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"The Role of Solar Wind on Earth's Magnetic Field Formation of Terrestrial Magnetosphere"

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Abstract

The magnetic field of the solar wind dominates main earth's field, creates a cavity in interplanetary space called the magnetosphere. The magnetosphere is shaped like a comet in response to the dynamic pressure of the solar wind. It is compressed on the side toward the sun to about 10 Earth radii and is extended tail-like on the side away from the Sun 60-100 Earth radii. The magnetosphere deflects the flow of most solar wind particles around the Earth, while the geomagnetic field lines guide charged particle motion within the magnetosphere ***(Chen, J.1998)[1]****. There was a technical difficulty observed by scientists, that the solar wind/interplanetary magnetic field system is not homogenous observed at any given time by two or more satellite. We hope that some future space mission will solve this problem.*

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I. Introduction

The solar wind moves out almost radially from the Sun, the rotation of the Sun gives the magnetic field a spiral form, at the orbit of the Earth. The angle between the field lines and the radial direction is about 45 degrees. Due to the supersonic nature of the solar wind, The earth's magnetic field is confined by the dynamo pressure of solar wind in a magnetospheric cavity that has a long tail consisting of two antiparallel bundles of magnetic flux that stretch in antisolar direction, known as magnetosphere. The pressure of the magnetic field and the plasma establishes equilibrium with the solar wind. The magnetosphere shrinks when the solar wind blows harder **(Giles, B. L.1993)[2]**. When the solar wind abates, the magnetosphere expands. The solar wind contains mass and momentum both. Consequently, earth's magnetic field probably eventually converges on the night side. The region in which the terrestrial magnetic field is thus enclosed by the solar wind is called the geomagnetospheric cavity. The geomagnetospheric cavity thus measures some 10 Earth radii in the solar direction and a considerable, but uncertain (extending from 60 to 100 R_E), distance in the direction away from the Sun.

The Terrestrial Magnetosphere

The pressure of the magnetic field and the plasma establishes equilibrium with the solar wind. The magnetosphere shrinks when the solar wind blows harder. When the solar wind abates, the magnetosphere expands. The solar wind contains mass and momentum both. It exerts a force outward from the Sun on every obstacle in its path. The earth's magnetic field is such an obstacle, **(**Schmeider, B.**1989)[3]**. Because the magnetic fields of the Earth and the solar wind are 'frozen in` to their respective plasma by the high electrical conductivity of the plasmas. Shock waves are formed in front of the earth's magnetosphere, and:

1Drives the magnetospheric convection system and energizes much of the plasma on the earth's magnetic field lines.
2Drives field line resonance and other geomagnetic pulsations.
3Creates geomagnetic activity.
4Heats the polar upper atmosphere.
5Drives large neutral atmospheric winds.

These changes in the solar wind plasma parameters (density, velocity, etc.) and interplanetary magnetic field (especially direction in relation to earth's own field) are very important for the study of magnetospheric and ionospheric physics, and the scientific community tries to have continuous monitoring of these parameters via satellites like IMP-8, ISEE, and Wind. The earth's magnetic field is confined by the dynamo pressure of solar wind in a magnetospheric cavity that has a long tail consisting of two antiparallel bundles of magnetic flux that stretch in antisolar direction, known as magnetosphere. **(Cahill and Amazeen, 1963)[4]** .Hence, the major effect of magnetized solar wind is to exert pressure, or normal stresses ($P = 2\ mnV^2$), where 'n` is the number of density of solar wind particles, 'm` is their mass and 'V` is velocity, is balanced by magnetic pressure gradient ($B^2/8\pi$) of dipole field of the Earth. Due to these pressures, in sunlit direction, the dipole field compressed till the balancing of this pressure, and creates a hemispherical shape at about 10 Earth radii. In the opposite direction to that facing the Sun, Because of the random motions of the particles in the solar wind, however, some pressure is exerted on the geomagnetic field in the direction perpendicular to winds motions. The geomagnetic cavity is also referred to as the magnetosphere, and the outer boundary of the cavity is known as magnetopause. **(Berchem and Russell, 1982)**[5] .The impact of a unidirectionally, streaming, unmagnetized plasma upon a dipole field was first studied by Chapman and Ferraro in a series of papers during 1931-33. The formation of the magnetosphere and its different regions such as bow shock, magnetopause, magnetosheath and magnetotail are shown in **Figure.1.**

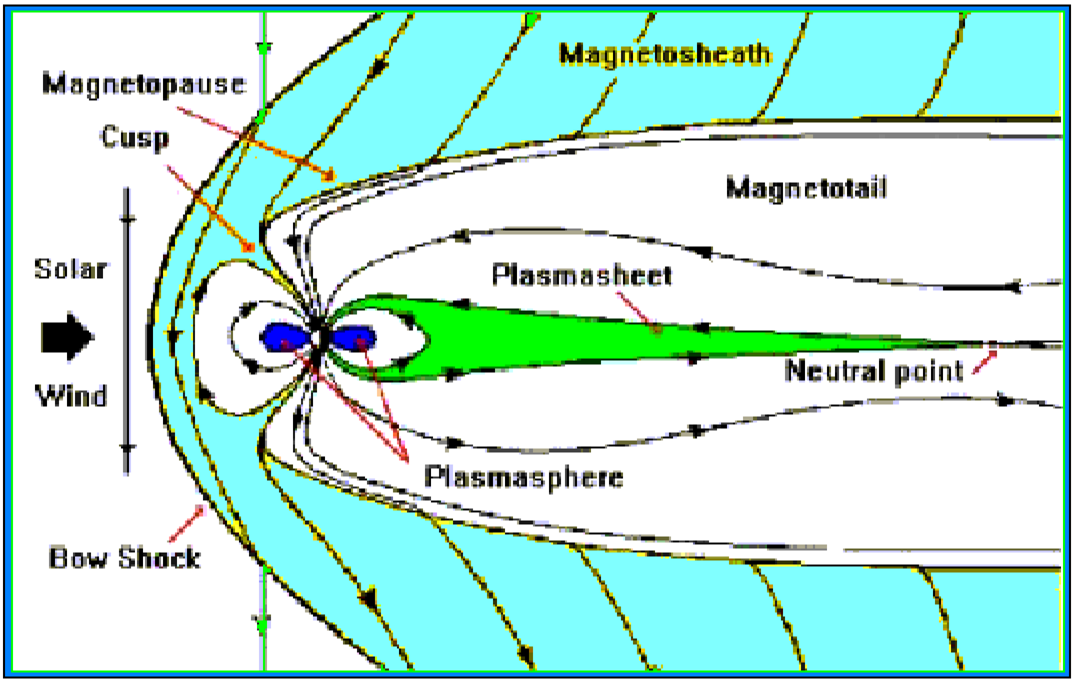

Figure.1. Shows the formation of the magnetosphere and its different regions such as bow shock, magnetopause, magnetosheath, magnetotail, cusp,plasma sheet, plasmasphere and neutral point.

The magnetosphere deflected by the flow of solar wind particles around the Earth, while the geomagnetic field lines guide the charged particle motion within the magnetosphere. Recently **(Bargatze,L.F.Baker,D. N.1985)**[6]**.** Space probes observations have revealed much important information about the field and plasma environment of the Earth and the solar system. The point at which solar wind strikes the magnetosphere is called the sub-solar points. Downstreams from the sunlit hemisphere the earth's magnetic field has a long cylindrical tail with a mean diameter of approximately 40-50 R_E, expanding to atleast 1000 R_E. A thin layer of plasma bisects the cylindrical magnetotail into northern and southern halves. This plasma layer is called the plasma sheet. The value of density and magnitude of magnetic field of plasma sheet are approximately 0.1 cm/sec and 2-5 nT respectively. It is generally believed that the most of magnetic field lines embedded in the plasma sheet have a closed configuration to constrain plasma sheet **(Feynman.J.1994)**[7] **.**Some models which have been suggested by various authors about formation of terrestrial magnetosphere are given as:

1**Chapman-Ferraro model -** An electric current is induced in the cloud as it first encounters the magnetic field of the Earth. This is a problem of boundary between collisionless unmagnetized plasma and a vacuum field. Essentially, equilibrium occurs when the plasma pressure balance the magnetic field pressure.

2**Tear Drop model -** Magnetosphere consist of closed field lines in which the interplanetary and magnetospheric plasma is perfectly conducting.

3**Axford and Hines model -** The solar wind drives magnetospheric convection by some type of viscous like interaction.

4**Reconnection model** (Open or Dungey model) **-** When the southward directed interplanetary magnetic field lines convected by the solar wind from an interaction region on the day side either join up with or reconnects with the Earth's magnetic field in the subsolar regions. This model is very useful to obtain the topology of magnetic field and motion of plasma flow near the neutral point.

The Bow Shocks

The frontal surface of the magnetosphere, where the solar wind has its first impact with geomagnetic field, is known as bow shock front, which are shown in The bow shock is a shock wave formed at a distance of 3-4 Earth radii or so**(Axford, W. I.1962)[8].**In front of the magnetopause by encounter of the supersonic solar wind with the obstacle on earth's magnetic field. Passing through the shock, which ranges in thickness varying from 100 km to 2 Earth radii, the solar wind is slowed, compressed, and heated. **Figure. 2.**

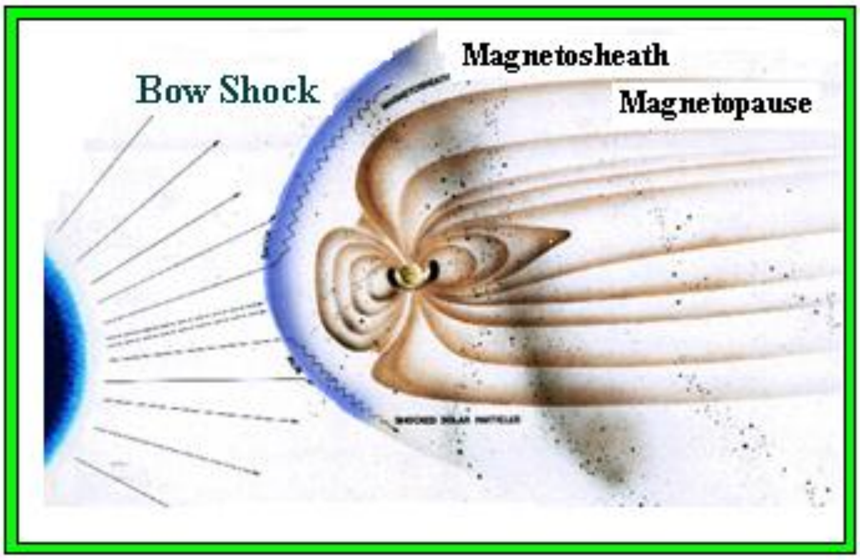

Figure 2. Shows the formation of the bow shock front. In this figure bow shocks are formed on frontal surface of the magnetosphere, where the solar wind has its first impact with geomagnetic field. The magnetosheath and magnetopause are also explained in this figure.

The region downstream of the bow shock, between the shock and the magnetopause that is occupied by the shocked solar wind plasma is known as the magnetosheath. Generally, three waves are needed for the magnetospheric disturbances, termed as: slow magnetosonic wave, intermediate wave and fast magnetosonic wave. The fast magnetosonic wave creates the bow shock in front of the earth 's magnetosphere. **(Alan, H.1994)[9].** The other two waves are present in the magnetosheath. together with the most typical interplanetary magnetic field direction close to the inner planets. Upstream foreshock in the dawn side is much larger than the downstream foreshock in the dusk side. The waves in the foreshock region are coming from several sources. Some of the waves are generated in the bow shock and propagate upstream. Other waves are generated by electrons and ions accelerated at the bow shock and reflected back into the solar wind or leaked from the magnetosheath back upstream **(Crooker, N. U.1994)[10]**. These back streaming particles generate waves through various instabilities and these waves are then convected with the solar wind flow toward the shock. Still other waves originate as newly created ions scatter and thermalize both in the extended coronas surrounding comets and in the exospheres of unmagnetized planets.

The magnetosheath

The region between the bow shock and the magnetopause is called the magnetosheath. The particles in this region originate from the shocked solar wind, can be defined from their charge state and composition**. (Akasofu,&Yoshida,S.-I.1967)[11]** The plasma density typically decreases from the bow shock to the magnetopause; however, it is always higher than the magnetospheric plasma density. The magnetic field is weaker than the magnetospheric field, and it is deflected near to interplanetary magnetic field orientation in the outer magnetosheath toward a draped orientation near the magnetopause. The energetic particles are much more abundant in the magnetosphere than in the magnetosheath. The magnetosheath particle having energies about 1 keV for ions, 100 eV for electrons and densities around 20 cm^{-3}. Fluctuations in the plasma parameters are very typical, and may be due to passages of solar wind features like shocks and tangential discontinuities or different types of waves. Variations are caused in the radial gradient of these parameters combined with radial motion of the bow shock - magnetosheath - magnetopause system, which can be driven by changes in the interplanetary magnetic field orientation The angle between the magnetosheath and magnetospheric magnetic fields defines the magnetic shear across the magnetopause. When the magnetic shear is low (< 30º), a magnetosheath transition layer, also known as plasma depletion layer is formed just outside of the magnetopause. The magnetic field direction inside the magnetosheath is important also for the proposed merging process with the geomagnetic field. It is the north-south direction of the field that matters in that case. **(Kahler, S. W.1992)**[12] The magnetosheath plasma forms an important part of the low energy dayside auroral precipitation. The plasma has an entry to the ionosphere via the dayside cusps and the magnetospheric boundary layer. A characteristic feature of magnetosheath is the existence of narrowband, whistler mode electromagnetic waves termed as lion roars. They occur in intense and sporadic bursts around 100 Hz, corresponding to 0.25-0.5 times of the electron cyclotron frequency, with average duration of 1-2 seconds.

The magnetopause

The magnetopause is t interface between the magnetosphere and the solar wind plasma. It plays a significant role in determining the nature of the coupling between these two plasma and field regions. Chapman and Ferraro (1931, 1932) were first to discuss the existence of a boundary of the earth's magnetic field. During 1950's, a concept of continuous solar wind emerged; it was obvious that such a feature should be a permanent feature of the magnetosphere. In the early 1960's, Explorer 10 and 12 provided the first measurements of this boundary that was called magnetopause. **(Gosling,J.T.,Bame,S.J.1993)**[13]. It plays an important role in space physics, since the coupling between the solar wind and magnetosphere occurs through it. Outside magnetopause are covered by the shocked solar wind region, magnetosheath, and just inside are the magnetospheric boundary layers.

In the first approximation, magnetopause is formed at a distance where the solar wind dynamic pressure equals the magnetic pressure of the earth's magnetic field. At this location, typically around 8-11 Re away on the Earth-Sun line, a large-scale dusk- ward (Chapman-Ferraro) current develops in the dayside magnetopause to cancel the earth's field outside. At the same time, the dipole field inside is increased, being now about the two times the nominal dipole value. Similar current flows around the magnetotail, but there the direction has to be reversed in order to cancel the field outside.. This current is closed via the cross-tail current. The thickness of the current layer is typically from several hundred to a thousand kilometers, which corresponds to several ion gyroradii. The magnetosphere presented above is of closed type that's described some dynamic events relating to Sun-Earth connection. The opening up the magnetosphere are consider, when the effects of interplanetary magnetic field and the magnetic reconnection are complicated.

The Polar Cusps

The magnetic field lines of the Earth can be divided into two parts according to their location on the sunward or tail ward side of the planet. Between these two parts on both hemispheres are funnel-shaped areas with near zero magnetic field magnitude called the polar cusps, are shown in **Figure .3**

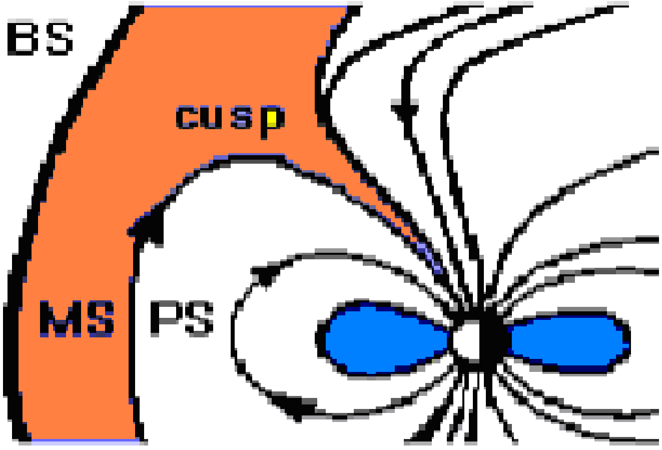

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Figure 3.Described the formation of polar cusps. These cusps are funnel-shaped areas with near zero magnetic field magnitude. They are located on the sunward or tail ward side of the planet.

They provide a direct entry for the magnetosheath plasma into the magnetosphere The high-altitude cusp, which is often called the exterior cusp, can be considered to be a part of the magnetospheric boundary layer system. The low-altitude cusp is the dayside region in which the entry of magnetosheath plasma is directed at low altitudes. Measurements have shown, that the cusp is highly confined region, extending about 2.5 hours in local time, but only about one degree or less in latitude. **(Borrini G.1982)**[14] **.**Due to strong dependence of the cusp position on IMF conditions, the statistical studies tend to show larger cusp regions. The magnetosheath plasma penetrating into the low-altitude cusp is responsible for the dayside auroral precipitation. Measurements by the Polar satellite have shown that ions in the MeV range are also present**.** These events have been called as cusp energetic particle events. Many types of waves and turbulent flows which have also access to the ionosphere via the cusp, are given as:

- Solar wind variations generated in the foreshock upstream of the bow shock.
- Radiation from the parallel and perpendicular shocks.
- Magnetosheath turbulence and waves.
- Magnetopause boundary variations.
- Flux-transfer events.
- Pressure variations.
- Kelvin-Helmholtz instability.
- Waves and particle variations, which take place in the boundary layers just inside the magnetopause.

The low-altitude cusp is the focus of these phenomena and ground observations are comprised of their superposition.

The Geomagnetic Tail

The geomagnetic tail is the region of the earth's magnetosphere that stretches away from the Sun behind the Earth. Its shape is analogous to the comet tail and the boundary of this region which has a long cylinder and cross-section of tail perpendicular to the Sun-Earth line are assumed to be a circle.The dynamic equilibrium arises open field lines, with a contact or mixing region between the solar and ionospheric plasmas. This surface drops to its lowest altitude, nearly into the ionosphere, at the cusp centre and then rises steeply as the plasma convects anti-sunward direction over the polar cap. It ultimately forming the inside boundary of the plasma mantle, contributing to make the solar-terrestrial plasma boundary as the plasma convects anti-sunward and into the wake region of stretched field that forms the geomagnetic tail. Pressure balance or acoustic propagation speeds define the shape of this boundary, **(Venkatesan, D.1994)**[15] while diffusion determines its sharpness.have shown that the field lines are the deep geomagnetic tail beyond about 100 R_E is still roughly parallel to the Sun-Earth line. A current sheet lies in the centre of the tail embedded within a region of hot plasma. The plasma sheet that separates two regions is called the tail lobes.**.**These two tail lobes connected magnetically to the polar region of the Earth are identified as the north and south lobes. The magnetic field in the north -south lobe is separated by current sheet. Early measurements showed that the geomagnetic field strength in the near-earth tail lobes is about 20 nT. In the high latitude lobe region of the geomagnetic tail, the plasma density is much less ($\sim 0.01\ \text{cm}^{-3}$) than in the plasma sheet. There is also a slight flaring of the field lines in the lobes. The formation of the plasma sheet begins near the geomagnetic equatorial plane at a geocentric distance of $(10 \pm 3)\ R_E$, its thickness is typically 5 R_E. The plasma sheet extends most of the way down the geomagnetic tail; however the thickness varies greatly during the geomagnetic storms. A region of very weak field, called the neutral sheet, halves the plasma sheet. The position of neutral sheet is very sensitive to the amount of magnetic flux in the tail region. Currently, the geomagnetic tail is an active field of research and many researchers are doing the work on this field.

The Earth's Radiation Belts

James Van Allen discovered the earth's radiation belts of trapped radiation near the Earth in 1958. The radiation belts of the Earth are made up of electrons, protons and heavier atomic ions. These charge particles are trapped inside the magnetosphere when its kinetic energy ($1/2\ \rho V^2$) is less than the dipole field energy ($B^2/8\pi$) and forms the earth's radiation belts. Van Allen had been exploring the upper atmosphere of the Earth with balloons that could measure radiation levels in the atmosphere. Van Allen and his team placed a Geiger counter and an altimeter on Explorer I, the first American spacecraft, to take radiation readings at different heights. During the flight, radiation levels seemed to increase and then suddenly drop to zero and then again to increase, then abruptly drop to zero. They observed and mapped the regions appearing as zero radiation level, and named as the earth's radiation belts. The radiation belts, like the plasmasphere, are toroidally shaped. There is an outer and an inner radiation belts. During the International Geophysical Year (1957-58), the various satellites Explorers, Pioneers and Sputniks, using the Geiger tube, **(Berchem,J.1982)**[16] Discovered two radiation belts around the Earth: (**i**) the inner, Kidney-shaped belt which was relatively stable and is postulated at about 1.5 R_E, consisting mainly of protons with energies ($E_p \geq 30$ Mev) and (**ii**) the outer, crescent-shaped belt lies between 3-4 R_E, which was relatively unstable and having large fluctuations in intensities of energetic electrons ($E_e \geq 1.6$ Mev) [Van Allen et al., 1958]. The outer and inner radiation belts are separated by a region of low counting rate, called the slot. Besides the radiation belts the magnetosphere is also filled with hot plasma, which forms the plasmasphere occupying a small part of the trapping regions. The inner magnetospheric currents, **Figure.4.**

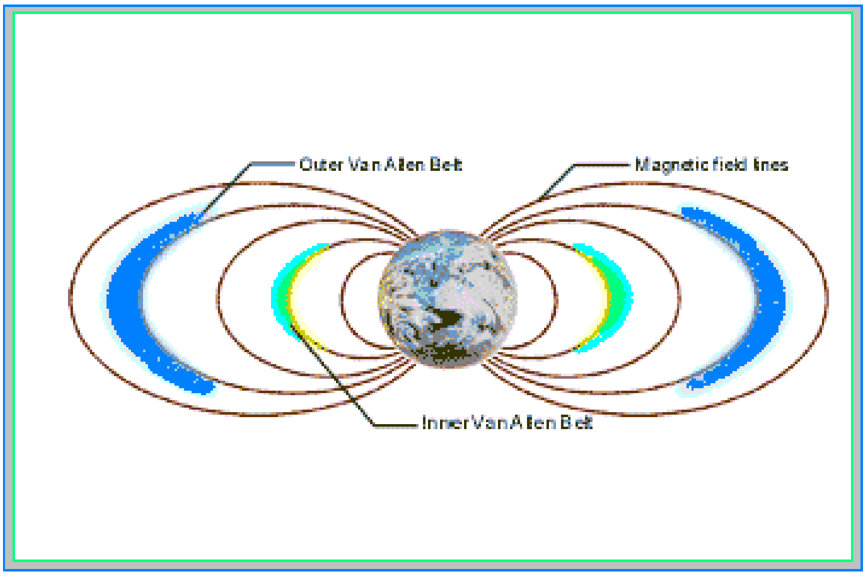

Figure 4. Described the formation of the Van Allen Earth's radiation belts of trapped radiation near the Earth. The inner and outer belts are also sketched in this figure.

known as ring current, flow circumferentially around the Earth in the energetic plasma and radiation belt particles. A circular path through the most conductive layers of that medium closes the currents that flow into and out of the ionosphere along the magnetic field lines. The formation of the inner and outer earth's radiation belts are sketched in

II. Conclusion

The geomagnetic cavity is also referred to as the magnetosphere, and the outer boundary of the cavity is known as magnetopause. Passing through the shock, which ranges in thickness varying from 100 km to 2 Earth radii, the solar wind is slowed, compressed, and heated. The low-altitude cusp is the dayside region in which the entry of magnetosheath plasma is directed at low altitudes. (**Farrugia, C. J.1996)**[17]**.** Measurements have shown, that the cusp is highly confined region, extending about 2.5 hours in local time, but only about one degree or less in latitude. Due to strong dependence of the cusp position on IMF conditions It ultimately forming the inside boundary of the plasma mantle, contributing to make the solar-terrestrial plasma boundary as the plasma convects anti-sunward and into the wake region of stretched field that forms the geomagnetic tail. have shown that the field lines are the deep geomagnetic tail beyond about 100 R_E is still roughly parallel to the Sun-Earth line. A current sheet lies in the centre of the tail embedded within a region of hot plasma. The plasma sheet that separates two regions is called the tail lobes.

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