Chapter 1

The Sun Shines on Us

In This Chapter

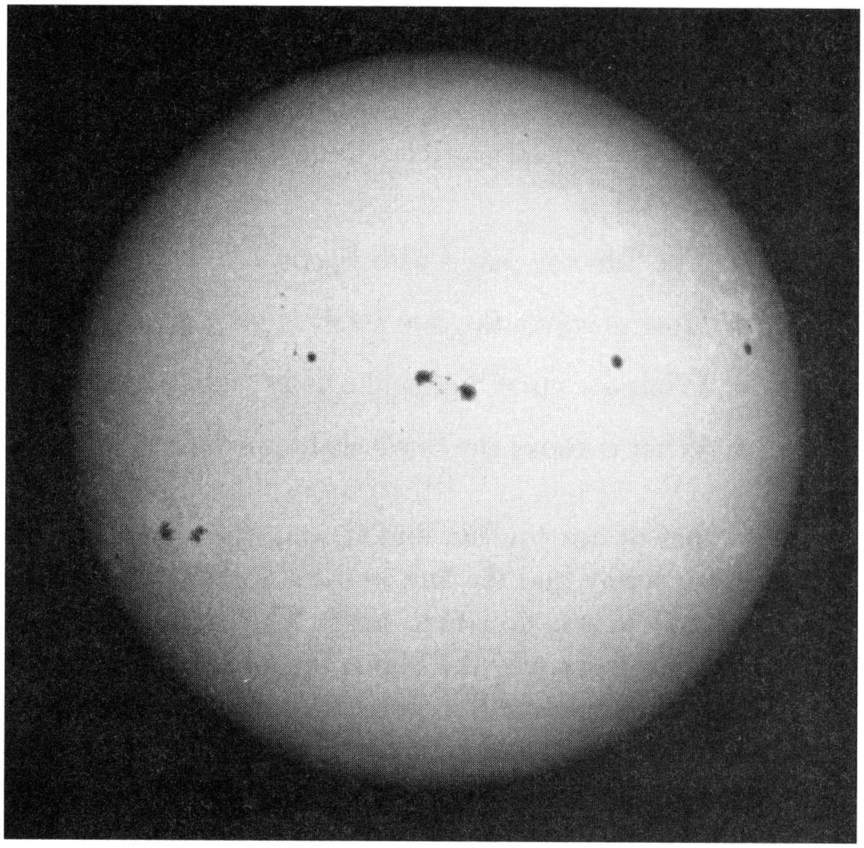
- The Sun compared with Earth
- How to watch the Sun safely
- What the quiet Sun is like daily
- What is above the Sun's visible surface

Whether or not you can find Orion, Andromeda, or other constellations, you can surely find the Sun in the sky. It's up in the daytime, so you don't even have to stay up late to see it. The ease of finding the Sun is but one of many reasons why the Sun is the most interesting astronomical object. Unlike the stars, the Sun noticeably changes from day to day, so there is always something going on up there. Furthermore, these changes on the Sun sometimes lead to explosions that end up affecting us on Earth. So although stars and galaxies are part of our universe, the Sun is an important part of our backyard.

Parts of the Sun

We on Earth have our feet on the ground but our heads in the air. The Sun's "ground" isn't as sturdy as our Earth's because the Sun is a giant ball of gas through and through. But the Sun also has what we call a surface and an atmosphere. The transparent part is the atmosphere, for the Sun as for the Earth. What we call the "surface" of the Sun is like the Earth's surface in that we can't see through it. And both the Earth and the Sun have interiors that are hidden from our view. In both cases, though, studying the surface in detail can reveal facts about the interior.

The Sun's surface is about a million miles across. Since the Earth is about 100 times smaller across, more than a million Earths could fit inside the Sun. From a distant star, looking back at the Sun, we would see giant planets like Jupiter and Saturn long before we could find a relatively tiny one like our Earth.



The Sun, with sunspots, photographed on an ordinary day through a special filter that cuts out 99.999 percent of the sunlight.

(National Solar Observatory/AURA/NSF)

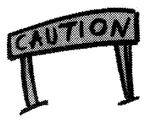
Solar Safety

You shouldn't stay out too long in the Sun, or you'll get sunburned and even start on your way to skin cancer. But looking at the Sun directly with your eyes is much more immediately hazardous. The Sun is so bright that on a normal sunny day, your eye blinks very quickly if the Sun comes into your field of view, and you turn your gaze away. So you wouldn't normally stare at the Sun. If you forced yourself to do so, you could cook your eyeball and cause permanent damage to your vision.

If you tried to look at the Sun with binoculars or a telescope, the Sun's rays would be concentrated into your eye. You could get a permanent blind spot immediately. So think about the Sun and look at its pictures in this book, in other books, or on the World Wide Web, but don't try to look at it directly unless you know how to do so safely.

Sunglasses or other ordinary filters, including even dark filters for cameras, don't make it safe for your eyes to stare at the Sun. Only special Sun filters, which pass only about one part in a million of the incoming sunlight, are safe to look through. (We'll say more about this in Chapter 5.)

It is good to be excited about the Sun, but don't be so excited that you run out and hurt your eyes.



Sun Safety

Never stare at the everyday Sun. It is so bright that you could damage your eyes temporarily or even permanently.

The only time you can ever look at the Sun directly is during the total part of a total solar eclipse. But no total solar eclipse will be visible from the United States or Canada until the year 2017. So unless you travel to see an eclipse, the rule is: No staring at the Sun.

The Quiet Sun

The *quiet Sun* is the way the Sun looks on a steady basis, which is basically how the Sun shines on a daily basis. In the next chapter, we will talk about the active Sun, the way the Sun changes from day to day and in a cycle over the years.

Sun Words

The **quiet Sun** is the everyday, nearly unchanging background Sun.

We humans, and almost all living creatures on Earth, get our light and heat from the Sun. Without sunlight, the Earth would be a cold, dark ball. The amount of energy we get for a given area on Earth (square meter, square inch, whatever) is called the *solar constant*. Wouldn't you know it? Space research has shown in the last decade or so that the solar constant isn't constant after all, but it is steady enough for us to have a standard value that goes with the quiet Sun.

Sun Words

The **solar constant** is the amount of energy that reaches a square meter (or other defined unit of area) of the top of the Earth's atmosphere each second.

The Solar Scoop

Do you have solar panels on your roof? Black pipes to absorb sunlight? If you have solar heating, you depend on more than just the solar constant. Scientists measure the solar constant as the amount of energy coming from the Sun each second in a square meter at the top of the Earth's atmosphere. Before that energy reaches your roof, it can be hidden or diffused by dust, clouds, or other impediments.

The Sun's Lower Atmosphere

The sunlight that we get comes from the top layer of the ball of gas that we call the Sun. Since the Sun is a *sphere*, which means a round ball in the Greek language that gave so many words to English, and the Greek word for "light" is *phot*, the layer that gives us sunlight is called the *photosphere*. Thus, *photosphere* is just the sphere from which the light comes. Really, it is only a shell and not a whole sphere, since all the light comes from the top layer. That layer is only a few hundred miles (alternatively, a few hundred kilometers) thick, which makes it a very thin shell surrounding an object a million miles (1.4 million kilometers) across.

What is the photosphere? It is a layer of gas that is heated enough to shine. Like all the Sun, the gas is about 90 percent hydrogen, about 9 percent helium, and less than 1 percent a mixture of the rest of the chemical elements. Heat trillions of tons of this gas up to 10,000°F (5,500°C—see Appendix D for more on temperatures), and it shines brightly. The photosphere gives off most of its energy in the middle part of the spectrum that we can see with our eyes, but it also gives off a lesser amount of every other kind of energy.

Sun Words

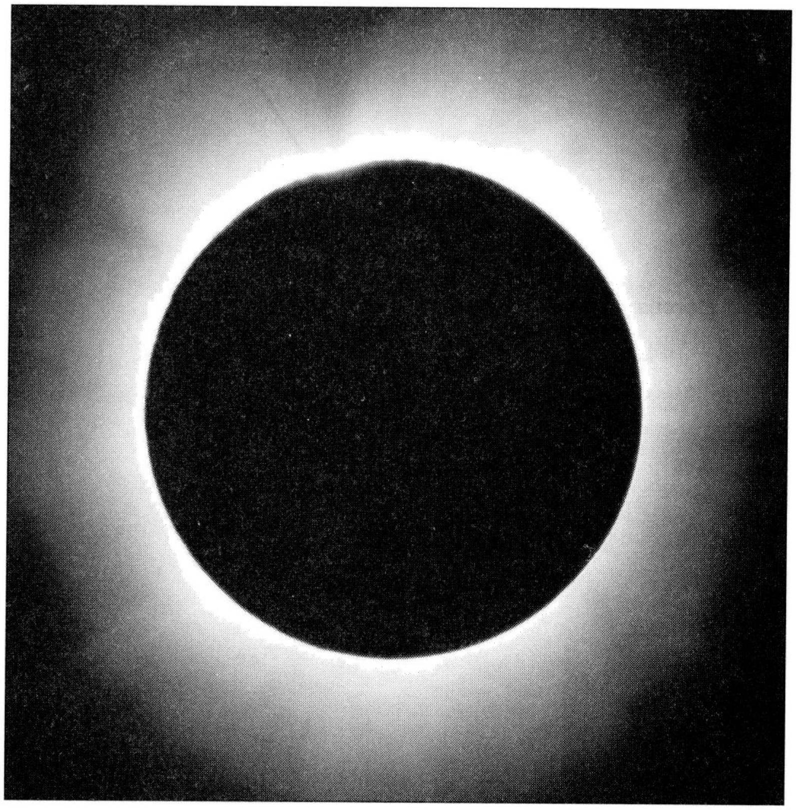
The **photosphere** is the surface that we see in visible light.

Eclipses and the Sun's Upper Atmosphere

Sometimes, about once every 18 months in a 100-mile-wide path across some parts of the Earth, the Moon hides the photosphere entirely. Only when this everyday surface is completely hidden do we have a *total eclipse* of the Sun. Total eclipses have long helped astronomers find out what the otherwise hidden parts of the Sun are like. The basic parts of the Sun were revealed and classified about 150 years ago, in the latter half of the nineteenth century.

Sun Words

A **total eclipse** occurs when the Moon entirely hides the Sun.



The white solar corona silhouetting the Moon, which appears dark, during the total solar eclipse of 2002.

(Jay M. Pasachoff and the Williams College Eclipse Expedition)

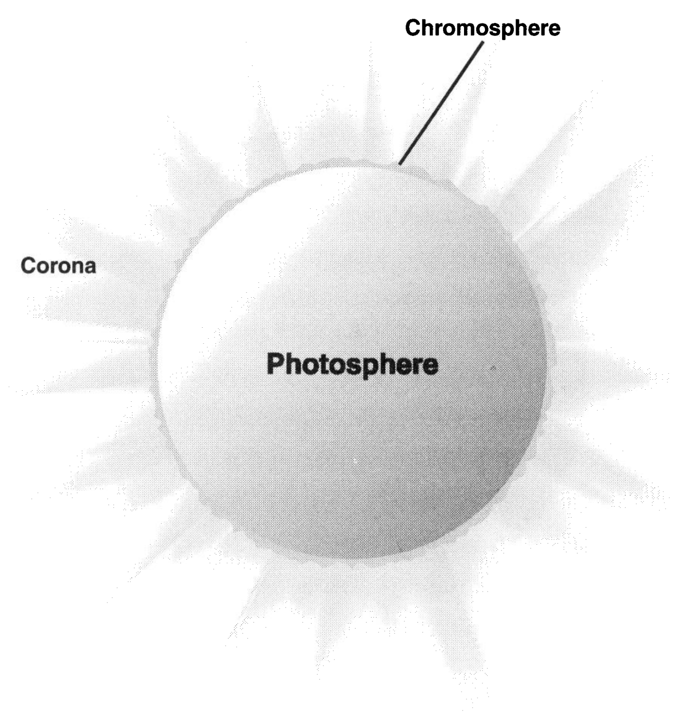
When the Sun's everyday surface is just barely covered in a total eclipse, a thin reddish band circles the Sun. Since the Greek word for color is *chroma*, and the reddish color seems to jump out at you after the whitish sunlight disappears, that part of the Sun is known as the *chromosphere*. It remains visible only for a few seconds at an eclipse, no matter how far you have traveled or how hard you try.

After a few seconds of a total eclipse, the chromosphere is covered up, and a halo of white light becomes visible around the Sun. It has really been there all along but has just been too faint to see. During a total eclipse, the sky becomes dark as night, or, at least, as dark as twilight. The darker sky allows the halo, known as the *corona* from the Latin word for *crown*, to be seen with the naked eye.

Sun Words

The **chromosphere** is the colorful shell around the Sun that pops into view at the beginning and the end of a total eclipse. The **corona** is the pearly white crown of light visible around the Sun at a total eclipse.

The parts of the solar atmosphere, the outer layers of the Sun.



Though the everyday surface of the Sun, the photosphere, is 5,800 kelvins (K), which may seem hot to you, the chromosphere can be twice as hot. And the corona can be 50 times hotter, millions of kelvins. A typical temperature for the corona is 2 million kelvins, which is about 4 million degrees Fahrenheit. One of the things that my team does at total solar eclipses is try to figure out why the temperature becomes so high in the corona.

Edmond Halley, for whom Halley's comet is named, described the corona as "pearly white"—that is, as milky white as a pearl of the quality used for jewelry. That description has stuck.

Above the Top

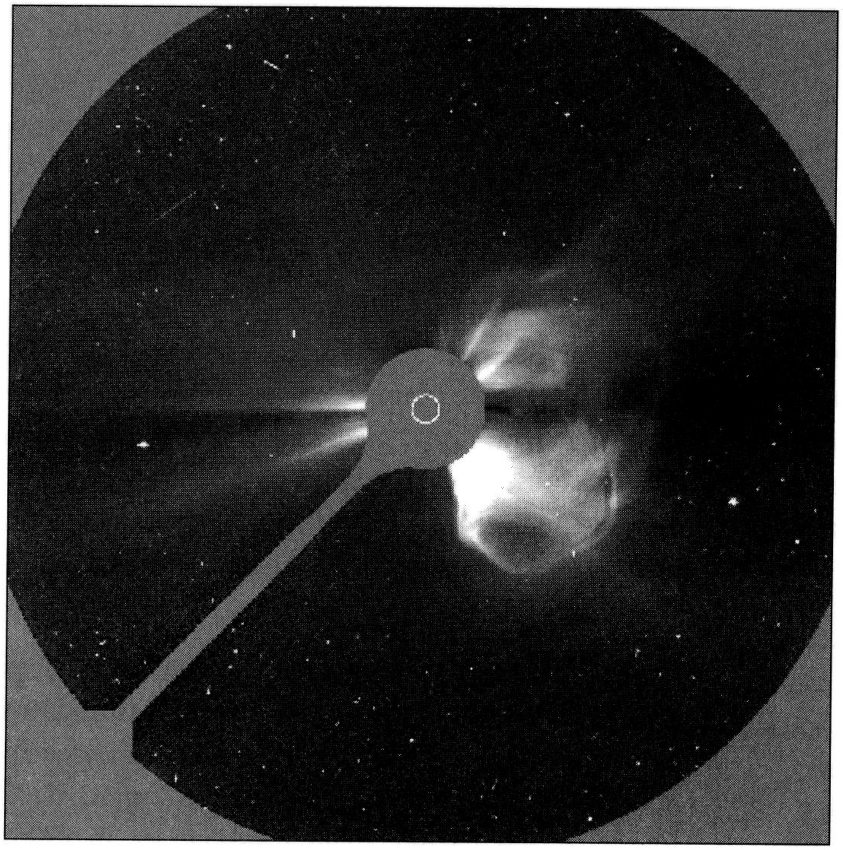
The solar corona that we see at eclipses extends a million miles or so into space, which is only about 1 percent of the distance between the Sun and the Earth. But a device is on board the Solar and Heliospheric Observatory (SOHO) spacecraft that makes an artificial eclipse of the Sun. Such a device is called a *coronagraph*. The coronagraphs working on SOHO

Sun Words

A **coronagraph** is a type of telescope that makes artificial eclipses.

are part of an experiment called the Large Angle Spectroscopic Coronagraph, or LASCO. They were built and are controlled by scientists at the U.S. Naval Research Laboratory in Washington, D.C.

Coronagraphs can't produce an image as good as those made at natural eclipses, but they can do some things that natural eclipses can't. In particular, the coronagraphs on SOHO have to hide the inner part of the solar corona, although they give hourly images of the corona outside that. The innermost coronagraph, so-called C1, no longer works. But C2 shows the Sun's corona from 1.5 to 6 solar radii, and C3 shows the Sun's corona from 3 solar radii to 32 solar radii. Thirty-two solar radii is 16 solar diameters, or about 16 million miles. So, using LASCO, we can see the corona as it extends about $^{16}/_{93}$ or $^{1}/_{6}$ of the way between the Sun and Earth.



The outer solar corona, imaged with the outermost of the three coronagraphs on SOHO. A disk blocks the center of the Sun and the inner corona; the size of the solar photosphere is outlined as a white circle.

(Naval Research Laboratory)

Still, the outer layer of the Sun, the corona, extends still farther. It is expanding, making what is called the *solar wind*, particles blowing outward from the Sun. We will say more about the solar wind when we discuss space weather. The solar wind was discovered by

Sun Words

The **solar wind** is the corona expanding into space.

analyzing the tails of comets and noticing that they moved about as though buffeted by a wind. Now we can study it directly, with spacecraft placed out in space to measure the solar particles as they go by.

A comet's tail is shaped by the solar wind. Here we see Comet Hale-Bopp, a comet that was bright to the naked eye in 1995. Comets this bright may appear only every decade or two.

(Jay M. Pasachoff)

The outer solar atmosphere goes even farther out. In fact, it goes past all the planets. Where it meets the magnetic field of planets, the planets are protected by a "bow shock" (pronounced to rhyme with "bow-wow," not "bow and arrow"), just as a boat moving through water has a shock wave in the water around its bow and trailing behind. But other than that, the Sun's influence extends billions of miles out into space. The region in which the Sun's influence dominates is called the *heliosphere.*

Sun Words

The **heliosphere** is the zone in which the Sun has more influence than interstellar space. The **heliopause** is the location where the interstellar space becomes more important than the solar influence; it marks the end of the heliosphere.

Two NASA *Voyager* spacecraft, which visited Jupiter, Saturn, Uranus, and Neptune, are still in touch with Earth, sending back messages about the conditions of the outer parts of the heliosphere. (Contact has been lost with two, earlier, *Pioneer* spacecraft, in 1995 and 2003, respectively.) They are beyond the orbits of Neptune and Pluto but haven't found the edge of the heliosphere yet. That edge, where the influence of interstellar space matches the influence of the Sun, is called the *heliopause.* Scientists expect that the spacecraft will pass entirely through the heliopause in the next few years. We have some indications that radio signals that we sent out have been bounced back by the heliopause.

The Earth is enveloped in a safety cocoon, in which our magnetic field interacts with the magnetic field of the heliosphere, protecting us on the Earth's surface from the solar particles.

The Solar Scoop

For a discussion of the *Pioneer* and *Voyager* missions through the outer solar system to the heliopause and beyond, see solarsystem.nasa.gov/missions/jup_missns/jup-p11.html and links from it.

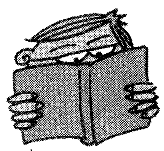
The Sun as a Star

The photosphere, chromosphere, and corona are the standard parts of the Sun. They are all we can see on a regular basis. In some sense, they are the basic Sun. We are particularly interested in studying them not only for themselves, but also because the Sun is a typical star in many ways. Billions of stars are hotter than the Sun, and billions of stars are cooler. Billions of stars are intrinsically brighter than the Sun, and billions are intrinsically fainter. And whatever we see on our Sun no doubt occurs on uncountable billions of other stars.

The Sun is a wonderful laboratory for scientists. It has nuclear fusion, but at a definitely safe distance of 93 million miles (150 million kilometers). It has layers, which are too narrow to be seen on distant stars but which must be on them as well. As we shall see, it even gives off particles that we detect on Earth. Similar particles must be hitting planets around other stars.

Our Sun is the dominant body in what we call our solar system. The solar system consists of nine or so major planets, tens of thousands of minor planets, and lots of smaller or less substantial bodies, such as meteorites and comets.

Perhaps the major discovery of the last decade is that our solar system is not the only system of planets around stars. More than 100 planets have been discovered orbiting other stars. We call them "extrasolar planets," or *exoplanets*, using the Latin sense of *extra-* as "outside" or "beyond." For most of these systems, which we can still call "solar systems," even though they are around other suns than our own, we know of only one giant planet, often much more massive than our own solar system's Jupiter. Our discoveries continue, now finding less massive planets,



Sun Words

Exoplanets are planets found around stars other than our Sun.

although they are still approximately the mass of Jupiter or Saturn. It may be a decade or two before our methods are sensitive enough to detect planets as puny as Earth, but we are sure they are there.

Anyway, because we have discovered planets and, in a few cases already, systems of several planets around other stars, we see that here, too, our Sun is typical. Our discoveries about the Sun must be multiplied by billions to show how much we are learning about all the stars in our universe.

The Least You Need to Know

- Never stare at the Sun, except during the total phase of a total solar eclipse.
- When we look at or image the Sun normally, we see its photosphere.
- The Sun's upper atmosphere includes the chromosphere and the corona.
- The corona expands into space as the solar wind, filling the heliosphere.
- More than 100 planets have been found orbiting other stars.