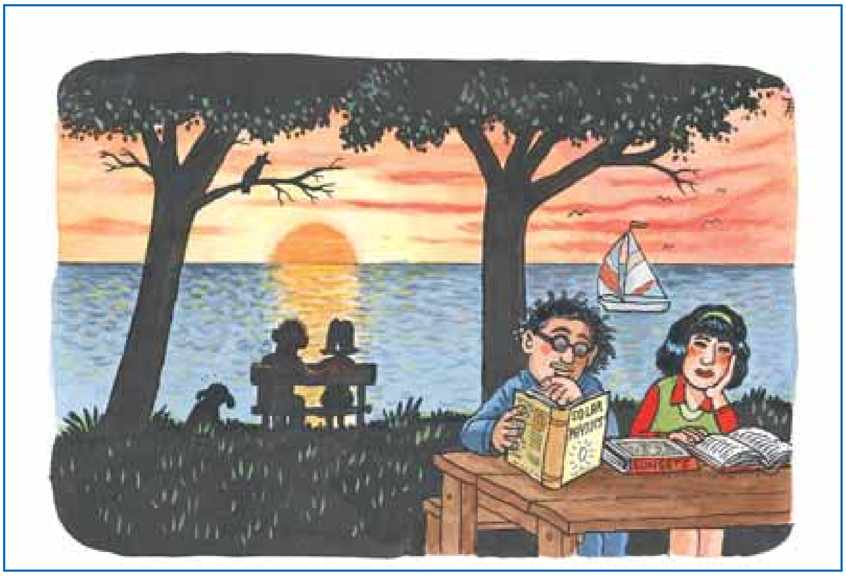
Activity 5 The Sun and Its Effects on Your Community



Goals

In this activity you will:

- Explore the structure of the Sun and describe the flow of solar energy in terms of reflection, absorption, and scattering.
- Understand that the Sun emits charged particles called the solar wind, and how this wind affects "space weather."
- Explain the effect of solar wind on people and communities.
- Understand sunspots, solar flares, and other kinds of solar activities and their effects on Earth.
- Learn to estimate the chances for solar activity to affect your community.

Think about It

Every day of your life you are subjected to radiation from the Sun. Fortunately, the Earth's atmosphere and magnetic field provides protection against many of the Sun's strong outbursts.

- **In what ways does solar radiation benefit you?**
- **In what ways can solar radiation be harmful or disruptive?**

What do you think? Record your ideas about these questions in your *EarthComm* notebook. Be prepared to discuss your response with your small group and the class.

Investigate

1. Use the data in *Table 1* to construct a graph of sunspot activity by year.

   a) Plot time on the horizontal axis and number of sunspots on the vertical axis.

   b) Connect the points you have plotted.

   c) Look at your graph. Describe any pattern you find in the sunspot activity.

Table 1 Sunspot Activity 1899 to 1998

Year	Number of Sunspots	Year	Number of Sunspots	Year	Number of Sunspots	Year	Number of Sunspots
1899	12.1	1924	16.7	1949	134.7	1974	34.5
1900	9.5	1925	44.3	1950	83.9	1975	15.5
1901	2.7	1926	63.9	1951	69.4	1976	12.6
1902	5.0	1927	69.0	1952	31.5	1977	27.5
1903	24.4	1928	77.8	1953	13.9	1978	92.5
1904	42.0	1929	64.9	1954	4.4	1979	155.4
1905	63.5	1930	35.7	1955	38.0	1980	154.6
1906	53.8	1931	21.2	1956	141.7	1981	140.4
1907	62.0	1932	11.1	1957	190.2	1982	115.9
1908	48.5	1933	5.7	1958	184.8	1983	66.6
1909	43.9	1934	8.7	1959	159.0	1984	45.9
1910	18.6	1935	36.1	1960	112.3	1985	17.9
1911	5.7	1936	79.7	1961	53.9	1986	13.4
1912	3.6	1937	114.4	1962	37.6	1987	29.4
1913	1.4	1938	109.6	1963	27.9	1988	100.2
1914	9.6	1939	88.8	1964	10.2	1989	157.6
1915	47.4	1940	67.8	1965	15.1	1990	142.6
1916	57.1	1941	47.5	1966	47.0	1991	145.7
1917	103.9	1942	30.6	1967	93.8	1992	94.3
1918	80.6	1943	16.3	1968	105.9	1993	54.6
1919	63.6	1944	9.6	1969	105.5	1994	29.9
1920	37.6	1945	33.2	1970	104.5	1995	17.5
1921	26.1	1946	92.6	1971	66.6	1996	8.6
1922	14.2	1947	151.6	1972	68.9	1997	21.5
1923	5.8	1948	136.3	1973	38.0	1998	64.3

The number of sunspots on the visible solar surface is counted by many solar observatories and is averaged into a single standardized quantity called the sunspot number. This explains the fractional values in the table.

2. *Table 2* contains a list of solar flares that were strong enough to disrupt terrestrial communications and power systems.
   a) Plot the data from *Table 2* onto a histogram.
   b) What pattern do you see in the activity of solar flares?

3. Compare the two graphs you have produced.
   a) What pattern do you see that connects the two?
   b) How would you explain the pattern?

Table 2 Strongest Solar Flare Events 1978–2001

Date of Activity Onset	Strength	Date of Activity Onset	Strength
August 16, 1989	X20.0	December 17, 1982	X10.1
March 06, 1989	X15.0	May 20, 1984	X10.1
July 07, 1978	X15.0	January 25, 1991	X10.0
April 24, 1984	X13.0	June 09, 1991	X10.0
October 19, 1989	X13.0	July 09, 1982	X 9.8
December 12, 1982	X12.9	September 29, 1989	X9.8
June 06, 1982	X12.0	March 22, 1991	X9.4
June 01, 1991	X12.0	November 6, 1997	X9.4
June 04, 1991	X12.0	May 24, 1990	X9.3
June 06, 1991	X12.0	November 6, 1980	X9.0
June 11, 1991	X12.0	November 2, 1992	X9.0
June 15, 1991	X12.0		

The X before the number is a designation of the strongest flares.
Source: IPS Solar Flares & Space Service in Australia.

Reflecting on the Activity and the Challenge

In this activity you used data tables to plot the number of sunspots in a given year and to correlate strong solar-flare activity with larger numbers of sunspots. You found out that the number of sunspots varies from year to year in a regular cycle and that strong solar flares occur in greater numbers during high-sunspot years. In your **Chapter Challenge**, you will need to explain sunspots and solar flares, their cycles, and the effects of these cycles on your community.

Geo Words

photosphere: the visible surface of the Sun, lying just above the uppermost layer of the Sun's interior, and just below the chromosphere.

chromosphere: a layer in the Sun's atmosphere, the transition between the outermost layer of the Sun's atmosphere, or corona.

corona: the outermost atmosphere of a star (including the Sun), millions of kilometers in extent, and consisting of highly rarefied gas heated to temperatures of millions of degrees.

Digging Deeper

THE SUN AND ITS EFFECTS

Structure of the Sun

From the Earth's surface the Sun appears as a white, glowing ball of light. Like the Earth, the Sun has a layered structure, as shown in *Figure 1*. Its central region (the core) is where nuclear fusion occurs. The core is the source of all the energy the Sun emits. That energy travels out from the core, through a radiative layer and a convection zone above that. Finally, it reaches the outer layers: the **photosphere**, which is the Sun's visible surface, the **chromosphere**, which produces much of the Sun's ultraviolet radiation, and the superheated uppermost layer of the Sun's atmosphere, called the **corona**.

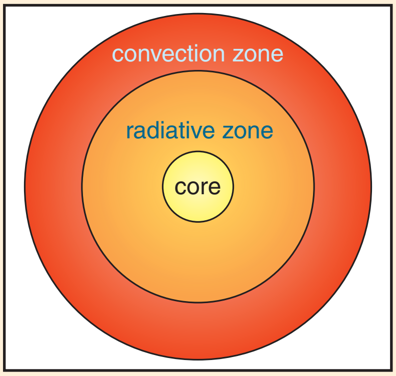


Figure 1 The layered structure of the Sun.

The Sun is the Earth's main external energy source. Of all the incoming energy from the Sun, about half is absorbed by the Earth's surface (see *Figure 2*). The rest is either:

- absorbed by the atmosphere, or
- reflected or scattered back into space by the Earth or clouds.

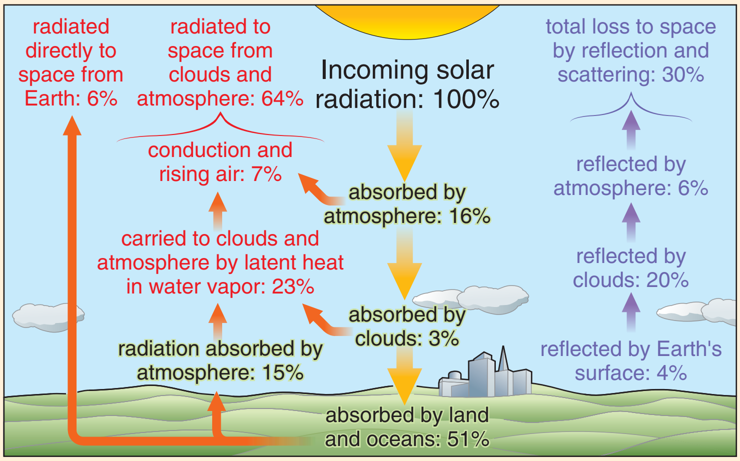


Figure 2 Schematic of Earth's solar energy budget.

Molecules of dust and gas in the atmosphere interfere with some of the incoming solar radiation by changing its direction. This is called scattering, and it explains the blue color of the sky. The atmosphere scatters shorter visible wavelengths of visible light, in the blue range, more strongly than longer visible wavelengths, in the red and orange range. The blue sky you see on a clear day is the blue light that has been scattered from atmospheric particles that are located away from the line of sight to the Sun. When the Sun is low on the horizon, its light has to travel through a much greater thickness of atmosphere, and even more of the blue part of the spectrum of sunlight is scattered out of your line of sight. The red and orange part of the spectrum remains, so the light you see coming directly from the Sun is of that color. The effect is greatest when there is dust and smoke in the atmosphere, because that increases the scattering. The scattered light that makes the sky appear blue is what makes it possible for you to see in a shaded area.

Figure 3 Dust and smoke in the atmosphere enhance the beauty of sunsets.

Most of the sunlight that passes through the atmosphere reaches the Earth's surface without being absorbed. The Sun heats the atmosphere not directly, but rather by warming the Earth's surface. The Earth's surface in turn warms the air near the ground. As the Earth's surface absorbs solar radiation, it re-radiates the heat energy back out to space as infrared radiation. The wavelength of this infrared radiation is much longer than that of visible light, so you can't see the energy that's re-radiated. You can feel it, however, by standing next to a rock surface or the wall of a building that has been heated by the Sun.

Geo Words

albedo: the reflective property of a non-luminous object. A perfect mirror would have an albedo of 100% while a black hole would have an albedo of 0%.

The reflectivity of a surface is referred to as its **albedo**. Albedo is expressed as a percentage of radiation that is reflected. The average albedo of the Earth, including its atmosphere, as would be seen from space, is about 0.3. That means that 30% of the light is reflected. Most of this 30% is due to the high reflectivity of clouds, although the air itself scatters about 6% and the Earth's surface (mainly deserts and oceans) reflects another 4%. (See *Figure 2* in the **Digging Deeper** section.) The albedo of particular surfaces on Earth varies. Thick clouds have albedo of about 0.8, and freshly fallen snow has an even higher albedo. The albedo of a dark soil, on the other hand, is as low as 0.1, meaning that only 10% of the light is reflected. You know from your own experience that light-colored clothing stays much cooler in the Sun than dark-colored clothing. You can think of your clothing as having an albedo, too!

The Earth's Energy Budget

The amount of energy received by the Earth and delivered back into space is the Earth's energy budget. Like a monetary budget, the energy resides in various kinds of places, and moves from place to place in various ways and by various amounts. The energy budget for a given location changes from day to day and from season to season. It can even change on geologic time scales. Daily changes in solar energy are the most familiar. It is usually cooler in the morning, warmer at midday, and cooler again at night. Visible light follows the same cycle, as day moves from dawn to dusk and back to dawn again. But overall, the system is in balance. The Earth gains energy from the Sun and loses energy to space, but the amount of energy entering the Earth system is equal to the amount of energy flowing out, on a long-term average. This flow of energy is the source of energy for almost all forms of life on Earth. Plants capture solar energy by photosynthesis, to build plant tissue. Animals feed on the plants (or on one another). Solar energy creates the weather, drives the movement of the oceans, and powers the water cycle. All of Earth's systems depend on the input of energy from the Sun. The Sun also supplies most of the energy for human civilization, either directly, as with solar power and wind power, or indirectly, in the form of fossil fuels.

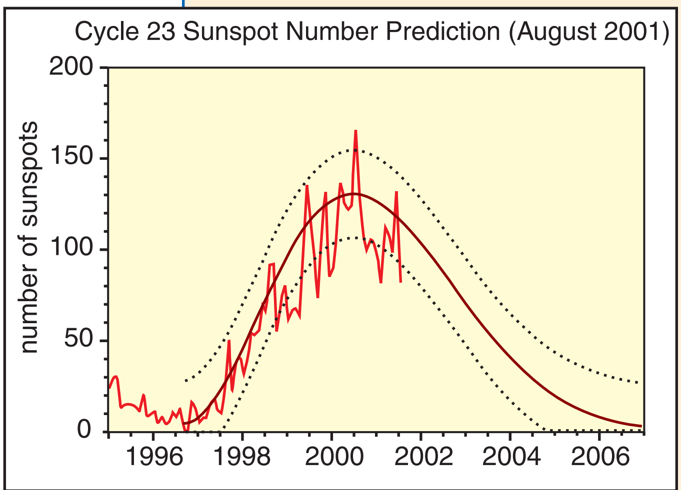


Figure 4 The jagged line represents the actual number of sunspots; the smooth dark line is the predicted number of sunspots.

Harmful Solar Radiation

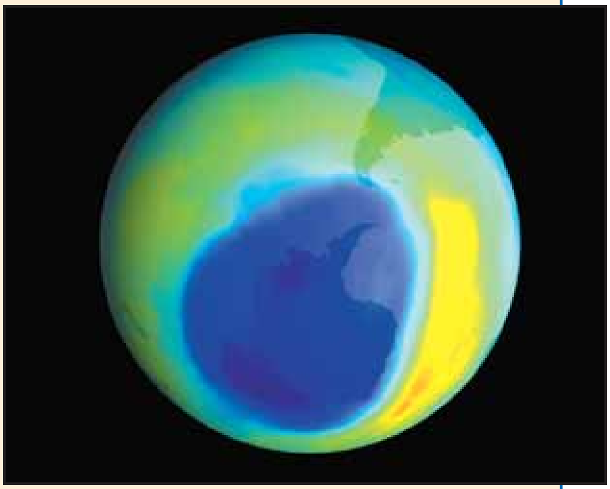


Figure 5 Depletion in the ozone layer over Antarctica. Rather than actually being a hole, the ozone hole is a large area of the stratosphere with extremely low concentrations of ozone.

Just as there are benefits to receiving energy from the Sun, there are dangers. The ill effects of sunlight are caused by ultraviolet (UV) radiation, which causes skin damage. The gas called ozone (a molecule made up of three oxygen atoms) found in the upper atmosphere shields the Earth from much of the Sun's harmful UV rays. The source of the ozone in the upper atmosphere is different from the ozone that is produced (often by cars) in polluted cities. The latter is a health hazard and in no way protects you. Scientists have recently noted decreasing levels of ozone in the upper atmosphere. Less ozone means that more UV radiation reaches Earth, increasing the danger of Sun damage. There is general agreement about the cause of the ozone depletion. Scientists agree that future levels of ozone will depend upon a combination of natural and man-made factors, including the phase-out, now under way, of chlorofluorocarbons and other ozone-depleting chemicals.

Sunspots and Solar Flares

Sunspots are small dark areas on the Sun's visible surface. They can be as small as the Earth or as large as Uranus or Neptune. They are formed when magnetic field lines just below the Sun's surface are twisted and poke through the solar photosphere. They look dark because they are about 1500 K cooler than the surrounding surface of the Sun. Sunspots are highly magnetic. This magnetism may cause the cooler temperatures by suppressing the circulation of heat in the region of the sunspot.

Sunspots last for a few hours to a few months. They appear to move across the surface of the Sun over a period of days. Actually, the sunspots move because the Sun is rotating. The number of sunspots varies from year to year and tends to peak in 11-year cycles along with the number of dangerously strong solar flares. Both can affect systems here on Earth. During a solar

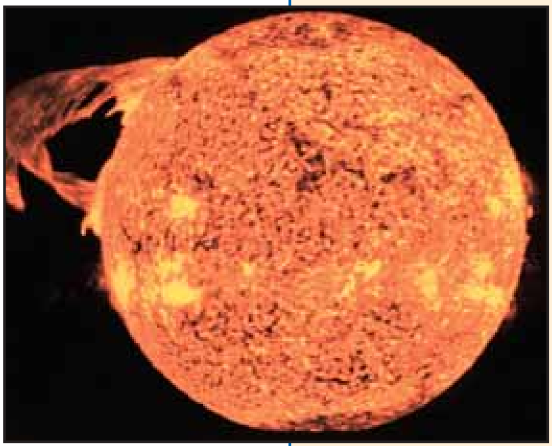


Figure 6 A solar flare.

flare like the one shown in *Figure 6*, enormous quantities of ultraviolet, x-ray, and radio waves blast out from the Sun. In addition, protons and electrons stream from flares at 800 km/hr. These high-radiation events can be devastating to Earth-orbiting satellites and astronauts, as well as systems on the ground. In 1989 a major solar flare created electric currents that caused a surge of power that knocked out a power grid in Canada, leaving hundreds of thousands of people without power. More recently, in 1997, radiation from a flare affected an Earth-orbiting satellite that carried telecommunications traffic. For at least a day people whose beeper messages went through that satellite had no service.

The flow of charged particles (also called a **plasma**) from the Sun is called the solar wind. It flows out from the solar corona in all directions and is responsible for "space weather"—the environment outside our planet. Like severe storms in our atmosphere, space weather can cause problems for Earth systems. Strong outbursts in this ongoing stream of charged particles can disrupt radio signals by disturbing the upper layers of the atmosphere. The sounds of your favorite short-wave radio station or the signals sent by a ham radio operator travel as radio waves (a form of electromagnetic radiation). These signals travel around the Earth by bouncing off the **ionosphere**, a layer of the atmosphere 80 to 400 km above the Earth's surface. The ionosphere forms when incoming solar radiation blasts electrons out of the upper-atmosphere gases, leaving a layer of electrons and of charged atoms, called **ions**. The ionosphere acts like a mirror, reflecting a part of the radio waves (AM radio waves in the 1000 kHz range) back to Earth.

Geo Words

plasma: a state of matter wherein all atoms are ionized; a mixture of free electrons and free atomic nuclei.

ionosphere: the part of the Earth's atmosphere above about 50 km where the atoms are significantly ionized and affect the propagation of radio waves.

ion: an atom with one or more electrons removed (or added), giving it a positive (or negative) charge.

Solar flares intensify the solar wind, which makes the ionosphere thicken and strengthen. When this happens, radio signals from Earth are trapped inside the ionosphere. This causes a lot of interference. As discussed above, solar activity can also be a problem for satellite operations. Astronauts orbiting the Earth and people aboard high-flying aircraft—particularly those who fly polar routes, where exposure to radiation may be greatest—also have cause to worry about space weather. To provide up-to-date information about current solar activity, the United States government operates a Space Environment Center Web site called "Space Weather Now."

At least one effect of space weather is quite wonderful. When the solar wind encounters the Earth's magnetic field, it excites gases in the Earth's atmosphere, causing them to glow. The charged particles from the solar wind end up in an oval-shaped area around the Earth's magnetic poles. The result is a beautiful display called an **aurora**, seen in *Figure 7*. People who live in northern areas see auroras more often than those who live near the Equator do. During periods of heavy solar activity, however, an aurora can be seen as far south as Texas and New Mexico. Auroras are often called the northern lights (aurora borealis) or southern lights (aurora australis). From the ground, they often appear as green or red glows, or shimmering curtains of white, red, and green lights in the sky.

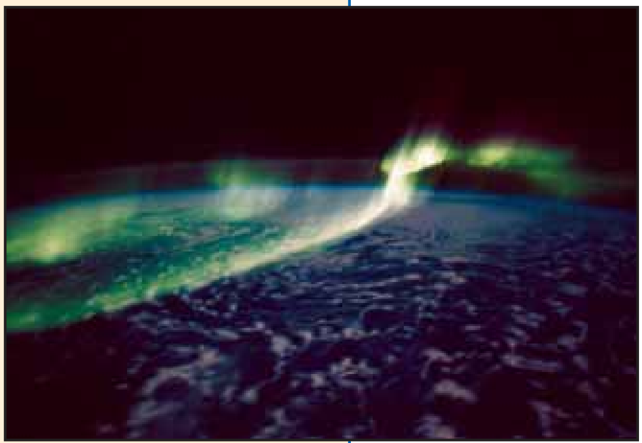


Figure 7 The aurora borealis or northern lights light up the sky in the Northern Hemisphere.

Collecting Data about the Sun

How do astronomers collect data about the Sun? From the ground, they use solar telescopes—instruments outfitted with special sensors to detect the different kinds of solar activity. There are dozens of solar telescope sites around the world. They include the Sacramento Peak Solar Observatory in New Mexico, the McMath Solar telescope in Arizona, and the Mount Wilson solar observatory in California. From space, they study the Sun using orbiting spacecraft like the Yohkoh satellite (*Yohkoh* is the Japanese word for "sunbeam"). Other missions include the Transition Region and Coronal Explorer (TRACE), the Ulysses Solar-Polar mission, the Solar and Heliospheric Observatory, the GOES satellites, and many others. These spacecraft are equipped with detectors sensitive to x-rays, radio waves, and other wavelengths of radiation coming from the Sun. In this way, scientists keep very close track of solar activity and use that information to keep the public informed of any upcoming dangers.

Some scientists theorize that sunspot cycles affect weather on Earth. They think that during times of high sunspot activity, the climate is warmer. During times of no or low sunspot activity, the climate is colder. A sharp decrease in sunspots occurred from 1645 to 1715. This period of lower solar activity, first noted by G. Sporer and later studied by E.W. Maunder, is called the Maunder Minimum. It coincided with cooler temperatures on Earth, part of a period now known as the "Little Ice Age." Similar solar minimums occurred between 1420–1530, 1280–1340, and 1010-1050 (the Oort minimum). These periods preceded the discovery of sunspots, so no correlation between sunspots and temperature is available. Solar astronomers number the solar cycles from one minimum to the next starting with number one, the 1755–1766 cycle. Cycle 23 peaked (was at a maximum) in the year 2000. (See *Figure 4*.) There is still much debate about the connection between sunspot cycles and climate.

Geo Words

aurora: the bright emission of atoms and molecules near the Earth's poles caused by charged particles entering the upper atmosphere.

Check Your Understanding

1. How do solar flares interfere with communication and power systems?
2. In your own words, explain what is meant by the term "solar wind." How does the Sun contribute to "space weather?"
3. Describe the Earth's energy budget.

Understanding and Applying What You Have Learned

1. Study the graph that you made showing sunspot activity. You have already determined that sunspot activity occurs in cycles. Using graph paper, construct a new graph that predicts a continuation of the cycle from 2001 to 2015. Indicate which years you think would see increased solar-flare activity and more dangerous "space weather."
2. The latest sunspot maximum occurred in 2001. Using the data from your sunspot-activity data table, predict the next sunspot minimum.
3. Make lists of the possible consequences of solar flares to the following members of your community: an air traffic controller, a radio station manager, and the captain of a ship at sea. Can you think of other members of your community who would be affected by solar activity?
4. You have read that Earth's albedo is about 0.30.
   a) In your own words, describe what this means.
   b) Is the Earth's albedo constant? Why or why not?
   c) How does changing a planet's albedo change a planet's temperature? Why does this occur?
   d) If Earth's albedo was higher, but Earth was farther from the Sun, could the Earth have the same temperature? Why or why not?

Preparing for the Chapter Challenge

You have been asked to help people in your community to understand how events from outside the Earth affect their daily lives. Write a short paper in which you address the following questions:

1. How has the Sun affected your community in the past?
2. How has the Sun affected you personally?
3. How might the Sun affect your community in the future?
4. What are some of the benefits attained from a study of the Sun?
5. What are some of the problems caused by sunspots and solar flares?
6. Explain how auroras are caused. Explain also why they can or cannot be viewed in your community.
7. Compare the chances of dangerous effects from the Sun with the chances of an impact event affecting the Earth.

Inquiring Further

1. **Viewing sunspots**

   If you have a telescope, you can view sunspots by projecting an image of the Sun onto white cardboard. Never look directly at the Sun, with or without a telescope. Stand with your back to the Sun, and set up a telescope so that the large (front) end is pointing toward the Sun and the other end is pointing toward a piece of white cardboard. You should see a projection of the Sun on the cardboard, including sunspots. If you map the positions of the sunspots daily, you should be able to observe the rotation of the Sun over a couple of weeks. Use the *EarthComm* web site to locate good science sites on the Internet that show daily images of solar activity. Search them out and compare your observations of sunspots to what you see from the large observatories.

   Work with an adult during this activity. Do not look at the bright image for long periods of time.

2. **Aurorae**

   Have people in your community ever seen the northern lights? Even if your community is not very far north, do some research to see if the auroras have ever been spotted from your community.

3. **Solar radiation and airplanes**

   Periods of sunspot maximum increase the dosage of radiation that astronauts and people traveling in airplanes receive. Do some research on how much radiation astronauts receive during sunspot minima and maxima. How much radiation do airplane passengers receive? How do the amounts compare to the solar radiation you receive at the Earth's surface? How do scientists balance safety with the issue of the extra weight that would be added to aircraft, spacecraft, or space suits to provide protection?

4. **The hole in the ozone layer**

   People who live near the South Pole of the Earth are at risk for increased ultraviolet exposure from the Sun. This is due to a thinning in the atmosphere called the ozone hole. Research this ozone hole. Is there a northern ozone hole? Could these ozone holes grow? If so, could your community be endangered in the future?

5. **History of science**

   Research the life of British physicist Edward Victor Appleton, who was awarded the Nobel Prize in physics in 1947 for his work on the ionosphere. Other important figures in the discovery of the properties of the upper atmosphere include Oliver Heaviside, Arthur Edwin Kennelly, F. Sherwood Rowland, Paul Crutzen, and Mario Molina.