Reflections on Refraction

A source of ancient imprecision still humbles astronomers

By PETER L. WEISS

An invisible sprite plays pranks on the lordly stars and planets passing across her realm. With mercurial whimsy, this natural trickster — atmospheric refraction — toys with their shapes and colors, and reroutes their celestial tracks, in her near-to-the-horizon domain.

Ancient skywatchers marking the motions of their heavenly gods and goddesses no doubt pondered the bloating of the setting sun and the air's other refractive effects. But not until the Greeks did early astronomers begin to understand the workings of this low-horizon imp.

Astronomers today are still learning. Despite the precision of modern science, astronomers cannot yet predict the time of sunrise or sunset closer than within 4 minutes, according to new research by Bradley E. Schaefer of NASA-Goddard Space Flight Center in Greenbelt, Md. Atmospheric refraction prevents greater precision, he reports, because it can change not only by a greater amount than previously believed, but also more rapidly and randomly.

Schaefer says his study of refraction also shatters long-held notions about the precision achieved by ancient astronomers.

Some engineers and scientists have claimed that the earthen mounds and rock circles of prehistoric observatories permitted extremely precise marking of horizon locations where celestial objects rose and set. In the 1980s, many astronomers began to question the claims of such high precision. The new refraction findings now dismiss most of these claims and markedly restrict the potential accuracy of nearly any such site designation, Schaefer says.

Indeed, adds John B. Carlson, director of the Center for Archaeoastronomy in College Park, Md., the new results provide "a fundamental set of limits and cautions" for people who study the ancient observatories.

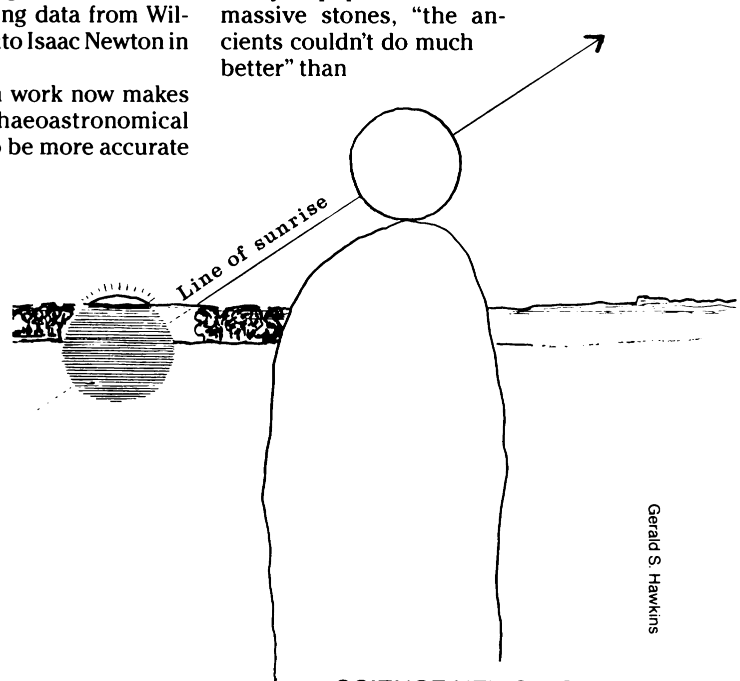
In general, light bends when passing from one transparent material into another of a different density — whether in a glass lens or through the layers of a planet's atmosphere. This bending, or refraction, shifts the apparent position of celestial objects. And because refraction deflects different frequencies — or colors — of light to different degrees, the light spreads out and separates into its rainbow colors as in a prism. Thus celestial objects acquire odd shapes and hues. Near the horizon, refraction-related distortion peaks because light from an object low in the sky must penetrate more air to reach the observer.

Most modern astronomers shun the horizon, as a rule, and compensate for the less severe, refraction-caused inaccuracies encountered at higher viewing angles. However, some still make low-horizon observations at sites like Stonehenge and the Pyramid of Cheops, hoping to reconstruct the astronomical habits and knowledge of ancient peoples — a field called archaeoastronomy. Or they try to fathom the physics of refraction's spectacular visual effects, such as the "green flash" — a rare, emerald glint peeled off the top of the rising or the setting sun by a prism of air layers.

Schaefer began his refraction study in order to predict those green flashes. He recruited help collecting data from William Liller at the Instituto Isaac Newton in Santiago, Chile.

Schaefer's refraction work now makes implausible most archaeoastronomical alignments claiming to be more accurate than about half a degree — equal to the diameter of the disks of the sun or the moon, undistorted by refraction. This new limit applies particularly at high latitudes, like that of Britain. There, celestial objects cross the sky on a slant relative to the horizon so that vertical shifts due to refraction strongly affect horizontal rising and setting positions — the kind marked by ancient rock alignments. Near the equator, however, accuracy more precise than one-half degree remains possible, Schaefer says, because celestial bodies travel along paths nearly perpendicular to the horizon.

The new findings promise to resolve a long-standing controversy in archaeoastronomy. Proponents of ancient precision — most notably the late Scottish engineer Alexander Thom — concluded that neolithic peoples must have studied heavenly motions as scientists, for the sake of knowledge itself. Others contend, however, that ancient observatories only served the relatively inexact observational demands of religion, calendar-keeping and agricultural planning. Without writing — to record and compare long-term measurements — or modern heavy equipment to handle massive stones, "the ancients couldn't do much better" than



The summer-solstice sunrise at Stonehenge grazes the tip of the so-called Heel Stone. At this fairly high latitude (51°N), celestial objects cross the sky along a path tilted relative to the horizon. Thus refraction, which changes the objects' apparent vertical position, significantly shifts their horizontal position as well, preventing highly precise horizon-marking.

make crude sightings of celestial objects, says Gerald S. Hawkins, the first person to decipher Stonehenge's astronomical significance.

Archaeoastronomers agree that several previous studies cast doubt on the claims of Thom and others. But Schaefer's new limit appears to destroy the theory of super-accurate prehistoric astronomy. "The whole structure that [Thom] made has collapsed," Hawkins told SCIENCE NEWS.

Schaefer reassessed the variability of atmospheric refraction in part by analyzing solar positions at sunrise and sunset. He also found evidence of its greater range by studying air-temperature profiles with a refraction-calculating computer program he developed. He and Liller collected measurements of the sun's angle from locations in Hawaii, North Carolina and Chile, and calculated the difference — due to refraction — between the true angular position of the sun given by astronomical tables and its apparent position. Because the North Carolina observations were recorded in a minute-by-minute sequence and the time of each was noted, Schaefer was also able to calculate the speed at which the atmosphere's refractivity changed.

The surprising uncertainty that Schaefer finds imposed even on modern astronomy might significantly affect the Moslem world. By Islamic law, the faithful must pray five times per day, but exactly when depends on the position of the sun: The first prayer must begin before sunrise, the last after sunset. Today, Moslems who are out of earshot of a mosque's loudspeakers rely on tables of prayer times — supposedly accurate to within 1 minute — or specially programmed digital watches and clocks. But Schaefer's findings indicate that "the values given in the tables [and by the timepieces] are not reliable, except to within 4 minutes," says astronomer Imad-ad-Dean Ahmad, an astrophysics consultant in Bethesda, Md. So Moslems will have to start praying earlier in the morning and later after dusk to be certain their prayer does not overlap forbidden periods, Ahmad says. "It will be a big change."

The new refraction findings might also affect any of several court cases each year where the precise timing of sunrise or sunset plays a crucial role, observes Leroy E. Doggett of the U.S. Naval Observatory in Washington, D.C. For instance, an attorney might need to know the precise time of sunset to check out whether the driver in a car wreck turned on the headlights soon enough. Doggett says the times given by daily newspapers — as supplied by the Naval Observatory — can err by as much as a couple of minutes; they are merely averages of many years' calculations for each date. To meet lawyers' requests for greater precision, Naval Observatory astronomers calculate (for a fee) the moment of sunset for specific locations and dates of interest — with a correction for refraction by an idealized "standard atmosphere." However, Doggett warns, the observatory gives no guarantee of accuracy because its astronomers cannot know how the real atmosphere varied from the ideal at the scene in question.

Schaefer's interest in the effects of refraction goes beyond such earthly matters. He uses a computer to travel through space and time in search of green flashes. A program he wrote that incorporates his new refraction findings can determine, he says, whether green flashes occur in "any sort of weird environment" — on Earth or elsewhere, in the dim past or in the far-off future.

Green flashes will persist even if all the Earth's ozone vanishes, his program reassures. And green gleams most likely twinkled above the Earth's "primordial ooze," Schaefer finds. No such luck, however, for present-day Mars or Jupiter, which, the program shows, lack green flashes.

With the program, "you can even hypothesize planets around Alpha Centauri," Schaefer says. But their green-flash potential "depends on the [kinds of] planets you construct." □