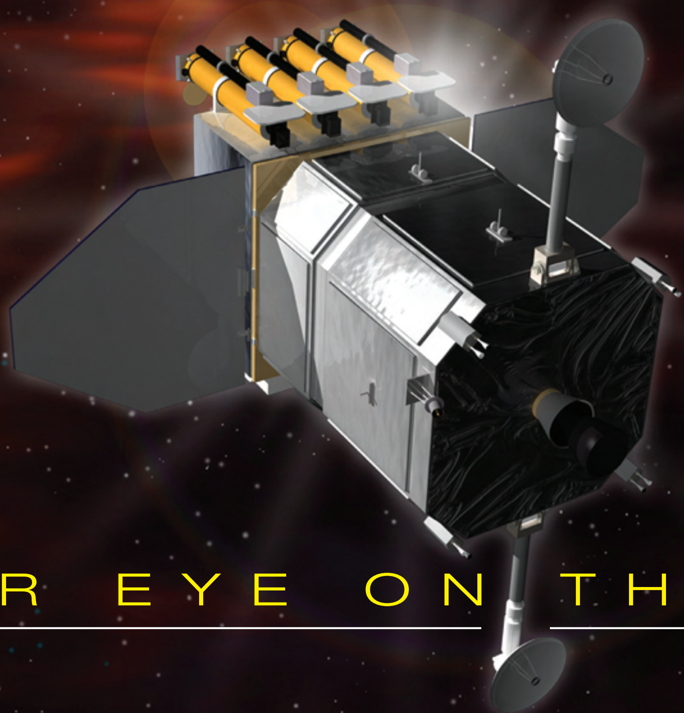
National Aeronautics and Space Administration

# SDO

## Solar Dynamics Observatory



OUR EYE ON THE SUN

A Guide to the Mission and Purpose of NASA's Solar Dynamics Observatory

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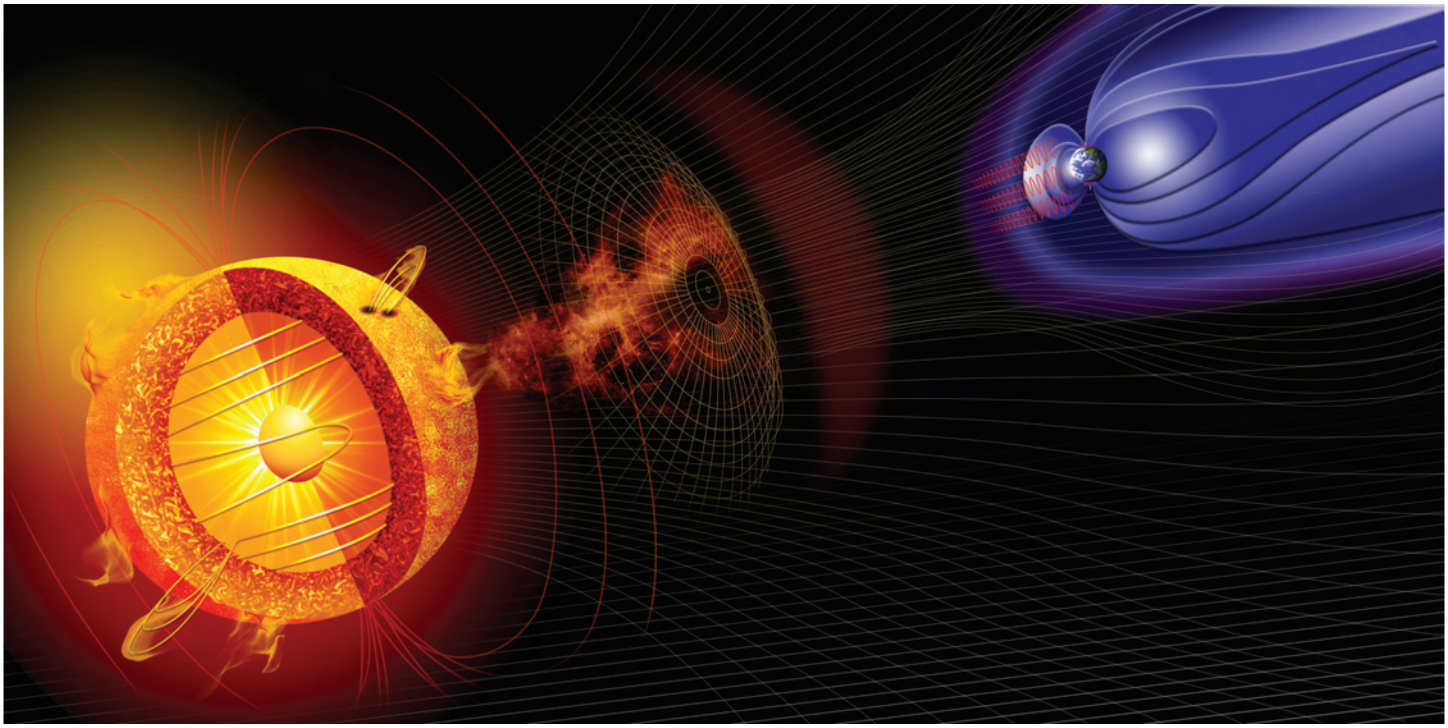
# Mission Description

SDO will study how solar activity is created and how space weather results from that activity. Measurements of the Sun's interior, magnetic field, the hot plasma of the solar corona, and the irradiance will help meet the objectives of the SDO mission.

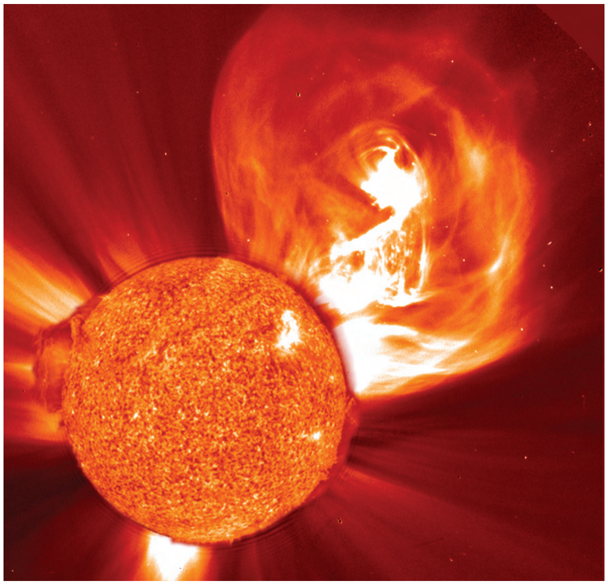
SDO will improve our understanding of the physics behind the activity displayed by the Sun's atmosphere, which drives space weather in the heliosphere, the region of the Sun's influence, and in planetary environments. SDO will determine how the Sun's magnetic field is generated, structured, and converted into violent solar events that cause space weather. SDO observations start in the interior of the Sun where the magnetic field that is the driver for space weather is created. Next, SDO will observe the solar surface to directly measure the magnetic field and the solar atmosphere to understand how magnetic energy is linked to the interior and converted to space weather causing events. Finally, SDO will measure the extreme ultraviolet irradiance of the Sun that is a key driver to the structure and composition of the Earth's upper atmosphere.

# SDO Science

Solar activity and variability are key concerns of our modern, increasingly technological society. Solar flares and coronal mass ejections can disable satellites, cause power grids failure, and disrupt communications. Furthermore, because the Sun is so powerful, even small changes in its irradiance could have effects on climate.



*Solar storm impacting Earth and its magnetic shield.*



*Solar storm shooting into space.*

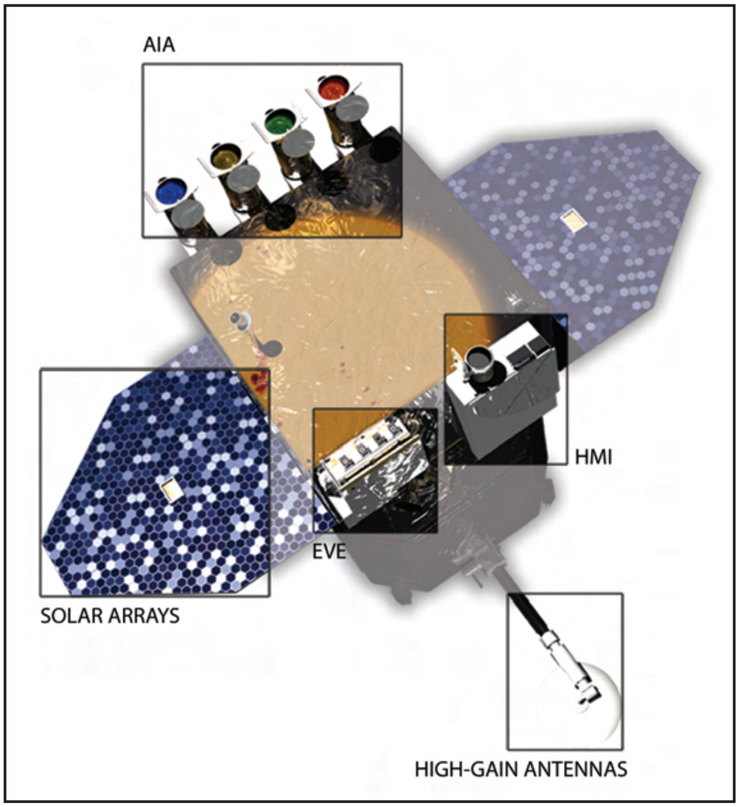
The Solar Dynamics Observatory (SDO) is designed to probe solar variability in a way that no other mission can match. High-speed cameras on SDO will take rapid-fire snapshots of solar flares and other magnetic activity. This will have the same transformative effect on solar physics that the invention of high-speed photography had on many sciences in the 19th century.

SDO doesn't stop at the stellar surface. A sensor on the observatory can actually look inside the Sun at the very source of solar activity—the solar dynamo itself. There SDO will find vital clues to the mystery of the solar cycle and help scientists predict the future of solar activity.

# SDO Instruments

## The Solar Dynamics Observatory has three main instruments.

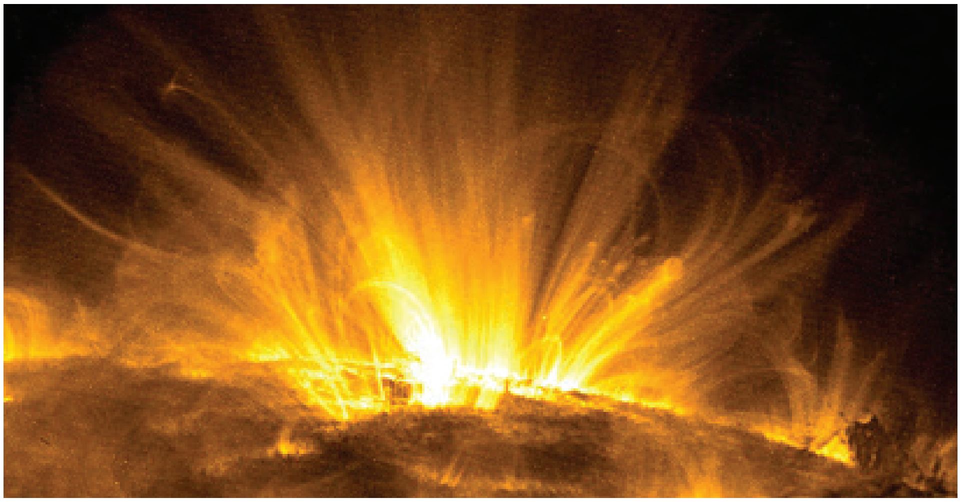
The **Atmospheric Imaging Assembly (AIA)** is a battery of four telescopes designed to photograph the Sun's surface and atmosphere. AIA filters cover 10 different wavelength bands, or colors, selected to reveal key aspects of solar activity. AIA was built by the Lockheed Martin Solar and Astrophysics Laboratory (LMSAL), Palo Alto, California. AIA's Principal Investigator is Dr. Alan Title of LMSAL.




*Identifying some features of the SDO spacecraft.*

The **Extreme Ultraviolet Variability Experiment (EVE)** will measure fluctuations in the Sun's ultraviolet output. The solar extreme ultraviolet (EUV) radiation has a direct and powerful effect on Earth's upper atmosphere, heating it, puffing it up, and breaking apart atoms and molecules. Researchers don't know how fast the Sun can vary at many of these wavelengths, so they expect to make many new discoveries about flare events. EVE was built by the University of Colorado, with Dr. Tom Woods of University of Colorado as the Principal Investigator.

The **Helioseismic and Magnetic Imager (HMI)** will map solar magnetic fields and peer beneath the Sun's opaque surface using a technique called helioseismology. A key goal of this experiment is to decipher the physics of the Sun's magnetic dynamo. HMI was built by the Lockheed Martin Solar and Astrophysics Laboratory of the Lockheed Martin (LMSAL), Palo Alto, California. The Principal Investigator for HMI is Dr. Phil Scherrer of Stanford.



*Magnetic activity on the surface of the Sun.*

## Atmospheric Imaging Assembly (AIA)

### What will AIA study?

The AIA will image the corona, or outer layer of the Sun's atmosphere, in multiple wavelengths nearly simultaneously.

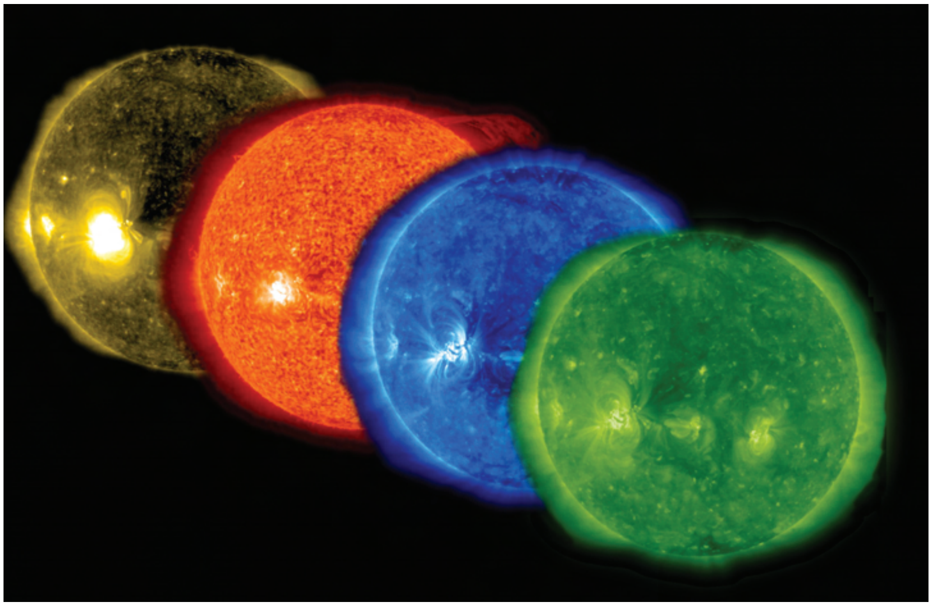
### How does it work?

AIA is an array of four telescopes that will observe the surface and atmosphere of our star with big-screen clarity and unprecedented time resolution. It's like an IMAX® camera for the Sun.

*The AIA instrument as it is being assembled. It is like an IMAX® camera for the Sun.*

AIA will produce a high-definition image of the Sun in eight selected wavelengths out of the ten available every 10 seconds. The ten wavelength bands include nine ultraviolet and extreme ultraviolet bands and one visible light band to reveal key aspects of solar activity. To accomplish this, AIA uses four telescopes, each of which can see details on the Sun as small as 725 km (450 mi) across—equivalent to looking at a human hair held 10 m (33 ft) away.

Because such fast cadences with multiple telescopes have never been attempted before by an orbiting solar observatory, the potential for discovery is significant. In particular, researchers hope to learn how storms get started near the Sun's surface and how they propagate upward through the Sun's atmosphere toward Earth and elsewhere in the solar system. Scientists will also use AIA data to help them understand how the Sun's changing magnetic fields release the energy that heats the corona and creates solar flares.

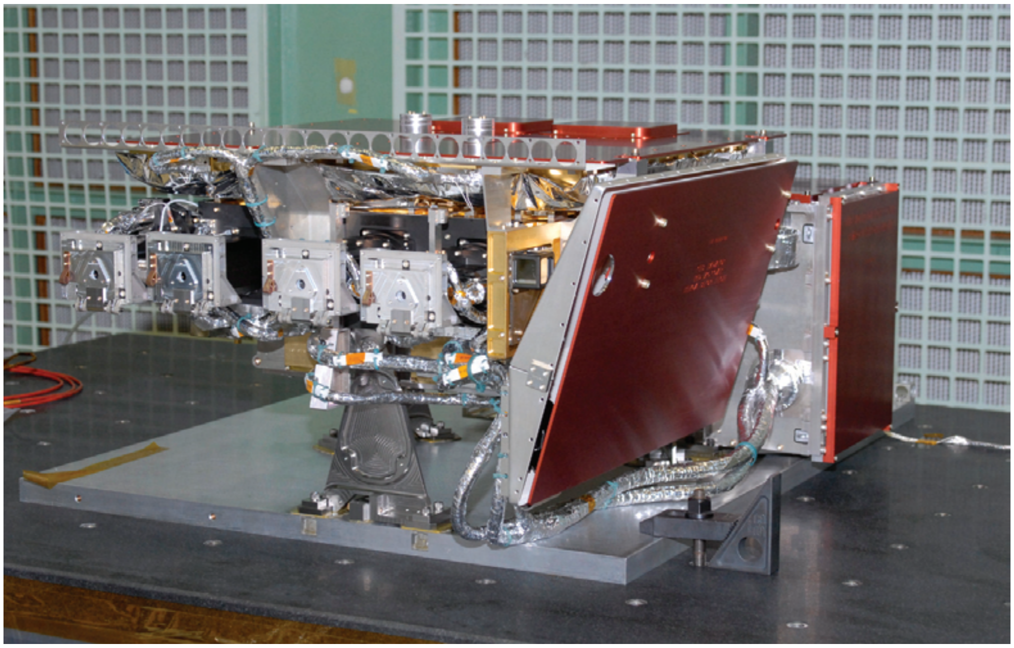


*The Sun, as observed by STEREO, in four wavelengths of extreme UV light and taken at nearly the same time. SDO will take images in 10 wavelengths every 10 seconds.*

## Extreme Ultraviolet Variability Experiment (EVE)

### What will EVE study?

Solar scientists will use the Extreme ultraviolet Variability Experiment (EVE) to measure the Sun's brightness in the most variable and unpredictable part of the solar spectrum. The extreme ultraviolet, or EUV, ranges in wavelength from 0.1 to 105 nm.



*This is the completed EVE instrument. It will have the highest time resolution (10 seconds) and the highest spectral resolution (better than 0.1 nm) ever achieved by a space-based solar observatory.*

EUV photons are much more energetic and dangerous than the ordinary UV rays that cause sunburns. If enough EUV rays were able to reach the ground, a day at the beach could be fatal. Fortunately, Earth's upper atmosphere intercepts the Sun's EUV emissions.

In fact, solar EUV photons are the dominant source of heating for Earth's upper atmosphere. When the Sun is active, EUV emissions can rise and fall by factors of hundreds to thousands in just a matter of seconds. These surges heat the upper atmosphere, puffing it up and increasing the drag on man-made satellites. EUV photons also can break the bonds of atmospheric atoms and molecules, creating a layer of ions that alters and sometimes severely disturbs radio communications and GPS navigation.

### How does it work?

EVE will allow solar scientists to monitor EUV emissions between 0.1 and 105 nm with the highest time resolution (10 seconds) and the highest spectral resolution (better than 0.1 nm) ever achieved by a space-based observatory. EVE also measures the very important Lyman $\alpha$ line at 121.6 nm, the single brightest line in the EUV. EVE will collect data 24 hours a day, 7 days a week, offering the first complete picture of solar EUV fluctuations that vary by factors of 2-100 over time scales of minutes.

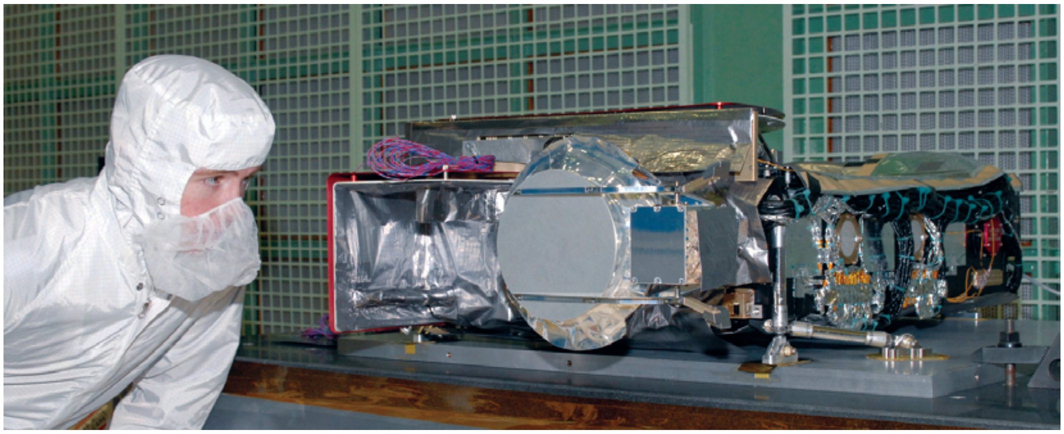
## Helioseismic and Magnetic Imager (HMI)

### What will HMI study?

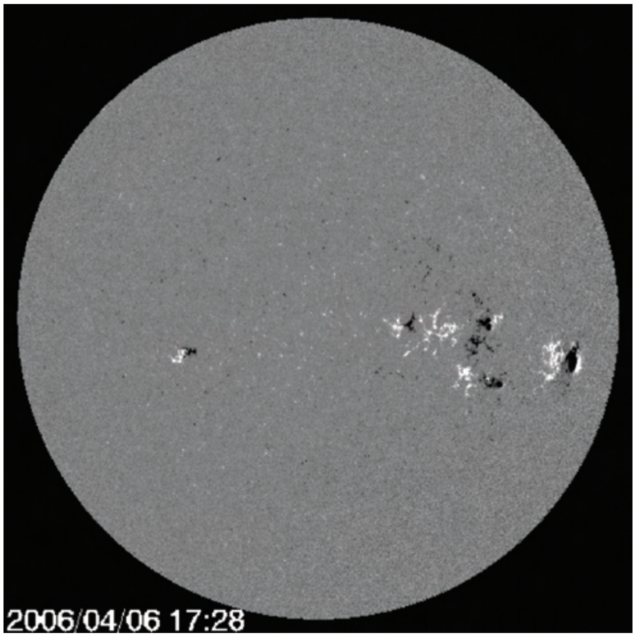
HMI will use the waves and magnetic field measured at the surface of the Sun to study the motions of material inside the Sun and the origins of the solar magnetic field.

### How does it work?

Solar physicists will use HMI to measure the waves rippling across the surface of the Sun and the magnetic field that erupts through the surface of the Sun. HMI measures the Doppler shift of a spectral line (the change in a wave's frequency when the source moves toward or away from an observer) to give the velocity over the Sun's entire visible disk. The Zeeman effect is used to interpret the polarization of the same line to give the magnetic field over the visible face of the Sun.



*The HMI instrument gets a close look as it is being assembled.*




*Magnetogram (magnetic image) of the Sun showing magnetically intense areas (active regions) in black and white.*

We use the wave data to study the inside of the Sun. As the waves travel through the Sun they are influenced by conditions inside the Sun. The speed of sound increases where solar material is hotter, so the speed and angle at which the wave is generated determine how far it will penetrate into the solar interior. The shallower the angle, the shallower the penetration; the steeper the angle, the deeper the wave will travel. It takes about 2 hours for a sound wave to propagate through the Sun's interior. The frequency and spatial pattern the waves make on the surface indicate where the waves have traveled. Scientists learn about the temperature, chemical makeup, pressure, density, and motions of material throughout the Sun by analyzing the detailed properties of these waves.

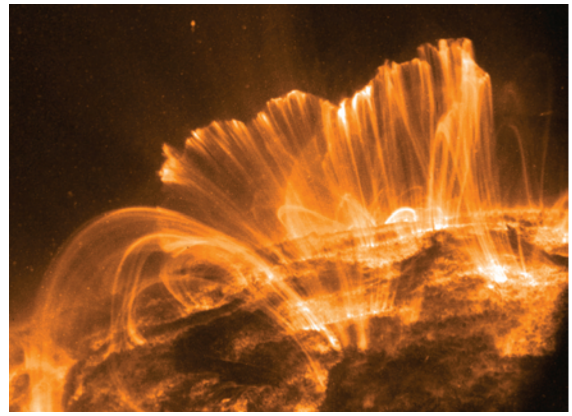
HMI will provide the first rapid cadence measurements of the strength and direction of the solar magnetic field over the visible disk of the Sun. Scientists use this information to understand how the magnetic field is produced and, when combined with measurements from AIA, how that field produces flares and CMEs, the storms of space weather.

# SDO Story Lines

## The Sun is a Variable Star

“The Sun is a variable star,” says Judith Lean of the Naval Research Lab in Washington DC. “It could have many surprises in store for us.”

“The Solar Dynamics Observatory is designed to study solar variability like no other spacecraft in NASA history,” says Lika Guhathakurta of NASA headquarters in Washington DC. “SDO may be considered the Solar Variability Mission.”



*Looping arcs of particles spiraling along magnetic field lines rising up from beneath the surface and back into the Sun.*

## Danger: Solar Storm Warning!

Human society depends on a network of interconnected high-tech systems for the basics of daily life. Power grids, GPS navigation, air travel, financial services, radio communications—they can all be knocked out by intense solar activity. According to the 2008 *Severe Space Weather Events—Understanding Societal and Economic Impacts: A Workshop Report* by the National Academy of Sciences, a century-class solar storm could cause twenty times more economic damage than Hurricane Katrina.

“Understanding solar variability is crucial,” says Lika Guhathakurta of Washington DC. “Our modern way of life depends upon it.”

The 11-year solar cycle is largely unpredictable. It’s not even 11 years long! No one knows when the next big solar storm will come.

“The solar minimum of 2008-2009 has taken us by surprise,” says David Hathaway of the Marshall Space Flight Center. “It highlights how far we still have to go to successfully forecast the solar cycle.”

SDO will observe the Sun faster, deeper, and in greater detail than previous observatories, breaking barriers of time-scale and clarity that have long blocked progress in forecasting dangerous solar storms.

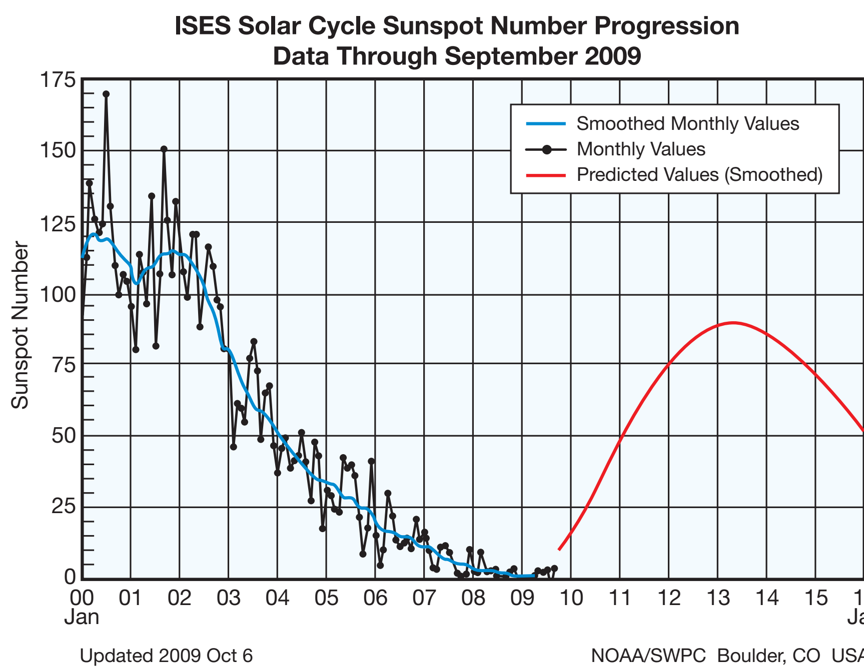



*Chart showing the progression and estimated track of the next solar cycle from 2000 to 2016.*

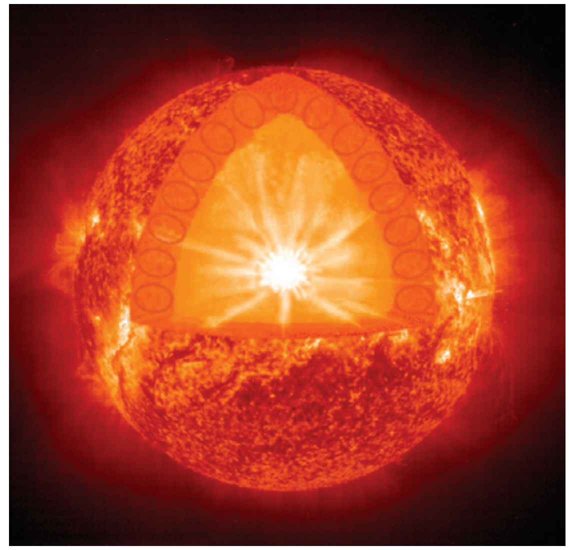
## SDO Can See Inside the Sun

A sensor on SDO called the “Helioseismic Magnetic Imager” (HMI) can see through the Sun’s surface to study what lies beneath.

“It is like taking an ultrasound picture of a baby still inside her mother,” says Dean Pesnell of the Goddard Space Flight Center, “the details are fuzzy but we can see many important things.”

“There’s a lot going on inside the Sun that we don’t understand,” says Todd Hoeksema, a solar physicist at Stanford University, where the HMI was built. “The Solar Dynamics Observatory is bound to deliver some big discoveries.”

A key target of HMI is the Sun’s inner magnetic dynamo, the source of all solar activity. It lies about 140,000 miles below the Sun’s surface.



*SDO will study the solar interior.*

“Understanding how the dynamo works is a holy grail for stellar physics,” says Pesnell.

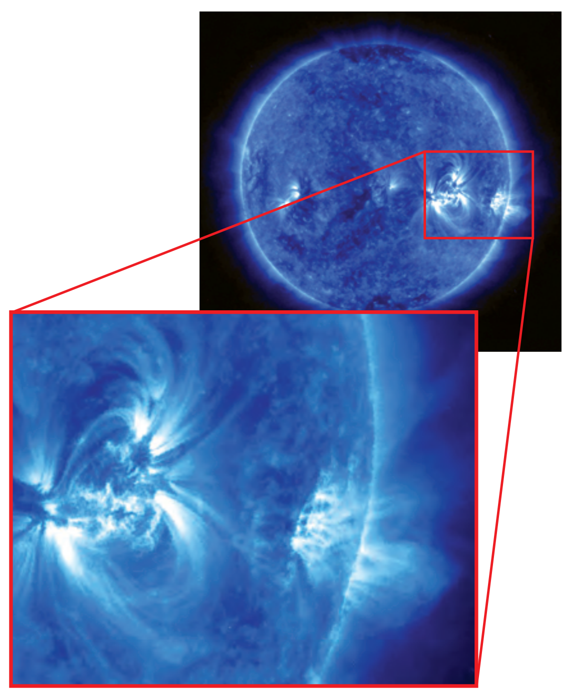
## High-Definition Movies of the Raging Sun… 24/7!

Imagine watching a high-definition movie that never stops. The enormous screen is filled with the raging Sun, unleashing huge solar flares and billion-ton clouds of hot plasma. The amount of data and images SDO will beam back per day is equivalent to downloading half-a-million songs each day.

“By some estimates, SDO will transmit as much as 50 times more science data than any mission in NASA history,” says Dean Pesnell of the Goddard Space Flight Center.

Images with 10 times greater resolution than high-definition television recorded every 0.75 seconds will reveal every nuance of solar activity.

“Because such fast cadences have never been attempted before by an orbiting observatory,” Pesnell adds, “the potential for discovery is great.”



*SDO’s images are super HD*

Researchers believe SDO’s high-speed photography of the Sun could have the same transformative effect on solar physics that the invention of high-speed photography had on many sciences in the 19th century.

Scientists, educators, and members of the general public will be able to browse this huge volume of data using a new software program called HelioViewer (www.Helioviewer.org). Files from different instruments can be combined, panned, and zoomed, giving researchers and others a powerful new way to view the Sun.

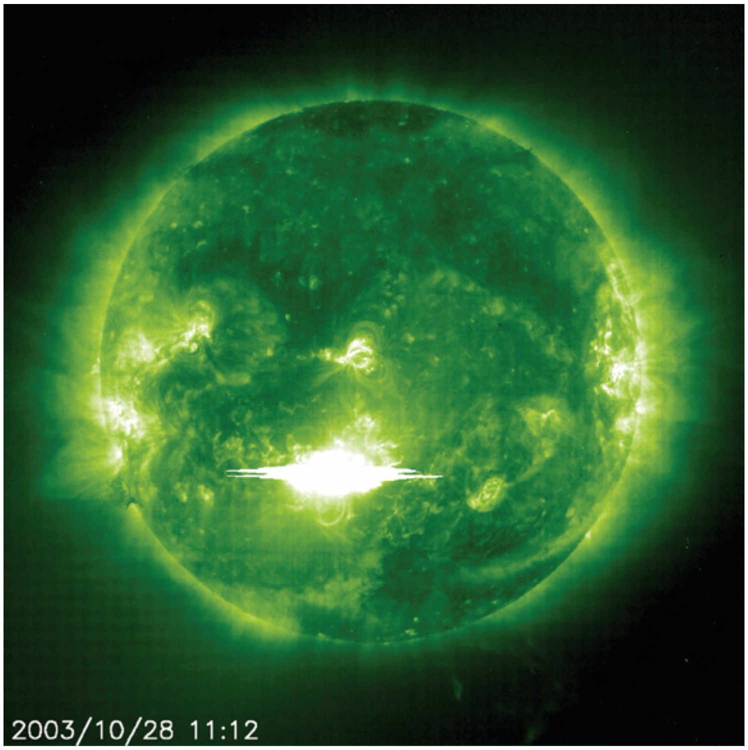
## Deadly Sunburns

SDO will observe the Sun at scorching "extreme ultraviolet" wavelengths. This is where the Sun is most variable.

"If human eyes could see extreme ultraviolet (EUV), no one would doubt that the Sun is a variable star," says Tom Woods of the University of Colorado.

EUV photons are high-energy cousins of regular UV rays that cause sunburns. Fortunately, our atmosphere blocks solar EUV; otherwise a day at the beach could be fatal.

During a solar flare, the Sun's extreme ultraviolet output can vary by factors of 2-100 over time scales of minutes. Surges of EUV photons heat Earth's upper atmosphere, causing the atmosphere to "puff up" and slowly drag down low-orbiting satellites. EUV rays also break apart atoms and molecules, creating a layer of ions in the upper atmosphere that can severely disturb radio signals.



*A powerful solar flare erupts as observed in extreme UV light.*

"EUV is where the action is," says Woods, the lead scientist for SDO's Extreme-ultraviolet Variability Experiment (EVE). "EVE will reveal the Sun as a variable star!"

## SDO is the First Mission of NASA's Living With a Star Program

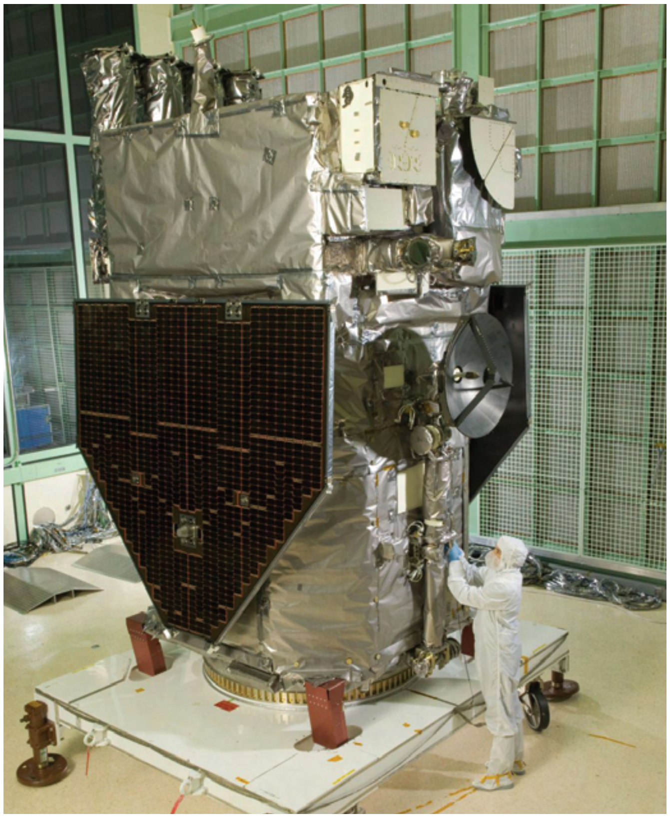
What if you woke up one morning and found your planet had been swallowed by the atmosphere of a star?

Get out of bed, look out the window. Auroras are dancing along the horizon. Dark sunspots crackle overhead—each little 'pop' is more powerful than a nuclear bomb. On TV, a weather forecaster warns astronauts, "a solar flare is sure to erupt," although he can't say exactly when. Moments later, the satellite signal begins to flicker.

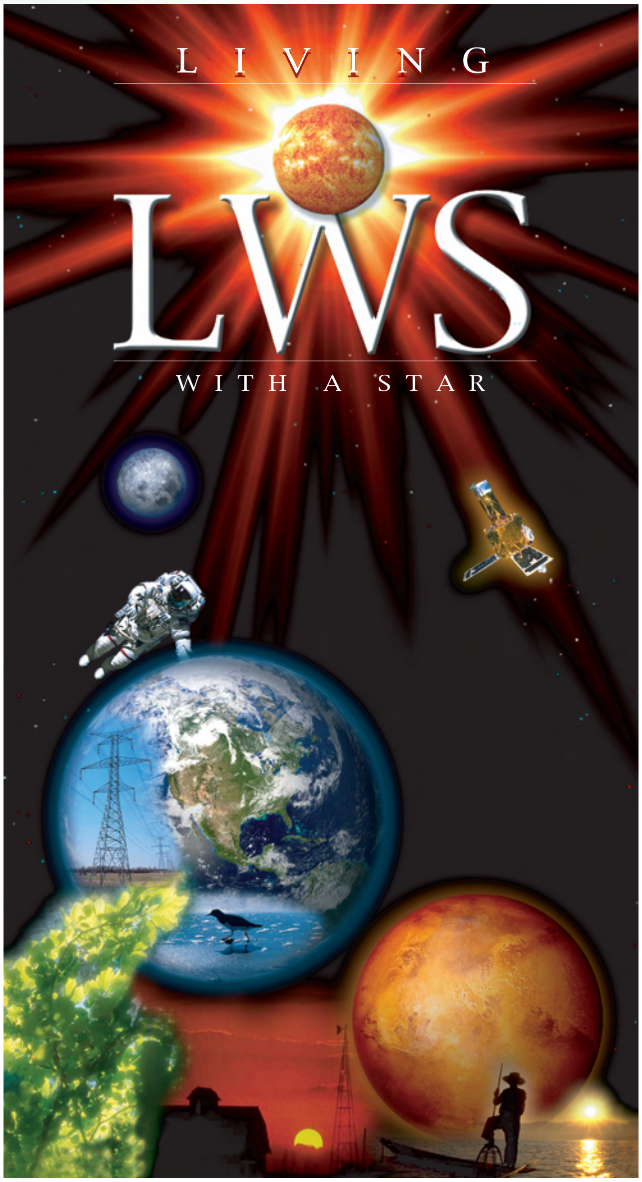
Where is this place? Welcome to planet Earth.

"It's true. Earth orbits inside the atmosphere of the Sun," says Lika Guhathakurta, program manager of NASA's Living with a Star (LWS) program. "Truly, we are living with a star."

The Solar Dynamics Observatory is the first mission of NASA's Living With a Star Program. It will reveal how solar activity affects our planet and help us anticipate what lies ahead.



*The SDO spacecraft getting a final checkout before heading to Cape Canaveral for launch.*



## Solar Dynamics Observatory: A Solar Variability Mission

For some years now, an unorthodox idea has been gaining favor among astronomers. It contradicts old teachings and unsettles thoughtful observers, especially climatologists.

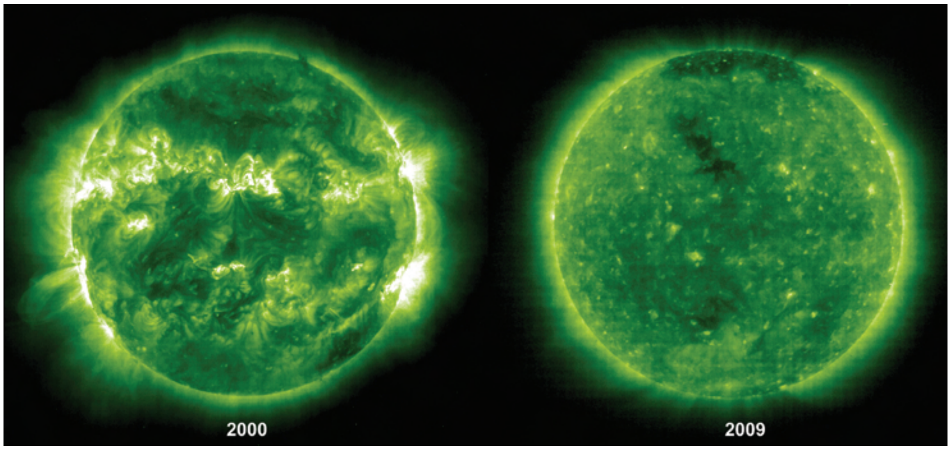
"The Sun," explains Lika Guhathakurta of NASA headquarters in Washington DC, "is a variable star."

But it looks so constant!

That's only a limitation of the human eye. Modern telescopes and spacecraft have penetrated the Sun's blinding glare and found a maelstrom of unpredictable turmoil. Solar flares explode with the power of a billion atomic bombs. Clouds of magnetized gas (CMEs) big enough to swallow planets break away from the stellar surface. Holes in the Sun's atmosphere spew million mile-per-hour gusts of solar wind.

And those are the things that can happen in just one day.

Over longer periods of decades to centuries, solar activity waxes and wanes with a complex rhythm that researchers are still sorting out. The most famous "beat" is the 11-year sunspot cycle, described in many texts as a regular, clockwork process. In fact, it is frustratingly unpredictable.




*A very dynamic Sun (left) compared to a Sun deep in solar minimum (right) helps to illustrate the extremes of a solar cycle.*

"It's not even 11 years," says Guhathakurta. "The cycle ranges in length from 9 to 12 years. Some cycles are intense, with many sunspots and solar flares; others are mild, with relatively little solar activity. In the 17th century, the cycle appeared to stop altogether for about 70 years, and no one knows why."

There is no need, however, to go so far back in time to find an example of the cycle's capriciousness. Right now the Sun is in the pits of a century-class solar minimum that almost no one seems to have predicted, and no one knows when it will end.

"The solar minimum of 2008-2009 has taken us by surprise," says David Hathaway of the Marshall Space Flight Center. "It highlights how far we still have to go to successfully forecast solar activity."

That's a problem, because human society is increasingly vulnerable to solar flare ups. Our modern world depends on a network of interconnected high-tech systems for the basics of daily life. Smart power grids, GPS navigation, air travel, financial services, emergency radio communications—they can all be knocked out by intense solar activity.

According to a 2008 study by the National Academy of Sciences, a century-class solar storm could cause twenty times more economic damage than Hurricane Katrina.

“Understanding solar variability is crucial,” says space scientist Judith Lean of the Naval Research Lab in Washington DC. “Our modern way of life depends upon it.”

Enter the Solar Dynamics Observatory—“SDO” for short—slated to launch in 2010 from the Kennedy Space Center in Florida.

SDO is designed to probe solar variability unlike any other mission in NASA history. It will observe the Sun faster, deeper, and in greater detail than previous observatories, breaking barriers of timescale and clarity that have long blocked progress in solar physics.

“SDO is the Solar Variability Mission,” says Guhathakurta, “and it is going to revolutionize our view of the Sun.”

The revolution begins with high-speed photography. A bank of multi-wavelength telescopes and cameras called the “Atmospheric Imaging Assembly” (AIA) will record IMAX®-quality images of the Sun every 10 seconds. For comparison, previous observatories have taken pictures at best every few minutes with resolutions akin to what you see on the web, not at a movie theatre. Researchers believe that SDO’s rapid-fire cadence could have the same transformative effect on solar physics that the invention of high-speed photography had on many sciences in the 19th century.

SDO doesn’t stop at the stellar surface. A sensor onboard SDO, the Helioseismic Magnetic Imager (HMI), can actually look inside the Sun at the solar dynamo itself.

The solar dynamo is a network of deep plasma currents that generates the Sun’s tangled and sometimes explosive magnetic field. It regulates all forms of solar activity from the lightning-fast eruptions of solar flares to the slow decadal undulations of the sunspot cycle.

“Understanding the inner workings of the solar dynamo has long been a ‘holy grail’ of stellar physics,” says Dean Pesnell of the Goddard Space Flight Center. “HMI could finally deliver this to us.”

The dynamo is hidden from view by about 140,000 miles of overlying hot gas. SDO penetrates the veil using a technique familiar to geologists—seismology. Just as geologists probe Earth’s interior using waves generated by earthquakes, solar physicists can probe the Sun’s interior using acoustic waves generated by the Sun’s own boiling turbulence. An instrument onboard SDO called the “Helioseismic Magnetic Imager” (HMI) detects the waves, which researchers on Earth can transform into clear pictures of the structures below the solar surface.

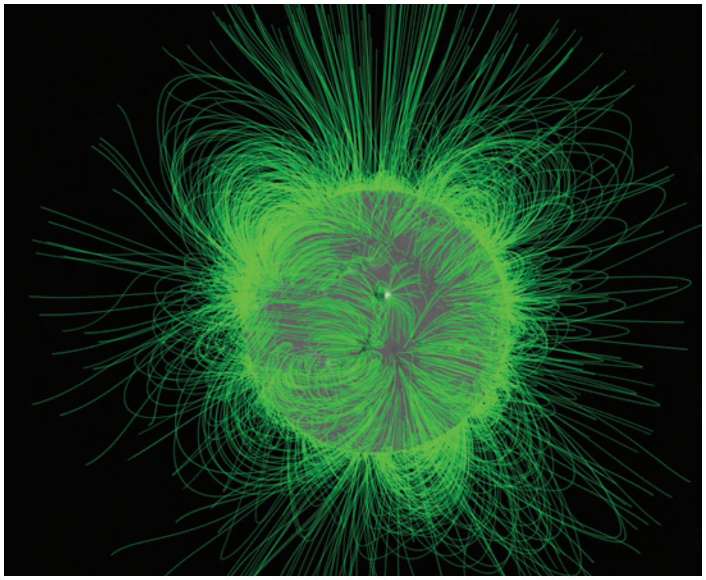
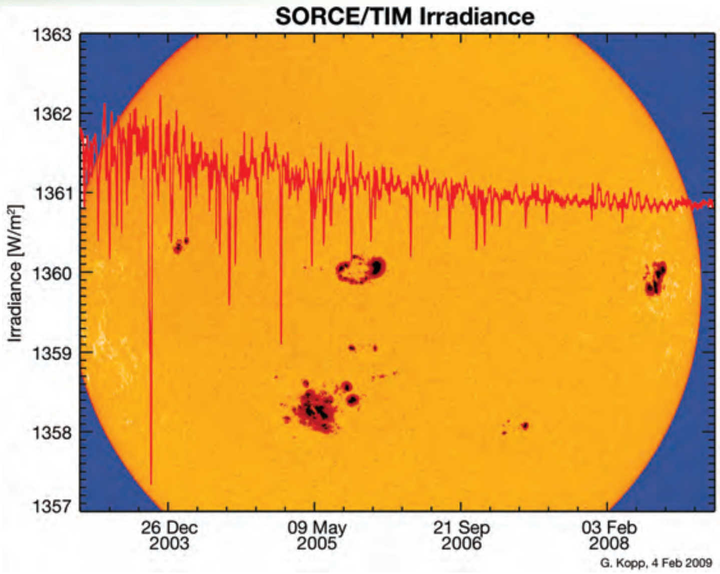


*Illustration of convoluted magnetic field lines extending out all over the Sun.*

## Solar Dynamics Observatory: The Solar Variability-Mission (Continued)




*Measurements from the SORCE mission indicate that the variability of total solar irradiance has decreased over the past six years.*

Just as geologists probe Earth's interior using waves generated by earthquakes, solar physicists can probe the Sun's interior using acoustic waves generated by the Sun's own boiling turbulence. An instrument onboard SDO called the "Helioseismic Magnetic Imager" (HMI) detects the waves, which researchers on Earth can transform into fairly clear pictures.

Finally—and of most immediate relevance for Earth—SDO will observe the Sun at wavelengths where the Sun is most variable—the extreme ultraviolet (EUV). EUV photons are high-energy cousins of regular UV rays that cause sunburns. Fortunately, our atmosphere blocks solar EUV; otherwise a day at the beach could be fatal. In space, solar EUV emission is easy to detect and arguably the most sensitive indicator of solar activity.

"If human eyes could see EUV wavelengths, no one would doubt that the Sun is a variable star," says Tom Woods of the University of Colorado.

During a solar flare, the Sun's extreme ultraviolet output can vary by factors of hundreds to thousands in a matter of seconds. Surges of EUV photons heat Earth's upper atmosphere, causing the atmosphere to "puff up" and slowly drag down low-orbiting satellites. EUV rays also break apart atoms and molecules, creating a layer of ions in the upper atmosphere that can severely disturb radio signals. According to Judith Lean, "EUV controls Earth's environment thoughout the entire atmosphere above about 100 km."

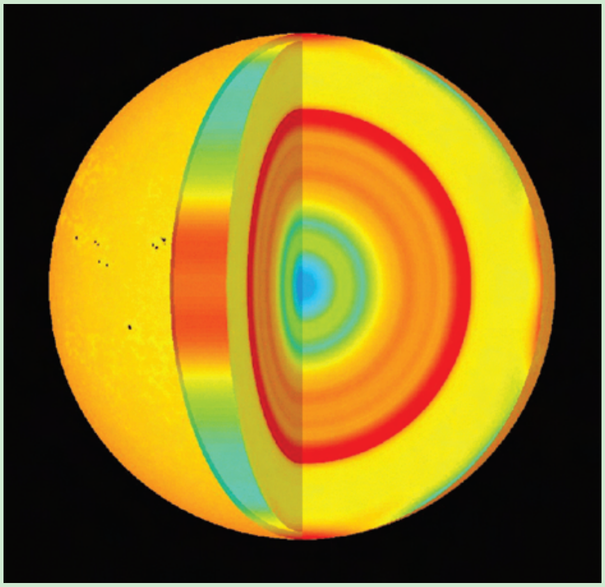
"EUV is where the action is," agrees Woods.

That's why Woods and colleagues built an extreme ultraviolet sensor for SDO called the EUV Variability Experiment ("EVE"). "EVE gives us the highest time resolution (10 sec) and the highest spectral resolution (<0.1 nm) that we've ever had for measuring the Sun, and we'll have it 24/7," he says. "This is a huge improvement over past missions."

Woods expects EVE to reveal how fast the Sun can change—"we really don't know," he points out—and to surprise astronomers with the size of the outbursts.

AIA. EVE. HMI. For the next five years, the Solar Dynamics Observatory will use these instruments to redefine our star and its potential for variability. What unorthodox ideas will they beam back? Old teachings beware!

## ***Solar Constant is an Oxymoron***


*SDO will be able to detect helioseismic waves inside the Sun.*

For years, astronomers were so convinced of the Sun's constancy, they called the irradiance of the Sun "the solar constant," and they set out to measure it as they would any constant of Nature.

By definition, the solar constant is the amount of solar energy deposited at the top of Earth's atmosphere in units of watts per meter-squared. All wavelengths of radiation are included—radio, infrared, visible light, ultraviolet, x-rays, and so on. The approximate value of the solar constant is 1361 W/m$^2$.

Measuring the solar constant from Earth's surface is difficult because of clouds, atmospheric absorption, and other complicating factors. So NASA has spent decades carefully measuring the solar constant from space. Today, the VIRGO, ACRIM, and SORCE instruments are measuring the Sun's irradiance vs. time with precisions approaching 10 parts per million per year. Future instruments scheduled for flight on NASA's Glory and NOAA's NPOESS spacecraft aim for even higher precisions.

To the amazement of many researchers, the solar constant has turned out to be not constant.

"Solar constant is an oxymoron," says Judith Lean of the Naval Research Lab. "Satellite data show that the Sun's total irradiance rises and falls with the sunspot cycle by a significant amount."

"It is like taking an ultrasound picture of a baby still inside her mother," says Dean Pesnell of the Goddard Space Flight Center, "the details are fuzzy but we can see many important things."

At solar maximum, the Sun is about 0.1% brighter than it is at solar minimum. That may not sound like much, but consider the following: A 0.1% change in 1361 W/m$^2$ equals 1.4 Watts/m$^2$. Averaging this number over the spherical Earth (divide by 4) and correcting for Earth's reflectivity (multiply by 0.7) yields 0.24 Watts for every square meter of our planet.

"Add it all up and you get a lot of energy," says Lean. "How this might affect weather and climate is a matter of—at times passionate—debate."

While the Solar Dynamics Observatory revolutionizes observations of the solar dynamo and extreme-ultraviolet variability, other NASA spacecraft will measure changes in the Sun's total irradiance and spectral irradiance at longer wavelengths. Working together, SDO and the others could shed new light on this important topic—perhaps revealing some other oxymorons as well.

## Avalanche! The Incredible Data Stream of SDO

When NASA's Solar Dynamics Observatory (SDO) leaves Earth aboard an Atlas V rocket, the thunderous launch will trigger an avalanche.

Mission planners are bracing themselves—not for rocks or snow, but an avalanche of data.

"SDO will beam back 150 million bits of data per second, 24 hours a day, 7 days a week," says Dean Pesnell of the Goddard Space Flight Center in Greenbelt, Md. That's almost 50 times more science data than any other mission in NASA history. "It's like downloading 500,000 iTunes® songs a day."

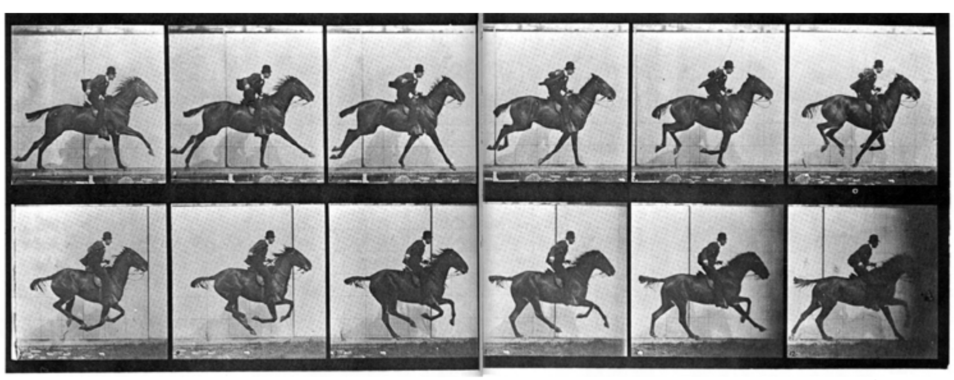
SDO is on a mission to study the Sun in unprecedented detail. Onboard telescopes will scrutinize sunspots and solar flares using more pixels and colors than any other observatory in the history of solar physics. And SDO will reveal the Sun's hidden secrets in a prodigious rush of pictures.

"SDO is going to send us images ten times better than high definition television," says Pesnell, the project scientist for the new mission. A typical HDTV screen has 1280 x 720 pixels; SDO's images will have almost four times that number in the horizontal direction and five times in the vertical. "The pixel count is comparable to an IMAX® movie—an IMAX® filled with the raging Sun, 24 hours a day."

*SDO will beam back 150 million bits of data every second*

Spatial resolution is only half the story, though. Previous missions have photographed the Sun no faster than once every few minutes. SDO will shatter that record.

"We'll be getting IMAX®-quality images every 10 seconds," says Pesnell. "We'll see every nuance of solar activity." Because these fast cadences have never been attempted before by an orbiting observatory, the potential for discovery is great.



*In early photography, high-cadence images revealed details of motion more than the human eye could see*

To illustrate the effect this might have on solar physics, Pesnell recalls the 18th century photographer Eadweard Muybridge, who won a famous bet for racehorse owner Leland Stanford. In those days, horses were widely thought to keep at least one hoof on the ground even in full gallop. That's how it appeared to the human eye.

“But when Muybridge photographed horses using a new high-speed camera system, he discovered something surprising,” says Pesnell. “Galloping horses spend part of the race completely airborne—all four feet are off the ground.”

Pesnell anticipates similar surprises from high-speed photography of the Sun. The images could upend mainstream ideas about sunspot genesis, what triggers solar flares, and how explosions ripple through the Sun’s atmosphere en route to Earth. The Solar Dynamics Observatory has three main instruments. The Atmospheric Imaging Assembly (AIA) is a battery of four telescopes designed to photograph the Sun’s surface and atmosphere. AIA filters cover 10 different wavelength bands, or colors, selected to reveal key aspects of solar activity. The bulk of SDO’s data stream will come from these telescopes.

*One of two large radio antennas that serve as SDO’s dedicated ground station near Las Cruces, NM.*

The Extreme Ultraviolet Variability Experiment (EVE) will measure fluctuations in the Sun’s ultraviolet output. EUV radiation Sun has a direct and powerful effect on Earth’s upper atmosphere, heating it, puffing it up, and breaking apart atoms and molecules. “We really don’t know how fast the Sun varies at these wavelengths,” notes Pesnell. “We’re guaranteed to learn something new.”

The Helioseismic and Magnetic Imager (HMI) will map solar magnetic fields and peer beneath the Sun’s opaque surface using a technique called helioseismology. A key goal of this experiment is to decipher the physics of the Sun’s magnetic dynamo.

To gather data from all three instruments, NASA has set up a pair of dedicated radio antennas near Las Cruces, New Mexico. SDO’s geosynchronous orbit will keep the observatory in constant view of the two 18-meter dishes around the clock for the duration of the observatory’s five-year mission. Not a single bit should be lost.

“We’re ready,” says Pesnell. “Let the avalanche begin!”

# SDO Mission Q&A

## WHAT IS SDO?

SDO stands for the Solar Dynamics Observatory.

## WHAT IS SDO'S PURPOSE AND MISSION?

SDO will study how solar activity is created and how space weather results from that activity. Measurements of the Sun's interior, magnetic field, the hot plasma of the solar corona, and the irradiance will help meet the objectives of the SDO mission.

## WHAT IS UNIQUE OR DIFFERENT ABOUT SDO?

SDO is a mission that utilizes, for the first time, a unique orbit to provide high-resolution solar magnetic field images, EUV images, and measurements of the solar UV flux falling on the Earth. It will provide new views of the solar interior and the subsurface structures. By some estimates, SDO will transmit as much as 50 times more science data than any mission in NASA history. Images with 10 times greater resolution than high-definition television recorded every 0.75 seconds will reveal every nuance of solar activity. SDO data rate is equivalent to downloading a half million songs a day. For context, the Solar and Heliospheric Observatory (SOHO) provides a picture of the Sun once every 12 minutes, and the Solar Terrestrial Relations Observatory (STEREO) once every 90 seconds.

## WHEN WILL SDO LAUNCH?

SDO is scheduled to launch no earlier than February 3, 2010.

## HOW LONG WILL THE SDO MISSION LAST?

SDO's primary science mission is anticipated to last 5 years. However, the satellite has enough fuel to last 10 years.

## WHERE WILL SDO ORBIT?

SDO will use a geosynchronous orbit at the longitude of New Mexico and inclined 28° from the equator. This allows continuous contact with the ground station near Las Cruces, New Mexico. The actual path in the sky will be a figure eight.

## WHAT IS THE EXPECTED COST OF THE SDO MISSION?

Mission managers anticipate the SDO mission will cost approximately $850 million, which includes the cost of the satellite, its launch, and 5 years of operations and data analysis.

## HOW WILL THE SDO MISSION BENEFIT THE AVERAGE PERSON?

The SDO mission will allow scientists to gain far better understanding of the causes of space weather that can disable satellites, cause power grid failure, and disrupt GPS communications. Also, insights gained from SDO observations will lead to an increased understanding of the role solar variability plays in changes in atmospheric chemistry and dynamics.

## ARE SOLAR STORMS A DANGER TO ASTRONAUTS?

Yes. The protons and plasma from large solar storms can expose astronauts, who aren't within Earth's protective atmosphere, to harmful or lethal amounts of radiation. By improving our ability to predict and understand these storms with instruments like those aboard SDO. The SDO mission will also help engineers design safer spacecraft for future astronauts.

## WHO WILL LOOK AT THE DATA PRODUCED BY SDO?

The solar science community of 2,000 researchers, the space-weather community, educators, and the public will look at SDO data. It is expected that SDO data will supplement the nation's operational space weather missions.

## WHAT SCIENCE INSTRUMENTS WILL SDO CARRY?

SDO will carry three science instruments: Atmospheric Imaging Assembly (AIA), Extreme Ultraviolet Variability Experiment (EVE), and Helioseismic and Magnetic Imager (HMI).

## WHERE WILL THE DATA BE STORED AND ARCHIVED?

Stanford University in Palo Alto, California, will analyze, archive, and manage the data from SDO's HMI and AIA instruments; Lockheed Martin's Solar and Astrophysics Laboratory (LMSAL) in Palo Alto, California, will create and serve data products from AIA; the University of Colorado Laboratory for Atmospheric and Space Physics in Boulder, Colorado, will analyze, archive, and manage the data from the EVE instrument.

## WHAT IS THE SOLAR CYCLE?

The Solar Cycle is an 11-year pattern in the number of sunspots, coronal mass ejections (CMEs), solar flares, and other solar activity. About every 11 years the Sun's magnetic field changes polarity from north to south. Eleven years later it flips back. People may have heard of this as the 22-year magnetic cycle because after two 11-year sunspot cycles the Sun's magnetic field will be back the way it was at the start of the 22 years. During solar minimum, the Sun may churn out strong CMEs every two days; that's approximately 180 CMEs per year, although only about 10 to 15 CMEs are directed at Earth. During solar maximum, the Sun averages five CMEs daily and sends about 100 to 150 CMEs toward Earth each year.

## WHAT IS SPACE WEATHER?

Space weather originates with the variable magnetic activity of the Sun. Activity on the Sun's surface, such as CMEs and solar flares, can cause high levels of radiation in space. This radiation comes to Earth as plasma (electrically charged particles) or electromagnetic radiation (light), including X-rays and ultraviolet wavelengths.

## WHAT IS THE DIFFERENCE BETWEEN SOLAR ACTIVITY AND SPACE WEATHER?

Solar activity describes events that take place on the Sun, while space weather describes the effect solar activity has on our planet, technology, and the magnetic organization of the solar system.

## HOW WILL SDO IMPROVE OUR KNOWLEDGE AND UNDERSTANDING OF SPACE WEATHER?

SDO will improve our understanding of the physics behind the activity displayed by the Sun's atmosphere, which drives space weather in the heliosphere and in planetary environments. SDO will determine how the Sun's magnetic field is generated, structured, and converted into violent solar events that cause space weather. SDO observations start in the interior of the Sun where the magnetic field that is the driver for space weather is created. Next, SDO will observe the solar surface to directly measure the magnetic field and the solar atmosphere to understand how magnetic energy is linked to the interior and converted to space weather causing events. Finally, SDO will measure the extreme ultraviolet irradiance of the Sun that is a key driver to the structure and composition of the Earth's upper atmosphere.

## WHAT IS HELIOPHYSICS?

Heliophysics is the exploration of the magnetic variable Sun, its effects on the planets of the solar system including Earth, and space environmental conditions and their evolution.

# Launch and Operations Quick Facts

- SDO is anticipated to launch no earlier than February 3, 2010.

- SDO is planned to launch aboard an Atlas V rocket from Cape Canaveral, Fla.

- Total mass of the spacecraft at launch is 3,100 kg (6,800 lb) that includes 290 kg (640 lb) for the instrument payload and 1,450 kg (3,086 lb) for the fuel.

- Overall length of the spacecraft along the Sun-pointing axis is 4.5 m (14.8 ft), and each side is 2.22 m (7.3 ft).

- Span of the spacecraft with extended solar panels is 6.5 m (21.3 ft).

- Mission operations center will be located at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

- SDO will be a major component of the Heliophysics System Observatory, a fleet of science missions developed by the NASA Heliophysics Division. Each mission concentrates on understanding a different aspect of the Sun and its heliosphere—the region of the Sun's influence in the galaxy.

- SDO is the first mission in NASA's Living With a Star program. The spacecraft's long-term measurements will give solar scientists in-depth information about changes in the Sun's magnetic field.

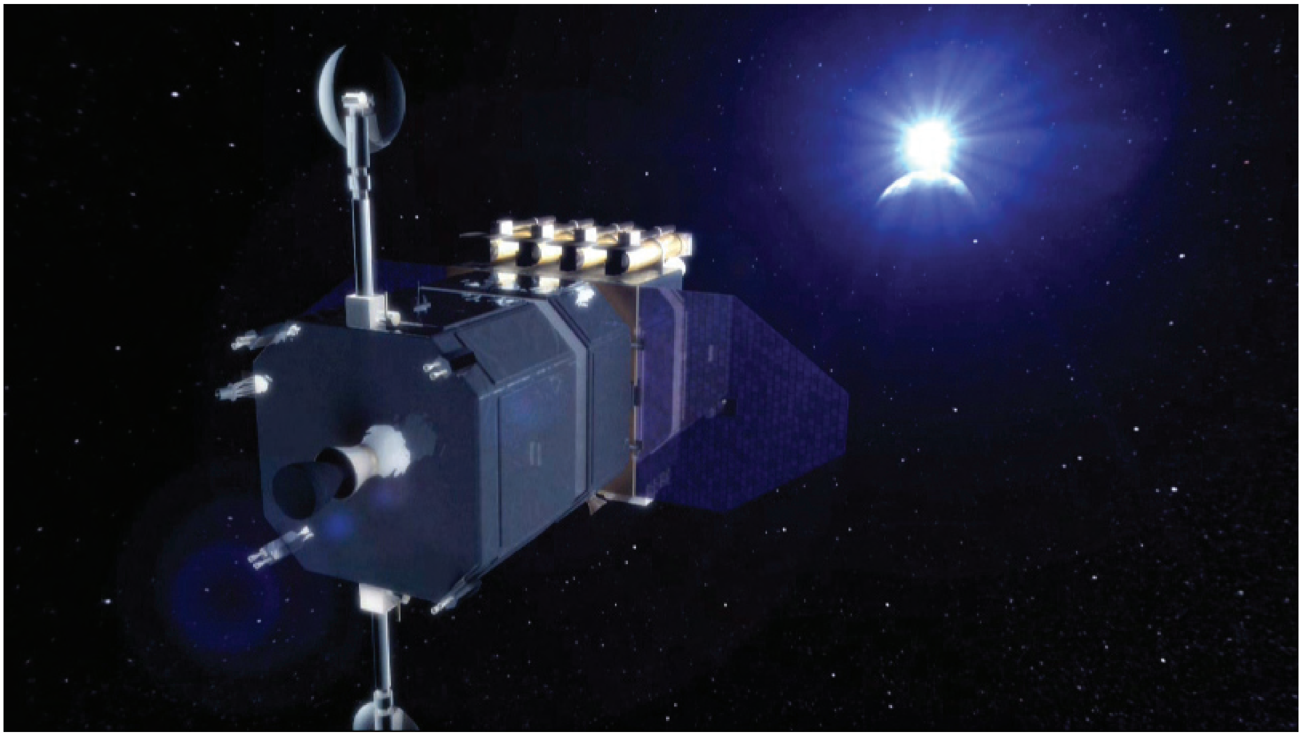


*Illustration of the SDO spacecraft keeping a watchful eye on the Sun, all day, every day.*

# NASA's Living With a Star Program

The goal of NASA's Living With a Star (LWS) Program is to provide the scientific understanding needed for the United States to effectively address those aspects of Heliophysics science that may affect life and society. The ultimate goal is to develop an understanding that will allow for predictive capability of the space weather conditions at Earth and in the interplanetary medium.

LWS missions have been formulated to answer specific science questions needed to understand the linkages among the interconnected systems that impact us. These missions will give us a far better understanding of the causes of space weather that can disable satellites, cause power grid failure, and disrupt GPS communications. Also, insights gained from SDO observations will lead to an increased understanding of the role solar variability plays in changes in atmospheric chemistry and climate. The coordinated LWS program includes strategic missions, targeted research and technology development, a space environment testbed flight opportunity, and partnerships with other agencies and nations.

LWS is a crosscutting program whose goals and objectives have the following links:

**Space Science:**
LWS quantifies the physics, dynamics, and behavior of the Sun-Earth system over the 11-year solar cycle.

**Earth Science:**
LWS improves understanding of the effects of solar variability and disturbances on terrestrial climate change.

**Human Exploration and Development:**
LWS provides data and scientific understanding required for advanced warning of energetic particle events that affect the safety of humans.

**Aeronautics and Space Transportation:**
LWS provides detailed characterization of radiation environments useful in the design of more reliable electronic components for air and space transportation systems.

**Biological and Physical Research:**
LWS defines the radiation environment beyond the Earth's magnetosphere to enable exploration of interplanetary space by humans.

### LWS Web Sites:

*Missions:*

| | |
|---|---|
| SDO | http://sdo.gsfc.nasa.gov/ |
| RBSP | http://nasascience.nasa.gov/missions/rbsp |
| BARREL | http://nasascience.nasa.gov/missions/barrel-1 |
| Solar Orbiter | http://nasascience.nasa.gov/missions/solar-orbiter |
| Solar Probe Plus | http://nasascience.nasa.gov/missions/solar-probe |

### Other Program Elements:

| | |
|---|---|
| LWS Targeted Research and Technology Program | http://lwstrt.gsfc.nasa.gov/ |
| Space Environment Testbed Flight Opportunity | http://lws-set.gsfc.nasa.gov/ |
| International Living With a Star Program | http://ilws.gsfc.nasa.gov/ |

# A Timeline of Solar Cycles

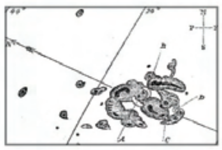
## Milestones of Solar Exploration

**1610**

Galileo Galilei is among the first to study the Sun & sunspots with a telescope

**1859**

First solar flare observed and sketched by Richard Carrington



**1908**

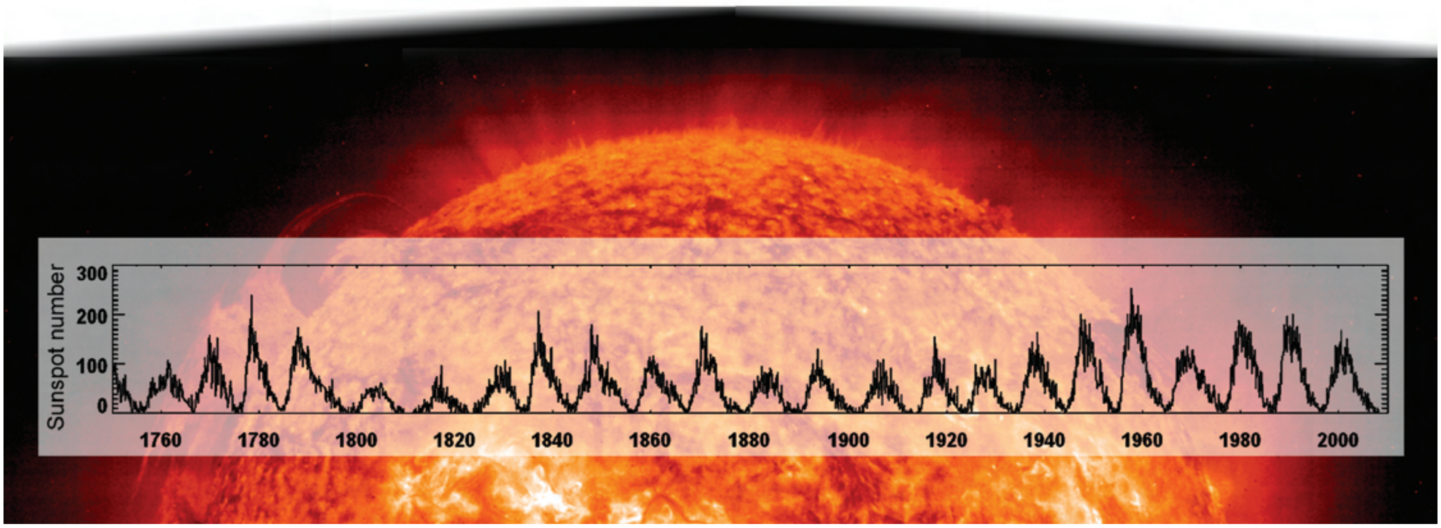
George Ellery Hale discovers magnetic fields in sunspots -- a key to under-standing solar activity

**1973**

Skylab's X-ray telescopes reveal coronal holes

**1995**

The Solar & Heliospheric Observatory (SOHO) begins sophisticated solar study mission




*The Monthly Sunspot Number since 1750*

## Some Major Solar Storms

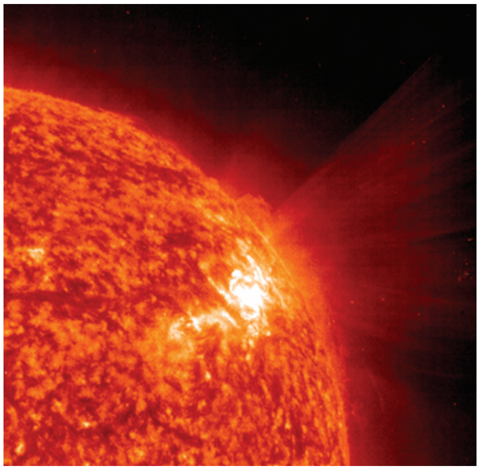
| | |
|---|---|
| 9/2/1859 | Strongest solar storm recorded, with aurora worldwide and telegraph disruptions |
| 5/13/1921 | Storm shuts down NY City transit system with induced ground currents |
| 3/25/1940 | Easter Sunday storm halts U.S. long distance phone service for hours; radio and wire services disrupted |
| 2/10/1958 | Radio blackout caused by one of the 10 strongest storms |
| 3/13/1989 | Quebec power grid collapses for nine hours |
| 10/29/2003 | “Halloween” storms cause numerous satellite problems and produce the brightest X-ray flare ever recorded |

# Acronyms and Abbreviations

| | |
|---|---|
| **AIA** | Atmospheric Imaging Assembly |
| **CME** | Coronal Mass Ejection |
| **EUV** | Extreme Ultraviolet |
| **EVE** | Extreme Ultraviolet Variability Experiment |
| **GSFC** | Goddard Space Flight Center |
| **H** | Hydrogen |
| **He** | Helium |
| **HF** | High Frequency |
| **HMI** | Helioseismic and Magnetic Imager |
| **ISM** | Interstellar Medium |
| **LASP** | Laboratory for Atmospheric and Space Physics |
| **NASA** | National Aeronautics & Space Administration |
| **NSSDC** | National Space Science Data Center |
| **RHESSI** | Reuven Ramaty High Energy Solar Spectroscopic Imager |
| **SDO** | Solar Dynamics Observatory |
| **SOHO** | Solar & Heliospheric Observatory |
| **STEREO** | Solar Terrestrial Relations Observatory |
| **TRACE** | Transition Region and Coronal Explorer |
| **TSI** | Total Solar Irradiance |
| **UV** | Ultraviolet |

# Abbreviations for Units of Measure

| | |
|---|---|
| **Hz** | Hertz—cycles per second |
| **K** | kelvin |
| **kg** | kilogram |
| **m** | meter |
| **MHz** | megahertz |
| **mm** | millimeter |
| **m/s** | meters per second |
| **nm** | nanometer |
| **W** | watt |
| **W/m²** | watts per meter squared |

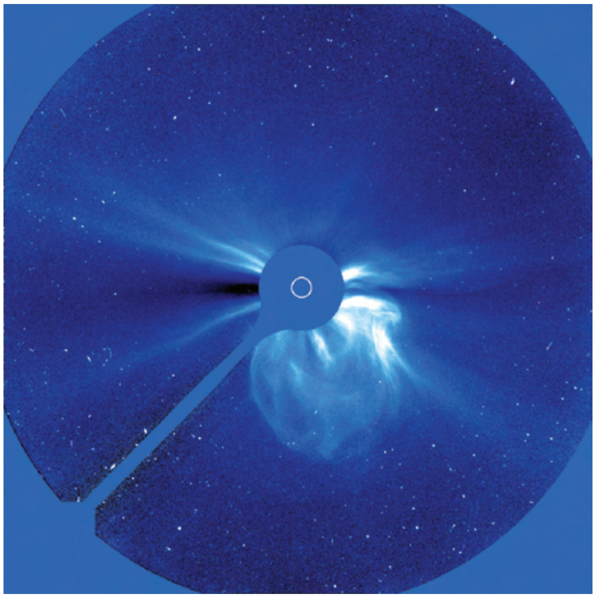


*A solar storm blasts particles and magnetic field out into space from an active region on the Sun.*

# Solar Science Glossary

**ACE** — Advanced Composition Explorer satellite (monitors the solar wind)

**Aurora** — A display of colored light in the atmosphere, caused by collisions between charged particles from a planet's magnetosphere and atmospheric gases near the planet's magnetic poles. Auroras are visible on Earth as the aurora borealis, or northern lights, and the aurora australis, or southern lights.



In this coronagraph, the white circle represents the size of the Sun.

**Chromosphere** — 2,500 km thick (1,600 mi) layer of plasma above the Sun's photosphere. Temperatures range from ~4500 K to 60,000 K (110,000 to 8,000°F). The word chromosphere means, literally, "color sphere" and refers to its reddish color when seen with the naked eye during a total solar eclipse.

**Convection** — The movement of matter due to changes in temperature and density. Warm material rises because it is less dense (lighter) and cool material sinks because it is more dense (heavier).

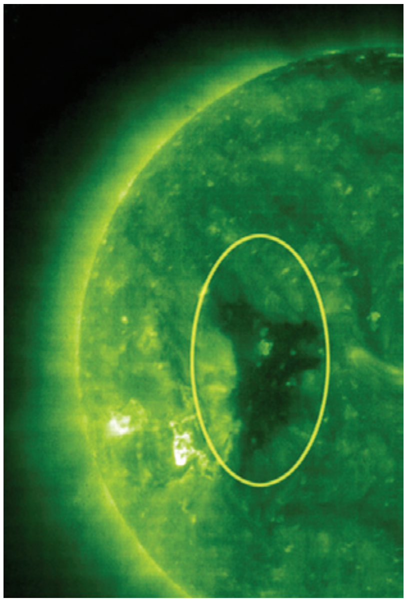
**Convective Zone** — The Sun is made up of different layers. From its center outward, the Sun's layers include the core, the convective zone, the radiative zone, the photosphere, the chromosphere, and the corona. The convective zone extends from just below the photosphere to the radiative zone. In this region convection currents transport the Sun's energy to the surface.

**Core** — The innermost layer of the Sun, where energy is released by the fusing together of nuclei to form heavier nuclei (nuclear fusion).

**Corona** — The outermost layer of the Sun's outer atmosphere. This halo of ions extends millions of miles into space and consists of a gas that is much thinner than Earth's atmosphere. The temperature is greater than one million kelvin. The corona is visible to the naked eye only during a solar eclipse.

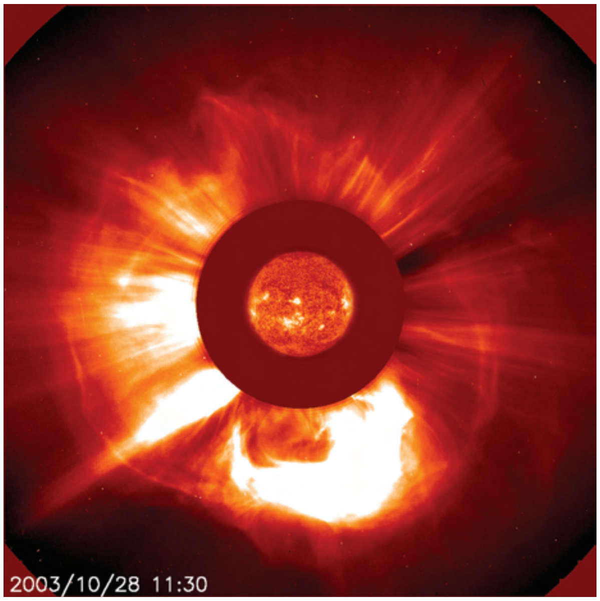
**Coronagraph** — An instrument designed to study the Sun's corona by covering the bright disk of the Sun. This instrument creates an artificial eclipse that allows us to see the Sun's faint outer atmosphere. Each STEREO observatory has two coronagraphs.

**Coronal Hole** — An area of the corona that appears dark when viewed in ultraviolet light. They are usually located around the poles of the Sun, but can occur at other latitudes as well. The magnetic field lines in a coronal hole extend out into the solar wind rather than coming back down to the Sun's surface. Because the magnetic field lines extend into space, they carry hot material with them and leave patches of the solar surface cooler.



A coronal hole in extreme UV light.

**Coronal Mass Ejection (CME)** — A catastrophic expansion of a part of the coronal magnetic field that causes a huge bubble of plasma and magnetic field to erupt from the Sun. A CME can last for several hours and travels though space at a million miles per hour. CMEs are usually accompanied by a solar flare. The charged particles and



A coronal mass ejection.

magnetic fields associated with CMEs can cause power and communications outages, damage to satellites, and health problems for astronauts. They usually take about three days to reach Earth, but very fast ones can arrive in under a day.

**Electromagnetic Radiation** — Energy that travels through space at the speed of light and moves by the interaction of electric and magnetic fields.

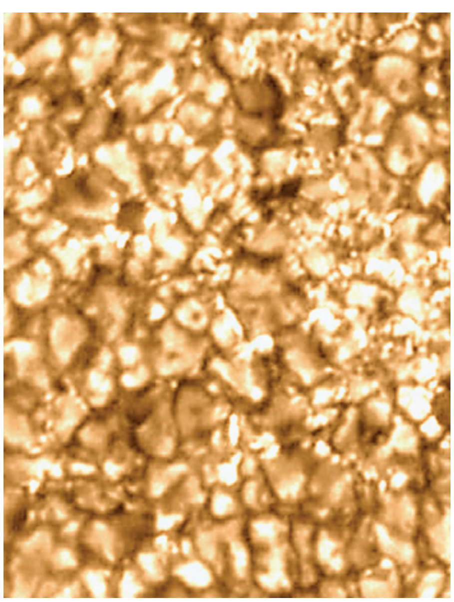
**Electromagnetic Spectrum** — The entire range of wavelengths of electromagnetic energy, including (from short to long wavelengths) gamma rays, X rays, ultraviolet light, visible light, infrared, and radio waves.

**Energetic Particles** — The atoms and molecules of a gas are in constant motion, colliding rapidly and filling all available space. The hotter the gas, the faster the atoms move, and the more energy each holds. In a plasma, the free ions and electrons behave the same way, though they are often much more energetic and move at a large fraction of the speed of light (300,000 km/sec or 186,000 mi/sec). Researchers believe high-energy particles in the solar wind are not merely heated, but actually accelerated by shock waves in front of CMEs and by electric and magnetic effects in flares.

**Faculae** — Bright blotches on the surface of the Sun that emit more radiation than surrounding areas and increase solar irradiance.

**Filament** — A prominence viewed against the solar disk. See prominence.

**Flare** — A rapid release of vast magnetic energy in a sunspot region, causing temperatures to rise tens of millions of degrees in a small area above the solar surface. The resulting radiation surge can cause blackouts of communication signals and damage to satellites. Flares can produce dangerous EUV radiation, X-rays, gamma rays, and high-energy protons.


Granules on the Sun's surface, with each about the size of Texas.

**Gamma Rays** — Created from nuclear reactions, these are the most energetic wavelengths of electromagnetic radiation emitted by the Sun.

**Geomagnetic Storm** — A worldwide disturbance of Earth's magnetic field, caused by solar activity. These storms can cause power outages, communications blackouts, health risks for astronauts in space, damage to satellites, and auroras.

**Granules** — Short-lived cells of plasma that carry heat to the Sun's surface via convection (rising and falling).

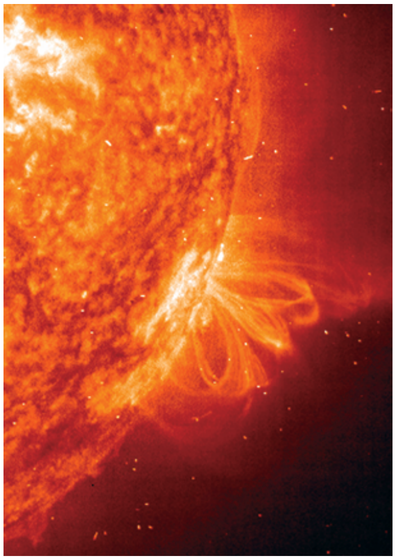
**Infrared** — The range of invisible radiation wavelengths from about 700 nm, just longer than red in the visible spectrum, to 1 mm, on the border of the microwave region.

**Ion** — An atom or molecule that has lost or gained one or more electrons and has become electrically charged as a result.

**Ionization** — A process that produces ions, typically collisions between atoms or electrons, or by interaction with electromagnetic radiation.

**Irradiance** — The amount of radiant energy from a selected source that falls on a surface in a given amount of time.

**Magnetic Loops** — Field lines illuminated by hot plasma flowing along the magnetic field lines.



*Magnetic loops*

**Magnetism** — A force generated by electrical currents and changing electric fields. Magnetism is responsible for almost every feature in the solar atmosphere, from sunspots to CMEs to flares.

**Magnetosphere** — An area around a planet in which the planet's magnetic field is stronger than the magnetic field carried by the solar wind.

**Maunder Minimum** — From 1645 to 1715, scientists believe there was a decrease in the total energy output from the Sun, as indicated by little or no sunspot activity. This period coincided with a climate event on Earth known as the Little Ice Age.

**Photosphere** — The Sun's surface, from which the light we actually see (with the human eye) is emitted. Temperatures average 5,800 K (9,900°F).

**Plasma** — Plasmas are materials whose atoms have lost electrons and become a mixture of ions and electrons. The Sun is made up of plasma created by hot temperatures. Lightning and fluorescent lights are earthly forms of this "thermal" plasma. Wires contain plasma created by the interactions of metal atoms. Because plasmas are dominated by charged particles, they interact strongly with electric and magnetic fields. Plasma is often considered the fourth state of matter (along with solid, liquid, and gas) as most of the matter in the universe is in a plasma.

**Prominence** — A structure in the corona consisting of cool plasma supported by magnetic fields. In visible light, prominences appear as bright structures over the solar limb, but dark when viewed against the bright solar disk. Prominences seen on the disk are also known as filaments. Prominences may become parts of CMEs.

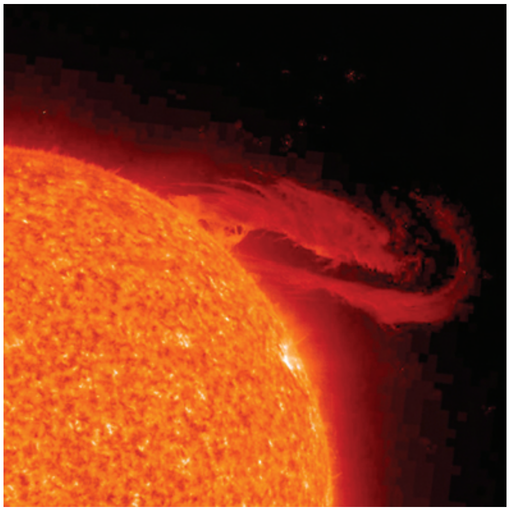
**Radiative Zone** — A layer of the Sun lying between the core and convection zone where energy travels outward through the slow radiation, absorption, and re-radiation of energy by tightly packed atoms.

**Radio Waves** — Electromagnetic radiation with a wavelength greater than 1 mm (beyond infrared).

**Solar Cycle** — An approximately 11-year pattern in the number of sunspots, coronal mass ejections (CMEs), solar flares, and other solar activity. About every 11 years the Sun's magnetic field changes from north to south, and then back again in another 11 years.

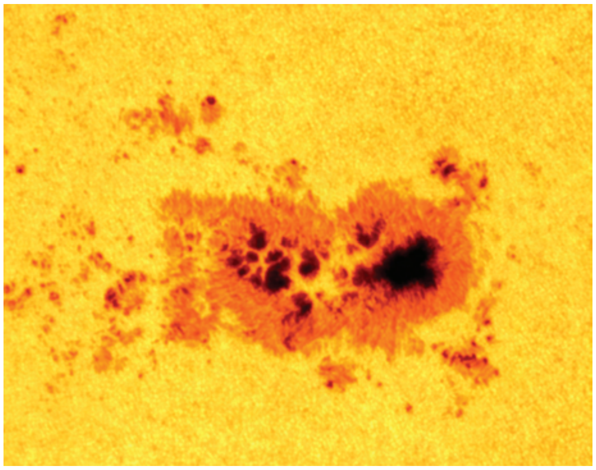
**Solar Spectral Irradiance (SSI)** – The amount of radiant energy of a particular wavelength that falls on a surface in a given amount of time.

**Solar Ultraviolet Irradiance** — The amount of energy released from the Sun in the ultraviolet portion of the spectrumat wavelengths shorter than 400 nm.

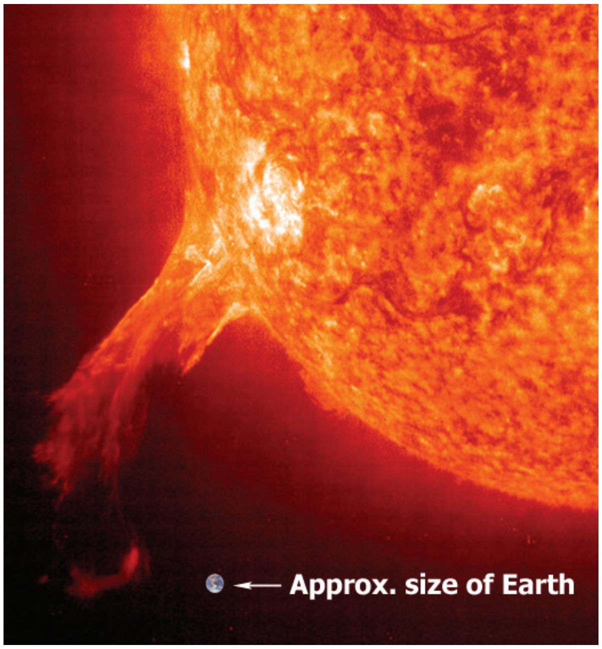


*A large solar prominence*

**Solar Wind** — A stream of plasma coming out of the Sun in all directions at very high speeds—an average of about 400 km/sec, or a million mph. Solar wind is responsible for the tails of comets pointing away from the Sun and for the shape of the magnetosphere around the planets. Solar wind can also have a measurable effect on the flight paths of spacecraft.



*Close-up of a sunspot group*




*Caption?*

**Space Weather** — Refers to conditions on the Sun, in the solar wind, and in Earth's space (magnetic field, ionosphere, and thermosphere) that can influence space- and ground-based technological systems and endanger humans working in space. Adverse conditions in the space environment can disrupt satellite operations, communications, navigation, and electric power distribution grids.

**Spectrograph** — A device that separates light by wavelength (color) in order to produce a spectrum that allows for the identification of elements within the light source.

**Sunspots** — Dark areas on the Sun created by strong magnetic fields beneath the Sun's surface. Sunspots appear dark because they are cooler than the surrounding areas of the photosphere. They range in size from 2,400 km (1,500 mi) to several times Earth's size. Sunspots usually occur in pairs or groups of opposite magnetic polarity that rotate with the surface of the Sun. They are the footprints of magnetic loops pushing through the surface and holding plasma below.

**Total Solar Irradiance** — The total amount of radiant energy from the Sun that falls on a surface in a given amount of time.

**Transition Region** — Area of the Sun's atmosphere with temperatures between those of the chromosphere and the corona, 20,000 and 1,000,000 K (35,000 and 1,800,000°F), respectively.

**Ultraviolet** — Electromagnetic radiation at wavelengths shorter than 400 nm.

**Visible Light** — Electromagnetic radiation from about 400 to 700 nm, which is detectable by the human eye.

**Wavelength** — The distance between one peak or crest of a wave (of light, heat, or other energy) and the next corresponding peak or crest. Wavelengths of light from the Sun range from radio waves to gamma rays.

**Zeeman effect** — A splitting of a spectral line into several components due to the presence of a static magnetic field. The Zeeman effect is measured using polarized filters. When astronomers measure the effect in absorption lines, it is called the Inverse Zeeman effect.

# SDO Mission Management

NASA's Solar Dynamics Observatory (SDO) is a five-year mission to study the Sun. As the first mission of NASA's Living With a Star Program, SDO will investigate the causes of solar variability. The spacecraft will study the solar atmosphere in many wavelengths simultaneously to determine how the Sun's magnetic field is generated and structured, and how this stored magnetic energy is converted and released in the form of the solar wind, energetic particles, and changes in solar irradiance. SDO will be managed by NASA's Goddard Space Flight Center for the Agency's Science Mission Directorate at NASA Headquarters in Washington DC.

**SDO Program Scientist**
Madulika Guhathakurta
NASA Headquarters
Madhulika.Guhathakurta@nasa.gov

**SDO Project Scientist**
William Dean Pesnell
NASA Goddard Space Flight Center
William.D.Pesnell@nasa.gov

**SDO Deputy Project Scientist**
Barbara Thompson
NASA Goddard Space Flight Center
Barbara.J.Thompson@nasa.gov

**SDO Deputy Project Scientist**
Phillip C. Chamberlin
NASA Goddard Space Flight Center
Phillip.C.Chamberlin@nasa.gov

**SDO Education & Public Outreach**
Emilie Drobnes
NASA Goddard Space Flight Center
Emilie.Drobnes-1@nasa.gov

**Public Affairs Contacts:**
Dwayne Brown • NASA Headquarters
Dwayne.C.Brown@nasa.gov

Don Savage • NASA Goddard Space Flight Center
Donald.Savage@nasa.gov

**SDO Program Executive**
Dana Brewer
NASA Headquarters
Dana.A.Brewer@nasa.gov

**SDO Project Manager**
Elizabeth Citrin
NASA Goddard Space Flight Center
Elizabeth.A.Citrin@nasa.gov

**SDO Deputy Project Manager**
Robert Lilly
NASA Goddard Space Flight Center
Robert.B.Lilly@nasa.gov

**SDO Web Sites for More Information:**
http://www.nasa.gov/sdo
http://sdo.gsfc.nasa.gov

**SDO Instrument Web Sites:**
http://hmi.stanford.edu
http://aia.lmsal.com
http://lasp.colorado.edu/eve

OUR EYE ON THE SUN

SOLAR DYNAMICS OBSERVATORY

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