Chapter

Introductory Chapter: The Magnetosphere

Ouerfelli Ghofrane, Khaled H. Mahmoud, Taha M. Eldebss and Khalid S. Essa

1. Introduction

The magnetosphere is the region dominated by magnetic fields from several celestial objects. Which physical phenomena are organized. Any planet with a magnetic field Earth, Jupiter, Saturn, Uranus and Neptune has its own magnetosphere. The Earth's magnetosphere is located beyond the ionosphere that is to say above 800 to 1000 km altitude. If there were no solar wind, the Earth's magnetic spectrum would be similar to that of an isolated bar magnet. In reality, the magnetosphere acts as a screen and protects the earth's surface from excess solar wind, which is harmful to life. It opposes the solar wind like a bridge abutment diverts the current of a river. On the other hand, the solar wind distorts the magnetic spectrum of the Earth, giving it a comet shape.

In 1600 a study of earth's magnetosphere began, thanks to William gilbert who discovered that magnetosphere is a cavity globally shaped by the magnetic field of the Earth and modified by the solar wind. Outside the magnetosphere finds the magnetosheath, separated from it by the magnetopause. Amongst the solar wind and the magnetosheath, a shock wave is created and this forms a boundary called the bow shock. At the lower limit of the magnetosphere is the ionosphere. Many sub-regions make up the magnetosphere, such as the polar horns, the auroral zones, the plasmasphere, the plasma sheet.

In our solar system there are some planets that have a magnetosphere, which is the area round a planet controlled by the planets magnetic field. And earth has the strongest one of all. This field is the secret of the development of life on earth since it ensures the protection and the continuity of the ecological system.

The reason of the field can be elucidated by dynamo theory. He realized that earth s magnetic field is nearly a magnetic dipole, with the magnetic field pole near the earths geographic north pole and the other magnetic field near the earth geographic south pole. This lets the compass usable for navigation.

Amongst these regions, the plasmasphere is toroidal in shape and populated by cold plasma of mainly ionospheric origin: electrons and positive ions (90% H^+ protons, less than 10% helium He^+, oxygen O^+, as well as some traces of heavier ions). It extends on average to equatorial distances of about 4-5 RE. However, this radial extension varies according to the geomagnetic activity. Indeed, in the case of a sharp increase in this activity, its outer boundary, the plasmapause, can be 2 RE, or on the contrary extend beyond 7-8 RE during long periods of geomagnetic calm. These variations in activity also disturb the structure on a small and medium scale. Thus, plasmasphere plumes connected to the plasmasphere can shape and turn with it. Furthermore, the plasmapause may be dotted with structures of density at small scales, hence the new name describing this region: the boundary layer of plasmasphere.

The internal magnetic field of planet earth is so strong. If we omit disturbances, the earth's magnetic field of internal origin can be pictured in first approximation as a dipole having an axis titled by about 12° with respect to the axis of rotation (**Figure 1**). Besides, the magnetic pole near earth's geographic North Pole is essentially the south magnetic pole. When it comes to magnets opposites attract. The magnetic field points in the direction of the Earth's surface in the northern hemisphere, and to space in the southern hemisphere. Its magnitude at the surface of the Earth is of the order of 50 μT at the equator. The interplanetary medium is permanently swept by a wind of particles electrically charged from the Sun. This wind, baptized solar wind by [2], is very little dense (5 cm^{-3}), but very fast (400 to 800 km/s).

The geographic north and south poles mention the points where the earth's rotation axis intercepts earth's surface. If you are holding a tennis ball amongst your thumb and forefinger and push on the side to create it spin. The solar wind is now to be a mixture of materials initiate in the solar plasma, constructed of ionized hydrogen (electrons and protons) with an 8% component of helium and trace amounts of heavy ions.

The solar wind has been distinguished inner toward the sun to the orbit of Mercury, and outward past the orbits of Uranus and Neptune. The flux of particles The stream of charged particles from the upper atmosphere of the Sun (Corona). Compose of ~92% ionized hydrogen (electrons and protons), ~8% components of alpha particles (helium), and trace amounts of heavy ions and atomic nuclei, with energies in the range between 1.5 and 10 keV. Acceleration mechanism is still not fully clear thermal energy alone cannot account for the high speeds of the solar wind.

The interplanetary medium is permanently swept by a wind of particles electrically charged from the Sun. The solar wind alters the Earth's magnetic field, creating a cavity called the magnetosphere (so named by Gold [1959]). Under the influence of the solar wind and the magnetic field it transports (the interplanetary magnetic field, or IMF1), the magnetosphere is compressed on the side of the Sun, called day side, but very extended in the anti-solar direction, called side night (**Figure 2**). As a result, the

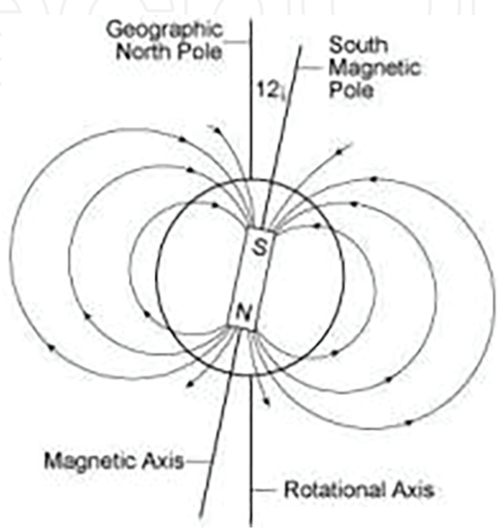

Figure 1.
Magnetic field of the earth in the absence of external disturbances [1].

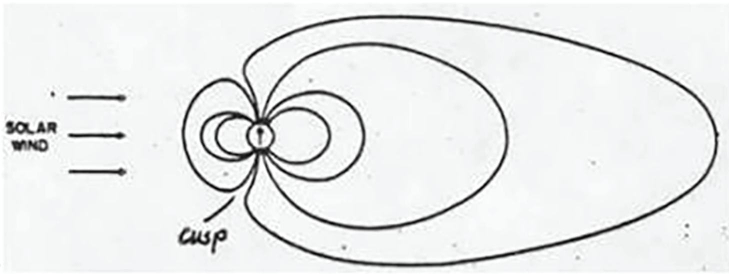

Figure 2.
The solar wind interaction with the Earth's magnetosphere prof. R. H. Holzworth, http://earthweb.ess.washington.edu/bobholz/ess515/.

distance amongst the outer boundary of the magnetosphere and the Earth is about 10 Earth radii (1 RE = 6371 km) from the dayside, while a tail magnetic field extending over several hundred terrestrial radii is formed on the night side [Ness, 1965].

2. The magnetosheath and the magnetopause

The magnetopause is the boundary between the magnetosphere, dominated by the magnetic field of the Earth, and the interplanetary medium, dominated by the solar wind (see the review by [3]). Its existence was first presented by [4]. The magnetopause is a relatively tight boundary in that it prevents the major part of the solar wind from entering the environment of the planet. The magnetosheath is a region in the vicinity of the magnetosphere, located amongst the shock and the magnetopause (see **Figure 3**). This is where the solar wind flows, mainly, bypassing the magnetosphere, after being slowed and heated through the impact. The plasma is denser there than in the wind solar upstream of the shock. It is a region where the plasma is turbulent, we measure a large electromagnetic stirring.

The magnetopause plays an important role in spatial physics, since the coupling amongst the solar wind and the magnetosphere is done through it. Note that the magnetosphere is not a static structure: it is in constant motion. On the one hand,

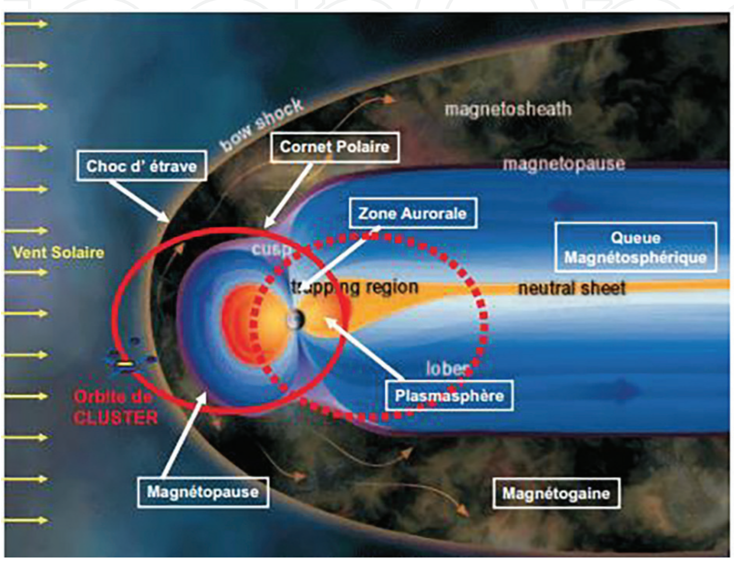

Figure 3.
Magnetosphere of the earth, with the main regions that compose it (according to ESA).

the orientation of Earth's magnetic dipole changes with its daily rotation and with its annual revolution around the Sun. On the other hand, the solar wind is characterized by a strong temporal variability on timescales ranging from seconds to years. The dimensions and shapes of these regions may change over time due to the natural variability.

The magnetopause is the boundary between the magnetosphere, dominated by the magnetic field of the Earth, and the interplanetary medium, dominated by the solar wind (see the review by Russell [3]). Its existence was first introduced by [4]. The magnetopause is a relatively tight boundary in that it prevents the major part of the solar wind from entering the environment of the planet. The magnetosheath is a region in the vicinity of the magnetosphere, located between the shock and the magnetopause (see **Figure 3**). This is where the solar wind flows, mainly, by passing the magnetosphere, after being slowed and heated through the impact. The plasma is denser there than in the wind solar upstream of the shock. It is a region where the plasma is turbulent; we measure a large electromagnetic stirring. Furthermore, the magnetopause plays an important role in spatial physics, since the coupling amongst the solar wind and the magnetosphere is done through it. Note that the magnetosphere is not a static structure: it is in constant motion. On the one hand, the orientation of Earth's magnetic dipole changes with its daily rotation and with its re- annual evolution around the Sun. On the other hand, the solar wind is characterized by a strong temporal variability on timescales ranging from seconds to years. The dimensions and shapes of these regions may change over time due to the natural variability. For example, when material from a solar corona eruption (a coronal mass ejection, or CME2) propagates through interplanetary space and reaches the Earth, the dynamic pressure of the solar wind is highly increased, so that the magnetopause is pushed toward the Earth. One of the effects of continuous minor fluctuations of the dynamic pressure of the solar wind is the oscillation movement of the magnetopause: this one oscillates in order to restore the balance between the magnetospheric pressure and the pressure of the solar wind. The movement of this boundary can also be induced by instabilities plasma. Spatio-temporal fluctuations are also known to make the magnetopause semi-permeable, and allow plasma of the magnetosheath to cross it, so forming the magnetospheric boundary layer. Various mechanisms allow this transfer of matter, such as magnetic reconnection [5], or the impulsive penetration of plasma elements [6].

2.1 Auroral zone

The auroral zones constitute two circular regions around the North magnetic poles and South, where auroras are commonly observed (**Figure 4**). Their geographical position was determined for the first time by [7], from a study statistics of aurora observations in the northern hemisphere. These light emissions re- result from the luminescence of the upper atmosphere because of the de-excitation of the molecules of the atmosphere. The molecules are previously excited by energetic electrons coming from the magnetosphere and precipitated into the atmosphere This region is also of immense interest because of the various types of waves that we observe, in the range of ultra-low frequencies, or ULF3 [Perraut et al., 1998], but also in the very low frequency range, or VLF4. They are mainly electrostatic waves, but some studies have also shown the existence of electromagnetic waves [8].

These waves play a huge important role in the areas auroral, and can be used to characterize the level of activity in this region of the magnetosphere. The results are

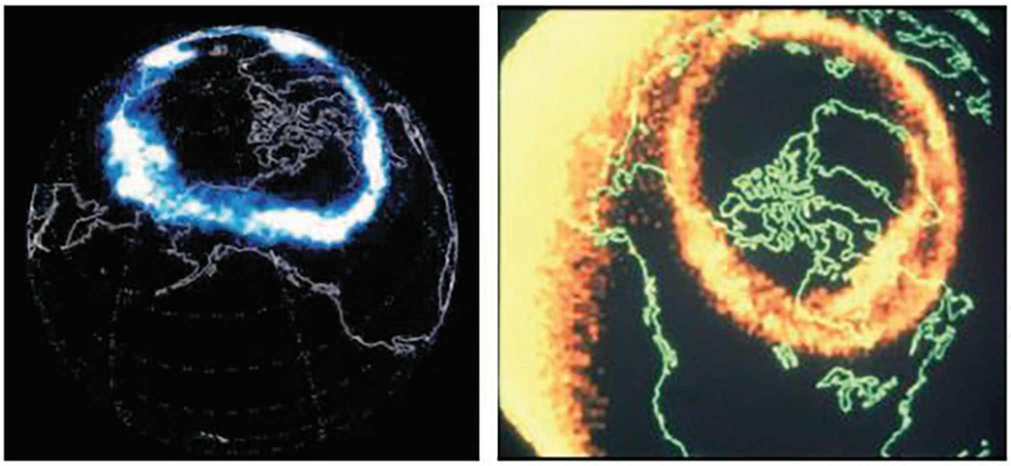

Figure 4.
Auroral oval in the northern hemisphere, observed by the IMAGE satellite (panel left), and by the polar satellite (right panel) (from NASA).

that, at mid- latitudes, VLF waves are known to disperse trapped energetic electrons, and eventually precipitate them into the Earth's atmosphere, where they can alter the propagation of radio waves.

2.2 The plasmasphere and the plasmapause

The internal magnetosphere notably includes the plasmasphere (**Figure 5**), which is a toroidal region surrounding the Earth, inhabited by cold plasma (a few eV or less) of mainly ionospheric origin (see the monograph by [9] and the review by [10]). In comparison with other regions of the magnetosphere, the density of the plasmasphere is really high (from 10 to 104 cm^{-3}). It is composed of electrons and positive ions: protons H+ (~ 90%), but also helium He^+, oxygen O^+ and some traces of heavier ions.

This plasma is mainly of ionospheric origin, and during periods of low geomagnetic activity, a process of filling from the upper layers of the ionosphere let the

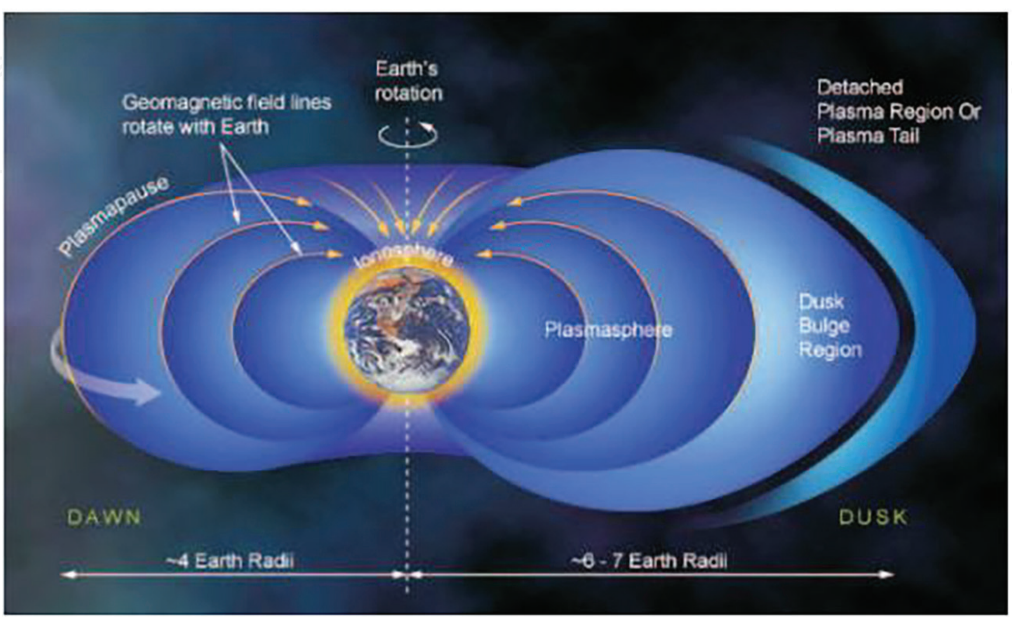

Figure 5.
General view of the plasmasphere (from "Windows to the Universe", http://www.windows.ucar.edu).

plasma to rise along the field lines magnetic and thus to fill the plasmasphere. This mechanism has not yet been fully elucidated and is currently the subject of numerous studies. The outer boundary of the plasmasphere was discovered simultaneously from ground observations of whistles [11], and from measurements on board satellites [12]; it was called plasmapause for the first time by D. Carpenter in 1966 [13]. It is characterized, in its simplest form, by a sudden drop in the plasma density by several orders of magnitude. Shape approaching that of a shell magnetic, this boundary can be located at the equator at a radial distance between 2 and 8 RE relying on the intensity of the geomagnetic activity. The plasmasphere occupies a region all the more extensive as the geomagnetic activity is weak. Plasmapause is not always a clear border, the density drop can be very irregular and occur on a wide range of geocentric distances. Carpenter and Lemaire [14] introduced recently the notion of “plasmasphere boundary layer”, or PBL5, thick border which covers all the regions where the density drop occurs, roughly between 103 and 10 cm^{-3}. Finally, the plasmasphere has an extension on the twilight side that is to say in the local time.

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