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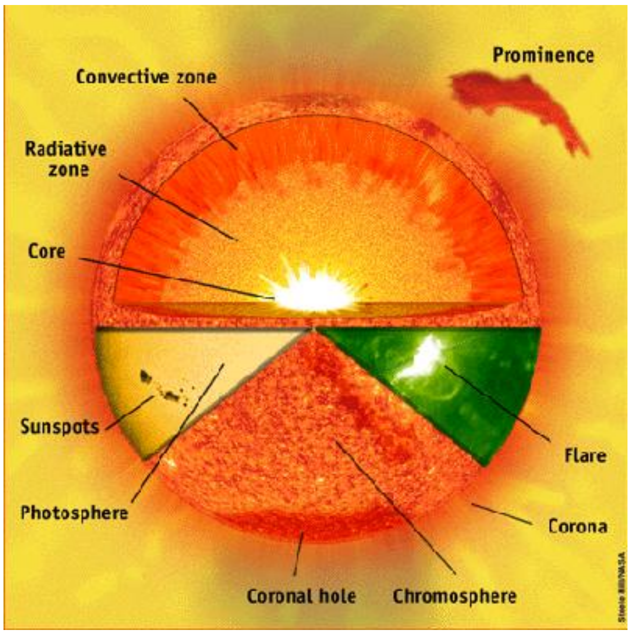
The Sun's Magnetic Field

The origin of the Sun's magnetic field is still somewhat a mystery to scientists and people all around the world. Many experiments have been done in history to obtain a better understanding of the Sun's magnetic field and what kind of effects it has on Earth and Earth's magnetic field, as well as on other planets in the solar system. NASA has created the Voyager and Ulysses that have been to space and returned with much needed information to understand the Sun and solar wind which can cause effects on the Earth, as well as understanding the Sun's poles and what causes the Sun's magnetic field.

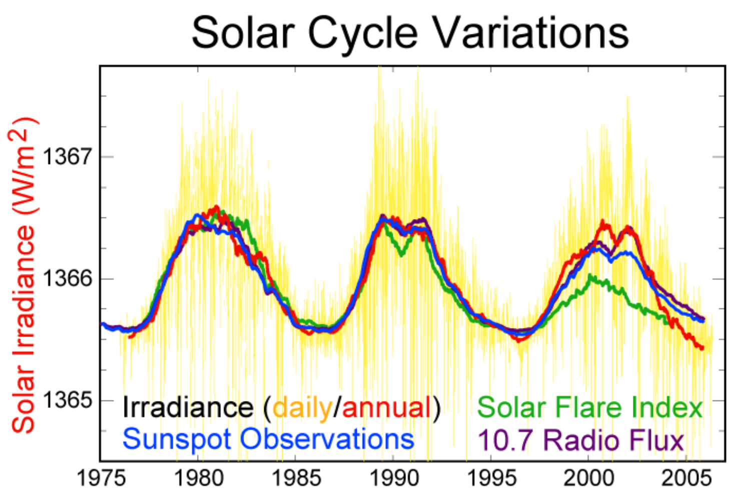
There have been many propositions and theories to explain exactly how the magnetic field originally came to be, but today it is still a great mystery among many scientists. To understand the solar cycle, we must first understand how the Sun generates light and heat. Sun converts light to heat in its core, which is the hottest part of the Sun. The light then exits the Sun, first going through the inner 70% of the Sun, which is the densest part. Once it exits the core, it goes through the outer 30% of the Sun which is called the Convection Zone. In the Convection Zone, Sun matter boils. Light and heat then escape the Convection Zone and enter the Atmosphere.

The temperature of the Sun decreases as it exits the Sun as we would assume is would, as the core is the hottest part of the Sun, so the farther out from the core, the lower the temperature should be. However, the temperature increases again once it passes through the photosphere, which is the visible surface of the Sun. The temperature then increases significantly in the Transition Zone, the part of the Sun in between the photosphere and the Corona, the outermost layer of the Sun. Once it reaches the Corona, the gas becomes so extremely hot that it loses electrons and causes x-rays to be emitted from the Sun. Why the temperature in the Sun increases after it reaches the photosphere is unknown to scientists today, but it still being studied in order to understand.



Sun and its different layers (http://static.howstuffworks.com/gif/sun-part.gif)

Many scientists believe the solar magnetic field generated from the solar cycle. Samuel Heinrich Schwabe discovered the solar cycle in 1843. He discovered that the solar cycle is the period in which much of solar activity repeats (“Solar Cycle”). The solar cycle is a twenty-two year cycle composed of two eleven year cycles. In the first eleven years of the solar cycle, there is a period of fewer sunspots caused by a weaker magnetic field, called the solar minimum. During the last eleven years of the solar cycle, there is a period of more sunspots caused by a stronger magnetic field, called the solar maximum. During the solar maximum, the strong magnetic fields slowly migrate towards the solar equilibrium so that by the end of the last eleven years, the magnetic field poles have reversed and a new solar cycle can begin (The Magnetic Sun).



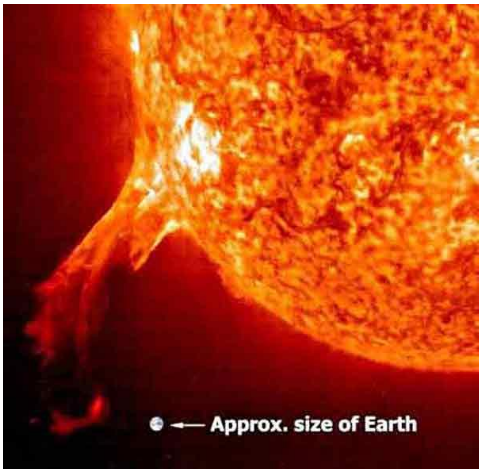
Solar Cycle Graph (http://upload.wikimedia.org/wikipedia/commons/0/0d/Solar-cycle-data.png)

Starting in 2008 and extending through 2009, which was towards the end of an eleven year cycle of the solar minimum, there was a severe lack of sunspots, flares and other storms. This lack of activity, which generally indicates the end of the eleven year cycle, lasted over a year longer than it should have. SOHO, the orbiting Solar and Heliospheric Observatory collected data which indicated that gas flow affects magnetic fields. It showed that the hotter the gas, the slower the magnetic field which causes a slower end to the solar minimum, and can cause the lack of sunspots to extend longer than usual. SOHO also provides us with a way to predict future solar cycles and how intense they could possibly be. Some solar outbursts can be extremely harmful to Earth and can disrupt satellites that orbit Earth as well as electric power grids, so being able to predict the time and intensity of the next solar cycle is crucial to keeping Earth safe (Cowan).

SOHO collected data that allowed scientists to explain that the hotter gas gets, the faster its flows which causes magnetic fields to be weaker and thus, the sunspots to decrease and increasing the length of the solar minimum. The strength of the polar magnetic field is what determines the length of the solar cycle. Stronger magnetic fields are what produce sunspot-generating magnetic fields inside the Sun. These magnetic fields allow the poles to switch and lets the next solar cycle begin. Weaker magnetic fields do now allow for sunspot-generating magnetic fields to be produced as fast, and cause sun-spots to be created slower and thus the next solar cycle is delayed in starting (Cowan).

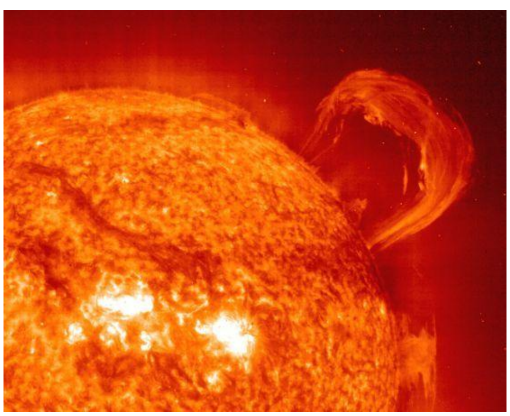
There are two major short-term effects that the Sun and solar wind can have on the Earth: solar flares and coronal mass ejections (CME). To understand these, we must first understand the plasma environment of the Sun that causes these short term effects. In the Sun, there is a high level of plasma pressure. Using Ohm's Law and Maxwell's Equations in such a system, it is shown that the plasma pressure and the magnetic field are frozen together in time. Because the Corona, the outermost layer of the Sun, has a very low density, the plasma pressure drops and the magnetic fields expand into loops. These loops trap the hot plasma and allows for magnetic reconnection, which is the process where magnetic field lines reconnect to other magnetic sources by splicing and reconnecting. This is what causes solar flares and coronal mass ejections (Harrison).

One of the short-term effects that the Sun's magnetic field can have on Earth is that of solar flares. Harrison explains that "a flare is an explosive event whereby the highly stressed magnetic fields within a solar active region suddenly release energy into the local plasma, most likely through magnetic reconnection" (Harrison). This release in energy causes the plasma to heat up and accelerate. Up to 10^{25} J of energy can be released in approximately ten minutes from this kind of explosion. Within 30 minutes, the Sun's Coronal structure, which is extended into the heliosphere, the small bubble formed by solar wind, has been covered in a "snowstorm of particles hit," which is a called a solar proton storm (Harrison). This can be an extremely damaging explosion, and because the particles are moving so fast, it leaves a very small window of time for warning, sometimes only between one and six minutes, which is not long enough to prepare for such an explosion (Harrison).



Solar flare from the Sun compared the approximate size of Earth (http://api.ning.com/files/rShNeomQNkUT9MtukdgLDz8tmpPj8MAipX*cSjVpm5L*lNYLqje8WbvrPsD4V0mgEVFPF7ueaRbocSBQfq4dOmAvg6fqyDLR/SolarFlareandProminence.jpg

The other main short-term effect of the Sun's magnetic field on Earth is the most dangerous as well: coronal mass ejections. This type of event causes a significant amount of the Sun's Corona to explode into space at extremely fast speeds. Basically, when the explosion occurs, a large plasma cloud enters space at fast speeds. The interaction of the cloud's magnetic field and the Earth's magnetic field cause the negative effects on Earth. The intensity of the effects depend on the speed of the cloud. If the cloud is directed toward Earth, it can "completely engulf the Earth-Moon system" (Harrison).



Coronal Mass Ejection from the Sun. (http://blog.silive.com/weather/2009/05/solarfilament.jpg)

Besides the negative effects solar wind can have on Earth, there are properties of the Sun that cause it to act the way it does. One property of the Sun's magnetic field is that of the Parker spiral. Developed by scientist Parker, the magnetic field originates in the Sun and then it is carried into space by solar wind. Because the Sun is rotating, it causes the magnetic field to rotate as well and form a spiral shape. The magnetic field points outward from the Sun in one hemisphere of the Sun, and inward in the other hemisphere of the Sun causing opposing magnetic fields and thus a rotation ("Sun's Magnetic Field").

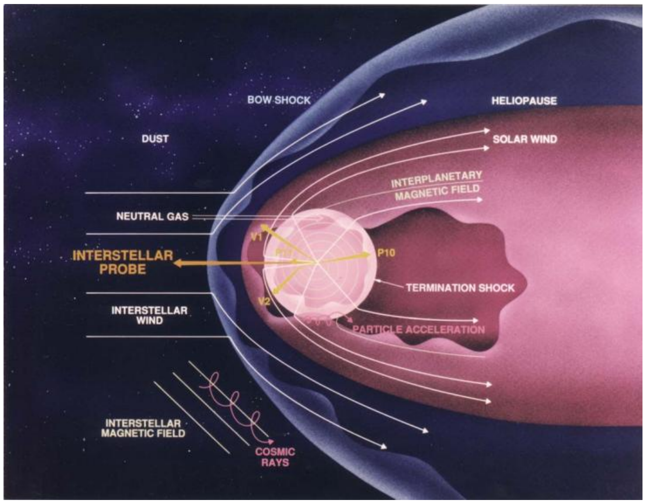
Another property of the solar magnetic field is that of the Zeeman Effect. From the Zeeman Effect, we are able to measure the intensity of the strength of the magnetic field of the Sun. When atoms, ions or molecules encounter a strong magnetic field, the strength of the magnetic field causes the spectral transition lines to split within the atom. Spectral transition lines split when atoms change energy levels for any reason, so when atoms enter a strong magnetic field, it causes the atoms to change energy levels at a rate proportional to the strength of the magnetic field. Thus, we can measure the strength of the magnetic field by measuring the number of spectral transition lines that split, because they are directed related to the strength ("Magnetic Field of Sun").

The idea to send a spacecraft into space to discover more about the Sun has been an idea for over 50 years. However, the capability of such an experiment, and the resources to do so was lacking. In the early 1970s, NASA and ESA, European Space Agency, created a plan for two spacecrafts to go to space together to orbit the Sun. They were to depart together towards Jupiter, and one would fly over the northern pole of the Sun, and the other would fly over the southern pole.

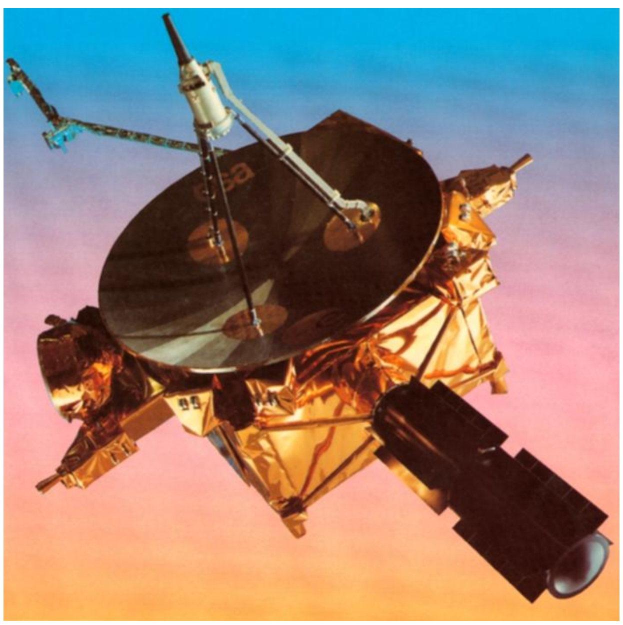
A joint ESA/NASA mission, Ulysses is charting the unknown reaches of space above and below the poles of the Sun. ("Surprises from the South Pole"

Unfortunately, when NASA became occupied with the Space Shuttle, price-cuts were made, and the NASA spacecraft to orbit the Sun was not going to go to space anymore. ESA decided to continue with the mission anyways, and send their spacecraft into space by itself to orbit the whole Sun. What was initially called the International Solar-Polar Mission was renamed Ulysses. When the Challenger disaster occurred, all space missions were put on hold, so Ulysses did not launch in 1986 like it was supposed to. However, when space missions began again in 1989, the Ulysses mission was started again and it was finally launched in 1990 ("Ulysses").

Ulysses has been launched three times before and has observed the Sun in 1994-5, 2000-1, and 2007 (NASA). It was the first spacecraft to go to space and explore both above and below the poles of the Sun. The main objective of Ulysses was to explore the poles of the Sun so we can understand more about the Sun and what causes the solar magnetic field and how to better predict the intensity of the magnetic field. Ulysses has studied solar wind during its orbit, which blows constantly and forms the heliosphere, which is a large bubble in space. The wind is caused by plasma exiting the Sun, and can have many effects on Earth. Ulysses was able to fly over 300 million kilometers above the Sun's northern pole, which is the greatest distance any spacecraft has flown ("Ulysses").



Sun's Heliosphere (http://interstellar.jpl.nasa.gov/interstellar/SmallPinkHeliosphere.jpg)



Ulysses Spacecraft (http://esamultimedia.esa.int/images/Science/ulysses/21_Ulysses_spacecraft_H1.jpg)

During its mission to space, Ulysses discovered many properties of the Sun and its magnetic field that scientists did not know before. As it was studying solar wind, it was able to take a three-dimensional picture of the heliosphere which is created from solar wind, and this was the first three-dimensional picture of the heliosphere in history. It also discovered that around the Sun's poles where the temperature is cooler, the wind expands itself to fill two thirds of the heliosphere, and the solar wind blows at a constant speed of 750 kilometers per second. These are just a few of the aspects about the Sun that Ulysses managed to collect during its mission ("Ulysses").

On its third mission to orbit the Sun, Ulysses was planned to orbit during the end of the solar cycle, or during the solar minimum. Although it was close to the end of its sunspot cycle, "the Sun showed that it is still capable of producing a series of remarkably energetic outbursts" ("Surprises from the Sun's South Poles"). Scientists are trying to figure out how charged particles that were emitted from the solar storms could have made it all the way to the poles. They suggest that the particles would have had to follow the magnetic field lines, but because it was near the solar minimum, the magnetic field should have been weaker and thus making it more difficult for particles to follow. This is the sort of question and uncertainty that scientists would like to uncover through the Ulysses mission to orbit the Sun ("Surprises from the Sun's South Poles").

The spacecraft was initially only supposed to survive for about five years. However, it managed to make three orbits of the Sun and measure almost two complete solar cycles. It provided more information about solar wind and solar magnetic field than ever thought possible. One important discovery Ulysses made is that solar wind has become weaker throughout the time Ulysses orbited the sun, and solar wind is continuing to get weaker, now being the weakest is has ever been in history. Ulysses has also measured data about the heliosphere, particularly noting dust particles and neutral gases that attempt to penetrate the heliosphere (Jet Propulsion Laboratory).

Ulysses was initially supposed to have two spacecrafts, each one orbiting one pole of the Sun. Once NASA decided not to let their spacecraft launch, it caused a huge setback for ESA. After much work, ESA reconfigured their spacecraft and decided to still launch it, but the Challenger exploded causing another setback. Ulysses was also only supposed to survive for about five years and no one ever expected it to retrieve the amount of information about the Sun and its poles that it did. Even with all of these setbacks and conflicts, ESA still managed to send a spacecraft into space and discovered much needed information about the Sun and solar wind and the poles of the Sun that has allowed scientists to begin even more research about space in general and certain effects it has on Earth.

This discovery allowed for future predictions of solar wind which, as I stated earlier, sometimes can have huge effects on Earth, some effects being the effect on electric grids and possible destruction of certain satellites that orbit Earth. All of these possible effects can be avoided with certain discoveries about the Sun and how it functions. However, these experiments have been long awaited by scientists, but not as easy to experiment with which has caused the delay in the findings. Once Ulysses was created, the possibility of discovering this information and finding this data was at the hands of scientists. Now there have been so many discoveries and they are beginning to make more predictions about when there might be solar flares or coronal mass ejection, which are the two main short-term explosions or events that can cause effects on Earth.

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