The Sun

How We Observe the Sun

We do not look at the Sun directly, because it is too bright and may damage our eyes. What we do instead is to have cameras look at the Sun for us. If the Sun is too bright for the camera, too, then we can do two things: put filters in front of the camera that allow only a little bit of light to pass through them, similar to welders' glasses, or collect light for the picture for a shorter amount of time.

In a photo camera, most of the time no light can reach the film in the back of the camera. When you press the button, a shutter opens and allows light to reach the film or detector so that an image is recorded. After some amount of time, called the exposure time, the shutter closes again, so that no more light can reach the film or detector. If you use an exposure time that is too short, then not enough light has been collected and the picture will be too dark. If your exposure time is too long, then too much light is collected and the picture will be overexposed and look white and washed out. If your exposure time is OK for the film but is still pretty long, then whatever you are taking a picture of may have moved or changed in the meantime and then the picture will be blurry.

With cheap photo cameras you cannot change the exposure time. It is fixed, usually at around 1/100 second. Such cameras are fine for taking pictures outside in sunlight, but not for inside where there is less light, or for taking astronomical pictures at night. More expensive photo cameras allow you to set the exposure time as short as 1/1000 second or as long as you want. You can use those cameras at night, but then you need long exposure times (a few seconds or even minutes) so you have to worry about things moving while you take the picture.

For looking at the Sun we nowadays use CCD cameras that allow us to see the pictures on our computers right away. Such cameras have a shutter and changeable exposure times, too. If the Sun is too bright, then we can make the exposure time shorter.

Most of the time we do not look at all colors of sunlight, but only at very particular colors (called spectral lines) that tell us about things (such as the pressure or speed or magnetic field strength on the Sun) that ordinary colors cannot tell us anything about. Only one color is much less light than all colors, and if you could look at just that one color of the Sun with your eyes then the Sun would appear to be very dim. So, most of the time we use exposure times around 1/10 second in our cameras - which is pretty long. If you took a picture of your friends with that exposure time then you could tell if they were waving their arms or moving around. You'd have to tell them not to move. In the same way, we have to worry about things moving in the images of the Sun.

[LS 7 December 1997]

How do we find out about the inside of the Sun?

Our knowledge of the inside of the Sun comes from models that solar physicists have constructed for the inside of the Sun, just like all other knowledge that we have of things we cannot actually see comes from models of those things. This knowledge is therefore only as good as the models themselves are.

In the case of the inside of the Sun, the model includes:

1. what materials we think are in the Sun and in what proportions at any given place in the Sun

2. the properties of that material, such as its temperature, density and pressure at every place
3. how easily radiation of various kinds is scattered (bounced around) by the material in the Sun at the temperatures and pressures that occur there
4. how easily radiation of various kinds is absorbed or emitted by the material
5. the laws of nature that combine these things, such as a so-called equation of state that tells which combinations of pressure, density, and temperature can occur under the conditions that prevail in every part of the Sun, and the equation of hydrostatic equilibrium which links gravity, density, and pressure.

We use the best numbers and relations we have for these things and then see what values the unknown things (such as the temperature in the center of the Sun) must have so that the model predictions for the things we can see on the outside of the Sun (such as the outside temperature, brightness, and size of the Sun) fit the best. The estimate for how long it takes energy to get from the center of the Sun to the surface (see above) follows from such models of the Sun.

During the last 25 years or so the number of measurements that we can use to fix the model and in that way probe the inside of the Sun has increased a lot. It turns out that the surface of the Sun vibrates all the time, sort of like the Earth vibrates after an earthquake, and like a bell rings when someone hits it. By studying the frequencies of these oscillations of the Sun we can learn something about the inside of the Sun, just like you can tell something about a material by listening to the sounds that it makes when something hits it.

There are millions of different vibrations going on inside and at the surface of the Sun all the time, and each of them depends differently on the temperature and pressure and so on inside the Sun, so they give us millions of numbers to compare with our models which means that we can get much more information about the parts we cannot see. At the moment the model predictions of these frequencies differ from the measurements by only about one part in a thousand or less, so we are confident that our models are pretty good. The branch of solar physics that studies these oscillations is called helioseismology.

Since the 1970s a new type of measurement has become possible that presumably comes directly from the center of the Sun, rather than from the surface to which all previous measurements were confined. This new measurement is that of neutrinos, which are particles that are generated alongside the X-rays in the center of the Sun. Neutrinos are extremely difficult to measure, so it has only recently become possible for us to do so. It is estimated that many billions of neutrinos coming from the Sun pass through your body every second, usually without even noticing it. The measured neutrino flux from the Sun is equivalent to one atom per 1000 years per kilogram (or per 2.2 lb) of the detector material being changed by the neutrinos! Out detectors currently have to be very big.

The number of neutrinos that we measure depends on the temperature in the center of the Sun, on how the rate of generation of neutrinos depends on the temperature, on how easily the neutrinos are absorbed or changed before they get to our detectors, on how efficient our detectors are at measuring them, and on how many detector signals may be due to earth-bound sources rather than to energy production in the Sun. When people combined the best known numbers for these things, they found that the measured number of neutrinos was only about a quarter of what was expected, so our model fails somewhere. It is not clear at the moment which of our assumptions is incorrect, so the measured neutrino flux is currently not able to give a more precise estimate for the conditions in the very center of the Sun than the existing models which are all fitted from surface measurements. Still, if we finally solve this neutrino problem then we'll have a great new way of understanding the inside of the Sun.

[LS 11 May 1997]

The temperature of the Sun

The Sun has different temperatures in different places. At the visible surface (the photosphere), the temperature is around 5700 K (9800 degrees F, 5400 degrees C) in most places, though in the center of big sunspots the temperature can be as low as 4300 K (7300 degrees F, 4000 degrees C). If you go into the Sun then the temperature increases to about 15.5 million K (28 million degrees F, 15.5 million degrees C). If you go away from the Sun, then the temperature first decreases a little but then it starts to rise until it gets to

millions of degrees there, too. Of course, there is not much material above the visible surface, so even though the temperature is very high the total amount of heat is very small.
For more information about temperatures and how we measure them in stars, see the Temperature Page.

The size of the Sun

The Sun has a diameter of 864,938 miles or 1,391,980 km. This is 109 times greater than the diameter of the Earth: 109 Earths one after the other would span from one side of the Sun to the other. The volume of the Sun is 1,299,400 times greater than the volume of the Earth: almost 1,300,000 Earths would fit inside the Sun (you'd have to squash the Earths so as not to leave any room between them). The mass of the Sun is 332,946 times greater than that of the Earth. About 99 percent of the mass in the Solar System is in the Sun. All the planets and comets and other stuff are much smaller and lighter than the Sun is. [LS 30 April 1997]

Where is the Sun?

To calculate the position of the Sun in the sky you can use the approximate formulas on Explanation Page 5. Two books which I have used a lot that contain formulas for calculating astronomical phenomena are the following:

- "Astronomical Formulae for Calculators" by Jean Meeus, published by Willmann-Bell, Inc. List price: about $15 US.
- "Astronomical Algorithms" by Jean Meeus, published by Willmann-Bell, Inc. List price: about $25 US.

The second book is an expanded version of the first. They both contain formulas for calculating the positions of all planets, the Sun, and the Moon, and many other formulas as well. If you buy the second book then you can also buy a floppy disk that contains programs based on the formulas in the book for calculating celestial phenomena.

The Sun is a Star

The Sun is a star. The Sun looks much bigger and brighter than the stars you see at night because the Sun is so much closer to us than the other stars are. The nearest star beyond the Sun is about a million times further away than the Sun is. If the Sun were that far away then it would appear as faint and as small as the other stars.

Not all stars are exactly the same. If you took all stars and put them in a circle around you so you could see them all at the same distance, then you'd notice that there are many differences between the stars. Some stars are much bigger and brighter than the Sun, such as Betelgeuse in the constellation of Orion. That star is about 700 times bigger than the Sun is and about 14,000 times as bright. It has a reddish color because it is cooler than the Sun.

Other stars are about as big and bright as the Sun, such as alpha Centauri in the constellation of the Centaur (Centaurus). That star is one and a half times as bright as the Sun and one and one fifth times as big.

And there are also stars that are smaller and fainter than the Sun, such as sigma Draco in the constellation of the Dragon, which is about one third as bright as the Sun and about half as big.

There are many more faint and small stars than big and bright stars, but because you can see bright stars from much further away than faint stars (just like you can see car headlights from much further away than you can see a candle) most of the stars you see at night are bigger and brighter than the Sun is.

The Sun is a very special star because it is so close to us. That means it can give us lots of light and warmth, and that we can study it in great detail to see how such a star works. That helps us to understand all the other stars, too.

[LS 7 April 1997]

Solar Energy

The energy density (per unit area) of sunlight decreases inversely proportional to the square of the distance to the Sun. The energy density at the distance of the Earth (1 AU) is equal to about 1370 W/m^2 - with slight variations with time.

The amount of energy that is somehow affected by a planet is equal to the energy density times the apparent surface area of the planet's disk. Some of the energy is reflected back into space without being absorbed by the planet. The fraction that is reflected is called the albedo. The following table lists the planets, their distance to the Sun in AU, their equatorial radius in miles, the energy density of sunlight at the planet (relative to the Earth = 1370 W/m^2), the energy density absorbed by the planet (relative to the Earth = 877 W/m^2), the total amount affected by the planet (disregarding albedo, and relative to the Earth = 5.6E16 W), and the total amount absorbed by the planet (including albedo, relative to the Earth = 3.6E16 W). For Pluto I've assumed it is about as close to the Sun as Neptune (which it is right now). For the other planets I've assumed they are at their average distance to the Sun.

For instance, Mars is on average 1.524 times as far from the Sun as the Earth, reflects 0.16 of the incident radiation, receives 0.431 times as much sunlight per unit area as the Earth, absorbs 0.565 times as much sunlight per unit area as the Earth, receives 0.122 times as much sunlight in total as the Earth, and absorbs 0.160 times as much sunlight in total as the Earth. "A" stands for the albedo.

Solar Energy

Planet	**dist**	**radius**	**A**	**E1**	**E2**	**L1**	**L2**
	AU	**mi**		**per unit area**			
Mercury	0.387	1516	0.06	6.67	9.80	0.976	1.43
Venus	0.723	3761	0.76	1.91	0.717	1.720	0.645
Earth	1.000	3963	0.36	1.00	1.000	1.000	1.000
Mars	1.524	2111	0.16	0.431	0.565	0.122	0.160
Jupiter	5.203	44423	0.43	0.0369	0.0329	4.34	3.87
Saturn	9.539	37449	0.61	0.0110	0.00667	0.882	0.538
Uranus	19.181	15882	0.35	0.00272	0.00276	0.0425	0.0433
Neptune	30.058	15388	0.35	0.00110	0.00112	0.0163	0.0166
Pluto	30	727	?	0.00111	?	0.0000374	?

From the amounts of energy per unit area we can estimate the surface temperature of each planet. This is described in the Temperature Page. [LS 20 April 1997]

Inclination of the Sun

The Sun rotates around its rotation axis, just like the Earth rotates about hers. The rotation axis of the Sun is tilted by 7.25 degrees relative to the perpendicular to the plane of the orbit of the Earth. That angle is the inclination of the Sun's rotation axis. Because this inclination is not zero, sometimes the Sun appears tilted a bit toward us, and sometimes it appears tilted away from us. The amount of tilt is at most equal to the inclination.

The rotation axis of the Earth is inclined over 23.5 degrees. This tilt causes the seasons on Earth.

[LS 1 April 1997]

Solar Wind

A steady stream of particles leaves the Sun all the time. This is called the Solar Wind. The solar wind blows throughout the solar system, and also past the Earth, where it has a speed of about 450 km/s or 1.6 million km/h or 1.0 million mph. It takes solar wind on average about 4-6 days to travel from the Sun out to the distance of the Earth. Solar wind consists mainly of the same ingredients as the Sun: nuclei of hydrogen (or protons) and helium (or alpha particles), and also electrons (or beta particles).

If the solar wind blows away from the Sun equally in all directions, then we can estimate the amount of material that leaves the Sun every second in the solar wind as about 1 thousand million kilograms, or about 2 thousand million pounds. The amount of mass that the Sun loses through the solar wind in a year is about 14 orders of magnitude smaller than the total mass of the Sun, so it is totally negligible compared to the total mass of the Sun.

The solar wind only flows away from the Sun, not towards it. There are two reasons for this: one is that the pressure of the Sun's radiation pushes the wind away from the Sun. Another reason is that the density of the solar wind decreases with increasing distance to the Sun. This is mostly a geometrical effect, because the material gets spread out over an ever increasing volume, and results in a pressure gradient: the gas pressure in the solar wind decreases with distance to the Sun, and that also generates a pressure force away from the Sun.

The Brightness of the Sun

The Sun emits about 4e26 watt of energy, enough to boil all the water in the Earth's oceans in about 6 seconds. Of that vast amount of energy, only about one part in 2 thousand million reaches the Earth, because the Earth is a very small target as seen from the Sun. The amount of energy from the Sun that reaches the Earth's surface every second is equivalent to an amount of gasoline enough to fill the tanks of about 90 million cars.

The energy output of the Sun is variable, but only to a very small degree. It is very rare for the Sun's luminosity to differ by more than 1.5 parts in a thousand from the average value. The solar cycle seems to be a main component in the brightness variations of the Sun. Perhaps the so-called Little Ice Age, between about 1640 and 1720, was a period when the Sun was a little bit less bright than it is now.

[LS 9-28 January 1997]

The Name of the Sun

Scientists use the name of the Sun in whatever language they happen to be talking or writing. So, the Sun is called "Sun" in English speech or writing, "Sonne" in German, "Soleil" in French, "Zon" in Dutch, "Helios" in Greek, "Sol" in Latin, Spanish, and Swedish, "Grian" in Irish, and "Haul" or "Huan" in Welsh. This large

number of different names for the Sun is only really a problem for someone who does not have a name for the Sun in his or her own language (for instance aliens from outer space in science-fiction books), or for someone who wants to make a star map that can be used with any language. In those cases the Latin name for the Sun ("Sol") is mostly used, because hundreds of years ago Latin was the language of science and scientists of those days always wrote about "Sol". (Incidentally, this "sol" appears in our words "solar" and "parasol".) So I guess you could say that Sol is the official name for the Sun, though most people (including the scientists) just use whatever the name of the Sun is in their own language.
Dr Aksnes, chairman of the Working Group for Planetary System Nomenclature of the International Astronomical Union (which decides on names for things in the Solar System, such as asteroids and craters on other planets and moons) responded to a question by Mr Sunspot, and it appears that the IAU has not decided on a single name for the Sun or Moon, but supports the common practice of using the name of the Sun or Moon in the language in which you write or talk about it. [LS 12-22 April 1996]

The Distance of the Sun

On average, the Sun is 93.0 million miles (149.6 million km) away from the Earth: That's about 400 times further away than the Moon is. Because the Earth follows an orbit around the Sun that has the shape of an ellipse (a slightly squashed circle), the distance of the Earth from the Sun changes a bit throughout the year. Around 2 January of each year the Sun is closest to the Earth, at 91.4 million miles (147.1 million km), and around 2 July of each year the Sun is furthest away from the Earth, at 94.5 million miles (152.1 million km). The point in the Earth's orbit that is closest to the Sun is called the perihelion of the Earth's orbit, and the point that is furthest away is called the aphelion.
Because a mile or kilometer is a very small distance when compared with distances in the Solar System, astronomers call the average distance between the Earth and the Sun an Astronomical Unit or AU, and express distances between the planets and the Sun in AU. For example, Jupiter is on average about 5 AU from the Sun, and Pluto about 39 AU. If the Earth were much closer to the Sun, then it would be too hot for us, and if the Earth were much further away from the Sun, then it would be too cold for us. We're at just the right distance. [LS 10 April 1996]

Why Study the Sun?

I can think of three reasons why astronomers study the Sun:

1. Because the Sun is so important to life on Earth. Almost all life on Earth depends in some way on sunlight and would be in big trouble if the Sun were to change a lot. It seems wise to study our main source of energy to see what we can expect from it in the future.
2. Because some events on the Sun (for instance solar flares) result in geomagnetic storms and interference with some electrical systems on Earth. See the Polarity Page and Mr Sunspot's Solar Cycle Page for more information about this.
3. Because we're just plain curious about what happens on and inside the Sun.

You may think that the Sun does not change a lot and so we don't have to worry about it. Are you sure? Volcanos sometimes erupt suddenly when people don't expect it. Can't the Sun do something similar? Only because astronomers have studied the Sun for many years and understand it reasonably well do we know that the Sun is most likely not going to change dramatically over the next few thousand million years, though there may be small or slow changes. Because the Sun is so important to life on Earth, small or slow changes might have large consequences. It seems wise to continue to study it.

This information was obtained from: http://www.nso.edu/sunspot/pr/mr_sunspot.html

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