

National Aeronautics and Space Administration



Mysteries of the Sun

PRESENTED BY NASA'S HELIOPHYSICS DIVISION OF THE SCIENCE MISSION DIRECTORATE

Mysteries of the Sun

Heliosphere	2
Anatomy of the Sun	4
Solar Cycle	6
Solar Storms	8
Earth's Magnetosphere	10
Earth's Upper Atmosphere	14
Space Weather	16
Credits	18

Prologue and Introduction

Now in the early 21st century, we know that the Sun is a star, composed mostly of hydrogen, at the center of the Solar System, and with planets orbiting around it. But ancient people didn't have access to the same tools we have today. Their understanding about the Sun was far more concerned with the day-to-day needs of living. As such, their notions have influenced the way we (still) think of the Sun.

Almost all life on Earth evolved with the Sun as a major influence. The rising and setting Sun defined the daily cycle we still respond to biologically. Ancient peoples were extremely dependent on the Sun for light; only the light from a full Moon gave any way to see in the night, and it wasn't until the discovery of fire that humans had a reliable way to see after the Sun went down. Its apparent movement in the sky provided clues on when to plant and harvest crops and gave us the concept of the year. The Sun was such an essential object that many ancient people treated it with reverence and considered the Sun a god. Many worshipped it and built monuments to celebrate it, such as Stonehenge in England.

The first accurate measurement of the distance to the Sun was made by the Greek philosopher Anaxagoras around 450 BC, and people continued to think that the Sun orbited the Earth for long after that. In 1453 AD Nicolaus Copernicus proposed a Sun-centered solar system. This theory gained support from Galileo and other astronomers by 1700 AD. By the mid-1800s, solar astronomy had advanced to the point where astronomers were carefully tracking sunspots and measuring absorption lines in the spectrum of the Sun. However, it was not until the 1920s and 1930s when the concept of nuclear fusion was well enough understood, to explain how the Sun could generate the enormous amounts of energy that emanates from it.

This book seeks to briefly outline our current knowledge of how the Sun works and how it affects the day-to-day workings of our technologically saturated world. Just as it did our ancestors, the Sun captivates us, and our study of it continues to reveal details that broaden our understanding of our solar system and the universe we live in.

Heliosphere

The heliosphere is the outer atmosphere of the Sun and marks the edge of the Sun's magnetic influence in space. The solar wind that streams out in all directions from the rotating Sun is a magnetic plasma, and it fills the vast space between the planets in our solar system. The magnetic plasma from the Sun doesn't mix with the magnetic plasma between the stars in our galaxy, so the solar wind carves out a bubble-like atmosphere that shields our solar system from the majority of galactic cosmic rays.

Heliotail

As the heliosphere travels through the interstellar medium, it leaves a long heliotail in its wake wave, much like a boat travelling through the water.



Bow Shock

Where the solar wind pushes against the competing force of the stellar wind, a bow (or shock) wave forms in front of the heliosphere.

Termination Shock

The point where the solar wind begins to interact with the local interstellar medium and slows down is called the termination shock.

Interstellar Space

Heliopause

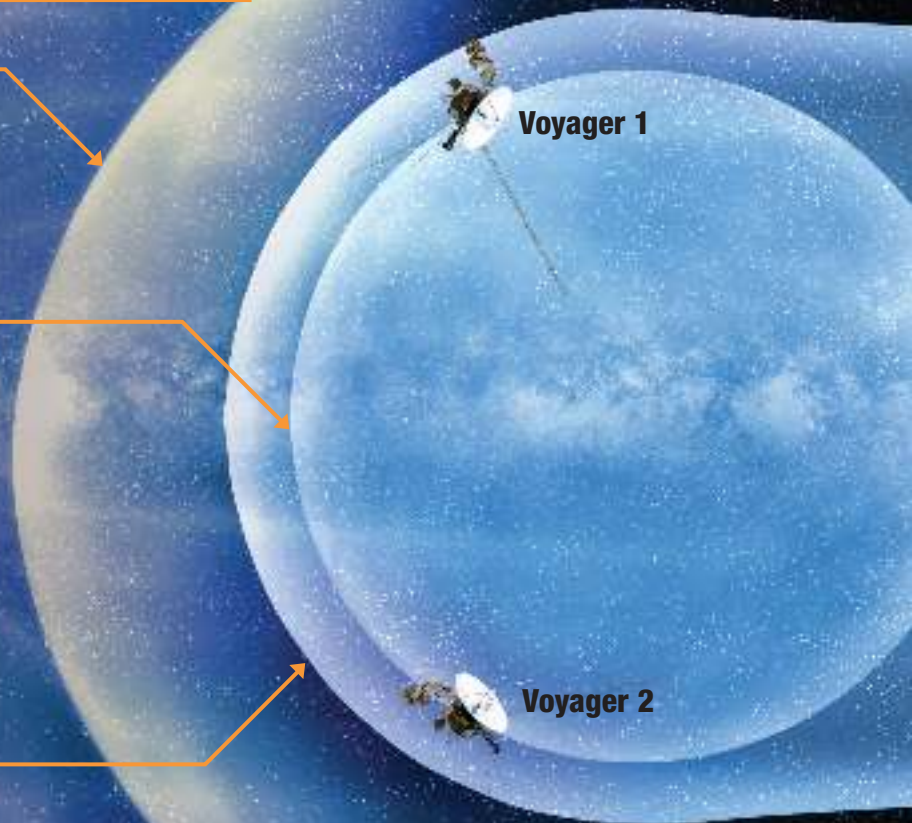
It is thought that the heliopause is where the solar wind is not strong enough to push back against the stellar wind and is stopped by the interstellar medium.

Heliosheath

The heliosheath is the region between the termination shock and the heliopause where the solar wind slows and compresses as it interacts with the interstellar medium.

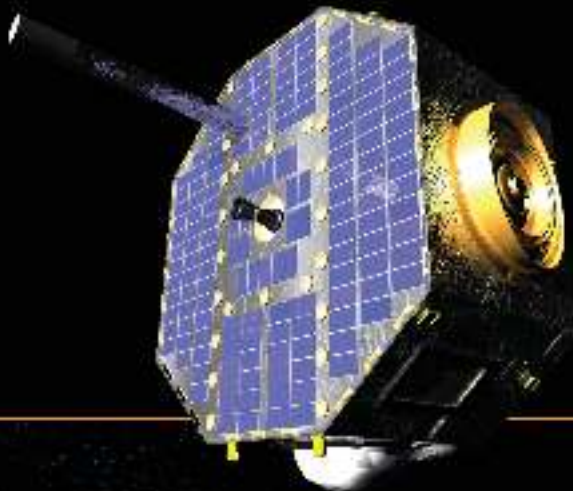
Voyager 1 & 2

NASA's Voyagers 1 and 2 spacecraft have reached the inner-most boundary of the heliosheath—twice as far from the Sun as Pluto's orbit.



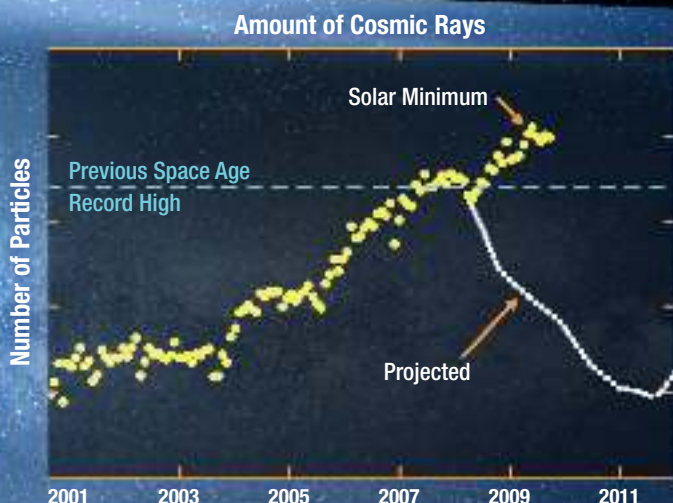
Interstellar Boundary Explorer (IBEX)

NASA's Interstellar Boundary Explorer (IBEX) is the first mission to map the heliosphere at the outer reaches of our solar system where the solar wind interacts with the interstellar space.



Variation of the Heliosphere

The number of cosmic rays entering our heliosphere has been measured since instruments could be placed in orbit above the Earth's protective atmosphere. Scientists monitoring the number of cosmic rays noticed that the number varies during the course of the solar cycle. During the prolonged solar minimum in 2009, the highest level of cosmic rays in the space age was recorded.



Energetic Neutral Atoms

Neutral atoms from the interstellar medium can enter the heliosphere and mix with the charged particles of the solar wind. As a charged particle interacts with a neutral atom, the particle can capture an electron and become neutral itself. This exchange does not affect its direction or speed, but the particle is no longer bound to magnetic forces and travels in a straight line.

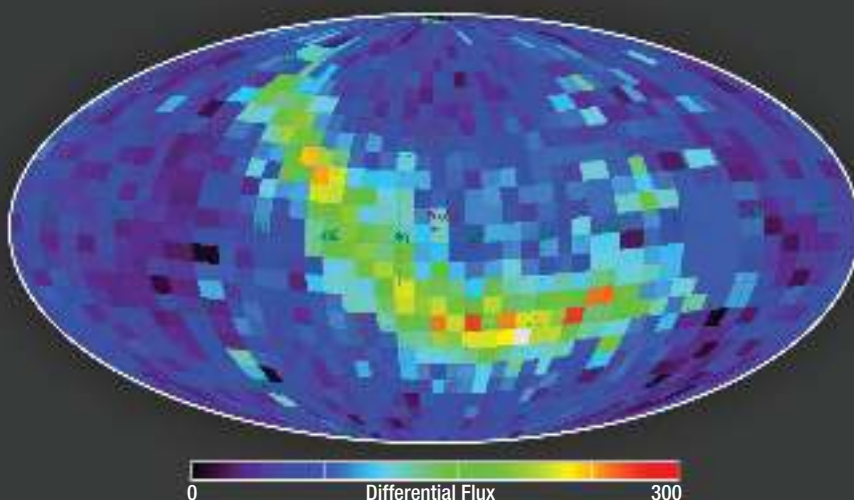


Solar Wind

The solar wind is a stream of charged particles ejected from the upper atmosphere of the Sun. It mostly consists of electrons and protons, and varies in temperature and speed over time. These particles can escape the Sun's gravity because of their high kinetic energy. The solar wind creates the heliosphere, a vast bubble that surrounds the Solar System.

Mapping the Heliosphere

NASA's Interstellar Boundary Explorer (IBEX) spacecraft can detect and chart the origins of energetic neutral atoms (ENAs) that reach as far into the solar system as the Earth. From these data, an all-sky map of the boundary is created. These spectacular maps from IBEX found that most ENAs originate in a band or ribbon that spans the entire sky. This "ribbon" is linked to the magnetic field that exists outside the heliosphere, in the interstellar medium.



Anatomy of the Sun

The Sun is an incandescent mass of hydrogen, helium, and other heavier elements. While it appears constant and unchanging from our vantage point on Earth, it actually has a dynamic and variable system of twisting magnetic fields that cause solar events of almost unimaginable power.

The Convection Zone

Energy continues to move toward the surface through convection currents of heated and cooled gas in the convection zone.

The Corona

The ionized elements within the corona glow in the x-ray and extreme ultraviolet wavelengths. NASA instruments can image the Sun's corona at these higher energies since the photosphere is quite dim in these wavelengths.

The Radiative Zone

Energy moves slowly outward—taking more than 170,000 years to radiate through the layer of the Sun known as the radiative zone.

Sun's Core

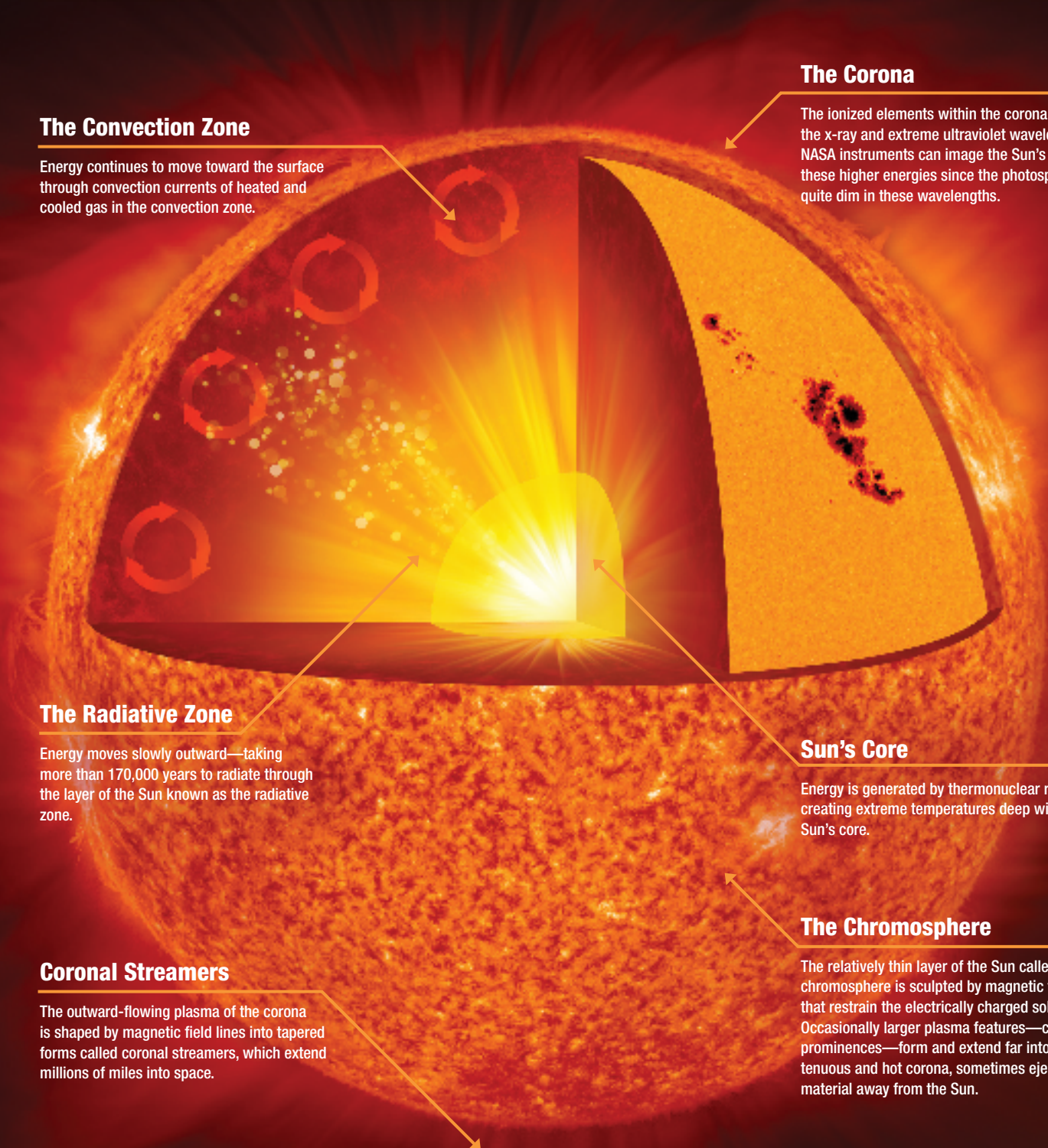
Energy is generated by thermonuclear reactions creating extreme temperatures deep within the Sun's core.

Coronal Streamers

The outward-flowing plasma of the corona is shaped by magnetic field lines into tapered forms called coronal streamers, which extend millions of miles into space.

The Chromosphere

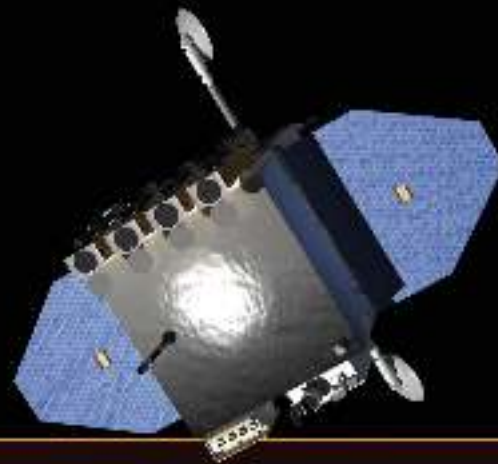
The relatively thin layer of the Sun called the chromosphere is sculpted by magnetic field lines that restrain the electrically charged solar plasma. Occasionally larger plasma features—called prominences—form and extend far into the very tenuous and hot corona, sometimes ejecting material away from the Sun.



Solar Dynamics Observatory (SDO)

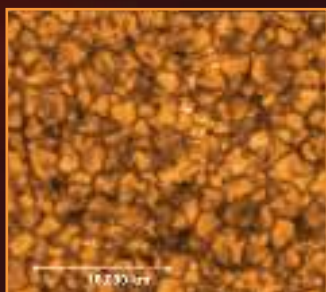
The Solar Dynamics Observatory (SDO) is designed to help us understand the Sun's influence on Earth and near-Earth space by studying the solar atmosphere on small scales of space and time and in many wavelengths simultaneously.

Data from SDO will help scientists study how the Sun's magnetic field is generated and structured and how this stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance.



The Photosphere

The photosphere is the visible layer of the Sun, about 100 km thick. Sunspots can be viewed in this layer, and the rotation of the Sun was first detected when the motion of these sunspots was observed.



Surface Texture

The photosphere is not smooth but rather looks as if it is composed of small grains or granules. These are the tops of convection cells that carry heat upward from deep within the Sun. Each granule in this image is about 1,000 km across.



Sunspots

Scattered among the convection cells are large clusterings of strong magnetic fields that block the upward flow of energy to the surface. These areas of reduced temperature cause Sunspots, relatively cooler regions that appear darker because they are radiating less energy into space.

Solar Phenomena

The sun may look unchanging, but it is far from a glowing ball of plasma. It is a dynamic body that exhibits solar flares, filaments and prominences, sunspots, spicules, and coronal mass ejections.



Prominences

A prominence is a large, bright feature extending outward from the Sun's surface. Prominences are anchored to the Sun's surface in the photosphere, and extend outwards into the Sun's corona. While the corona consists of extremely hot ionized gases, known as plasma, that do not emit much visible light, prominences contain much cooler plasma.

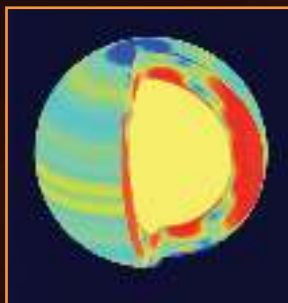


Coronal Loops

Coronal loops form the basic structure of the lower corona and transition region of the Sun. These highly structured and elegant loops are a direct consequence of the twisted solar magnetic flux within the Sun. The number of coronal loops can be directly linked with the solar cycle. It is for this reason coronal loops are often found with sunspots at their footpoints.

The Sun's Rotation

Since the Sun is a ball of gas, it does not rotate uniformly. On the surface, the Sun's equatorial regions rotate faster than the polar regions. However, in the Sun's interior, the portion of the convection zone closest to the surface rotates faster at the equator and slower at the poles. The portion of the convection zone just above the radiative zone rotates slower at the equator and faster near the poles.

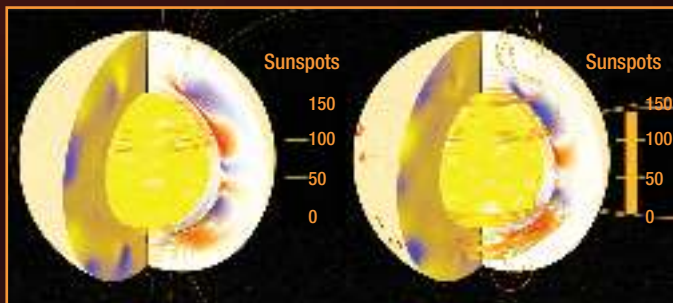


Rotation Speed

In this graphic, the colors show changes in speed rather than the actual rotation rate. Red-yellow is faster than average and blue is slower than average. There are clear bands of faster and slower than average rotation. These bands persist through at least the upper 12,000 miles. Portraying the data this way highlights the smaller scale variations in the change in rotation from the equator to the poles.

Solar Dynamo

The differential rate of rotation between the radiative and convection zones is thought to give rise to the formation of solar magnetic fields and to be the source the Solar Dynamo—the physical process that drives the solar cycle of magnetic activity. The variation in rotation speeds within the convection zone twists the magnetic fields, causing them to deform and shear as they weave their way outward toward the surface of the Sun.



The Solar Cycle

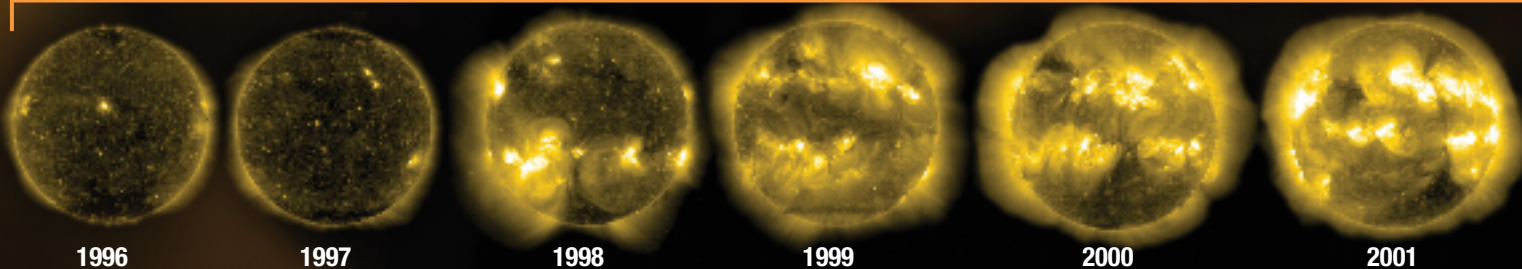
The Solar Cycle is the observed high and low sunspot activity that repeats about every 11 years. Sunspots are dark areas on the solar surface that contain strong magnetic fields that emerge through the solar surface and allow an area to cool slightly. This area appears as a dark spot in contrast with the very bright photosphere. Groups of sunspots, especially those with complex magnetic field configurations, are often the sites of solar flares. This makes the sunspot cycle a useful way to mark changes in the Sun's activity.

A Solar Cycle as seen by SOHO

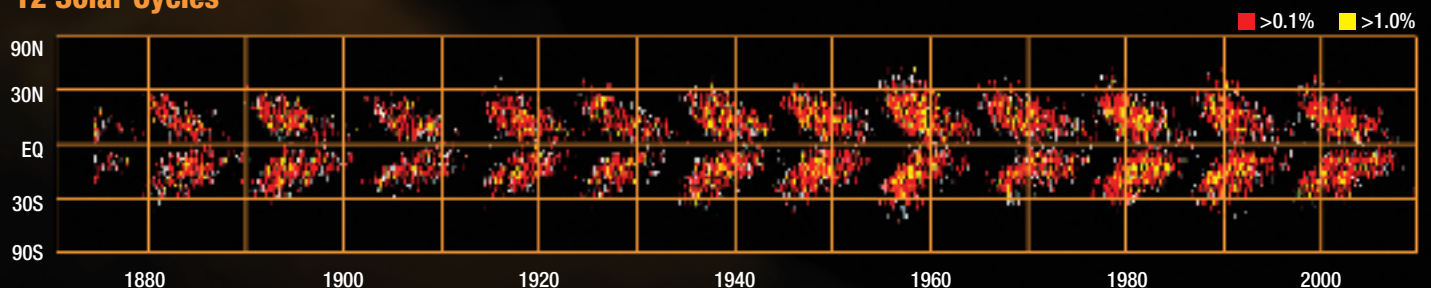
NASA's Solar and Heliospheric Observatory (SOHO) spacecraft has captured enough images of the Sun to illustrate an entire solar cycle. These full-disk images of the lower corona reveal solar cycle 23 from minimal solar activity to maximum activity and then back to minimum conditions. Solar minimum refers to the period of time when the number of sunspots is lowest, when the Sun may go many days with no sunspots visible.

During solar maximum, solar activity is at its height, and there may be several hundred sunspots in a day. Overall, the Sun is predominantly active over the 11-year life cycle with relatively few years when the Sun might be described as "quiet." During solar maximum, activity on the Sun and the effects of space weather on Earth are high.

1 Solar Cycle



12 Solar Cycles



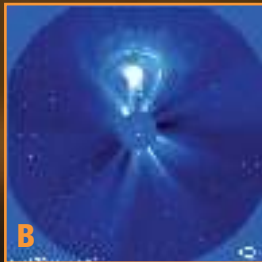
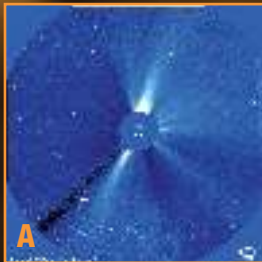
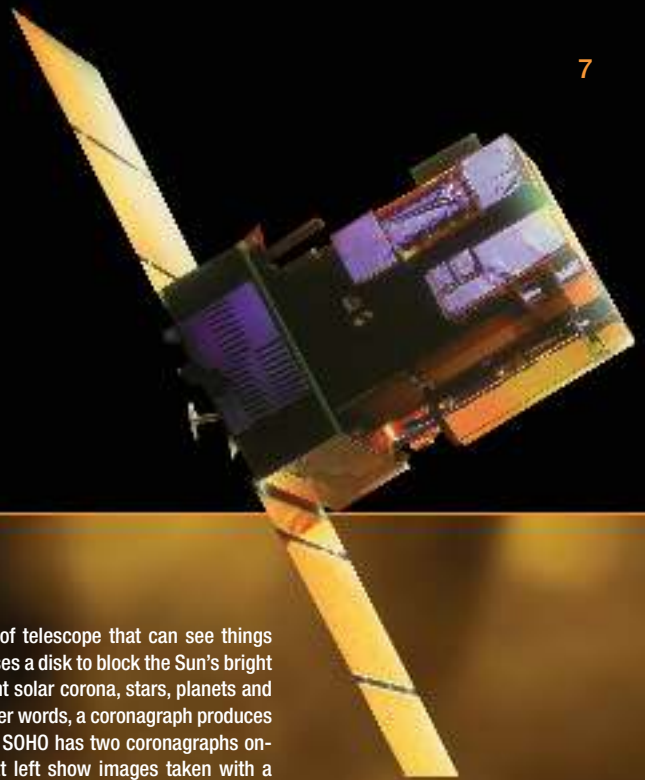
The Butterfly Diagram

When the number of sunspots (color) and their location (degrees latitude) are plotted over time (years), the solar cycles form a pattern like the wings of a butterfly. Sunspots are typically confined to an equatorial belt between -35 degrees south and +35 degrees north latitude. Sunspots form at higher latitudes at the beginning of a solar cycle and closer to the equatorial region as the cycle reaches maximum solar activity.

The chart shown above is a modern version of the sunspot "butterfly diagram" of astronomer Edward Maunder, who was first to identify the pattern after studying how sunspot latitudes changed over time. Scientists are still studying why this migration of sunspots occurs; understanding this phenomenon could reveal something about how the Sun's internal magnetic field is generated.

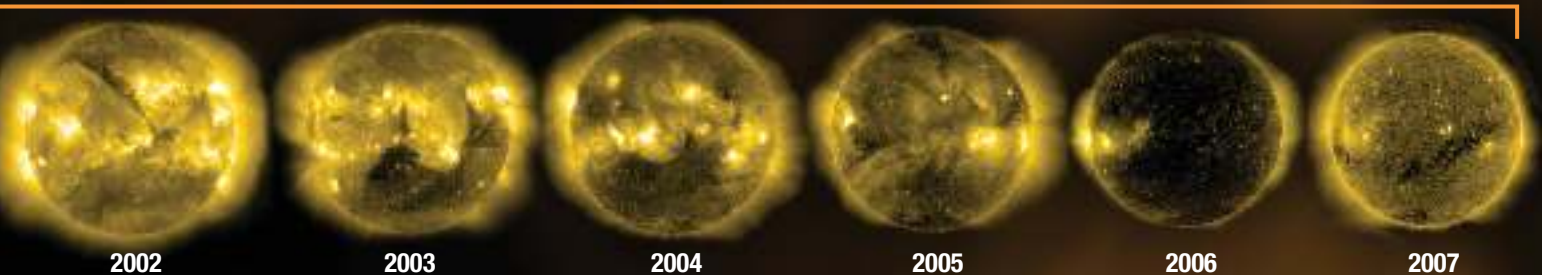
The Solar & Heliospheric Observatory (SOHO)

The Solar & Heliospheric Observatory (SOHO), launched in 1995, captures images of the Sun every 12 minutes. Scientists can now view images of the Sun throughout an entire solar cycle.

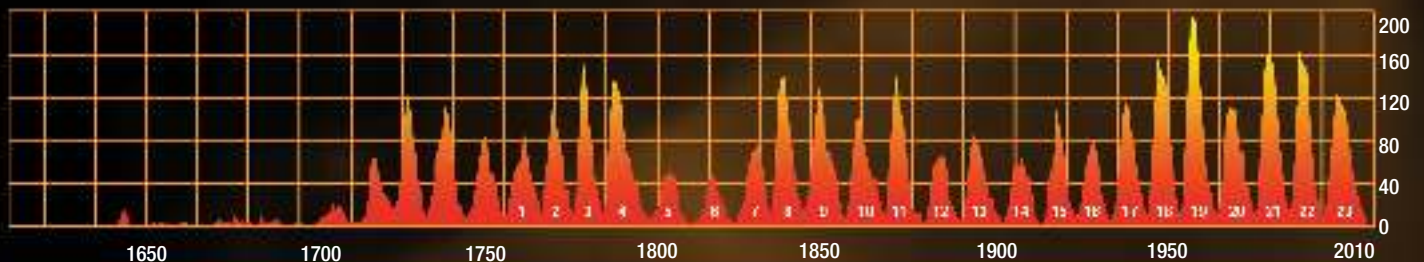


SOHO Coronagraph

A coronagraph is a type of telescope that can see things very close to the Sun. It uses a disk to block the Sun's bright surface, revealing the faint solar corona, stars, planets and sungrazing comets. In other words, a coronagraph produces an artificial solar eclipse. SOHO has two coronagraphs on-board. The two images at left show images taken with a coronagraph: one at the solar minimum (A), and one at the solar maximum (B).



23+ Solar Cycles



Timeline of Solar Cycles over 400 Years

Sunspots have been observed and recorded since Galileo's time in 1610. But it wasn't until 1849 that the Zurich Observatory started a continuous daily record. From these early observations scientists have been able to construct a timeline of solar cycles that spans more than 400 years.

While early observations were not as extensive, well-documented records show a period of very few sunspots (a prolonged sunspot minimum) from 1645 to 1715, which is called the Maunder Minimum. This period corresponds to the "Little Ice Age," when

temperatures across the Northern Hemisphere plunged and alpine glaciers extended over farmland, sea ice extended from the Arctic, and even canals in the Netherlands froze.

NASA scientists are continuing to study the links between solar activity and climate, and understanding the Sun's natural variations is key to these ongoing climate studies. NASA missions continue to collect data about the Sun's activity and variability to help us better understand the extent to which solar activity is influencing present-day climate change.

Solar Storms

Solar flares, coronal mass ejections, high-speed solar wind, and solar energetic particles originate from solar storms. All solar activity is driven by the solar magnetic field. Magnetic fields that cause sunspots are also the catalyst for solar storms.



The High-Definition Sun

The background is the First Light Image from NASA's Solar Dynamics Observatory. It is a full-disk, multiwavelength extreme ultraviolet image of the sun taken on March 30, 2010. False colors trace different gas temperatures. Reds are relatively cool (about 60,000 Kelvin, or 107,540 F); blues and greens are hotter (more than 1 million Kelvin, or 1,799,540 F).

STEREO

The Solar TERrestrial RELations Observatory (STEREO) consists of two nearly identical observatories: one ahead of Earth in its orbit, the other trailing behind. Together they provide scientists with a unique, side-view perspective of the Sun-Earth system. Scientists can now study the three-dimensional structure of coronal mass ejections and the flow of energy and matter from the Sun to Earth. STEREO is a key addition to the fleet of space weather-detection satellites, providing more accurate alerts regarding the arrival time of Earth-directed solar ejections.



Solar Flares

Solar flares are storms that appear as explosive bright spots on the surface of the Sun and come from the release of magnetic energy associated with sunspots. Flares occur when considerable amounts of magnetic field energy are suddenly converted to heat and light. The subsequent blast sends out electrically charged particles (electrons, protons, and heavier particles) that are accelerated in the solar wind. The radiation from one of these blasts can have the energy equivalent of ten million volcanic eruptions. They can last from minutes to hours. NASA instruments can monitor flares across the spectrum, including x-rays such as the above x-ray image from SDO.

Solar Prominence

A solar prominence (also known as a filament) is a large, bright feature extending outward from the Sun's surface. Prominences are anchored to the Sun's surface in the photosphere and extend outward into the Corona, the Sun's hot outer atmosphere. The red-glowing looped material is plasma, a hot gas comprising electrically charged hydrogen and helium. The prominence plasma flows along a tangled and twisted structure of magnetic fields generated by the Sun's internal dynamo.

A prominence forms over time frames of about a day. A stable prominence may persist in the corona for several months, looping hundreds of thousands of miles into space. An erupting prominence occurs when such a structure becomes unstable and bursts outward, releasing the plasma. Scientists are still researching how and why prominences are formed.



Coronal Mass Ejection

A coronal mass ejection (CME) occurs when magnetic forces overcome pressure and gravity in the solar corona. This lifts a huge mass of solar plasma from the corona and creates a shock wave that accelerates some of the solar wind's particles to extremely high energies and speeds. This in turn generates radiation in the form of energetic particles. An average CME can dump about 1,500 gigawatts of electricity into Earth's atmosphere—about twice the power-generating capacity of the entire United States!

Earth's Magnetosphere

The magnetosphere protects the Earth from solar wind that streams from the Sun carrying energetic, charged particles. NASA satellite observations have confirmed that the magnetosphere is always in place, but variations in the solar wind cause it to change size and shape



Earth's Magnetic Field

The magnetosphere is a magnetic shield formed by the Earth's rapidly spinning liquid metal core that generates a magnetic field with a north and south pole.

Plasmasheet & Magnetotail

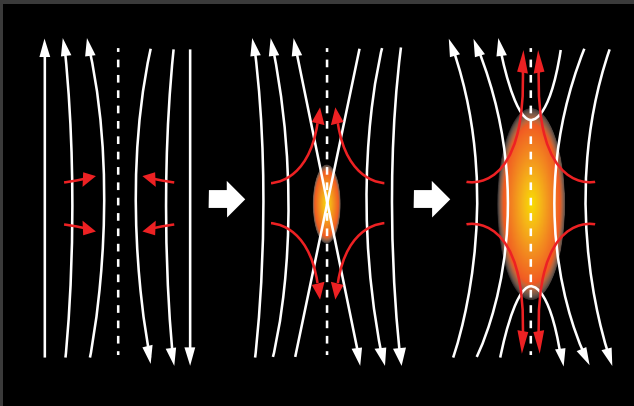
Charged particles from the Sun leak into the magnetosphere over the northern and southern magnetic poles and travel to the magnetotail, adding to a reservoir called the plasmasheet.

Magnetic field lines

The pressure of the solar wind flattens the nose of the magnetosphere and drags the field lines into a tail.

Bow Shock & Magnetopause

A bow (or shock) wave forms upstream—much like when a boat moves through water—and most of the oncoming plasma is diverted around the outer boundary of the magnetosphere, called the magnetopause.



Magnetic Reconnection

Particles can also enter during magnetic reconnection. When the polarity of the solar wind is opposite to that of the magnetosphere, the magnetic field lines of the incoming plasma will connect with the field lines of the magnetosphere. This reconnection is an explosive process that catapults charged particles into the magnetosphere.

This phenomenon is not well-understood yet by scientists, but whenever reconnection occurs, an explosive burst of plasma results. This ultimately disrupts Earth's upper atmosphere, causing auroras and space-weather events.

Magnetospheric Multiscale Mission (MMS)

The Magnetospheric Multiscale (MMS) mission, comprising four spacecraft with identical instruments, will make three-dimensional measurements of the magnetosphere to help scientists better understand the process of magnetic reconnection.

Reconnection

During a solar storm, charged particles fill the plasma sheet reservoir until it bursts. Magnetic reconnection explosively releases particles into the inner magnetosphere. A picture of a circulatory system emerges as these particles add to the inner magnetosphere.

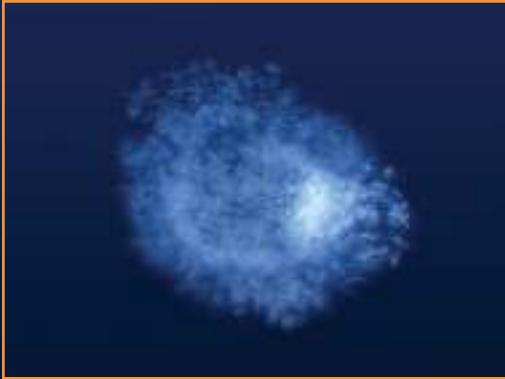


THEMIS All-Sky Imagers

The THEMIS All-Sky cameras, based here on Earth, take images and movies of the aurorae (Northern Lights) by looking up into the sky from horizon to horizon. The cameras take images and movies in black and white, gathering all the visible light from the aurora that they can. In this way, they can record even very faint aurora that our eyes cannot see. These cameras are placed in 20 locations, spread out across Canada and Alaska, where the Northern Lights are most likely to be seen. The images from the All-Sky Camera deployed by THEMIS are shown in the image to the left.

Earth's Magnetosphere

The inner magnetosphere is composed of three populations of charged particles that are trapped in the Earth's magnetic field. These particles move in circular motions—or gyrate—around the field lines but rarely interact with each other.



Ring Current

The ring current is a population of medium-energy particles that drift around the Earth, with protons drifting in one direction and electrons drifting in the opposite direction.



Plasmasphere

The plasmasphere is composed of low-energy particles that drift up from the ionosphere, forming a sphere-like reservoir of very cold, fairly dense plasma that co-rotates with the Earth.

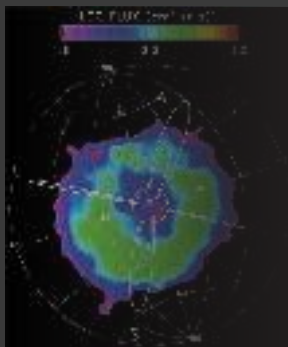
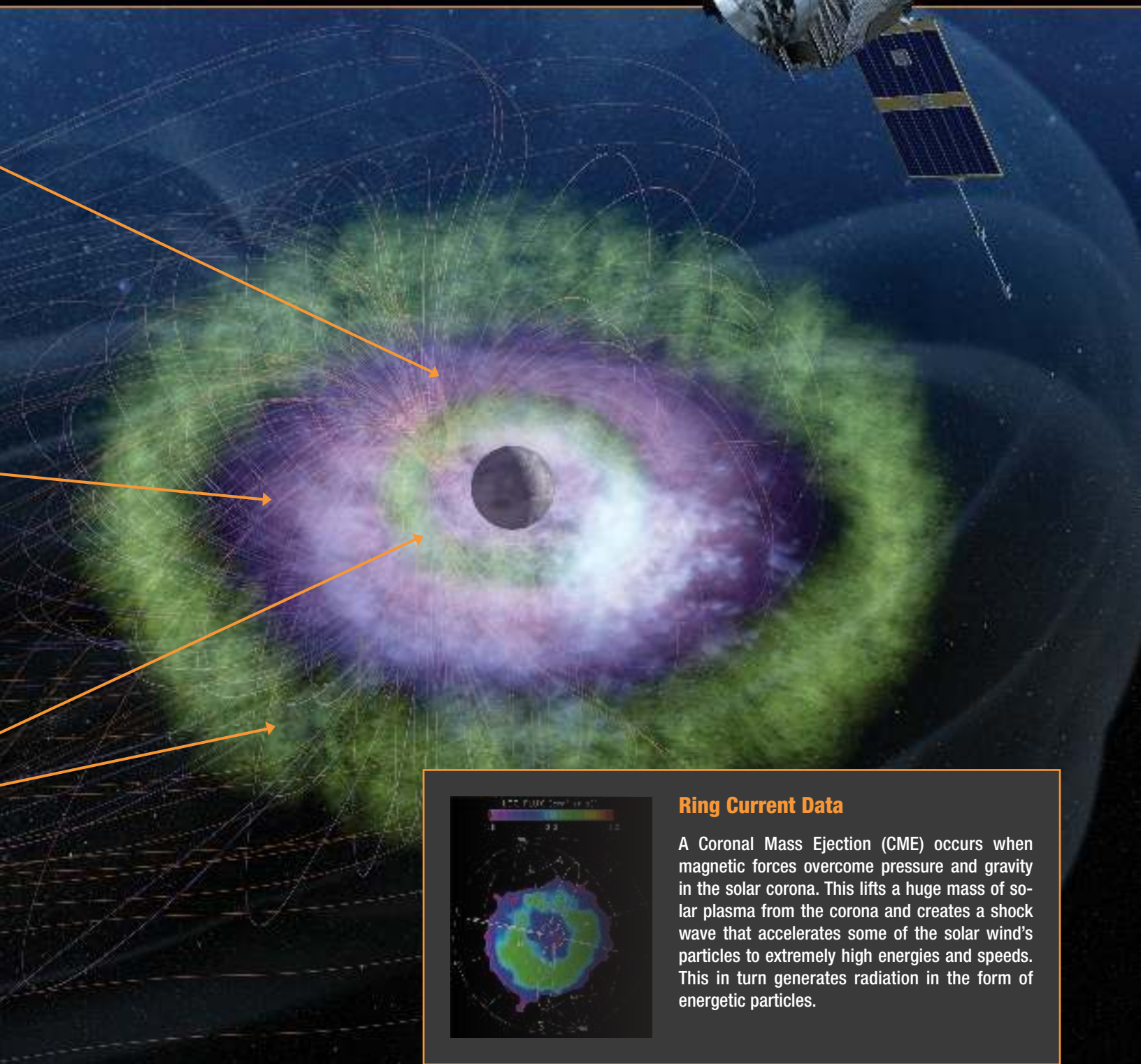
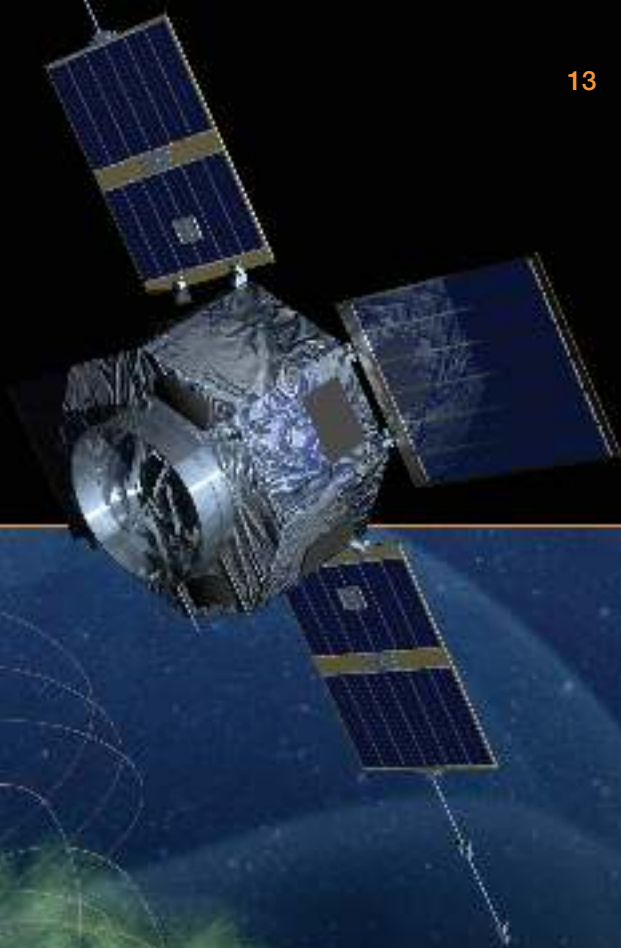


Van Allen Radiation Belts

The Van Allen Belts consist of high-energy particles that are trapped in two regions. These particles move along the field lines toward the poles until they are reflected back, creating a bouncing movement. Particles with a high enough velocity along the magnetic field will follow the field lines to the poles and enter the upper atmosphere.

RBSP

NASA's Radiation Belt Storm Probes (RBSP) mission will help scientists better understand the processes in the radiation belts. The technological challenge for RBSP is to withstand the very energetic trapped electrons and ions in the radiation belts that are extremely harmful to spacecraft. The Space Station flies below the Van Allen belts, well inside the protective cover of the Earth's magnetosphere. Most unmanned spacecraft missions are designed so they pass through these belts relatively quickly.



Ring Current Data

A Coronal Mass Ejection (CME) occurs when magnetic forces overcome pressure and gravity in the solar corona. This lifts a huge mass of solar plasma from the corona and creates a shock wave that accelerates some of the solar wind's particles to extremely high energies and speeds. This in turn generates radiation in the form of energetic particles.

Upper Atmosphere

The Earth's atmosphere has four primary layers: the troposphere, stratosphere, mesosphere, and thermosphere. These layers protect our planet by absorbing harmful radiation.

Thermosphere 53–375 Miles

In the thermosphere, molecules of oxygen and nitrogen are bombarded by radiation and energetic particles from the Sun, causing the molecules to split into their component atoms and creating heat. The thermosphere increases in temperature with altitude because the atomic oxygen and nitrogen cannot radiate the heat from this absorption.

HUBBLE SPACE TELESCOPE
370 Miles

WEATHER SATELLITES
250 Miles

INTERNATIONAL SPACE
STATION
250 Miles

Mesosphere 31–53 Miles

Studying the mesosphere is essential to understanding long-term changes in the Earth's atmosphere and how these changes affect climate. Since the mesosphere is responsive to small changes in atmospheric chemistry and composition, it could provide clues for scientists, such as how added greenhouse gases may contribute to a change in temperature or water composition in the atmosphere.

SOUNDING ROCKET
50–1,500 Miles

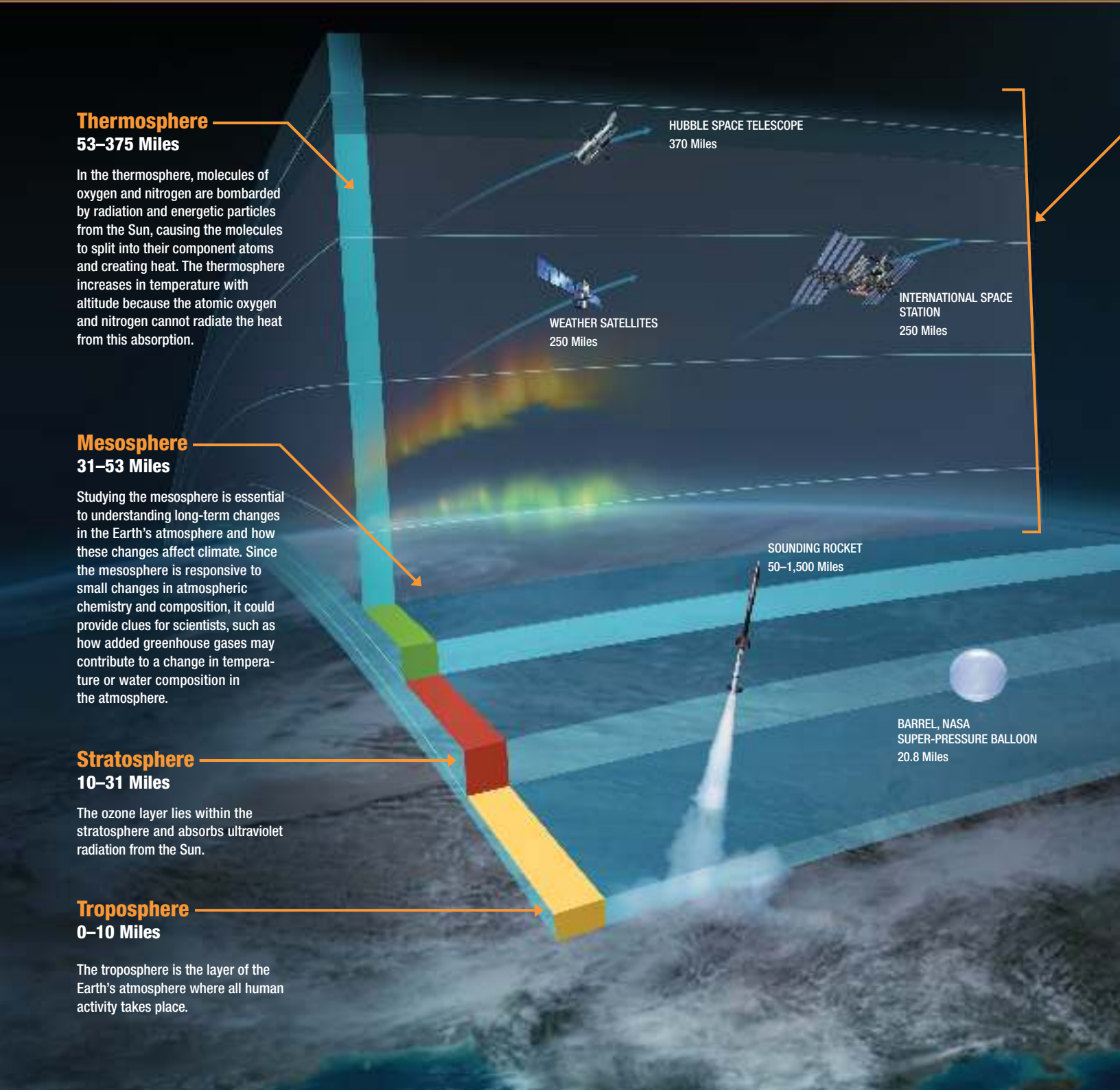
Stratosphere 10–31 Miles

The ozone layer lies within the stratosphere and absorbs ultraviolet radiation from the Sun.

BARREL, NASA
SUPER-PRESSURE BALLOON
20.8 Miles

Troposphere 0–10 Miles

The troposphere is the layer of the Earth's atmosphere where all human activity takes place.



Aeronomy of Ice in the Mesosphere (AIM)

NASA's Aeronomy of Ice in the Mesosphere (AIM) satellite can remotely sense night-shining clouds in the mesosphere. These noctilucent clouds are made of ice crystals that form over the summer poles at an altitude too high and a temperature too cold for water-vapor clouds.



Ionosphere

The ionosphere is a layer of plasma formed by the ionization of atomic oxygen and nitrogen by highly energetic ultraviolet and x-ray solar radiation. The ionosphere extends from the middle of the mesosphere up to the magnetosphere. This layer cycles daily as the daytime exposure to solar radiation causes the ionization of the atoms that can extend down as far as the mesosphere. However, these upper atmospheric layers are still mostly neutral, with only one in a million particles becoming charged daily. At night, the ionosphere mostly collapses as the Sun's radiation ceases to interact with the atoms in the thermosphere. There are still small amounts of charged atoms caused by cosmic radiation.

Rockets, Balloons, and Satellites

NASA scientists use balloons to collect *in-situ* measurements in the atmosphere. However, the mesosphere and thermosphere are too high for balloons to reach, so scientists use instruments on sounding rockets and satellites to gather more detailed measurements of the upper atmosphere.

Communication

A unique property of the ionosphere is that it can refract short-wave radio waves, enabling communication over great distances by “bouncing” signals off this ionized atmospheric layer. Variability of the ionosphere can interrupt satellite communication, such as errors in GPS signals for commercial air navigation. During solar storms, this layer can even shut down communication between ground stations and satellites.



Noctilucent Clouds in the Mesosphere

Evidence of change in the behavior of noctilucent clouds has been observed by the AIM mission. Recent data show dramatically lower ice content, leading scientists to speculate about changes in weather conditions and pole-to-pole atmospheric circulation.



BARREL

The Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) is a balloon-based mission to augment the measurements of NASA's RBSP spacecraft. BARREL seeks to measure the precipitation of relativistic electrons from the radiation belts during two multi-balloon campaigns operated in the Southern Hemisphere.

Space Weather

Our planet's magnetosphere protects us from charged particles ejected from the Sun during solar storms. However, some of these particles can flow along Earth's magnetic field lines into the upper atmosphere and induce geomagnetic storms. One of the results is a dazzling dance of colored light in the night sky, also known as aurora borealis and aurora australis (for Northern and Southern lights). When these particles enter the upper atmosphere, they collide with and excite oxygen and nitrogen atoms, creating the brilliant colors we can see with the naked eye.

While the Earth's magnetic field protects Earth from the most harmful effects of space weather, some energy can be transferred to our magnetosphere and induce geomagnetic storms. These storms can produce spectacular and colorful auroras but can also be hazardous to our societal infrastructure.

Pipelines and Power lines

On the Earth's surface, changes in these fields can induce corrosive electrical currents through gas and oil pipelines as well as surges in transformers and power lines.

Airline Tracking Over the Poles

Geomagnetic storms can disturb the Earth's ionosphere and can completely wipe out high frequency radio communication around the Earth's poles for days. These disturbances with radio communication can be particularly hazardous to the growing number of aircraft flying over the poles. Geomagnetic storms can disrupt navigation, communication and electrical systems on the aircraft and even expose the air crew to high levels of radiation.

Global Positioning

The disturbed state of the ionosphere can also impact our society and economy by disrupting communication with satellites. Disruptions can occur in our day-to-day business activities such as ATM and gas pump transactions and cell phone reception. Disruptions with GPS communication satellites can not only impact car navigation systems but also navigation systems on tractors used for precision farming and those on commercial fishing vessels, which can impact our food supply.

Astronauts and Satellites

Above our atmosphere, satellites orbiting through the Earth's radiation belts and the solar wind are affected when energetic ions accelerated by solar storms disrupt their on-board computers and degrade their instrumentation and solar panels. Astronauts that live and work in space on the International Space Station can be exposed to high doses of radiation during solar storms—even when they are inside.

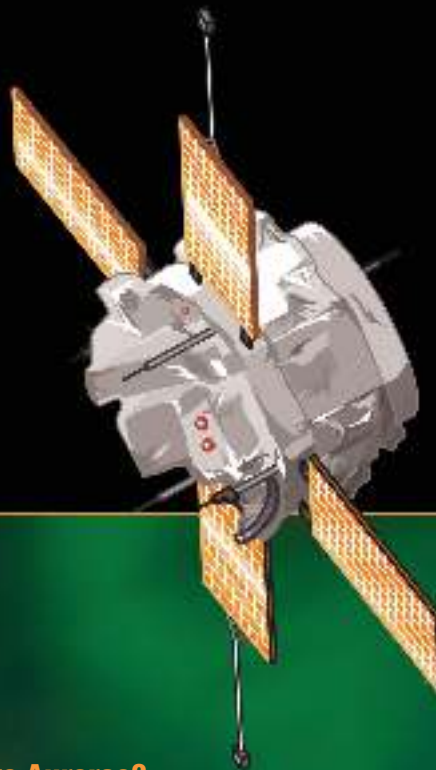


Satellite View of Quebec Outage

A series of solar flares, coupled with a CME in March 1989, produced intense magnetic storms that left millions of people throughout substantial regions of Quebec, Canada without power. It lasted 12 hours and affected 5 million people at an eventual cost of more than \$2 billion. Electrical outages are common, but the ones caused by solar storms are different: they can potentially cover entire continents due to their large scale nature.

ACE

The Advanced Composition Explorer (ACE) is a mission which observes particles of solar origin spanning the energy range from solar wind ions to galactic cosmic rays. Its data is an important piece of today's space weather prediction capability.

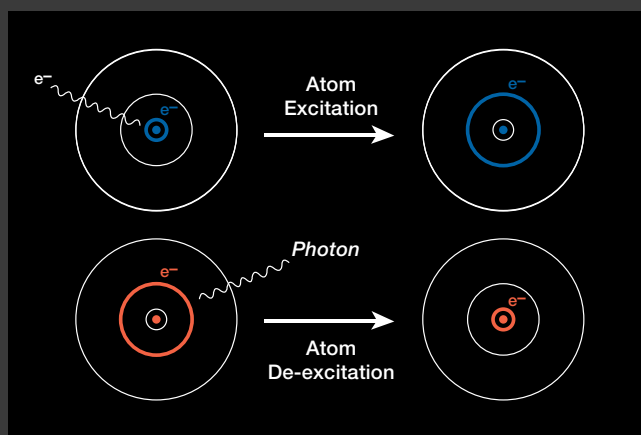


What are Aurorae?

Activity on the Sun emits radiation and high-energy particles into the space environment, affecting the solar wind, the Earth system, and the other planets. Space weather refers to these conditions and their influence on our planet and the technology our society depends upon.

Aurora From Space

A small number of solar particles constantly precipitate from the Magnetosphere, forming a background aurora that can be seen from space. The picture to the left was taken from the ISS at 250 km (100 km higher than where they form) and clearly shows their characteristic oval shape.



Excited Atoms

Aurorae usually occur between 40 and 200 miles above the Earth's surface. There, incoming electrons from the solar wind excite oxygen or nitrogen atoms in the atmosphere. When an atom is excited, one of its electrons moves into a higher energy state.

As this higher energy state is unstable for the atom, the electron in the high energy level will spontaneously lose energy and emit a photon (light) as a wave length specific to the amount of energy being released. For oxygen, this light is typically green, while for nitrogen, it is typically red. It is these colors that give aurorae their distinctive colors.

Credits

Book Credits

Author: Ginger Butcher

Design and illustration: Jenny Mottar

Copyediting: C. Claire Smith

Special Thanks to NASA Science Mission Directorate and Ruth Netting

Created under the HITSS contract to NASA Headquarters by InDyne, Inc. and V! Studios, Inc.

Image Credits

Cover Illustration: *Jenny Mottar*; **Page 2-3:** *Heliosphere Background image*, Troy Bensech; **Page 3:** *Energetic iron nuclei*, NASA, Cosmic Ray Isotope Spectrometer, ACE; *Solar Wind*, Troy Benesch; *Mapping the Heliosphere*, NASA, IBEX; **Page 4:** *Sun Cut-away*, Jenny Mottar; **Page 5:** *Surface Texture*, NASA, Hinode JAXA/NASA/PPARC; *Sunspot*, Vacuum Tower Telescope, NSO, NOAO; *Prominences*, NASA, SDO/AIA; *Coronal Loops*, NASA, TRACE; *Rotation Speed*, Solar Oscillations Investigation (SOI) group at Stanford University, Palo Alto, CA; *Solar Dynamo*, NASA/Goddard Space Flight Center Scientific Visualization Studio; **Page 6-7:** *Solar Cycle*, NASA, Solar and Heliospheric Observatory (SOHO); **Page 6:** *Sunspot Butterfly Diagram*, The solar group at NASA Marshall Space Flight Center; **Page 7:** *SOHO Coronagraph*, NASA; **Page 8-9:** *Multiwavelength extreme ultraviolet image of the sun*, NASA/Goddard/SDO AIA Team; *400 Years of Sunspot Observations*, NASA; **Page 9:** *Solar Flare*, NASA's Solar Terrestrial Relations Observatory (STEREO); *Coronal Mass Ejection*, NASA, SOHO; **Page 10-11:** *Earth's Magnetosphere Background image*, Troy Benesch; **Page 10:** *Earth's Magnetic Field*, Glatzmaier-Roberts geodynamo model; **Page 11:** *THEMIS All-Sky Imagers*, NASA; **Page 12-13:** *Inner Magnetosphere Background Image and insets*, Troy Benesch; **Page 13:** *Ring Current Data*, NASA's IMAGE spacecraft; **Page 15:** *Noctilucent Clouds*, Jan Erik Paulsen; *Barrel Image*, NASA / NSF ; **Page 16-17:** *Canadian Northern Lights*, Dave Dyet; **Page 16:** *Satellite View of Quebec Outage*, Chris Elvidge, U.S. Air Force; **Page 17:** *The Aurora Borealis*, or *Northern Lights*, shines above Bear Lake, Eielson Air Force Base, Alaska, Senior Airman Joshua Strang; *Aurora From Space*, taken from the International Space Station;