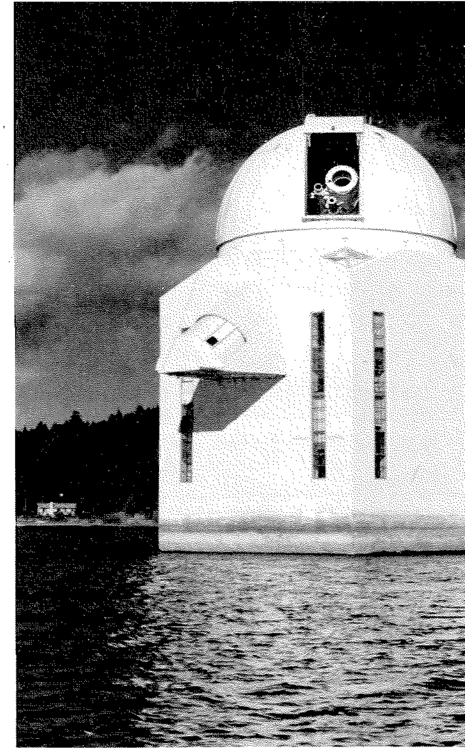
SURFboard

The Sun Also Polarizes

The sun is generally a placid, even-tempered star, but it has a violent side. Flares—tongues of solar gas, many times larger than the earth—erupt outward from the sun's surface. These same eructations disgorge high-energy electrons, x-rays, and other particles, playing hob with the earth's ionosphere, disrupting radio communications, and draping the polar skies with the neon curtains of the aurora. These outbursts are thought to be driven by the sun's writhing magnetic field, but studying that field isn't as easy as holding a compass up at the sun. Studying it at Caltech's Big Bear Solar Observatory will be a lot easier in the future, however, thanks to a system that Glenn Eychaner, a senior in geophysics, developed there this past summer.

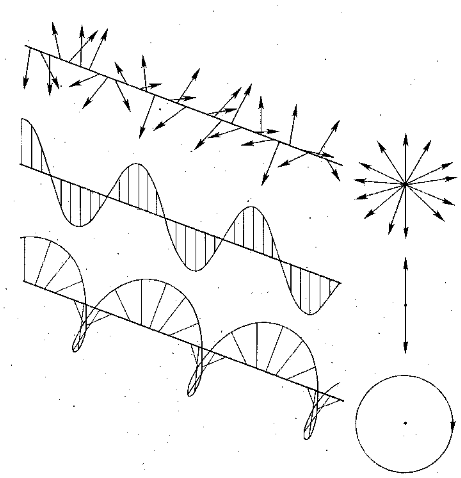
The sun's magnetic field is extremely complex. A diagram of the earth's field close to the planet looks rather like half an apple, with the north and south poles at opposite ends of the core, and the apple's skin representing a typical magnetic field line. A close-up diagram of the sun's field, however, looks more like an untidy ball of yarn the cat has been playing with—loops of magnetic field emerge from the sun's surface at many points, each of which is a magnetic pole. These points are usually visible as sunspots, and the loops connect sunspot pairs of opposite magnetic polarity. There may be dozens of sunspot pairs, as well as more complex groupings, on the sun's surface during a particularly active episode.

The sun's magnetic field is hard to measure directly, even though it's much stronger than the earth's—about 10 times stronger at the solar poles, and as much as 6,000 times stronger in the middle of a sunspot. Fortunately, light waves passing through a magnetic field become partially polarized—the waves become aligned with one another. (Unpolarized light waves are random—some go up and down, others move sideways, and the rest vibrate in any old direction.) A three-dimensional magnetic field polarizes light in two ways. The transverse field—the part perpendicular to the observer's line of sight—produces linearly polarized light whose waves lie in planes parallel to the field. The longitudinal field—the part along the observer's line of sight—produces circularly polarized light whose waves are still randomly aligned, but rotate clockwise or counterclockwise in unison. Thus, photographing the sun through a clockwise-polarized filter, say, gives a picture whose brightness at any point is proportional to the field strength. The resulting image is called a magnetogram. (The effect is actually so small as to be unobservable, except in monochromatic light—light of a single wavelength. Thus magnetographs—the instruments that make magnetograms—also contain filters to admit only the desired wavelength. These wavelengths aren't limited to the ones at which hydrogen and helium emit light. Much

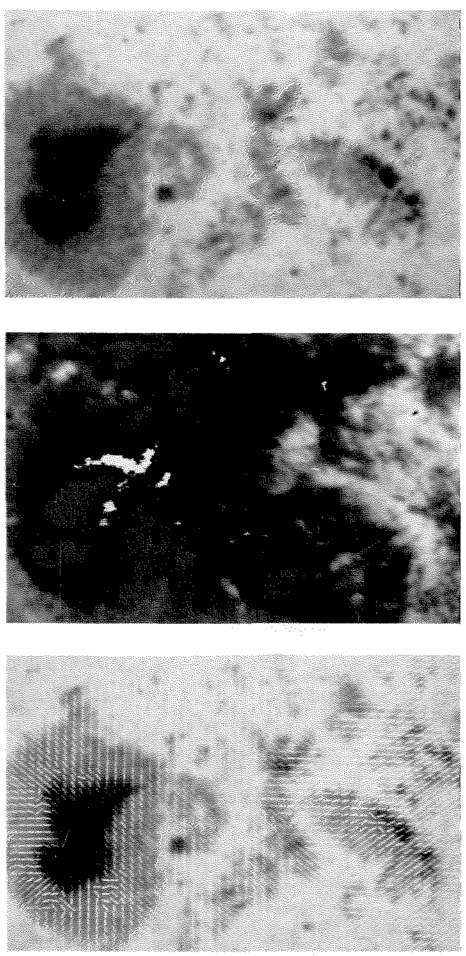


Above: The three-story Big Bear Solar Observatory sits in the middle of Big Bear Lake to minimize atmospheric turbulence. The 26-, 10-, and 8-inch telescopes are visible in the dome. The "nose" projecting from the building's side houses a spectroheliograph.

Below: Unpolarized light waves are random (top), while plane-polarized light waves lie in a plane (middle), and circularly polarized light waves rotate together (bottom).



**Top: A sunspot group as seen in 6103-Angstrom light, an emission line of neutral calcium.
Middle: A longitudinal magnetogram of the same area. Clockwise areas appear bright and counterclockwise areas dark in proportion to the field strength. The white areas inside the black are artifacts.
Bottom: The transverse magnetogram superimposed on the sunspot group. Flares are expected where field lines meet at an angle, as along the diagonal toward the lower right corner.**



valuable information can be gleaned from the emissions of heavier elements such as iron or calcium.)

It takes only two images—one each through a clockwise and a counterclockwise filter—to make a longitudinal magnetogram, which have been in use since the 1950s. Making a transverse magnetogram is much harder, because the polarization signal is much smaller. Creating a transverse magnetogram entails reconstructing the field from a compilation of images polarized in different directions—time-consuming even for a computer. A system at the George C. Marshall Space Flight Center in Huntsville, Alabama, can crank out a magnetogram in about three hours, but most researchers need months to produce one.

Eychaner's system generates transverse magnetograms in seconds. The system was built as a SURF (Summer Undergraduate Research Fellowship) project sponsored by Harold Zirin, professor of astrophysics and director of the Big Bear Solar Observatory, in collaboration with BBSO postdoc John Varsik. The system uses BBSO's video magnetograph. Two linearly polarized filters with axes at 45° to each other were added to the set of circularly polarized filters already on the magnetograph's computer-controlled filter wheel. Eychaner fed the video output to a computer, which he programmed to construct transverse magnetograms. The computer records the brightness of every pixel, or point in the video image, as seen though each linear filter, as well as the true brightness when neither filter is in the light path. The field's strength and direction are calculated by comparing each true brightness with the polarized brightnesses. The system displays the transverse field as a pattern of line segments oriented along the lines of force, like iron filings sprinkled around a bar magnet. Each segment's brightness corresponds to the field's local intensity. The magnetogram can be superimposed upon an unpolarized image of the same region to show the sunspots, or onto a longitudinal magnetogram.

The image processor has a limited capacity, so the system averages blocks of eight pixels on a side when making images of the entire sun. The operator can scan these images and zoom in on a particularly interesting region, telling the system to process that region on a pixel-by-pixel basis.

"We believe that solar flares get their energy from the sun's magnetic field," says Zirin. "There's really no other source that can release so much energy in so small a volume over so short a time. But as luck would have it, the longitudinal field, which is easy to measure, doesn't seem to change much during flares. So we think that the transverse field is where everything happens, and there are other arguments for this as well." Adds Eychaner, "We expect to see large variations in the transverse field and a strong longitudinal field all along where the flares are happening. The theory says that flares occur when the transverse field goes from a high-energy state to a low one. The field lines start out straight, in a low-energy state. But the regions of north and south polarity are constantly moving past each other, so the field lines connecting them get bent, and as they bend they go to higher energy states. A flare occurs when the lines break suddenly, snapping back and becoming straight again. It's sort of a magnetic earthquake. And flares happen very quickly. A small one may last only half an hour, and the real action doesn't last more than a few minutes. That's why we wanted to develop a system that could get six or eight clear pictures during the crucial first few minutes of a flare, so that we could see how they develop."

The summer's work was plagued by computer crashes and other minor problems. One problem was that the observatory's 26-inch reflector and 10-inch refractor telescopes affect polarized light differently, yet the system was supposed to be compatible with both instruments. That problem was finally licked with a custom-built filter plate for the 26-inch. The system therefore didn't get fully up and running until almost September. But as *E&S* went to press, the BBSO group had just detected their first transverse field change associated with a flare. "I think we're seeing a real effect," says Zirin. "Now we're trying to observe other flares to confirm it."□—*DS*