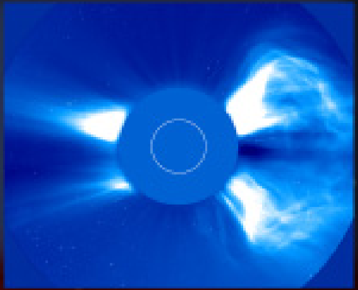
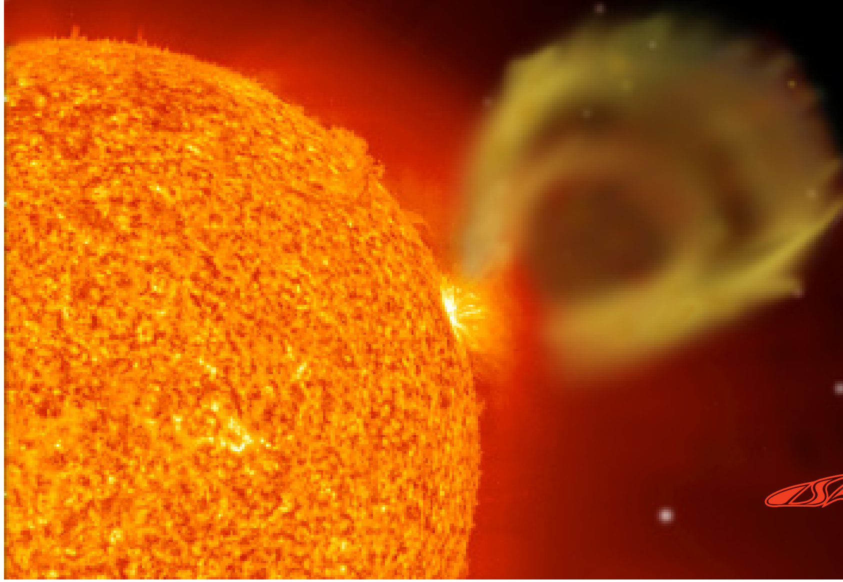
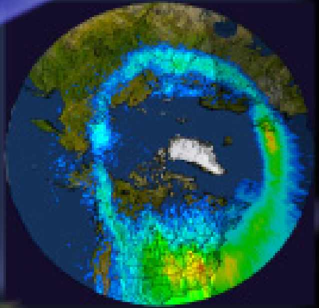
Storms from the Sun

Coronal Mass Ejections Light Up the Sky



Particles are blasted from the Sun . . .



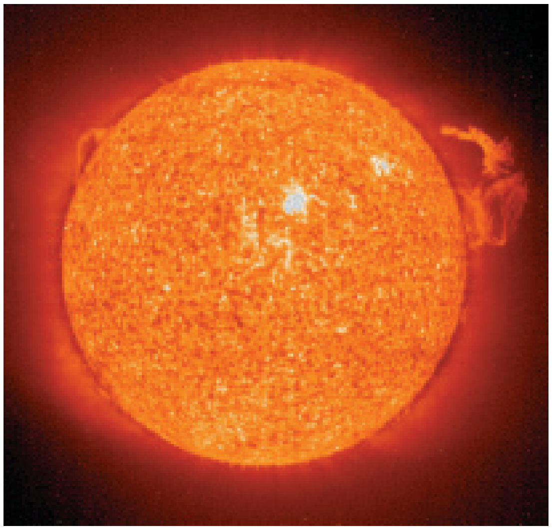


Millions of amps surge through our atmosphere . . .

Credit: Jan Curtis

. . . And make bright Northern lights.

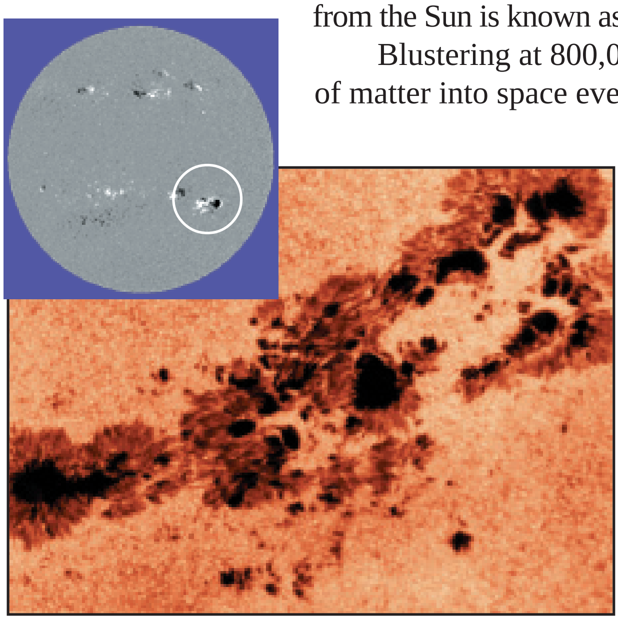
Bubble, Bubble, Toil and Trouble



A close-up of the Sun (shown in ultraviolet light) reveals a mottled surface, bright flares, and tongues of hot gas leaping into space.

Looking at the sky with the naked eye, the Sun seems static, placid, constant. From the ground, the only noticeable variations in the Sun are its location (where will it rise and set today?) and its color (will clouds cover it or will the atmosphere make it turn pink or orange?) But our Sun gives us more than just a steady stream of warmth and light. The Sun is turbulent and dynamic, provoking the cosmic equivalent of winds, clouds, waves, precipitation, and storms which bathe us in energy and star dust.

The Sun is a huge thermonuclear reactor, fusing hydrogen atoms into helium and producing million degree temperatures and intense magnetic fields. 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 steady stream of particles blowing away from the Sun is known as the solar wind.

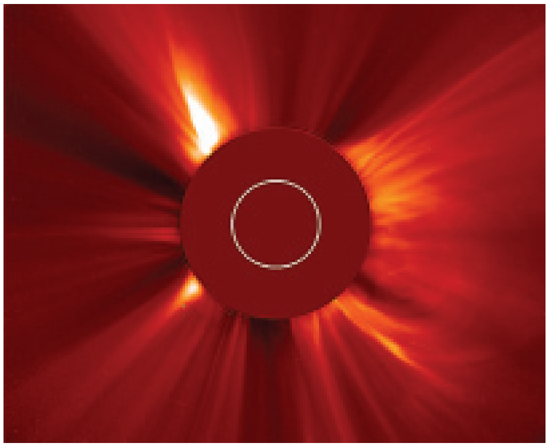


Though they look like burns in the face of the Sun, sunspots are actually much cooler than the rest of the surface.

Blustering at 800,000 to 5 million miles per hour, the solar wind carries a million tons of matter into space every second (that's the mass of Utah's Great Salt Lake). It's not the mass or speed, however, that makes the solar wind potent. In fact, the solar wind would not even ruffle the hair on your head because there are too few particles in the breeze (our air is millions of times denser than the solar wind). Instead, it is the energy and the magnetic fields associated with that plasma that buffet Earth's protective magnetic shield in space (the magnetosphere). Though less than 1% of the solar wind penetrates the magnetosphere, that's enough to generate millions of amps of electric current in our atmosphere and to cause occasional magnetic storms in the space around Earth.

If the character of the solar wind is like the everyday winds on Earth—mild, steady, and global—then sunspots and solar flares are like lightning and tornadoes—potent, but localized. 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 much of their energy is tied up in intense magnetic fields 1000 times stronger than the magnetic field of Earth.

On the other hand, solar flares appear as explosive bright spots on the surface of the Sun. Flares occur when magnetic energy built up in the solar atmosphere near a sunspot is suddenly released in a burst equivalent to ten million volcanic eruptions. Radiation—including radio waves, X rays, and gamma rays—and electrically charged particles emanate from the Sun following a solar flare (though most of it is blocked by Earth's atmosphere and magnetic field). The strongest flares occur just several times per year, while weaker flares are relatively common, with as many as a dozen a day during the Sun's most active periods.

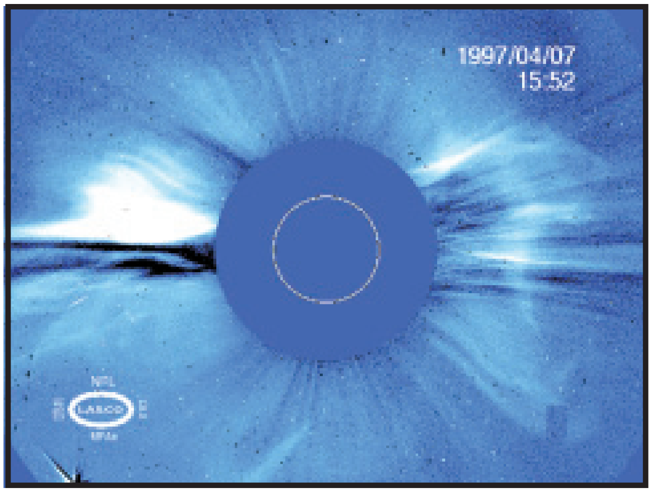


The use of an occulting disk—the orange and white circle in the center of the photo—allows scientists to see the solar wind streaming away from the Sun

Hurricane Sol

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. Temperatures in this region exceed one million degrees Celsius, 200 times hotter than the surface of the Sun.

How the corona can be so much hotter than the surface remains a mystery to scientists, but most suspect that it has to do with the complicated magnetic fields that burst from the interior and extend above the surface in great arches and loops. The buildup and interaction of these magnetic loops—which can stretch over, under, and around each other—seems to supply the energy to heat the corona and produce the violent explosion of a CME.



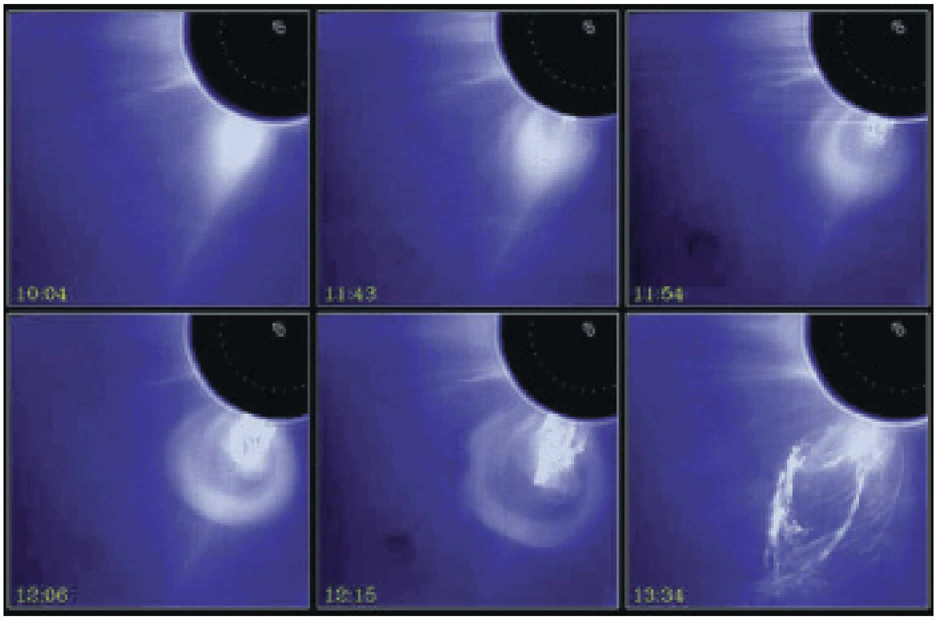
When scientists see a faint halo around the Sun (expanding around the disk), they know a coronal mass ejection is headed for Earth.

According to some of the newest observations and theories, the larger and higher 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, this network of magnetic loops restrains the plasma and magnetic fields trying to rise into the corona. This causes tremendous upward pressure to build. Eventually, some of the overlying magnetic loops merge and cancel each other, cutting a hole in the magnetic net and allowing the CME to escape at high speed.

Researchers compare this process to filling a balloon with helium. If you inflate it without holding it down, the balloon will slowly drift upward. But if you hold the balloon down with a string, you generate increasing force as you fill it, causing it to push upward. Once you let go of the string, the balloon shoots skyward.

Once it escapes the Sun's gravity, a CME speeds across the gulf of space at velocities approaching one million miles per hour (400 km/sec), with the fastest CMEs accelerating to 5 million mph. 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 packs a punch comparable to that of a hundred hurricanes combined.

Just hours after blowing into space, a CME cloud can grow to dimensions exceeding those of the Sun itself, often as wide as 30 million miles across. As it plows into the solar wind, a CME can create a shock wave that accelerates particles to dangerously high energies and speeds. Behind that shock wave, the CME cloud flies through the solar system bombarding planets, asteroids, and other objects with radiation and plasma. If a CME erupts on the side of the Sun facing Earth, and if our orbit intersects the path of that cloud, the results can be spectacular and sometimes hazardous.



The bubble of plasma in a CME expands and grows more potent until it escapes from the magnetic and gravitational energy of the Sun.

STORMS fr

Storm Front

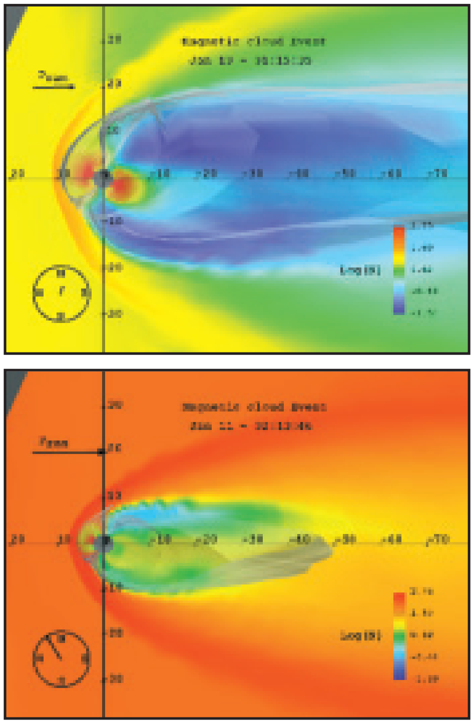
Coronal mass ejections occur at a rate of a few times a week to several times per day, depending on how active the Sun may be. And because of the size of the plasma clouds they produce, the odds say Earth is going to get hit by a CME from time to time. Fortunately, our planet is protected from the most harmful effects of the radiation and hot plasma by our atmosphere and by an invisible magnetic shell known as the magnetosphere. Produced by Earth's internal magnetic field, the magnetosphere shields us from 99% of the Sun's plasma by deflecting it into space.


Photo Credit: Jan Curtis

Seen here over Alaska, auroras are native to the far northern and southern lands. The most powerful magnetic storms can bring auroras all the way to Texas.

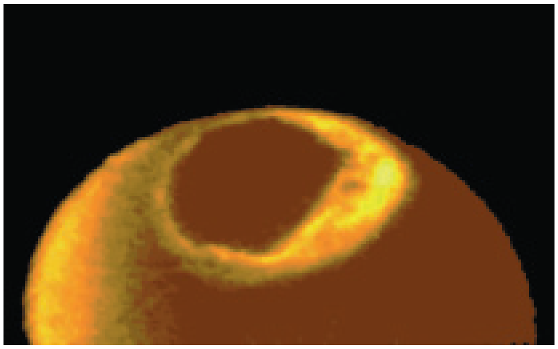
But some energetic particles do enter the magnetosphere from time to time, migrating in through Earth's magnetic tail or funneling in near the North and South Poles, where the magnetic field is weakest and the magnetosphere is partially open to space. The flow of plasma into our magnetosphere can induce magnetic storms, alter Earth's magnetic field as measured on the ground, and produce the phenomena known as auroras.

Many things can happen in the magnetosphere during a magnetic storm because a lot of energy is being dumped into the system. When stimulated by plasma from the Sun or from the far reaches of the magnetosphere, the electrons, protons, and oxygen ions of surrounding Earth become denser, hotter, and faster. Due to their motion, these particles produce as much as a million amperes of electrical current, a jolt of power that can decrease the relative strength of Earth's magnetic field. Some of the current flows along Earth's magnetic field lines and into the upper atmosphere. The passage of electric current through the upper atmosphere and the loss of electrons and protons from the upper magnetosphere can cause the atmosphere to warm, expand, or become more dense.



A computer simulation of the magnetosphere shows how a CME cloud can compress our magnetic field and increase its intensity.

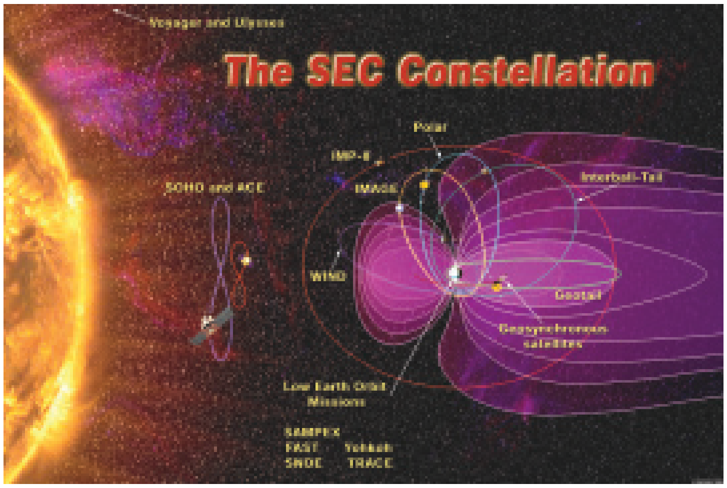
Also, excited particles inside the magnetosphere can plunge into the upper atmosphere, where they collide with oxygen and nitrogen. These collisions—which usually occur between 40 and 200 miles above ground—cause the oxygen and nitrogen to become electrically excited and to emit light (fluorescent lights and televisions work in much the same way). The result is a dazzling dance of green, blue, white, and red light in the night sky, also known as aurora borealis and aurora australis ("Northern and Southern lights"). Auroras can appear as colorful, wispy curtains of light ruffling in the night sky, or sometimes as diffuse, flickering bands. Either way, they tell us that something electric is happening in the space around Earth.



Though they grow more intense when a CME hits Earth, auroras are present every day.

Seeing the Invisible

Auroras are a visible sign of the magnetic mayhem in our atmosphere, but beyond that, the human eye can't detect much of what we call space weather. That's because most of the material flowing from Sun to Earth is too diffuse or too dim—when measured against the background of space or the brightness of the Sun—to be seen by most telescopes or cameras.



The orbits of Sun-Earth Connection satellites allow scientists to see the entire system from many angles

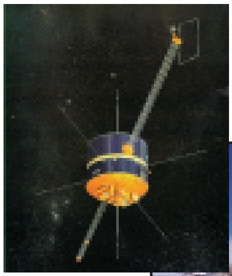
For instance, since the corona is only visible to the naked eye during an eclipse, scientists must use an occulting disk—which blocks the light from the solar surface to create an artificial eclipse—to detect what the Sun is spitting into space. Some of the most important recent advances in understanding and tracking coronal mass ejections have come from cameras that can resolve the faint light of the corona and detect the CMEs as they head toward Earth.

In order to "see the invisible," space physicists rely on telescopes that detect visible light, ultraviolet light, gamma rays, and X rays. They use receivers and transmitters that detect the radio shock waves created when a CME crashes into the solar wind (the equivalent of a sonic boom in space). They employ particle detectors to count ions and electrons, magnetometers to record changes in magnetic fields, and cameras to observe auroral patterns above the Earth.

All of these instruments and many others are the tools of the hundreds of scientists participating in the International Solar-Terrestrial Physics (ISTP) program, a global effort to observe and understand our star and its effects on our environment. An armada of more than 25 satellites carry those instruments into space, and together with ground-based observatories, they allow scientists to study the Sun, the Earth, and the space between them. Individually, the spacecraft contributing to ISTP act as microscopes, studying the fine detail of the Sun, the solar wind, and the boundaries and internal workings of Earth's magnetic shell. When linked together with each other and the resources on the ground, they act as a wide-field telescope that sees the entire Sun-Earth environment.

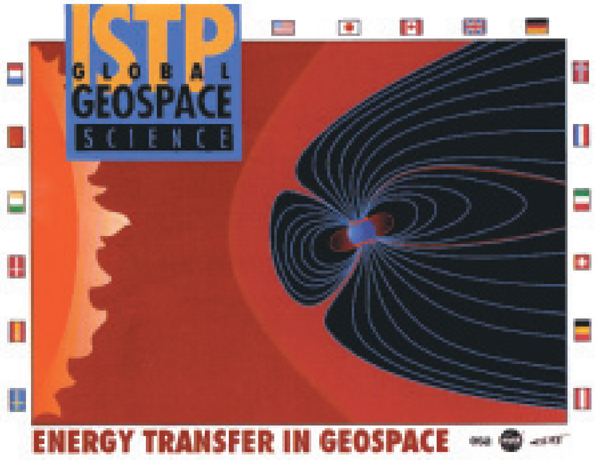
SOHO

Polar



Sondrestromfjord radar

The spacecraft of ISTP—principally, Wind, Polar, Geotail, and the Solar and Heliospheric Observatory (SOHO)—allow physicists to observe all the key regions of Earth's space. They study the interior of the Sun, its surface and corona, the solar wind, and Earth's magnetosphere, including the auroral regions and Van Allen radiation belts. Orbiting as far as one million miles and as close as two hundred miles above Earth, the spacecraft of ISTP make coordinated, simultaneous observations of the Sun and of activity in the magnetosphere. Working together with ground observatories, these spacecraft can—for the first time in history—track CMEs and other space weather events from origin to arrival. Someday, they might even be able to predict when such storms will happen.



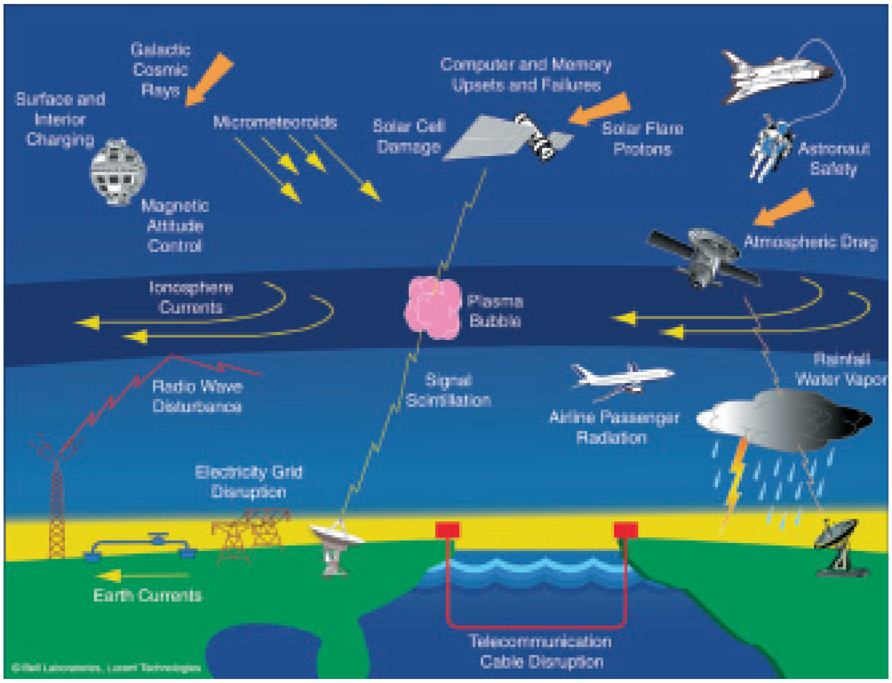
ISTP includes spacecraft from NASA, the European Space Agency, Japan's Institute of Space and Astronautical Science, and Russia's Space Research Institute.

rom the SUN

Blackouts, Burnouts, and Bummers

Aside from bright auroras, there are less benevolent effects of the connection between Sun and Earth. In fact, bright auroras are merely a visible sign that the balance of electrical and magnetic energy in Earth's magnetosphere has been upset. With the average CME dumping about 1500 Gigawatts of electricity into the atmosphere (double the power generating capacity of the entire United States), big changes can occur in space. Those changes can wreak havoc on a world that has come to depend on satellites, electrical power, and radio communication—all of which are affected by electric and magnetic forces.

For the satellites dancing in and out of the radiation belts and the solar wind, CMEs and magnetic storms can be perilous. For instance, a series of flares and coronal mass ejections in March 1989 produced a potent magnetic storm. After the particles and energy from the Sun bombarded the Earth, more than 1500 satellites slowed down or dropped several miles of altitude in their orbits due to increased drag.



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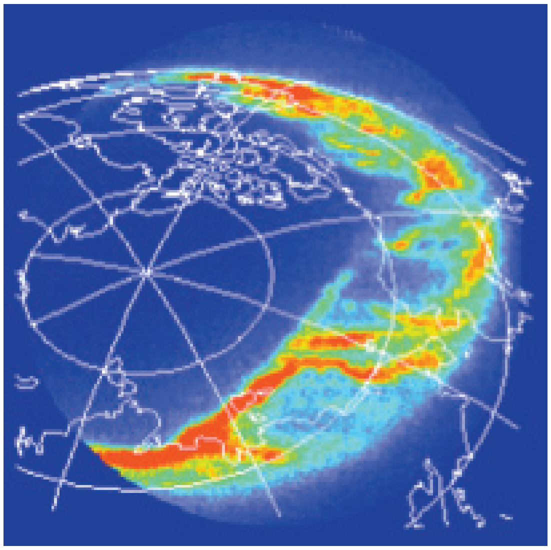
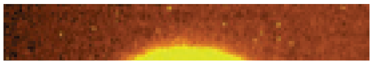
The effects of magnetic storms—what scientists call space weather—extend from the ground to geostationary orbit and beyond.

But atmospheric drag isn't the only effect CMEs can have on satellites. When excited and accelerated by a storm, high-energy electrons can degrade the solar panels used to power satellites and can upset and even shut off computers on a spacecraft. The increased flow of electricity in Earth's space also can cause electrical charge to build up on the surface of a spacecraft. That charge can eventually be released as a damaging spark (a spark like the one you get when you touch a friend after dragging your feet on a carpet). In 1994, two Canadian satellites were shut down when each was electrically shocked during magnetic storms; as a result, telephone service across Canada was disrupted for months. Similarly, in January 1997, an American satellite went dead just hours after a CME struck the magnetosphere. The loss of that satellite disrupted television signals, telephone calls, and part of a U.S. earthquake monitoring network.



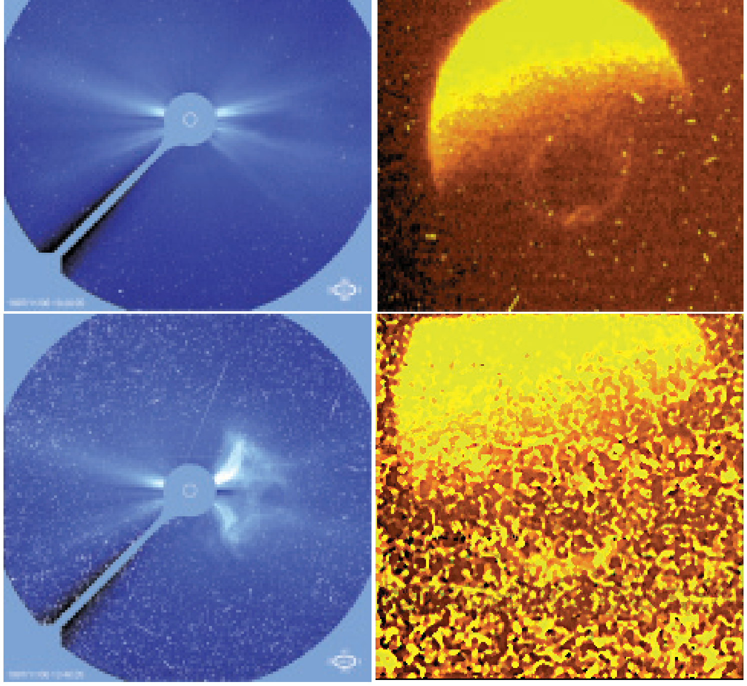
Magnetic storms, like this one seen in ultraviolet light, can wreak havoc on radio communications and electric power stations.

Magnetic storms also play havoc with radio signals, which are bounced off Earth's ionosphere (the outermost layer of our atmosphere, made up mostly of plasma) as a sort of natural relay station. In March 1989, listeners in Minnesota reported that they could not hear their local radio stations, but they could hear the broadcasts of the California Highway Patrol. In the extreme, magnetic storms can completely wipe out radio communication around Earth's North and South Poles for hours to days.



On the ground, magnetic storms can affect the strength of Earth's magnetic fields. Changes in magnetic fields can produce surges in power lines and strong electrical currents in gas and oil pipelines. The extra current can cause pipelines to corrode and deteriorate faster than they would naturally; in power lines, the extra electricity can burn out transformers and cause brownouts and blackouts. During the March 1989 storm, a transformer burned up at a power plant in New Jersey, and a whole system was blown out at a power station in Quebec, leaving 6 million people without electricity for hours, some for days.

Since so much modern information is relayed by satellites and other advanced technology—from automated teller machines and television broadcast signals to the Global Positioning System and disaster warning networks—CMEs pose a natural and technological hazard to life on Earth.



These images from SOHO (left) and Polar (right) show particles from the Sun bombarding the satellites. SOHO sees the solar wind in the first image, then a snow of protons accelerated by a CME. Polar looks down on the aurora and Earth's dayglow before the protons smack the camera.

Make Your Own Sun-Earth Connections

Thanks to the Internet, it is easy for you to keep up with the latest observations and breakthroughs in the study of Sun and Earth. In fact, anyone who can access the World Wide Web can study the Sun, Earth's magnetosphere, and interplanetary space, because that is where ISTP scientists receive and share their data. You can see this poster come to life with video clips or read it in Spanish at http://www-istp.gsfc.nasa.gov/istp/outreach/cmeposter/index.html.

Many of the observations made by ISTP are available within hours to days after they are made, allowing you to witness science in action. In particular, every time a CME lifts off the Sun and heads toward Earth, you can watch the storm develop by viewing some of the same images and data sets that space physicists are using. So don't wait for science to show up in your textbooks or magazines—look over a scientist's shoulder and watch it happen.

Mission to Geospace

To learn more about how and why physicists study the space around Earth, go to http://www-istp.gsfc.nasa.gov/istp/outreach. The site includes easy-to-read articles and primers; a place to question and read about real scientists; activities, images and movies; and an extensive library of news items and articles about the latest and greatest discoveries from our neighborhood in space.

SOHO Explore

To learn more about the Sun as seen through the keen eyes of the Solar and Heliospheric Observatory, go to http://sohowww.nascom.nasa.gov/explore/. The site includes exercises, a paper model, image sets, posters, and a place to get all your Sun questions answered.

Getting the Latest on Space Weather

Whether it's the chances for auroras or the number of sunspots, a good site to get up-to-date information is http://www.spaceweather.com/

International Solar Terrestrial Physics Program

To see the same raw, unedited data and images that ISTP scientists view, visit http://www-istp.gsfc.nasa.gov/istp/. These pages can be quite technical, but they are the real deal.

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 Coronograph (LASCO) instrument on SOHO.

Materials: ruler, calculator, and a set of CME images from the LASCO instrument on SOHO. You can use the ones here or gather another set from http://sohowww.nascom.nasa.gov/gallery/LASCO/las001.gif

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:

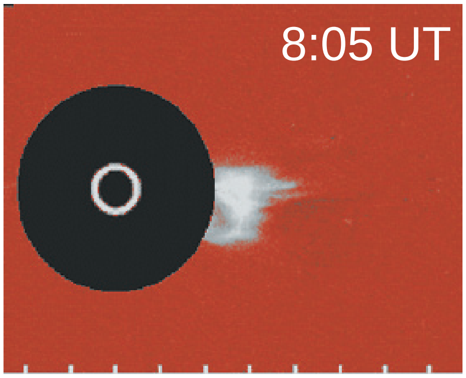
$$\frac{\text{actual distance of feature from Sun}}{\text{diameter of the Sun (1.4 million km)}} = \frac{\text{position of feature as measured on image}}{\text{diameter of Sun as measured on image}}$$

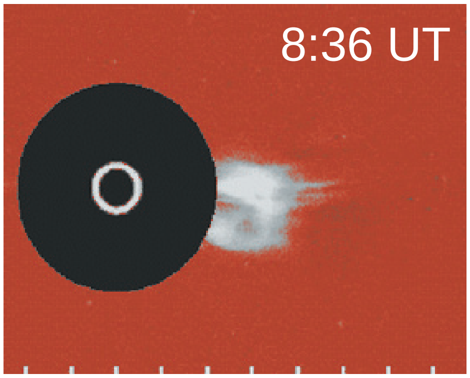
Using the distance from the Sun and the time (listed on each image), you can calculate the average velocity. Velocity is defined as the rate of change of position. Using the changes in position and time, the velocity for the period can be calculated using the following equation: $v = (s_2 - s_1) / (t_2 - t_1)$, 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.

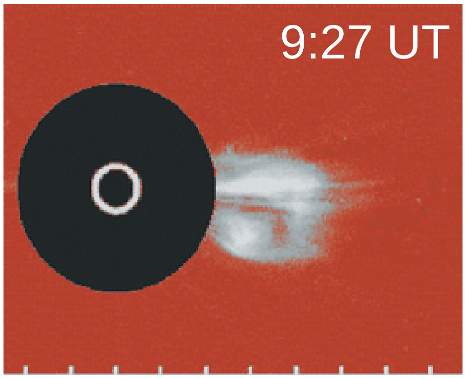
Universal Time	Time Interval	Position	Avg. Velocity	Avg. Acceleration
8:05				
8:36				
9:27				
10:25				
11:23				

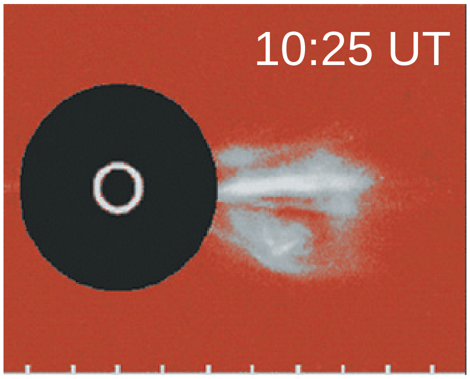
Further Questions and Activities

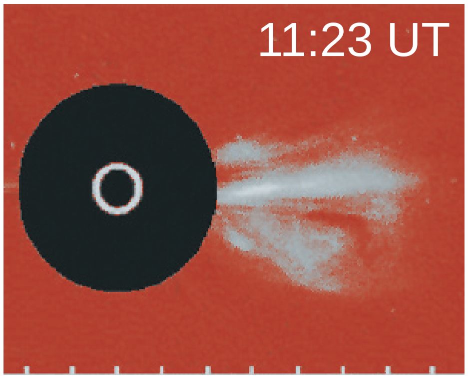
- Select another feature, trace it, and calculate the velocity and acceleration. Is it different from the velocity and acceleration of the other feature you measured? Scientists often look at a number of points in the CME to get an overall idea of what is happening.
- How does the size of the CME change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











Credit: This activity is based on "Sun Centered Physics,"
a set of lesson plans developed by Linda Knisely.

NASA Resources for Educators

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Educator Resource Center Network (ERCN)

To make additional information available to the education community, NASA has created the NASA Educator Resource Center (ERC) network. Educators may preview, copy, or receive NASA materials at these sites. Phone calls are welcome if you are unable to visit the ERC that serves your geographic area. A list of the centers and the regions they serve includes:

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NASA Educator Resource Center
NASA Ames Research Center
Mail Stop 253-2
Moffett Field, CA 94035-1000
Phone: (650) 604-3574
http://amesnews.arc.nasa.gov/erc/erchome.html

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http://www.grc.nasa.gov/WWW/PAO/html/edteachr.htm

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NASA Educator Resource Center for
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Houston, TX 77058
Phone: (281) 244-2129
http://www.spacecenter.org/educator_resource.html

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NASA Kennedy Space Center
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Kennedy Space Center, FL 32899
Phone: (321) 867-4090
http://www-pao.ksc.nasa.gov/kscpao/educate/edu.htm

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Virginia Air & Space Center
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Hampton, VA 23669-4033
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http://www.vasc.org/erc/

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Phone: (256) 544-5812
http://erc.msfc.nasa.gov

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Visitor Center Building J-17
Wallops Island, VA 23337
Phone: (757) 824-2298
http://www.wff.nasa.gov/~WVC/ERC.htm

Regional Educator Resource Centers offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as regional ERCs in many states. A complete list of regional ERCs is available through CORE, or electronically via NASA Spacelink at http://spacelink.nasa.gov/ercn.

NASA's Education Home Page serves as the education portal for information regarding educational programs and services offered by NASA for the American education community. This high-level directory of information provides specific details and points of contact for all of NASA's educational efforts, Field Center offices, and points of presence within each state. Visit this resource at the following address: http://education.nasa.gov.

NASA Spacelink is one of NASA's electronic resources specifically developed for the educational community. Spacelink serves as an electronic library to NASA's educational and scientific resources, with hundreds of subject areas arranged in a manner familiar to educators. Using Spacelink Search, educators and students can easily find information among NASA's thousands of Internet resources. Special events, missions, and intriguing NASA Web sites are featured in Spacelink's "Hot Topics" and "Cool Picks" areas. Spacelink may be accessed at: http://spacelink.nasa.gov.

NASA Spacelink is the official home to electronic versions of NASA's Educational Products. A complete listing of NASA Educational Products can be found at the following address: http://spacelink.nasa.gov/products.

NASA Television (NTV) features Space Station and Shuttle mission coverage, live special events, interactive educational live shows, electronic field trips, aviation and space news, and historical NASA footage. Programming has a 3-hour block—Video (News) File, NASA Gallery, and Education File—beginning at noon Eastern and repeated four more times throughout the day. Live feeds preempt regularly scheduled programming.

Check the Internet for programs listings at: http://www.nasa.gov/ntv. For more information on NTV, contact:

NASA TV
NASA Headquarters - Code P-2
Washington, DC 20546-0001
Phone (202) 358-3572

NTV Weekday Programming Schedules (Eastern Times)

Video File	*NASA Gallery*	*Education File*
12–1 p.m.	1–2 p.m.	2–3 p.m.
3–4 p.m.	4–5 p.m.	5–6 p.m.
6–7 p.m.	7–8 p.m.	8–9 p.m.
9–10 p.m.	10–11 p.m.	11–12 p.m.
12–1 a.m.	1–2 a.m.	2–3 a.m.

How to Access Information on NASA's Education Program, Materials, and Services (EP-2002-07-345-HQ)
This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the ERC network, or electronically via NASA Spacelink.

Please take a moment to evaluate this product at http://ehb2.gsfc.nasa.gov/edcats/educational_wallsheet. Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank You.

EW-1998-03-003-GSFC (Rev. 11/02)