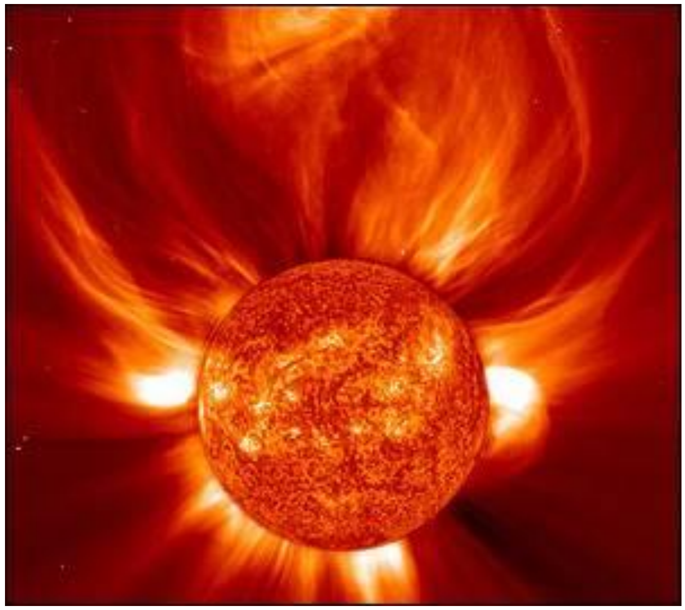
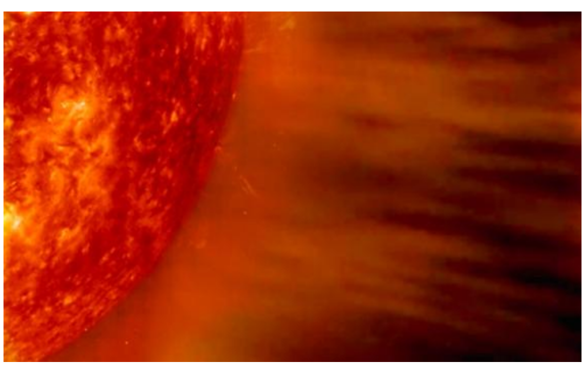
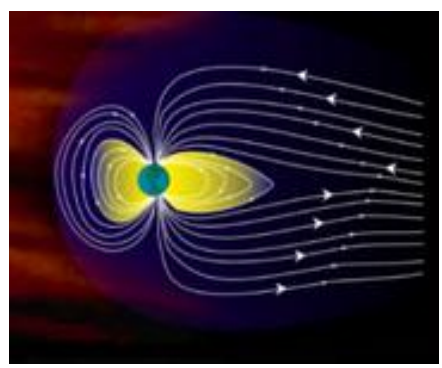


Sun-earth connections

Taking a Closer Look at the Sun

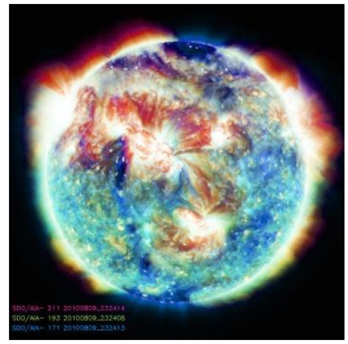




The Sun is Still News

Bigger, better, different

Scientists are still looking for better ways to study the Sun, and finding things the people of Galileo's time would have marveled at. This guide will look at how these new methods for examining the Sun are changing our understanding of solar phenomena. We'll also explore the sunspot cycle, and the known and possible effects solar activity has on Earth.

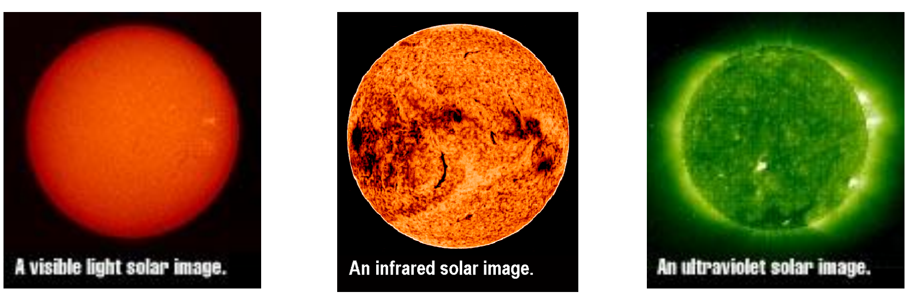


Composite image of the Sun taken by the Solar Dynamics Observatory (SDO) satellite launched in 2010.

Today's telescopes

The modern development of the telescope has greatly extended what astronomers can see. Today, scientists use cameras mounted on powerful telescopes to take pictures of the Sun's surface magnified hundreds of times. According to David Dearborn, who is a stellar physicist at Lawrence Livermore National Laboratory when he's not studying archaeoastronomy in Peru, "The scientists in Galileo's time had instruments with less ability to see detail (less resolution). They could see clearly that there were dark regions on the Sun, but they couldn't see any of the fine structure."

In Galileo's time observers could only use visible light, while telescopes today operate in different wavelengths. People now use instruments that measure the light more precisely than the eye can, and using various filters and detectors, measure wavelengths, or "colors" beyond the visible: *ultraviolet*, *infrared*, and even *x-rays* and *gamma rays*. Viewing the non-visible light that the Sun emits not only gives scientists new ways to examine the Sun but new ways to contrast and compare results.



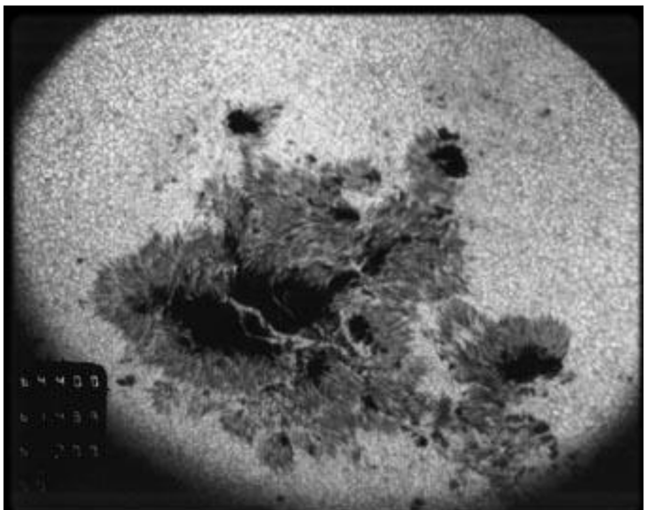
Pictures of the Sun from 3 different telescopes, in different parts of the full spectrum of electromagnetic radiation (light).

Recently, space satellites have revolutionized the study of the Sun. They provide clear images free from distortion caused by the Earth's atmosphere, detect wavelengths of light that are filtered out by the atmosphere, and have the unique advantage of uninterrupted views of the Sun (ground telescopes must contend with clouds and the day-night cycle). With these new tools, scientists have begun to unravel the mysteries of the Sun.

So what *is* a sunspot?

Scientists have used their bigger, better telescopes to learn more about what sunspots are. George Fisher, a solar astronomer at the University of California, describes how scientists think of sunspots today: "A sunspot is a dark part of the Sun's surface that is cooler than the surrounding area. It turns out it is cooler because of a strong magnetic field there that inhibits the transport of heat via *convection* in the Sun. The magnetic field is formed below the Sun's surface, and continues out into the Sun's extended outer atmosphere, or *corona*."

Multiple sunspot groups in an image from the Solar and Heliospheric Observatory (SOHO) satellite (2001).



Both parts of the sunspot, the darker umbra and the somewhat lighter penumbra, are visible in this image from Big Bear Observatory (1989).

Sunspot anatomy

Sunspots are made up of two parts: a dark, roughly circular central disk called the *umbra*, and a lighter outer area called the *penumbra*. The term "umbra" means "shade" in Latin; "penumbra" means "almost shade." A single sunspot has a finite lifetime in which it appears, grows, and gradually disappears. Of course, we may not observe the disappearance if it happens after the Sun has rotated the sunspot to the Sun's opposite side.

How big are sunspots?

The scale of the Sun is hard to fathom. The Sun is so large that over 100 Earths could fit across its diameter. It is so dense that it takes ***millions of years*** for photons produced at the core to make their way to the Sun's surface! The Sun has been radiating light and heat for the past four or five billion years. The sunspots to which this guide is devoted appear as tiny spots on the Sun – but an average-sized sunspot is as large as the Earth!

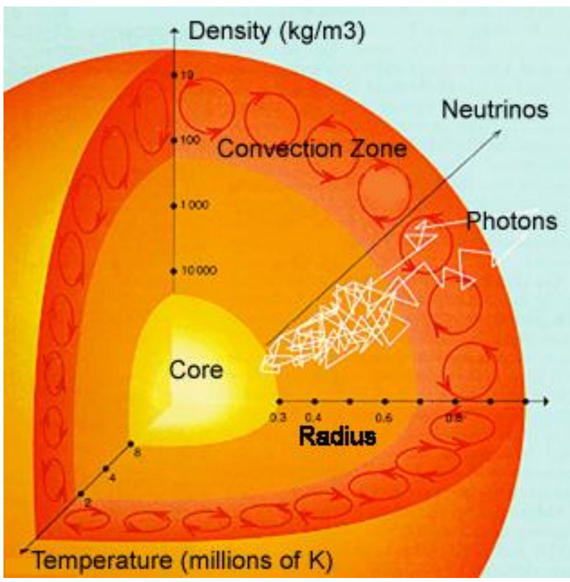
An x-ray image of the sun. This image is a composite of two pointings of Yohkoh spacecraft. The Yohkoh spacecraft is a Japanese satellite. (1992)

Where Sunspots Happen

About the Sun

To better understand the process that creates sunspots we first need to learn more about the Sun. The Sun is by far the largest object in the Solar System, containing more than 99.8% of the total mass of the Solar System (Jupiter contains most of the rest).

The Sun is made of about 90% hydrogen and 8% helium, with traces of many other elements. Over time, the *nuclear fusion* reactions that fuel the Sun's core are converting hydrogen into helium, changing the ratio of these two elements. These reactions create a tremendous amount of energy, which appears as light and heat: the motion of atoms and particles within the Sun.



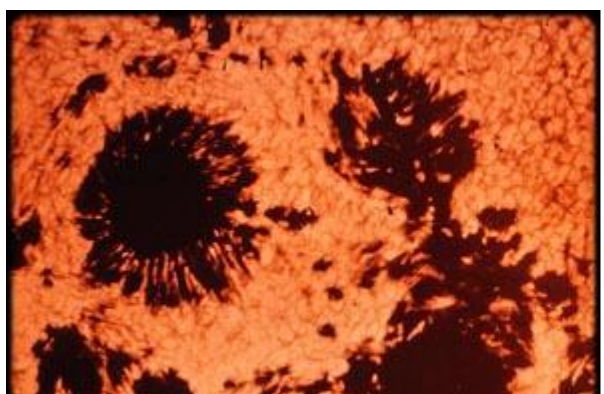
Solar zones

Scientists think of the Sun as being made of several layers, or zones. The central region in which fusion burns hydrogen to power the Sun is called the *core*. The energy produced leaks out through the *radiation zone*, which is still very dense, into the *convection zone*. Here, flows of hot charged gas called *plasma* carry energy from the bottom of this layer outward to the Sun's visible surface, or *photosphere*.

Convection: what goes up...

This moving of heat in a flow of matter is *convection*; it works the same way in a pot of water on the stove, where a current of water heated at the bottom carries energy toward the surface. After some of the energy is released in steam, the cooled water sinks back down, is re-heated, and starts up again in a circular pattern. The circulating plasma flows in the Sun's convection zone "rise" (move outward) all over the Sun to release heat in the solar atmosphere, then sink back inward to be re-heated.

The circulating motion of the convection layer at the Sun's surface, or photosphere, creates the granular pattern in the area outside of the sunspots shown here. Each granule is a separate flow of hot plasma from the interior. Next, we'll look at the role of the convection layer in the creation of sunspots.



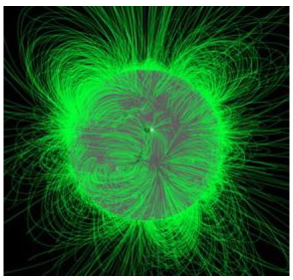
An image of the region around a sunspot. The mottled appearance is due to turbulent eruptions at the surface of the sun.

The Sun's Magnetism

The Sun, like Earth, generates a magnetic field that extends out into space. However, the Sun's magnetic field changes both its shape and intensity over the surface, and over time, much more rapidly. Why is that? We'll need to learn some basics about how the solar magnetic field works, to see how these fluctuations can cause sunspots.

Magnetic fields from electrons

Have you ever made a magnet by winding wire around a nail and hooking the ends to a battery? This works because moving electrons, like the electric current in the wire, generate a magnetic field. The magnetic field lines go through loops of wire and the nail, and the nail becomes a magnet. Something similar happens in the Sun.



This computer visualization shows convoluted magnetic field lines extending out all over the sun.

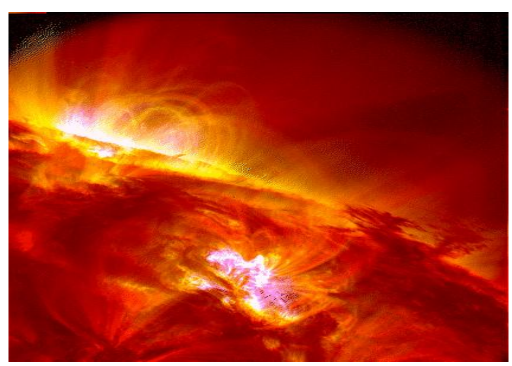
Magnetic fields from convection?

In the Sun, the flows of hot plasma in the convection zone create the solar magnetic field. The plasma is a hot gas "soup" with many free charged particles (electrons and protons). The moving charges are a current, and produce magnetic fields, just like the current in coils of wire around the nail. What's different in the Sun? The convection current is driven by the heat from the Sun's fusion, instead of a battery.

David Dearborn refers to the flows as the "solar *dynamo*," saying, "So there you have mechanical motion, and that mechanical motion is involved in generating the magnetic fields that cause sunspots." Scientists like Dearborn believe that convection creates the varying magnetic field at the Sun's surface, but the ultimate reasons for each fluctuation in the flows and fields are not well understood. The Sun's rotation is also an important force. The next generation of solar scientists may unravel the workings of this immense powerhouse.

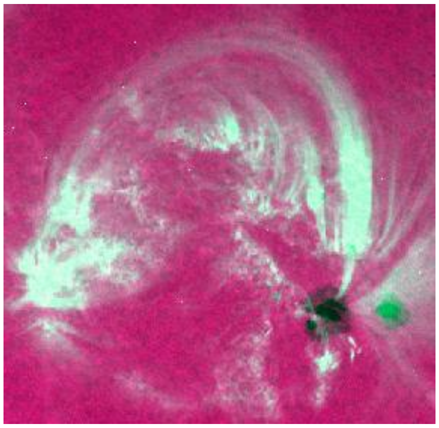
Sunspots have magnetic pressure

Sunspots are regions of very strong magnetic field, where the field lines get so crowded together that they push up through the surface, bringing some of the hot plasma with them in a spectacular arc, or loop. We see the end of the loop as a sunspot on the Sun's visible surface, or photosphere. This dense bundle of field lines creates huge *magnetic pressures*. What is magnetic pressure? We know what pressure is in a gas: if you compress some gas, like squeezing a balloon, it tries to push out again.



X-ray images from the TRACE satellite like this (and the one on the following page) show loops of solar magnetic field lines. Each loop is a dense bundle of field lines.

David Dearborn explains, “If you take those places where there are concentrations of magnetic field and put them together, they have pressure of their own. You can feel magnetic pressure when you take two magnets and take the ends of the same polarity and try to put them together. They just don’t want to go together. That’s magnetic pressure.” The more the magnetic field lines are scrunched together, the more they want to push apart again.



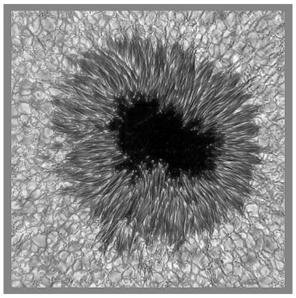
Sunspots mark the places where the magnetic field lines emerge and reenter into the photosphere (TRACE).

Balance pressures to keep cool

Think of a sunspot as a bubble, surrounded by the gas pressure of the photosphere, the surface layer that produces light. For the sunspot to exist, its pressure outward must balance the inward pressure of the region outside. David Dearborn elaborates on how magnetic fields keep sunspots cooler: “Outside a sunspot, you have only gas pressure, which depends on the temperature. In the sunspot you have both gas pressure and magnetic field pressure combined.” Since the pressure must be in balance, magnetic pressure inside the sunspot allows the gas pressure to remain lower than the areas outside. This actually slows the convective motion which ordinarily brings hot matter up from the interior of the Sun, making the sunspot cooler.

inside sunspot		*outside*
[P(gas) + P(magnetic)]	**=**	**[P(gas)]**

Fisher says sunspots are still quite hot: “Instead of being about 5800 degrees *Kelvin* like the rest of the photosphere, the temperature of a sunspot is more like 4000 degrees Kelvin. But that is still very hot, compared to anything here on Earth.” This means the magnetic pressure inside the sunspot is so strong it can cool down a part of the ***surface of the Sun*** by almost one third!



Considerably darker

Since sunspots are about one third cooler than the surrounding materials, they are much darker. Dearborn explains, “If you have a piece of gas or iron and you heat it up and ask how much light it emits, you can measure it. If you then double the temperature, the amount of light that’s emitted...is almost ***eight times as much***.” In other words:

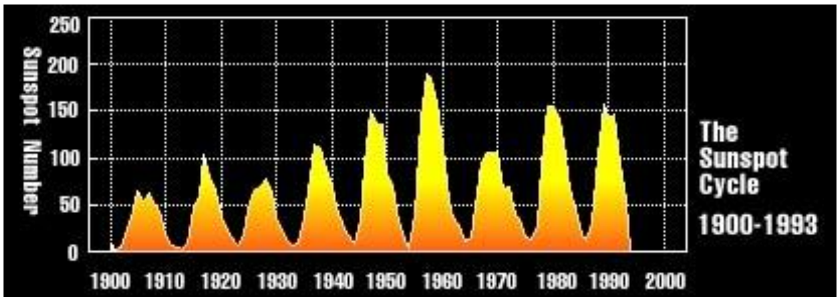
Small change in temperature = Big change in brightness

Reverse this process for a hot object being cooled, and it follows that while sunspots are moderately cooler they are much darker than other parts of the Sun’s surface.

The Sunspot Cycle

Cycles have been around

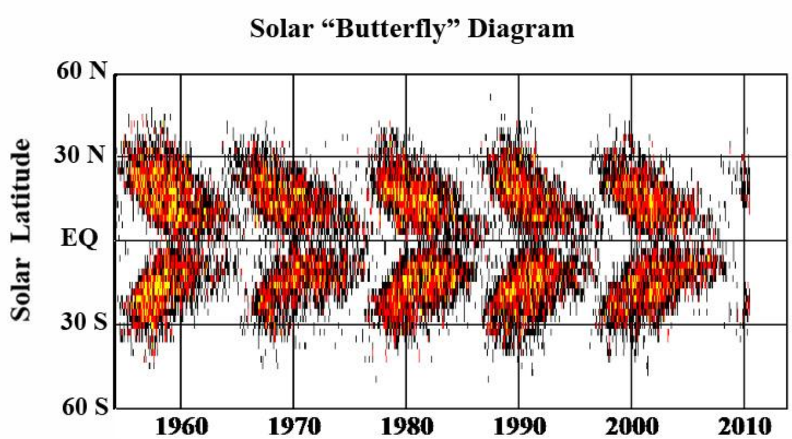
In the last few decades, we've started to understand the forces behind sunspots, but we've known for over a 150 years that sunspots appear in cycles. The average number of visible sunspots varies over time, increasing and decreasing on a regular cycle of between 9.5 to 11 years, on average about 10.8 years. An amateur astronomer named Heinrich Schwabe, was the first to note this cycle, in 1843. The part of the cycle with low sunspot activity is referred to as *solar minimum,* while the portion of the cycle with high activity is known as *solar maximum.*



In fact they go around twice

By studying the Sun's magnetic field, modern astronomers have discovered that the cycle covers twenty-two years, with each eleven-year cycle of sunspots followed by a reversal of the direction of the Sun's magnetic field. According to Fisher, "the overall magnetic field structure changes in a way that is very interesting. It turns out that if the magnetic fields primarily point from west to east in the Northern Hemisphere (of the Sun), they point from east to west in the Southern Hemisphere. In the next eleven-year cycle, the fields are reversed. So the cycle is really twenty-two years."

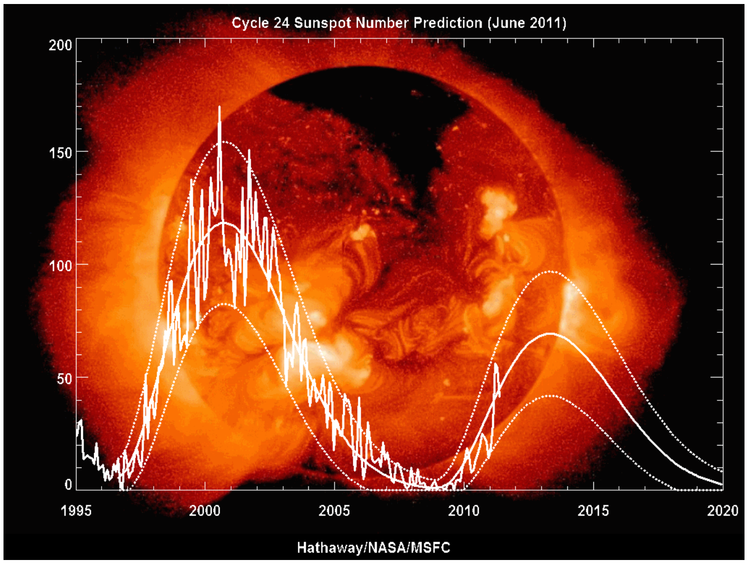
Migration



Sunspots appear mostly in the low latitudes near the solar equator. In fact they almost never appear closer than 5 or further than 40 degrees latitude, north or south. As each sunspot cycle progresses, the sunspots gradually start to appear closer and closer to the equator. The sunspot locations for the most recent 11-year cycles are shown in this "butterfly" diagram. The locations "migrated" toward the equator (0 latitude) from both hemispheres throughout these cycles.

The next solar cycle

Although sunspots tend to come and go in 11 year cycles, it's still very difficult to predict exactly when one cycle will end and the next will begin. It's also quite difficult to predict how strong an upcoming cycle will be (i.e. how many sunspots will appear during the cycle's maximum).



The last cycle began in 1996 and peaked around 2001. In 2007 the number of sunspots was getting very low and experts were predicting that the next cycle would soon begin. Most agreed that it would be a very strong cycle with large amounts of solar activity peaking in 2012. However, experts were surprised when the Sun remained relatively spotless for several years - the deepest and longest solar minimum in the past century. The current cycle finally began revving up in early 2010, much later and weaker than predicted. This new information caused the predictions to be refined, and now most experts agree that the current cycle will be relatively weak with a maximum occurring sometime in mid-2013. Over a span of just a few years, surprises from the Sun forced expert predictions for the next cycle to change drastically, from very strong to very weak. In fact some recent evidence (as of June 2011) suggests that the Sun might soon be entering a period with little to no sunspot activity for years or even decades. We still have much to learn about the fundamental causes of the solar cycle.

Do sunspots affect Earth's climate?

From 1645 to 1715, there was a drastically reduced number of sunspots. This period of reduced solar activity, which was first noticed by G. Spörer, was later investigated by E.W. Maunder, is now called the *Maunder Minimum*.

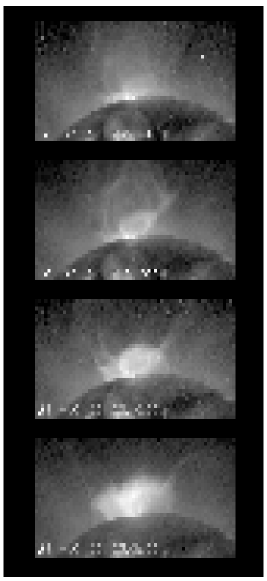
That same period of time was also unusually cold on Earth. Similar periods of low solar activity seem to have occurred during the Spörer Minimum (1420-1530), the Wolf Minimum (1280-1340), and the Oort minimum (1010-1050). This succession of low-temperature periods is now called the "Little Ice Age," and the corresponding pattern of extreme sunspot minima has led to speculation that sunspot activity may affect the Earth's climate. There is ongoing debate amongst experts about how much influence the Sun has on climate change. However, the climate is a very complex system and most agree that the Sun isn't the major player in the climate changes Earth has experienced over the past few decades.

Sun-Earth Connections

The Sun provides nearly all the Earth's energy. Its light provides energy for photosynthesis in plants and algae, the basis for the food chain, which ultimately feeds all life on Earth. However some solar phenomena, including sunspots, can affect Earth and humans in other, less benign ways.

Seeing (sun) spots

Besides possibly affecting our climate, sunspots affect life here on Earth in other significant ways. As early as the nineteenth century, scientists noticed that high levels of activity on the Sun, like *flares* and sunspots, were followed shortly by strong fluctuations in electronic instruments on Earth, and changes in natural phenomena like the *aurora*. They wondered what caused these changes.



Massive solar explosions

Scientists have discovered much about what causes these events. According to Dearborn, "The sunspot itself, the dark region on the Sun, doesn't by itself affect the Earth. However, it is produced by a (solar) magnetic field, and that magnetic field doesn't just stop, it comes to the surface and expands out above the surface...." These magnetic field lines interact with each other in complex ways, often twisting and shearing, which can cause them to cross and reconnect, releasing large amounts of energy. The charged plasma above the surface of the Sun can become trapped by these fields. When the fields quickly change, they accelerate and heat the plasma releasing large amounts of energy in the form of light and some particles in a matter of minutes. This is called a *solar flare*. A slightly different, yet much bigger, magnetic event can cause colossal amounts of plasma particles to burst up and out into space over a period of hours in a *coronal mass ejection* (CME). Earth can be affected in many ways by these solar events. X-rays and Gamma-rays from solar flares impact the outermost atmosphere, while energetic particles and magnetic fields from coronal mass ejections bombard Earth's magnetosphere causing what are called geomagnetic storms.

This NASA illustration shows the earth's magnetosphere and its interaction with the sun.

An aurora viewed from space. This image was taken by the crew of the Space Shuttle Endeavor in April of 1994.

Auroras

Ordinarily, Earth's magnetic field protects human activity from most of the particles and magnetic fields coming from the Sun, deflecting them with its own magnetic pressure. As George Fisher describes it, the Earth has a protective cocoon of magnetic field called the *magnetosphere*, and it normally shields us from the Sun's magnetic field, and the other energetic particles of the *solar wind*. However, sometimes we can still see effects from solar activity in the form of heightened, spectacular displays of the Aurora Borealis and the Aurora Australis, otherwise known as the Northern and Southern Lights. For example, during a flare or coronal mass ejection a large cloud of plasma breaks away and hits the Earth's magnetosphere, and disturbs it. This disturbance causes charged particles (which were already previously trapped inside Earth's magnetosphere) to follow the magnetic field lines into Earth's poles. When they hit the atmosphere they excite the gases there and cause them to glow, similar to how a neon light works. These excited, glowing gases create the beautiful displays that we call aurora.

Geomagnetic Storms

Energetic electromagnetic bombardments can also disrupt power grids and radio transmissions on Earth, often producing power surges and static on the radio. Satellites can be disabled or even brought down. Why?

Star wars for satellites

Since most satellites are outside of the protection of the Earth's atmosphere, they are the first to get hit by the severe geomagnetic storms that can result from solar activity. According to Dearborn, "As the accelerated energetic gas particles from the Sun interact with the magnetic field that the Earth has, and as they slide around the Earth they form current sheets that satellites have to deal with. Satellites move from a region of space that has one charge to an area that has another charge, and when they cross those boundaries, the surface of the satellite can suddenly change polarity as it moves into a region where there is a different electric field. You get arcing and you get electric currents flowing inside the satellite in places where they're not supposed to flow, and that can be very bad for the satellites."

Skylab's time in orbit was cut short by solar activity. The space station fell to the earth in July 1979.

A real drag

In addition to these changes from negatively charged to positively charged states (polarity), which can damage sensitive electronics, the increased solar emission also causes the Earth's atmosphere to "puff out." According to Fisher, this creates increased drag on orbiting satellites. This increased drag can cause satellites to fall in from their orbits more rapidly than predicted. The 100+ ton Skylab station is a good example. Launched in 1973, the station was supposed to remain in orbit until the 1980s. The purpose of Skylab was, among other things, to study the Sun. Ironically, due to increased solar activity, Skylab re-entered Earth's atmosphere in 1979-- raining debris over the Indian Ocean and parts of Western Australia.

High-energy particles get through

Some of the high-speed charged particles from the Sun penetrate the Earth's magnetosphere, where they can create waves of magnetic energy. This can interfere with both the flow of electric current in wires and the transmission of radio waves through the air. If the waves of energetic particles are strong enough, power grids can be overloaded, and radio signals drowned out.

As Dearborn says, "The particles from the Sun that get a little deeper into the Earth's magnetic field can get trapped in the field..., which produces the aurora that we can see and enjoy. But at the same time, they produce a lot of radio interference, especially at the lower radio frequencies, which can be so loud that you have difficulty broadcasting."

More on Sunspots and Climate

Though the connection between sunspot activity and the Earth's climate is still being debated, phenomena like the "Little Ice Age" that occurred during the Maunder Minimum from 1645-1715, seem to show evidence of some connection.

Sunspots mean the Sun is brighter?

Even though sunspots are darker, cooler regions on the face of the Sun, periods of high sunspot activity are associated with a slight increase in the total energy output of the Sun. Dark sunspot areas are surrounded by areas of increased brightness, known as *plages*. Some parts of the solar spectrum, especially ultraviolet, increase a great deal during sunspot activity. Even though ultraviolet radiation makes very little contribution to the total energy that comes from the Sun, changes in this type of radiation can have a large effect on the Earth's atmosphere, especially in the chemistry of the outer atmosphere, like the production of ozone and sulfuric acid.


Most experts seem to agree that more research is needed to understand the possible connection between sunspots and the earth's climate.

Researchers still uncertain

According to George Fisher, "It's controversial whether the solar cycle has an effect on the Earth's climate. One thing that is known for sure is that solar activity, which is what we call the general feature of having magnetic fields on the Sun, changes the Sun's luminosity — that is, how much energy is coming out of the Sun — on the level of a few tenths of a percent. That could change the Earth's climate in this cyclical way, but it's controversial."

Complex systems

The controversy is due to the complexity of the Earth/atmosphere system. It is difficult to disentangle the many factors that contribute to climate change. For instance, are the effects of global warming or ozone depletion more influenced by changes in solar activity? Or possibly by human activity?

Dearborn is also cautious about ascribing climate effects to sunspot cycles: "People have speculated, but I don't think the connection is absolute yet....there is some speculation that sunspots result in climate effects, but that's a very, very hard area, and one that requires much more research before we can be certain of climate effects."

Who will find out?

Currently, there are scientists whose research with this kind of data makes them believe that the Sun has the strongest influence on all climatic changes here on Earth — that known climate changes can be shown to correlate to changes in solar activity. Others believe that human activities, such as burning fossil fuels or clear-cutting forests, may also be important, or even more powerful.

Everyone agrees that more research into Sun-Earth connection science needs to be done. How does the extra ultraviolet light associated with sunspots affect the atmosphere? Do geomagnetic storms produce chemical reactions the atmosphere? How could you compare the effects of human activities and changes in the Sun over time? You might want to think about what type of investigation you'd want to do next. What question would you try to answer?

Solar Science Terms

Active Region: A temporary area of the solar atmosphere in which plages, sunspots, faculae, flares, and other features of the Sun can be observed.

Archaeoastronomy: The study of the astronomical practices, celestial lore, mythologies, religions and world views of all ancient cultures. Referred to, in essence, as the "anthropology of astronomy," to distinguish it from the "history of astronomy."

Aurora: A faint visual (optical) phenomenon on the Earth associated with geomagnetic activity, which occurs mainly in the high-latitude night sky. Typical auroras are 100 to 250 km above the ground. The Aurora Borealis occurs in the Northern Hemisphere and the Aurora Australis occurs in the Southern Hemisphere.

Convection: The organized flow of large groups of molecules based on their relative densities or temperatures. A hot fluid or gas will move upward, and a cooler liquid or gas will sink downward.

Convection zone: The solar layer just below the photosphere, in which plasmas circulate between the Sun's radiation zone and the solar atmosphere, carrying energy outward.

Core: Center of the Sun, where gravitational pressure forces hydrogen ions (protons) to fuse into helium, releasing energy in the form of radiation.

Corona: The outermost layer of the solar atmosphere, characterized by low densities and high temperatures, often several million degrees Kelvin.

Coronal Mass Ejection (CME): Coronal mass ejections are explosions in the Sun's corona that spew out high-energy charged particles. CME's can seriously disrupt the Earth's environment through radiation, which arrives only 8 minutes after being released, and through very energetic particles pushed along by the shock wave of the CME, usually arriving days later.

Dynamo: Any mechanism that uses the physical motion of free electric charges to increase the strength of a magnetic field.

Flare: A sudden eruption in the vicinity of a sunspot, lasting minutes to hours, caused by the release of large amounts of magnetic energy in small volume above the solar surface.

Flux: A measure of the density of magnetic field lines over a surface area. Flux/area is proportional to the average force on a charged particle on the surface.

Gamma Rays: Extremely high-energy radiation observed during large, very energetic solar flares. Gamma rays are more energetic and have shorter wavelengths than all other types of electromagnetic radiation.

Geomagnetic Storm: A worldwide magnetic disturbance. The term was coined by Alexander von Humboldt (1769-1859). After journeying the length of Siberia, Humboldt convinced the Czar to set up a network of magnetic observatories across the Russian lands, and additional stations were established throughout the British Empire, from Toronto to Tasmania. This network clearly showed that magnetic storms were essentially identical all over the world: a steep decrease of the field over twelve to twenty-four hours, followed by a gradual recovery, which lasted one to four days. The change in the magnetic field was small, but its world-wide scale suggested that something quite big was happening out in space.

Humbolt, Alexander von: A naturalist who gained attention by exploring the jungles of Venezuela, Humboldt devoted much of his life to the promotion of science. He produced five volumes of "Kosmos" (starting the modern usage of that term), an encyclopedic account covering the broad spectrum of the sciences. It was "Kosmos" that brought to the world's attention the discovery of the sunspot cycle by Heinrich Schwabe.

Infrared (IR): The infrared includes electromagnetic radiation at wavelengths just beyond the visible spectrum. Infrared wavelengths are longer than visible radiation and shorter than microwave radiation. Humans perceive infrared radiation as "radiant heat."

Kelvin: A temperature scale with the same division as the Celsius (centigrade) scale and with the zero point at 0 degrees absolute. Room temperature is about 295 degrees Kelvin (295K).

Magnetic Field: A field of magnetic force lines, usually referred to here as the pattern of magnetic force emanating from and surrounding the Sun or any of the planets.

Magnetic Pressure: The resistance of magnetic field to being compressed in space, for instance by the presence of another field. Pressure on a magnetic field crowds field lines together, and the field pushes back with its own pressure.

Magnetosphere: The Earth's magnetic field and its area of influence above the atmosphere; Earth's "magnetic atmosphere." Specifically the outer region of Earth's ionosphere, starting at about 1000 km above Earth's surface and extending to about 60,000 km and to at least 100 Earth radii on the side away from the Sun.

Maunder Minimum: A period from 1645 to 1715, when the average number of sunspots was unusually low. It was investigated by E. W. Maunder, and corresponds to a time called the "Little Ice Age", when temperatures were unusually cold.

Nuclear Fusion: The joining of atoms under tremendous temperatures and pressures to create atoms of a heavier element. In the Sun, four hydrogen atoms are fused to create each helium atom. Two of the hydrogen's protons become neutrons in the process.

Penumbra: The brighter area that surrounds the darker umbra or umbrae at the center of a sunspot.

Photosphere: The lowest layer of the solar atmosphere, where the Sun's visible spectrum of light (electromagnetic radiation) is released. It is visible "surface" we see in white-light images of the Sun.

Plage: An extended bright area of an active region that exists from the emergence of the first magnetic flux until the widely scattered remnant magnetic fields merge with the background.

Plasma: A gas of charged particles, such as electrons and ionized (charge) nuclei, often hydrogen nuclei (protons). This occurs when atoms of a gas are torn apart by high temperatures, pressures, and/or electromagnetic fields.

Radiation zone: Layer just outside the Sun's core, where energy is transported mostly in the form of radiation. This region, while too cool for fusion to occur, is still very dense and hot- about 4 million degrees Kelvin.

Solar Maximum: The month(s) during the Solar Cycle when the twelve-month mean (average) of monthly average sunspots numbers reaches a maximum. The most recent solar maximum occurred in July 1989.

Solar Minimum: The month(s) during the Solar Cycle when the twelve-month mean (average) of monthly average sunspot numbers reaches a minimum. The most recent minimum occurred in September 1986.

Solar Wind: The outward flow of plasma (high-energy charged particles) from the Sun. Average speeds are about 350 km/sec.

Sun: One of the 100+ billion stars in our galaxy. 1,390,000 km diameter. Temperature at the core: 15,600,000 K. Temperature at the surface: 5800 K.

Sunspot: A temporary concentration in the magnetic field on the Sun, where convection of hot matter from the Sun's interior is inhibited, resulting in a cooler, darker area on the photosphere of the Sun. The average sunspot is about the same diameter as the Earth.

Sunspot Cycle: Regular increase and decrease of sunspots and other solar activity, which are thought to be physically related. Sunspots go through one cycle of activity in approximately 11 years. The Sun's magnetic polarity reverses between every cycle.

Ultraviolet: Electromagnetic radiation at shorter wavelengths and higher energies than the violet part of visible light.

Umbra: The term for the dark area at the center of a sunspot.

X-rays: Electromagnetic radiation of very short wavelength, and very high energy. X-rays have shorter wavelengths than ultraviolet light, but longer wavelengths than gamma rays.