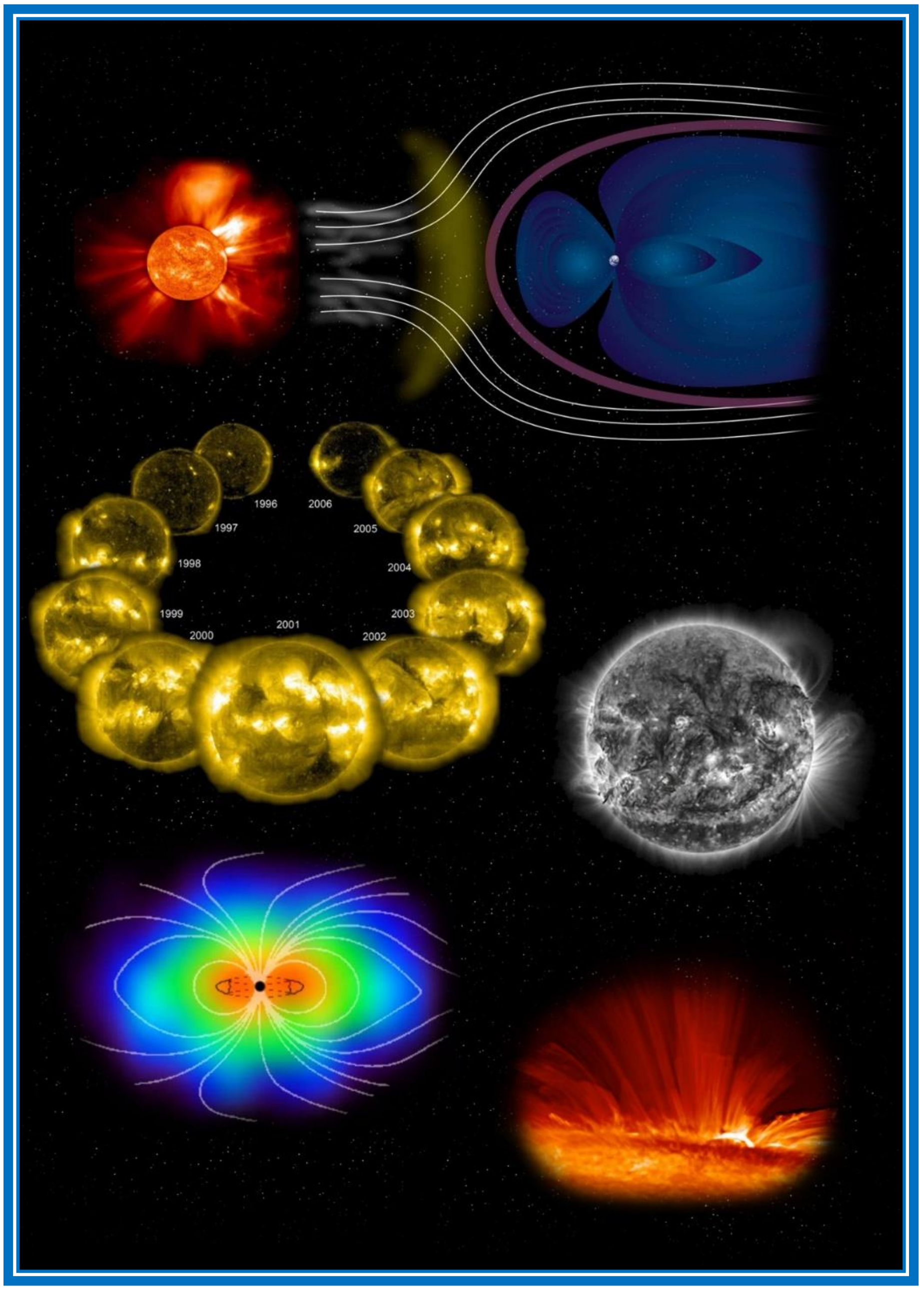
The Magnetic Sun

CESAR's Booklet



Introduction to planetary magnetospheres and the interplanetary medium

Most of the planets in our Solar system are enclosed by huge magnetic structures, named magnetospheres that are generated by the planets' interior magnetic field. These magnetospheres form the biggest structures in our Solar System with their size being 10-100 times bigger than the planet itself. This if the heliosphere is not included. The solar wind moves around these magnetic "bubbles" and interacts with them. A planet's magnetosphere can either be induced by the interaction of the solar wind with the ionosphere (comets, Venus) of the body or via a dynamo process (Mercury, Earth or giant planets).

Now we know that there are magnetic structures. The second question is: what they are and how do we know about their shapes? The shape of it is determined by the strength of its magnetic field. Furthermore, as the flow of the solar wind passes the field, the motion of a solar charge particle goes in the direction of the magnetosphere's lines. Charged particles are present in all magnetospheres, though the composition of the particles and density varies from one planet to another. The particles in the magnetosphere may originate from the ionosphere of the planet, the solar wind or on satellites or ring particles whose orbits are entirely or partly within the magnetic field of the planet.

The motion of these charged particles increases to great scale electric fields and currents, which affect the magnetic field and the motion of the particles through the field. It may perhaps not be unexpected that the interaction between magnetic field, charged particles and electric fields generates very complex physical processes which are frequently not well understood.

While most of the information and data we have is derived from in situ spacecraft measurements, atoms and ions in certain magnetospheres have been detected from Earth through the discharge of photons at visible and ultraviolet wavelengths. Electrons that accelerate are known to discharge photons at radio wavelengths, visible at frequencies reaching from some hertz to gigahertzes. Emissions like those were studied from Jupiter in the 1950's, and shaped the first indication that planets other than ours may have magnetic fields that are strong.

A short introduction to magnetic fields

We can first introduce the term magnetic field and what it really is. An area of effect that is exerted by a magnetic force has a magnetic field. This field is usually focused along two poles, a south and a north. To create a magnetic field, one needs to use a magnetically sensitive material, for example iron magnets, or by moving charged particles (for example, an electric current) which creates a force. This can be a pushing or pulling force.

Here are some fundamentals about a magnetic field. First, it is not possible to divide a magnetic field. It is a dipole and will always be so. Dipole is as it sounds something that has two poles. It will simply change in its strength. Atoms in magnetically sensitive materials can be turned around in their orientation to match a larger and stronger magnetic field. Additionally, a changing magnetic field can cause electric currents. Electric currents are simply electric charges that are moving in a distinct path. Their movement can, in turn also create a magnetic field: sometimes this is as large as the magnetosphere of our Sun, or it can be as small as the domain of the atom. The other thing to know when it comes to a magnetic field is that opposites attract to each other. Similar poles in magnets will repel each other every time, while at the same time poles that are opposite in nature will be attracted each other.

Magnetic field of the Sun/Stellar magnetic field

Our star is very magnetically active. It has a strong and shifting magnetic field that differs from year-to-year. It reverses the direction of its poles after every solar maximum. This happens during one solar cycle. As far as we know, one solar cycle takes about 11 years to be completed.

Also, the magnetic field of the Sun leads to many effects that are together named solar activity. This activity includes solar flares, prominences, sunspots, and difference in the solar winds that carry material through our Solar System.

The effects of solar activity also can be seen from Earth. These refer to the auroras, or northern lights, at reasonable to high altitudes. Also, the disturbance of radio communications and electric power is often due to the stellar magnetic field. It also changes the structure of Earth's outer atmosphere. Lastly, it is believed to have played a huge role in the formation and development of the Solar System.

The matter in the Sun is all in the form of charged gas at high temperatures, also known as plasma. Because it is a gas, and not solid, this makes it possible for the equators of the Sun to rotate faster than it does at higher latitudes.

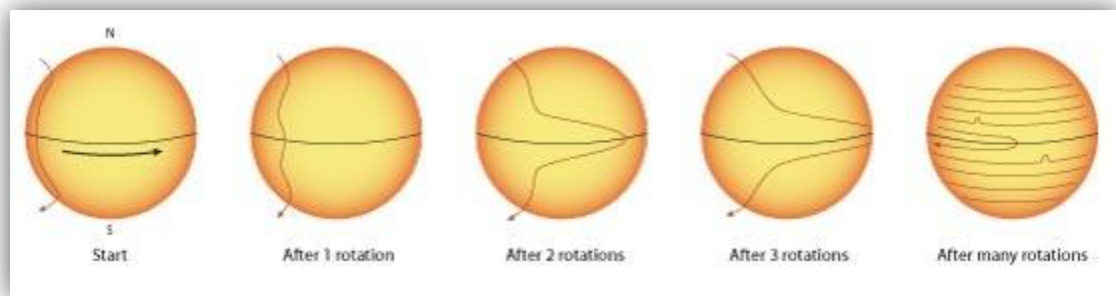


Figure 2: *The rotation of the Sun's magnetic field.* *Credit: NASA/ IBEX*

Look at Figure 1. The Sun´s equator takes 25 days to complete a rotation compared to 35 days at higher altitudes. With the equator moving in a faster pace than the other areas of the Sun, the magnetic field lines will twist together over time. This will then produce loops in the magnetic field, which in turn will erupt from the surface of the Sun and create the formation of the Sun's intense sunspots and other known solar events as we have seen before.

The twisting action also creates the solar dynamo, which allows it to constantly create magnetic field. The 11-year solar cycle of magnetic activity as the magnetic field of the Sun reverses itself around every 11 years (polar flip).

The magnetic field of the Sun is not only surrounding the Sun, its field ranges beyond the Sun itself. The plasma from the Sun transmits its magnetic field into space, producing what is known as the interplanetary magnetic field. The interplanetary magnetic fields are at first stretched radially away from the Sun due to the plasma moving along the magnetic field. The fields below and above the solar equator have different polarities that points away and towards from the Sun leads to an existing of a thin layer of current in its equatorial plane. This is called the heliospheric current sheet. As the distance from the Sun increases, the rotation of the Sun twists the current sheet and magnetic field into a structure that looks like the Archimedean spiral structure called the Parker spiral. Below is a figure showing this phenomenon.

Figure 3: *The purple are is the Heliospheric current sheet, with the planets crossing it. Credit: Wikipedia*

The dipole component of the solar magnetic field is much weaker than the interplanetary magnetic field. To compare them, the dipole magnetic field at the photosphere is roughly 50–400 μT. It then reduces with the distance in cube to approximately 0.1 nT at the Earth's distance. On the other hand, some spacecraft's has observed the interplanetary field at the location of the Earth and the results was that its value is about 5 nT in strength. This is roughly hundred times more than the strength of it close to the Sun. Why does it behave like this? Well, the dissimilarity is due to the magnetic field that is produced by the electrical currents in the plasma that is surrounding the Sun.

Geomagnetic storms

A geomagnetic storm, also recognized as a magnetic storm, is a disruption in the magnetic field of the Earth. This disruption is triggered by coronal mass ejections (shortly CMEs) by changes in the speed of the solar wind that comes from the Sun. These are in other words huge outbreaks from the outer layer of the atmosphere of the Sun, that is, from the corona. The material related with these solar outbreaks contains mostly of electrons and photons, with energy of a few thousand electron volts (meaning a temperature of about 1 million degrees).

A geomagnetic storm usually begins between 24 and 36 hours after a CME, when an enhanced density of solar plasma reaches the magnetosphere of the Earth at much higher speed than normal, causing changes within the magnetosphere. Usually, a magnetic storm then continues for 24 to 48 hours, but some can even last as long as days. Once every decade (more or less), some really powerful storms can happen, with the most severe happening once every century. They happen when particles with high energy from a solar storm interact with the ionosphere and magnetosphere, generating a flow of energetic particles and disturbing the magnetic and electric currents in the atmosphere. Some effects of a magnetic storm include strong induced currents in power lines, powerful auroras, harm to satellites, etc.

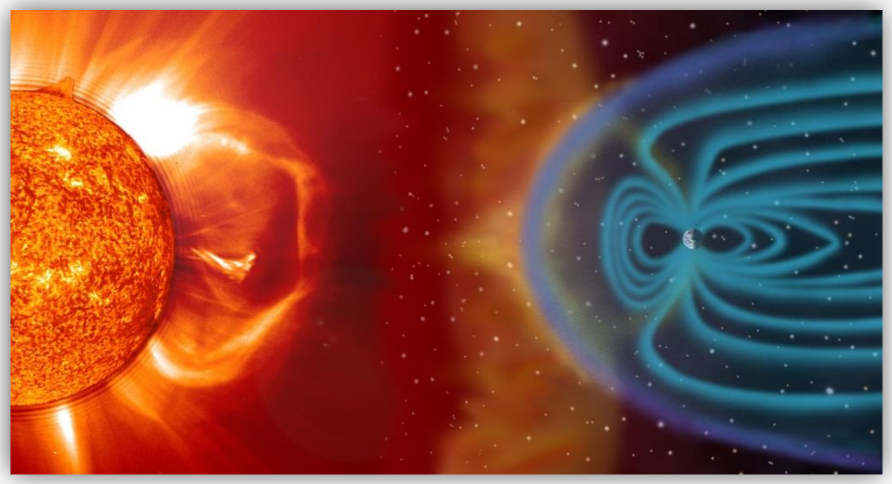
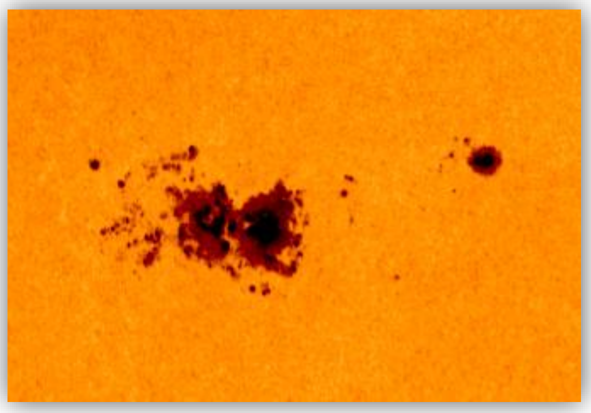


Figure 4: *An image of a Coronal Mass Ejection leaving the Sun. Basically, CMEs are huge gas bubbles bounded by the magnetic field lines of the Sun, ejected from it over the course of several minutes – sometimes even a couple of hours. The cloud of charged solar particles that is travelling towards the Earth can interact with the magnetosphere and cause anything from radio interference to failure of sensitive electromagnetic equipment, or even increased aurorae activity.* *Credit: ESA/NASA*

Sunspots

As we mentioned, a sunspot is part of the photosphere that is disturbed by powerful magnetic activity, this magnetic activity slows down the convection of hot material from below, thus decreasing its surface temperature in that area. These areas have a magnetic field that is about 2,000 times more powerful than the one Earth has, and much higher than anywhere else on the Sun.



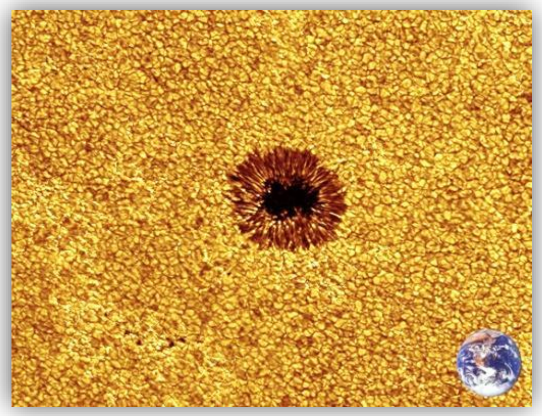


Figure 5: *Pictures of sunspots. On the left is a group of sunspots: usually the part on the right has one magnetic pole (for example "north"), and the part on the left has the other pole (for example, "south"). The image on the right is a close-up image of one spot, with the size of the Earth in comparison.*
Credit: ESA/NASA

Because of the strong magnetic field, the magnetic pressure inside the spot grows, while at the same time, the atmospheric pressure inside it drops, so that the combination matches the atmospheric pressure outside the spot. This then decreases the temperature compared to its surroundings since the concentrated magnetic field stops the flow of new, hot gas from the Sun's interior to the surface. Even if the sunspots are still extremely hot and bright, they look darker since they have a cooler temperature than their surroundings. The black areas of the sunspots are called the "umbra" (shadow is the translation) and the surrounded or lighter area is titled the "penumbra" (almost shadow is the translation).

To put it in numbers, the photosphere has a normal temperature of about 5500 Celsius degrees, whereas the temperature of a sunspot is approximately 4000 Celsius degrees. The temperature difference leaves them visible as noticeable dark spots. Sunspots have a habit of being in pairs that have magnetic fields pointing in opposite directions (as a magnet does).

The average sunspot is about the size of our planet. Yet, sunspots come in diverse sizes reaching from hundreds to tens of thousands of kilometres across.

Scientists that observe the sun often measure the total area (size) of all the sunspots seen on the Sun every day. This is to get an idea of how active the Sun is. Lastly, sunspots seem to be permanent but they are not. Individual sunspot groups might last for a few weeks; and the number of sunspots visible on the Sun's surface rises and falls in roughly regular cycles.

To measure the solar activity in terms of number of sunspots we use the "Wolf number". This number is given per day and counts both the number of sunspots and the group of sunspots on the Sun's surface. Plotting the Wolf number in a diagram is possible to visualize the solar cycle too.

i. The Maunder Butterfly Diagram

Sunspots usually appear at the beginning of every new solar cycle and can often be seen in groups. We can conclude that groups of sunspot mostly show up in a particular belt between the heliographic latitude of 5° and 35°. There are much smaller number of groups out of these belts, and above 40° there is almost no presence of them. These sunspots have latitudes that differ with a remarkable pattern during the solar cycle. When the cycle reaches a minimum (small number of sunspots), sunspots appears even closer to the Sun's equator, and as a new cycle starts again, sunspots again appear at high altitudes (new maximum). As mentioned, a noticeable pattern occurs and we get the "butterfly" pattern, a pattern that was first discovered by Edward and Annie Maunder in 1904.

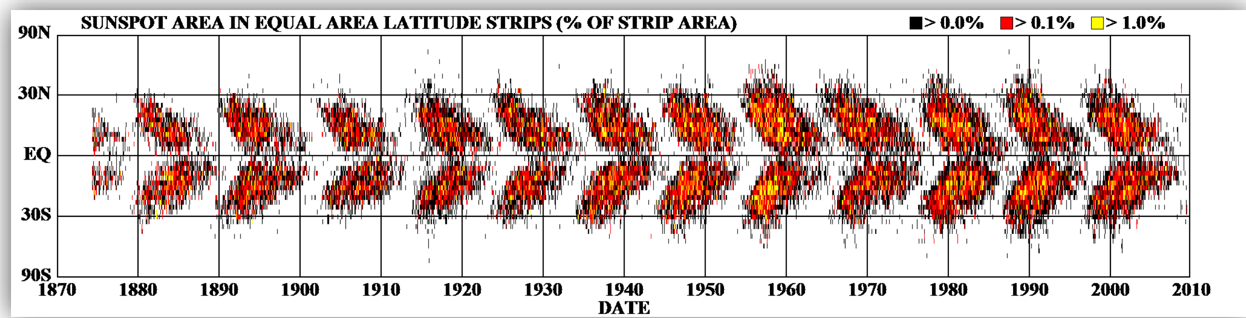


Figure 7: The Butterfly diagram *Credit: NASA*

Edward and Annie were the first to notice this pattern by plotting the position (latitude) of the spots versus time. The areas of the sunspots were not considered in this diagram, and are still not.

A German astronomer named Samuel Schwabe, noticed in the middle of the 19th-century, that the number of visible sunspots on the disk of the Sun falls and rises in nearly regular 11-year cycle. This was concluded after many years of diligent solar observations. Now, we call this period a solar cycle.

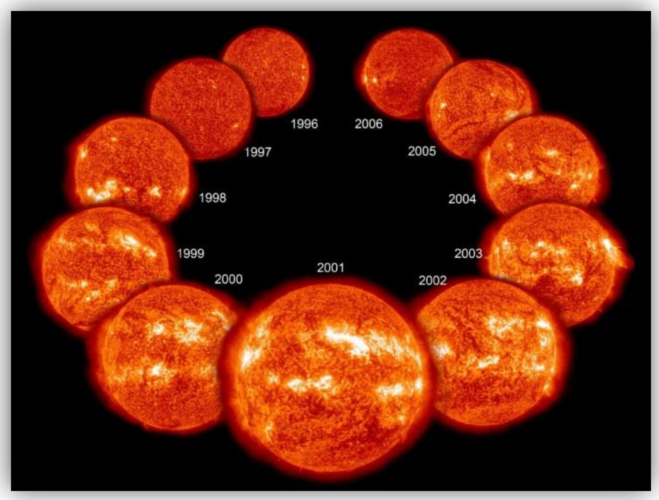


Figure 8: This image shows a solar cycle, from 1996 to 2006. In 2001, there was a solar maxima and it is easy to see all the sunspots and active regions. *Credit: ESA/NASA*

The magnetic poles of the Sun reverse and come back every 22 years, and it has two sunspot cycles that happen at 11 year intervals within each of its cycles: 11 years is the time to change one pole from magnetic north to south (or south to north).

This regular cycle can be traced back to the first telescopic observation of our Sun which happened in the 1600s, and has been documented in cumulative detail by modern astronomers right up to the current day.