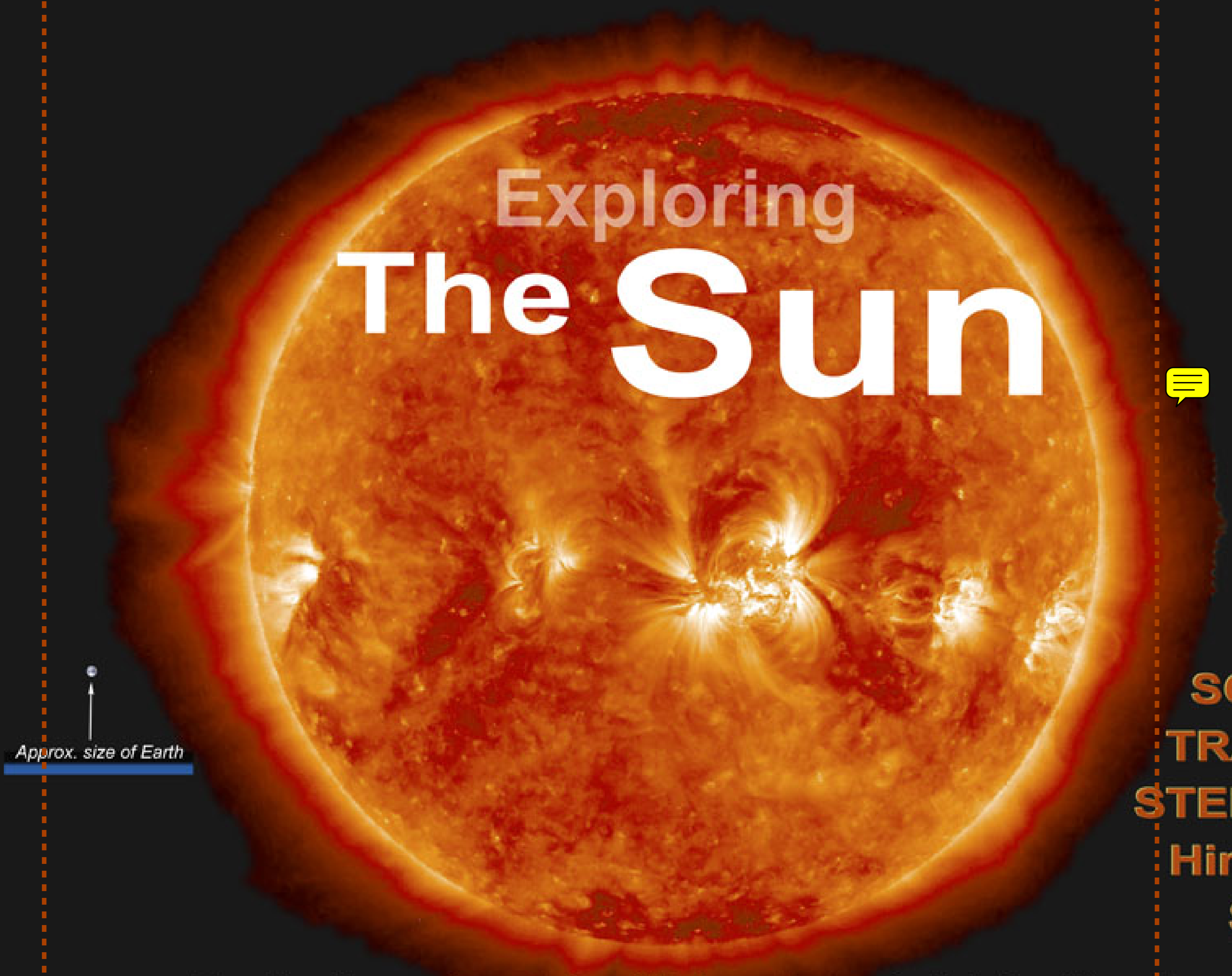
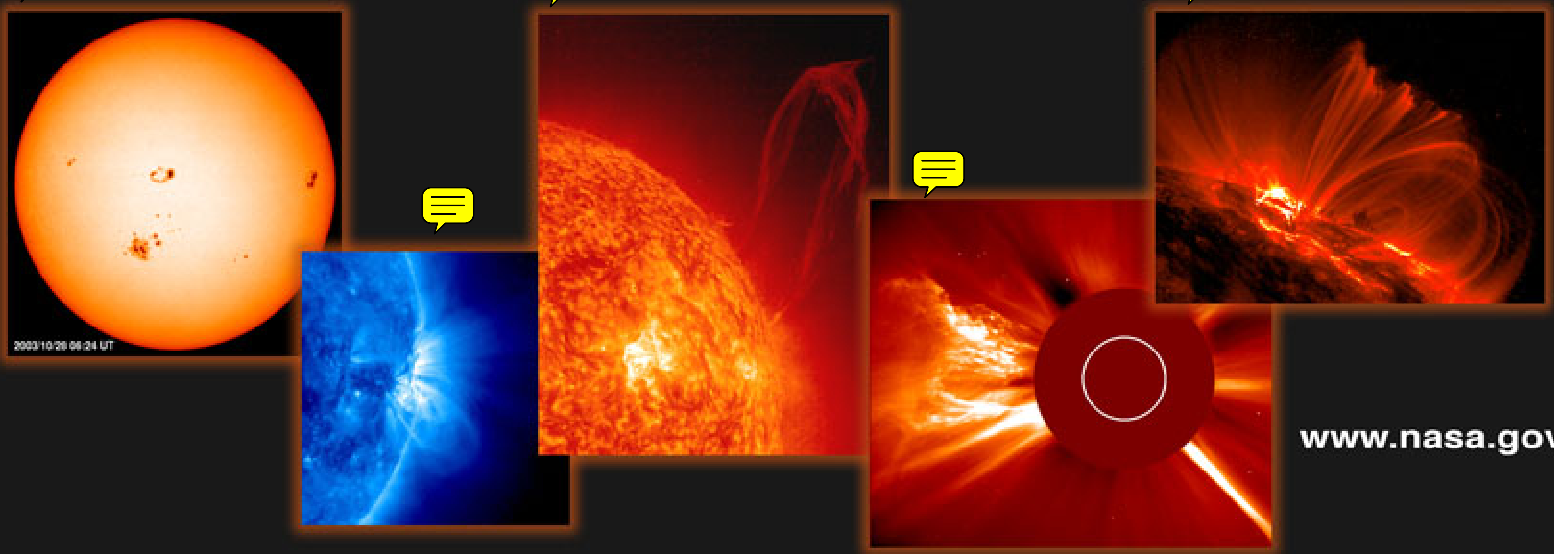
National Aeronautics and Space Administration

Exploring The Sun



SOHO
TRACE
STEREO
Hinode
SDO

The Sun is our closest star. We have learned a lot about it and its effects here on Earth and beyond, and NASA missions are helping us learn more. Let's explore what we know about the Sun . . .



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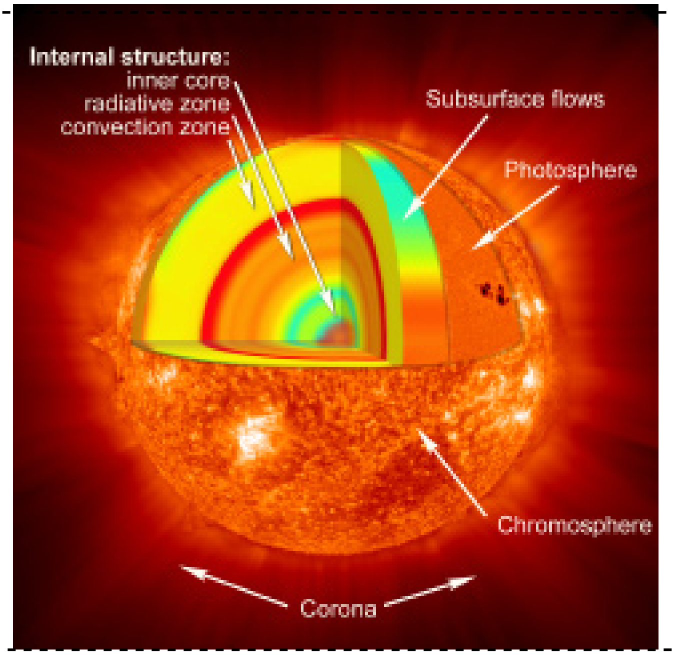
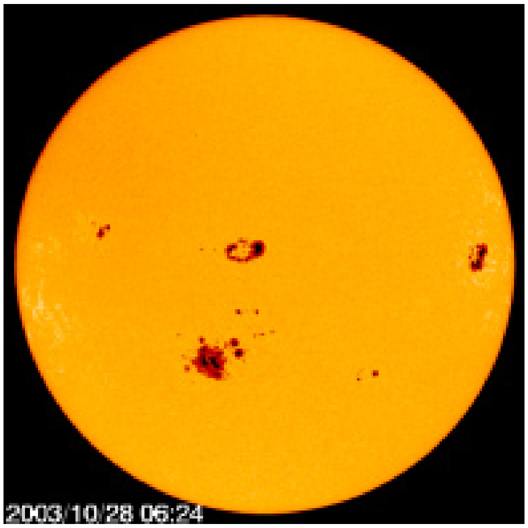
Our Star, The Sun

Looking up at the sky with the naked eye, the Sun seems static, constant. It provides the warmth and light that supports life on Earth. From the ground, the only noticeable variations in the Sun are its location (where will it rise and set today?) and its color (will the atmosphere make it turn pink or orange?) Scientists have learned a lot more about the Sun in the past 400 years. We know that the Sun is the center of our solar system and it rotates about every 27 days. At its core a huge thermonuclear reactor fuses hydrogen atoms into helium, its two most common elements, producing million degree temperatures. Near its surface, the Sun is like a pot of boiling water, with bubbles of hot, electrified gas—actually electrons and protons in a fourth state of matter known as plasma—circulating up from the interior, rising to the surface, and bursting out into space. The surface temperature is a much milder 6,000 degree C.



Major parts of the Sun

How big is it? The Sun is basically an average star in size and shares many similarities with most stars. The Sun is about one million miles (1.6 million km) across, which means that almost 110 Earths could be placed side by side across it. Even more astonishing, one million Earths could fit inside it, like gum balls in a bubble gum machine. Yet, since Earth is 93 million miles (150 million km) away from it, the Sun hardly seems to be so huge, appearing from Earth to be about the size of the Moon. The relatively small Moon, though, is a mere 250,000 miles (400,000 km) from Earth -- that's why it appears to be Sun-sized. The next closest star, Alpha Centauri, is over four light years away (the distance that light travels in one year is a light year) and just twinkles in the night sky like the other stars. Because the Sun is by far our closest star, we can learn a great deal about all stars by studying it.

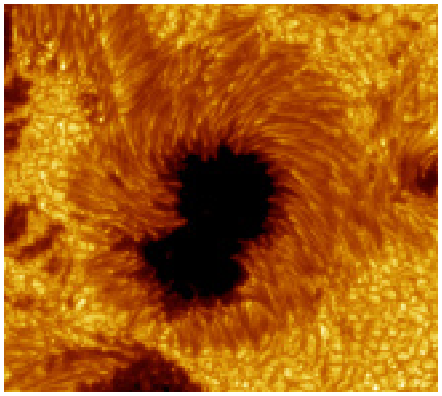


Credit: SOHO, NASA/ESA

Several large sunspots

Sunspots

Sunspots are dark splotches on the Sun caused by the appearance of cooler (3000 degrees Celsius) areas amidst the roiling gases on the surface (6000 degrees C). These areas are cooler because intense magnetic fields, 1000 times stronger than the magnetic field of Earth, prevent hot plasma from rising to the surface. An average sunspot is about the size of Earth. The largest ones can be 20 times the size of Earth. These spots are often the source of solar storms like the larger coronal mass ejections (CMEs) and smaller, but more intense, solar flares.



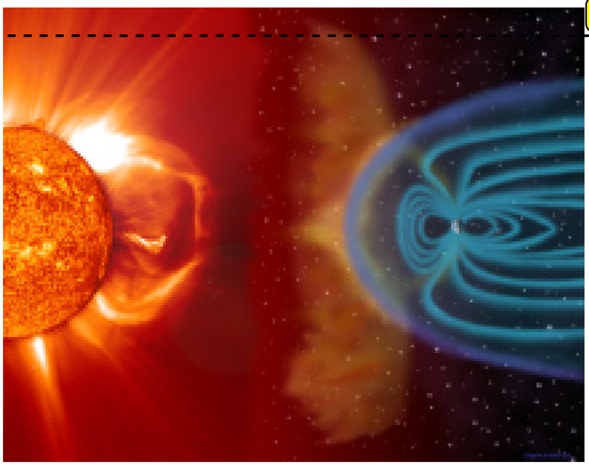
Credit: Swedish Solar Telescope

Close-up of a sunspot

Many people do not realize that the Sun goes through an 11-year solar cycle of activity, usually measured by the numbers of sunspots. At its peak, the Sun sports a large number of spots, many of them quite big; near its minimum period, there are often no sunspots at all. The next peak period of high activity should occur around 2012. The number of solar storms also changes with the solar cycle. At its peak, the Sun can produce many solar storms a day.

Space Weather from the Sun

One of the most important solar events from Earth's perspective is the coronal mass ejection (CME), the solar equivalent of a hurricane. A CME is the eruption of a huge bubble of plasma from the Sun's outer atmosphere, or corona. The corona is the gaseous region above the surface that extends millions of miles into space. Thin and faint compared to the Sun's surface, the corona is only visible to the naked eye during a total solar eclipse. Complicated magnetic fields extend from the interior to create great arches and loops above the surface. The buildup and interaction of these magnetic loops seems to supply the energy to produce the violent explosion of a CME.


Credit: SOHO, NASA/ESA

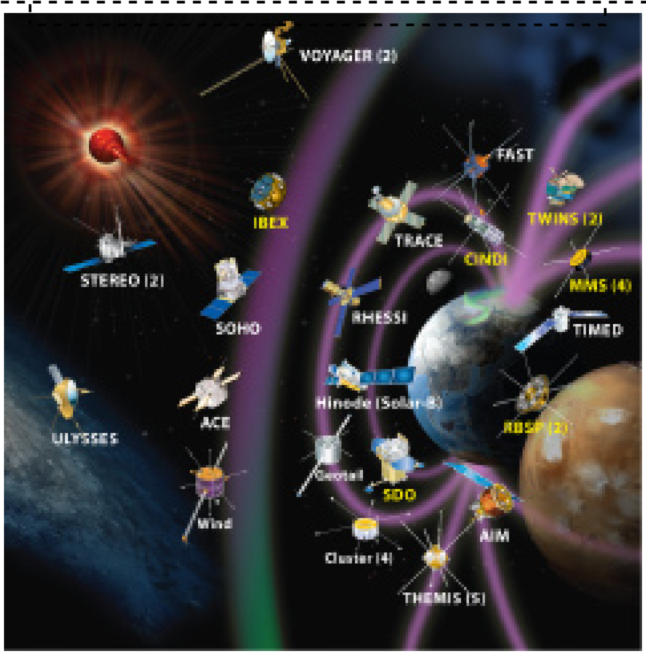
Solar storm striking Earth's magnetic shield (shown in blue)

The magnetic loops of the Sun's field are believed to hold down the newer fields emerging from below the surface. They also tie down the hot plasma carried by those fields, much like a net holding down a hot-air balloon. Scientists suggest that this causes tremendous upward pressure to build until the magnetic field breaks apart, allowing a CME to escape at high speed.

A CME plasma cloud races through space at speeds from near one million miles per hour (400 km/sec) to 5 million mph, which means if it is directed towards Earth, it would reach us in one to five days. A typical CME can carry more than 10 billion tons of plasma into the solar system, a mass equal to that of 100,000 battleships. The energy in the bubble of solar plasma is comparable to a hundred hurricanes. Its energy and magnetic fields associated with that plasma impact Earth's protective magnetic shield in space (the magnetosphere).


Credit: Dominic Cantin

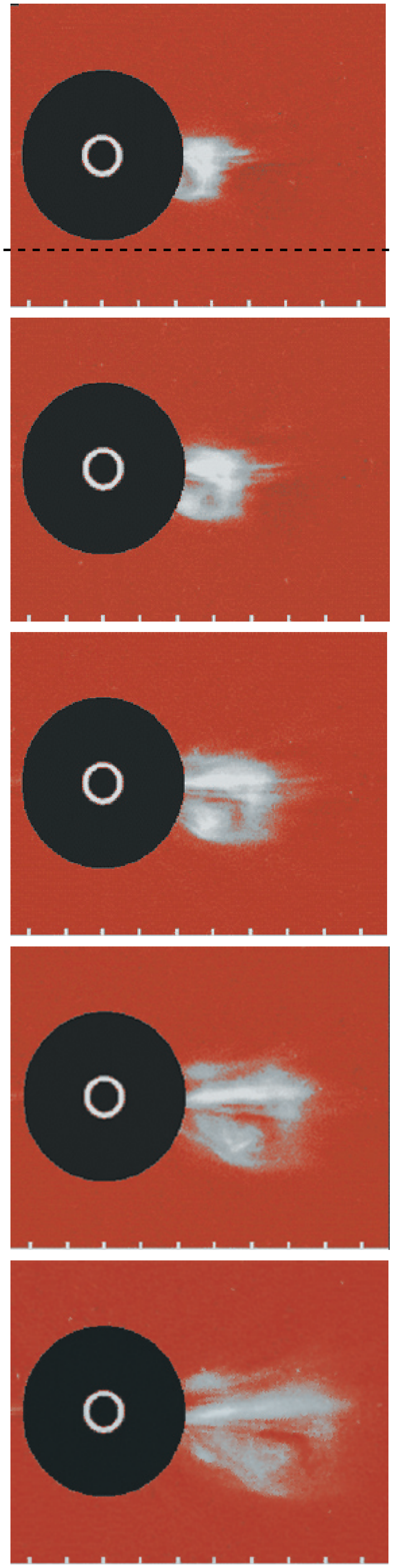
What are the effects on Earth and its people? The energy from a CME does not directly reach the surface of Earth. The cloud is blocked by our own magnetosphere, then slides around to the back side of Earth, where it can inject energy into Earth's magnetosphere, exciting particles trapped there. Under certain conditions, the particles follow the magnetic field lines down to Earth near the Poles. The visible signs of this activity are beautiful aurora (often called Northern and Southern lights), shimmering curtains of colorful glowing lights seen in the night sky (right). However, at times various kinds of technology suffer harmful effects: satellites fail, electric generators get overloaded; and communication and navigation equipment become disrupted. Astronauts can even become ill by solar storm radiation.



NASA's fleet of solar and magnetospheric missions (not to scale)

Scientists at NASA are working hard to find ways to better observe and then predict when these solar storms will occur and how Earth will respond. The graphic (left) identifies all of the current (white) and future (yellow) missions involved in this effort. The Solar and Heliospheric Observatory (SOHO) spacecraft (launched 1995) has been a major workhorse for solar studies, observing the Sun 24/7 with 12 instruments. TRACE (1999) studies smaller areas of the Sun's surface in greater detail. STEREO (2006) observes the Sun from two separate spacecraft that can provide a 3D perspective of solar events. Hinode (2007) captures very detailed images and data on the Sun. And the Solar Dynamics Observatory (2008) will essentially take over SOHO's role, but bring to bear new and greatly enhanced instruments. Together with the other spacecraft and projects in place, NASA will be able to model all types solar activity and impacts from the Sun to Earth and even beyond. If human spaceflight is going to carry astronauts to the Moon, Mars, and even further, we need to know much more about predicting solar storms.

Measure the Motion of a Coronal Mass Ejection



Activity: Calculate the velocity and acceleration of a coronal mass ejection (CME) based on its position in a series of images from the Large-Angle Spectrometric Coronagraph (LASCO) instrument on SOHO.

Materials: ruler, calculator, and a set of CME images from the LASCO instrument on SOHO. You can use the ones shown here or gather a set from http://soho.nascom.nasa.gov/classroom/lessons/rdat_cme_imgs.html

Background: An important part of space weather research is to measure the velocity of CMEs and their acceleration as they leave the Sun. This is done by tracing features in the CME and measuring their positions at different times. In the sequence of images shown on the right, you can see a CME erupting from the Sun on the right side of the coronagraph disk. The white circle shows the size and location of the Sun. The black disk is the occulting disk that blocks the surface of the Sun and the inner corona. The lines along the bottom of the image mark off units of the Sun's diameter.

Procedure: Select a feature of the CME that you can see in all five images—for instance, the outermost extent of the cloud, or the inner edge. Measure its position in each image. Your measurements can be converted to kilometers using a simple ratio:

$$\frac{\text{actual distance of feature from Sun}}{\text{diameter of the Sun (1.4 million km)}} = \frac{\text{position of feature as measured on image}}{\text{diameter of Sun as measured on image}}$$

Using the distance from the Sun and the time (listed on each image), you can calculate the average velocity. Velocity is defined as the rate of change of position. Using the changes in position and time, the velocity for the period can be calculated using the following equation: $v = (s_2 - s_1) / (t_2 - t_1)$, where s_2 is the position at time, t_2; s_1 is the position at time, t_1. The acceleration equals the change in velocity over time; that is, $a = (v_2 - v_1) / (t_2 - t_1)$, where v_2 is the velocity at time t_2; v_1 is the velocity at time t_1. You can record your results in a table.

Universal Time	Time Interval	Position	Avg. Velocity	Avg. Acceleration
8:05				
8:36				
9:27				
10:25				
11:23				

To see a video clip of this CME, go to: http://soho.nascom.nasa.gov/classroom/lasco_cme.mov

Further Questions and Activities

- Select another feature, trace it, and calculate the velocity and acceleration. Is it different from the velocity and acceleration of the other feature you measured? Scientists often look at a number of points in the CME to get an overall idea of what is happening.
- How does the size of the CME change with time? What kind of forces might be acting on the CME? How would these account for your data?

Mapping Magnetic Fields

Objectives: Students will learn about the poles of bar magnets, detect and draw a magnetic field using compasses, and that magnets have invisible magnetic fields, just as the Earth and Sun have magnetic fields.

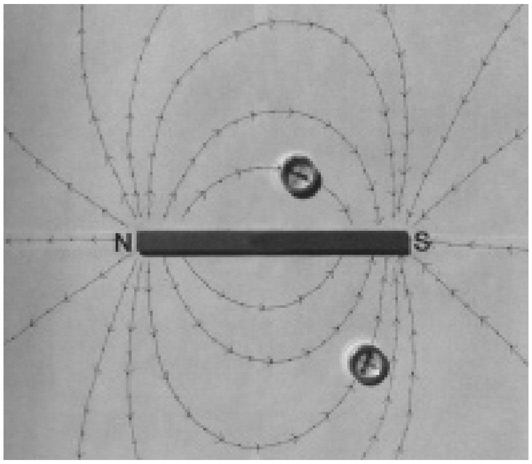
Materials (per group of two students): two compasses; 2 Alnico bar magnets; 4 sheets of 8" x 11" paper; paper clips; pencils; ruler; tape.

Pre-Activity: Ask students about their experiences with magnetism and their ideas about what it is and what causes it. Ask whether or not Earth is magnetic and how they know this. Also what a magnetic compass is and what it does.

Procedures:

Step 1 -- Allow students to experiment with the magnets. Suggest they try to get the magnets to attract and repel each other and other objects like paper clips and rulers.

Step 2 -- Teach the students how a compass works by having them hold the compass so the disk is horizontal and the N-S (North-South) markings are facing up. Have them align the line marked "N" with the arrow inside the compass. Explain how compasses are used in the wilderness.



Bar magnet with mapped magnetic fields

Step 3 -- Have each group tape some white paper together and place the bar magnets on top and in the middle of the taped paper. Tell them that they will now begin to trace the magnetic force field. To make the tracings, have them do the following:

a. Draw a dot somewhere near the magnet and place the center of the compass over it.
b. Draw a dot at the location of the arrowhead (or tail) of the compass needle.
c. Move the compass center to this new dot and again draw a dot at the location of the compass needle head (or tail).
d. Remove the compass from the paper and draw lines connecting the dots with arrows indicating the direction that the compass points.
e. Repeat steps c and d until the line meets with the magnet or paper's edge.
f. Pick another spot near the magnet and repeat the process.

Have them continue until they have the lines surrounding the magnet as shown in the picture: a di-pole (two-pole) pattern of force field showing magnetic field lines.

Hints: We recommend using AlNiCo (i.e., aluminum, nickel and cobalt) or cow magnets rather than Chrome-Steel as they hold their magnetism longer. Also, remember that compasses can easily change polarity when a bar magnet is dragged across the compass needle without allowing the needle to move.

Assessment Questions: What do you notice about the interaction of the bar magnets? What do all the mateirals that repond to the magnet have in common? What happens when you bring a compass near a magnet? (The Complete Teachers' Guide is available for download at: http://cse.ssl.berkeley.edu/exploringmagnetism)

Additional Resources

Sun-Earth Day event and solar resources:	http://sunearthday.nasa.gov
Daily space weather news and aurora predictions:	http://spaceweather.com
Simple matching Suns activity (middle school):	http://soho.nascom.nasa.gov/classroom/matching_activity.html
Daily images/movies of the Sun:	http://soho.nascom.nasa.gov
Solar 3D images/movies (need 3D glasses):	http://stereo.gsfc.nasa.gov/gallery/3dimages.shtml
NASA produced educational multimedia materials:	http://core.nasa.gov
Solar Dynamics Observatory mission:	http://sdo.gsfc.nasa.gov
Space weather center educational activities:	http://www.spaceweathercenter.org/
Interactive space weather poster (in PDF):	http://soho.nascom.nasa.gov/spaceweather/lenticular/SWpost_movies.pdf
Information about solar cycles:	http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

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To engage with an interactive version of this poster with movies and additional resources, go to: http://soho.nascom.nasa.gov/classroom/for_students.html