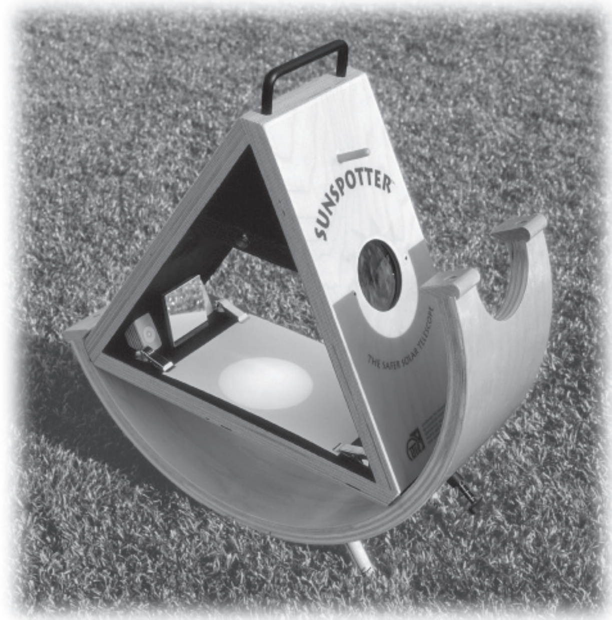

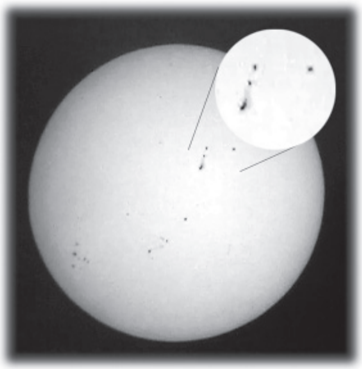

A Manual for the Care and Use of the SUNSPOTTER®

THE SAFER SOLAR TELESCOPE

By

Philip M. Sadler, Ed.D.

and Mary Lou West, Ph.D.

"An instrument that is really unique and brilliant, with an attractive design that is truly a work of art. The finished wood mounting is highly functional yet graceful and elegant enough to put on the coffee table in the living room."

— Alan Gould, Lawrence Hall of Science
University of California, Berkeley

SUNSPOTTER®

THE SAFER SOLAR TELESCOPE

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NOTES

THE AUTHORS

Philip Sadler earned a B.S. in Physics at MIT and later his Ed.M. and Ed.D. at Harvard University. He taught 7^{th} and 8^{th} grade science and mathematics while developing the STARLAB Portable Planetarium. At Harvard, Dr. Sadler has prepared nearly 200 new science teachers. As F.W. Wright Senior Lecturer in Astronomy, he teaches Harvard's oldest continually taught course in science, Celestial Navigation. Dr. Sadler directs one of the largest research groups in science education in the U.S., based at the Harvard-Smithsonian Center for Astrophysics. This group develops innovative curriculum, creates award-winning television programs on learning and science, and conducts research on how children learn science. Dr. Sadler has been honored with the prestigious Journal of Research in Science Teaching Award in 1999 for "the most significant contribution to science education research" in the preceding year. This work is publicized in the widely acclaimed video made with Matthew Schneps, "A Private Universe." He has won the American Institute of Physics' top prize for educational software several times and in 2002 was awarded the Astronomical Society of the Pacific's Brennan Prize for contributions to high school astronomy teaching.

Mary Lou West is a Professor in the Department of Mathematical Sciences at Montclair State College in Upper Montclair, New Jersey, where she teaches popular courses in physics and astronomy. She holds a BA and MS from Cornell University and a Ph. D from Columbia. Awards for her work include: Best Astronomy Day Activities in the USA (1994), Meritorious Team Award in the COMAP Math Modeling Contest (1999), and a NASA IDEAS grant (1998-9). She is involved in studying the local cavity in the interstellar medium, and the history of women's contribution to astronomy.

INTRODUCTION

Why did we develop the Sunspotter? One clear spring day, the sun approached us very distraught from all the recent attention paid to the moon, planets, stars, and galaxies. *"I am the best astronomical object for children to observe,"* the sun argued, *"since I am up during school hours. Yet, so few seem to notice me."* We comforted the sun for being taken for granted and promised to remedy this sad state of affairs.

In talking to teachers, we discovered that safety concerns dissuade them from attempting solar observations. Dire warnings are everywhere, since our eyes are too sensitive to look at the sun except at sunset when its light has been significantly dimmed. The sun's light must be filtered by optically dense filters, welder's goggles, or aluminized Mylar. These remove enough light for comfortable and safe viewing. Others find that a telescope projecting the sun's image onto a white screen works well. Such an arrangement must be monitored at all times lest the filter slip or someone peeks through the finderscope, hurting their eyes.

Our Sunspotter builds on this direct projection method, but it makes the bright rays of the sun more inaccessible to fingers and eyes. Best of all, the Sunspotter encourages kids to gather their own data and not rely upon authorities alone. Their observations lead easily into numerical predictions, natural bridges to mathematical modeling, illustrating the scientific method at work.

Behind it all, it is astronomy's appeal that fascinates both young and old. Finding our connections to the wider universe focuses us beyond that which we experience in our daily lives. In considering the large spaces and huge objects of astronomy, our worldly troubles, that which the writer Osip Mandelstam called "the fleas of life," are cast as insignificant in comparison to the wonders of the heavens.

Most of all, the Sunspotter was designed to be fun to learn and fun to use. Plus, it makes the sun happy to be the center of attention.

Philip M. Sadler, Ed.D.
Mary Lou West, Ph.D.

A Quick Start to Using the Sunspotter

It is easiest to learn how to use the Sunspotter from someone who already knows. There is a certain amount of gentleness and patience required in finding the sun's image the first time, so don't rush yourself. If you are a new user with no one around to help you, just refer to the instructions on the back of the Sunspotter or follow these steps:

1. Take the Sunspotter outside and place it on a stable surface such as a picnic table or a brick wall. (Looking through a window usually gives fuzzy images, especially through old wavy glass.)
2. Put the instrument in the sunlight with the large lens (objective lens) pointing roughly at the sun (southeast in the morning, south at noontime, southwest in the afternoon). Remember that the Sunspotter must be able to "see" the sun. It cannot work in the shade.
3. Unscrew the "capture screw" that holds the triangle to the cradle until it pops free. The triangular part of the Sunspotter should be able to slide freely on its cradle base.

In aiming, the Sunspotter is adjusted so that the shadow of the gnomon disappears.

4. Notice the gnomon (stubby wooden rod) on the outside surface of the Sunspotter just above the large objective lens. This provides the first step in aiming at the sun. Move the whole apparatus by tugging sideways on a cradle leg and then gently sliding the triangle resting in the cradle

The Company

In 1977 Philip M. Sadler founded Learning Technologies Inc. to manufacture the STARLAB Portable Planetarium and other educational equipment. Over the years STARLAB has grown to be the world's best selling planetarium. On its way, it has been adopted by many schools, museums, camps, and individuals, often bringing astronomy to rural schools for the first time. Since 1977, STARLABs have been sold in over 50 countries around the world, with sales representatives on 5 continents.

Learning Technologies also distributes Project STAR Hands-on Science Materials, which began as a National Science Foundation funded project at the Harvard-Smithsonian Center for Astrophysics. Project STAR activities are based on the philosophy that students will better learn a concept when they first explore and then test their theories with hands-on, model-building exercises. These include inexpensive celestial spheres, spectrometers, and scale models of all kinds.

Learning Technologies also offers training, customer service, technical support and curriculum materials relevant to its products.

For Service or Information Contact

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E-mail: starlab@starlab.com

NRC National Standards

The Sunspotter fulfills some of the National Research Council's National Committee on Science Education Standards for science education. Some of the relevant standards are:

Content Standard D: Earth and Space Science

GradesK-4, all students should develop an understanding of:

1a. objects in the sky: the sun provides the light and heat necessary to maintain the temperature of the earth.

2a. changes in the earth and sky: objects in the sky have patterns of movement. the sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons.

Grades 5-8, all students should develop an understanding of:

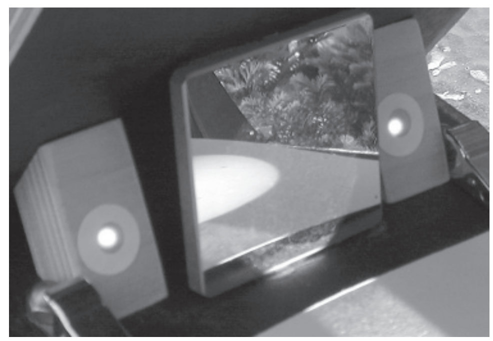
1a. earth in the solar system: the earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. the sun, an average star, is the central and largest body in the solar system.[see unifying concepts and processes]

1b. most objects in the solar system are in regular and predictable motion. those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.

1c. the sun is the major source of energy for phenomena on the earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. seasons result from variations in the amount of the sun's energy hitting the surface, due to the tilt of the earth's rotation on its axis and the length of the day.

until the shadow of the gnomon shrinks and then disappears.

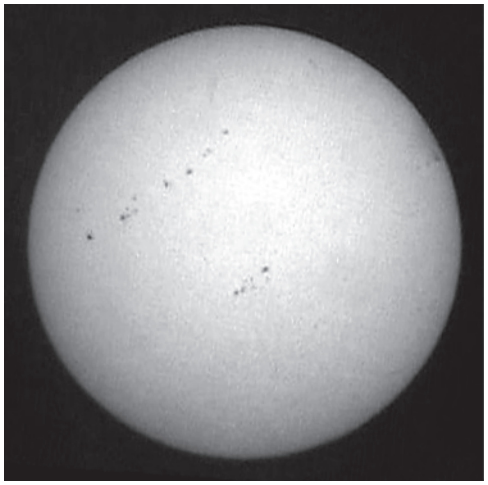
5. If you cannot make the gnomon shadow disappear, the sun is probably too low in the sky. The cradle has a low side for the low sun as well as a high side for midday. Two positions allow us to view the sun at different elevations above the horizon. If the sun is low, then have the telescope point at the sun over the low side of the cradle; if the sun is high in the sky then have the high side of the cradle pointing toward the sun. (Pick up the triangle by its handle, flip around the cradle, and set the triangle down again on the cradle.) The triangle can now be adjusted to point at the low sun.



After adjusting to make the gnomon's shadow disappear, carefully adjust the position of the Sunspotter in its cradle to center the dots of sunlight in the targets.

6. There are two small white circles on the wooden pads flanking the large flat mirror. They are on the inside corner of the triangle opposite to the objective lens. These are the targets for the final step of locating the sun's image. If you have made the gnomon's shadow disappear, then you should see two little dots of sunlight near the target circles. Adjust the Sunspotter ever so gently to move those dots into the target circles.
7. You should be rewarded by a big image of the sun appearing on the viewing screen. Adjust the image to be in the center of the viewing screen with tiny movements of the cradle leg and the triangle's position on the cradle. You will have to adjust the Sunspotter every minute or so to keep the full disk of the sun visible on the white card.

Activity 1 — Predict First, Then Look



Sunspotter image photographed on August 15, 2000

Prediction is an important part of science. It calls upon prior experiences. Often such ideas can seem fuzzy or way off the mark, but thinking back prepares you for observing more carefully. Ask your students open-ended questions in preparation for using the Sunspotter, such as:

a. **What do you think you will see with this solar telescope?** List these ideas on the board.

b. **Can you draw what the sun will look like?** You can then compare these drawings later to what they have seen. (This will bring up predictions, many of which may be misconceptions.)

It is helpful to set up the Sunspotter with a white paper and just observe. Start by just looking at the image with kids. Don't take data or make drawings initially. Rely upon the students' observations. For almost every student, this will be a special experience that they have never had before. Let the wonder emerge. There will be gasps of surprise. Don't explain what they are seeing. Let the sun completely drift off the paper (this will take about two minutes) and then ask some provocative observation questions:

1. What did you notice (e.g. spots, movement, colors, edges)?

of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.

Historical Perspectives

a) Grades 6 through 8:

1. Telescopes reveal that there are many more stars in the night sky than are evident to the unaided eye, the surface of the moon has many craters and mountains, the sun has dark spots, and Jupiter and some other planets have their own moons.

b) Grades 9 through 12:

1. Using the newly invented telescope to study the sky, Galileo made many discoveries that supported the ideas of Copernicus. It was Galileo who found the moons of Jupiter, sunspots, craters and mountains on the moon, and many more stars than were visible to the unaided eye.
2. Writing in Italian rather than in Latin (the language of scholars at the time), Galileo presented arguments for and against the two main views of the universe in a way that favored the newer view. That brought the issue to the educated people of the time and created political, religious, and scientific controversy.

AAAS BENCHMARKS IN ASTRONOMY

THE PHYSICAL SETTING

a) By the end of the 2nd grade, students should know that:
   1. The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day. The sun, moon, and stars all appear to move slowly across the sky.

b) By the end of the 5th grade, students should know that:
   1. Telescopes magnify the appearance of some distant objects in the sky, including the moon and the planets.
   2. Stars are like the sun, some being smaller and some larger, but so far away that they look like points of light.

c) By the end of the 8th grade, students should know that:
   1. The sun is a medium-sized star.
   2. The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive.

d) By the end of the 12th grade, students should know that:
   1. The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the earth and to behave according to the same physical principles. Unlike the sun, most stars are in systems of two or more stars orbiting around one another.
   2. Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle an avalanche of data and increasingly complicated computations to interpret them; space probes send back data from the remote parts

2. Do you think those little spots are from the Sunspotter or part of the sun?
3. How can you tell? Maybe they are just dirt on the lens. (If you obscure part of the objective lens the sunspots will still be visible.)
4. How many spots do you see? Are there any groups of spots? How many spots are in a group?
5. Does the image move fast? Why do you think it is moving? Roughly how long does it take to move through its own diameter? Is the image moving in a certain direction? Is it moving up or down also?
6. What color does the sun seem to be?
7. How would you describe the edge of the sun? Is it sharp or fuzzy?
8. Can you see any bright or dark spots other than the sunspots?
9. Did you see any clouds or birds or airplanes cross the sun's image? (They are surprising, and VERY cool to see.)
10. Do you think you can draw the sun? How might you do it?
11. How would you find out more about the sun and what you have seen?

End by having teams of students set up the Sunspotter themselves and observe the sun.

Later inside, discuss what is hard and what is easy in using a Sunspotter for the first time. Discuss the quality of the image. Have students draw from memory what they observed. Compare drawings among students. Compare these drawings to what they had drawn before going outside. Discuss the differences.

Have students make predictions of how the sun's image might change.

a. Do you think you will see the same thing in an hour?
b. In a day? In a month? In a year?
c. At sunrise or sunset?

Activity 2 — Tracing the Sun

Students drawing sunspots. One moves the paper with a circle outlining the edge of the sun while the other draws features.

Tracing the sun's image offers high accuracy and must be done only by one team drawing at a time. A single person can do this by himself or herself, but two people working as a team are much more effective. A copy of the sunspot record form can be made by drawing a circle of the proper size and adding labeled blanks for the name, the date and time of the observation. Making copies will speed the data collection process.

To begin tracing, first align the Sunspotter telescope. Then one person gently holds the sunspot record form on the viewing screen and positions it under the sun's image. The second person traces the first sunspot seen, usually the largest one. The first person moves the paper slightly to realign it with the sun's image, so that the person with the pencil can trace the next spot seen. The pencil must be held lightly. Cooperation is the key to an accurate drawing, as the paper is moved between each tracing of a spot. If a mistake is made it is best not to try to erase it at the moment. Just draw a little line through the mistake and finish the whole tracing. Later the errant mark can be erased thoroughly. Usually one needs to move the Sunspotter itself several times before the tracing is finished.

Don't rush your partner. Finish with a reference line on the record form after all the sunspots have been

Sunspotter Specifications

Telescope Type
875mm total path folded refractor
F 11, fixed focus
altitude-azimuth design
56x equivalent magnification

Objective Lens
2-element, air-spaced achromatic
700 mm FL, fully coated
61.7 mm diameter stopped down to 57.0 mm

Field Lens
4-element, 12.5 mm FL Plössl
fully coated, 10 mm aperture

Mirrors
one @ 50 mm x 50 mm x 10mm,
two @ 25 mm x 25 mm x 5 mm
<1/4 wave flatness

Solar Image Diameter
approximately 85 mm (3.25")

Field of View
.75° (1.5 solar diameters)

Pointing Range
altitude 0°-30°, 30°-90° (reversed), azimuth 0°-360°

Pointing Aids
2.2 cm gnomon (±30°)
22 cm pinhole projection (±3°)

Frame Construction
15mm 9-ply (cradle),
20mm 20-ply (telescope)
Baltic plywood

Overall Dimensions
height	40cm (16")
length	37cm (15")
width	15 cm (6")

Total Weight
3 kg (6.6 lb.)

CARING FOR YOUR SUNSPOTTER

Your Sunspotter is a precision optical device and should be treated as you would a camera or any other telescope. Do not touch the optical surfaces, they can be smudged by fingerprints or scratched. Since the sun is bright, the dimming of light by dust on the mirrors is usually of little concern. You can dust off surfaces with a camel hair brush or lens cleaning fluid and lens paper. Dust can be blown off gently if it needs to be. Do not scrub the mirrors or lenses, since you might remove their protective coatings.

Always put the blue fabric cover over your Sunspotter when you are not using it. This keeps dust and lint from accumulating on the mirrors and lenses. Store it in a cool, dry location, safe from rough handling.

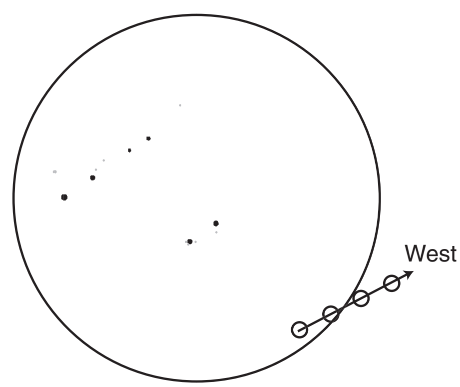
Sometimes the sun's image appears a bit blurry and you may wish to refocus the telescope. This is rarely the fault of being misfocussed since the sun is very far away and the telescope's dimensions are very stable. We have found a less-than-clear image is usually the result of poor seeing conditions. The Earth's atmosphere can be very turbulent, especially nearer the horizon. Also wispy clouds and pollution can interfere with a clear image. If the sky is not clear blue and objects miles away are not crisp to your vision, the sun will not be sharp either. Astronomers usually worry about "seeing" conditions at night, but they are much worse during the day when only the sun and moon can be viewed by telescope.

If you wish to refocus the telescope, loosen the screw holding in the field lens on the side of the horizontal support. Be sure to keep your fingers clear of the focused rays of the sun coming out of the lens. This can get hot. Move the field lens up and down a few millimeters until the sun's image is the sharpest and tighten the set screw again. The telescope focus is set at the factory. Adjustments will probably not be needed over the life of the instrument.

The Sunspotter is rugged and built to withstand years of active use. If any repairs are needed, call Learning Technologies for advice first. The instrument can then be shipped back to our company.

traced. This is done by centering the image on the viewing screen and once again aligning the form under the image. Hopefully, the tracings of the spots will fall on the spots themselves! Now, the form is not moved with the sun's image. Instead, we want to record the direction of the sun's motion.

Pick an easily seen spot near the edge of the sun on the side towards which the image is moving. It is best to draw these as faint circles every five seconds or so around your moving spot. Four circles are enough to indicate clearly the direction the image is moving. This motion is toward the west. (Note that north is 90° from this direction. North is not "up" on the drawing except at local noon.) Later, a reference line can be drawn outwards from the edge of the sun's circle. Draw this short line with a transparent ruler through the center of the sun's disk (remember that tiny cross on the record form) and parallel to the parade of circles marking the drift motion of the sunspot you drew. This reference line will allow you to line up images taken at different times of the day, and is important to have on every tracing.[1] Always record the time of day and date on the record form, and a note about the weather and clarity of the sky.



Sunspotter Drawing with Alignment Circles

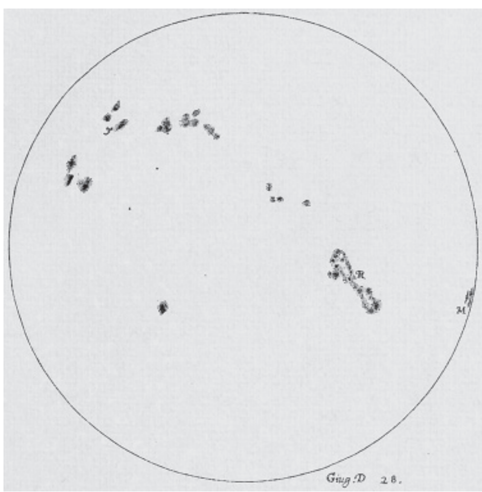
There are many daily images of the sun to be found on the Internet. Try *www.spaceweather.com* which provides an image from the SOHO spacecraft.

[1]Thanks to Professor Robert Noyes of Harvard for this suggestion.

Activity 3 — Freehand Sketching

Freehand sketching is what an artist does, drawing without tracing. First you look at the object, then draw it on your sketch pad in your lap. Many people can engage in this process at the same time. It is easiest if everyone is prepared with a pre-drawn circle on their paper. The circle can be roughly the size of the sun's image or much larger, as you prefer.

Start by aligning the Sunspotter telescope. Try to put the image right in the middle of the viewing stage. Look at the image and draw any spots you see, trying to preserve their relative positions and sizes. Have one student responsible for repositioning the image when it moves too far. Always record the time of day and date on your drawing. You may have to erase and redraw parts of the image, but since the face of the sun changes little, you can adjust your drawing until it looks best.



Galileo's Drawings of the Sun on June 28, 1613

Make sure you comment on the fact that there were no cameras when sunspots were first discovered. All images had to be hand drawn. Galileo's sunspot drawings from 1613 make very interesting objects for discussion (*http://es.rice.edu/ES/humsoc/Galileo/Things/g_sunspots.html*).

different kinds of glass to reduce colored fringes in the sun's image. The path of the rays of the sun are then folded by three mirrors within the enclosure to bring them to a prime focus above the crosspiece. The rays pass through an "eyepiece" lens which magnifies the image and projects it upon a viewing screen on the base of the triangle.

A crosspiece holds the eyepiece lens in position and also helps to stiffen the structure of the telescope. The eyepiece can be shifted in position slightly by loosening the retaining screw to adjust the focus. This is rarely needed since the sun's distance does not change appreciably.

The viewing screen is located inside the enclosure making it viewable from the sides of the apparatus by many students at once and allowing for easy tracing.

Pointing is aided by two means of alignment since the angular size of the sun is only 1/2°. A gnomon is used for primary initial alignment. A finer alignment is achieved through the use of another set of apertures astride the primary lens through which rays of the sun land on a pointing target. Supporting the telescope on three feet makes it more stable.

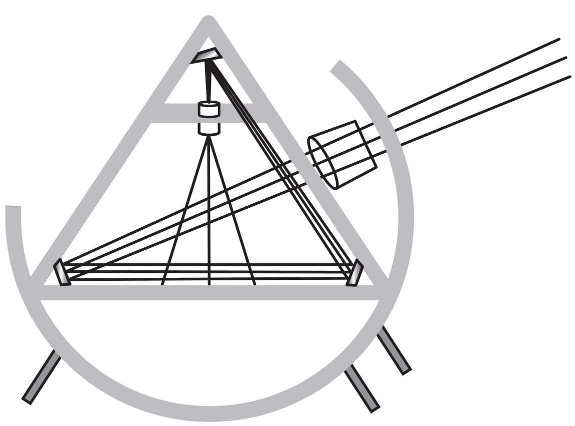
The alignment of the instrument is eased through an integral telescope mount. The triangular telescope shape sits upon a semicircular cradle. The unit can be aimed to study any altitude of the sun from 0° to 30° in one position and 30° through 90° by reversing the cradle. The telescope is designed so that its center of mass stays in the same point in space above the base, reducing the chance of it shifting in position after it is aligned. Four clips secure a piece of paper so that the user can draw the sun and its sunspots.

HOW DOES THE SUNSPOTTER WORK?

The Sunspotter is a folded, projection telescope designed for viewing the sun. The folded design was developed by Dan Janosik in the 1980s. Learning Technologies' Phil Sadler and Bruce Bloomfield made patentable improvements in the design in 2000. The telescope now has excellent optics and is sturdily constructed from Baltic plywood.

Although the Sunspotter looks complicated, it is a classic refractor folded up into a triangle. How long would it be if it were unfolded into a straight line? The prime focus is 700 mm long and ends just above the horizontal support. It is another 175mm down to the viewing screen.

You can trace out the path of the beam of light from the sun as it bounces from mirror to mirror inside the Sunspotter to fully understand how it works. Use a small piece of paper to follow the light carefully all the way from the entrance lens (the objective lens) through the small lens (the field lens) to the viewing screen. The concentrated beam can get hot, so do not use your finger. Take care not to ignite the paper.



The triangular telescope enclosure has an aperture to admit the sun's light. Centered in the aperture is the telescope's objective lens. The sun's rays pass through the objective lens into the enclosure. The lens is large and achromatic, resulting in a bright, clear image. This lens is made of two separate lenses of

ACTIVITY 4 — CHANGES HOUR TO HOUR

Not only does the sun's image move across the viewing screen in a few minutes during a tracing session, but it also rotates during the day. What is the cause of this? (Can you guess?)

This Sunspotter telescope is an *altitude-azimuth* telescope design, which results in image rotation. This is true for all alt-az telescopes. They are popular among amateur astronomers who view the stars at night because they do not require a wedge and tedious polar alignment. Their disadvantage is that they make astrophotography with long exposures impossible because the image turns slowly throughout the exposure. We can overcome this image rotation for the Sunspotter if we remember to draw a reference line pointing west on each drawing. For comparison and analysis the images can be rotated backwards until their reference lines coincide.

1. How much does the sun's image rotate in an hour?
2. Does the Sun's image turn at the same rate all day?
3. If you could image the sun below the horizon would it continue to turn or would it reverse its motion?

Activity 5 — Changes Day to Day

After you have traced the sunspots for several days you will notice that the sunspot groups appear to march in formation across the face of the sun. After a week or two they disappear over the edge of the sun's disk. Here are some photographs showing sunspot motion over several days.

What is the cause of this mass movement? Galileo was the first person to record the sunspots and their motion, and realize that this meant that the sun was rotating on its own axis. This was a surprising and exciting idea in the 1600s because it meant that the Earth was not the center of all motions. By carefully recording the changing positions of the sunspots and making a graph one can even figure out the rotation period for the sun. Based on the drawings to the right, how many days do you think it is?

Can you predict when a large sunspot is due back on the front of the sun? Mark this on your calendar and then check it out.

Did it appear for you right when you predicted it? What power you have!

The Best Websites About the Sun

All URL's begin with http://

The Sun Has Spots!

Classroom activities for grades 8-12 include use of Stonyhurst Grids and graphing instructions.

www.thursdaysclassroom.com/09mar00/hi_school/coolspots_menu.html

Stonyhurst Disks

Pre-made drawings of the sun's latitude and longitude lines.

www.meadows3.demon.co.uk/html/stonyhurst.html

Spaceweather

Up-to-date information about the sun and its effects on the earth including the latest 10-day movie of sun observations.

www.spaceweather.com

Sunspotters Club

The Astronomical League's program to encourage observation and drawing of the sun's disk.

www.astroleague.org/al/obsclubs/sunspot/sunsptcl.html

Ask the Space Scientist (About the Sun)

Great answers to questions.

image.gsfc.nasa.gov/poetry/ask/asun.html

Stanford Solar Center

Providing solar on-line activity resources for the joy of solar science exploration.

solar-center.stanford.edu/

Sunspots and the Solar Cycle

Predicting and monitoring the sun.

www.sunspotcycle.com

The Sun Today

Pictures taken from the SOHO telescope outside the Earth's atmosphere.

sohowww.nascom.nasa.gov/data/realtime-update.html

Sunspot History

From a Hawaiian telescope, daily B&W pictures of the sun with daily archived images since January 1995.

koa.ifa.hawaii.edu/MWLT/mwlt.html

Galileo's Data

See Galileo's 35 sunspot drawings from 1613.

es.rice.edu/ES/humsoc/Galileo/Things/g_sunspots.html

The Sun from Space

The detailed sun imaged in x-rays, ultraviolet, white light, and magnetic field.

www.lmsal.com/YPOP/ProjectionRoom/latest.html

BOOKS ABOUT THE SUN

RECOMMENDED FOR BEGINNERS

Robert Estalella, **Our Star. The Sun.** Hauppauge, NY: Barron's Educational Series, 1993.

Robert Gardner, **Science Project Ideas about the Sun.** Springfield, NJ: Enslow Publishers, 1997.

Jane Kelly Kosek, **What's Inside the Sun?** New York: PowerKids Press, 1999.

Patrick Moore, **The Sun and Moon.** Brookfield, CT: The Millbrook Press, 1995.

Cynthia Pratt Nicolson, **The Sun.** Buffalo, New York: Kids Can Press, 1997.

Jenny E. Tesar, **The Sun.** Des Plaines, IL: Reed Educational & Professional Publishing, 1998.

Gregory L. Vogt, **The Sun.** Brookfield, CT: The Millbrook Press, 1996.

Niki Walker, **The Sun. (Eye on the Universe).** St. Catharines, ON: Crabtree, 2001. ISBN 0-86505-692-7.

RECOMMENDED FOR TEENS AND ADULTS

Robert W. Noyes, **The Sun, Our Star**. Cambridge, MA: Harvard University Press, 1982.

Donat G. Wentzel, **The Restless Sun.** Washington, DC: Smithsonian Institution Press, 1989.

Peter O. Taylor, **Observing The Sun.** Cambridge, England: Cambridge University Press. ISBN 0-521-40110-0, 1991.

ADVANCED (THE REFERENCES FOR THIS MANUAL)

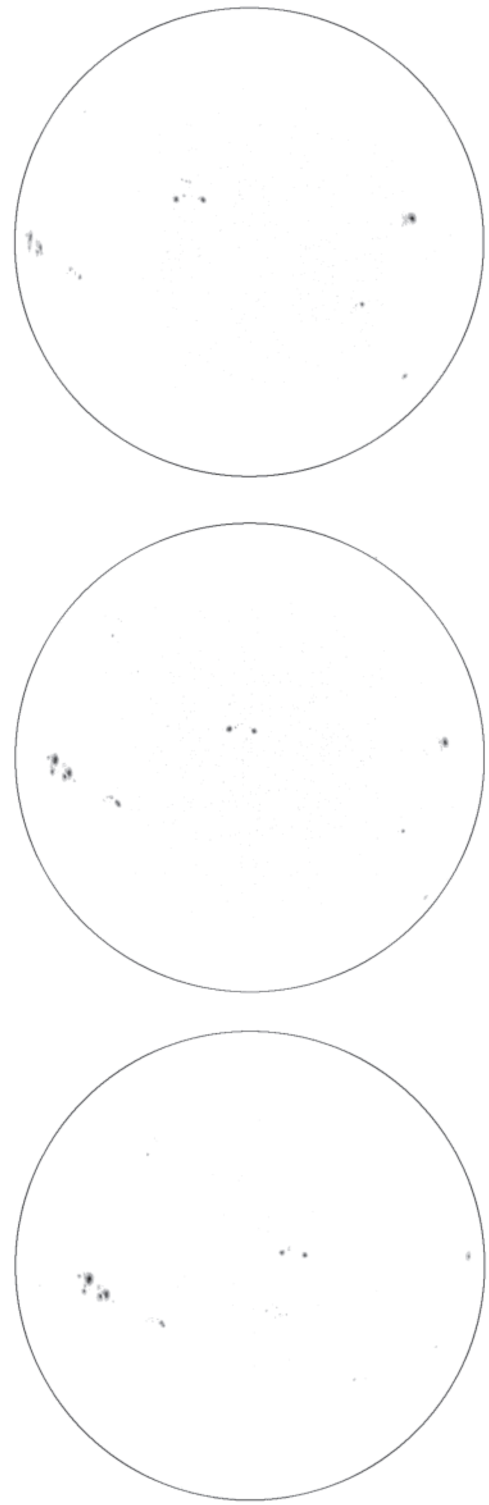
Leon Golub and Jay M. Pasachoff, **Nearest Star — the surprising science of our Sun.** Cambridge, MA: Harvard University Press, 2001.

Kenneth R. Lang, **The Cambridge Encyclopedia of the Sun.** Cambridge, UK: Cambridge University Press, 2001.

Richard E. Hill, **The New Observe and Understand the Sun.** Washington, DC: Astronomical League, 2000.

Observer's Handbook of the Royal Astronomical Society of Canada, University of Toronto Press, 2001.

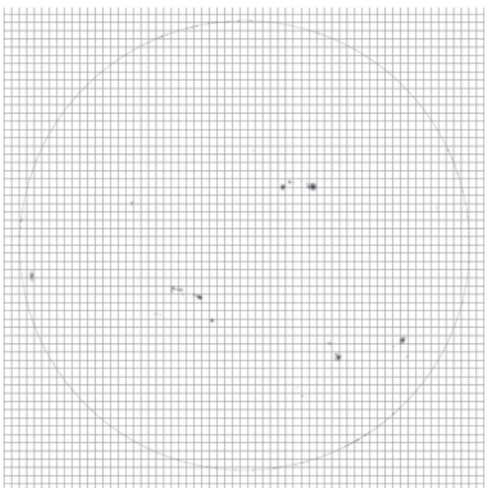
Carolus J. Schrijver and Alan M. Title, "Today's Science of the Sun," **Sky & Telescope Magazine,** Feb.2001, p. 34, and Mar. 2001, p. 34.



Images drawn one day apart from May 29-31,2002

Activity 6 — Sunspot Area

Some days we see only tiny spots on the sun, other days there are huge ones. A transparent overlay of fine grid paper allows us to estimate the area of the largest sunspot on each day, and also to estimate the total area covered by all the spots put together. Keep records for a few weeks then try to answer this question. Is the total area covered by sunspots a constant? That is, do lots of small spots equal the area of a few large ones?



This drawing is of a large group of sunspots on June 8, 2002 with an overlay grid. Each square in this picture is .04% of the full face of the sun.

The University of Arizona developed a set of activities based on the free software from The National Institutes of Health called "Image." NIH Image is available from *http://rsb.info.nih.gov/nih-image/* and can be used to estimate the area of a sunspot by drawing a rectangle enclosing it. Daily pictures of the sun for 1999 and 2000 from the Kitt Peak Vacuum Telescope are included on the CD-ROM, or you can get recent images from the Internet at *ftp://ftp.noao.edu/kpvt/daily*.

As with many things, a sunspot begins small, then grows, then shrinks and finally disappears. We can investigate this development using a plastic overlay of a fine grid such as millimeter graph paper.

Solar Vocabulary

Many science teachers think it is best to observe a phenomena first and only then define a scientific name, as the need arises. Here are some scientific terms useful in talking about the sun.

Aurora — Faint lights in the night sky caused by the sun's emissions.

Corona — The part of the solar atmosphere only visible to the naked eye during a solar eclipse.

Differential Rotation — The different speeds of rotation of the sun's surface.

Disk — The round appearance of the surface of the sun against the sky.

Penumbra — The outside area of a sunspot made up of dark and bright features.

Photosphere — The surface of the sun that is visible to us, where sunspots can be seen.

Plage — A faint, large, bright area around most sunspots.

Prominence — Dark filaments seen on the sun's surface which stand off from the limb when viewed on edge.

Solar Cycle — The 11-year cycle in the number of sunspots and other activities of the sun.

Solar Flare — A release of energy and mass from the sun in a specific region.

Solar Limb — The edge of the sun's disk as seen in the sky. It appears slightly darker than the rest of the sun.

Solar Eclipse — When the moon is directly between the earth and the sun, blocking the solar disk and revealing the corona.

Sunspot — Areas on the sun which appear darker because they are relatively cooler than the area around them.

Umbra — The darker inner region of a sunspot with a temperature of 4,200° K.

Activity 8 — Counting Sunspots

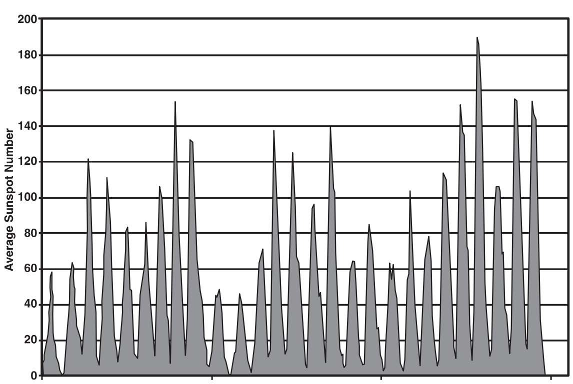
After you have sketched the sunspots for various days during several weeks you will notice that the number of sunspots changes. Of course, the local weather has a big effect, but we mean that even on very clear days there are sometimes not very many sunspots. The official sunspot number for a day is calculated as:

Sunspot Number =

(10 x number of groups) + number of individual spots

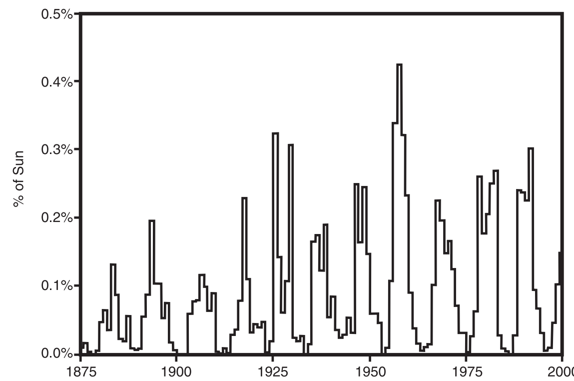
You might think that this over-emphasizes the groups of sunspots, but a group often has many tiny spots in it that cannot be discerned with a Sunspotter or other small telescope. The hard part is deciding what constitutes a group. By recording your calculation of sunspot number and then comparing it to the official one (found at *http://sec.noaa.gov/ftpdir/indices/DSD.txt*) you can figure out your personal calibration coefficient.

People have noticed that the number of sunspots gradually changes over an 11 year cycle. It was first noticed by Heinrich Schwabe, a Swiss pharmacist who kept records of the sun on his lunch hour in the 1850s.



Graph of average monthly sunspot numbers for the last 300 years.

Measure the area of the spot each day and then plot these area numbers vs. date. Is the growth or the death of the sunspot quicker? Is it symmetrical?



The fraction of the sun's surface covered in spots is calculated daily as a percentage of the visible surface. Here is the data averaged yearly from 1880 to 2000 from the Royal Greenwich Observatory.

Accumulate the area curves for many different sunspots, and then attempt to do sunspot sociology:

a. Is the curve for sunspots in the northern hemisphere different from the curves for sunspots in the sun's southern hemisphere?

b. Does the lifetime depend on the maximum area of the sunspot?

c. Does the lifetime depend on the number of other sunspots in the same group?

d. Does the lifetime depend on a sunspot's latitude?

Activity 7 — Life Cycle of a Sunspot

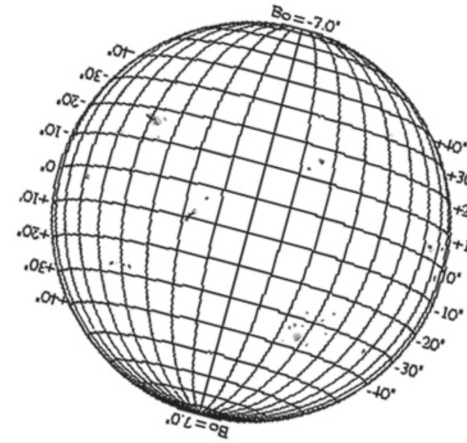
Each sunspot has a position on the sun's surface which can be specified by a latitude and a longitude, just as places on the Earth can be. Because the sun spins on its own axis (see Activity 4), it has an equator as well as a north pole and a south pole.

Because the plane of the Earth's orbit around the sun is almost in the same plane as the sun's equator, we see the sun's equator almost in the middle of the sun's face. This is the "west reference line" we draw on every tracing done with the Sunspotter. Measuring a sunspot's latitude up or down from this line is a good first approximation. This would mean that sunspots would track across the sun's face on perfectly straight lines. However, the tilt of the sun's polar axis to the pole of the Earth's orbit plane is actually 7.25°. This means that the sun's north pole is sometimes pointed slightly towards us and sometimes pointed slightly away from us. In these months sunspots will track across the sun's face on shallow curved lines.

In addition, as the earth orbits the sun, our axis is not always aligned with that of the sun. The earth's axis is tilted with respect to our orbital plane by 23.5°. Sun drawings must be turned clockwise or counter clockwise to account for this alignment as well.

Special diagrams called Stonyhurst disks or grids have been created to make it easier to track sunspots in solar latitude and longitude. Stonyhurst charts are available on the Web (*http://www.meadows3.demon.co.uk/html/stonyhurst.html*). Accompanying them are instructions for how use them. You must choose the right one for your particular month and tilt it the right number of degrees. Making copies of these charts and using the proper one for the date allows us to measure the sunspot's latitude. A sunspot tends to stay at the same solar latitude, but changes in its apparent longitude as time goes on.

The sun's axis appears to tip toward or away from the Earth by 7.25 degrees in a cycle each year. Professional astronomers use the Stonyhurst grids for 0, 1, 2, 3, 4, 5, 6, and 7 degrees of tip, north and south. You can make a plastic overlay of these grids.



This is a sample of a Stonyhurst Disk with spots drawn on it. More information and disks of different sizes are available from several websites, such as: http://www.meadows3.demon.co.uk/html/stonyhurst.html

Line up the west end of the equator on the overlay with your "west reference line" and center the circles.

The statistics of thousands of sunspots over many years show that the sun's rotation period also depends on the solar latitude of the sunspot. The sun's equator rotates in somewhat less time than the higher latitudes in either hemisphere. On any day there are likely to be sunspots at several different solar latitudes. However, this will not be sufficient to notice this velocity effect. The variation of period with latitude is a subtle effect, so the more data the better.

Over a period of about eleven years sunspots erupt closer and closer to the sun's equator, starting at about 40 degrees latitude north or south. A plot of the latitude of each spot vs. time is called a "butterfly diagram." The next cycle of solar activity begins when there are few spots and they are seen at 40 degrees latitude once again.