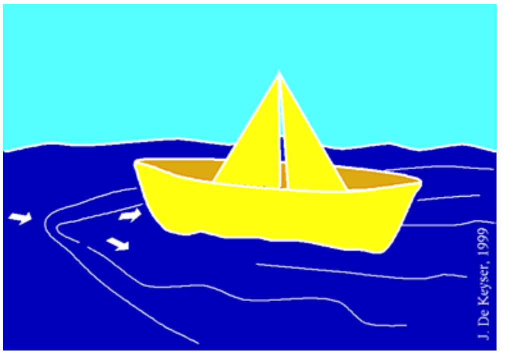
Structure of the Magnetosphere

By J. De Keyser

The complex structure of the magnetosphere is the result of the interplay between the charged particles originating in the upper layers of the terrestrial atmosphere, whose motion is guided by the Earth's magnetic field, and the solar wind particles carrying the interplanetary magnetic field. The magnetosphere can be defined as the space filled primarily with particles from terrestrial origin.

The boundary of the magnetosphere

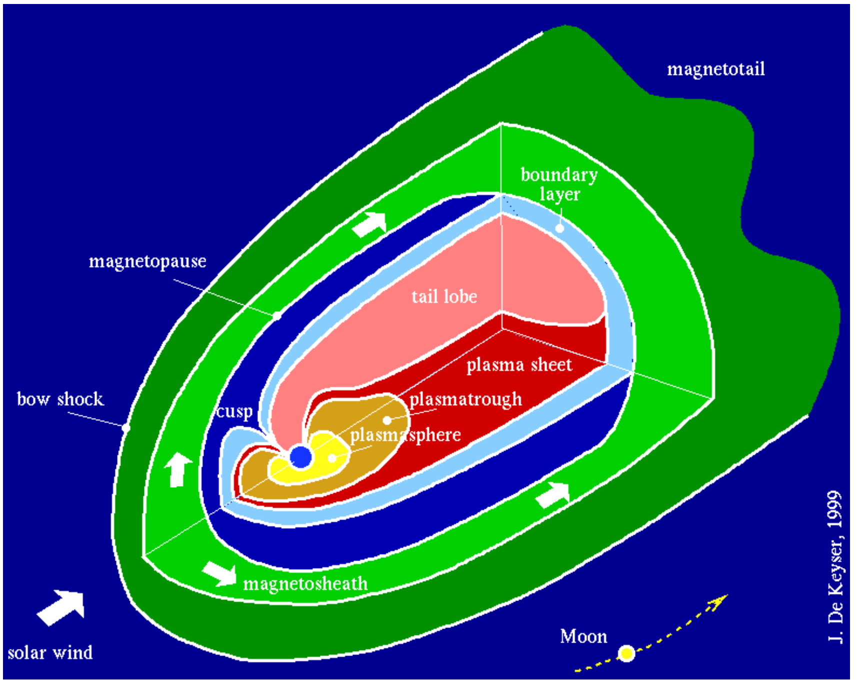


The nature of the boundary of the magnetosphere is illustrated by the following analogy. Consider a boat that moves through the sea. In front of the boat a bow wave is formed : that bow wave demarcates the region in which the boat disturbs the flow of the water. The water behind the bow wave is forced to flow smoothly around the boat's hull. Behind the boat a wake is formed.

The solar wind - magnetosphere interaction is very similar to the flow of water around the boat. The solar wind consists of particles that are mainly of solar origin. It is pervaded by the interplanetary magnetic field. A bow shock is formed in front of the Earth's magnetosphere, demarcating the region where the solar wind flow is affected by the presence of the Earth. At the bow shock the supersonic solar wind is slowed down and becomes subsonic. The solar wind in the magnetosheath, the region between the bow shock and the Earth's magnetosphere, is forced to flow around the Earth's magnetosphere and is compressed.

The impermeable outer surface of the magnetosphere, where the total pressure (the sum of the ram pressure and the thermal and the magnetic pressures) of the compressed solar wind precisely balances the total pressure inside the magnetosphere, is called the magnetopause.

As shown in the accompanying figure, the magnetopause has a shape that is elongated and stretched out in the antisolar direction, forming a long magnetotail, which is in a sense similar to the wake behind the boat.



The subsolar point, also known informally as the “nose" of the magnetopause, is normally situated at an upstream stand-off distance of about 10 R_E (Earth radii), while the bow shock stand-off distance is typically 15 R_E. The length of the tail is hundreds of R_E.

Note the particular cusp regions above the magnetic poles; these are regions where solar wind can enter relatively easily into the magnetosphere.

The picture sketched above is an oversimplification. Indeed, the magnetosphere is not a static structure. Rather, it is constantly in motion, as the orientation of the Earth's magnetic dipole varies with the Earth's daily rotation and with its yearly revolution around the Sun, and as the solar wind is characterized by a strong time-variability on time scales ranging from seconds to years. As a consequence of this time-variability, the sizes and shapes of the regions may change with time. For instance, when material from a solar coronal eruption (a so-called coronal mass ejection) travels through the interplanetary medium and hits the Earth, the dynamic pressure of the solar wind is strongly enhanced so that the bow shock and the magnetopause are pushed inward, producing a magnetospheric storm.

One of the effects of the continuous minor fluctuations in solar wind dynamic pressure is the oscillating motion of the magnetopause. Spatio-temporal fluctuations are also known to render the magnetopause semi-permeable, so that some magnetosheath plasma can cross it, thus forming the magnetospheric boundary layer.

The interior of the magnetosphere

While the behaviour of the plasma in the outer regions of the magnetosphere is dominated by the solar wind conditions, the inner magnetosphere is strongly connected to the Earth's <ionosphere>. It can be easily understood that the inner region, called the plasmasphere, which consists of dense cold plasma largely of ionospheric origin, must be corotating more or less with the Earth. The plasmasphere is situated on closed terrestrial magnetic field lines. Its outer boundary is called the plasmapause. The plasmatrough is situated outside the plasmapause; it also lies on closed field lines. It is very tenuous and does not corotate.

The magnetotail consists mainly of two tail lobes of opposite magnetic polarity. Each lobe is the magnetospheric extension of magnetic field lines originating in the polar cap ionosphere. The lobes are separated by the plasma sheet, which contains hot plasma. The plasma sheet is a very dynamic region. Changes in the interplanetary magnetic field may trigger unstable behaviour in this region (in a process known as a magnetospheric substorm). The plasma sheet is located on magnetic field lines that have their ionospheric footpoint in the auroral oval; the hot plasma sheet particles are therefore responsible for the production of the aurora.

The radiation belts

For the sake of simplicity, the above figure does not include the radiation belts: these are regions that contain very energetic particles that are "trapped" in the Earth's magnetic field, that is, they circle around the Earth in complicated orbits. Such particles originate from different sources; some come from the solar wind, some from the Earth's upper atmosphere, some from cosmic rays originating in the distant Universe.

The geocorona

The magnetosphere is an almost completely ionized collisionless plasma. Nevertheless, a large cloud of neutral hydrogen surrounds the Earth, the geocorona Since collisions are so rare, this neutral cloud can co-exist with the plasma in the inner regions of the magnetosphere with relatively little interference.