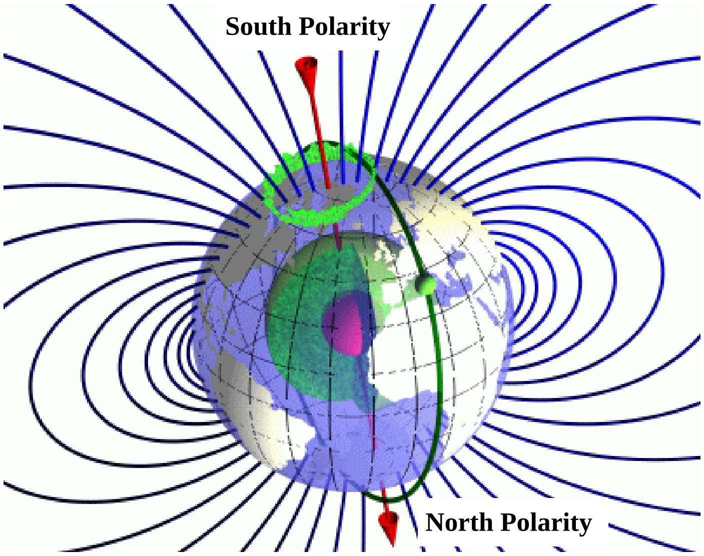
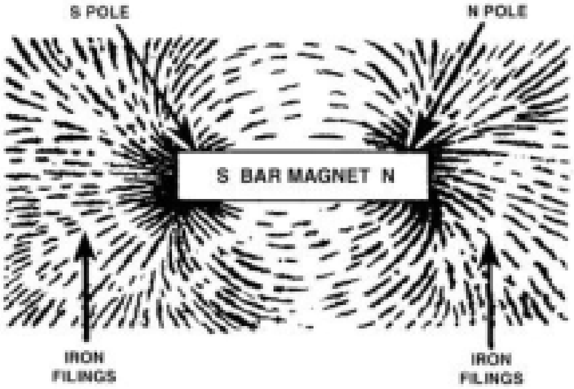
Chapter 2: Investigating the Earth's Magnetism

For hundreds of years, sailors have relied on magnetic compasses to navigate the oceans. These sailors knew that Earth's magnetic north pole was not in the same place as the geographic North Pole, and they were able to make the necessary corrections to be able to determine where they were (and, more important, how to get home!). In modern times, we have found that the magnetic North Pole does not even stay in the same place, but moves around a significant amount. Small corrections are needed in order to use the magnetic pole for navigation purposes.

Earth has a magnetic field that has a shape similar to that of a large bar magnet . To the north is the magnetic north pole, which is really the south pole of Earth's bar magnet. (It has to be this way since this pole attracts the north pole of the compass magnet!) The Sun also has a magnetic field that is more complicated than, but similar to, that of Earth. The Sun, through its solar wind, has a large impact on the shape of Earth's magnetic field.

The magnetic field of Earth is generated by currents flowing in the liquid outer core region. Like all magnetic fields, it has a north and south polarity. The Earth's field extends over one million miles into space in some directions.





This is the magnetic field of a bar magnet. Notice the symmetry and direction of the field lines. Remember, the magnetic North Pole is not located in the same place as the geographic North Pole.

As the solar wind flows outward from the sun and encounters Earth's magnetic field, it pushes the Earth's field in on the side toward the sun and stretches it out on the side away from the sun. The result is a magnetic field shape that is not symmetric in the same way as the field of a bar magnet.

The region around Earth where Earth's magnetic field is located is called the **magnetosphere** (Figure 2). Outside this region, in the region called **the Interplanetary Magnetic Field (IMF)**, the solar magnetic field is strongest. The boundary line between the magnetosphere and the IMF is called the **magnetopause**. The part of the magnetosphere that extends from Earth away from the sun is called the **magnetotail**.

On the sun side, the magnetosphere extends to a distance of about 10 Earth radii (10 **Re**) under normal solar conditions. On the side away from the sun, the magnetosphere is stretched by the solar wind so it extends a great distance. (For comparison, the moon orbits at a distance of about 60 Re .)

Conditions on the sun, and the related solar wind, are not constant over time. When the sun is at the active stage of the approximately 11-year solar cycle, solar flares and CMEs are more common. This increased activity can result in large-scale disturbances of the magnetosphere called magnetic storms. The most common effect of a magnetic storm is an increase in the **Aurora Borealis**, or Northern Lights. In the Southern Hemisphere, they are called the Aurora Australis or the 'Southern Lights'.

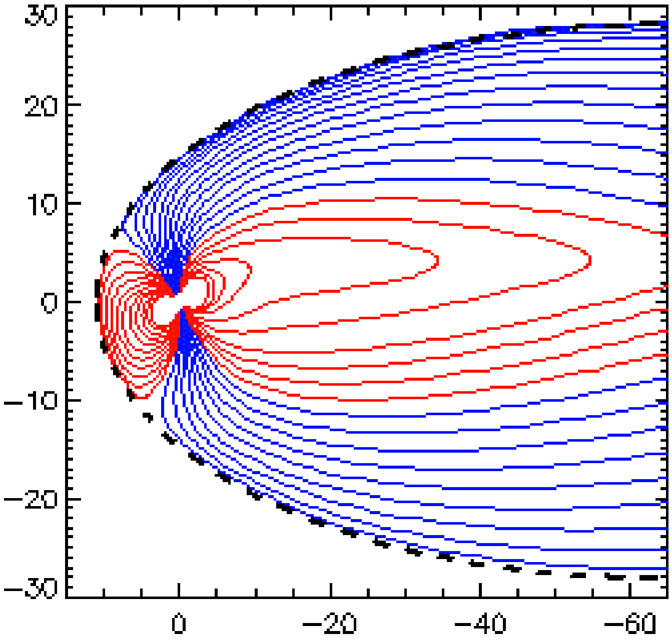


Figure 2. Earth's magnetosphere. The sun is located far to the left at a distance of 22,900 **Re.** Earth is located at (0,0). The dashed line is the magnetopause. The unit of distance in the diagram is the Earth radius (Re) equal to 6378 kilometers.

Other effects are also observed and some of them are dangerous and can cause serious damage. These effects include:

1. Induced currents in power company transformers that can cause overload conditions and damage equipment. It is thought that a magnetic storm that resulted from a CME caused the blackout in the northeastern United States and eastern Canada in 1989.
2. Induced currents in pipelines can cause an increase in corrosion and can lead to leaks and breaks. The Alaskan oil pipeline was designed to minimize this effect.
3. Astronauts in space can be exposed to dangerous levels of charged particles. For this reason, extra-vehicular activities on the space shuttle would be curtailed if a solar storm were predicted or observed.
4. Heating of the atmosphere by solar particles causes the atmosphere to expand. The increased friction causes satellites to lose energy and descend into the atmosphere. This is the process that, over time, is thought to have caused the decay of the orbit of Skylab in the 1970's.
5. Satellites in high orbits are subjected to energetic charged particles that can cause damage to electronic components. Failure of some communication satellites, which are in geosynchronous orbits, has been attributed to the impact of severe solar storms..
6. Radio communications can be disrupted because of changes in the ionosphere caused by solar flares.

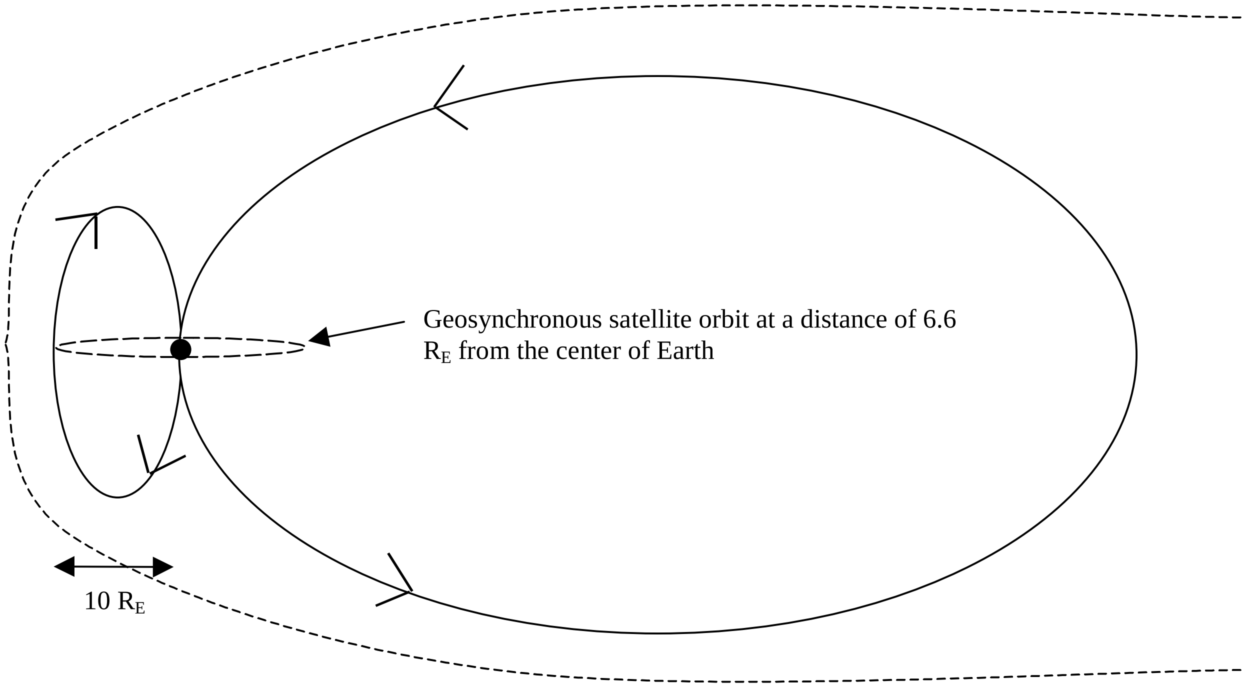


Figure 3. The magnetosphere under quiet solar conditions. The dashed line is the magnetopause. The arrows show the polarity of the field. For example, converging arrows indicate a south-type polarity (over the North Geographuic Pole)

The two main effects on the magnetosphere of magnetic storms are:

1. The magnetopause in the sunward direction is pushed in from its normal distance of 10 Re .
2. The magnetotail is pinched inward.

The added pressure on the sunward side increases the number of particles that are forced into the magnetosphere. During severe solar storms, this boundary can pass inside the orbits of geosynchronous satellites and subject them to the direct effects of the solar storm. In the magnetotail, charged particles are following the magnetic field lines down the tail away from Earth. When the magnetotail gets pinched in, a phenomenon called **magnetic reconnection** can occur. This happens when magnetic field lines within the magnetotail are forced together in such a way that they try to cross (which is not allowed for magnetic field lines) and, instead, reconnect forming a shorter, closed magnetic field line in place of the extremely long field lines extending down the magnetotail. Figures 4, 5 and 6 show the reconnection process.

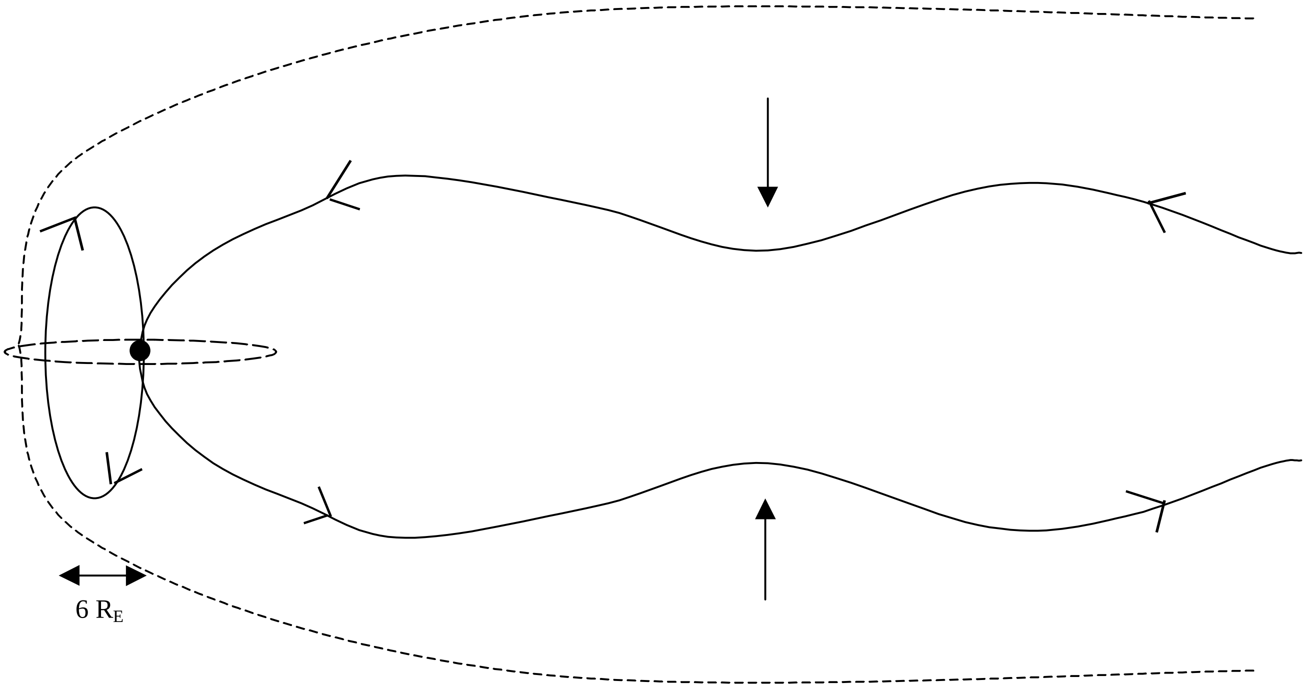


Figure 4. The magnetosphere under active solar conditions after a CME. The sunward magnetopause has been pushed in to 6 Re and the magnetotail has been pinched in (filled arrows). Note that the geosynchronous orbit now extends outside of the magnetopause.

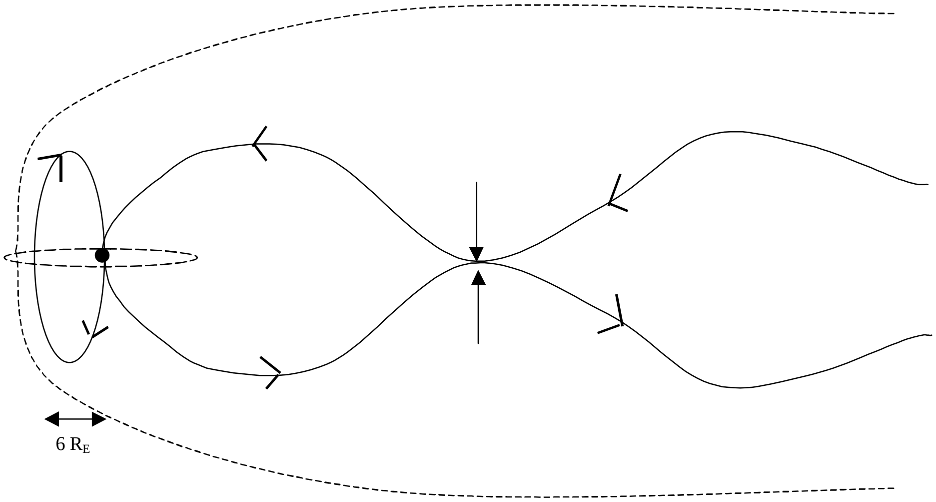


Figure 5. The arrows indicate the point of magnetic reconnection.

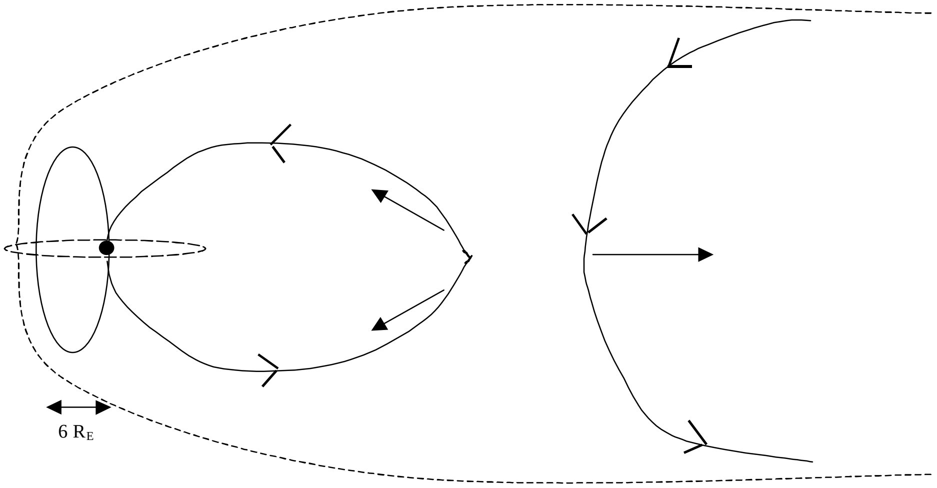


Figure 6. The magnetic field lines just after reconnection. The filled arrows indicate the direction of movement of the magnetic field lines which carry with them all of the charged particles moving along them at the time of reconnection. Also note how the polarity of each field line remains the same, i.e the arrows point in the same direction along each line before and after reconnection.

The process of reconnection results in large numbers of particles moving with high energy both toward and away from Earth. It is thought that the process that carries particles away from Earth is similar to, but on a smaller scale than, the process on the Sun that results in a CME. Of interest here, though, are the particles that are brought back toward Earth as the reconnected field line rebounds into position nearer Earth. Some of these charged particles find an easy path north and south into the auroral zones and some of them are captured near Earth and held there by magnetic field lines forming the radiation belts. As these particles move along magnetic field lines north and south, they rebound back along the field line from the polar regions. As they bounce back and forth, the charges migrate slowly around Earth in the region from about 2 Re to about 7 Re. This movement of charge is known as the **ring current**.

IMAGE will measure the location of the magnetopause, the brightness and location of the aurora and the composition, energy and location of the ring current.