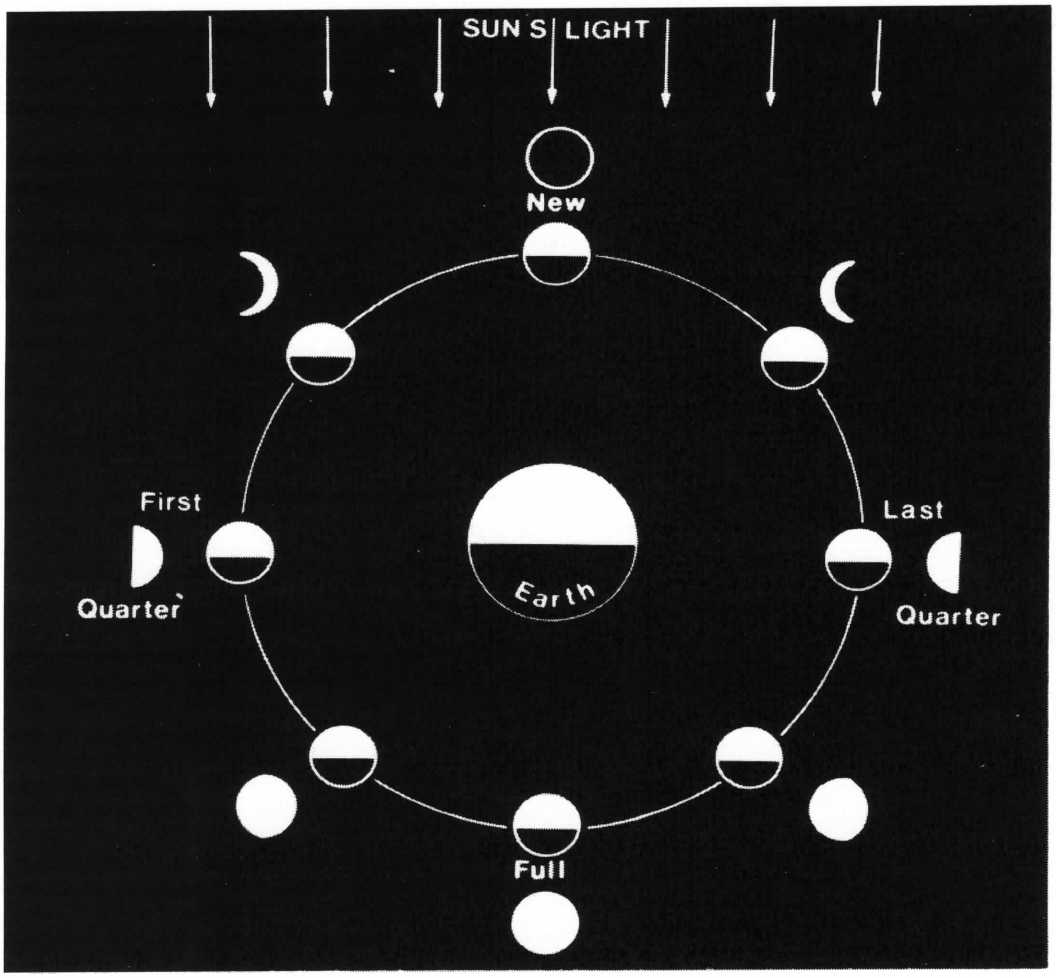
Despite the many examples of ancient and prehistoric solar observatories, there are many monuments that do not fit the pattern. There are calendars in use, too, that are not calibrated by the sun. This should come as no surprise, however, for the moon's rapid and obvious changes also provide a ready means for keeping track of the date, and a lunar calendar is still used in the Islamic world. A lunar calendar is serviceable enough for day-to-day activities, but it has the disadvantage of getting out of step with the seasons. Reconciliation of the lunar and solar calendars required much of the energy expended by the calendar reformers of Western Europe. Of course, if the solar year contained an exact number of lunations, or lunar cycles, the two calendars would remain in phase. For better or worse, they do not, and lunar calendars are often restricted to religious use. The date of Easter is still determined by the moon. This means that on our civil, solar calendar the date of Easter can wander several weeks.

Each daily rotation of the earth brings the moon into view over the eastern horizon and sets it down below the west. This pattern would be similar to the sun's, but the moon is in orbit around the earth. From the earth the moon appears to move eastward through the stars, about 12½ degrees each day. Because the apparent motion of the moon is eastward, the earth must rotate 12½ degrees further to the east each day to again bring the moon into view. The earth requires approximately fifty minutes to rotate through the additional angle, and therefore moonrise is delayed about fifty minutes from one day to the next.

As the moon moves in its orbit about the earth, the moon's position with respect to the sun and the earth changes. Shining only by the reflected light of the sun, the moon alters its appearance. Only one half of the moon is illuminated at one time; the rest is shadow. Through the course of the month the half of the moon that faces earth cycles from complete darkness to complete illumination and back to darkness again. The moon is said to be full when the earth-facing side is fully lighted. The time from full moon to full moon is the synodic month, and it lasts about twenty-nine and a half days. The word "synodic" derives from a root word which means a "coming together," or conjunction. In astronomy, "conjunction" refers to a close configuration in the sky of two objects, but the term "synodic" has been extended to successive corresponding phases of the moon.

The cycle of the lunar phases is simple and familiar. During the two days or so that the moon is in conjunction with the sun, the moon's lighted half faces away from earth, and we see no moon, or a new moon. As the illuminated portion of the moon shifts into view, the moon appears to grow brighter and more complete from night to night. During this period the moon is said to be "waxing." First we see a thin crescent that is most noticeable in the early evening. It hangs like the smile of the Cheshire Cat over the western horizon, and it sets a while after the sun.

About one quarter of the way through the synodic month, the angle between the moon, earth, and sun is 90 degrees, and a so-called half moon is visible. This phase is called "first quarter," however, in reference to the progress of the monthly cycle. The new moon, in conjunction with the sun, rose and set with the sun. A first-quarter moon is 90 degrees from the sun, and therefore this moon rises about six hours after sunrise and sets about six hours after sunset.



In a single "moonth," or month, the moon orbits the earth and passes through a complete sequence of phases. The word "moon" is related to an ancient word which means "to measure," and the pattern of lunar phases may have been one of the first cycles used by people to measure the passage of time. (Griffith Observatory)

The moon continues to wax through a near full, or gibbous, phase. Both sides of the moon's edge, or limb, are convex. This bulging appearance explains the term "gibbous," meaning "humped." Full moon occurs when the moon is opposite the sun. Therefore the full moon rises when the sun sets, and moonset occurs at sunrise.

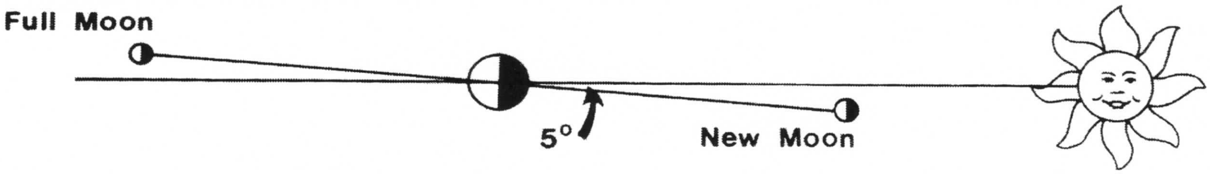
During the second half of the month the phase of the moon progresses through a symmetric set of phases: gibbous, half, crescent, and back to new. The moon is said to be "waning" during this period of ever diminishing brightness. The half-moon phase of the waning moon finds the other half of the earth-facing side of the moon illuminated. This phase marks the end of the third quarter and the beginning of the last quarter of the synodic month. It is called "third" or "last quarter." The third-quarter moon is 90 degrees from the sun but on the other side of the moon's orbit from first quarter. Therefore the third-quarter moon rises about six hours after sunset and sets about six hours after sunrise. The relationship between the phase of the moon and the position of the sun permits us to tell time by simply observing the phase of the moon and its angle in the sky. We count time by the sun's position, but the moon can be used to infer the sun's position and would be useful as a clock, especially when it was visible during the night.

Not only do the moon's phase and its times of rising and setting change each day, but the horizon positions of moonrise and moonset also change. If the moon orbited directly above the earth's equator so that the moon's path would coincide with the celestial equator, no changes in the position of moonrise or moonset would be observed. Instead, the moon's path falls close to the ecliptic, and so its rising and setting positions roughly coincide with those of the sun, though not at the same place at the same time. The moonrise oscillates between an extreme northeast point to an extreme southeast point and back to the northeast again, but the moon goes through this cycle in a month rather than in a year. Because the full moon rises opposite the sun, the full moon that occurs near the time of the summer solstice will rise in the southeast, opposite the northwest-setting sun. In winter the sun sets in the southwest, and so the full moon rises in the northeast, near the summer solstice sunrise point. Through the course of a single month the moonrise at new moon coincides with the sunrise. At full moon, moonrise is opposite the sunset. For first and last quarter, the moonrise occurs in between. The pattern follows the seasons as tabulated below.

MOONRISE POSITION

	summer	*fall*	*winter*	*spring*
New	northeast	east	southeast	east
First quarter	east	southeast	east	northeast
Full	southeast	east	northeast	east
Third quarter	east	northeast	east	southeast

If the moon's path coincided exactly with the ecliptic, the full moon would rise at the same position at the same time of the year every year. Different phases would occupy that same moonrise point at other times of the year every year. Furthermore, an eclipse of the sun would occur each month at new moon. We would likewise expect to see an eclipse of the moon each month at full moon. Of course, eclipses don't occur that frequently, and the reason is the inclination, or tilt, of the moon's orbit. The moon's orbit is inclined approximately 5 degrees to the earth's orbit around the sun.



The moon's orbit around the earth is tilted 5 degrees to the earth's orbit around the sun. For this reason the moon, the earth, and the sun do not always fall on the same line at every new and full moon. (Griffith Observatory)

The inclination of the moon's orbit might be expected to oscillate the moon to an angular extreme above and below the celestial equator each month, just as inclination of the ecliptic carries the sun above and below the celestial equator each year. The exact value of the extreme positions, or declinations, would depend on the orientation of the moon's orbit to the earth's orbit. If it is imagined that the maximum extreme positions are reached in the summer, with the new moon at a declination of 28½ degrees (23½+5) above the celestial equator, the full moon of that same month would be found at 28½ degrees below the celestial equator. On the horizon, moonrise at new moon would be positioned a little north of the summer solstice sunrise point. Moonrise at full moon would fall a bit to the south of the winter solstice sunrise point. Eclipses would occur only at the new and full moons that fall on the ecliptic and, therefore, midway between the two extremes. In this situation eclipses would be expected in spring and fall.

We can as easily imagine the moon's orbit to be turned so that the moon appears below the ecliptic when the sun and the ecliptic are highest in the sky, in summer. Under these circumstances the new moon will rise a bit south of the summer solstice sunrise point, and its declination will be 18½ degrees (23½—5). Similarly, the full moon would rise a bit north of the winter solstice sunrise point in the southeast and would have a declination of —18½ degrees.

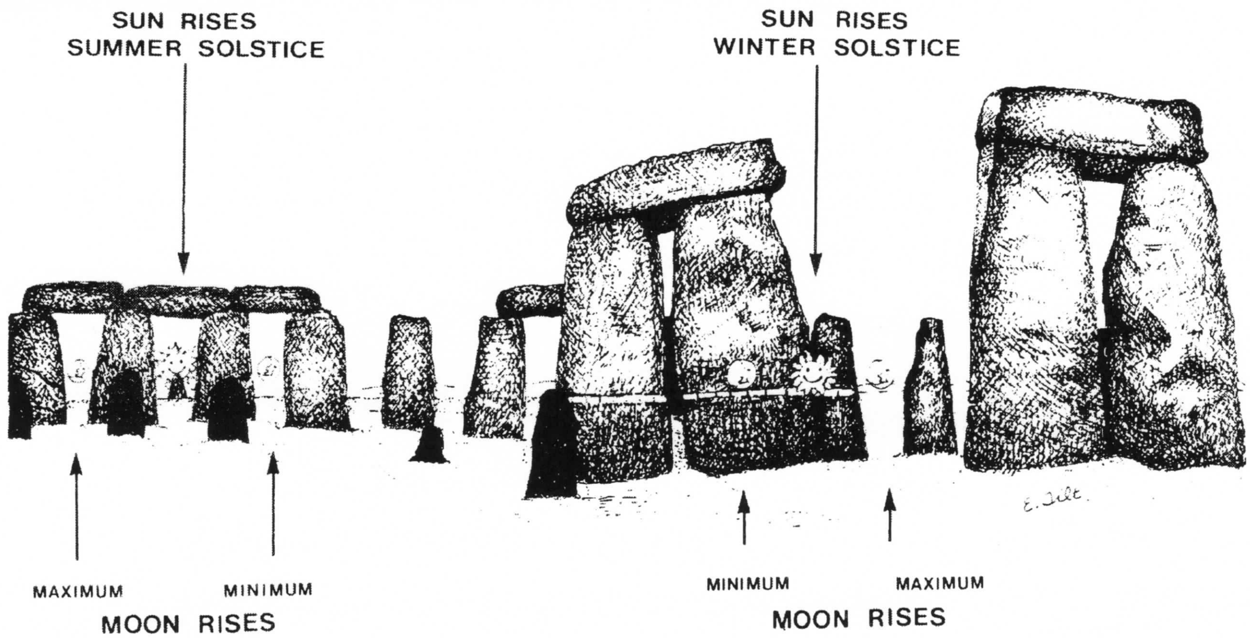
As noted above, the exact values of the positions of the lunar extremes depend on exactly how the tilted orbit of the moon is oriented. Assuming the orientation held constant, we would expect the moon to reach the same extremes each month, and, furthermore, we would expect to see the full cycle of the moon's phases at that extreme during the course of the year. The full moon would be seen at the extreme north position once during the year, in winter, and the other phases would be seen there throughout the rest of the year. The situation is not so simple, however. The moon's orbit precesses, or turns, with respect to the earth's orbit. The moon's path in the sky therefore varies with respect to the equator and ecliptic.

The moon's orbit revolves from east to west. The motion of the moon in its orbit is from west to east. The precession of the moon's orbit is in the opposite sense and is therefore called a regression. The intersections of the moon's orbit with the ecliptic are called the "nodes" of the moon's orbit, and a line drawn to connect the two nodes is called the "line of nodes." The backward precession of the moon's orbit is therefore called the "regression of the line of nodes." This line can be imagined to turn in a counterclockwise direction when the orbit is viewed from the north celestial sphere. Regression of the line of nodes is very important information, for eclipses can only take place when the centers of the sun, moon, and earth all fall along the same line. This is equivalent to the requirement that the new and full moons occupy either of the nodes when the sun does, or that the sun, earth, and moon all fall along the line of nodes.

A solar eclipse is caused by the passing of the moon directly in front of the sun to obscure the sun's light. Although the sun is about four hundred times larger than the moon, the sun, by coincidence, is also about four hundred times farther away. The sun and the moon appear to be roughly the same size in the sky (about ½ degree), and the moon is able to eclipse the sun, provided it coincides with the sun's position in the sky. This can only happen where the sun's path and moon's path coincide, on a node.

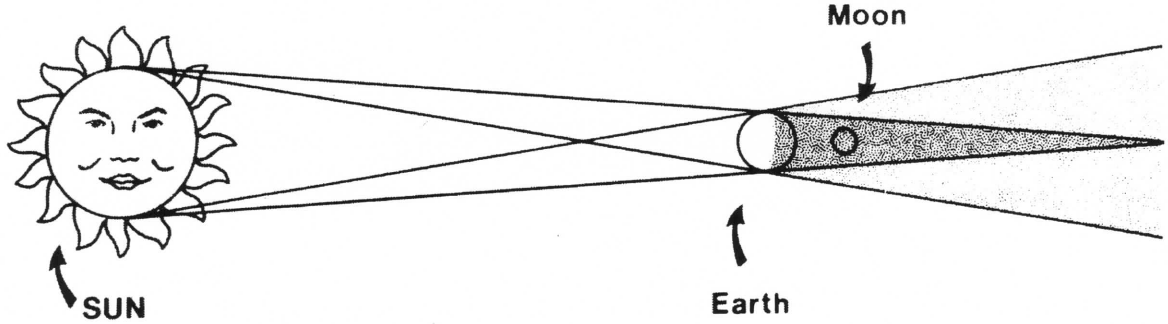
Lunar eclipses occur when the moon passes into the earth's shadow. The earth's deep shadow, or umbra, is always present and extends approximately 855,000 miles into space. The shadow is cone-shaped and at the distance of the moon's orbit (only thirty earth diameters away) is about 5,700 miles across. The moon's diameter is about 2,160 miles. The shadow at the moon's orbit is about two and a half times larger than the moon, and if the moon falls within the shadow, it will be eclipsed. The earth's shadow is centered on the line that connects the earth and the sun. A lunar eclipse can occur only when the shadow also falls upon the moon. For this to happen, the sun and moon must occupy opposite nodes of the moon's orbit.

The earth perturbs the moon in its orbit. These gravitational forces cause the line of nodes to precess, and a complete regression takes 18.61 years to complete. Over an 18.61-year period the northern moonrise extreme moves from a maximum to a minimum and back to a maximum. The same is true for the southern moonrise. The period of maximum extreme has been called the "major standstill" by Alexander Thom; the minimum corresponds to his "minor standstill." The moon does not really stand still, but it reaches close to the extreme declination with little noticeable change from month to month for several months. In that way a standstill is analogous to a solstice, or "sun standstill," but the



The standstill limits of the moonrise and the solstice limits of the sunrise as seen from the center of Stonehenge indicate that considerable movement of the sun and moon could be observed on the horizon over the course of their cycles. Stones block the view of some of the southern risings, but these were probably not intended to be seen from the monument's center. (Griffith Observatory)

A lunar eclipse may occur when the moon crosses the ecliptic. If the sun is on one node and the moon on another, the earth, moon, and sun fall on the same line—the line of nodes—and the moon enters the earth's shadow and is eclipsed. When the moon is exactly between the earth and the sun, its shadow may just reach the earth to produce a solar eclipse. (Griffith Observatory)



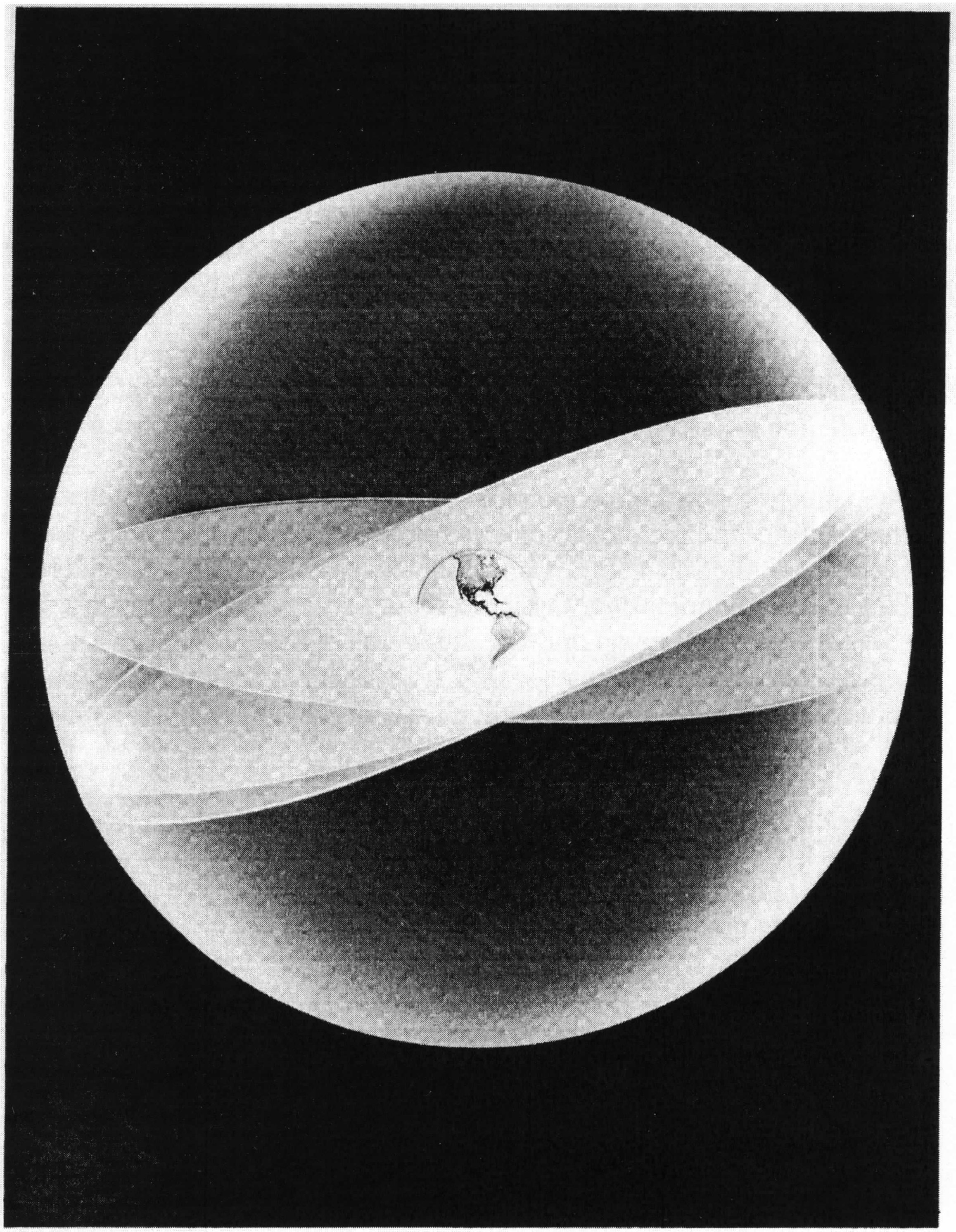
parallel doesn't really hold. In the year of a major standstill, the winter full moonrise will reach its northernmost position. In the same year the summer full moonrise reaches its southernmost extreme. In 9.3 years the minor standstill occurs. Now the winter full moon still rises in the northeast but as far south of the summer solstice sunrise point as it ever reaches. In the summer of the same year the full moon still rises in the southeast but as far north of the winter solstice sunrise point as it will reach that cycle. Although this pattern is virtually correct, it should be remembered that the period of regression is not an even multiple of tropical years but eighteen and a fraction. This means that the standstills will not occur at exactly the same time of year each year they occur.

The changing position of moonrise is also accompanied by a change in the height of the moon as it crosses the sky. This effect is particularly noticeable for the full moon, whose light is so important to a culture lacking electric illumination. Over the 18.61 year cycle, the difference in the height of the full moon and the difference in the duration of its appearance above the horizon may well have been of concern to prehistoric and ancient peoples, especially those in the more northern latitudes where the effect is more pronounced.

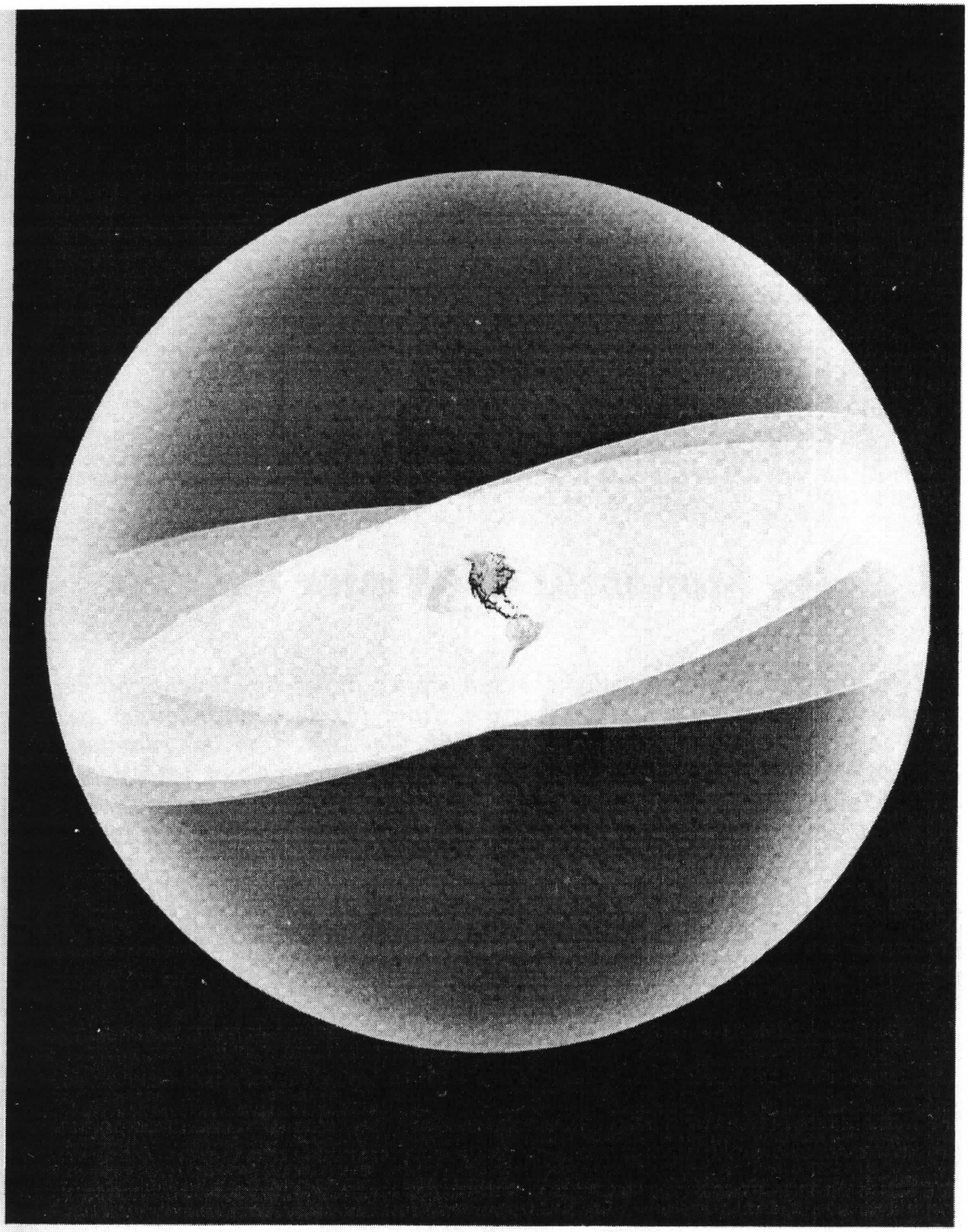
One node of the moon's orbit marks the moon's passage from below the ecliptic to above it and is called the "ascending node." The opposite node is naturally the "descending node." It takes 346.62 days, or one eclipse year, for the sun to travel from the ascending node to the descending node and back again to the start. An eclipse year is approximately twenty days shorter than a tropical year because the ascending node regresses eastward to meet the sun about twenty days earlier each year. If we characterize the sun's occupation of a node as an eclipse season, eclipse seasons occur twice a year, or once every 173.31 days. They each arrive about twenty days earlier than the year before.

An interval of 27.21 days is required for the moon to complete the circuit from one coincidence with the ascending node to the next. This period is called a "draconic month," and it is shorter than the synodic month by a little over two days. Most of this is a result of the earth's motion in orbit about the sun, but a small part of the difference is generated by the eastward regression of the ascending node to meet the moon before it reaches the same phase it displayed while at the node the previous month.

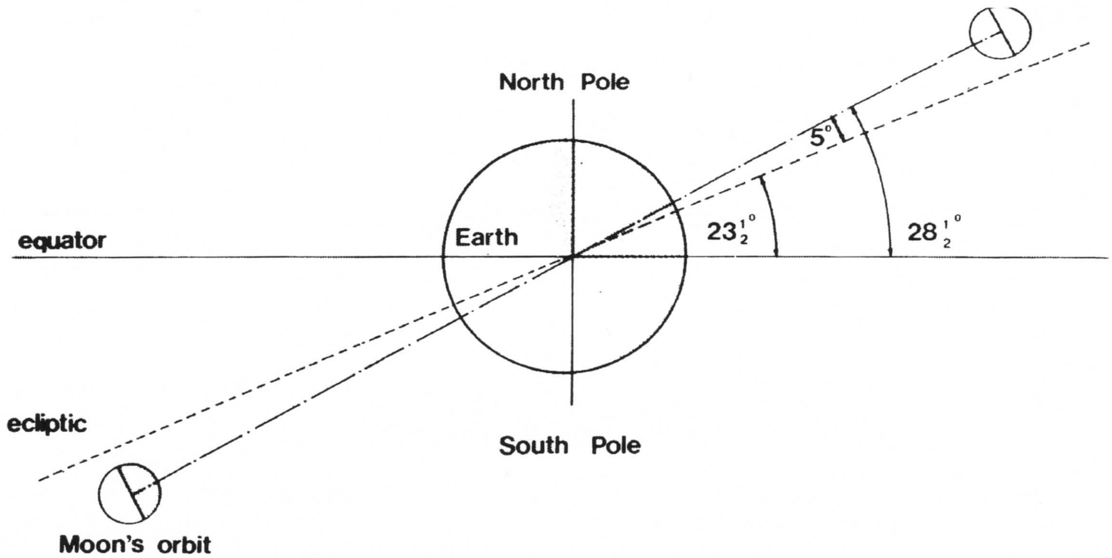
Complicating the already complex lunar motion is a small wobble that causes the moon's declination to oscillate plus or minus nine arc minutes on top of its expected cyclical variations. The slight oscillation is called the "inclination perturbation." It is caused by the tilt of the moon's orbit and the difference in the sun's gravitational force on



At the time of the major standstill, the moon's orbit carries the moon well above and well below the ecliptic in a single month. In this picture the disc of the moon is shown at both its extremes, above and below the ecliptic. (Griffith Observatory, John Lubs)



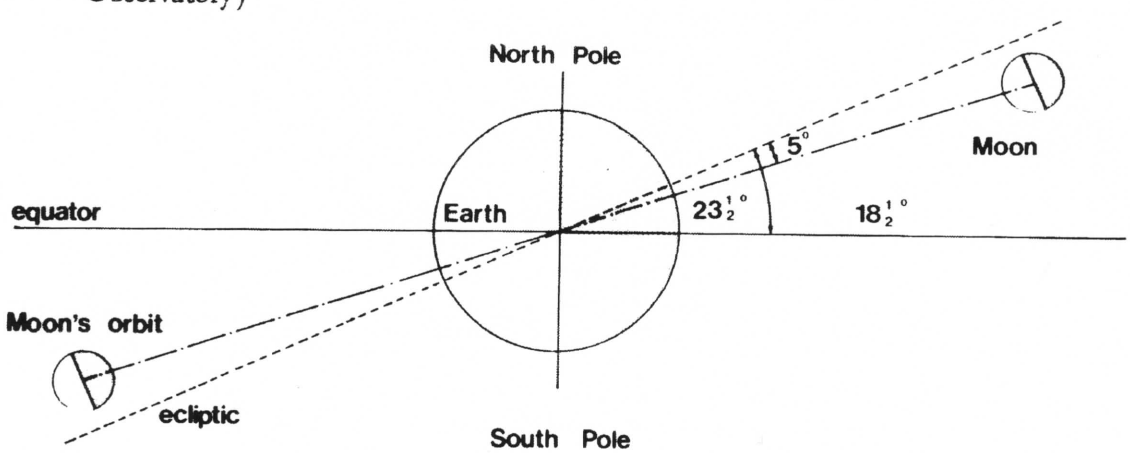
The minor standstill occurs 9.3 years after the major standstill. Now for several months the moon's orbit allows the moon to swing each month between limits that are well inside the extremes of the ecliptic, that is, between the solstices. Again, the moon is shown on opposite sides of its path. (Griffith Observatory, John Lubs)



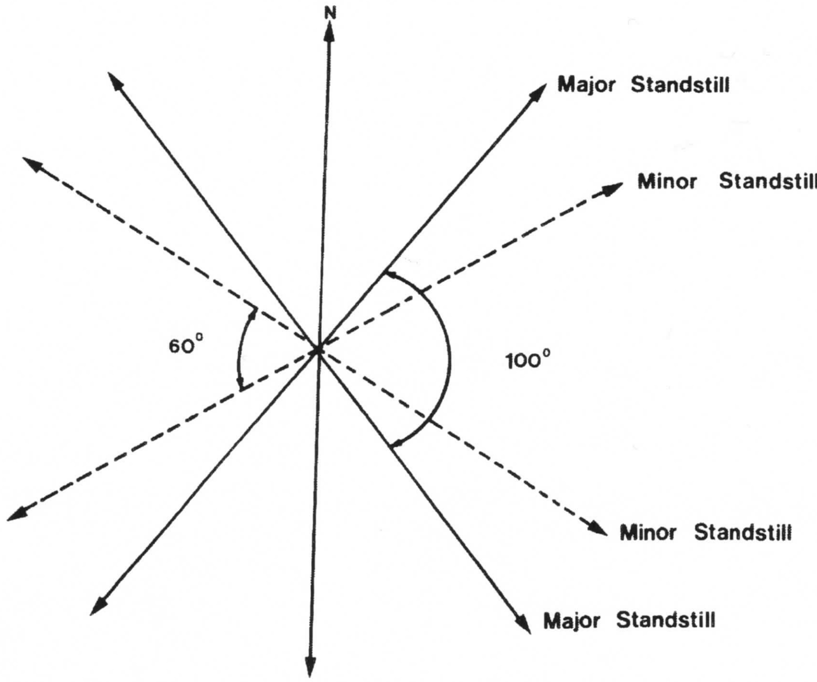
Major Standstill at Winter Solstice

At the time of winter solstice the sun shines more directly on the earth's southern hemisphere—in this diagram, from the left. At summer solstice the sun would shine from the upper right. The line from the sun therefore represents the ecliptic. The earth's equator makes an angle of 23½ degrees to the ecliptic, and here, at the time of major standstill, the moon's orbit is set 28½ degrees to the equator. New moon occurs when the moon is roughly in the same direction as the sun 28½ degrees below the celestial equator. Full moon, on the other hand, finds the moon opposite the sun and 28½ degrees above the equator. (Griffith Observatory)

The minor standstill will find the moon's orbit now set 18½ degrees (23½—5) *to the celestial equator. Here at winter solstice again, the sun shines from the lower left and parallel to the ecliptic. The new moon, again below the celestial equator, will reach a position 10 degrees closer to the equator than at major standstill. Similarly, full moon at maximum height above the equator will be 10 degrees lower than 9.3 years earlier.* (Griffith Observatory)

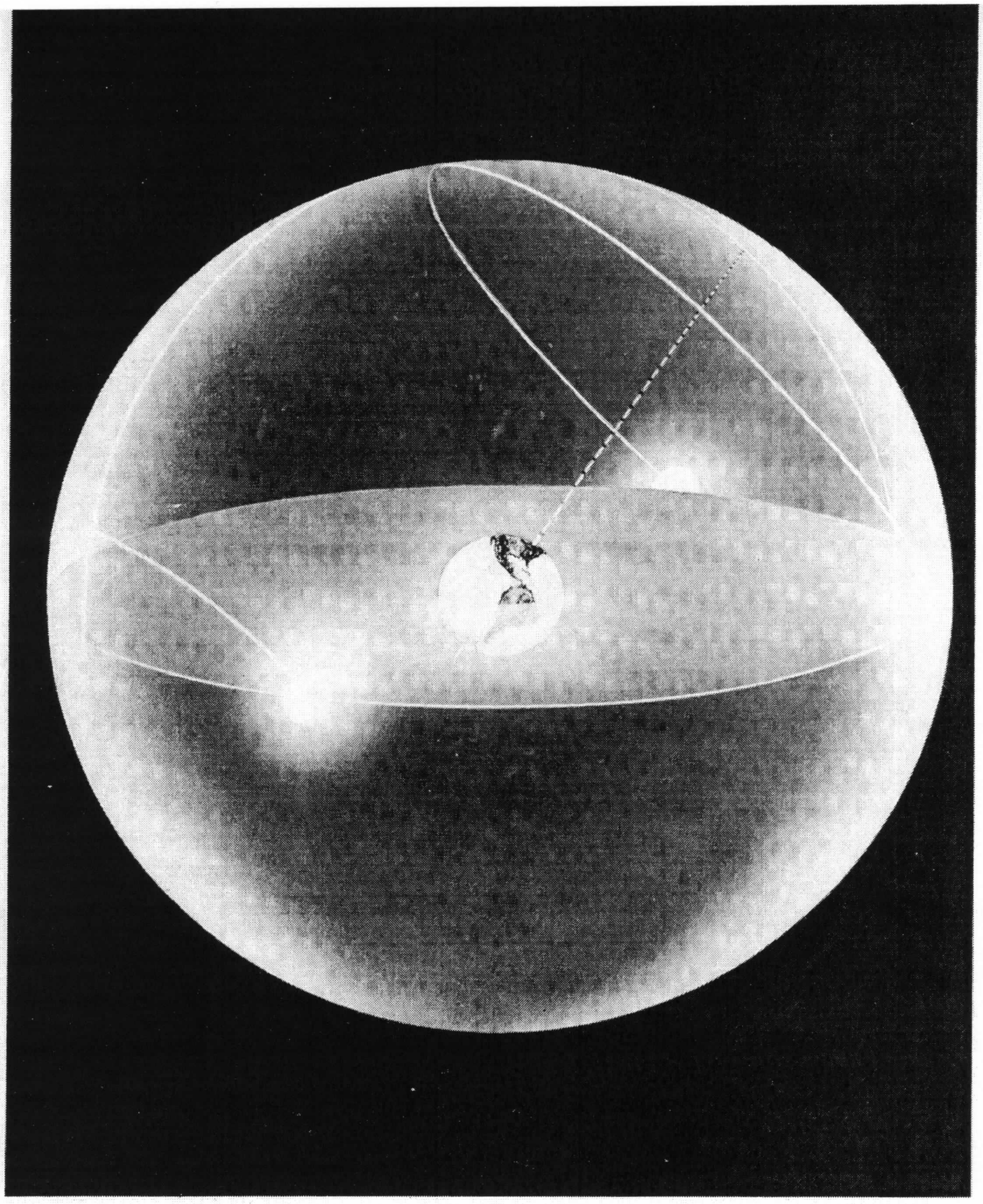


Minor Standstill at Winter Solstice

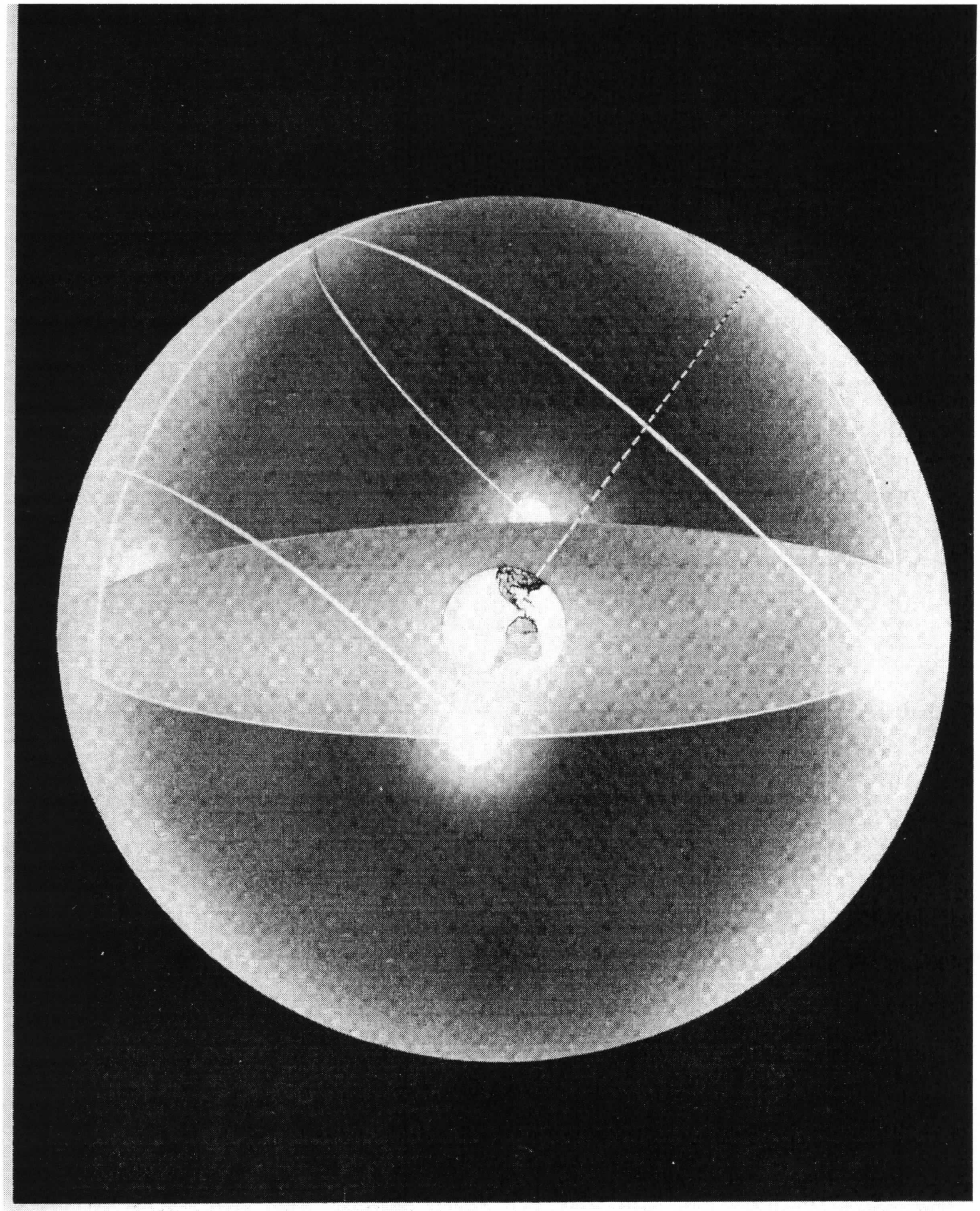


Extreme Azimuths Of The Moon At Stonehenge

During the 18.61-year lunar standstill cycle, the separation between northern and southern moonrises is observed from the latitude of Stonehenge to vary from 100 degrees at the major standstill to 60 degrees at the minor standstill, 9.3 years later. These shifts in moonrises and moonsets are large and dramatic. (Griffith Observatory)



The path of the full moon during the nights near the winter solstice carries the moon from its northeastern rising point high overhead and allows it to set in the northwest. The full moon rises at sunset and sets at sunrise, and, conveniently, the moon shines throughout the long winter night. In summer the full moon rises in the southeast, transits low across the southern sky, and sets in the southwest. The night is short, as is the path of the moon across the sky. In this illustration, at the major standstill, the moon's monthly northern extremes are as far north as they are ever observed. Similarly, the southern extremes are at their greatest limit. (Griffith Observatory, John Lubs)



At minor standstill the moon's behavior is basically the same. Now, however, the winter full moon does not rise and set so far to the north, nor does the summer full moon reach so far south. The moon is never seen inside these inside limits of its risings and settings during the course of the entire 18.61-year cycle. (Griffith Observatory, John Lubs) either side of the orbit. When the moon is on the solar side of its orbit, it experiences a different force than when it is on the far side of its orbit. The inclination perturbation is at its maximum positive value when the sun is at a node. During the next 173.3 days, or half an eclipse year, the sun moves to the other node. Over the same interval the inclination perturbation has gradually diminished to zero, dropped to its maximum negative displacement, increased back to zero, and once again achieved its maximum positive shift.

To see how all of the motions of the moon combine to allow it to reach a maximum declination, north or south, we must consider the standstills. A standstill occurs when the nodes coincide with the equinoxes. At major standstill the ascending node and the vernal equinox are near each other. After 9.3 years the descending node and the vernal equinox will coincide, and it will take another 9.3 years to go from this minor standstill back to the major standstill. The maximum effect of the inclination perturbation will be visible when the sun is at either node. At major standstill this occurs at the time of vernal equinox and at the time of autumnal equinox. At the time of vernal equinox the moon occupies its greatest declinations north and south at first and third quarter respectively. The situation is reversed at the time of autumnal equinox. To observe the moon on the horizon at night in spring, we must observe the setting first-quarter moon to obtain the northernmost position. In autumn the rising third-quarter moon provides the necessary information.

The subtle inclination perturbation was discovered in the sixteenth century by Tycho Brahe, the Danish astronomer, but it may have been suspected by tenth-century Arab astronomers. By contrast, the 18.61-year cycle of standstills has such an obvious effect on the moonrises, moonsets, and the moon's time above the horizon that it was probably known from prehistoric times. Alexander Thom offers evidence that the inclination perturbation was also observed by Neolithic astronomers.

Many small variations in the motion of the moon and the earth alter the exact relationship between the earth, moon, and sun when the sun and moon nearly occupy the nodes. Eclipses can occur only when the moon and the sun are within certain angular limits of the nodes. These ecliptic limits are determined by the apparent sizes of the moon and the sun and their distances from the earth. The ellipticity of the earth's and moon's orbits and the precession of the moon's line of nodes all complicate the timing of an eclipse. Furthermore, the area on earth over which an eclipse may be seen, when it does occur, is limited for a lunar eclipse and even narrower for a solar eclipse. All this makes the prediction of eclipses a difficult and tricky business. Even a successful method may not be confirmable. It is possible through accumulation of records, nevertheless, to construct a cycle of eclipses which will help predict future eclipses. One such cycle is called the "saros." The saros is a sequence of eclipses for which similar conditions repeat, about every eighteen years. Although the saros can be used to anticipate an impending eclipse, it does not permit an infallible prediction.

Without a written language a culture would find the saros and other eclipse cycles difficult to apply. It may be possible to predict eclipses through direct observation of the moon's position, if it were known that the maximum positive displacement of the inclination perturbation occurs at the eclipse seasons. The perturbation cycle is going on all of the time, but the displacement is normally mixed in with the other contributions to the moon's declination. The perturbation maximum can only be detected at one of the standstills, when the perturbation shifts the moonrise and moonset slightly beyond the expected position on the horizon. Once the observation is made, a Megalithic astronomer need only count days until half an eclipse year has gone by. Since the perturbation maximum can be observed only at the standstills, the prehistoric astronomers could not afford to miss them. As it is, the cycle can only be calibrated every 9.3 years, or possibly when an eclipse is observed. Alexander Thom has assembled considerable evidence that the Megalithic people built Stonehenge and other sites, including Temple Wood in Argyll, in Scotland, as precise lunar observatories where genuine, practical astronomy was carried out.

THE SUBTLE STARS

Observations of stars could have been made easily by prehistoric astronomers. The daily rotation of the earth would have been reflected not only in the sun's motion across the sky in the daytime but also in the risings and settings of stars at night. The earth's annual orbiting of the sun makes itself felt by changes in the rising and setting points of the sun throughout the year in the duration of daylight. The sun is also moving through the constellations of the background stars, but because the sun is so bright, we cannot see this motion directly. Astronomers in prehistory would have noticed, however, that some groups of stars dominated the winter nights and others the summer.

A calendar could be calibrated by the first or last appearance of a group like the Pleiades, or Seven Sisters. It is said that the Celtic peoples attached special significance to the Pleiades at their dawn rising, which coincided with Beltane, or May Day. The Aztecs measured the completion of one fifty-two-year cycle and the beginning of the next by the date of culmination of the Pleiades at midnight. Teotihuacán, in central Mexico, antedates the Aztecs by over a thousand years, yet the entire plan of this huge metropolis was based upon the direction of the setting of the Pleiades.

Entire sequences of stars were used by the Egyptians to tell time at night, and their choice of stars and calendar calibrator was responsible for our present convention of twenty-four hours in the day. One more example of this kind of thing is mentioned by Alexander Thom, who suggested that the Megalith Builders also used certain bright stars as nighttime clocks.

Stars were used to calibrate the solar calendar and to mark the progress of the seasons. One of the best stellar phenomena for these purposes is the heliacal rising. A star rises heliacally when it is first visible in the dawn sky, before sunrise. There is a period during the year when a particular star rises in the nighttime. Gradually the sun catches up to that star. The sun's motion along the ecliptic carries it around the sky. For a period of a few months the star rises in the daytime, when the sun is up. The star is invisible. Eventually the sun moves far enough east of the star to permit the star to rise before the sun. The star can then be seen again, and its first dawn appearance is its heliacal rising.

The heliacal rising of Sirius, the Dog Star, was extremely important to the Egyptians. During one period of their history, the heliacal rising of Sirius occurred at the same time as the summer solstice and, by coincidence, at the same time of the Nile inundation. The Nile and the agricultural cycle dominated Egyptian life. The Egyptians based their calendar upon them. The calendar was calibrated, and the year began, with the heliacal rising of Sirius. John Eddy interprets alignments at the Big Horn Medicine Wheel in Wyoming as indicators of a sequence of heliacally rising, bright stars which warned the Plains Indians who used this site of the impending cold weather.

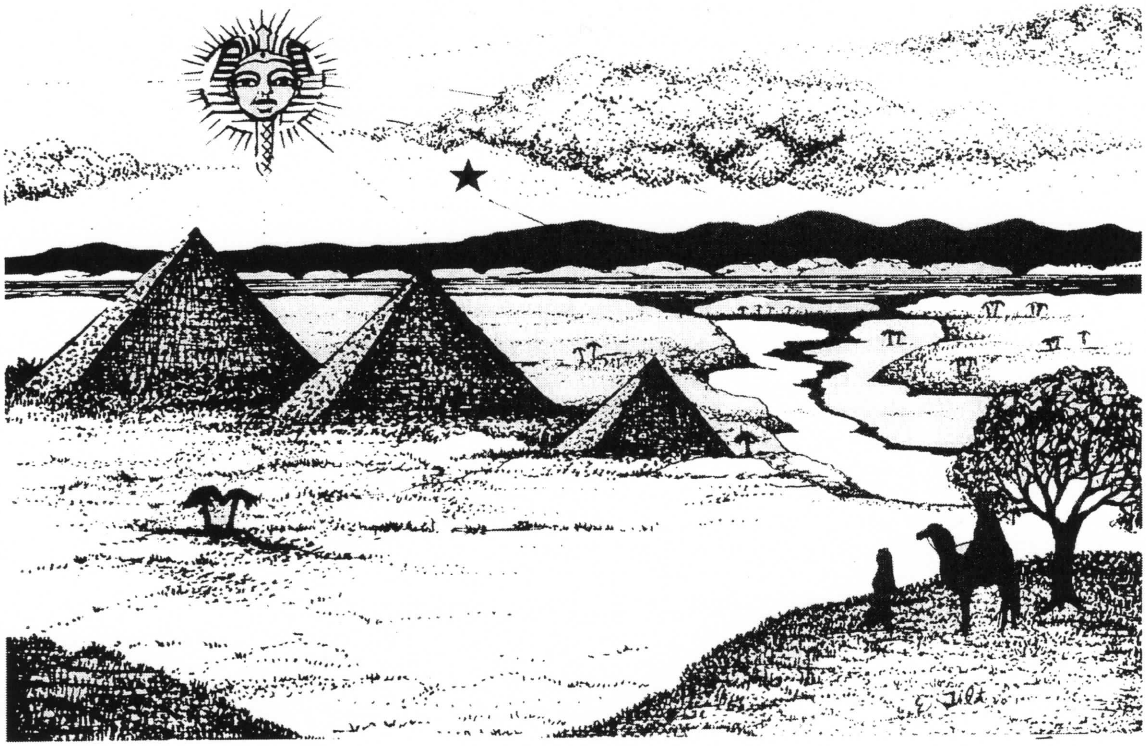
Most cultures have synthesized a celestial geography from the patterns of stars of the night sky. Groups of stars are associated together to form constellations. The constellations often represent or symbolize important elements of the culture's mythology. We do not know for certain who invented the constellations still in use today. Certainly many were in use as early as 500 B.C. in Babylonia, but their antiquity may be greater.

Unlike the sun and the moon, stars do not visibly move with respect to one another. Year after year the cycle is repeated. However, over several centuries another motion of the earth, called "precession," will gradually affect the seemingly immutable stars. Precession is a wobble of the earth's polar axis. The wobble is caused primarily by the gravitational pull of the sun and the moon on the earth's equatorial bulge. Instead of spinning with its axis forever fixed in one direction, the earth wobbles around like a top spinning on the floor. The top's period of precession is a few moments. For the earth twenty-six thousand years are needed. During this period the north pole swings around the sky, sometimes pointing toward our north star, Polaris, and sometimes toward another star. The equinoxes and the solstices shift with respect to the background stars. Stars of the summer sky are later seen in winter and still later, at the cycle's end, in summer again. A star that lines up with some monument at a certain epoch will not line up with that monument several centuries later. The motion is subtle, but it can be detected if observations are made over a long period. The earliest known direct reference to precession is that of the Greek astronomer Hipparchus (second century B.C.), who is credited with discovering it. Adjustments of Egyptian temple alignments, pointed out by Sir Norman Lockyer, may well indicate a much earlier sensitivity to this phenomenon, however. Recently Giorgio De Santillana and Hertha von Dechend, both historians of science, in *Hamlet's Mill* (1969), have argued that much mythological narrative is really a symbolic description of the earth's precession as viewed in the stars.

IN SEARCH OF ANCIENT ASTRONOMIES

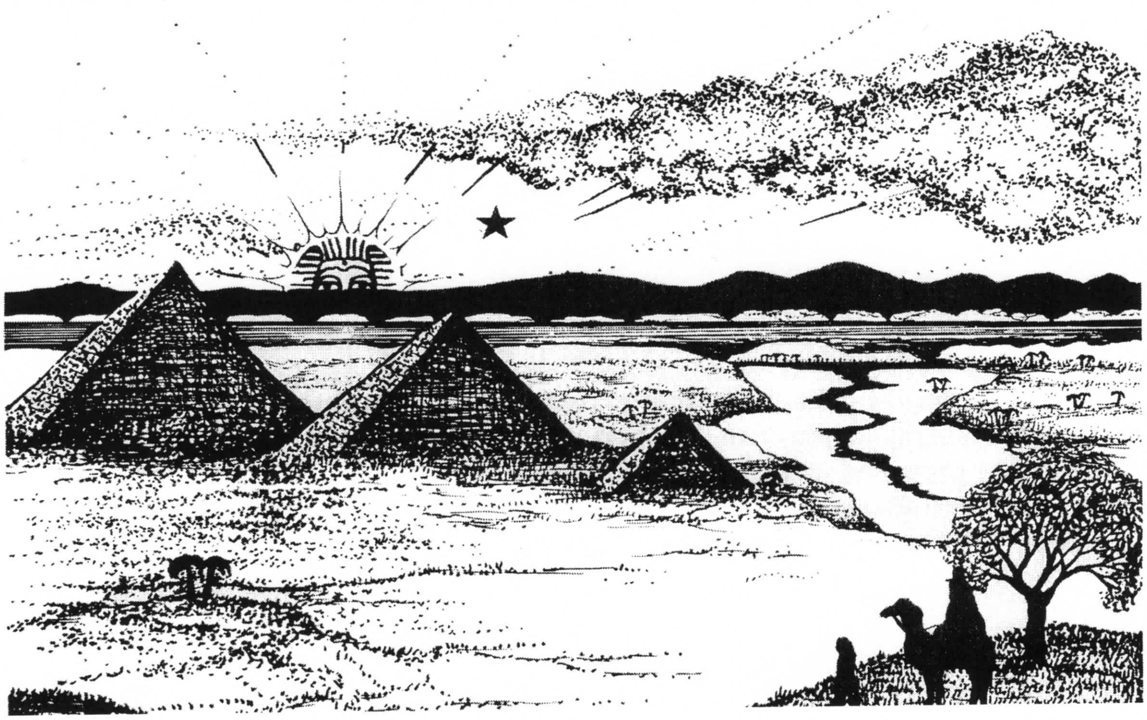
Evidence of the astronomical orientation of monuments is found in many places, but we still do not know how long humans have been making astronomical observations. It is often thought that scientific astronomy began with the Greeks, but this is simply not so. The Babylonians developed a sophisticated system of keeping records and methods of calculation that indicate careful observation of the sun, moon, and planets. It is known that they attempted to predict eclipses. But astronomical observation is also possible in preliterate societies. We have no idea how long people, or creatures resembling people, have been watching the sky. We are not certain when a sense of time first became part of the human consciousness. It is not difficult to imagine, with the evidence of human fossils dated at 4 million years, that we have been noticing the sky for some time. Tallies of the moon's phases may have been made in the Paleolithic Age. Even today we find aborigines using a gnomon to determine time and seasons astronomically.

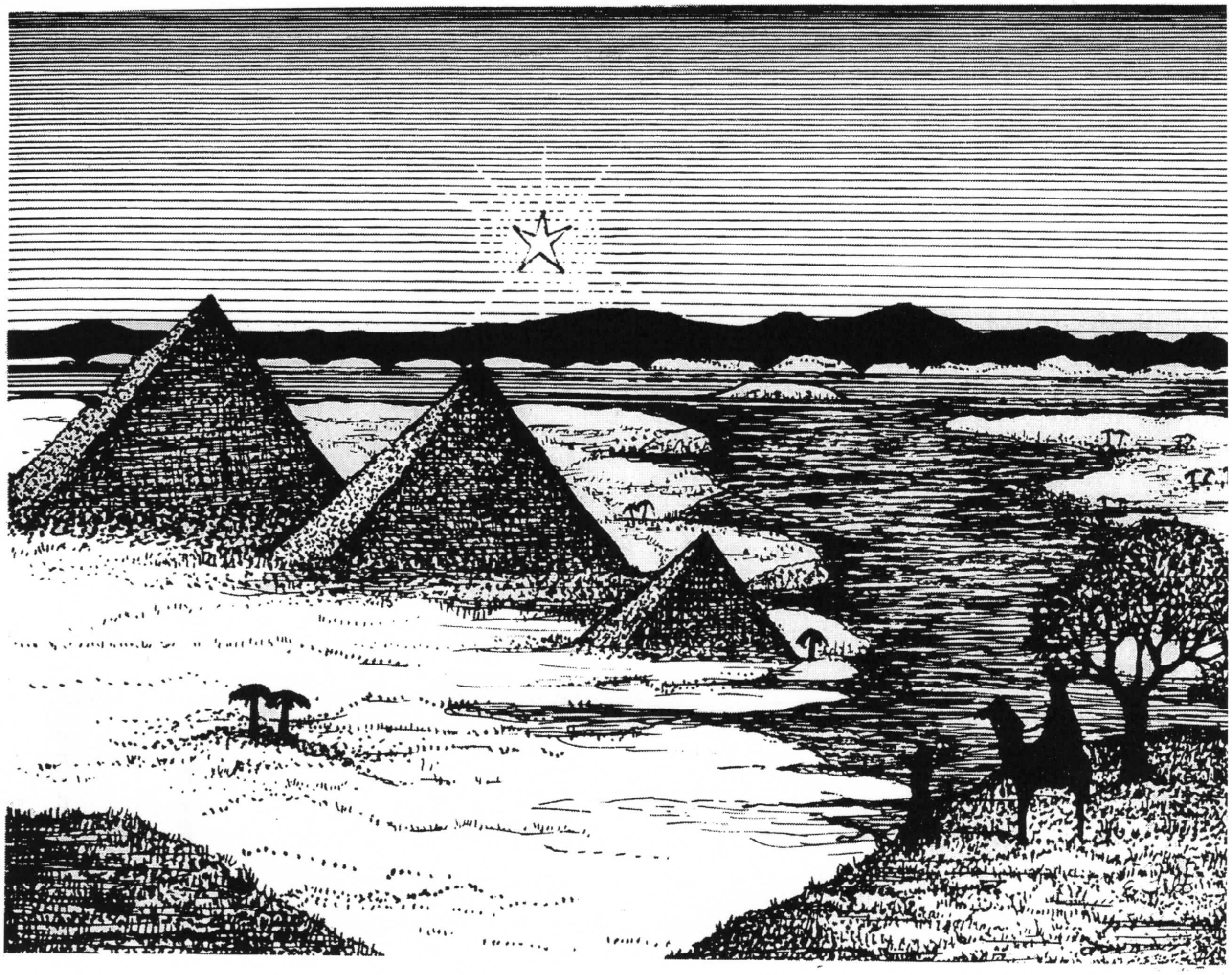
Alexander Marshack, formerly research fellow at the Peabody Museum of Archaeology and Ethnology, in *The Roots of Civilization* (1972), proposed that Paleolithic notations on bones correspond to lunar observations. Other suggestive markings on cave walls evoke the same suspicion. Some of the bones Marshack has analyzed are in-



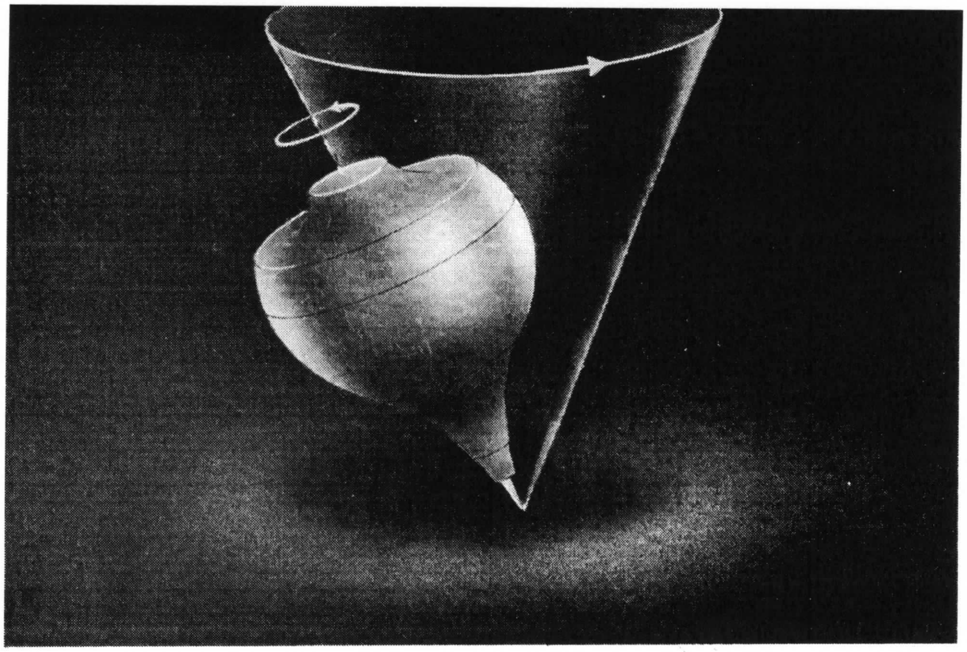
The time is late spring in ancient Egypt. Sirius has risen in the east, across the Nile from the pyramids, but the sun is already up. Sirius, therefore, cannot be seen yet when it rises. (Griffith Observatory)

The motion of the earth in its orbit around the sun makes the sun appear to move east with respect to the stars. A few weeks before the summer solstice the sun rises when Sirius rises, but the glare of the dawn is still too bright to allow Sirius to be seen. (Griffith Observatory)



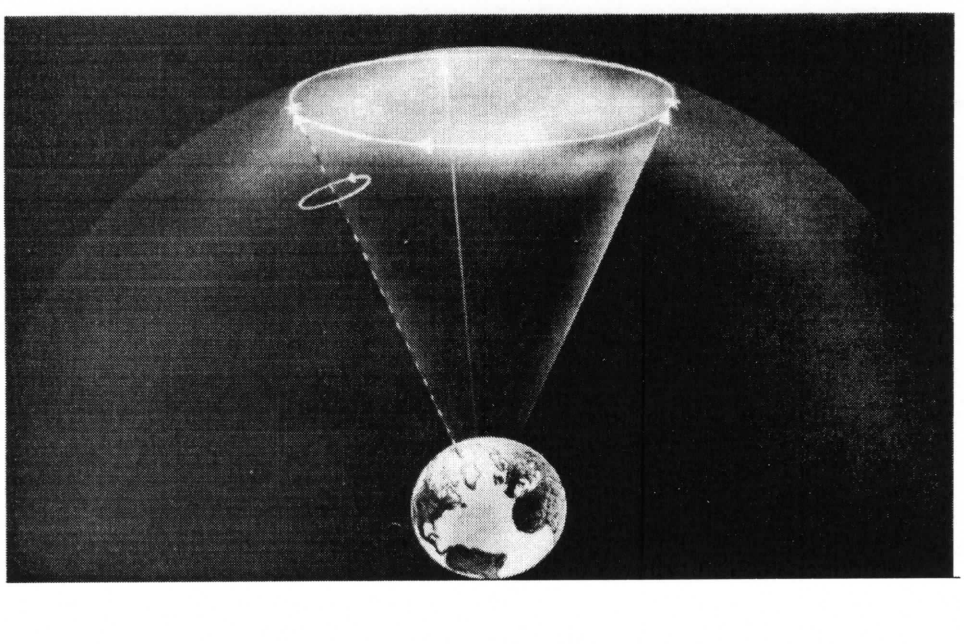


Finally, the sun has moved far enough to the east of Sirius to permit Sirius to be seen, for the first time this year, in the predawn sky. By coincidence it is the summer solstice. This heliacal rising of Sirius roughly coincided with the flooding of the Nile, and for the Egyptians this association of star, river, and summer solstice was of great importance. (Griffith Observatory)



Precession of the earth is similar to the wobbling of a spinning top. Gravity tries to pull the top down to the floor, but because the top is spinning, this force makes the top swivel as it spins. (Griffith Observatory, John Lubs)

The gravitational attraction of the moon and sun acts to straighten the earth's axis upright with respect to the ecliptic. The earth is spinning, however, and so these forces cause the earth to precess, or swivel, with a period of twenty-six thousand years. The axis of the earth now points toward Polaris along the dashed line pointing to the upper left, but precession will shift this axis toward the star Vega twelve thousand years from now along the line pointing to the upper right. This shift of the position of pole in turn shifts the rising and setting points of stars, but the effect takes a few centuries to become noticeable. (Griffith Observatory, John Lubs)



scribed with simple sequences of lines. The sequences are spaced, and from one set to the next the style may change. The lines may be vertical in one set and slanted in the next. Some bones, are more complex. The Blanchard bone, a small piece of bone found in the Dordogne region of France inscribed by some Cro-Magnon individual about twenty thousand years ago, has a complicated pattern of marks. The shapes of the marks vary, and the sequence curves around in a serpentine pattern. In Marshack's view the turns in the sequence represent, on one side, the times of dark, new moon, and on the other, bright, full moon. Statistical analyses may not support Marshack's interpretations, but similar batons and sticks are carved for the same purpose by the Nicobar Islanders in the Bay of Bengal.

The impact of the seasons on human activity is evident. The keeping of the calendar and the telling of time probably prompted, at some time in prehistory, observation of the moon and sun. Or perhaps it was the other way around. We may never be able to know how people at this stage of cultural development viewed the world around them. But we can guess. The sun, as seen from the earth, is simultaneously the cause of the seasons and the indicator of their passing. To understand, even superficially, how early people might have regarded the sun, we must integrate these two roles of the sun into a single concept. Perhaps in this way we can incorporate ourselves into the prehistoric landscape. By unifying the immediate experience of a natural event with its symbolic meaning, we may at least get some imperfect idea of how prehistoric people regarded and approached the world around them. True sun worship would amount to a sensible recognition of the sun's importance to cycles of life on earth and practical observation of the sun's behavior, which reveals the pattern of its effects. The moon and the stars may well have been understood in similar terms.

Perhaps the urge to orient the landscape of space and time is a fundamental, practical response of the human brain, an attribute of our minds that permits them to function at all in the chaos of events and objects that make up the universe around us. This urge may be what prompted us to observe the sky and become astronomers in the first place. Our ancestors may have pulled patterns from the sky and incorporated them into their architecture.

More often than not we have only the ruins to guide us. If we can extract from the European megaliths, the New World ceremonial centers, or the Egyptian temples evidence of observation of the kinds of obvious and important astronomical phenomena discussed here, we may gain some insight into the needs and the evolution of the human mind.