STONEHENGE

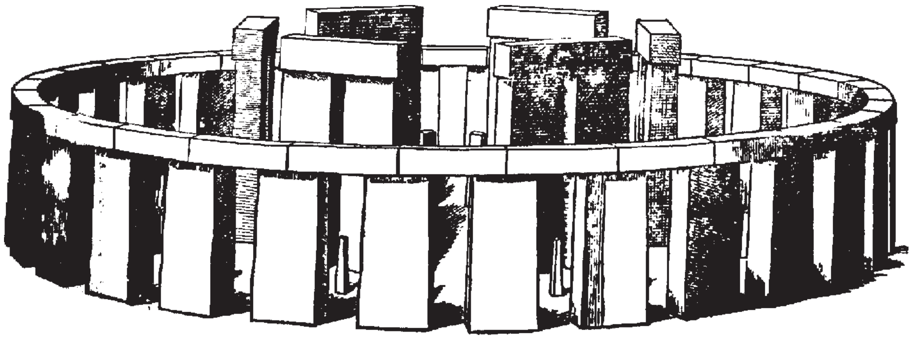
A PROGRAM FROM THE HOLT PLANETARIUM

by Alan J. Friedman

Jointly published by

the Lawrence Hall of Science, University of California, Berkeley, California

and the New York Hall of Science, Flushing Meadows Corona Park, New York



from *Stone-Heng, Restored*,
by Inigo Jones
17th Century

Development and publication of *Stonehenge* was made possible by grants from the Holt Foundation and from the National Science Foundation (Grant Number MDR-9053778). Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Holt Foundation or the National Science Foundation.

For latest information, valuable links, and resources relating to the PASS series, visit:

http://www.lhs.berkeley.edu/pass

Additional copies of the *PASS* Volumes may be purchased from:

Learning Technologies, Inc.
40 Cameron Avenue
Somerville, MA 02144
800-537-8703

LHS

Acknowledgements

Programs involving Stonehenge are a staple of planetariums around the world, especially since the publicity surrounding Gerald Hawkins' 1965 book, *Stonehenge Decoded*. I wrote the original version of this *Stonehenge* program in 1972 for use as the opening program in the William K. Holt Planetarium at the Lawrence Hall of Science, University of California, Berkeley. As far as I know, this was the first participatory program inviting visitors to share the excitement of Hawkins' theory.

The idea for a participatory, activity-based program on Stonehenge was inspired by a horizon-marking planetarium lesson I saw given by Bob Andress in the Warrensville Heights school planetarium in Ohio. The first trial of the key Stonehenge activity was made with the help of Mr. Andress and his students.

This activity-based program has been adapted, improved, and performed at the Holt Planetarium and many other planetariums for the past twenty years. I am grateful for comments and suggestions received over these years from many students, planetarians, and scholars. I would particularly like to thank Dr. George Reed, West Chester State College, for his encouragement, and the participants in the Summer 1992 Astronomy and Space Sciences workshop in Berkeley for their critiques.

Dr. Edwin C. Krupp, Director of the Griffith Observatory and Planetarium, and a distinguished authority on archaeoastronomy, kindly read and commented on this latest revision of the original *Stonehenge* activity-based program. Alan Gould developed the activities and special effects, and Dr. Joseph Snider provided the Solar Motion Demonstrator activity. The responsibility for any inaccuracies is mine.

Photos and Illustrations

All photographs of Stonehenge and Uxmal are by the author or Dr. Krupp, as noted on the slide list. Cover collage elements: Solar Eclipse photo by Peter Michaud, and Stonehenge photo by Hawkins. Title page silhouette based on cover photo. Diagrams of Stonehenge alignments are by Alan Gould, based on Gerald Hawkins' originals. Drawings suggesting how Stonehenge might have been constructed are by Alan Sorrell, British Crown Copyright—reproduced with permission of the Controller of Her Britannic Majesty's Stationery Office. John Erickson created the photocopy master for the Stonehenge Mask Assembly (p.4). All other illustrations in this volume are by Alan Gould.

Planetarium Activities for Student Success (PASS)

Series Editors: Cary Sneider, Alan Friedman, and Alan Gould

If you have access to a planetarium for teaching about astronomy, space science, and other subjects, this series of books is for you. Designed for both experienced planetarium professionals and teachers who will be using a planetarium for the first time, these volumes provide a wealth of field-tested strategies and practical suggestions for presenting entertaining and educationally effective programs for students.

The first four books provide a general orientation to astronomy and space science education with applications for both the planetarium and classroom settings. Each of the remaining volumes presents a complete planetarium program and related classroom activities. We hope you will find the materials useful in your work with students and teachers, as well as springboards for your imagination and creativity.

Volume 1: Planetarium Educator's Workshop Guide

Participatory planetarium programs involve students actively in the planetarium environment. The most effective programs are both entertaining **and** educational. This guide introduces the theory and practice of developing effective planetarium programs through a series of thought-provoking activities and discussions.

Volume 2: Planetarium Activities for Schools

This volume provides a wealth of effective planetarium activities for elementary and middle school students, as well as ideas for developing new activities for students of any age.

Volume 3: Resources for Teaching Astronomy & Space Science

There is a wide spectrum of resources for teaching astronomy and space science in elementary and middle schools. This annotated resource guide has the best resources that we have found, including school curricula, books, periodicals, films, videos, slides, professional organizations, planetariums, and telescopes.

Volume 4: A Manual for Using Portable Planetariums

Primarily a "how-to" manual for setting up and using a portable planetarium, this guide has many suggestions useful for teaching school programs in **any** planetarium.

Volume 5: Constellations Tonight

In this participatory version of a classic night sky planetarium program, students receive star maps and have an opportunity to use them to find constellations in the planetarium sky. Classroom activities include creating constellations and using star maps.

Volume 6: Red Planet Mars

Students discover Mars three different ways during this planetarium program. They find the red planet by observing it over a period of several nights as it moves against the background stars. Then they view it through a telescope and try to map its surface. Finally they see Mars via space probes. Classroom activities involve students in modeling the solar system, and creating creatures that could survive under different planetary conditions.

Volume 7: Moons of the Solar System

This program begins with observations of the Earth's Moon and a modeling activity that shows why the Moon goes through phases and eclipses. Then the students look at Jupiter's four major moons on a series of nights and figure out how long it takes each one to circle Jupiter. Finally, the students journey through the Solar System to see many moons through the "eyes" of modern spacecraft. Classroom activities involve students in performing experiments in crater formation, using moon maps, and designing lunar settlements.

Volume 8: Colors from Space

What can we learn about the stars and planets from their colors? Answering this question requires a fundamental understanding of why we see color. During this program, students deepen their understanding through a series of activities in which they "travel" to an imaginary planet circling a red sun, and experiment with color filters and diffraction gratings. Related classroom activities include making secret messages that can only be decoded with color filters, and then using the same filters to view nebulae and planets.

Volume 9: How Big Is the Universe?

Based partly on ideas from the short film *Powers of Ten*, this program surveys distances and sizes of things in the universe. Starting with ordinary things on Earth that students are familiar with, they move to progressively more distant astronomical objects: the Moon, the Sun, the Solar System, nearby stars, the Milky Way galaxy, and clusters of galaxies. Students use various methods to determine distance: parallax, "radar," and comparing brightness of objects. Classroom activities include students writing their complete galactic address, making a parallax distance finder, finding the distance to the "Moon," and activities about the expanding universe.

Volume 10: Who "Discovered" America?

Students ponder the meaning of the word *discover* in this program. Can one "discover" a land where people are already living? Students learn the reasons and methods by which Columbus navigated to the "New World," and some of the impacts of his voyages on Native Americans. They also find that certain myths about Columbus are untrue. He was not, for example, alone in believing that the Earth is round. Students also learn about other explorers who "discovered" America long before Columbus's time. Classroom activities include determining the shape and size of the Earth, using quadrants to determine latitude, and modeling lunar eclipses.

Volume 11: Astronomy of the Americas

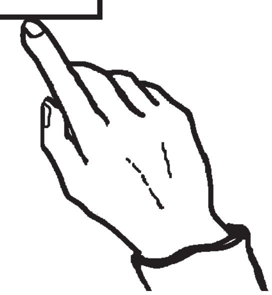
There are hundreds of Native American cultures, each with distinctive views of the heavens. There are also common threads in many of those cultures. In this program students visit five cultures: the Hupa people of Northern California, plains and mountain tribes that have used Medicine Wheel in Northern Wyoming, the Anasazi of Chaco Canyon in New Mexico, the Mayan people in Mexico and Central America, and the Incan people in Peru. Students observe moon cycles and changes in the sunrise and sunset positions on the horizon and learn how solar observations help Native Americans stay in tune with the harmonies of nature. Classroom activities include the Mayan and Aztec number systems, observing changes in real sunset positions, and learning how Venus can appear as either the "Morning Star" or "Evening Star."

Volume 12: Stonehenge

In this program, students learn what Stonehenge is and how it could have been used by its builders as a gigantic astronomical calendar. They also learn how astronomer Gerald Hawkins discovered one of Stonehenge's probable functions, by actively formulating and testing their own hypotheses in the planetarium. Along the way, they learn a lot about apparent solar motion, and the creation of the research field of "archaeoastronomy." Classroom activities include constructing a special Solar Motion Demonstrator to represent the entire yearly cycle of solar motion.

Stonehenge

Contents



Stonehenge

Planetarium Program

Preface

Stonehenge, a prehistoric stone monument in southern England, is one of the best known structures in the world. Its strangely beautiful shapes, rough symmetry, and above all its mystery have made it an attraction and fascination for centuries. Articles, pamphlets, scholarly books, and novels have been written about it. Its silhouette has appeared on the covers of travel guides, rock music albums, freshman astronomy textbooks, and religious tracts.

Interest in Stonehenge among scholars intensified dramatically in the past three decades as archaeologists have made major strides in learning about the neolithic (new stone age) and bronze age people who lived in England at the time Stonehenge was built. The public became entranced by the ideas of Gerald Hawkins, a young astronomer, who boasted in 1963 that he had “decoded” Stonehenge, and that it was an astronomical observatory and eclipse predictor. The debate over the more speculative of Hawkins’ claims has still not ended, but his basic ideas have convinced most scholars that astronomy did indeed play a more important role in the design of Stonehenge than had been suspected. The excitement also helped to stimulate a whole generation of investigators who are studying the new science of “archaeoastronomy,” and who have learned much about the importance of astronomy to ancient peoples around the world.

This planetarium program seeks to take advantage of the continuing fascination with Stonehenge, and the dramatic story of Hawkins’ hypothesis, to communicate to students important aspects of how science works. New ideas about Stonehenge were invented, explored, refined, and tested at other ancient structures around the world. Some of these sites, particularly in the Americas, turned out to have astronomical alignments far more accurate and indisputable than does Stonehenge itself.

Thus the Stonehenge story is an excellent example of the human drama of science, with all its inspiration, mistakes, controversy, and, in the end, immense satisfaction in having glimpsed a little more of how the universe works.

Objectives

In this planetarium program, students will be able to:

1. Describe the appearance, age, and long-standing puzzles about the purpose of Stonehenge.
2. Explain the origins and basic components of Gerald Hawkins’ hypothesis that Stonehenge could have been used as a naked-eye observatory for horizon astronomy.
3. Perform an investigation, using the planetarium, to test Hawkins’ hypothesis through the search for possible horizon alignments.
4. Describe, qualitatively, the pattern of the Sun’s horizon position at rising and setting throughout the year, and the relation of the Sun’s apparent motion to the seasons.
5. Describe how Hawkins’ ideas were applied to other sites.
6. Increase their estimation of the intelligence, ingenuity, and dedication of ancient peoples.

Note: This program, with only minor adjustments, has been used extensively with audiences from 3rd grade through adult.

Materials

The key activity in this program involves searching for horizon events, and then comparing those events with alignments of the stones at Stonehenge. Two basic tools are needed: horizon markers which students use to record rising and setting locations on the horizon, and indicators for the alignments Hawkins found at Stonehenge.

1. A horizon marker for each member of the audience. Students are going to watch for horizon events, risings or settings they think may have been important to ancient people. They need to mark those events along the planetarium horizon.

Students need to be able to stand near the horizon in your planetarium to use these markers. In a STARLAB or other small planetarium that may be easy, but it is more difficult in a bigger planetarium with two or more rows of concentric seats, or in a planetarium with uni-directional seating. In those cases, you can adapt the program by assigning a different small group of students to stand at the horizon and mark objects for each round of the experiment.

Version I. A marker that can hang from the cove. The marker can be a wood, cardboard, or plastic strip, about 5 centimeters wide and 40 centimeters tall. Fasten a hook on the back so that the marker can be hung on the cove to mark a position on the horizon. The markers should be numbered or lettered, so that participants can remember which one is their own. See Figure 1. The markers could also be attached by having small pieces of velcro™ attached to the back, and a band of the mating material all around the dome at the horizon. In a STARLAB, it's best to attach the "hook" component of the velcro™ on the markers, and the "loop" or fuzzy part on the dome.

Version II. Sticky paper dots or squares. This fast, cheap alternative to a prepared marker is being used by many planetariums, particularly small units and portables like STARLAB. Your nearest stationery store will have rectangles in various sizes (3M Post-its™) as well as self-adhesive disks in many sizes and colors (Avery is a major brand). Fluorescent red dots in the 3/4 inch diameter size work well for STARLABS. A few dollars will purchase a supply of a thousand dots.

The only trick is to choose material in a color and size that is easily visible in a dim planetarium, and has the right degree of stickiness. Too weak an adhesive can mean markers not sticking or falling off too soon, especially if the dome is dirty; too strong an adhesive might mean work for you cleaning them off after each program.

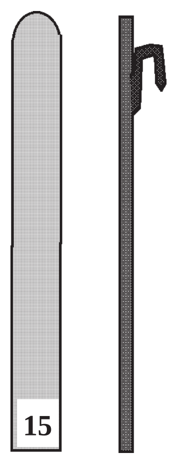


Figure 1

2. Stonehenge alignment indicators on the dome. The alignment indicators are four simple rectangular archways, like the Stonehenge "trilithons," projected or fabricated of cardboard. They are placed so that the planetarium's Sun will rise and set in these openings on the solstices, the longest and shortest days of the year, at the latitude of Stonehenge, 51 degrees north. The solstices are usually June 21 and December 21, although variations in our calendar with respect to the actual motion of the Earth around the Sun vary the actual dates by a day or so from year to year.

Version I: a cardboard-drum silhouette projector. See Figure 2. A drum-shaped ice cream container, from your local ice cream shop, makes a fine structure for this projector, but any cylinder will do. You can cut the cylinder into two parts, along the axis, so that each half can project over half of the dome without the main star projector getting in the way.

The cutout Stonehenge outline does **not** have to be precise except in one feature: the larger archway openings must line up with the extreme northern and southern risings and settings of the Sun in your planetarium when set for the latitude of Stonehenge. The outline you will project cannot be a straightforward representation of Stonehenge in any event, since Stonehenge consists of several concentric rings of stones. Thus this projector is not intended to show a literal Stonehenge horizon, but rather to represent four of the key alignments which are discussed in the program.

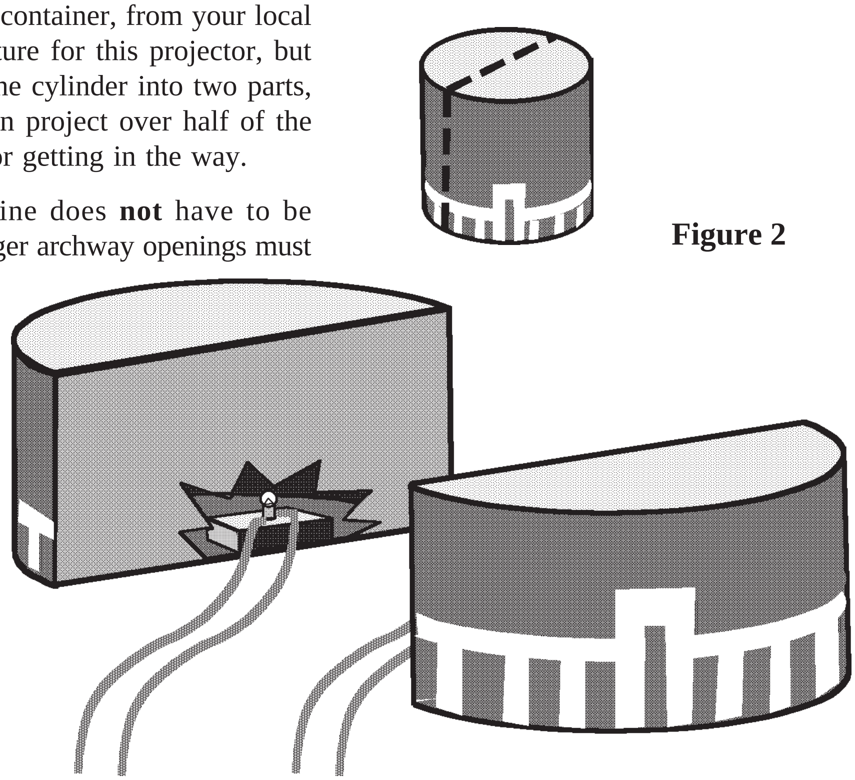
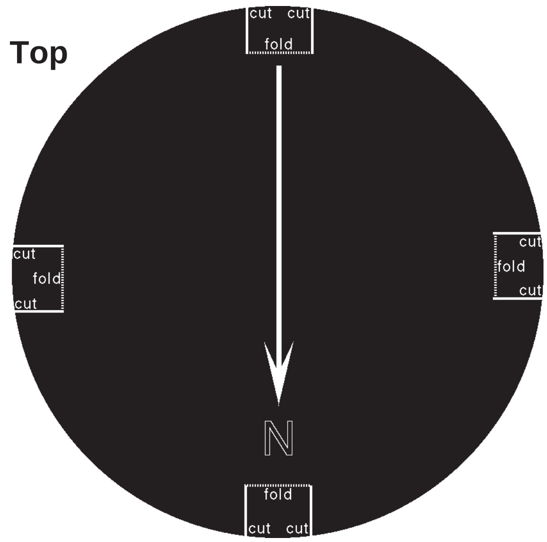


Figure 2

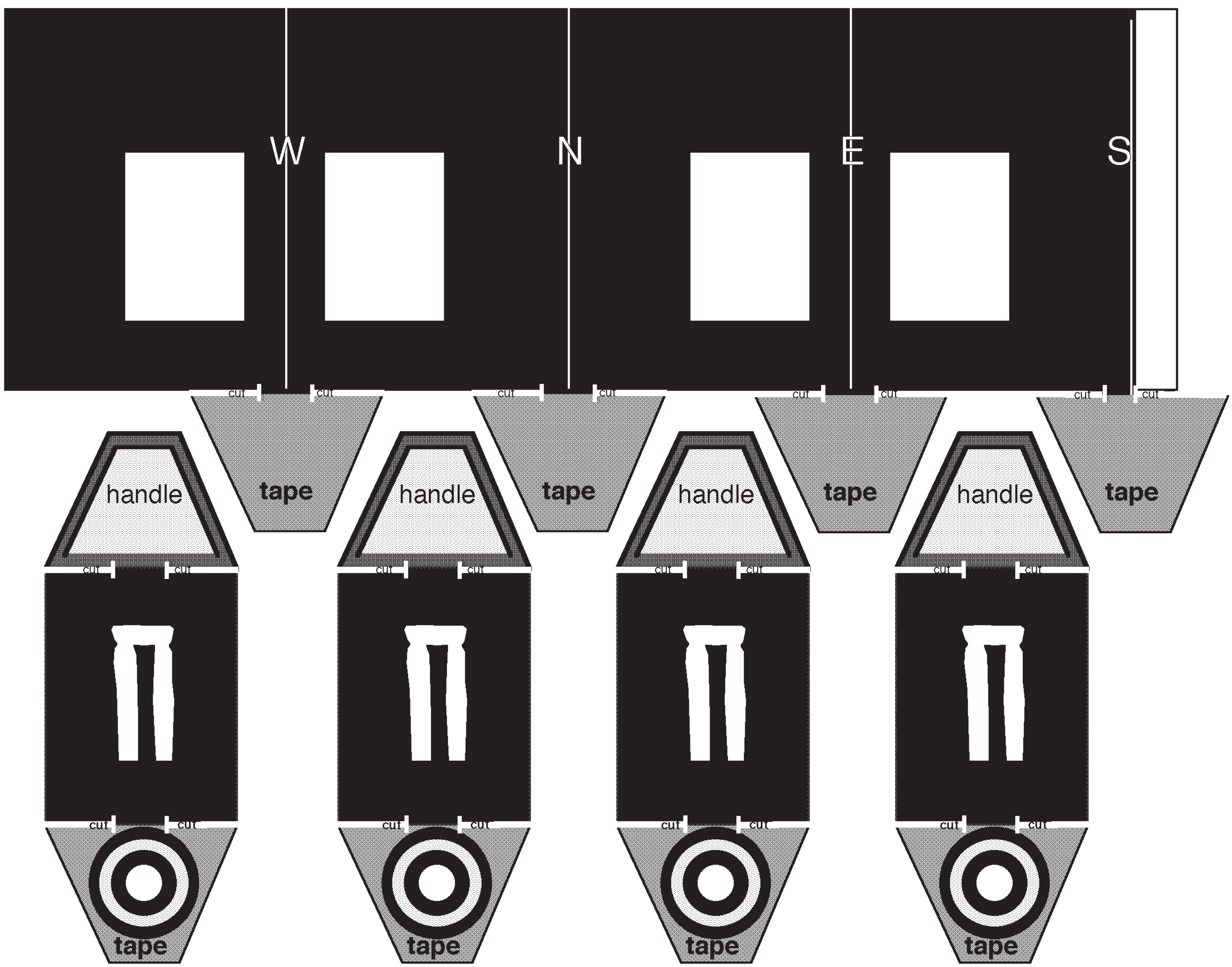
You'll need to experiment with your cutouts so that the archway openings are in the correct horizon positions, and then mount the projector securely so that the alignments are not changed by mistake. A check immediately before the program is advised.

A simple silhouette/shadow projector like this produces a very impressive result. Even the unevenness in brightness of the projected shapes serves to good effect, appearing to represent the worn, pitted surfaces of the stones.

Stonehenge Mask Assembly
Master for Photocopy



Window Cylinder



Trilithon Masks

Version II: a photocopy mini-silhouette projector. This is the same basic idea as the cardboard drum, but in a miniature, one unit version (Figure 3a), particularly suited for a portable planetarium like the STARLAB.

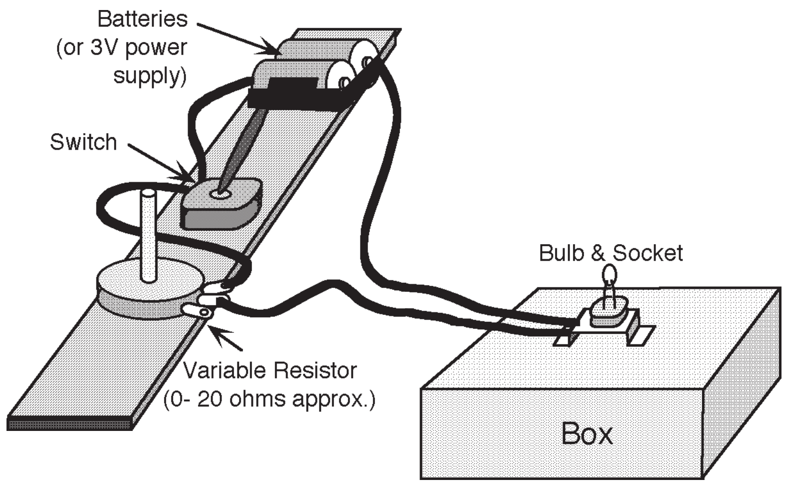


Figure 3a

There are many ways to do this, but one simple way is essentially the versatile "mini-brute-force" horizon projector described in PASS Vol. 11, p.2, adapted to project the Stonehenge alignments. Assemble the electrical parts as shown in Fig. 3a using a #605 light bulb, a Mini-mag lite® flashlight bulb, a STARLAB main star bulb, or other suitable light bulb with a very small filament as the light source. (The variable resistor is optional.) Photocopy the Stonehenge Mask Assembly (master on page 4) onto a transparency and form the Stonehenge Mask Assembly as follows:

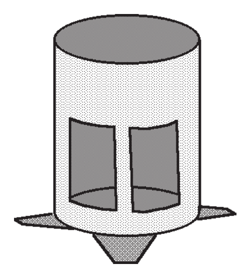
a. Cut out the six parts of the mask assembly: the Top, the Window Cylinder piece, and the four individual Trilithon Masks. Cut in slits (indicated by the word "cut"). Optional: with a hobby knife or small sharp scissors, cut out the four windows in the Window Cylinder piece. This will make the projected trilithon images brighter and clearer.

b. Fold the "tape" and "handle" tabs as shown in Fig. 3b. There are four on the Window Cylinder, and two on each of the Trilithon Masks. Also fold where indicated on the Top piece.

Figure 3b

c. Roll the Window Cylinder piece into a cylinder so that the N, E, S, W, marks read backwards as seen from the outside (frontwards as seen from the viewpoint of the lightbulb; Fig.3c). Tape the seam without covering any windows or letters.

Figure 3c



d. Position the Window Cylinder around the light bulb so that the light bulb is centered in the Cylinder. Tape the Cylinder tabs securely to the projector box top. (Fig. 3d.)

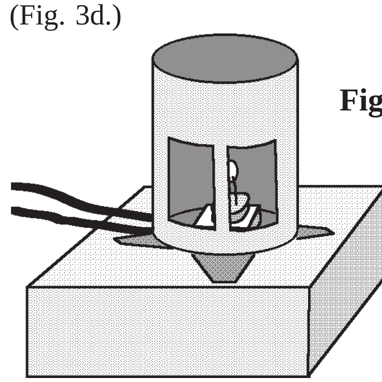


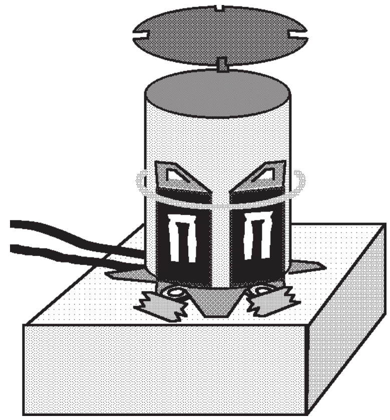
Figure 3d

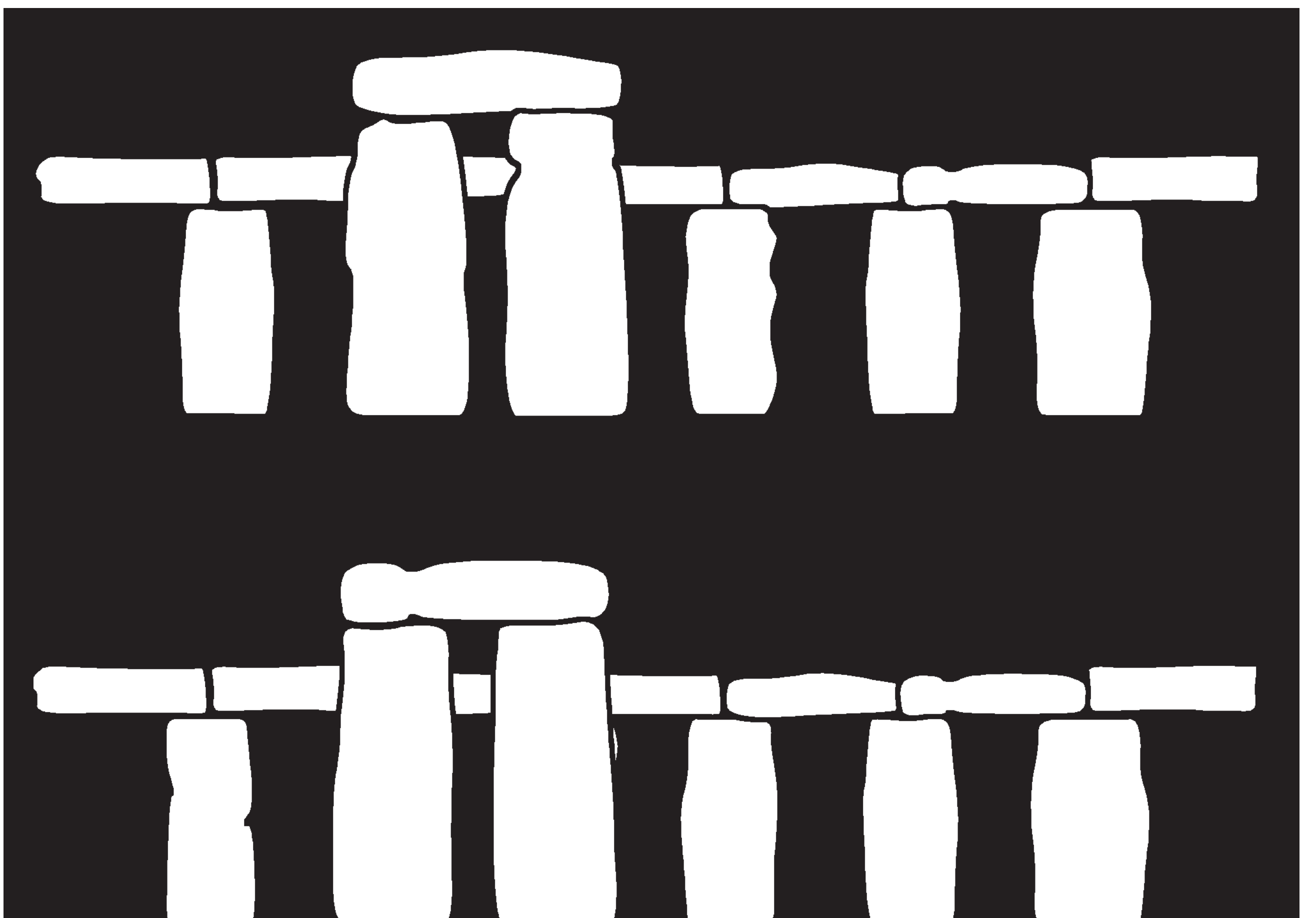
e. Lightly tape Trilithon Masks in front of the four clear windows of the Window Cylinder. Put a rubber band around the tops of them. (Fig. 3e.) The top tabs of the Trilithon Masks facilitate adjusting their positions during set-up for the Stonehenge program.

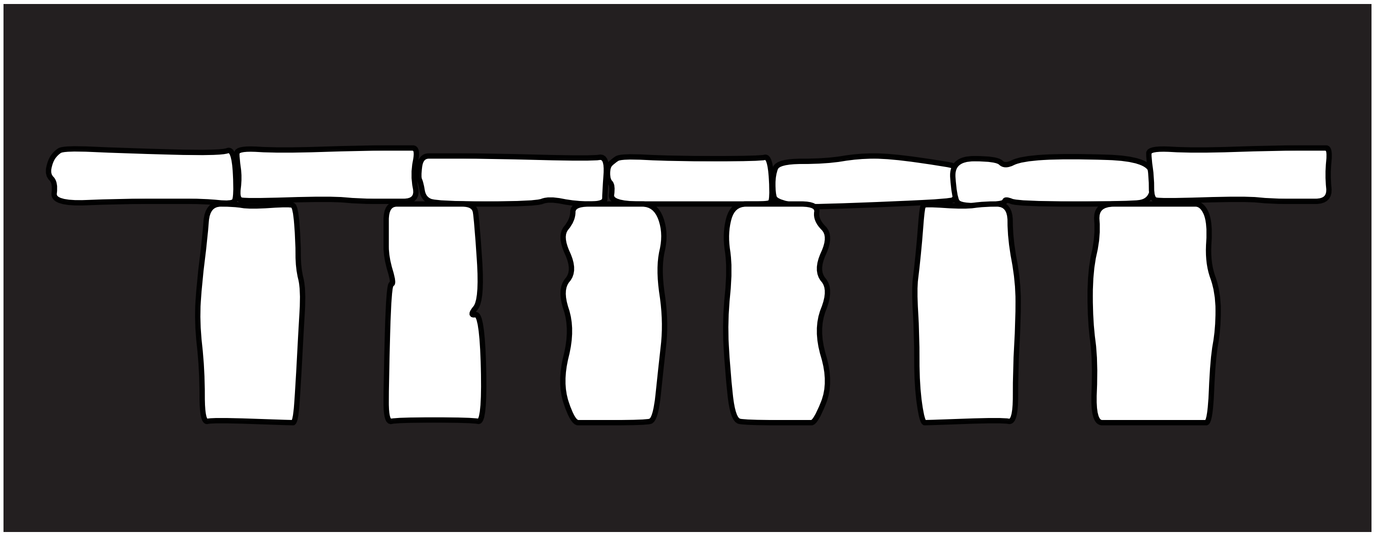
In setting up for the program, the Trilithon Masks need to be lightly taped in place, carefully adjusted so that they accurately mark the solstice sunrises and sunsets, and then taped more securely in place. This works fine, but you must be careful to check the position of the projection masks just before the program to see that all four archways show up in the correct position on the horizon. Moving the masks just a millimeter can throw your alignments off so that the Sun fails to appear in the proper archways.

Version III: a regular planetarium horizon panorama projection system showing the alignment archways. If your planetarium has a horizon projection system, and you can prepare slides for it, you can prepare simple artwork such as shown here for four archways and adjust the alignment positions as discussed above.

Figure 3e







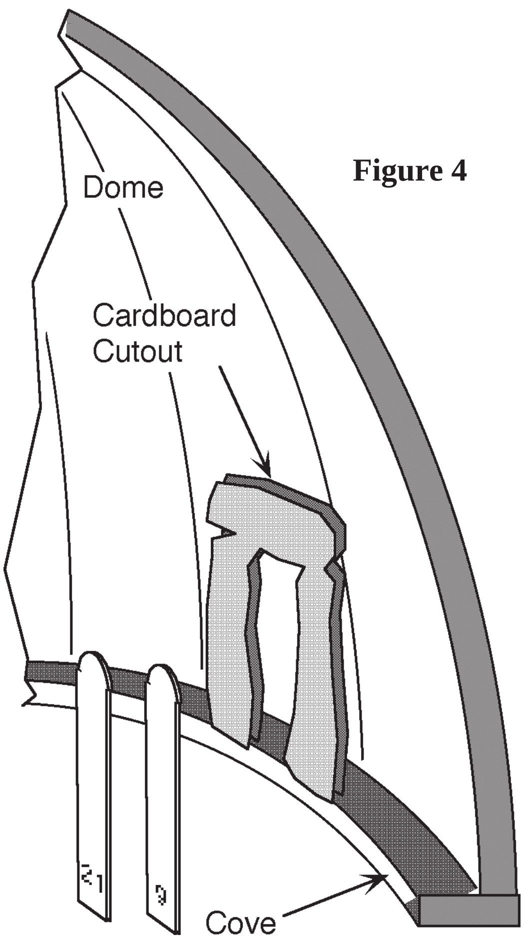


Figure 4

Version IV: full-size cardboard archways to be attached directly to the dome with tape, velcro™ or paper clips (if you have a perforated dome). A low-tech alternative to the projectors above is to use four large cardboard pieces (Figure 4) attached to the cove. The only major disadvantage to this quick solution is that these alignments cannot be turned on and off with the flip of a switch, so they need to be installed during the program to create the dramatic moment when you compare horizon events discovered by your students with Hawkins' Stonehenge alignments. The installation can be done if you have prepared in advance unobtrusive markers (like pieces of tape or thumbtacks) installed on the bottom of the cove. Students can use those markers to position the cardboard archways quickly.

Stonehenge Slides

1. View of horizon around Stonehenge
2. Closeup of one of the great “trilithon” archways
3. Stonehenge with the “Heel Stone” at the far right
4. Diagram of the large inner stones as they might have been originally, according to Hawkins
5. Diagram of a possible alignment
6. Photograph of that view, which is mostly obscured
7. Diagram of a second possible alignment
8. Photograph of that view, which is mostly obscured
9. Diagram of a third possible alignment
10. Photograph of that view, which is clear to the horizon
11. Photograph of another trilithon alignment
12. Diagram of alignments repeated by four outer stones
13. Sketch of how a large stone might have been transported
14. Diagram of how a large stone might have been set upright
15. Facade of the “Governor’s Palace” at Uxmal, Yucatán, Mexico
16. Closeup of the facade covered with Chac and Venus symbols
17. View from the central doorway with Cehtzuc visible as a slight bump on the center of the horizon

Sources: Slides 1, 2, 3, 6, 8, 11, 17 by Alan J. Friedman. Slides 10, 15, and 16 by E. C. Krupp. Slides 13 and 14 from drawings by Alan Sorrell, Her Majesty’s Stationery Office. Slides 4, 5, 7, 9, 12 by the Holt Planetarium, after Hawkins.

Setup

1. Precession, if available, set at minus 3550 years (the last major phase of Stonehenge was completed about 1550 BC)
2. Latitude set at 51 degrees north
3. Check for correct alignments of the Stonehenge archway indicators with sunrise and sunset on the solstices
4. Annual motion set to today's date (if you happen to be close to either of the solstices, you might want to select another date)
5. Diurnal motion set for shortly before sunrise
6. Set slide projectors for first slide
7. Sun, Moon, and daylight on
8. Planets on unless one or more by coincidence happen to be at the same position as a solstice Sun, in which case they should be left off
9. Stonehenge alignment indicators off

Note: The summer and winter solstices occur on, or within one day, of June 21 and December 21 respectively. As noted earlier, the actual date can vary by a day or so from year to year because our calendar does not track the motion of the Earth around the Sun exactly. Most small planetariums, like STARLAB, do not show these variations and the extreme risings and settings always occur on June 21 and December 21. For convenience, therefore, this script will use June 21 and December 21 as the solstice dates.

Recommendations for Using the Script

We don't expect the script which follows to be memorized (as an actor might memorize a part) but to be used as a guide in learning, rehearsing, and improving presentations. We recommend that you read the script once or twice, then work with it in the planetarium, practicing the projector controls, slides, special effects, and music. You should be able to imagine yourself presenting information, asking questions, and responding to participants. For your first few presentations, you can have the script on hand, using major headings as reminders of what to do next.

The script is organized in blocks or sections. The purpose of these separations is only to help you learn and remember what comes next. Once you have begun a section, the slides or special effects and your own train of thought will keep you on track. When beginning a new section, make the transition logically and smoothly.

Directions for the instructor are printed in *italics*, the instructor's narrative is printed in regular type, and directions and questions to which the audience is expected to respond are printed in ***bold italics***. There is no point in memorizing narration word-for-word since what you need to say will depend upon the participants. The language you use and the number and kinds of questions you ask will depend on how old the participants are, how willing they are to respond, and how easily they seem to understand what is going on.

We believe that the most important elements of the program are the questions and the activities since these involve the audience in active learning. If you must shorten your presentation, we recommend that you borrow time from the narration.

Planetarium Show Script

Gradually dim daylight — fade out music as stars, Moon and planets appear.

Good evening. The sky above us may look like an ordinary nighttime sky, but for today's presentation, entitled "Stonehenge," we have transported you to southern England, on today's date, but 3550 years ago. *(Use the next sentence if your planetarium shows precession.)* The stars are in slightly different positions than what we are accustomed to seeing. The constellations are in their familiar shapes. The sky is darker, of course, since there are no cities, no street lights, and no smog — just a few campfires nearby. This is how the sky looked to the final builders of Stonehenge.

Has anyone here visited Stonehenge?

If so, ask them to describe the setting and the stones. Begin the slides if appropriate.

Image 1: View of the horizon around Stonehenge.

This is how the area where we are camped looks in the daytime.

How would you describe the landscape?

(gently rolling hills, plain, grassy, pretty, peaceful, etc. — accept all reasonable answers, encourage discussion.)

OPTIONAL SECTION, GOOD FOR OLDER STUDENTS

Look at the little sign on a post, just beyond the fence.

You cannot see the front of the sign, but it says "No Parking."

Also notice the tree on the right side of the picture.

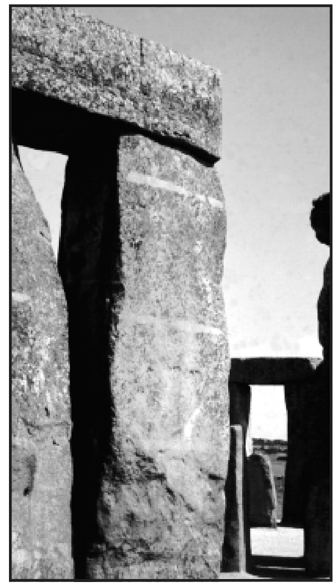
It is a typical tree for the area.

Now from what you already know about the approximate height of "No Parking" signs, how tall would you estimate a typical tree in the area of Stonehenge might be?

Accept several estimates, and ask for explanations of how the estimate was made. For example: "Roadside signs like this are typically just out of reach by an adult, so they must be about 3 meters (10 feet) tall. The tree looks to be the same distance but twice as tall, so it is about 6 meters (20 feet) tall."

So the countryside is gentle, rolling hills, with fairly low trees, perhaps 5 - 6 meters (16 to 20 feet) tall. Maybe that explains why visitors to this site, for thousands of years, have been so amazed by what was directly behind the photographer's back when he took this picture...

Image 2: Closeup of one of the great "trilithon" archways.



...we see these remarkable, huge stone blocks, each standing 7 meters (twenty-four feet) tall, higher than the trees in the area. ***How much do you think a stone like that weighs?***

Archaeologists have determined these large stones weigh 45,000 kilograms (fifty tons) each, as much as two dozen cars! The original boulders that these stones were cut from are not native to this part of England — some came from 40 kilometers (25 miles) away, while some of the smaller stones, weighing a few thousand kilograms (a few tons) may have been brought here from 400 kilometers (250 miles) miles away.

There is evidence that when the Romans founded colonial outposts in what is now England, they visited Stonehenge.

How long ago would that have been? (Hint: When did the Roman empire send tax collectors to their far-flung colonies?) *(According to the New Testament Bible about 2000 years ago, or 1 BC, Jesus was born in Bethlehem where his mother went for a Roman empire census.)*

The Romans who visited Stonehenge had no idea who built it or why. It didn't even have a name (Stonehenge is a relatively recent name, only a few hundred years old). When the Romans visited, 2000 years ago, Stonehenge was *already* a ruin.

We now know the monument was as old to them as their civilization is to us now. We know that Stonehenge was built in stages between 2800 and 1550 BC. So it is more than twice as old as the ancient Roman buildings like the Coliseum in Rome.

Image 3: Stonehenge with the "Heel Stone" at the far right.

Archaeologists believe that the people who built Stonehenge used few if any metal tools, and may not have known how to use a wheel. Yet they assembled and pounded and gouged these monster stones and planted them upright in the ground to create the structure we see today. Throughout history people have wondered why the builders went to so much trouble. Since the builders left no writing or pictures to explain, there are few clues to help us understand the purpose of Stonehenge — other than the stones themselves.

What would you guess were some reasons why Stonehenge might have been built? *(Accept all reasonable answers, and list at the end.)*

Now, with your help, we will see what a young astronomer, Gerald Hawkins, who visited Stonehenge on a vacation, guessed about the ancient monument, and what may explain at least part of the answer to the question, "why?"

Gerald Hawkins, Astronomer and Tourist, Makes a Guess

Hawkins started with the fact, discovered a few hundred years ago. On the first day of summer, the longest day of the year, the Sun as seen from the central area will rise just over this stone *(indicate the stone on the far right with a pointer).* That stone is called the "Heel Stone" (a modern name like "Stonehenge" itself). Having one alignment is not too surprising. It could be coincidence. On the other hand, many modern churches and temples have been aligned to that direction on the horizon, since many people have felt that the longest day of the year is of special importance. This day has marked the midpoint of many calendars and the first day of others.

One alignment does not go far towards explaining all these massive stones. Hawkins' inspiration was to ask himself the question: "If one stone at Stonehenge marks one astronomical alignment, the sunrise on the longest day of the year, might the other stones have marked other astronomical events?"

Activity #1—Predicting Today's Sunset

To see what marking an astronomical event means, let's try to record an astronomical event ourselves: where the sun rose on today's date *(give the current date)*, but 3550 years ago.

Even planetariums with precession settings cannot adjust for the small change in inclination of the Earth's axis, which affects the position of sunrise and sunset. Thus we are taking artistic license here. In contrast to our simplified presentation in the planetarium, the computer programs used by Hawkins and other researchers must take into account many factors which affect observed rising and setting positions, including local terrain, atmospheric refraction, and the shift in inclination of the Earth' axis.

Lower daylight, diurnal motion on slow. Stop diurnal when the disk of the Sun is half-way above the horizon, and raise daylight. (Sunrise and sunset can also be defined with the disk standing tangent on the horizon, or tangent just below the horizon, but we will use half-way as the rise/set position for this program.)

Let's mark the position of sunrise. *(Demonstrate how to place a horizon marker at the sunrise position.)*

Now let's predict where sunset happened on this same day, 3550 years ago. First I'll speed up the planetarium, as if the Earth were spinning faster. *(Turn on diurnal and let the audience watch the sun rise to noon. Stop diurnal.)*

It's about noon on this day, 3550 years ago. ***Have you decided where the Sun will set? Then take your pointer and go over and place it where you predict the Sun will set. Remember your pointer so you can tell how close your prediction is.***

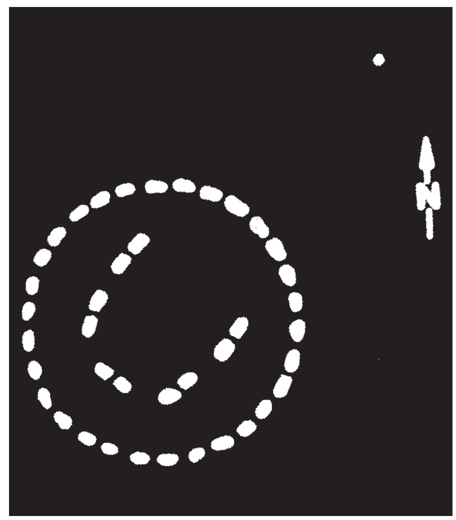
Point out wide range of guesses: due to our indoor life, we usually have a poor notion of sunset position. Many students will place their pointers exactly at West.

Begin diurnal motion, continue to sunset (Sun half-way down). Congratulate the person coming closest. Have students retrieve their pointers, leaving only the two which mark the sunrise and sunset.

Reconstructing Stonehenge

Gerald Hawkins guessed that if Stonehenge marked one alignment with a celestial object, the Sun, it might mark others as well, like the sunrise and sunset we just recorded, or the risings or settings of stars or planets. To test that suspicion, his hypothesis, Hawkins first had to "reconstruct" Stonehenge, at least on paper, to see what alignment markers might have been present when Stonehenge was in use.

Image 4: Diagram of the larger inner stones.

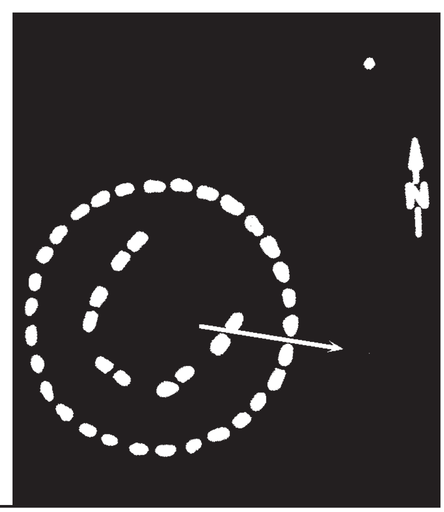


This map of Stonehenge, as seen from above, shows what Gerald Hawkins imagined Stonehenge would have looked like when it was finished, about 1550 BC. He has drawn in missing stones and positioned fallen stones back upright. Stonehenge today is in far from perfect condition. In the 18th century, you could visit Stonehenge, rent a sledgehammer, and take home a piece for a souvenir.

Standing in the center of the monument *(point out)*, Hawkins would not have been able to see much horizon at all—there seemed to be no especially significant views from the center. Even the famous Heel Stone sunrise alignment did not go through the exact center of the monument. It is important that Hawkins then asked another question, because if he hadn't, he might have given up, thinking that there were no other astronomical directions marked by Stonehenge.

What additional questions might you ask about possible alignments? As you *(guessed or did not guess)*, Hawkins asked himself if there might be significant views of the horizon if you stood at places **besides the center.**

Image 5: Diagram showing a possible alignment.

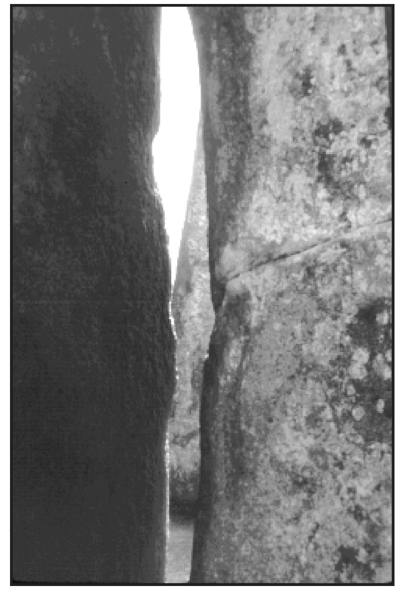


Standing in front of these two stones *(point out on diagram)* you would be looking through a narrow gap between two of the giant stones.

"Trilithon" is the name modern people have given to a set of two stones capped by a third huge stone. Now, looking through the archway of the trilithon in the direction shown by the arrow on the map *(point out)* you could see all the way to the horizon only if the outer ring of stones does not block your view.

But remember those stones are thick, and somebody took a lot of trouble making them rectangular blocks, with smooth sides. So if you stick your head in the gap, and try to look along this arrow, here is what you would actually see:

Image 6: Photograph of that view, which is mostly obscured.



Would you say that this is a good view of the horizon? *Accept answers without saying "right" or "wrong," suggesting that we compare it with the other possible view.*

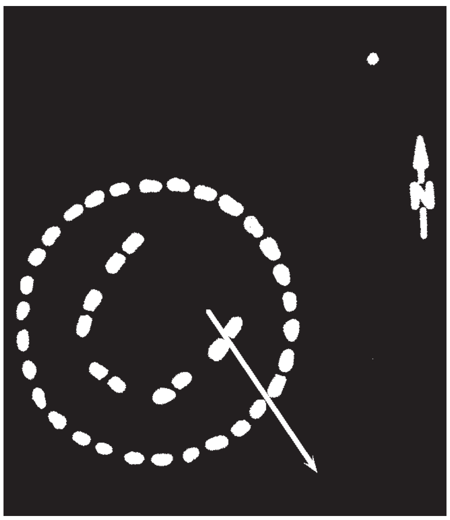
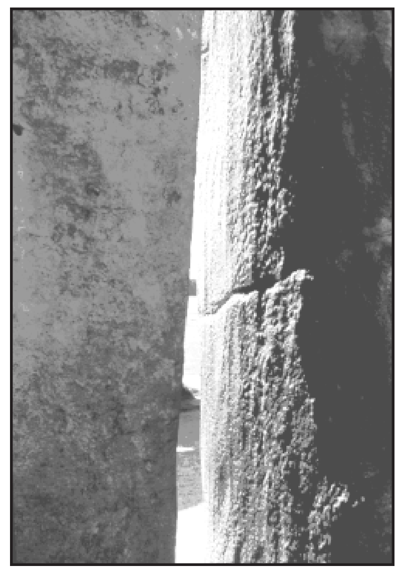


Image 7: Diagram of a second possible alignment through the same trilithon.

Now let's try standing in the same spot, but looking in a slightly different direction *(point out arrow)*. We would then see this:

Image 8: Photograph of that view, which is also obscured.



Well, what do you think of this view?

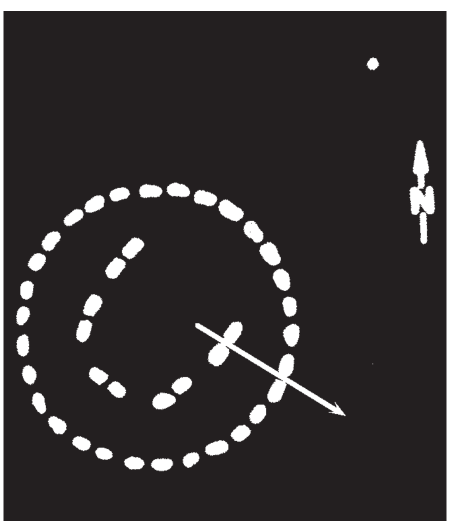


Image 9: Diagram of a third possible alignment through the same trilithon.

Let's try looking through the trilithon and these two stones this time *(point out)*. Here is what you can see now.

Image 10: Photograph of that view, which is clear to the horizon.

Pause for audience comments about how this view compares with the last two views.

The builders of Stonehenge were very careful to place their stones in just the right spots, and then to pound and scrape them. And one result was that each of the trilithons provides one or two narrow but good views of the horizon.

Image 11: Photograph of another trilithon and its alignment with other stones.

Here is the view through another trilithon. Look how carefully the narrow gaps restrict your view to just one direction on the horizon. Hawkins argued that these alignments were probably not accidental, because it took a lot of work to pound lumpy boulders into the straight edge rectangles which create these views.

The next surprise for Hawkins was that the views he had found were in directions repeated by **other,** outlying stones at Stonehenge.

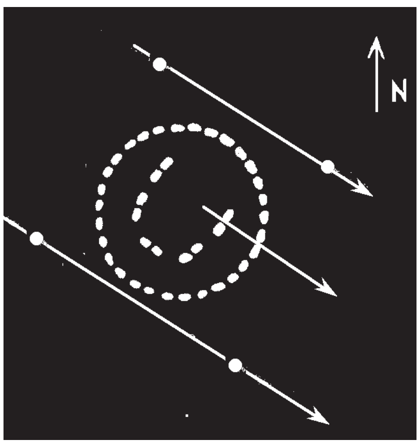


Image 12: Diagram showing previous trilithon alignment repeated by other features at Stonehenge.

This diagram shows the positions of a few of the smaller stones at Stonehenge which archaeologists had previously thought to be placed randomly, or to be fragments of now-destroyed other rings of stones. Hawkins found that sighting along these features repeated some of the important directions that he found established by the trilithons.

Within a variation of about 1 degree, these three lines of sight are parallel. In the same manner, Hawkins found a total of ten alignments he thought might be important. He knew that one of those marked the position where the Sun rises on the longest day of the year.

What other astronomical objects might the alignments at Stonehenge keep track of by pointing to their rising or setting positions?

Note responses and repeat the list at the end.

To answer this important question, Hawkins turned to a computer. He fed into it a diagram of Stonehenge, the one you have seen, and information about the positions of the stars, the Sun, Moon, and the planets as they appeared to the builders of Stonehenge. He then asked the computer: "Did something important happen (like the rising or setting of some celestial body) at these ten points on the horizon?"

Activity #2 — Marking More Risings and Settings

We can give our planetarium the same information that Dr. Hawkins gave his computer. Right now the stars, Sun, Moon, *(and planets, if you are using them)* are positioned as they would be on today's date, but 3550 years ago, the time when the giant trilithons were erected.

The first stages of Stonehenge were built much earlier, 4800 years ago, in 2800 BC. While the stars change their rising and setting positions substantially, the Sun and Moon positions change only a little.

And here *(turn on Stonehenge alignment indicator or install Stonehenge alignment arches)* we have four of the major, repeated alignments as determined by Hawkins.

Do any of these alignments match the sunrise and sunset we marked earlier? *(No.)*

Leave those markers in place. Turn off Stonehenge alignment indicator, or remove alignment arches.

At this point, Professor Hawkins made some more guesses, hypotheses, about what astronomical events might be marked by these special directions, and then tested them on his computer. We are going to do precisely the same thing here in the planetarium. We are going to experience a night at Stonehenge, 3550 years ago. I can speed up the rotation of the Earth, and make the night seem to go by in about three minutes.

You can each decide to mark the risings or settings of bright stars, planets, Sun, Moon, star groups, or whatever else you happen to see on the horizon where you are standing.

We are ready to begin. Remember what object you marked when you finish, and leave your marker in place when you sit down.

Turn on diurnal motion, slowly enough so that students will be able to mark risings and settings of their choice. Turn down daylight and fade in music. **As you go through the night, ask what objects students are tracking.** *Some students will be watching bright stars in the north, such as the Big Dipper. When their stars fail to set, and start going up again, point out the existence of these "circumpolar" stars, stars which never go below the horizon. As the Sun starts to rise, turn on sunrise and gradually, full daylight. Stop at midmorning, fading out music and sunrise.*

Good morning! We have lots of risings and settings marked, and now we can see which, if any, agree with the directions marked by Stonehenge. ***Ask several students to describe what they marked, how it moved through the sky, and to point out their markers.***

Turn on Stonehenge projector and reduce daylight.

Have we solved the mystery of Stonehenge?

As you might imagine, Professor Hawkins was also disappointed when his computer gave him this same result. There were one or two stars which agreed with one or two alignments, but that could have been just coincidence. To succeed, he needed something to work consistently with **all** his alignments.

Turn off Stonehenge alignment indicator (or remove arches).

Activity #3 — Tracking the Migration of Sunset

Well, there we are. We know what doesn't work. It may be discouraging, but scientists who have an idea usually keep trying until they have exhausted every possibility.

OPTIONAL: If you have time, you can call for other suggestions and try them now, like the Moon in different phases, or the planets.

We have considered alignments on today's date, but 3550 years ago. ***Would changing the date by a week or a month make any difference in where things rise or set?***

Let's find out if the Sun will set in a different place on a different day from today. ***Which marker shows where it set last night? Which shows where it rose today?*** *Ask students to remove all other markers.*

Now let's try next week *(next month if you have a projector like STARLAB which permits only monthly adjustments).* I will run quickly through the day, but as I do I will also advance the date to one week *(one month)* from today.

Keeping daylight up, turn off the Sun and stars and advance annual motion in positive direction for however long it takes for your instrument to advance one week (this is done manually, by moving a plug from one hole to another, on a STARLAB). Turn on daily motion, then turn the Sun on again. During this operation, you can take a vote as follows:

Let's take a vote. How many think the Sun will set in the same place next week as it did today? How many think it will set farther to the south? To the north?

Count and summarize vote. Stop diurnal motion when the Sun is at mid-afternoon, one week (one month) later.

We are close to sunset. Will someone please mark the position of the Sun when it sets? The date is now one month (one week) later.

Run diurnal motion until the Sun sets.

Who made the best prediction? *(Note the direction the sunset position moved, north or south, on today's date.)*

Now let's see if that sunset is marked by Stonehenge. *Turn on, then off, Stonehenge indicator.* Too bad — we still don't have it. Of course, the day we just tried is just *(repeat date you used)*.

Is there anything special about that date? Can anyone suggest a date that is special in some astronomical way every year?

Get list of dates and repeat at the end. Included will generally be the holidays, birthdays, and shortest and longest days of the year. The latter two will generally be on the list, but include these yourself if nobody else does.

Which date from our list shall we try?

If time permits, try as many dates as possible, in the order they will come up as you advance annual motion (or uncover the Sun hole on a STARLAB). Let visitors mark sunrise and sunset positions. Point out the migration of the positions to the north or the south, depending on the season in which you started.

Between each date, turn the Sun off and stars off, and advance annual motion until you are at the next date you wish to try. Run daily motion until you are just before sunrise before turning the sun on.

Eventually you arrive at the next solstice. Adjust the order of seasons below according to your particular starting dates. The following assumes you started between June 21, and December, and are approaching winter. If you started January to May, make appropriate changes.

Happy holidays. Here we are at December 21, just before sunrise. ***Please remove all the markers, and we will start fresh by marking where the Sun rises on this date, the morning before the shortest day of the year.*** Today is the day called the "winter solstice" and it varies slightly on the calendar but always occurs within a day of December 21.

Turn diurnal motion on until sunrise (Sun's disk halfway up), then stop.

Will whoever is closest please place your marker to indicate the position of sunrise? Notice how far to the south the Sun is rising. Indeed, this is the farthest south the Sun will ever rise as seen from this place on Earth. From today on, the Sun will begin rising back toward the north, farther every day.

Start diurnal motion again, and continue through the day, stopping at sunset. Use daylight, sunrise and sunset lights as desired.

You may have noticed that the sun did not get very high in the sky at any time today. It is also up for a much shorter time than it has been on other days. Indeed, this is the most southerly rising, most southerly path, briefest journey of the Sun all year. And that is why this is officially the start of winter! The northern hemisphere receives less energy from the Sun today than it will any other day of the year.

It is interesting to note all the things that happen around December 21. Christmas occurs around then, and so do Chanukah and New Year's Day, and numerous other religious and secular special days. Apparently many peoples have noted the extreme position of the Sun, the brief hours of sunlight on this day. Perhaps they wished to urge the Sun to come back north, eventually bringing longer days and warmer weather. By the way, our calendar does not track the Sun perfectly so some years the shortest day happens to be December 20 or December 22.

It is now sunset on the winter solstice, the shortest day of the year. Let's mark the position of sunrise on this special day. ***Will whoever is closest please place your marker to indicate the spot?***

Shall we test our most recent hypothesis, that sunrise and sunset on astronomically significant days might be marked by Stonehenge's alignments?

Turn on Stonehenge indicator and observe alignment.

Congratulations! Now we have learned that these stones could be used to mark the shortest day of the year by indicating the positions of sunrise and sunset on that one day.

Now that we have found the significance of two of the special alignments which Gerald Hawkins identified, would anyone like to suggest what we should do to find the other two major alignments? Any other dates on our list you want to try?

A good technique is to wait for several suggestions and vote to decide what to do. Since the longest day is now the most logical candidate, it is very rare that this will not work.

Turn off Stonehenge indicator. Turn on the sun, and adjust the planetarium to pre-dawn on June 21.

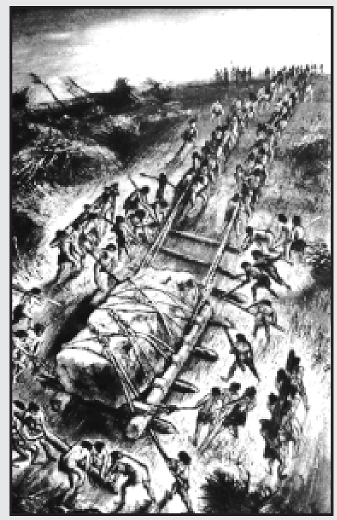
OPTIONAL SECTION

If you have time in the program while waiting for the projector to advance to the next solstice, this section treats a question of general interest.

How was Stonehenge Built?

How was Stonehenge built? No one knows for sure, but archaeologists have pieced together a plausible version of how Stonehenge was built. These are artists' conceptions, and, of course, we don't really know how the builders of Stonehenge were dressed.

Image 13: sketch of how a large stone might have been transferred.

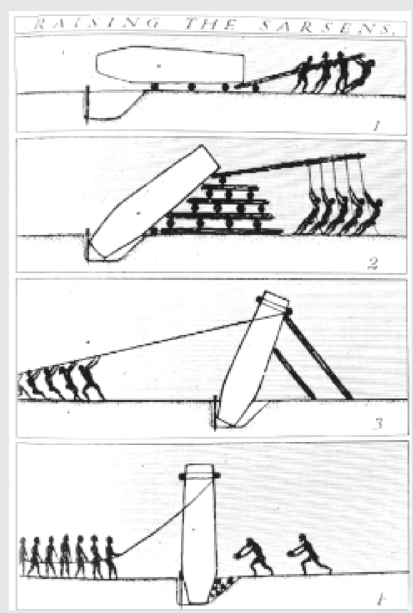


We do know a little about the builders of Stonehenge. The first parts of Stonehenge were built about 2800 BC, 4800 years ago, by "neolithic" (new stone age) farmer/herders. Over the centuries these original people assimilated with the "Beaker People," so-called because they made distinctive clay beakers for drinking, and these people continued building at Stonehenge. The final stages, including the giant trilithons, were built about 1550 BC, 3550 years ago, by the Wessex people, descendants of the earlier cultures.

None of the builders of Stonehenge had wheels or horses, so they faced a formidable task in moving the giant stones by hand from the nearest quarry, 40 kilometers (25 miles) away. This theory about how they did it involves dragging the stones, by teams of perhaps one hundred men, over the ground by rolling the stones on logs. Note that the stone they are dragging is not finished to the smooth, flat surfaces that most of the biggest stones have. Boulders don't come in nice rectangular shapes, so after the stones reached the site, they had to be literally pounded into shape. Since the workers didn't have metal tools, they shaped the huge stones by chipping off chunks with other stones.

Some of the smaller stones (a few tons each) came from a quarry ten times farther away. These could have been brought most of the way on rafts.

Image 14: Sketch of a large stone being set upright.



This is an illustration about how the stones were raised. First, a pit was dug, with one slanted side. Notice the reinforcement wooden stakes on the opposite side—remnants of these have actually been found. The stone was then levered into position by building up the lever pivot in stages.

No matter how it was done, this was a formidable task that could not have been done in a few years or even a few decades. Archaeologists have established that the building of Stonehenge took place in a number of stages, spanning many generations. People worked on Stonehenge for over 1000 years. Can you think of any projects in modern times that are likely to last so long?

Begin daily motion to show sunrise on June 21.

We have now arrived on June 21, the longest day of the year. ***Will whoever is closest please mark the point when the Sun is just half way up?***

After marking, turn on diurnal and continue to sunset. During the minute or so necessary, you can invite questions or summarize proceedings so far.

This is the first day of summer, the longest day of the year. In contrast to December 21, notice how far **north** the Sun rose, how **high** in the sky it gets, and how **long** the path will be, giving us a long, hot day.

Hawkins' Conclusion

Slow diurnal so that sunset can be marked accurately.

Will whoever is closest to the sunset point mark it for us please?

We have now marked the four most extreme risings and settings of the Sun; farthest north and farthest south. We are now ready for the final test. If Stonehenge does indicate these directions in the main four alignments, we will have established that Stonehenge **could** have been used as an astronomical calendar.

Turn on Stonehenge indicator.

Well—remarkably good agreement! Within a degree or so, the stones do mark the sunrise and sunset extremes.

Why might Stonehenge have been built with solar alignments?

Why might it have been so important for the ancient builders of Stonehenge to know for sure when the shortest or longest days of the year had arrived?

If the participants do not respond, you might suggest that the builders were farmers and/or herders. This will usually spark ideas about marking dates for harvesting, transferring animals, etc. You might add that people may even have migrated in those days since they had no way to avoid extremes of weather (no heating or air-conditioning). A calendar like Stonehenge is useful since weather is *likely to be unpredictable, and a long Indian Summer might leave you stranded in snow if you didn't realize how late in the season it was.*

Because many of the archway openings leave a degree or more of uncertainty, the accuracy of these horizon markings would not have made a very precise calendar. Ceremony and religion have always been important, however, so it is more likely that Stonehenge could have been a ceremonial site incorporating the motions of the Sun in its design.

Professor Hawkins has been rewarded for asking the right questions. Both the planetarium and his computer have verified that the alignments he found could have astronomical importance. We have seen that four main alignments mark sunrise and sunset on shortest and longest days of the year. The other six alignments turn out to coincide approximately with six of the eight extreme **moonrise** and **moonset** positions. The Moon has a much more complex cycle than the Sun, and there are eight extremes in a period of about 18 years, instead of just four in one year like the Sun.

Gerald Hawkins' theory and his findings about Stonehenge made him instantly famous, and controversial, among people who had been fascinated by Stonehenge, especially those who had been studying it all their lives. His results were certainly provocative, but there were problems. Hawkins was not trained as an archaeologist, and when he tried to use his findings to say more about the Stonehenge builders, he seemed to be unaware of what more traditional archaeologists had been learning. The alignments he deduced were based on crude maps of Stonehenge; professional archaeologists knew that a better survey was needed for such precise work.

Over the next decade Hawkins' ideas were challenged, and errors he made were pointed out mercilessly. Much better surveys were done. The system for establishing the dates of Stonehenge (radiocarbon dating) was improved, changing the best date for the beginning of Stonehenge by 800 years. Other investigators recalculated Hawkins' data and tried his ideas out on other sites, throughout Britain, and also in other countries.

What is the result of all this work? Most researchers in the field now believe that Hawkins' basic idea was correct, and that one or more astronomical alignments do play a significant role in understanding why Stonehenge was built the way it was. While Hawkins describes Stonehenge as an observatory or primitive computer, most investigators now see Stonehenge more as a ceremonial site which incorporates solar alignments. The Moon alignments, because they are incomplete and also contain large uncertainties, are less convincing.

Perhaps the most important result of Gerald Hawkins' investigation is that a whole generation of astronomers have learned something about archaeology, and a generation of archaeologists have learned a lot of astronomy. Indeed, there are now investigators with solid knowledge of both fields, who study the new field of "archaeoastronomy" and are revising our ideas about our ancestors.

OPTIONAL SECTION

Here is one example of what archaeoastronomy has learned, taken from dozens of exciting discoveries in the Americas.

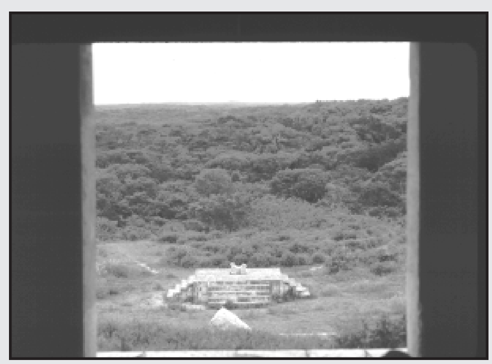
Image 15: Facade of the "Governor's Palace" at Uxmal.

This ruined but still magnificent building we call the "Governor's Palace." It is on the Yucatán peninsula in Mexico. It was the work of the great Mayan civilization which ruled this area for hundreds of years. This building was constructed around 750 AD, in a city called Uxmal *(Ush-mall)*, but it faces the horizon at a different angle from that of the rest of the buildings of that city. Could that angle imply some astronomical alignment?

Image 16: Close-up of the Facade of the Governor's Palace.

The front of the building gives a clue. The elaborate carvings repeated hundreds of times show a Mayan god named Chac, who has a big hooked nose. And in each carving his forehead is decorated with a figure made up of disks and a curved line, which is the Mayan symbol of the god, and the planet, which we call Venus. Venus was very important in Mayan religion and ritual, and they kept careful records of its motions. Armed with their new awareness of the importance of astronomy to ancient people, investigators made careful surveys of the building and the surrounding area.

Image 17: View out of the central doorway of the Governor's Palace.



Here is the view from the central doorway of the Palace. Looking out over a carved pillar and a small platform, can you see a tiny bump on the horizon? That turned out to be a small pyramid in another Mayan site called Cehtzuc *(Kayt-zuc).* The line of sight from the central doorway of the Palace to the tip of that pyramid marks the extreme southernmost rising point of...***can you guess?*** The planet Venus. The accuracy is within 1/30th of one degree.

That is as good as the best Stonehenge alignment *(the earthen "avenue" enclosing the Heel Stone),* and much more precise than the trilithon alignments, which have an uncertainty of a degree or so.

Uxmal was built more than 3,000 years after Stonehenge, on another continent. We are learning that interest and knowledge about astronomy was part of the development of nearly every society on Earth.

The three paragraphs which follow are a summary of the topic. You may wish to shorten this for younger students, or enrich it with material from the Bibliography which follows, for older students or students with special interests in, for example, Native Americans.

The astronomical experiment you have just done is perhaps a part, but only a part, of the answer to a centuries-old puzzle. Stonehenge was probably a dramatic stage for religious ceremonies, and those may well have been astronomically-timed. Sunrise on the longest day of the year, marked with great accuracy by an earthen "avenue" which encloses the Heel Stone, is universally agreed to be a deliberate astronomical alignment. Hawkins' trilithon alignments, which we have explored, remain controversial, however.

The Heel Stone itself marks the solstice sunrise today, but would not have been an accurate marker at the time when Stonehenge was built. There has been speculation that the Heel Stone has tilted over since its original installation, or that there were one or more other, now missing stones, which along with the Heel Stone would have framed an accurate solstice alignment.

Mysteries remain, and we continue to wonder about the people who built and used Stonehenge. The construction, from placement of the first stone to the completion of various rings of stones, took more than a thousand years and involved different cultures in different eras. How much about the uses and the astronomy of Stonehenge was passed on from builder to builder? How much was invented or re-invented throughout that millennium?

Some astronomers, including Hawkins, have credited these ancient peoples with even more complex knowledge. They suggest that the Stonehenge builders used other features of Stonehenge to predict eclipses with considerable accuracy, although few investigators accept this hypothesis. Alexander Thom, a civil engineer who doubted Hawkins' theories and criticized his crude maps, systematically surveyed hundreds of ancient sites. He found many with astronomical alignments, and has even suggested that neolithic people had a standard of length, centuries before the first known standards.

We hope you have enjoyed our excursion into the new science of archaeoastronomy. It is a wonderful example of how careful, persistent investigators, starting out with only a vague idea and little hard data, can teach themselves to see in a new way how our ancestors have looked at the universe.

Discover More About Stonehenge

Recommended Resources on Stonehenge and Archaeoastronomy

ANTHONY F. AVENI, "Archaeoastronomy: Past, Present, and Future," *Sky and Telescope*, November 1986, 456-460. A fine summary of the growth and recent activity of the field. Aveni is an expert on archaeoastronomy of Mesoamerica and Peru, and has many books and articles on western hemisphere sites.

AUBRY BURL, *The Stone Circles of the British Isles*, Yale University Press, 1977. This is the basic book for stone circle fanciers. It has a complete bibliography, descriptions of essentially all the circles, and an excellent introduction to archaeological research. Burl presents all the theories even-handedly. See also Burl's book on a favorite circle—*Prehistoric Avebury*, Yale University Press, 1979.

D. V. CLARKE, T. G. COWIE, & ANDREW FOXON, *Symbols of Power at the Time of Stonehenge*, Her Majesty's Stationery Office, 1985. This lavishly illustrated book, originally the catalog for an exhibition, pays little attention to archaeoastronomy but provides a wealth of information on the people in Britain at the time when Stonehenge was being built. Beautiful color photographs show archaeological finds. (The dates given for Stonehenge in this book do not use the recently corrected radiocarbon dates, which place Stonehenge several hundred years earlier.)

GERALD HAWKINS, *Stonehenge Decoded* (in collaboration with John B. White), Doubleday, 1965; and *Beyond Stonehenge*, Harper & Row, 1973. Personal accounts of Hawkins' work. The astronomical explanations are good, and in *Stonehenge Decoded* the excitement is high. Hawkins does not do justice to Alexander Thom's work in either book.

FRED HOYLE, *On Stonehenge*, W. H. Freeman, 1977. The best presentation of the astronomy of archaeological work. Hoyle's interpolation theory of Stonehenge astronomy is underrated by the archaeologists (see MacKie, below), but is novel and plausible. His speculations beyond the physical evidence are interesting but very elaborate.

E. C. KRUPP, *In Search of Ancient Astronomies,* Doubleday, 1977, and *Echoes of the Ancient Skies*, Harper & Row, New York, 1983. The earlier book contains essays by several of the most important researchers covering work around the world. Krupp's own summary of Stonehenge astronomy is the best concise review of this work. *Echoes* provides a solid and entertaining review of many aspects of modern archaeoastronomy, including much new material on American sites and an extensive bibliography.

EUAN MACKIE, *Science and Society in Prehistoric Britain*, Elek, London, 1977. MacKie reviews basic knowledge about stone circles and British pre-history, with special emphasis on the work of Alexander Thom. MacKie presents a good case for Thom, and draws analogies and further inferences about Thom's work. The astronomy and statistics are not confidently presented, and the work by Hoyle is passed over too quickly and sarcastically.

JEREMY SABLOFF, ed., *Archaeology: Myth and Reality*, W. H. Freeman, 1982. A range of opinions on controversial issues in archaeology, including astronomical interpretations. Includes an article by Glyn Daniel, who does not accept any conclusions of the Hawkins or Thom ideas.

Archaeoastronomy, The Bulletin of The Center for Archaeoastronomy. A journal of review and discussions published by The Center for Archaeoastronomy, University of Maryland, College Park, MD 20742.

Worldwide Web Connections

and update information may be found at

http://www.lhs.berkeley.edu/pass

Stonehenge

Classroom Activities

Azimuth and Horizons

> *In the next few activities, your students will explore changes in sunrise and moonrise positions over long periods of time. To prepare, they must become familiar with the system of describing the position of something on the horizon in terms of horizontal angle measurements, called "degrees of azimuth."*

Materials

For each student:

1 Compass Directions Diagram

Preparation

Prepare a master for photocopying Compass Directions Diagrams, by first making two photocopies of the diagrams on page 29, and then pasting them onto a single sheet of paper. From your master, make enough photocopies so that each of your students has a Compass Directions Diagram.

In Class

1. *Explain to your students that they will be marking sunrise and moonrise positions.*

You will be using exact measurements of sunrise and moonrise positions obtained from a "computer planetarium." But in order to understand those measurements, you need to become familiar with measuring positions along the horizon in "**degrees of azimuth**." There are 360° of azimuth around the entire horizon.

2. *Hand out a Compass Directions worksheet to each student.*

Draw a circle on the chalkboard.

You are looking down on your viewing position. Notice that only three directions are marked: N, SW, and WNW. ***What does the "N" stand for?*** *(North.)*

Have the students mark the abbreviations of the other "cardinal" directions (East, South, and West) on their worksheets. Mark E, S, and W on the appropriate spots on your chalkboard circle after the students have marked their papers.

3. ***What does the "SW" stand for?*** *(Southwest.)*

Have them mark the abbreviations of the other three midpoint directions (Southeast, Northwest, and Northeast) on their worksheets.

Mark SE, NW, and NE on your chalkboard circle after the students have marked their worksheets.

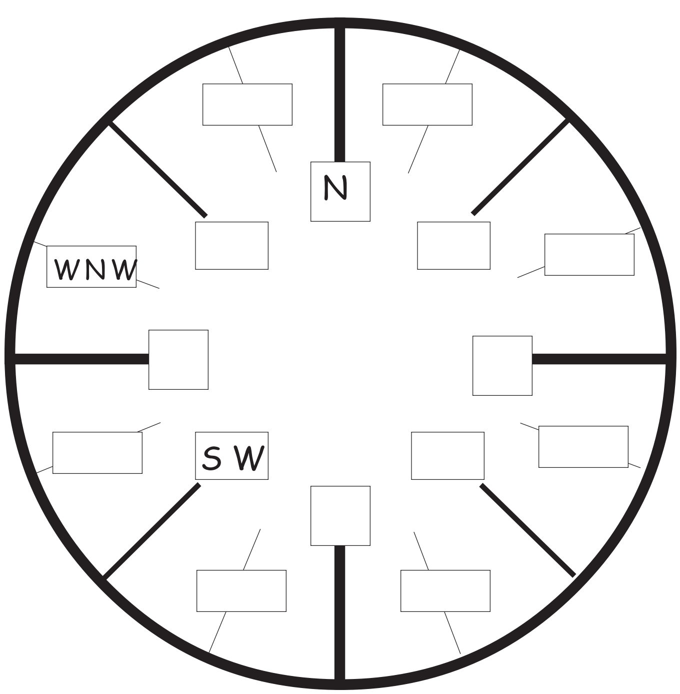
4. ***What does the "WNW" stand for?*** *(West Northwest, or halfway between West and Northwest.)*

Have the students mark the abbreviations of the other 7 directions (North Northwest, North Northeast, East Northeast, East Southeast, South Southeast, South Southwest, West Southwest, and West Northwest) on their worksheets. Mark NNW, NNE, ENE, ESE, SSE, SSW, WSW, and WNW on your chalkboard circle after the students have marked their worksheets.

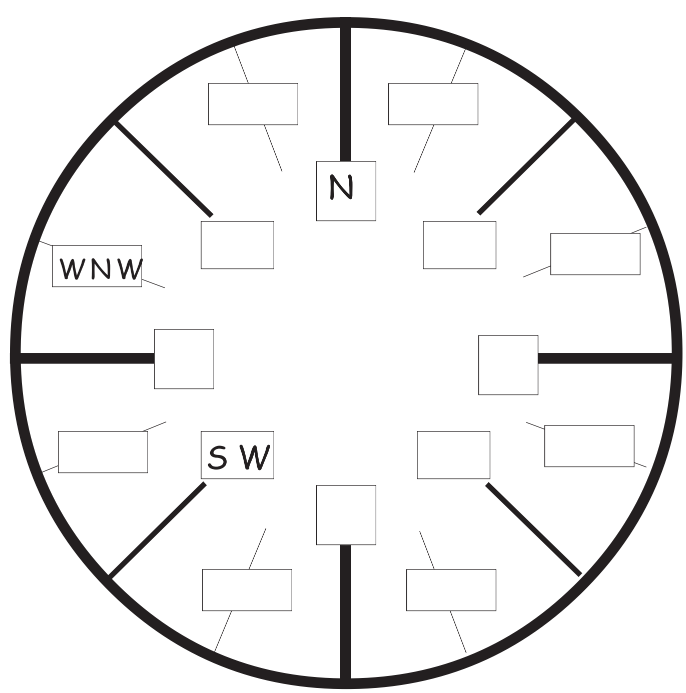
5. ***How many arc degrees are in a complete circle?*** *(360°)* To measure exactly where something is on the horizon, we measure its azimuth in degrees, with zero degrees defined as due North and increasing values going clockwise around the circle. For example, the azimuth of North is 0°. What is the azimuth of South? (180°) Of East? (90°) In even more precise measurements, each degree can be subdivided into 60 ***minutes***.

Have your students write in the azimuth below each respective direction on their Compass Directions Diagrams and confirm their answers with a class review when they are finished.

Compass Directions Diagram



Compass Directions Diagram



Creating a Horizon Sun Calendar

This activity is for students to do at home. When they complete it, they will have created a Horizon Sun Calendar for a month. According to Gerald Hawkins' theory, Stonehenge also provides such a calendar on a monumental scale, marking special days of the year.

Materials

❒ Pencil and Paper

❒ Magnetic Compass

❒ Watch or Clock

What to Do at Home

1. Select a position where you can observe the setting Sun every evening. Note where on the horizon the Sun sets on a given night. Note exactly where you are standing or sitting when you make your observation. Make a drawing of the horizon in that general area.
2. Using a magnetic compass, mark the compass directions Northwest, West, and Southwest on your drawing.
3. Once or twice a week for the next month, mark the location where the Sun sets for each clear day, and record the date and time of the sunset. Be sure always to make your observations from exactly the same spot.
4. Discuss results in class. Does the Sun set further to the south, further to the north, or in the same place on later days as compared with the first day?
5. When the students have completed the activity, tell them that they have created a Horizon Sun Calendar. On that same month next year, if the Sun is in one of the marked positions, it will tell them what date it is. Suggest that they keep their calendar for a year to see if that is true.

[This activity is also used in Volume 11 of the PASS series.]

Going Further

1. After about a month, look at your calendar. Can you find any relationship between the location of sunset and the time of sunset?

2. Observe the same star set each night for a period of about a week. Make a drawing of the horizon and mark the star's setting point along with the date and time. Be sure to observe from exactly the same spot. ***Does its setting point change in the same way that the Sun's does?***

3. Try to guess where the Sun would set three months later. How about six months later? Mark those guesses on your horizon picture (in pencil). Check your guesses after the months have gone by.

4. Could you devise a way to make a full-year calendar using the information in this activity?

5. Make a Horizon Sun Calendar based on observations of the rising point of the Sun.

6. If possible, note the location of sunset on March 21 or September 21. These are called the "equinox" dates, when day and night are of equal length. The position of sunset on those two days is said to be almost exactly due West. Does your compass agree? If not, why might they not agree? Which do you think is more accurate?

The compass can be off by 10° or more, because of local magnetic fields (buildings, iron ore) and global deviations in the Earth's magnetic field. Sailors must carry charts showing these errors in magnetic compass directions so their navigation will be accurate.

The solar directions on the equinoxes are far more accurate than compasses, although they too are subject to some errors. The Earth's atmosphere, which bends around the globe, "refracts" the Sun's light, like a lens, so that the setting Sun is not exactly where it appears to be. This effect also means that day and night are not exactly the same length, even on the equinox. Finally, since the Earth's orbital period (365.26 days) is not exactly the same as the calendar year (365 days), the date of the equinoxes may vary by a day or so from March 21 and September 21.

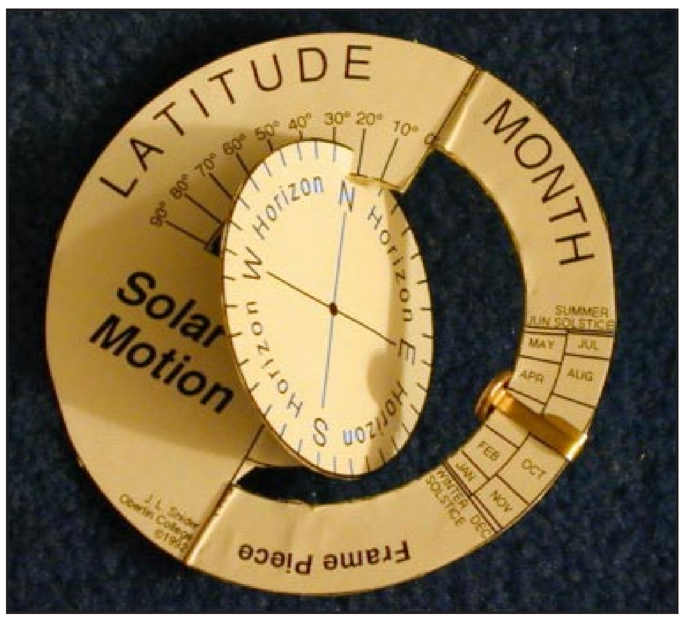
7. Gerald Hawkins' theory about Stonehenge implies that ancient people in southern Britain to have been intensely interested in the motions of the Sun throughout the year. ***Were ancient people elsewhere interested in the motions of the Sun or other astronomical bodies?*** Invite your students to research the astronomical interests of their own ancestors, or of any cultures they find particularly interesting. The references in the bibliography on page 25 are good starting points.

Solar Motion Demonstrator

From paper, glue, and a brass fastener you can build a remarkably powerful device which accurately models the apparent motion of the Sun, any time of year, from any place in the northern hemisphere of Earth. It's a simple, direct way to learn the pattern of the changing solar rising and setting points—just what the builders of Stonehenge, according to Gerald Hawkins, wanted to mark. You can go far beyond Stonehenge, however, and see how the Sun moves as seen from the Equator, the North Pole, or your own hometown.

The Solar Motion Demonstrator was designed by Professor Joseph L. Snider of Oberlin College. The design and directions for use are copyrighted by Professor Snider. You may reproduce them as needed for your own classroom or planetarium (but not for commercial purposes).

Materials



- ❐ Solar Motion Frame and Horizon Disk cutout sheets (photocopy masters on page 34 and 35)
- ❐ Photocopy paper or heavy card stock sufficient for providing each student with one Solar Motion Frame and one Horizon Disk (using blue paper for the frame and green for the disk makes an attractive product)
- ❐ One long (1 inch) brass paper fastener (the type with spreadable flat prongs) for each student
- ❐ Manila file folders (one for every student)
- ❐ Rubber cement or glue stick (can be shared by 2 or more students)
- ❐ Scissors for every student (If you will be cutting these out for the students, you may want to use a hobby knife or retractable-blade paper cutter which can cut more accurately.)
- ❐ Optional: spray rubber cement instead of gluestick (available from art supply stores)
- ❐ Optional: newspapers if you are using spray glue, or will be cutting with a hobby knife

Before Class

It takes more time to read these instructions than to make a Solar Motion Demonstrator, so don't let the number of steps put you off.

If you want to save time and the gluing in this section, you can buy very low cost classroom kits, attractively printed on heavy color stock, with one finished device and all materials for 24 students, from:

The Science Source
P. O. Box 727
Waldoboro ME 04572
Phone (207) 832-6344

As you can see from the templates on pages 34 and 35, two pieces are needed for each device: the Solar Motion Frame and the Horizon Disk. These pieces must be mounted on a stiff backing. This can be achieved by gluing the Solar Motion Frame to a double thickness of manila file folder material, and by gluing the Horizon Disk to a single thickness of manila file folder.

As an alternative, you can copy the templates onto heavy card stock. The Solar Motion Frame then needs to be glued to only a single thickness of manila file folder, and the Horizon Disk does not need to be mounted at all.

1. Make enough copies of the Solar Motion Frame page and the Horizon Disk page so that each student will have one frame and one disk. If possible use blue paper. To make an even more attractive model, copy the frames on blue paper (to represent the sky) and the disks on green paper (to represent the Earth).

You can do the next three steps yourself to save time in class, or let your students do this themselves.

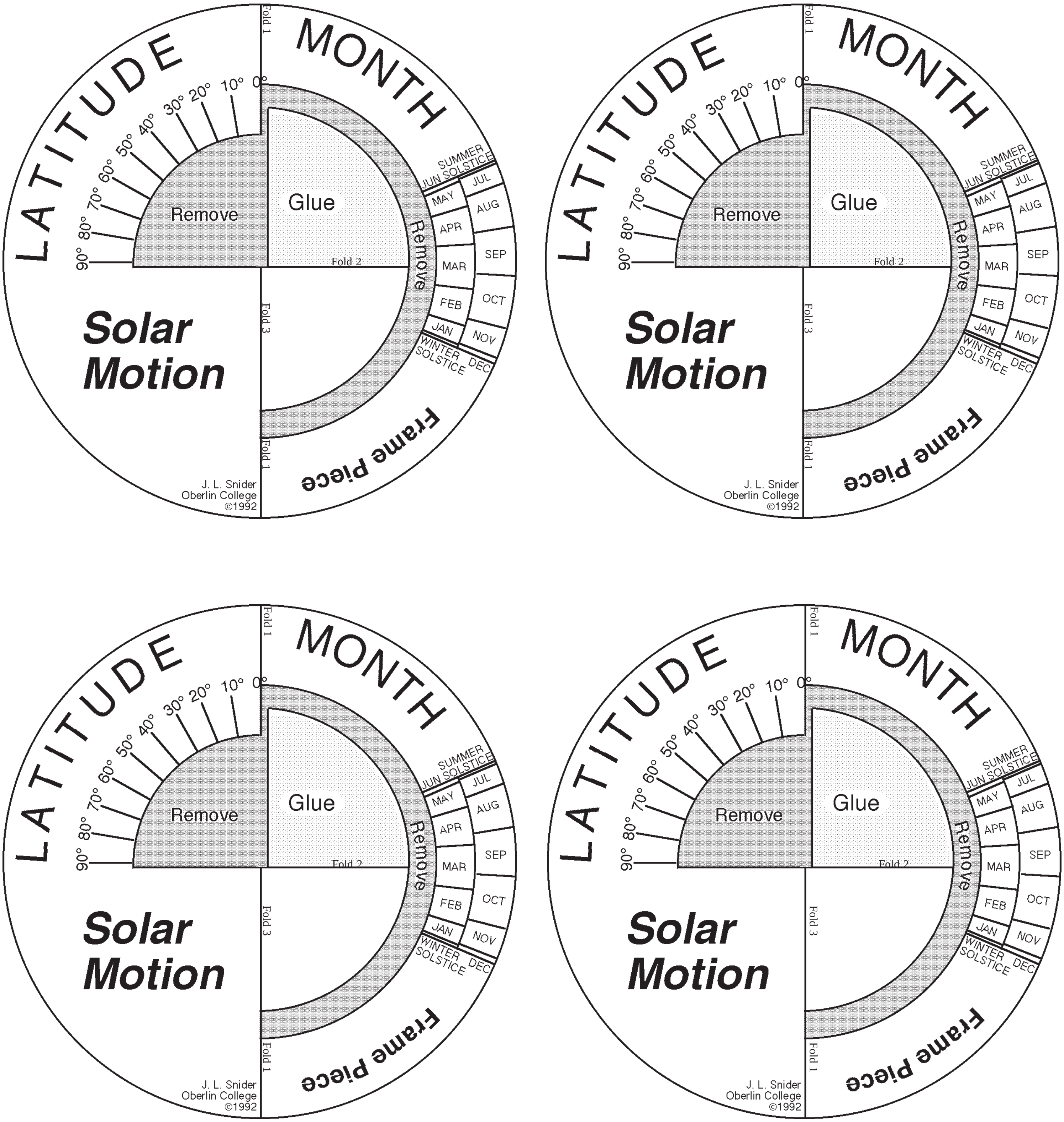
Spray-on rubber cement adhesive, available from art supply stores, is the fastest way to apply glue, but use this in a well-ventilated room, with lots of newspaper under your work to catch the excess spray. Brush-on rubber cement is cheaper but also requires a well-ventilated room. Glue sticks are an inexpensive, non-toxic, alternative.

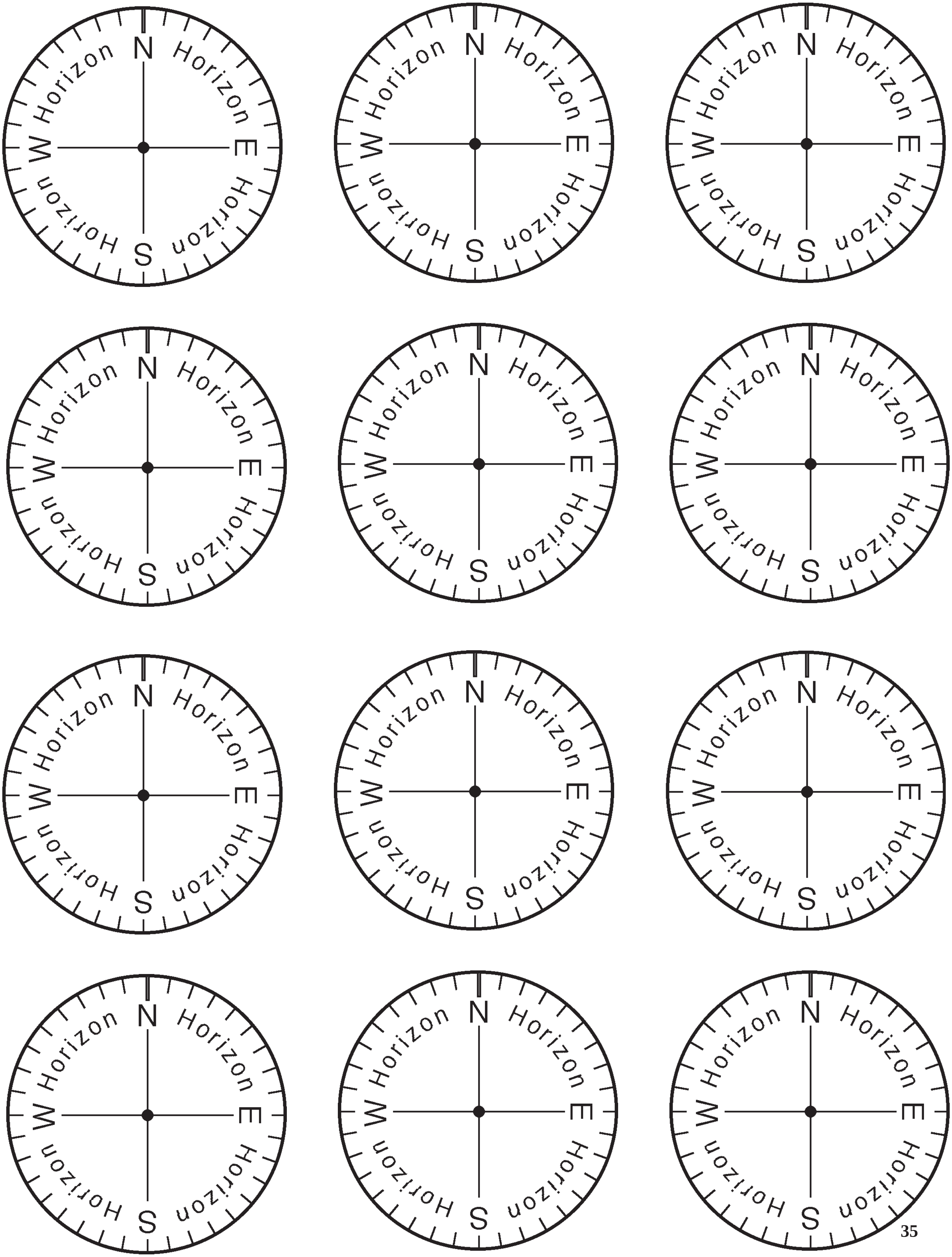
2. Glue the Horizon Disks to a single thickness of manila file folder stock.

3. Glue the Solar Motion Frames to a stiffer backing material, made by gluing two pieces of manila file folder material together.

4. Using scissors or a paper cutter, separate the Solar Motion Frames and the Horizon Disks, so that you can pass out one of each piece to each student. The final trimming and assembly should be done by the students.

Solar Motion Demonstrator Frame Piece:
Master for Duplication




N
Horizon
E
Horizon
S
Horizon
W
Horizon

Solar Motion Demonstrator: In Class

Part 1: Making the Solar Motion Demonstrator

1. You are going to make a remarkable device that accurately models the motion of the Sun as seen from any place in the Northern Hemisphere, at any time of the year.

Give each student a Solar Motion Frame piece and a Horizon Disk piece. Hand out scissors and glue.

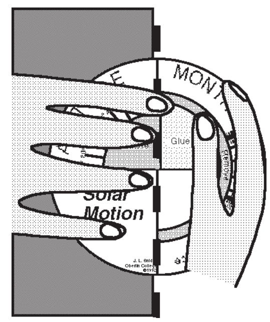
Go through each of the steps below, allowing time for each student to finish before moving to the next step.

2. With scissors cut out the Solar Motion Frame along its circular outline.

3. Carefully cut out the portions of the Frame marked “Remove” using scissors, a hobby knife, or paper cutter blade.

4. Crease the frame along a straight line passing through the hinge fold line (Folds 1 & 3: dividing the Frame vertically), by resting it against the sharp edge of a table or counter top. Line the Frame up with the edge of the counter top and rub it with the back of your scissors or other hard object until an indented groove is visible. Turn the Frame over and make an indented groove on the other side as well.

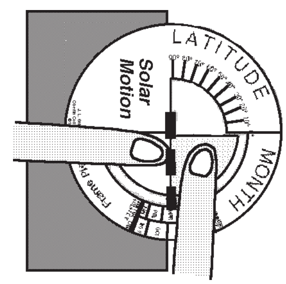
Steps 4 & 6



5. Repeat this creasing process for the short fold line (Fold 2) below the “Glue” section of the Frame.

6. Fold the Frame along the creased lines (Fold 1) so that the month half of the Frame swings all the way around to touch the latitude half of it. Repeat, pivoting the month piece in the opposite direction.

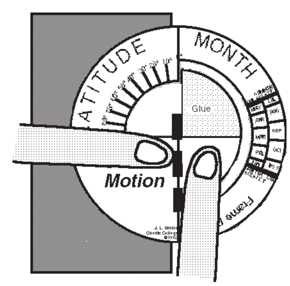
Steps 5 & 7



7. Fold the flap marked “Glue” (Fold 2) away from you and down as far as it will go, as seen from the printed side of the Frame. Bring it back to its original, flat, position.

8. Fold both the flap marked “Glue” and the quarter-circle below it with no printing on it (Fold 3) away from you as far as they will go, until the backside of the blank quarter-circle hits the backside of the Frame. Bring them back to their original, flat, position.

Step 8

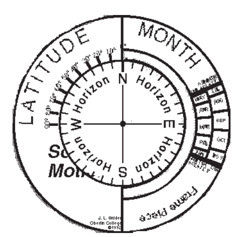


9. Use scissors to cut out the Horizon Disk along its circular outline.

10. Cut a small slot in the side of the Horizon Disk at the position of North. This slot should not be any wider than the cardboard is thick, and should be approximately 3 mm (1/8 inch) long.

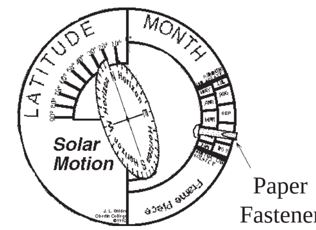
11. Apply rubber cement or glue to the portion of the Frame labelled “Glue.” Press the northeast quadrant of the disk against the glued portion of the Frame. Position the disk so that its north-south line lines up with the frame’s hinges, and the mark for West is positioned over the 90-degree mark on the Frame. Make sure that the outer edges of the disk and Frame are accurately aligned. The correct alignment of Frame and disk is essential to the working of the device.

Step 11



12. When the glue is dry pivot the disk on its hinge away from you through 90 degrees, and then slip the slot over the latitude scale. Make sure that the plane of the disk is perpendicular to the plane of the Frame.

13. Slip a paper fastener over the piece marked “MONTH,” so that the head of the fastener is on the inner edge of the piece. Bend the head so that its plane is perpendicular to the plane of the piece. Bend one of the paper fastener’s prongs around the edge of the piece so that its end lies flat against the front of the piece. Bend the other prong around and over the first one, so that its end lies flat on top of the first prong, behind the piece. The paper fastener should fit snugly around the piece, and also be easily moved to cover the appropriate date on the “MONTH” piece.



Your “Solar Motion Demonstrator” is finished!

Part 2: Using Your Solar Motion Demonstrator

How the Solar Motion Demonstrator models the Sun and the Earth:

• The “Horizon Disk” represents a piece of the surface of the Earth. You can imagine a tiny observer (represented by the black dot in the center), able to look out at the horizon in any direction, including North, East, South, and West.

• The round head of the brass paper fastener represents the Sun.

• The swinging “Month” arm of the Frame has two functions. Setting the Sun marker at the desired month adjusts for the time of the year. Swinging it from one side to the other (preferably East to West) moves the Sun in its apparent daily path over the Earth.

• The “Latitude” part of the Frame is used to adjust the Horizon Disk to set the imaginary observer at any latitude from the Equator (0°) to the North Pole (90°).

To use the Solar Motion Demonstrator, pivot the Horizon Disk along the North-South axis so that the right hand side of the disk moves away from you through 90 degrees. Line up the slot in the Horizon Disk with the edge of the Frame where it is labeled “Latitude.” Slip the slot in the Horizon Disk over the Frame and align it with the latitude of your location (or one you may be interested in). The Horizon Disk must be perpendicular to the latitude part of the Frame. Next, slide the “Sun” along the outer rim of the Frame to the appropriate month.

The edge of the Horizon Disk represents the visible horizon for some imaginary person standing at the black dot in the center of the disk. To see the path the Sun makes across the sky for that particular latitude and time of year, swing the month portion of the Frame completely from the “East” to the “West” as marked on the Horizon Disk.

Compare the location of the sunrise and sunset at different times of the year. How does the length of day change with the seasons? At what latitude must you be so the Sun does not set on the longest day of the year (the summer solstice)? What would the Sun’s motion look like if you lived at the North Pole?

You can answer these and many other questions with your Solar Motion Demonstrator.

Part 3: Activities

1. Where Will the Sun Set?

Hold the device in one hand so that the Horizon Disk is horizontal. Imagine that you are very small and standing at the black dot at the center of the Horizon Disk. It would look like a large open field with a clear horizon all around you. The geographical directions of North, East, South, and West are marked around the horizon. With your other hand, smoothly pivot the piece which carries the paper fastener "Sun." As the head of the paper fastener rises above the plane of the Horizon Disk, it represents sunrise and the beginning of daytime in the imaginary world of the Horizon Disk.

When the head of the paper fastener dips below the plane of the Horizon Disk, it represents sunset and the beginning of nighttime. The perimeter of the Horizon Disk is marked in 10-degree increments. You can read the direction to the point on the horizon where the Sun sets directly from the Horizon Disk.

For example, if you are at 40 degrees north latitude, and it is late June, the Sun will set about 30 degrees to the north of west. Use your device to check this example. If you can, take the device outdoors at sunset. Align the Horizon Disk so that "N" on the disk points toward true North. Keep the Horizon Disk horizontal and raise it to eye level. Sight along the line joining the central black dot and the paper fastener head when it is located at the sunset position. This line should point to the place on the horizon where the Sun will set.

Compare the position of sunset where you live with sunset at Stonehenge (51 degrees north latitude). On a given day, does the Sun set further to the North? South? Is there any day at which the Sun sets at the same place for Stonehenge and for you? (Hint: there are two days of the year when the answer is yes.)

2. How High is High Noon?

As you swing the "Sun" around, it gets higher in the sky above the horizon. This is its "angular height" above the horizon. If you imagine yourself to be at the location of the black dot, facing the Sun, the angular height of the Sun is the angle between your line of sight to a point on the horizon directly beneath the Sun and your line of sight to the Sun. The Sun reaches its greatest angular height at a time halfway between the times of sunrise and sunset; this time is not noon on your clock—it depends on where you are located in your time zone, whether or not you are on daylight savings time, and on details of the Earth's motion around the Sun.

By using your Solar Motion model, you can get a sense of how large this maximum angular height is for various times of the year.

3. Where will the Sun Rise?

Answer this question in the same way that you found where the Sun sets. Try using the device some day at sunrise, sighting across it to check that the Sun actually rises where the device predicts that it will. On any particular day, the Sun will rise just as many degrees north or south of East as it sets north or south of West.

4. Is Daytime as Long as Nighttime?

Pivot the piece carrying the "Sun" at a constant rate over its entire range. This corresponds to one rotation of the Earth, which takes 24 hours. Notice that the Sun lies above the horizon for part of this motion (daytime) and below it for the remainder (nighttime). You can determine the relative lengths of day and night in this way.

5. When are Day and Night Equally Long?

Use the device to show that on two particular days of the year, the Sun rises due East and sets due West for any latitude. Find the two months in which these days occur. These days are called the "spring equinox" and the "fall equinox" and are the only two days of the year when days and nights are of equal duration. The word "equinox" comes from the words meaning "equal night."
Answer: the two equinox days occur in March and September.

6. When Will the Noon Sun be the Highest or Lowest in the Sky?

Use the Solar Motion device to find the month in which the largest angular height at noon occurs. In which month does the smallest angular height at noon occur? Also, in which month does the longest day of the year occur? In which month is the shortest day of the year?

Answers: Largest angular height at noon and longest day of the year is in June, at the summer solstice. Smallest angular height at noon and shortest day of the year is in December, the winter solstice.

The word "solstice" comes from the words meaning "Sun stands still." Most of the year the rising and setting positions of the Sun are changing, moving further towards the north or south depending on the seasons. On the solstices, the rising and setting positions stop their motions north and south, and then head back in the opposite direction.

7. Why Does the Earth Have Seasons?

Move the paper fastener "Sun" up to its June position. Pivot the "Sun" and observe the relative lengths of day and night and the maximum angular height of the "Sun." Do the same with the "Sun" moved down to its December position. This demonstrates the two most important factors responsible for the seasons: the period of time over which the Sun's rays strike the ground (the length of day), and the angle at which they strike the ground.

8. Can You Always See a Sunset?

Actually, there are places on Earth where the Sun doesn't set. Explore the range of latitudes and times of year for which the paper fastener "Sun" remains above the Horizon Disk as you pivot it through an entire rotation. This corresponds to a 24-hour day, with the Sun still above the horizon at midnight. The phrase "land of the midnight Sun" is often used to describe the places where this occurs. For an observer anywhere north of the "Arctic Circle" (about $66^1/_2$°latitude) the Sun will not set on at least one day of the year.

9. When and Where Will the Sun Pass Directly Overhead?

A point in the sky directly over your head is called the **zenith**. To find out when and where the Sun passes through the zenith, move the "Sun" to a position late in June and pivot it through its daily motion to see if it passes directly overhead (assuming that you are at the location of the black dot at the center of the Horizon Disk). Change the latitude setting of the Horizon Disk until you find a latitude at which the Sun passes through the zenith for an observer at that latitude. Explore the range of latitudes and times of year for which the Sun passes through the zenith.

Answer: For an observer north of the "Tropic of Cancer" (at about $23^1/_2$ degrees north latitude) the Sun will never pass through the zenith. People who live along the Tropic of Cancer can see the Sun at the zenith only in June at the summer solstice. For lower latitudes than this, the Sun will pass through the zenith on only two days of the year. Can you tell approximately which days these are?

South of the equator, the behavior is similar, but the order of months on the Solar Motion Demonstrator would have to be reversed for southern latitudes. Observers along the Tropic of Capricorn (at $23^1/_2$ degrees South) see the Sun at the zenith only in December on their summer solstice. People South of the Tropic of Capricorn never see the Sun at the zenith.

10. What Path Does the Sun Take at the Equator?

Set the Horizon Disk to a latitude of 0°. Imagine that you are an observer positioned at the black dot at the center of the Horizon Disk. Vary the time of year and see how the path of the Sun across the sky changes. What can you say about how the rising Sun appears to move in relation to the horizon? Notice that the setting Sun moves in the same way. At what times of year does the Sun pass through the zenith? *Answer*: March and September (the equinoxes)

11. What is the Motion of the Sun for an Observer at the North Pole?

Set the Horizon Disk to a latitude of 90°. Again, imagine that you are positioned at the black dot at the center of the Horizon Disk. Vary the time of year and see how the path of the Sun across the sky changes. What can you say now about the motion of the Sun in relation to the horizon? Do you see that there will be six months of light and six months of darkness at the North Pole?

12. Would Stonehenge work if it were moved to your home town?

Set the Horizon Disk for the latitude of Stonehenge, 51° north latitude. Write down the rising and setting positions of the Sun for the summer and winter solstices. Now set the Horizon Disk for the latitude where you live. Again record the rising and setting positions of the Sun for the summer and winter solstices.

Unless you live close to the same latitude as Stonehenge, you will find that the rising and setting positions are different. To make a Stonehenge in your hometown, you would have to redesign Stonehenge, changing its symmetry, to make it function as a solstice marker in the way Hawkins suggests.

Ideas for Further Activities:

You will be able to think of other ways in which you can use the “Solar Motion” device to increase your understanding of how the Sun appears to move in relation to the earth. Here are three.

1. Imagine yourself standing at the black dot at the center of the Horizon Disk. Try holding the “MONTH” piece fixed in space with your right hand, as you turn the rest of the device through its complete range of motion. As you do this, think of the Sun as being fixed in space, while the Earth’s rotation turns you around with respect to the Sun. This is more nearly the situation in real life.

2. Try using the device as a compass. Set the “Solar Motion” model to your latitude and the time of year. Go outside and hold the device so that the Horizon Disk is horizontal. Pivot the “MONTH” piece and at the same time turn the compass piece (keeping its plane horizontal) so that the “N-S” line points in various directions. Your objective is to make the shadow of the “MONTH” piece be as thin a line as possible, while at the same time the shadow of the paper fastener “Sun” falls on the black dot at the center of the Horizon Disk. When you have achieved this, the Horizon Disk will show you the correct geographic directions.

3. Try constructing a giant Solar Motion Model. You can use a photocopier to enlarge the Frame and the Horizon Disk. You might want to mount these on stiffer cardboard, artists’ “foamcore” material, or plywood. You may need to make stronger hinges out of cloth, or use metal hinges from a hardware store.

Sunrises at Stonehenge

In the Stonehenge planetarium show, your class begins learning about the patterns of change in sunrises that have been repeating in yearly cycles for aeons past and will continue in yearly cycles for aeons to come. The builders of Stonehenge were attuned to these cycles as were most cultures throughout history until, perhaps, our own, when the move to great cities and the use of artificial lighting have made solar motion less visible and less crucial for our daily lives. In this activity, your students perform a detailed study of the yearly cycle of sunrises. According to Gerald Hawkins and his followers, the giant stones of Stonehenge mark the solstice extremes in this cycle.

Materials

For each student:

❒ 1 Sunrise Table and Chart for the year 2000 (master on page 45)

❒ 1 pencil

❒ Optional: a colored pen or pencil.

Before Class

1. Photocopy each of the above sheets for each student.
2. Separate the tables from the charts using a paper cutter.

In Class

1. Let's pretend that we are near Stonehenge in Southern England. We have a clear view of the horizon and can watch the Sun rise every day of the year.

If the students have already seen the Stonehenge planetarium program, ask them to recall what they learned about how the position of sunrise changes throughout the year:

What's the longest day of the year? (about June 21, the Summer Solstice.)

On the Summer Solstice, does the Sun rise to the north or the south of East? (The Sun rises to the north of East in the summer.)

What's the shortest day of the year? (about December 21, the Winter Solstice.)

On the Winter Solstice, does the Sun rise to the north or south of East? (The Sun rises to the south of East in the winter.)

2. We are going to make a chart that will show how the sunrise postions change throughout the year.

Hand out a blank sunrise chart to each student. (Do not hand out the tables yet.) Point out the words "Azimuth of Sunrise" along the bottom. Review concepts from Azimuth and Horizons *activity (p. 28):*

What does azimuth mean? (Azimuth means the direction in degrees, as marked on a compass.)

What is the azimuth of North? (0°) ***East?*** (90°) ***South?*** (180°)

If the Sun were to rise exactly in the Northeast (halfway between North and East), what would the azimuth of sunrise be? (45°)

3. ***How far to the North will the Sun rise on the Summer Solstice, as seen from Stonehenge?***

Ask a few students to share their guesses with the rest of the class. Then, show the students how to indicate their guesses on the chart. Find the month of June along the left, and the azimuth of the guess on the chart. Place a pencil dot in the box that indicates both the month of June and azimuth of sunrise. For example, if they think that the builders of Stonehenge will see sunrise exactly in the Northeast on June 21, they should put a dot in the box to the right of June, and above 45°.

4. ***Place a pencil dot showing the azimuth of sunrise for each of these four important dates***:

Summer Solstice, about June 21

Winter Solstice, about December 21

Spring Equinox, about March 21

Fall Equinox, about September 21

5. ***Use your pencils to join the four pencil dots with a smooth curve, showing how you think the sunrise point will change between the four important dates.***

Invite them to share their predictions with their neighbors. Invite some of the students to share their predictions with the whole class.

6. Here is a Table of Sunrise positions at Stonehenge.

Hand out the Table of Sunrise Positions at Stonehenge.

The table shows the actual azimuth of sunrise as we would see it if we made observations at Stonehenge today. ***Use a colored pencil or pen to plot each position on your chart with an "x," and then to use the pen to connect the x's with a smooth line.***

7. ***Compare your paper with your neighbors'.***

Check that they have all plotted the positions of sunrise correctly. Lead a discussion to help the students interepret their results.

How close did your predictions come to the actual observations?

How far to the North did the Sun rise on the Summer Solstice? How far to the South did it rise on the Winter Solstice? Is that more or less than you predicted? (Summer 49°, Winter 128°)

When does the Sun rise due East? (On September 21 and March 21).

Do you think the Sun goes through the same pattern every year? If so, how do we know? (Ancient peoples around the world saw the same pattern of the Sun every year that we still see today!)

The exact dates of solstices and equinoxes changes from year to year, but are always within a day or two of March 21, June 21, September 21, and December 21. This is because the length of the calendar year (365 days) is not exactly the same as the solar year 365.26 days—this is also why we need leap year. For example, in the year 2000, the Summer Solstice will actually occur on June 20, and the Winter Solstice on December 21. You may wish to add that modern measurements indicate that even the azimuth angles change very slightly over the centuries because of slight changes in the tilt of the Earth's axis with respect to its orbit.

Table of
Sunrise Positions at Stonehenge in the year 2000

Latitude: 51°17' N

Date	Time	Position	Date	Time	Position	Date	Time	Position
01/20	8:03 am	122°	05/20	4:11 am	55°	09/20	5:54 am	87°
02/20	7:14 am	106°	06/20	3:53 am	49°	10/20	6:43 am	106°
03/20	6:11 am	88°	07/20	4:18 am	54°	11/20	7:36 am	121°
04/20	5:03 am	69°	08/20	5:05 am	69°	12/20	8:12 am	128°

Chart of Sunrise Positions (Year:________ Latitude:_________)

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
Jan																			
Feb																			
Mar																			
Apr																			
May																			
Jun																			
Jul																			
Aug																			
Sep																			
Oct																			
Nov																			
Dec																			
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180

(North) (East) (South)

Azimuth of Sunrise

Going Further

1. It is very interesting to explore more precisely the day to day change in the azimuth of sunrise. For this purpose, the table below shows the azimuth of sunrise on two or more successive days for each month of the year. Make a copy of the table for each student. Explain that these tables are more precise because the azimuths are given with degrees *and* minutes (minutes indicated by the symbol " ' "). There are 60 minutes in each degree. After the students have studied the table for a while, ask

During which months does azimuth of sunrise change the most from one day to the next? (March and September)

During which months does the azimuth of sunrise change the least? (June and December)

What are the exact dates of the solstices for the year 2000? (December 21 and June 20)

2. Instead of handing out the sunrise tables, have the students create their own, using a computer with astronomical "planetarium" software that can compute precise sunrise positions. For example, the data compiled on page 45 was generated by the *Voyager* program (from Carina Software, 830 Williams St., San Leandro, CA 94577; 510-352-7328) for Macintosh computers. An appropriate program for IBM-compatible computers is *AstroInfo*, which gives daily Sun and Moon risings and settings, with azimuth angles. It is available from Zephyr Services, 1900 Murray Ave., Dept. A, Pittsburgh, PA 15217; phone 800-533-6666. *NIGHTSKY*, also for IBM-compatibles, is a similar program to Voyager in that it produces star charts as well as tables. It is available from Southwest Astronomy, 4242 Roma NE, Albuquerque, NM 87108. *NS Lito* (a simple version of *NIGHTSKY*) is available as freeware on computer services such as Compuserve.

3. Make a similar sunrise position chart for another year to verify that it is essentially the same shape.

4. The latitude of Stonehenge is 51˚17' N. Use a computer program to generate a table of sunrise positions for the latitude of your school.

More Sunrise Positions at Stonehenge in the year 2000

Latitude: 51°17' N

Date	Time	Position	Date	Time	Position	Date	Time	Position
01/20	8:03 am	122°09'	06/19	3:53 am	49°06'	09/22	5:57 am	88°56'
01/21	8:03 am	121°46'	06/20	3:53 am	49°03'	09/23	5:58 am	89°27'
02/20	7:14 am	106°40'	06/21	3:54 am	49°06'	09/24	6:00 am	90°09'
02/21	7:12 am	106°05'	06/22	3:54 am	49°07'	10/20	6:43 am	106°02'
03/18	6:16 am	90°05'	06/23	3:54 am	49°08'	10/21	6:45 am	106°41'
03/19	6:13 am	89°19'	06/24	3:55 am	49°18'	11/20	7:36 am	121°37'
03/20	6:11 am	88°45'	07/20	4:18 am	54°34'	11/21	7:38 am	122°04'
04/20	5:03 am	69°57'	07/21	4:19 am	54°52'	12/19	8:11 am	128°07'
04/21	5:01 am	69°24'	08/20	5:05 am	69°10'	12/20	8:12 am	128°13'
05/20	4:11 am	55°22'	08/21	5:06 am	69°37'	12/21	8:12 am	128°14'
05/21	4:10 am	55°03'	09/20	5:54 am	87°43'	12/22	8:13 am	128°13'
06/18	3:53 am	49°09'	09/21	5:55 am	88°14'	12/23	8:13 am	128°07'
						12/24	8:13 am	128°00'

Many Moonrises

Many scientists who have studied Stonehenge agree with Gerald Hawkins that the stones mark sunrises and sunsets on important days of the year. However, few agree with Hawkins that Stonehenge also marks the extreme rising and setting positions of the Moon, since the evidence for Moon alignments is weaker than for the Sun. In this activity, the cycles of the Moon unfold in stages for your students. This activity is best done after the Stonehenge planetarium program, and after the previous classroom activity, Sunrises at Stonehenge.

Materials

For each student:

- ❒ 1 Table of Moonrises for January, 1993 (master on p. 49)
- ❒ 1 Table of Northern Moonrise Extremes for 1993 (master on p. 49)
- ❒ 1 Table of Northern Moonrise Extremes, 1994-2015 (master on p. 49)
- ❒ 1 Chart of Moonrises for January 1993 (master on p. 50)
- ❒ 1 Chart of Northern Moonrise Extremes, 1993-2015 (master on p. 51)
- ❒ 1 pencil
- ❒ a colored pen or pencil
- ❒ Overhead transparencies of the tables and charts

Before Class

1. Photocopy each of the above sheets for each student.
2. Use a paper cutter to separate the Tables so that they can be handed out separately.
3. Plot the points on each chart yourself so that you see the overall patterns.

In Class

1. *Ask your students to recall how the sunrise position changes over time.*

How long is the sun's cycle; that is, how long until the pattern of sunrises and sunsets repeats itself?

When is the sunrise farthest north? When is it farthest south?

2. Let's try to predict how the ***moonrise*** position might change over time.

Hand out a blank Chart of Moonrises for January 1993 to each student. Announce the position of moonrise on January 1 (from the Table of Moonrises for January, 1993). Ask each student to mark this position on the chart. Check to see the position is marked correctly.

Does the Moon actually rise every day of the month? We may only notice moonrise when it occurs in the evening.

Ask your students if they have ever seen the Moon in daytime, or ever seen it rise in the daytime. If students are very skeptical, you may wish to assign them to look for the Moon in the daytime on the next appropriate date. Seeing a daytime moonrise is an interesting challenge.

Have each student draw a vertical line or curve that shows his or her prediction for how the position of moonrise will change throughout January 1993.

3. *Hand out a Table of Moonrises for January 1993 to each student.*

Have them plot the moonrise position for each day on the chart.

How close was your guess? When and where was the northerly extreme? When and where was the southerly extreme?

Unlike the Sun, which takes a full year to go from most northerly sunrise to most southerly and back again, the Moon goes through such a cycle in only a month. ***But is the cycle the same each month? Each year? Does the Moon go to the same extremes each month, just as the Sun does each year?***

4. *Hand out a Table of Northern Moonrise Extremes for 1993 to each student.*

This is a Table of Northern Moonrise Extremes for 1993. ***Please look at your Table of Moonrises for January of 1993 to find the first two moonrise extremes of 1993 (for January and February). Enter them in the two blank spaces at the beginning of your Table of Northern Moonrise Extremes for 1993. Does the Moon rise at the exact same northern extreme each month?*** *(No.)* ***How is it changing?*** *(The northern moonrise extreme seems to be creeping south!)*

5. *Hand out a blank Chart of Northern Moonrise Extremes for 1993-2015.*

Have the students first fill in the average position of the northern extreme moonrises for 1993 in the first blank space in their table. They can estimate the average from the Table of Northern Moonrise Extremes for 1993. Challenge the students to guess (draw on the blank chart) the pattern of extreme northern moonrises for the period 1993-2015.

7. *Hand out a Table of Northern Moonrise Extremes for 1993-2015 to each student.*

Have them plot the northern moonrise extreme positions on the chart. How close were their guesses? Ask them to describe the pattern.

Look carefully at the data. ***Is there a year in which the numbers appear to begin repeating themselves?*** *(The years 1994-1997 match the years 2012-2015 to within a degree.)* This larger pattern of moonrise positions repeats itself about every 18 years. This cycle is helpful in predicting eclipses of the Sun and Moon.

Table of Moonrises for January, 1993 at Stonehenge

Date	Time	Azimuth	Date	Time	Azimuth	Date	Time	Azimuth
01/01	11:10 am	73°	01/13	11:28 pm	102°	01/26	08:41 am	91°
01/02	11:31 am	66°	01/15	12:48 am	111°	01/27	08:58 am	83°
01/03	11:57 am	60°	01/16	02:06 am	118°	01/28	09:16 am	76°
01/04	12:30 pm	55°	01/17	03:19 am	124°	01/29	09:36 am	69°
01/05	01:16 pm	52°	01/18	04:26 am	127°	01/30	09:59 am	67°
01/06	02:07 pm	51°	01/19	05:24 am	128°	01/31	10:28 am	57°
01/07	03:15 pm	53°	01/20	06:12 am	127°	02/01	11:04 am	53°
01/08	04:33 pm	58°	01/21	06:50 am	123°	02/02	11:51 am	51°
01/09	05:56 pm	65°	01/22	07:21 am	119°	02/03	12:51 pm	52°
01/10	07:21 pm	74°	01/23	07:45 am	112°	02/04	02:02 pm	55°
01/11	08:45 pm	83°	01/24	08:06 am	106°	02/05	03:23 pm	61°
01/12	10:11 pm	93°	01/25	08:24 am	98°	02/06	04:48 pm	69°

Table of Northern Moonrise Extremes for 1993
At Stonehenge

Date	Northern Moonrise Extreme	Date	Northern Moonrise Extreme
01/06		07/16	53°
02/02		08/12	53°
03/01	53°	09/08	54°
03/29	53°	10/06	54°
04/25	53°	11/02	54°
05/22	53°	11/29	55°
06/19	53°	12/26	55°

Table of Northern Moonrise Extremes at Stonehenge, 1993-2015

(Latitude 51°17')

1993		**2001**	**51°**	**2009**	**45°**
1994	**55°**	**2002**	**48°**	**2010**	**48°**
1995	**58°**	**2003**	**45°**	**2011**	**51°**
1996	**60°**	**2004**	**42°**	**2012**	**54°**
1997	**60°**	**2005**	**42°**	**2013**	**57°**
1998	**58°**	**2006**	**40°**	**2014**	**59°**
1999	**57°**	**2007**	**42°**	**2015**	**60°**
2000	**53°**	**2008**	**44°**		

Chart of Moonrise Positions at Stonehenge in January, 1993

(Latitude 51°17')

(North)										(East)									(South)
Jan	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20																			
21	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
22																			
23																			
24																			
25																			
26																			
27																			
28																			
29																			
30																			
31																			
Feb 1	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
2																			
3																			
4																			
5																			
6																			
7																			
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
	(North)									(East)									(South)

Azimuth of Moonrise

Chart of Northern Moonrise Extremes at Stonehenge 1993-2015

(Latitude 51°17')

(North) (East) (South)

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1993																			
1994																			
1995	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1996																			
1997																			
1998																			
1999																			
2000	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
2001																			
2002																			
2003																			
2004																			
2005	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
2006																			
2007																			
2008																			
2009																			
2010	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
2011																			
2012																			
2013																			
2014																			
2015																			
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180

(North) (East) (South)

Azimuth of Moonrise

Going Further

1. What is the pattern of southern Moonrise extremes? Have your students try to predict the pattern of southern moonrise extremes on their charts. They can then use the tables below to plot the southern moonrise extremes on their charts and see how close their predictions were.

1993 Moonrise Extremes at Stonehenge

Date	Northern	Southern	Date	Northern	Southern
02/15		128°18'	07/28		126°18'
03/01	52°38'		08/12	53°14'	
03/14		127°28'	08/25		126°37'
03/29	52°30'		09/08	53°54'	
04/10		127°34'	09/21		125°59'
04/25	52°56'		10/06	54°05'	
05/07		126°57'	10/18		124°56'
05/22	53°24'		11/02	54°24'	
06/04		127°20'	11/15		125°45'
06/19	52°54'		11/29	54°36'	
07/01		127°07'	12/13		125°48'
07/16	53°22'		12/26	55°04'	

2. Instead of handing out the moonrise tables have the students create their own, using a computer with astronomical "planetarium" software that can compute precise moonrise positions. For example, the data compiled on pages 49-50 was generated by the *Voyager* program (from Carina Software, 830 Williams St., San Leandro, CA 94577; 510-352-7328) for Macintosh computers. For IBM-compatible computers, *AstroInfo* gives daily Sun and Moon risings and settings, with azimuth angles. It is available from Zephyr Services, 1900 Murray Ave., Dept. A, Pittsburgh, PA 15217; phone 800-533-6666. *Moontimes*, also from Zephyr, is excellent for lunar computations (for IBM-compatibles). *NIGHTSKY*, also for IBM-compatibles, is a similar program to Voyager in that it produces star charts as well as tables. It is available from Southwest Services, 1900 Murray Ave., Dept. A, Pittsburgh, PA 15217; phone 800-533-6666. *NS Lito* (a simple version of *NIGHTSKY*) is available as freeware on computer services such as Compuserve.

Southern Moonrise Extremes at Stonehenge 1994-2015 (Latitude 51°17')

1994 .... 125°	2006 .... 140°
1995 .... 122°	2007 .... 138°
1996 .... 121°	2008 .... 137°
1997 .... 119°	2009 .... 135°
1998 .... 122°	2010 .... 131°
1999 .... 124°	2011 .... 129°
2000 .... 126°	2012 .... 126°
2001 .... 129°	2013 .... 124°
2002 .... 132°	2014 .... 122°
2003 .... 135°	2015 .... 120°
2004 .... 136°	
2005 .... 137°	

3. Chart moonrises for another latitude.

4. Invite your students to discuss whether they believe ancient peoples like those at Stonehenge could have determined such long-term patterns as the moonrise cycle. Factors which make this difficult are the weather, which may make many moonrises invisible, and the need to keep information intact over many years. How could pre-literate cultures do this? Possible solutions are keeping information in graphic form (charts) or in oral tradition (as chants or incantations). What other examples can students discover of long-held complex information from ancient times?