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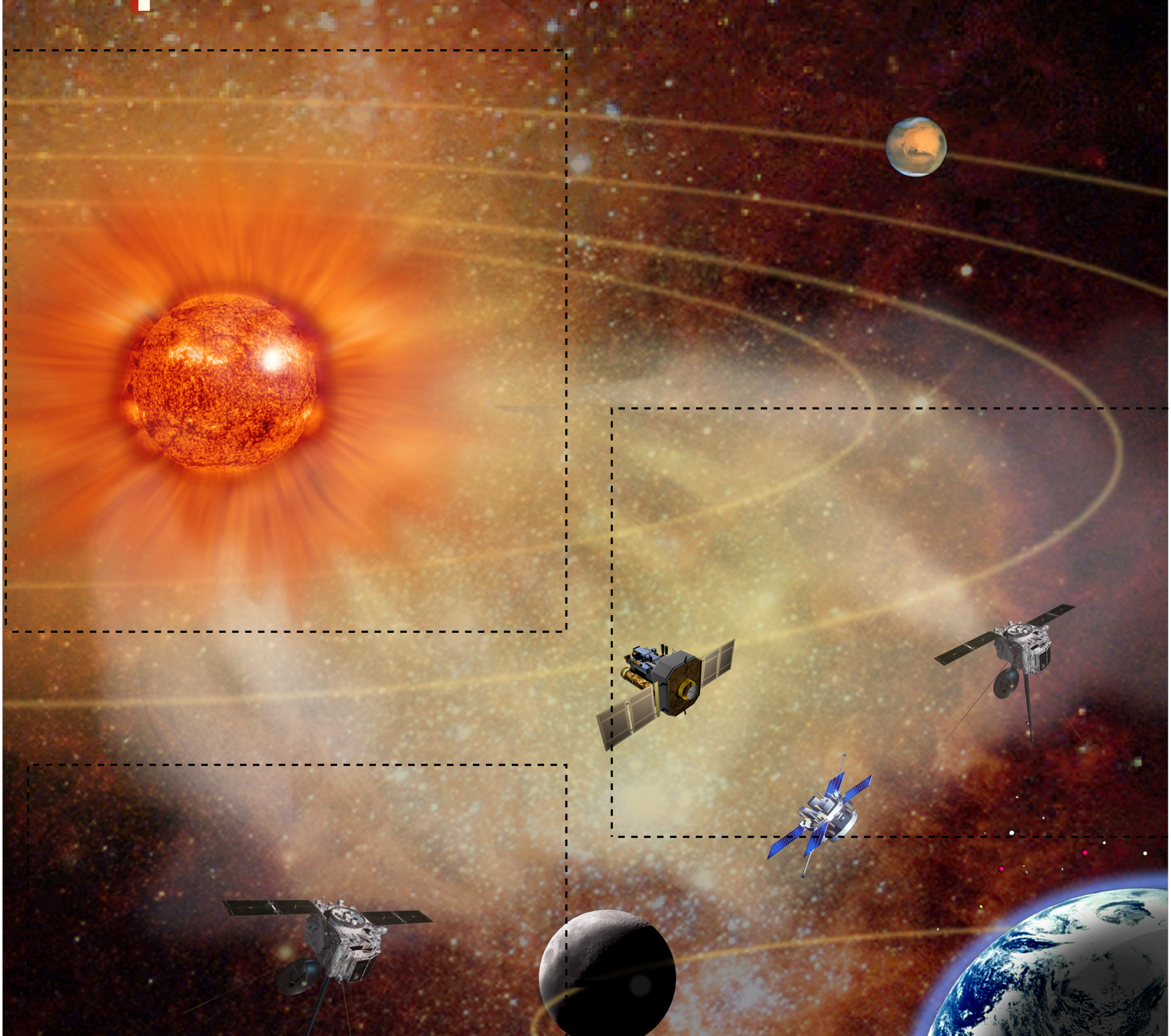
Space Weather

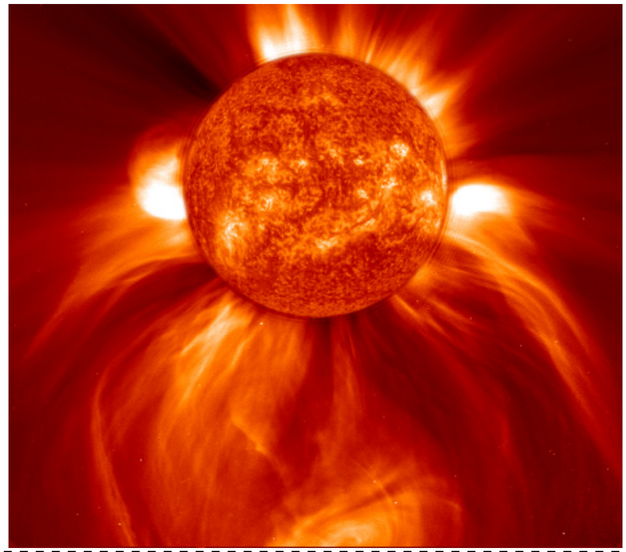


Living in the Atmosphere of the Sun

What is the forecast for the next solar storm?
Astronauts and many people on Earth need to know, and that is just what scientists and a fleet of NASA spacecraft are trying to figure out.

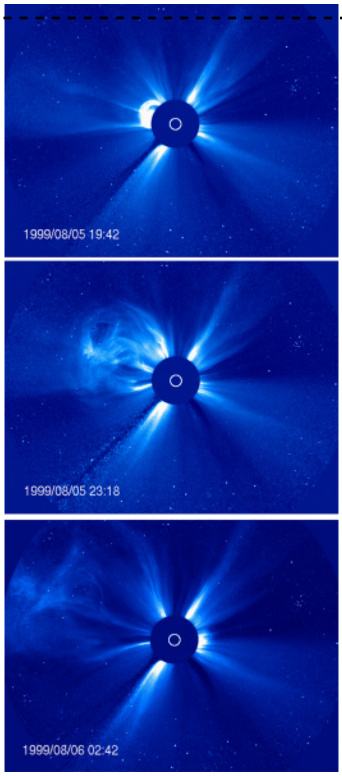
Is There Really Weather in Space?

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 regularly bathes us and the rest of our solar system in energy in the forms of light and electrically charged particles and magnetic fields. While visible sunlight is almost steady, sometimes the Sun's other outputs get turbulent and dynamic. The result is what we call space weather.



SOHO, NASA/ESA

Composite image of the Sun in UV light and a strong solar storm



SOHO, NASA/ESA

Time series of a CME blasting out from the Sun

The Sun is a huge thermonuclear reactor, fusing hydrogen atoms into helium and producing million degree temperatures and intense magnetic fields. The outer layer of the Sun is like a pot of boiling water, with bubbles of hot, electrified gas—electrons and protons in a fourth state of matter known as plasma—circulating up from the interior and rising to the surface. In ways that are still not understood, this results in solar magnetic fields and a steady stream of particles blowing away from the Sun known as the solar wind. The solar wind, the Sun's outermost atmosphere, reaches well beyond the solar system's planets.

Moving at 800,000 to 5 million miles per hour, the solar wind carries a million tons of matter into space every second. Its speed, density and the magnetic fields associated with that plasma affect Earth's protective magnetic shield in space (the magnetosphere). Most of the time the effects are benign, but when sunspots appear, it is a potential sign of a space weather storm coming. Sunspots are dark splotches on the Sun caused by the appearance of cooler (4000 degrees Celsius) areas amidst the roiling gases on the surface (6000 degrees C). They are cooler because their intense magnetic fields, 1000 times stronger than the magnetic field of Earth, reduce the normal flow of energy to the visible surface of the Sun. They are closely watched by space weather forecasters because, like high and low pressure systems on Earth, they hold signs of the severity of what's to come.

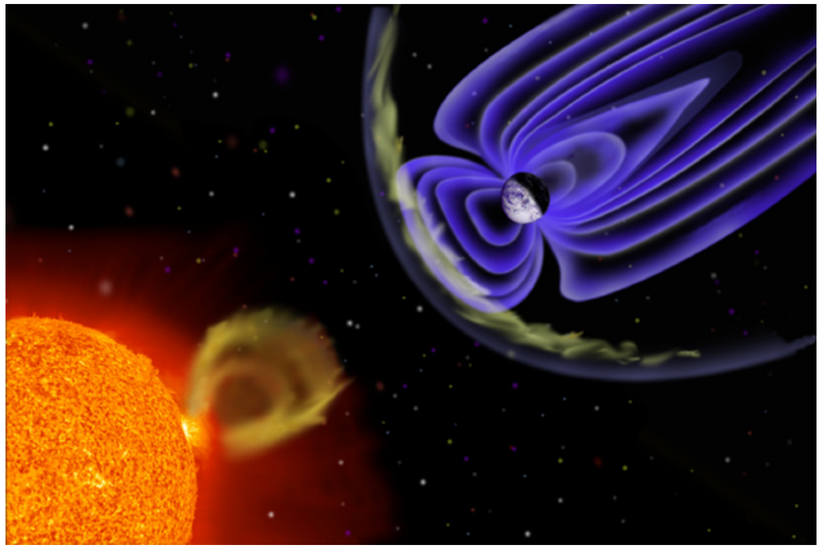
The Big Solar Storms

There are two kinds of solar storms. 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 blast from the Sun following a solar flare. 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 other important solar event 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. Temperatures in this region exceed one million degrees Celsius, 200 times hotter than the surface of the Sun.

A number of theories attempt to explain the occurrence of a CME. The magnetic fields in the corona are affected by both new fields emerging from below the surface and by the motions of the plasma at the surface, which carry the fields with them. They can become twisted, and thus energized in localized regions, often creating sunspots. Overlying magnetic fields are like a net holding down a hot-air balloon, restraining the plasma and twisted magnetic fields. Tremendous upward pressure builds. Eventually, some of the magnetic loops merge and burst through the magnetic net, creating a CME.

Observations show that a CME speeds across the gulf of space at speeds of up to several million miles per hour (up to 2500 km/sec)! A typical CME can carry more than 10 billion tons of extra plasma into the solar system, a mass equal to that of 100,000 battleships. A CME cloud typically grows to dimensions much larger than the Sun, as wide as 30 million miles across. As it plows into the solar wind, a CME can create a shock wave that accelerates some of the solar wind's particles to dangerously high energies and speeds that create radiation. Behind that shock wave, the CME disturbance travels through the solar system, impacting planets, asteroids, and other objects with enhanced plasmas and magnetic fields. If a CME erupts on the side of the Sun facing Earth, and if its path includes the location of Earth in its orbit, the results can be spectacular and sometimes hazardous.



Steele Hill, SOHO, NASA/ESA

Illustration of a solar storm heading towards Earth and later impacting the magnetosphere, our magnetic defensive field

Making Electrical Connections

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. The odds say Earth is going to get hit by a CME, now and then, and it does. 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.

But some magnetic energy is transferred from the CME to our magnetosphere from time to time, often 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 energy into our magnetosphere can induce magnetic storms, alter Earth's magnetic field as measured on the ground, and produce the phenomena known as auroras.

A lot of energy is being dumped into the Earth's magnetic 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. These particles produce as much as a million amperes of electrical current. Some of the current flows along Earth's magnetic field lines and into the upper atmosphere.

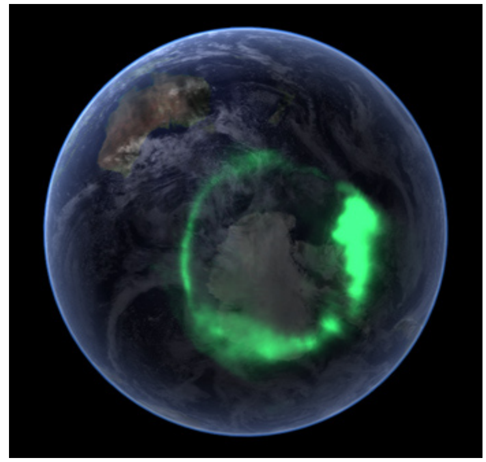
Pekka Parviainen

Curtains of colorful aurora shimmer in the night sky above Iceland. They occur 40 - 200 miles above the Earth.

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. They are visible evidence that something electric is happening in the space around Earth.

When Earth Gets Pounded

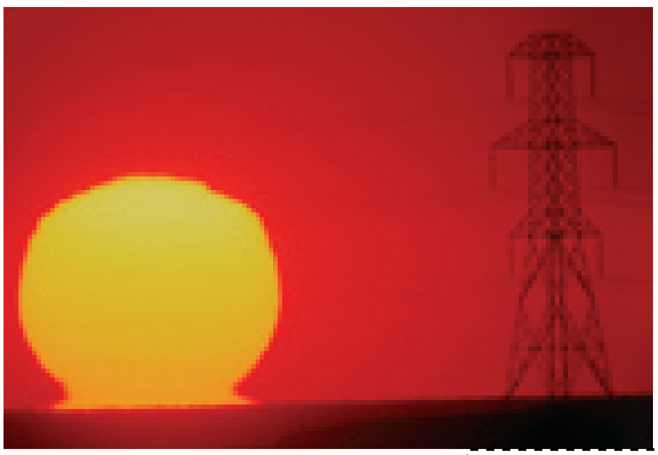
Aside from bright auroras, there are less pleasant effects of the connection between Sun and Earth. In fact, bright auroras are merely a visible sign that the balance of electrical and magnetic energy in Earth's magnetosphere has been upset. With the average CME dumping about 1500 Gigawatts of electricity into the atmosphere (double the power generating capacity of the entire U.S.), big changes can occur in space. Those changes can jar a world that depends on satellites, electrical power, and radio communication—all of which are affected by magnetic storms. For example, a series of flares and CME in March 1989 produced intense magnetic storms that left millions of people in Quebec, Canada without power for days in some cases.



NASA/IMAGE. Space Science Visualization Lab

Charged particles (shown as green) enter Earth's atmosphere in an oval shape near the Poles

For the satellites orbiting through the belts of radiation around Earth and the solar wind, CMEs and magnetic storms can be especially perilous. Energetic ions accelerated by a storm can degrade the solar panels used to power satellites and can upset computers on spacecraft. Energized plasmas in Earth's space can cause electrical charge to build up on the surface of a spacecraft that can lead to a damaging spark. In 1994, two satellites were shut down during magnetic storms–telephone service across Canada was disrupted for months. During the March 1989 period mentioned above, more than 1500 satellites slowed down or dropped several miles in their orbits due to increased atmospheric drag along their paths. Since 1996 solar storms have disrupted at least 14 satellites, causing about $2 billion dollars in losses.



Sigurdur Stefnisson

Electrical currents caused by magnetic storms from the Sun can overload and upset power grids

Magnetic storms also upset radio signals, which are bounced off Earth's ionosphere (the outermost layer of our atmosphere) as a sort of natural relay station. Magnetic storms can completely wipe out radio communication around Earth's Poles for days. Communications from ground to satellites and back are also upset due to the effect of the disturbed state of the ionosphere on those signals. So much modern information is relayed by satellite, from GPS to automated teller machines, that even day-to-day business disruptions can occur.

On the ground, magnetic storms affect the strength of Earth's magnetic fields. The changes in the field can produce surges in power lines and transformers, and corrosive electrical currents in gas and oil pipelines. The 1989 Quebec incident showed just how disruptive space weather effects can be, even to us on the surface of the Earth.

Astronauts live and work in space on the Space Station, and even when they are inside, they can get high doses of radiation during solar storms. In one week an adult can get the equivalent of 100 chest X-rays. With plans for astronauts to travel to the Moon and eventually to Mars, NASA must develop methods for forecasting, tracking solar storms, and providing shielding for astronauts who are directly exposed to space weather on a daily basis.

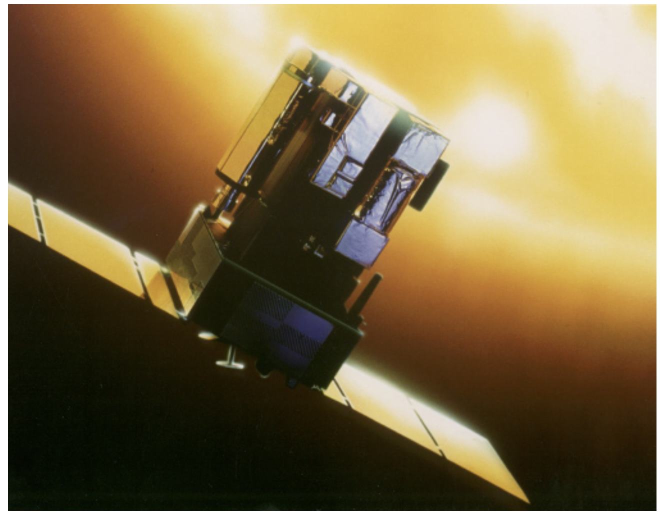
Johnson Space Center, NASA

Astronauts must be shielded from the sometimes dangerous radiation produced by the Sun's stormy activity

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. For instance, since the corona is only visible to the naked eye during a solar 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. Important advances in understanding and tracking coronal mass ejections have come from cameras that can pick up 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 faint visible light, ultraviolet light, gamma rays, and X rays. They use receivers and transmitters that detect the radio emissions created when a CME crashes into the solar wind and produces a shock wave. Particle detectors count ions and electrons, magnetometers record magnetic fields, and UV and visible cameras observe auroral patterns above the Earth.



SOHO, NASA/ESA

The SOHO spacecraft provides us with an early warning system for detecting disruptive solar activity

A number of spacecraft are already in space to learn more about the Sun and its impact on Earth and space travelers, including the Solar and Heliospheric Observatory, (SOHO), Advanced Composition Explorer (ACE), Transition Region and Coronal Explorer (TRACE), Ulysses and more. SOHO continues to observe the Sun 24 hours a day. After over 10 years in space, it has led to major advances in our understanding of space weather.

New spacecraft and instruments are being developed to create a coordinated fleet that will further monitor the Sun's activity and uncover the secrets of space weather. The STEREO mission (2006) will watch CMEs and their results from two identical spacecraft, one ahead of Earth and one behind, to give scientists, for the first time, a three dimensional perspective. The main science goal is to learn about the nature and origins of coronal mass ejections. At the same time, the Solar-B Earth-orbiting telescope mission will provide complementary images of the details of the CME source regions on the Sun. In 2008 the Solar Dynamics Observatory (SDO) is scheduled to provide images and data about the Sun at a higher cadence than ever before. SDO will also probe the forces under the surface that drive much of solar storm activity and measure any changes in the Sun's energy output. Essentially, it will be the next generation SOHO. Other NASA solar missions are being planned, among them THEMIS (2006) and Radiation Belt Storm Probes (2012) to study solar storm interactions with Earth's magnetosphere and radiation belts. The next few years will be exciting ones for solar scientists.

And beyond these efforts, 2007-08 will be **International Heliophysical Year** (IHY). In association with the United Nations, IHY will work to further advance world-wide coordination of scientific research on the Sun's behavior and how Earth responds to it. IHY will also bring the beauty and relevance of this area of science to the rest of the world.

Related Links:

International Heliophysical Year	http://ihy2007.org/
Sun-Earth Connection Education Forum	http://sunearth.gsfc.nasa.gov/
Sun-Earth Day event resources	http://sunearthday.nasa.gov/
Space weather resources on the SOHO site	http://soho.nascom.nasa.gov/spaceweather/lenticular/
Daily images and movies from SOHO	http://soho.nascom.nasa.gov/
Space weather news and updates daily	http://spaceweather.com/
NASA's Living with a Star Program	http://lws.gsfc.nasa.gov/
Solar Dynamics Observatory mission	http://sdo.gsfc.nasa.gov/
STEREO mission	http://stereo.gsfc.nasa.gov/index.shtml
TRACE mission	http://trace.lmsal.com/
NOAA's Space Environment Center	http://www.sec.noaa.gov

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