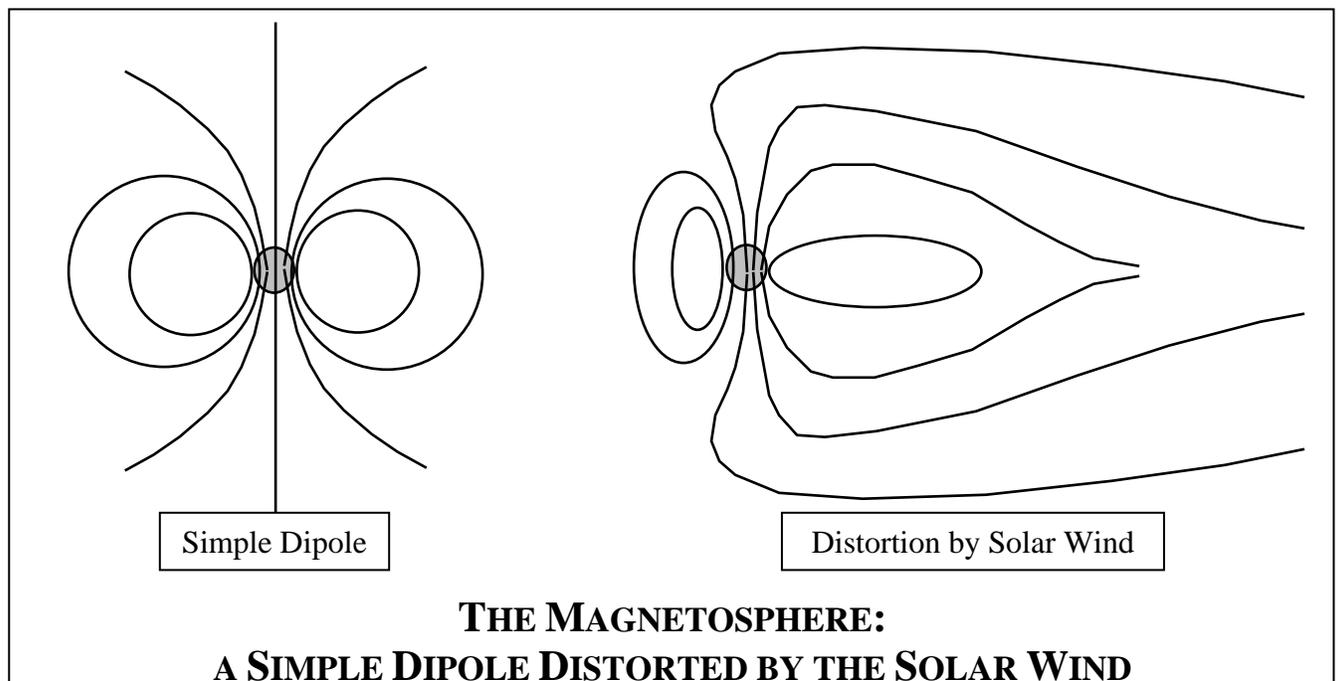


The Structure of the Magnetosphere

The earth's magnetic field would resemble a simple magnetic dipole, much like a big bar magnet, except that the solar wind distorts its shape. As illustrated below, the solar wind stretches the earth's magnetic field into a bullet shape, forming the large cavity known as the "magnetosphere." The magnetosphere is that region dominated by the Earth's magnetic field. Close to the earth's surface the magnetic field approximates a dipole field, but further out the field becomes increasingly distorted.

The magnetosphere is blunt on the sunward side, extending out 10 to 12 R_E , earth radii (64,000 – 75,000 km), toward the sun. The magnetosphere also has a long tail on the anti-sunward side, extending thousands of Earth radii (millions of kilometers) in the direction away from the sun. This portion of the magnetosphere is called the "magnetotail." Although much of the magnetosphere is nearly a perfect vacuum, its huge size allows energy in the solar wind to drive electric currents and set plasma in motion within the magnetosphere and earth's upper atmosphere. Since all space operations occur in the magnetosphere, it is important to recognize how the magnetospheric activity impacts various operations in space. Let's look at the various parts of the magnetosphere.



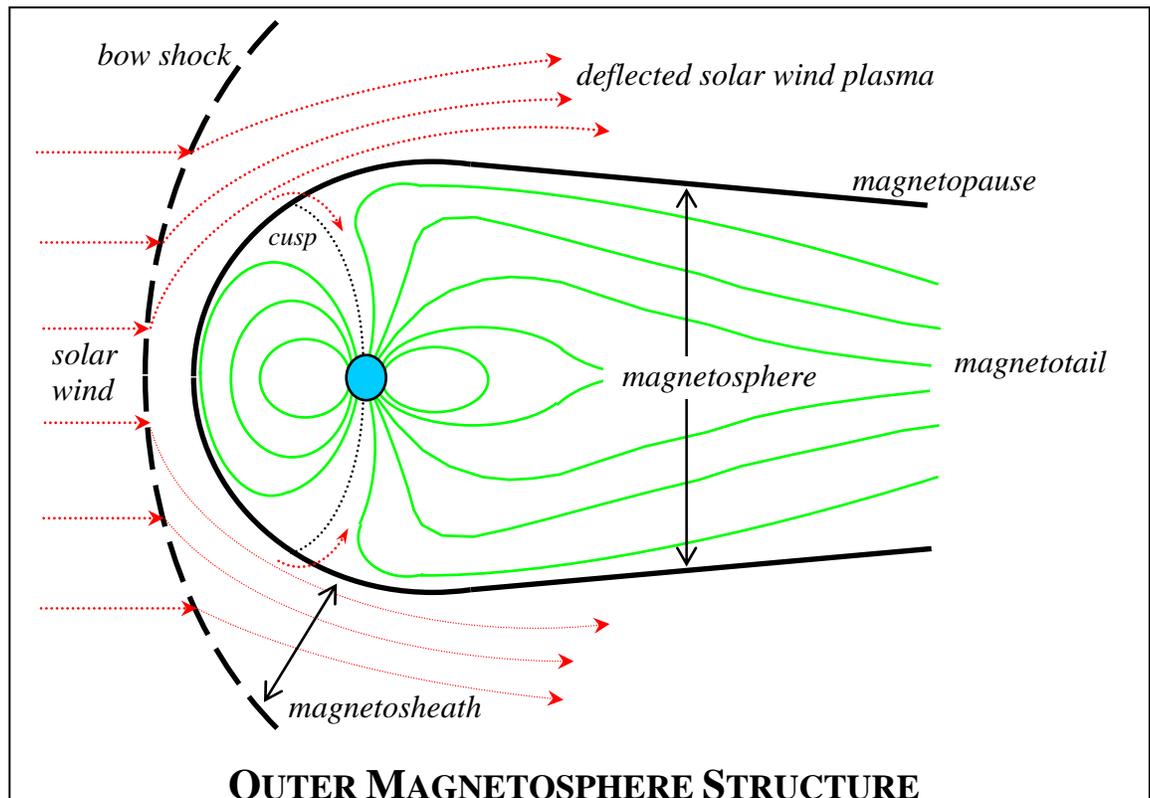
Structure of the Outer Magnetosphere

Bow Shock. Since the solar wind is fully ionized plasma and carried with it a magnetic field, the IMF, it cannot cross into the earth's magnetic field, but it can distort it. The bow shock is the shock front where the solar wind is suddenly slowed from supersonic to sonic speeds as it plows into solar wind plasma that has built up at the nose of the magnetopause. The bow shock marks the transition from undisturbed to turbulent solar wind flow. The bow shock is much like the aerodynamic shock wave that forms when a blunt object is placed in supersonic flow. The diagram below illustrates this.

Magnetopause. The magnetopause is the surface at which the particle pressure of the advancing solar wind plasma is balanced by the earth's magnetic field pressure. In other words, the magnetopause marks the boundary of separation between the IMF and the earth's magnetic field. Solar wind plasma cannot easily cross the magnetopause. The location of the magnetopause changes as the speed of the solar wind changes ($10 - 12 R_E$ down to $6 - 7 R_E$). It is much like an open umbrella held against the gusty wind—the umbrella moves in and out in response to different wind speeds.

Magnetosheath. The magnetosheath is the region of turbulent solar wind plasma located between the bow shock and the magnetopause. The plasma is compressed and heated at the nose of the magnetopause but accelerates in the antisolar direction as it moves around the magnetosphere. The IMF in the magnetosheath is also disturbed from its original orientation in the ambient solar wind.

Magnetotail. The magnetotail is that region where the earth's magnetic field lines are drawn back in the antisolar direction by the motion of the solar plasma attempting to pass around the magnetopause. The solar plasma draws the tail backward for millions of kilometers where it eventually becomes indistinguishable from the IMF. Beyond about $10 R_E$ the magnetic field lines of the earth's field are essentially parallel to those of the IMF.



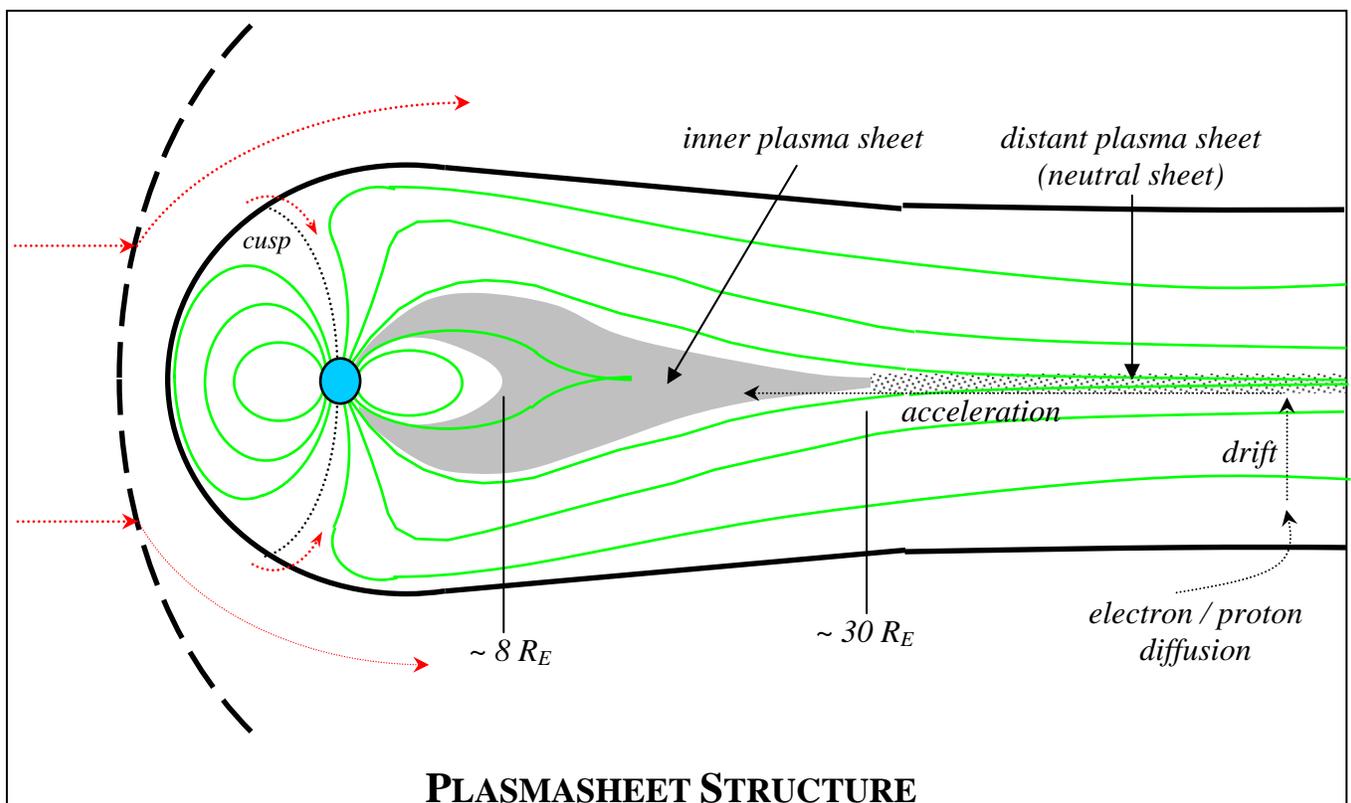
Structure of the Inner Magnetosphere

Plasmasheet. The plasma sheet is a region of concentrated hot plasma that extends from down the magnetotail. The diagram below shows these details.

The distant plasma sheet (neutral sheet) The magnetotail is divided into two lobes. Magnetic field lines in the northern lobe are directed toward the earth, and those in the southern lobe are directed away from the earth. Such a configuration can persist only if plasma concentration exists between the lobes in the region of field direction reversal. This plasma concentration, which stretches down the magnetotail from about $30 R_E$, is called the neutral sheet. Protons and electrons from the solar wind diffuse across the magnetopause in the magnetotail, drift toward the plasma sheet, and accelerate earthward.

Electric current flows from dawn to dusk in the neutral sheet in order to keep the magnetic lobes separated. This is called the cross-tail current. The energy of electrons in the neutral sheet range from 200 eV to more than 12 keV. Proton energy ranges from 1 to 20 keV.

The inner plasma sheet is the plasma sheet region extending inward from about $30 R_E$ to about $8 R_E$ (in the antisolar direction) and further inward as it tapers north and south toward the geomagnetic poles. The magnetic field lines of the inner plasma sheet are closed, but still tear-shaped.



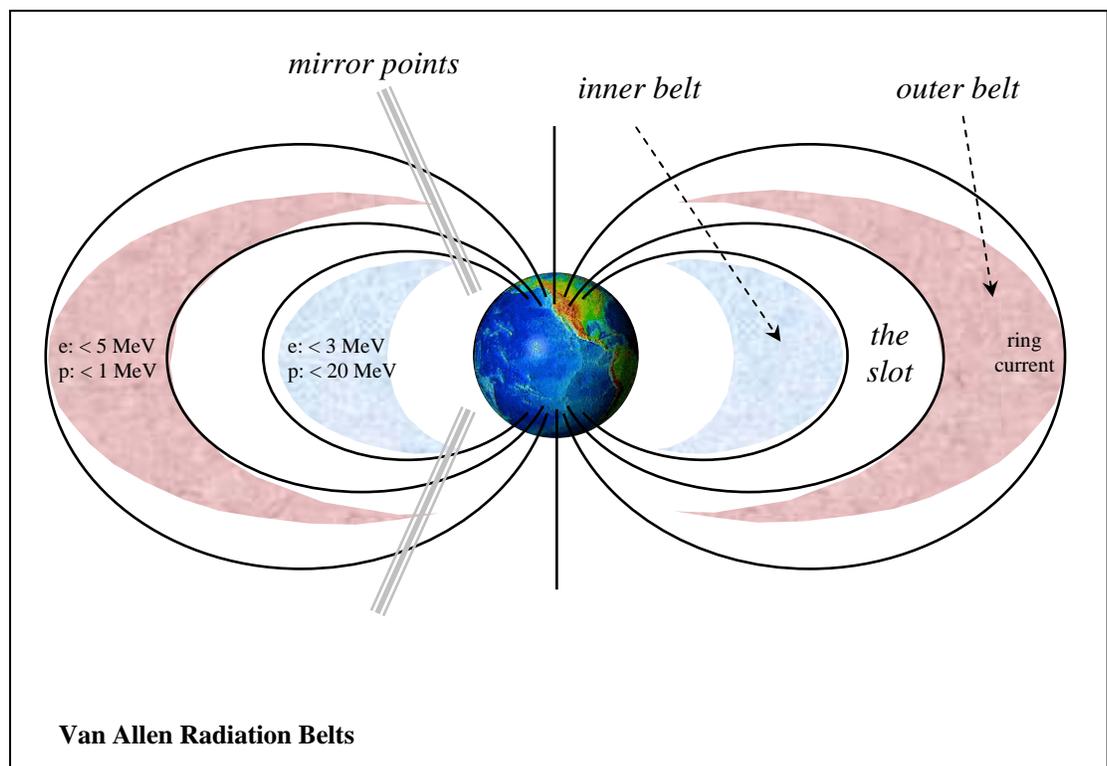
Van Allen Radiation Belts. Within the earthward edge of the inner plasma sheet ($1 - 8 R_E$), magnetic field lines are less distended and more dipole-shaped. Here high-energy charged particles are trapped.

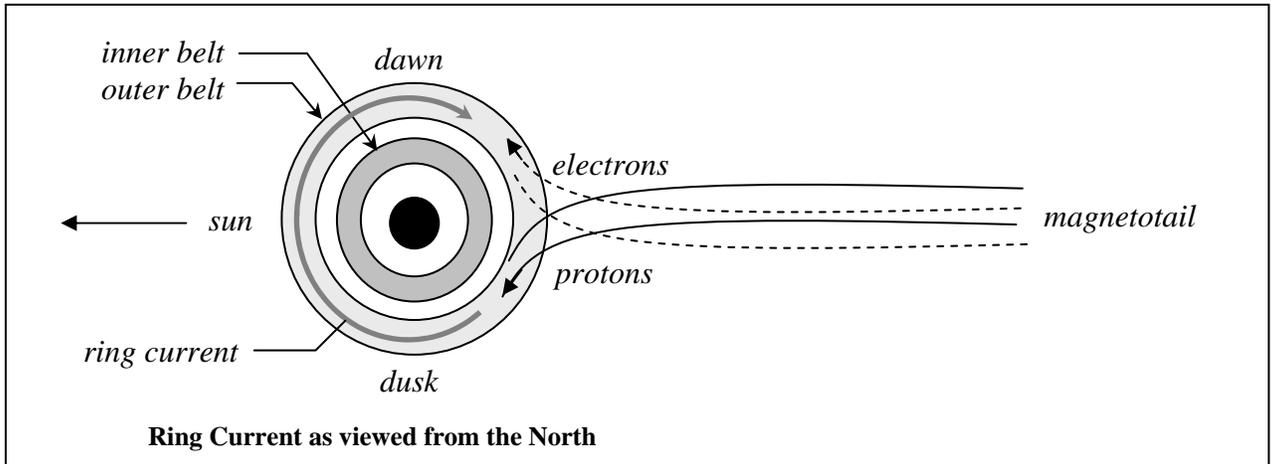
Charged particles spiral around magnetic field lines, reflecting from the magnetic mirror points near the magnetic poles. Electrons with energies greater than 40 keV tend to be found throughout this region. Protons, on the other hand, are concentrated in two “radiation” belts, the Van Allen belts. The existence of two belts is a consequence of where the protons originate.

The outer Van Allen belt has a maximum proton density out to about $4 - 5 R_E$, (16,000–20,000 km). It contains low-energy protons (~200 keV to 1 MeV) of solar wind origin. Recall that protons and electrons from the solar wind diffuse across the magnetopause in the magnetotail, drift toward the plasma sheet, and accelerate earthward. On arrival from the plasmasheet, these particles are injected into the outer Van Allen belt. The protons are deflected westward by the earth’s magnetic field, and the electrons are deflected eastward. This net result causes the “ring current,” which is co-located with the outer Van Allen belt (shown on next page).

The inner Van Allen belt has a maximum proton density out to about $1\frac{1}{2} R_E$ (~5000 km). It is composed high-energy protons (up to hundreds of MeV) primarily of terrestrial origin. Cosmic rays strike the earth’s upper atmosphere, and ionize neutral atoms. The ions absorb the kinetic energy of the cosmic ray and follow magnetic field lines leading to the inner Van Allen belt. Since the inner belt is more dipole-shaped, particles can be trapped for hundreds of years. Unlike the outer belt, the particles of the inner belt co-rotate with the earth.

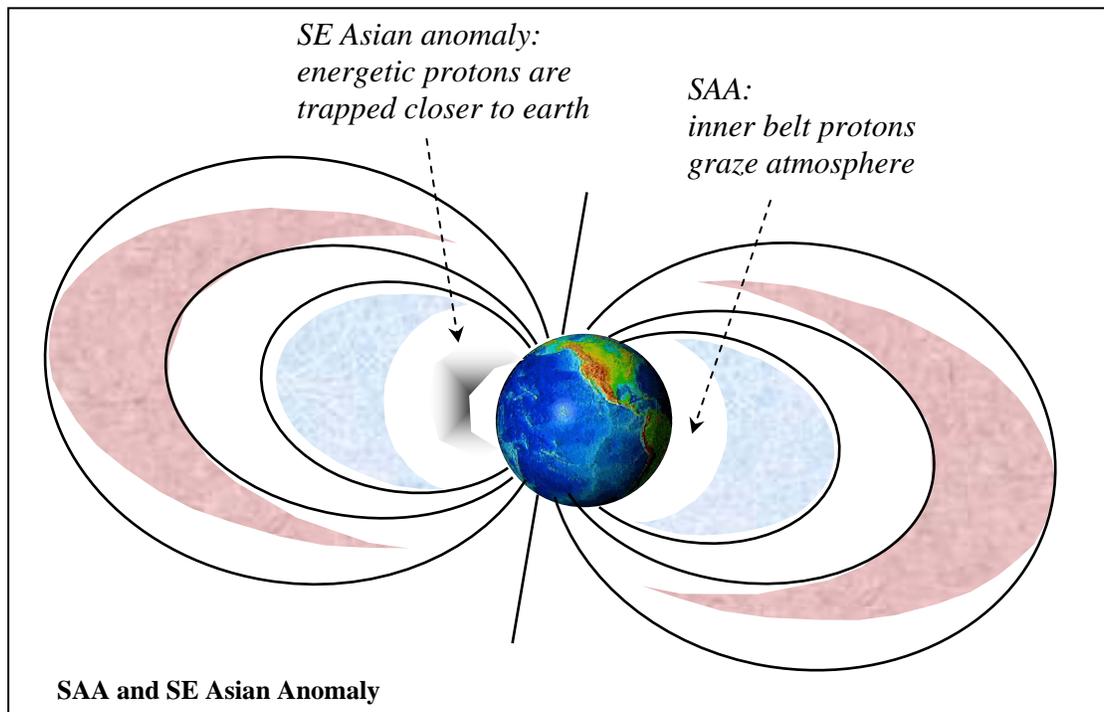
The slot lies between the two belts. The proton density here is much less than in either of the two belts. The slot also identifies the *plasmopause*—the outer edge of plasma (electrons and protons) that co-rotates with the earth. Outside of this boundary, the plasma does not co-rotate with the earth.





South Atlantic Anomaly revisited. The tilt and offset of the earth's magnetic dipole axis combine to put the earth's surface in the region of the South Atlantic Ocean further away from the dipole axis than elsewhere on the planet. The following figure exaggerates this offset to illustrate how this results in the inner Van Allen radiation belt being located closer to the atmosphere over the South Atlantic than anywhere else at that latitude. Charged particles, as they slowly drift around the planet, graze the upper atmosphere over the western South Atlantic Ocean. These energetic particles ionize atmospheric atoms, which causes significant and unexpected heating. This is the South Atlantic Anomaly, or SAA.

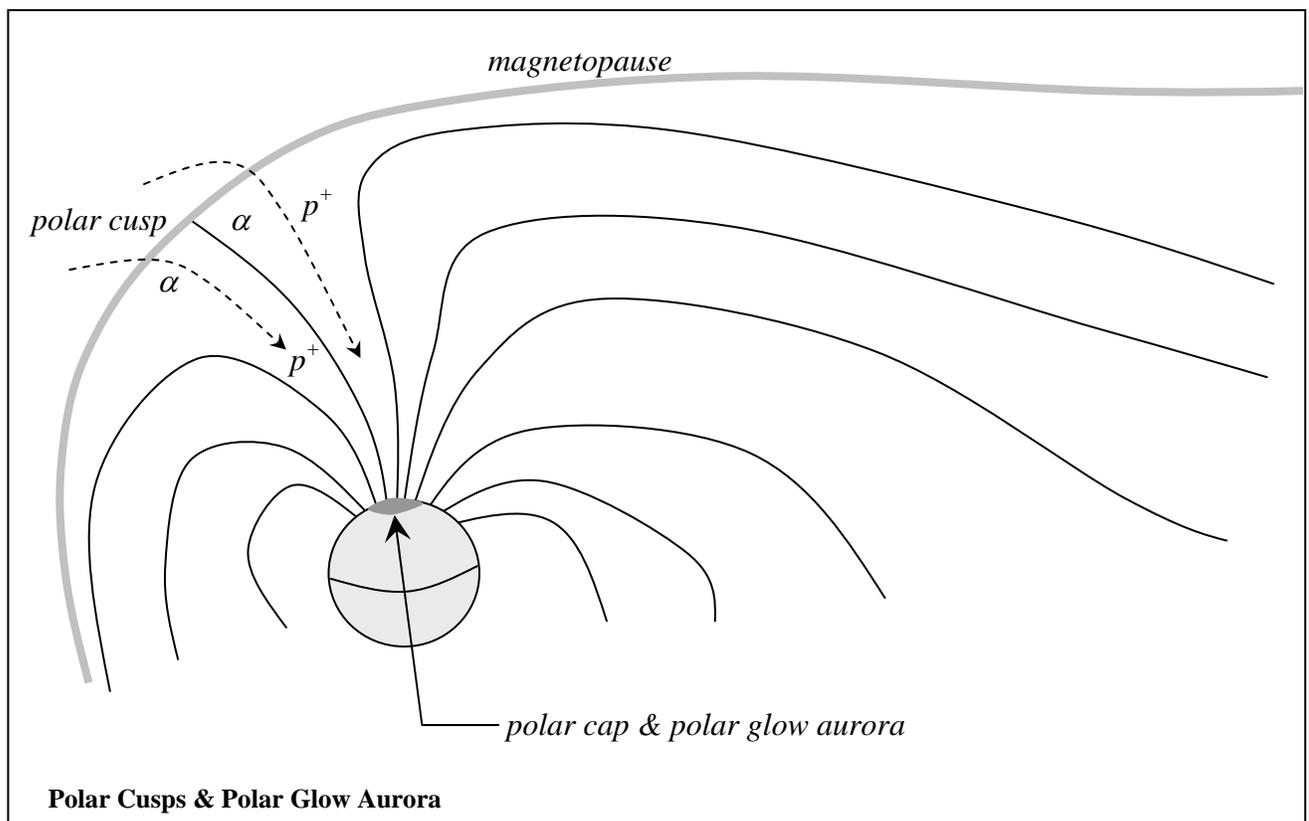
SE Asian Anomaly revisited. Conversely, the earth's surface is *closest* to the dipole axis in the region of southeastern Asia. Here, protons with the highest energies can be trapped because the strongest trapping magnetic fields exist over this region. These protons can penetrate deeper into the earth's atmosphere, ionize, and heat regions of the middle atmosphere (down to about 50km). This is the SE Asian Anomaly.



Polar Structures

The Polar Cusps are two small regions where the earth's magnetic field is perpendicular to the magnetopause. One each exists above the magnetic poles of the earth. This geometry allows a trickle of charged solar wind protons and alpha particles to directly enter the magnetosphere.

The Polar Cap. The solar wind particles that enter the polar cusps are funneled along magnetic field lines straight to the earth's atmosphere where they ionize atoms and emit light. This occurs within the *polar caps*, regions in the Arctic and Antarctic within about 20° of the geomagnetic poles. This steady stream of particles causes a weak, diffuse glow extending over a large part of the polar cap; this is called "polar glow aurora." The following diagram illustrates this.



The Auroral Oval. Some particles coming from the magnetotail are shunted north and south along magnetic field lines as they approach the earth. If they don't get reflected at the magnetic mirror point before they strike the earth's atmosphere, they cause the "discrete aurora." This is the well-known Northern Lights, or Aurora Borealis. The Southern Lights are called the Aurora Australis.

This auroral area is a rough oval band, whose center is displaced about 3° to 4° off the magnetic pole and lies toward the night hemisphere of the earth. The midnight portion of the oval is the most active because it is the best connected magnetically to the magnetotail—the source of accelerated particles. The equatorward edge of the oval is sharp and distinct; the polar edge is much less so.

The Auroral Zone. As the earth turns, the auroral oval basically remains fixed. The oval then sweeps out an area called the auroral zone, which includes the geomagnetic latitude range between 61° and 73° .

The diagram below illustrates the auroral oval and auroral zone.

