Chapter 17

High Above the Clouds

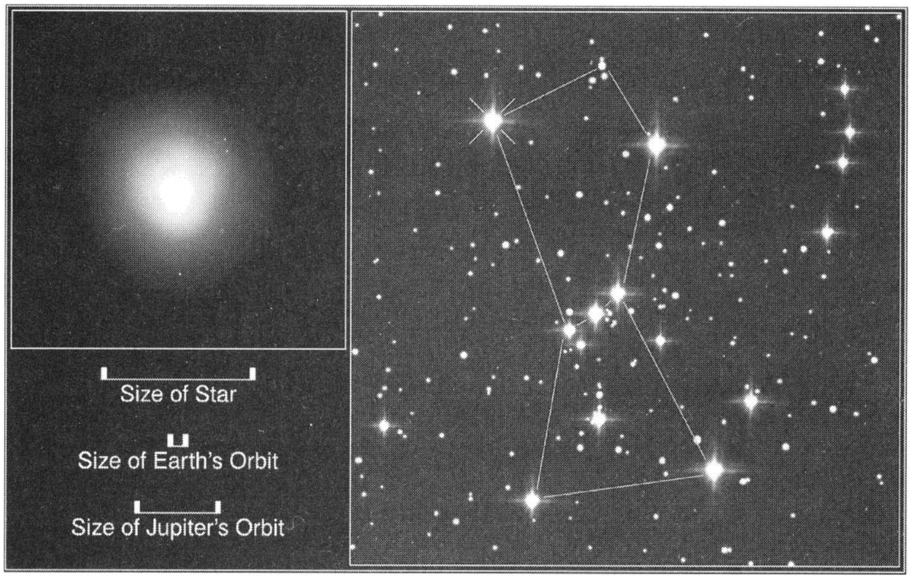
In This Chapter

- Solar versus nighttime observatories
- Seeing versus transparency
- Putting solar telescopes on towers or out in lakes
- Altitude and infrared

Most people's mental pictures of observatories involve giant telescopes peering up at the night sky. But the Sun is up only in the daytime, a profound observation that changes everything. Scientists observing the Sun have to peer through an atmosphere roiling with the heat from the very object they are trying to study. Observing the Sun requires more differences from traditional astronomy than merely getting up in the morning instead of staying up all night.

The Sun Shines in the Daytime

On a dark night, if you are far from lampposts and other city or town lights, you can see perhaps 3,000 stars. Each of those stars is a mere point of light to us on Earth. Even using the largest telescopes in a straightforward manner does not enlarge the images of stars; the images remain points. Only a special technique now being intensively developed, involving linking separate but adjacent telescopes, has been able to detect structure on the surfaces of any stars or to measure the sizes of stars. And the Hubble Space Telescope has been able to detect only giant blobs of structure on the star Betelgeuse, a supergiant star in the constellation Orion that is relatively close to us.



A bright area on Betelgeuse, a supergiant star in the constellation Orion, imaged with the Hubble Space Telescope. This amount of detail is the most ever seen on the surface of a star other than the Sun.

(Andrea Dupree [Harvard-Smithsonian CfA], Ronald Gilliland [STScI], NASA, and ESA)

Telescopes that study stars, therefore, are used as light buckets, collecting as much light as possible and funneling it to a small area on a detector. The light from a star often is directed through a spectrograph, which spreads the light into its component colors. Or, it may be viewed through a series of broadband filters, each of which passes a range of colors. But in all those cases, all the light from each star is treated together. No detail on a star's surface can be analyzed.

Fun Sun Facts

The Sun covers about ½° across the sky. (Scientists often say that it subtends—that is, covers—½° of arc.) Compare this angle with the 360° of a full circle. The width of your thumb at the end of your outstretched arm covers about 2°, so your thumb more than covers the Sun.

In these standard angular measures, each degree is divided into 60 minutes of arc, and each minute of arc is subdivided into 60 seconds of arc. So a degree contains $60 \times 60 = 3{,}600$ seconds of arc, and the Sun's diameter covers around 1,800 seconds of arc. Telescopes on Earth can resolve detail about 1 second of arc, so 1,800 pixels, each 1 second of arc across, cover the Sun's diameter. A two-dimensional image of the Sun covers roughly πr^2, the area of a circle, with radius (r) equal to 900 arc seconds, so the Sun's disk covers roughly 2,500,000 arc seconds.

The case for the Sun is very different. Compared with the 360° of a full circle, the Sun covers a half degree in the sky. Scientists and mathematicians talk of parts of a circle as "arc," and divide degrees into 60 minutes and each minute into 60 seconds. This half degree is, in turn, the same as 30 minutes of arc. Unaided, the human eye can see detail about 1 minute of arc across (we often say "1 arc minute," for short). That would be about the size of a moderately large sunspot. To see any smaller angle, we need a telescope.

Sun Safety

Even though sunspots seen with the naked eye have been reported for hundreds of years at sunset, when the Sun is sufficiently dimmed by Earth's atmosphere, you must look at the Sun only through a special solar filter that brings the sunlight intensity down to a safe level.

In principle, the larger a telescope is, the finer the details it can resolve. Something the size of the pupil in the human eye, which is perhaps 6 mm across, resolves about 1 arc minute, 1/30 of the Sun's diameter. Something 60 times bigger resolves detail about 60 times smaller—that is, 1 arc second. And 60 times bigger than 6 mm is 360 mm, which is about 15 inches. But at about 1 arc second, the turbulence in Earth's atmosphere keeps you from seeing finer detail. An average-quality observation site for an amateur astronomer might be limited to detail larger than about 3 arc seconds. A high-quality professional site is traditionally said to have a limit of about 1 arc second. The very best sites, such as the Mauna Kea Observatory, at 4,215 meters (13,800 feet) of altitude in Hawaii, has "seeing" (image steadiness) that reaches perhaps 0.4 arc seconds. The Hubble Space Telescope can see about 0.1 arc seconds in the visible part of the spectrum.

Because of the limitations of the Earth's atmosphere, it has not been generally thought important to build very large solar telescopes. After all, the Sun is so bright that we usually get enough light even with a smaller telescope. Only at the present time is there a major project underway to build a solar telescope of a size comparable to that of even the previous generation of large nighttime telescopes, as we discuss in Chapter 19.

The Sun Isn't Up at Night

The air isn't usually as steady during the day as it is at night. After all, energy from the Sun is coming down to Earth through the air, heating it. Columns of rising air have different densities from surrounding air, which makes the light passing through them bend every which way. Therefore, images during the day are ordinarily not as clear as images at night.

The property of unsteadiness in images that is introduced by turbulence in the air is known as *seeing*. Bad seeing introduces a couple of effects. One is called dancing, in which the image moves around the sky a little. If you are taking a photograph, the image will blur because of its motion during the time that the shutter is open. (In some cases, you can take a lot of very short exposures, each of which has finer resolution, and add them together later after aligning them.) Another is straightforward blurring.

> **Sun Words**
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> **Seeing** is the quality that describes how steady images are.

When the adaptive optics system was turned on at the Keck 2 telescope, to counteract the effects of seeing by distorting one of the telescope's mirrors, the image size improved by a factor of over 10. This infrared image of a star improved from the blurry half an arc second (left) to the more pinpoint 1/20 of an arc second (right); both images are shown to the same scale.

(Keck II AO Facility/NASA/LLNL)

> **Solar Scribblings**
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> Astronomers hope for "good seeing" when they go observing. A polite way to send off a friend to an observing session is "I hope the seeing is good." That means that you are hoping for steady air that will allow good resolution on the images.

Another effect that astronomers worry about is *transparency*. Transparency is how clear the sky is—that is, what fraction of the incoming light gets through the atmosphere. The transparency varies from day to day and also varies with angle in the sky. Near the horizon, you are looking through several times as much air as you are when you look straight up, so the transparency goes down. Astronomers say that there is extra *extinction*.

Solar astronomers hold up their thumbs a lot against the sky, blocking out the Sun to see how clear the sky is. On a clear mountaintop site, the sky can appear steady blue up to the edge of your thumb. From sea level or close to it, you can usually see the sky getting brighter and whiter as you get closer to your thumb (and to the solar disk that is hidden by it). Never at sea level do you have a sky that is as deep blue as it is at a high altitude.

Sun Words

Transparency is how clear the atmosphere is.

Extinction is how much of incoming light is absorbed before it reaches us.

It is possible to have good seeing and bad transparency; conversely, it is possible to have bad seeing and good transparency. For example, an atmospheric inversion can cause smog to settle over a city—for which the Los Angeles area has been famous. That smog lowers the transparency, but the stagnant air can lead to good seeing. So a smoggy day can have good seeing yet bad transparency. On the other hand, a day that is made clear by wind whipping around can have blurred images because of bad seeing, yet it can have good transparency.

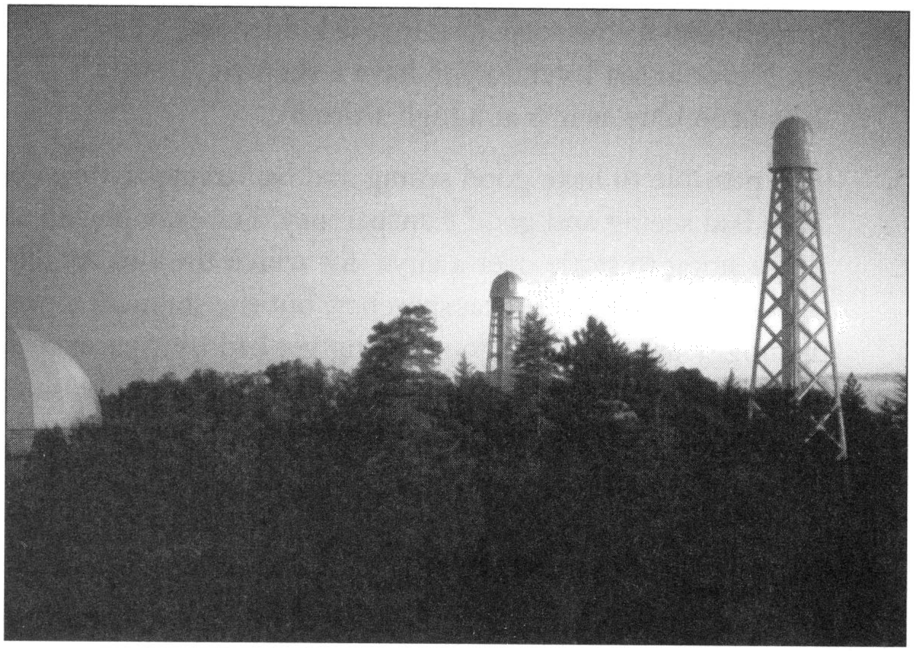
Solar Scribblings

Some of the best solar movies of all time were made in an asphalt-paved parking lot in Burbank, California, a far cry from the scenic mountains or mountain lakes of other solar observatories. The site was chosen because the Lockheed Corporation, an aerospace company, supported a group of scientists studying the Sun, and it was convenient for them to observe right out their back door. They called their location the Lockheed Solar Observatory. Because of the smog, the site often had excellent steady seeing over periods of hours, even though the transparency was lousy.

Higher Telescopes

One way of eliminating the turbulence that comes from solar heating of the ground is to put the entrance aperture of your telescope at the top of a tower and build the telescope as an integral part of the tower. Two solar towers at the Mt. Wilson Observatory, overlooking Los Angeles, have been there for almost 100 years. The original tower is 60 feet (18 meters) high. George Ellery Hale discovered the magnetic field of sunspots with this tower telescope in 1908. The other tower is even higher, 150 feet (45 meters), to provide higher dispersion in the spectra it takes. Since the Sun is up in the daytime, the bright nighttime lights of today's Los Angeles aren't relevant to solar observation.

Scientists using the towers continue to make daily magnetic-field images of the Sun as well as other images. Some of the measurements are used for helioseismology. In each case, the tower is only part of the telescope; the light is reflected downward from mirrors at the top of the tower through a lens and into a pit deep below the mountaintop. It is then bounced back up to the observing room, which is at mountaintop level.



The 60-foot and 150-foot solar tower at the Mt. Wilson Observatory, now operated by UCLA.

(UCLA)

Not all mountaintops are good for observatories. To have a good site, you must have not only altitude, but also a steady flow of air. The Hawaiian shield volcanoes, such as Haleakala on the island of Maui and Mauna Loa on the island of Hawaii, have such gentle slopes that the air flows in a calm, laminar fashion across and above them. Thus, solar observatories are located at each of those places. But random mountains like Pike's Peak may have turbulent air above them, and we don't put solar observatories there.

Cutting Down on Turbulence

Another way to get a smooth flow of air above your observatory is to put it in the middle of a lake. The best way to do so is to put it on a small island, though you can make an artificial island, as was done in the middle of Big Bear Lake in the San Bernardino Mountains a couple of hours west of Los Angeles in California. Because of its location in the lake, the seeing is steady for long periods of time, and the Big Bear Solar Observatory is famous for movies of changing solar phenomena.

Solar Scribblings

The story has it that astronomers realized that lakes might be useful sites for solar observatories from an observation made at the Sacramento Peak Observatory in the mountains above Alamogordo, New Mexico. Someone noticed that the seeing seemed to improve at one of the telescopes when they were watering the lawn. It was but a small step from watering the lawn, with evaporating water diminishing the turbulence of the air flowing above it, to seeking out a full lake.

Turbulent air makes bad seeing not only above the telescope, but also in the telescope itself. The hot beam of solar light causes rising and falling air currents within the telescope's tube. A first round of rejection is a filter that cuts out the infrared part of the solar light. Such a filter has to be placed at the front of the telescope tube. Second, fans within the tube might distribute the air, to keep it from turbulence. The most drastic solution is to evacuate the telescope tube, making a vacuum inside. Devoid of air, the inside of the tube cannot contribute to turbulence.

Let It All Come Through

Our eyes are most sensitive at the colors of light that the Sun emits most strongly—especially in the orange, yellow, and green. But other kinds of light exist that we don't see. In particular, beyond the red end of the spectrum, we have infrared.

Solar Scribblings

Even though William Herschel had discovered the planet Uranus in 1781, he did not rest on his laurels. About 200 years ago, Herschel was experimenting with sunlight, spreading it into a spectrum. He put a thermometer into the different colors to check their temperatures. He was surprised to find that his thermometer showed an excess temperature even when he held it beyond the red, compared with off to the side. He had discovered infrared, named from the Latin *infra-*, meaning "beyond."

Many things in solar astronomy are studied better in the infrared than they are in the visible. The magnetic field of sunspots, for example, shows up particularly well in infrared spectra. But infrared observations have lagged behind optical observations in all kinds of astronomy for both atmospheric and instrumental reasons.

The instrumental reason is that particles—photons—of infrared light each contain less energy than individual photons of visible light. The infrared photons, in particular, do not have enough energy to affect ordinary film. Though some infrared films exist that barely detect the part of the infrared immediately adjacent to the red, the infrared extends far beyond that. Observing infrared well had to await the invention of sensitive electronic detectors for that part of the spectrum.

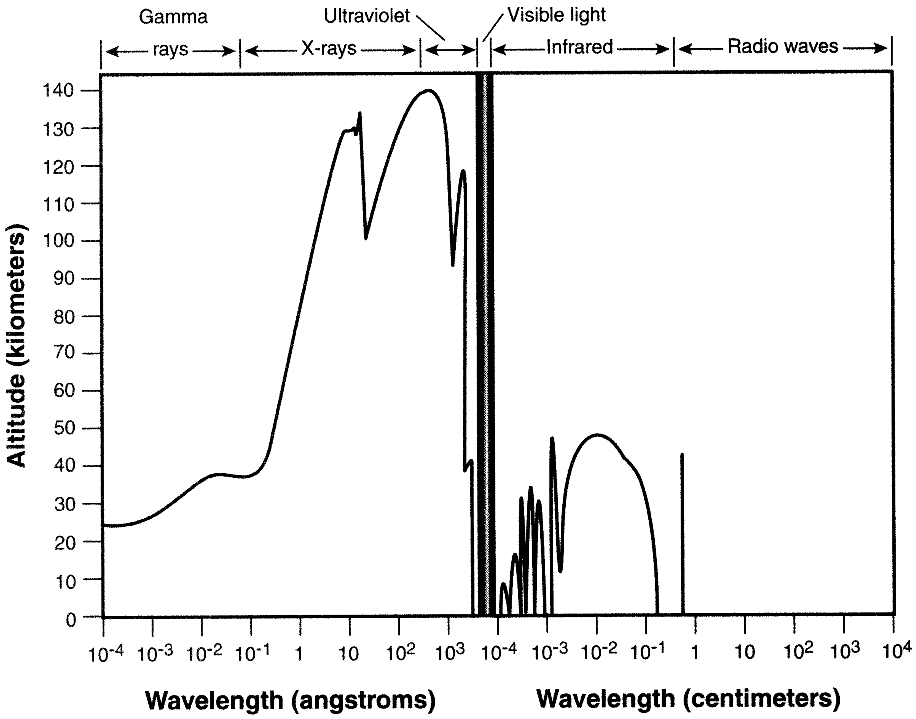
Solar Scribblings

The first infrared detectors had only one detecting element, but at the dawn of the twenty-first century, infrared detectors with hundreds of pixels existed. This resolution is still far short of optical detectors, which now contain millions of pixels. Still, the infrared space observatory that NASA planned to launch in 2003 to be equivalent in scale to the Hubble Space Telescope and the Chandra X-Ray Observatory should be able to produce reasonably detailed infrared images. Another infrared camera was rejuvenated in 2002 aboard the Hubble Space Telescope. But neither of these infrared devices can look at the Sun without being blown out. Only special solar telescopes and spacecraft are ever purposely pointed at the Sun.

The atmospheric reason for limitations in infrared observing stem from the fact that water vapor absorbs infrared. Since there is water vapor in the Earth's atmosphere, little of the infrared comes through to the Earth's surface. Though the atmosphere is opaque to most of the infrared, some bands of infrared color come through. We say that they come through "windows of transparency," though the windows are merely in the spectral coverage.

The higher and drier the site is, the better infrared radiation can be observed. So observatories at high sites, like the Mauna Kea Observatory at 4,215 meters (13,800 feet) of altitude, have telescopes optimized to observe the infrared. The Mauna Loa Observatory, on a Hawaiian mountain facing Mauna Kea, is similarly high. But only in recent years have infrared detectors developed enough to make it worthwhile to devote a lot of effort to infrared solar observations.

Infrared can be observed well from high-flying airplanes. NASA had its Kuiper Airborne Observatory aloft through the late 1990s, but it was retired to devote the budget to next-generation aircraft: Stratospheric Observatory for Infrared Astronomy (SOFIA), a joint project of NASA and the German Space Agency. SOFIA carries a 2.5-meter (100-inch) telescope, larger than any previous telescope aloft or in space, and is to start its work in 2005. Though the Kuiper Airborne Observatory carried out most of its observations pointed at objects other than the Sun, it did make some notable solar observations. For example, it was used to observe infrared radiation near the limb of the Sun during a solar eclipse.



Windows of transparency, showing which parts of the spectrum reach the Earth's surface. The whole visible part of the spectrum, but only narrow bands in the infrared, are in windows of transparency.

The Least You Need to Know

- Solar observatories need different conditions than nighttime ones.
- Good seeing and good transparency are not necessarily linked.
- Solar telescopes can be on towers, lakes, or high mountains.
- New instrumental capabilities are improving infrared solar observations.
- High altitude is needed for the best infrared observations.
- An instrumented airplane will fly high in order to observe the infrared.