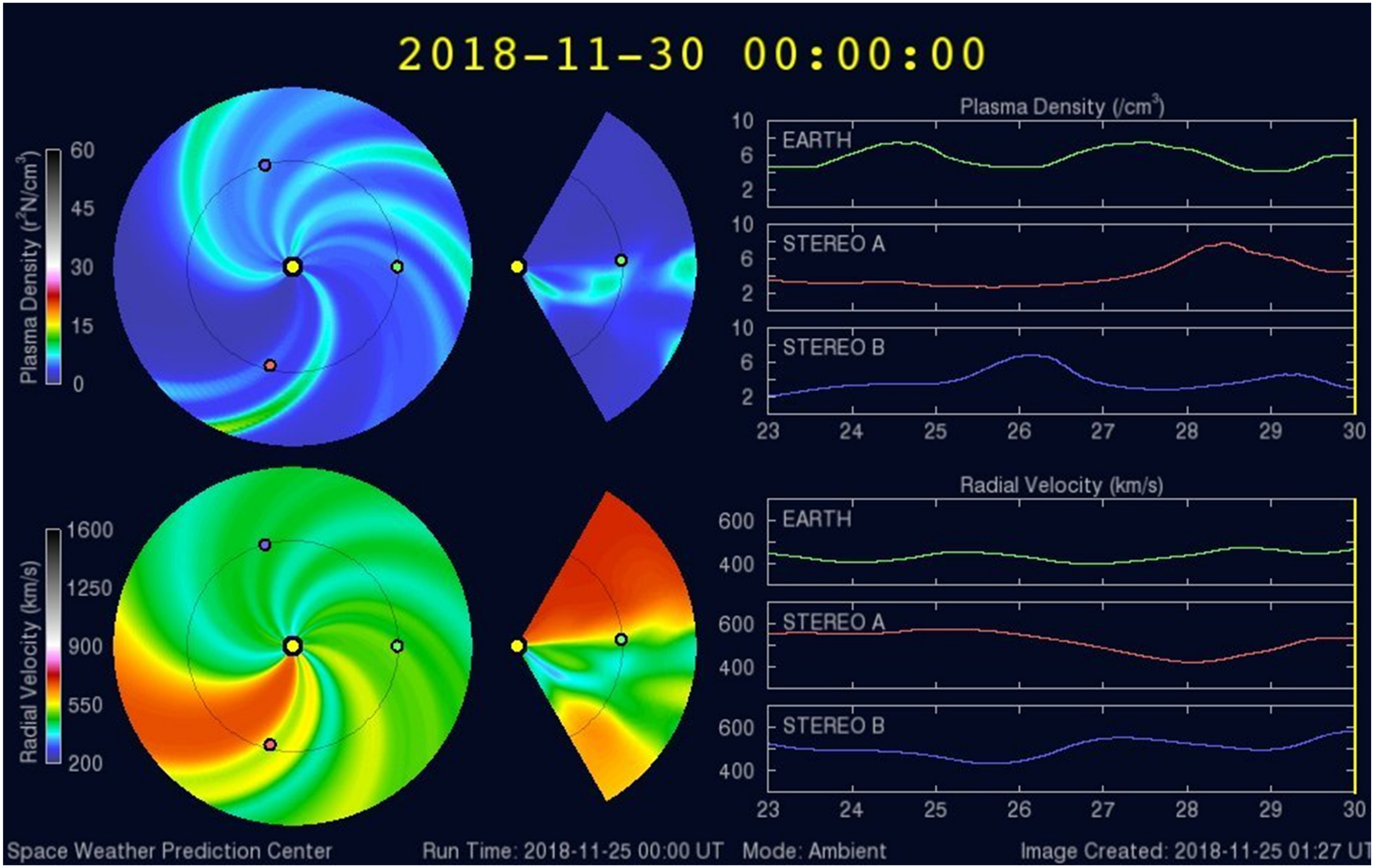
# 23. Magnetosphere.

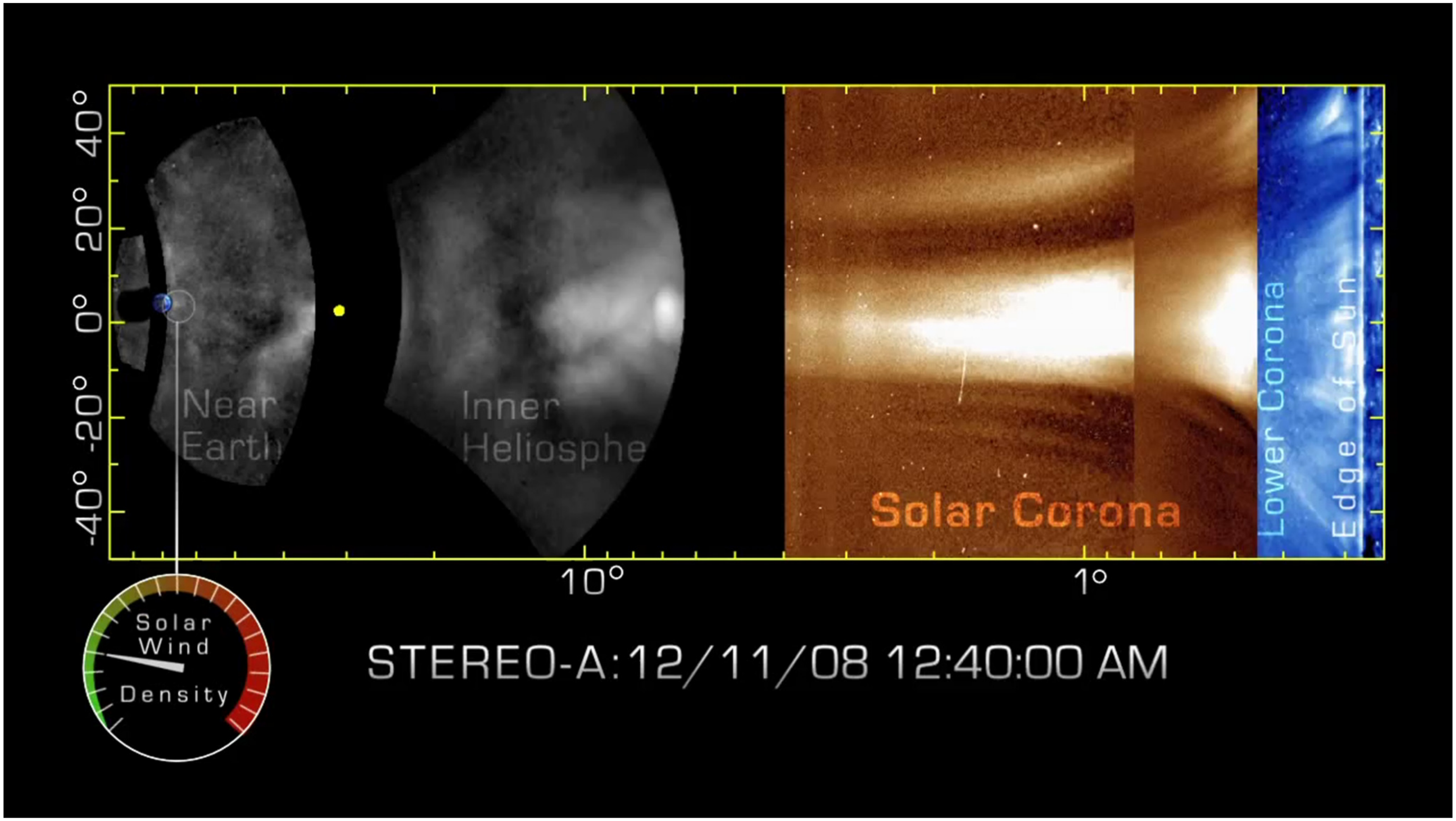
# Magnetosphere

- Interaction of the solar wind with the Earth's magnetic field
- Formation of the magnetosphere
- Structure of the magnetosphere
- Magnetic reconnection in the magnetosphere
- Storm and substorms
- Radiation belts

**WSA-ENLIL Solar Wind Prediction Model (MHD)**
http://www.swpc.noaa.gov/products/wsa-enlil-solar-wind-prediction

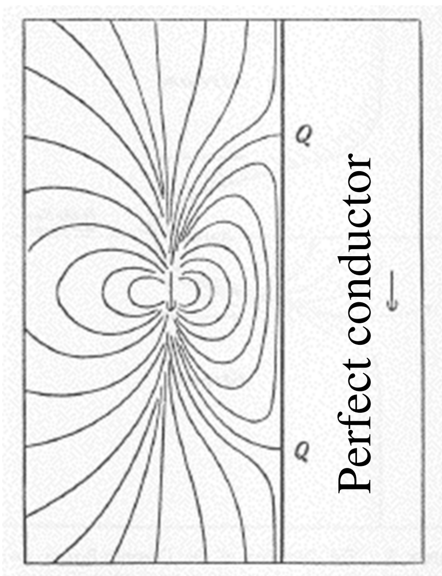


## STEREO-A tracks a Coronal Mass Ejection from the Sun to Earth.

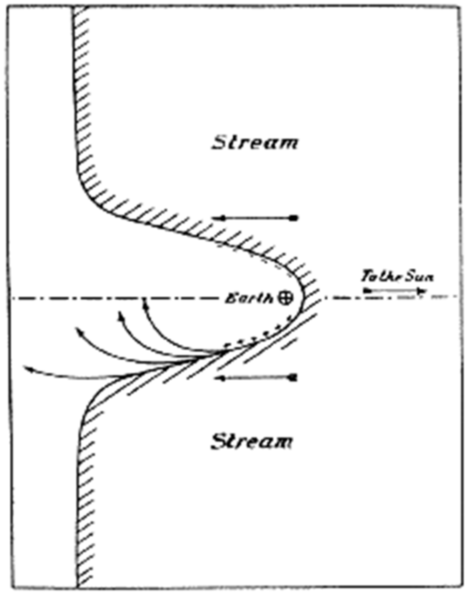



When the CME first left the sun, it was cavernous, with walls of magnetism encircling a cloud of low-density gas. As the CME crossed the Sun-Earth divide, however, its shape changed. The CME "snow-plowed" through the solar wind, scooping up material to form a towering wall of plasma. (DeForest, 2011)

# Chapman and Ferraro model



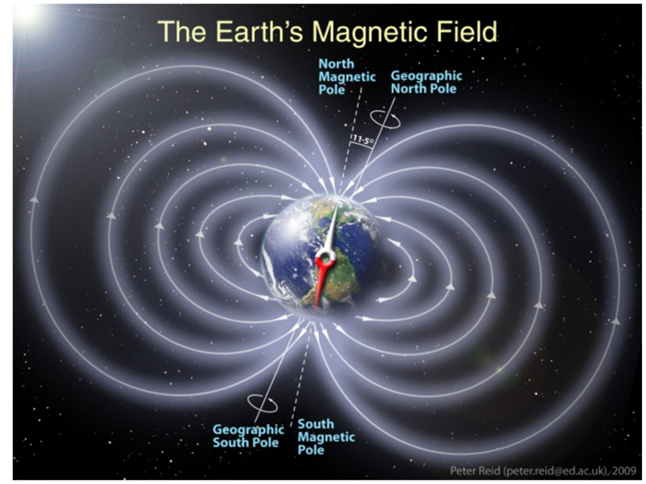

The Earth's dipole field (left), flattened by the addition of the field of an image dipole (right), as proposed by Chapman and Ferraro.




The formation of the Chapman-Ferraro cavity. Arrows trace the paths of ions and electrons by which Chapman and Ferraro proposed to account for ring current effects.

- Back in 1930 Chapman and Ferraro foresaw that a planetary magnetic field could provide an effective obstacle to the solar-wind plasma.
- The solar-wind dynamic pressure presses on the outer reaches of the magnetic field confining it to a magnetospheric cavity that has a long tail consisting of two antiparallel bundles of magnetic flux that stretch in the antisolar direction.
- The pressure of the magnetic field and plasma it contains establishes an equilibrium with the solar wind.

# The Earth's Magnetic Field (Spherical Coordinates)



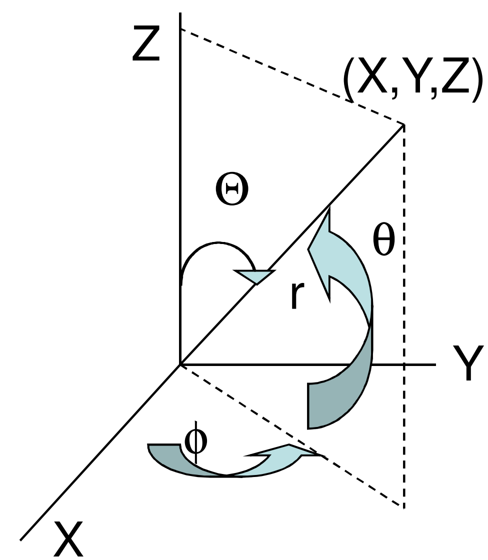

- To a first approximation the magnetic field of the Earth can be expressed as that of a dipole. The dipole moment of the Earth is tilted ~$11^0$ to the rotation axis with a present day value of $8x10^{15}Tm^3$ or $30.4x10^{-6}TR_E{}^3$ where $R_E$=6371 km (one Earth radius).
- In a coordinate system fixed to this dipole moment

$$B_r = 2M_E r^{-3}\cos\Theta$$

$$B_\theta = M_E r^{-3}\sin\Theta$$

$$B_\varphi = 0$$

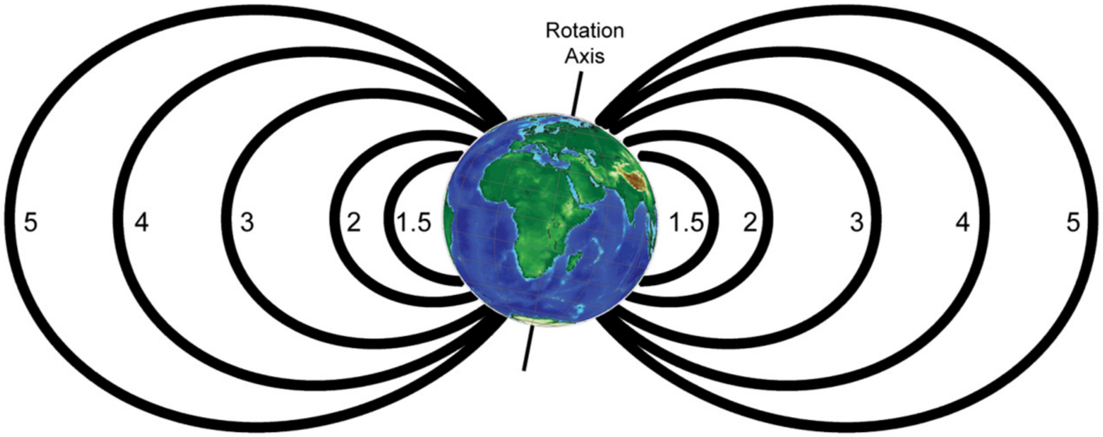
$$B = M_E r^{-3}(1+3\cos^2\Theta)^{\frac{1}{2}}$$




where $\Theta$ is the magnetic colatitude,

and $M_E$ is the dipole magnetic moment.

# Dipole Magnetic Field Lines and the L-shell Parameter




The magnetic field line for a dipole.
Magnetic field lines are everywhere tangent to the magnetic field vector.

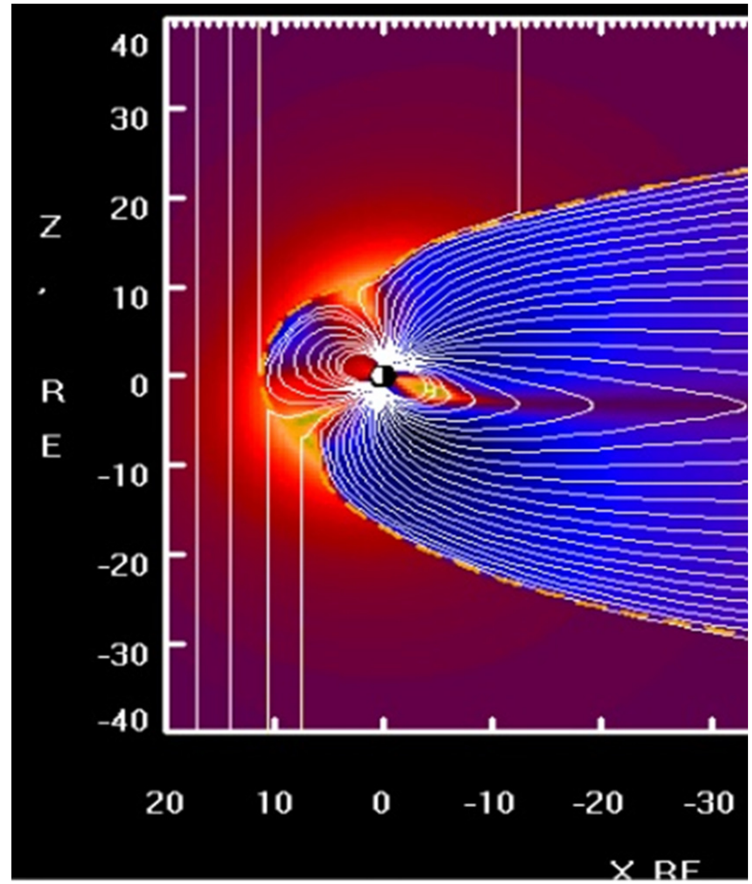
$$\frac{dr}{B_r} = r\frac{d\Theta}{B_\theta}; \quad \frac{dr}{r} = \frac{B_r}{B_\theta} d\Theta = 2\frac{\cos\Theta}{\sin\Theta} d\Theta = 2\frac{d\sin\Theta}{\sin\Theta}$$

$$\log r = 2\log(\sin\Theta) + C \Rightarrow \; r = r_0 \sin^2\Theta$$

- where $r_0$ is the distance to equatorial crossing of the field line. It is most common to use the magnetic latitude $\theta$ instead of the colatitude
- $r / R_E = L\cos^2\theta$ where $L$ is measured in $R_{E.}$

# Properties of the Earth's Magnetic Field

- The dipole moment of the Earth presently is ~$8\times10^{15}$Tm$^3$ ($3\times10^{-5}$T$R_E{}^3$).
- The dipole moment is tilted ~$11^0$ with respect to the rotation axis.
- The dipole moment is decreasing.
  - It was $9.5\times10^{15}$Tm$^3$ in 1550 and had decreased to $7.84\times10^{15}$Tm$^3$ in 1990.
  - The tilt also is changing. It was $3^0$ in 1550, rose to $11.5^0$ in 1850 and has subsequently decreased to $10.8^0$ in 1990.
- In addition to the tilt angle the rotation axis of the Earth is inclined by $23.5^0$ with respect to the ecliptic pole.
  - Thus the Earth's dipole axis can be inclined by ~$35^0$ to the ecliptic pole.
  - The angle between the direction of the dipole and the solar wind varies between $56^0$ and $90^0$.



# Three Kinds of Pressure

- Dynamic pressure is like pressure of a flowing fluid

$$P_D = \rho V^2$$

where ρ is the mass density (g/cm$^3$) and V is the velocity (cm/s).

- Thermal pressure of a fluid even if it is stationary.

$$P_T = nkT$$

where $n$ is the number density (cm$^{-3}$), $k$ is the Boltzman constant (1.38x10$^{-16}$ erg K$^{-1}$) and $T$ is the temperature.

- The magnetic field can also exert pressure

$$P_B = \frac{B^2}{8\pi}$$

where B is the magnetic field intensity (Gauss).

# Solar Wind Pressure at the Earth

- Assume that the solar wind has a velocity of 400km/s, density of $5cm^{-3}$, temperature of $2x10^5K$, and magnetic field strength of $5nT=5x10^{-5}$ G.

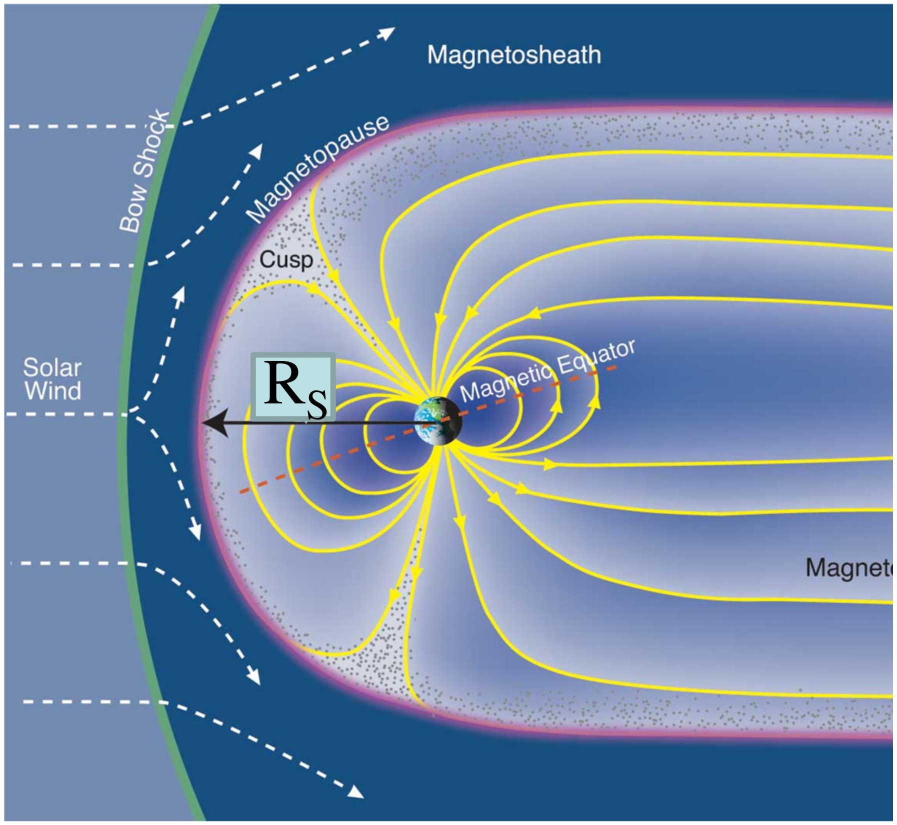
$$P_D = \rho V^2 = 1.4\times10^{-8}\, dyn/cm^2$$

$$P_T = nkT = 1.4\times10^{-10}\, dyn/cm^2$$

$$P_B = \frac{B^2}{8\pi} = 1.0\times10^{-10}\, dyn/cm^2$$

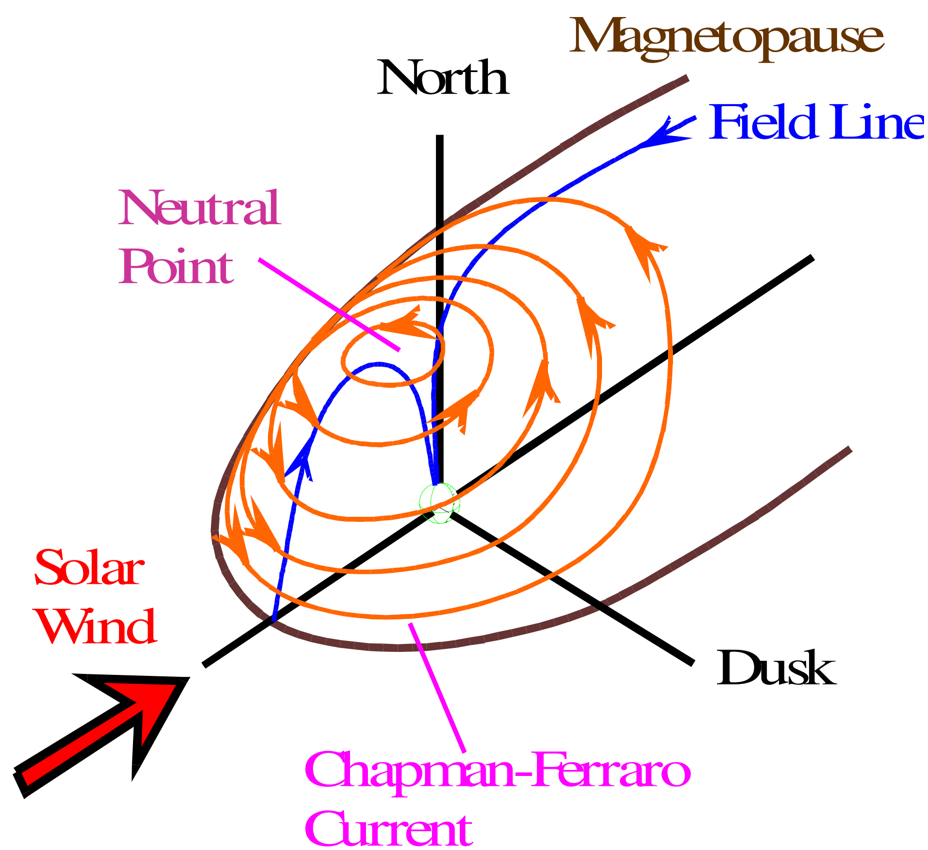
# Forming the Magnetopause

- The solar wind is supersonic and passes through a **bow shock** where the direction of flow is changed so that most of the solar wind plasma is deflected to either side of the magnetopause.
- The zone of shocked solar wind plasma is the **magnetosheath.**
- The dynamic pressure is much larger than the thermal pressure or magnetic pressure in the solar wind.
- Within the magnetosphere the magnetic pressure of the Earth's internal field dominates.
- To a good approximation the boundary (the magnetopause) between the region dominated by the solar wind and the region dominated by the Earth (the magnetosphere) can be found by balancing the solar wind dynamic pressure with the magnetic pressure of the Earth.



# Shielding the Earth from the Solar Wind

- Ideally when the pressures are in balance the Earth's field will be shielded from the solar wind in a cavity called **the magnetosphere**.
- The interaction sets up **Chapman-Ferraro currents** on the boundary which cancel the Earth's magnetic field outside.
- Near the pole there is a singular point in the field where |B| = 0. This is called the *neutral point*.
- The C-F current circulates in a sheet around the neutral point
- This current is symmetric about the equator with a corresponding circulation around the southern neutral point



# The Location of the Magnetopause

- The magnetic field inside the boundary is the total field from dipole and boundary current. For an infinite planar sheet current the field would be exactly doubled. Inside a spherical boundary the multiplication factor is 3. The factor f must lie in this range .
- Equate and substitute for the dipole strength variation with distance.
- Solve for the dimensionless standoff distance $L_s$.

$$P_D = P_S$$

$$P_D = \rho V^2$$

$$P_S = \frac{(fB_S)^2}{8\pi}$$

$$k\rho V^2 = \frac{f^2 B_S^2}{8\pi}$$

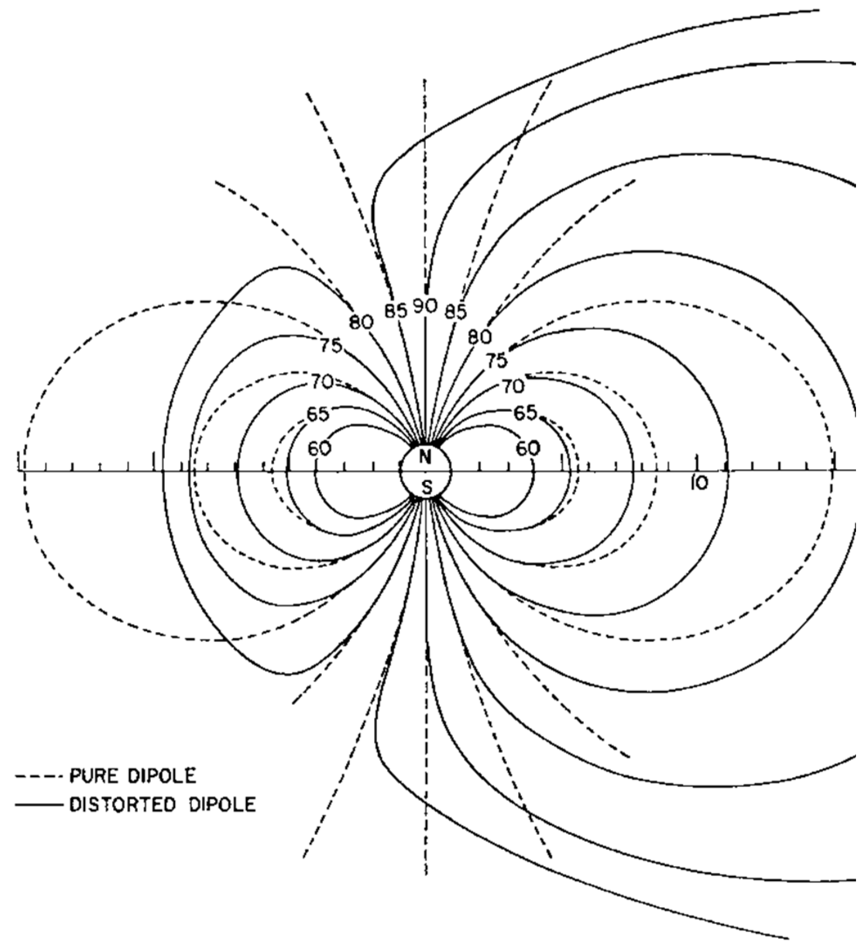
$$B_S = B_0 \left( R_E / R_s \right)^3$$

Where k~0.9 is the elasticity of particle collisions and f is the factor by which the magnetospheric magnetic field is enhanced by the boundary current. $R_s$ is the subsolar standoff distance. $B_0$ is the field at the surface of the Earth.

$$L_s = \left( \frac{R_s}{R_E} \right) = \left[ \left( \frac{f^2}{k} \right) \left( \frac{B_0^2}{8\pi\rho V^2} \right) \right]^{\frac{1}{6}}$$

# The Effect of Magnetopause Currents

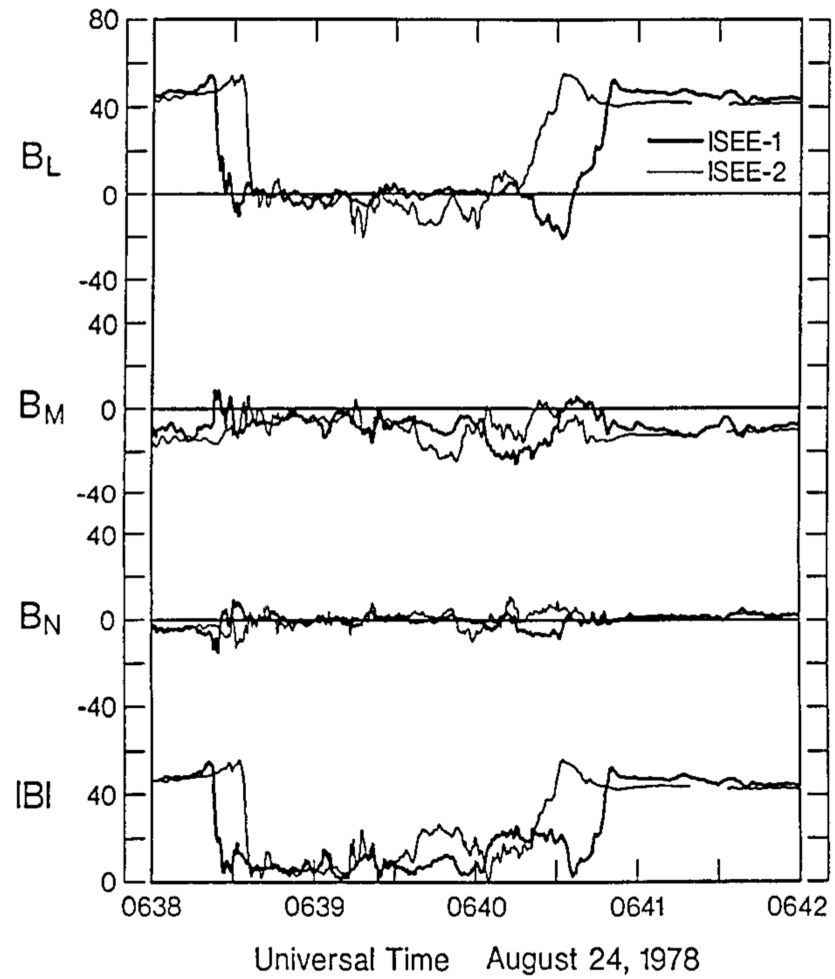
- Close to the Earth the dipole field dominates and there is little distortion
- Further away there is a significant change in the shape of the field lines with all field lines passing through the equator closer to the Earth than dipole field lines from the same latitude.
- All dipole field lines that originally passed through the equator more than 10 $R_E$ sunward of the Earth are bent back and close on the night side
- The neutral point separates the two types of field lines




$L_S$~10

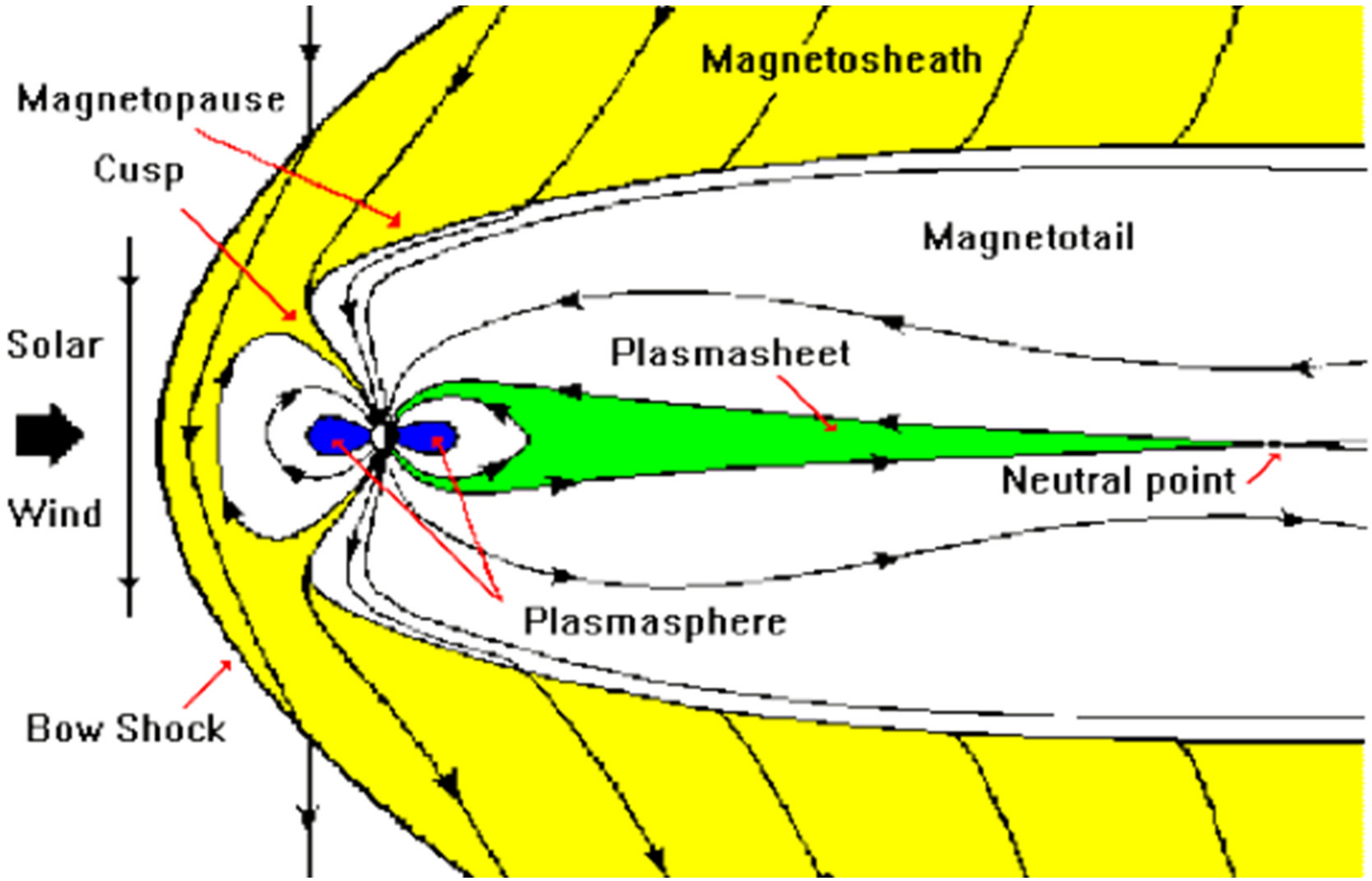
# Observing the Magnetopause

- Data from two spacecraft show two crossings of the boundary.
- Initially both spacecraft are inside the magnetosphere (strong field).
- The boundary moves inward and crosses first the ISEE-1 spacecraft (thick line) and later the ISEE-1 spacecraft (thin line).
- Some time later the boundary reverses and moves outward appearing first at ISEE-2 and later at ISEE-1.
- The spacecraft separation along the average normal divided by the time delay gives the boundary velocity.
- The time profile scaled by the velocity gives the spatial profile of the boundary
- The thickness of the magnetopause varies from 200 to 18000 km with a most probably thickness of 700 km.



# The Magnetotail

- Behind the Earth the solar wind extends the magnetosphere a long distance(>3000$R_E$) away from the Earth on the night side forming the magnetotail.

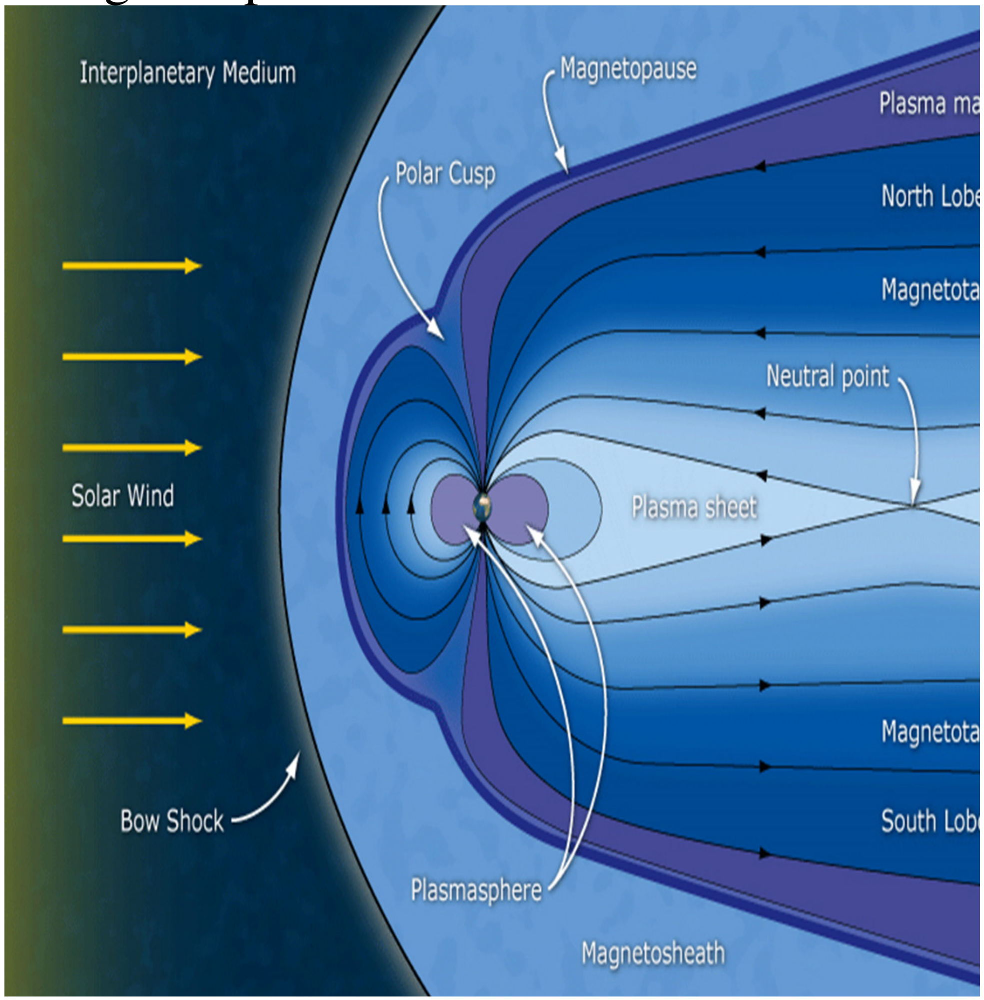


# The Magnetotail

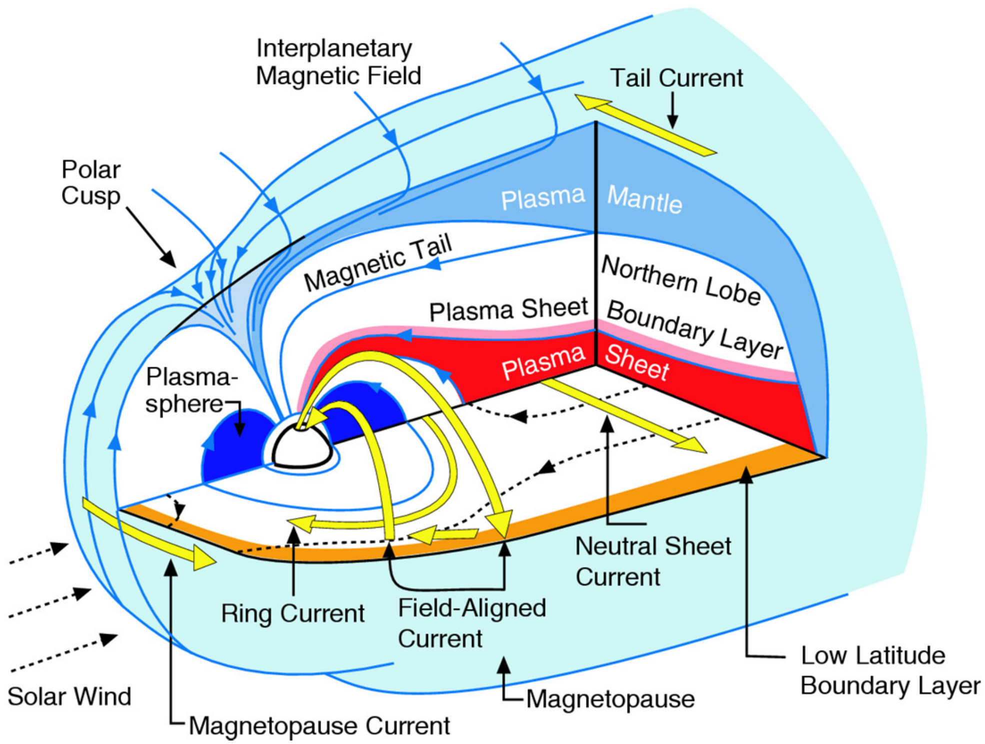
A current sheet lies in the middle of the tail and separates it into two regions called the lobes.

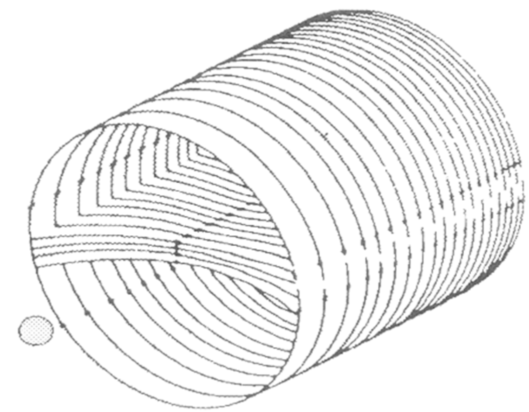
- The magnetic field in the north (south) lobe is directed away from (toward) the Earth.
- The magnetic field strength is typically ~20 nT.
- Plasma densities are low (<0.1 $cm^{-3}$). Very few particles in the 5-50keV ( 1eV = $1.6 \times 10^{-19}$J it is the energy an electron gains by being accelerated through one volt) range. Cool ions observed flowing away from the Earth with ionospheric composition. The tail lobes normally lie on "open" magnetic field lines.

The **magnetotail** acts as a reservoir for plasma and energy. Energy and plasma from the tail are released into the inner magnetosphere aperiodically during magnetospheric substorms.



# The Equatorial Current Sheet




- The tail lobes are separated by an equatorial current sheet extend across the tail from dawn to dusk.
- Magnetically induced currents must close – these close on the tail magnetopause.
- A current creates a magnetic field.

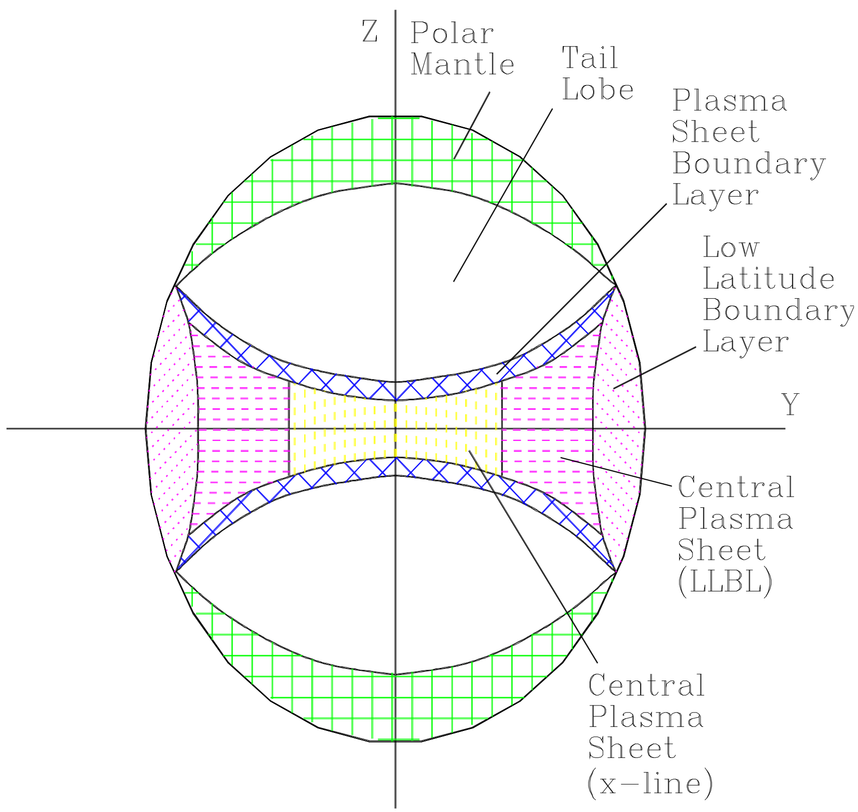
# The Cross Section of the Tail

• The plasma sheet is found between the lobes in the tail.

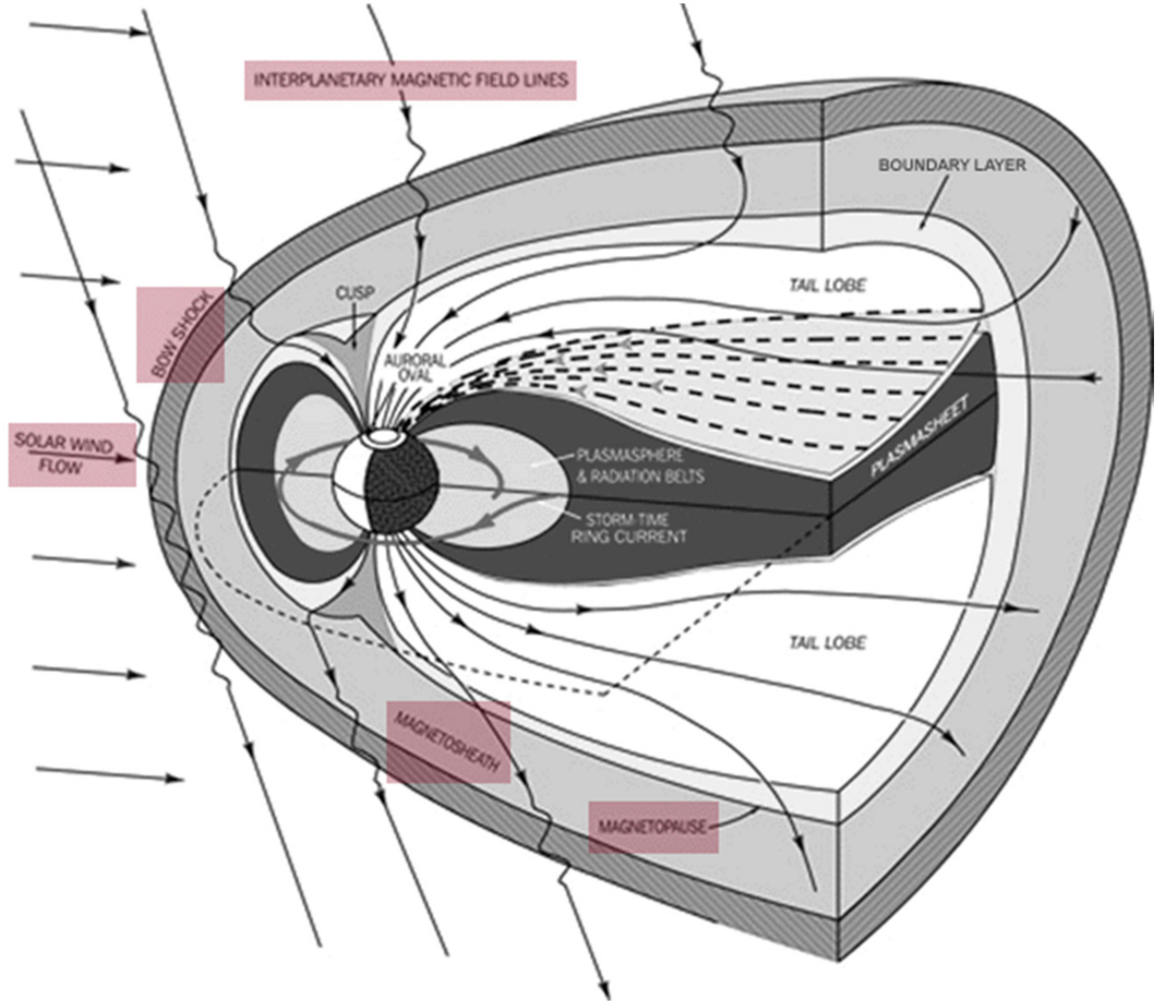
• It contains hot (3keV ions and 1keV electrons).

• Observers have identified small regions within the plasma sheet (red, yellow and blue). The boundary layers are less than $1R_E$ thick.

• The plasma (polar) mantle is found near the magnetopause (green).

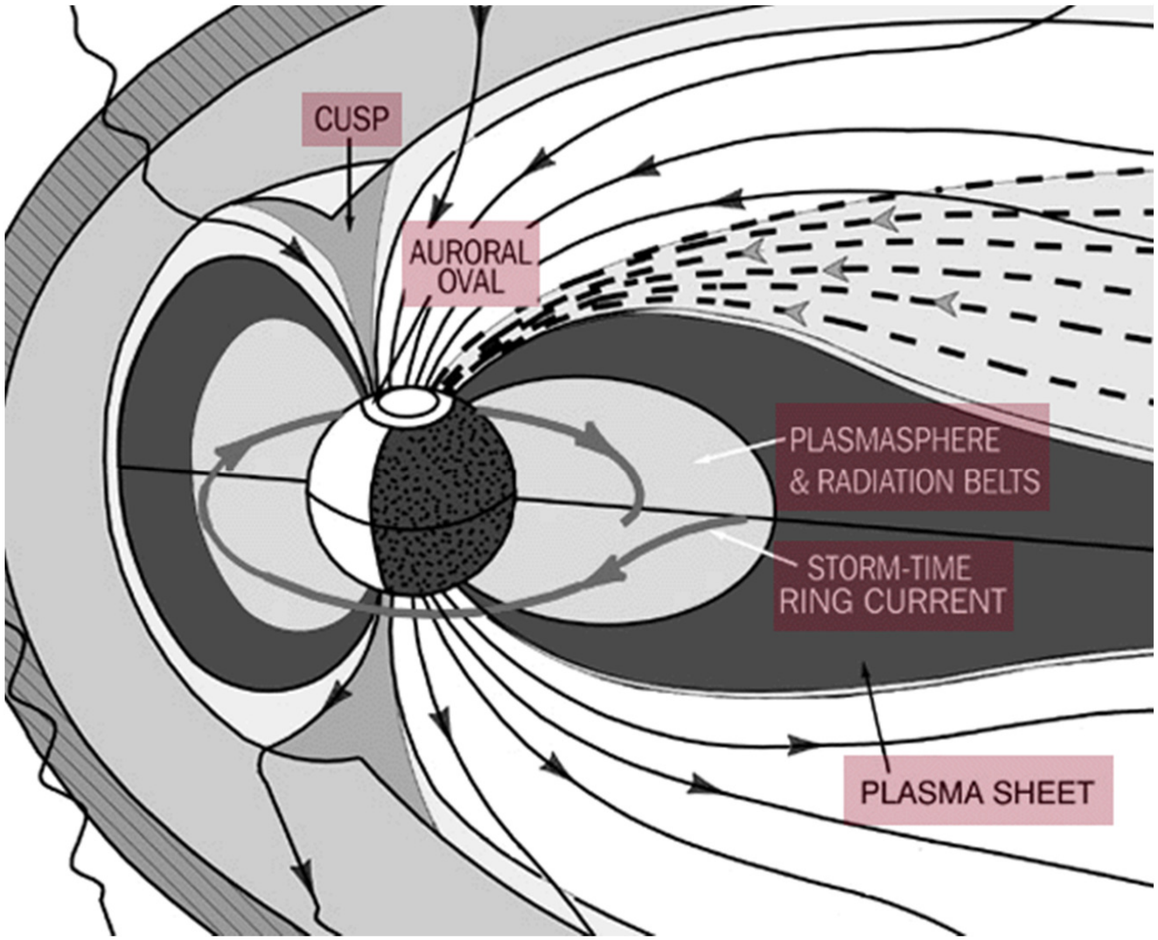


# 3D Diagram of Magnetosphere

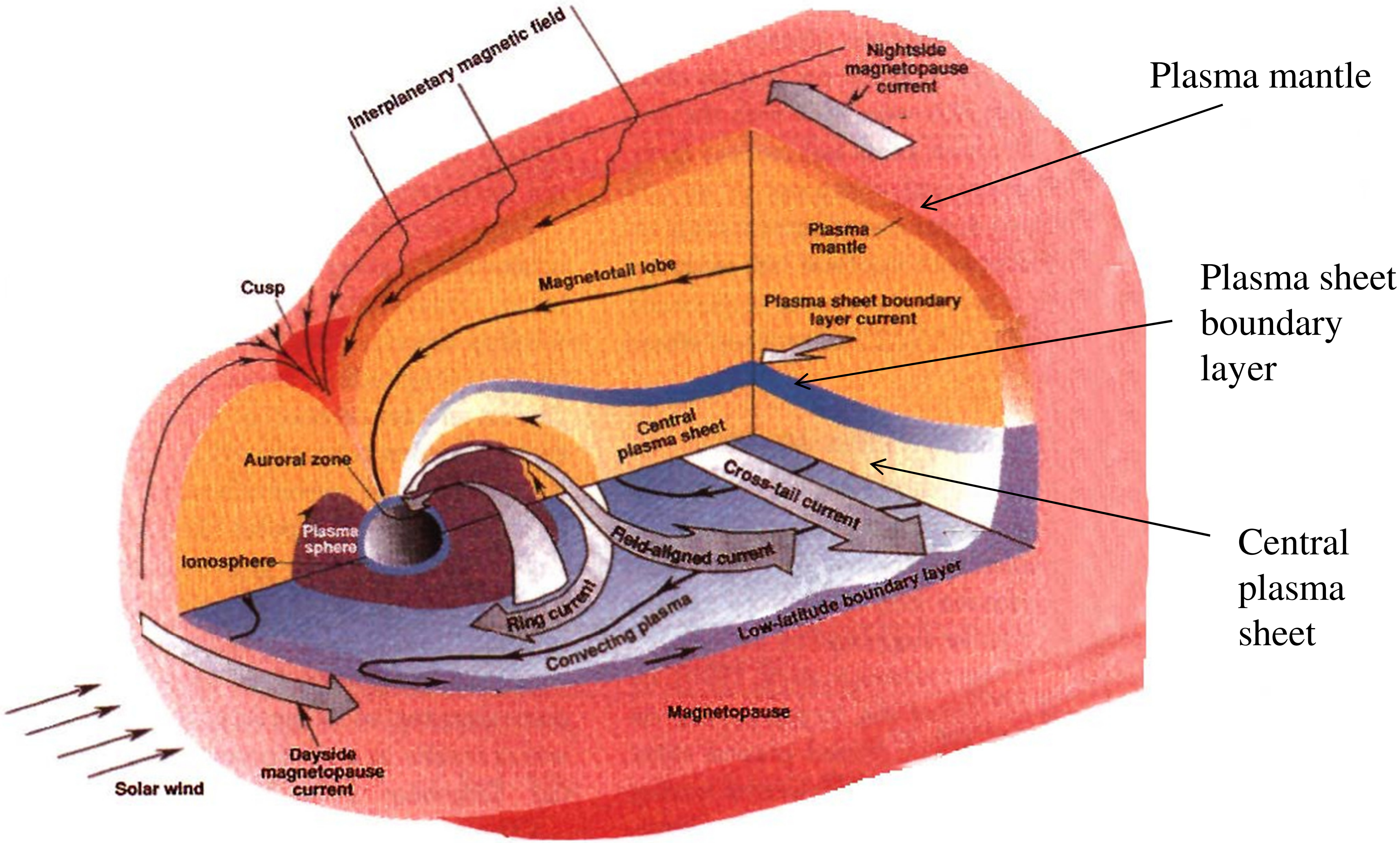



**The interaction with the solar wind deforms the Earth's basically dipolar magnetic field, compressing the field lines on the day side and stretching them out to form a long comet-like tail (the magnetotail) on the night side. On the day side, the magnetosphere extends out to a distance of approximately 10 Earth radii (under quiet conditions), while the magnetotail extends several hundred Earth radii in the antisunward direction. The magnetosphere contains various large-scale regions, which vary in terms of the composition, energies, and densities of the plasmas that occupy them. The sources of the plasmas that populate these regions are the solar wind and the Earth's ionosphere; the relative contributions of these two sources to the magnetospheric plasma vary according to the level of geomagnetic activity.**

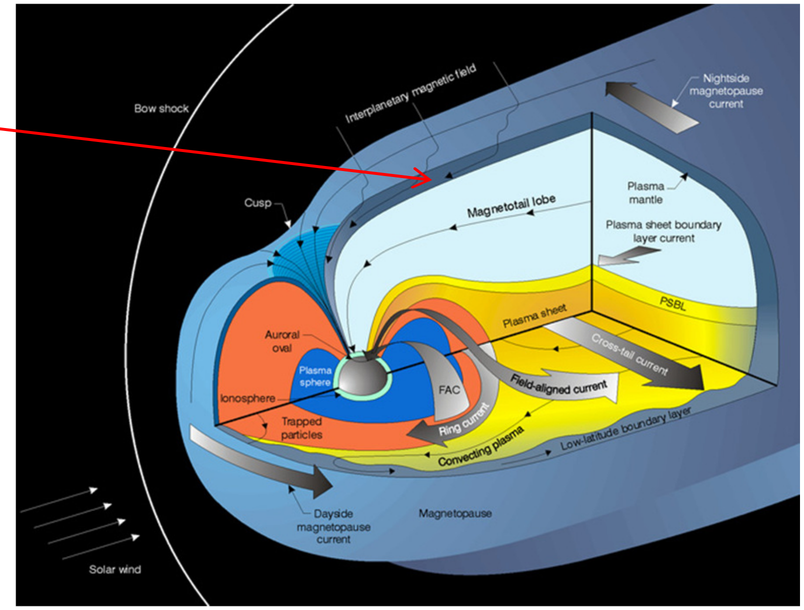
# Inner Magnetosphere contains Plasmasphere and Radiation Belts



# 3D View of the Magnetosphere



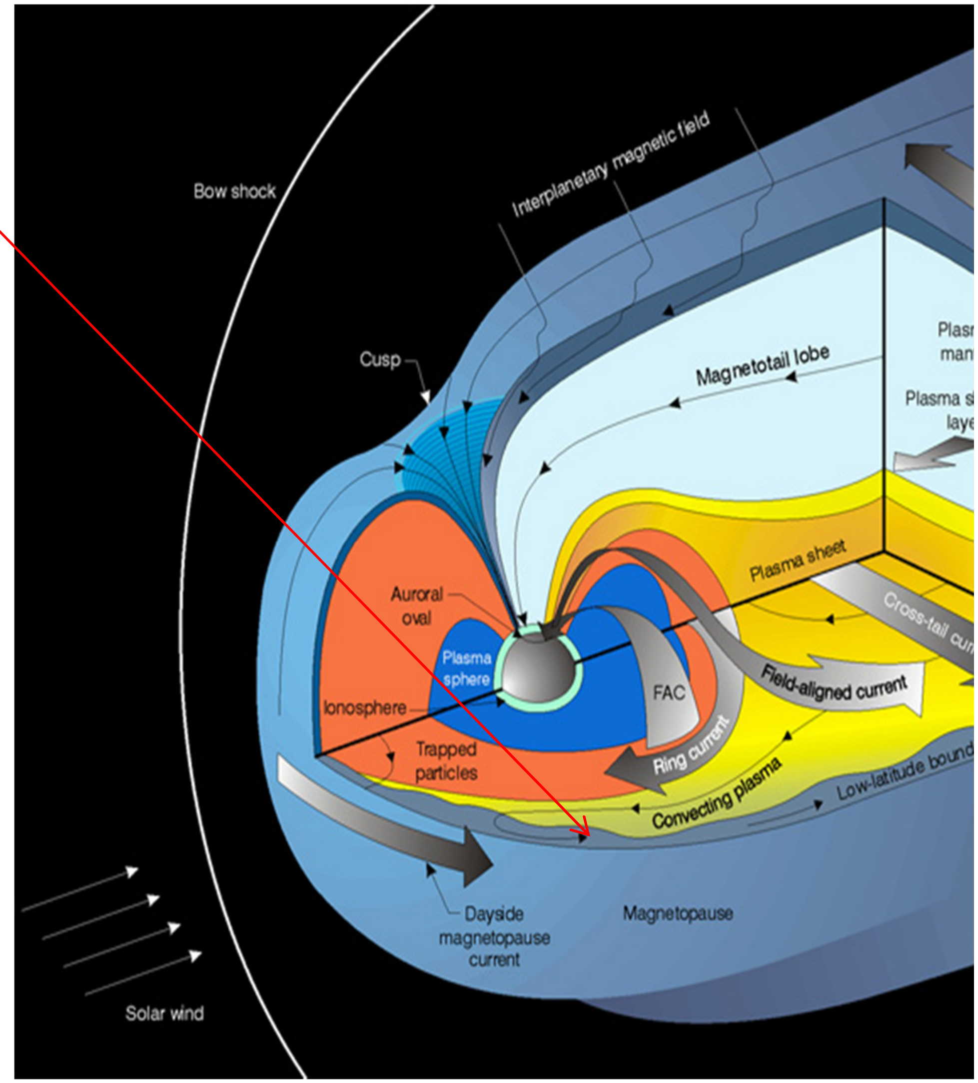
# Magnetotail Structure – Plasma Mantle, Plasma Sheet Boundary Layer and Central Plasma Sheet




- The plasma mantle has a gradual transition from magnetosheath to lobe plasma values.
  - Flow is always tailward
  - Flow speed, density and temperature all decrease away from the magnetopause.
- Plasma sheet is separated from the tail lobes by the plasma sheet boundary layer (PSBL).
- Ions in the PSBL typically flow at hundreds of km/s parallel or antiparallel to the magnetic field.
  - Frequently counterstreaming beams are observed: one flowing earthward and one flowing tailward.
  - The PSBL is thought to be on “closed” magnetic field lines.
- The central plasma sheet (CPS) consists of hot (kilovolt) particles.
  - The CPS is usually on “closed” field lines.

# Magnetotail Strucrture – the Low Latitude Boundary Layer

- The low latitude boundary layer (LLBL) contains a mix of magnetosheath and magnetospheric plasma.
  – Plasma flows can be found in almost any direction but are generally intermediate between the magnetosheath flow and magnetospheric flows.
  – The LLBL extends from the dayside just within the magnetopause along the flanks of the magnetosphere forming a boundary between the plasma sheet and the magnetosheath.



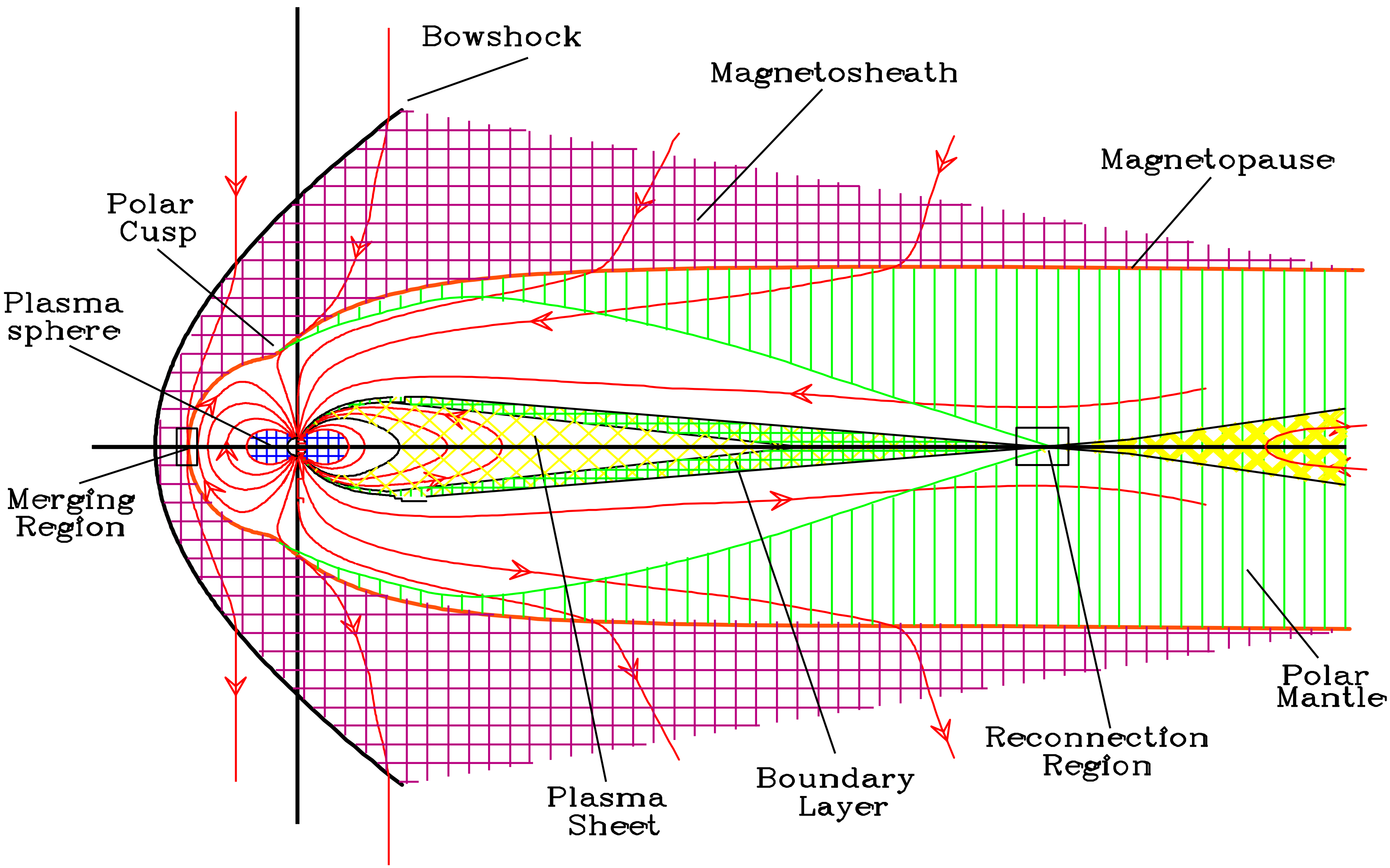
# Typical Magnetotail Plasma and Field Parameters

| | Magneto-sheath | Tail Lobe | Plasma-Sheet Boundary Layer | Central Plasma Sheet |
|---|---|---|---|---|
| n ($cm^{-3}$) | 8 | 0.01 | 0.1 | 0.3 |
| $T_i$ (eV) | 150 | 300 | 1000 | 4200 |
| $T_e$(eV) | 25 | 50 | 150 | 600 |
| B (nT) | 15 | 20 | 20 | 10 |
| $\beta$ | 2.5 | $3x10^{-3}$ | $10^{-1}$ | 6 |

• Beta is the ratio of the plasma thermal pressure to the magnetic pressure

$$\beta = \frac{nkT}{B^2/8\pi}$$

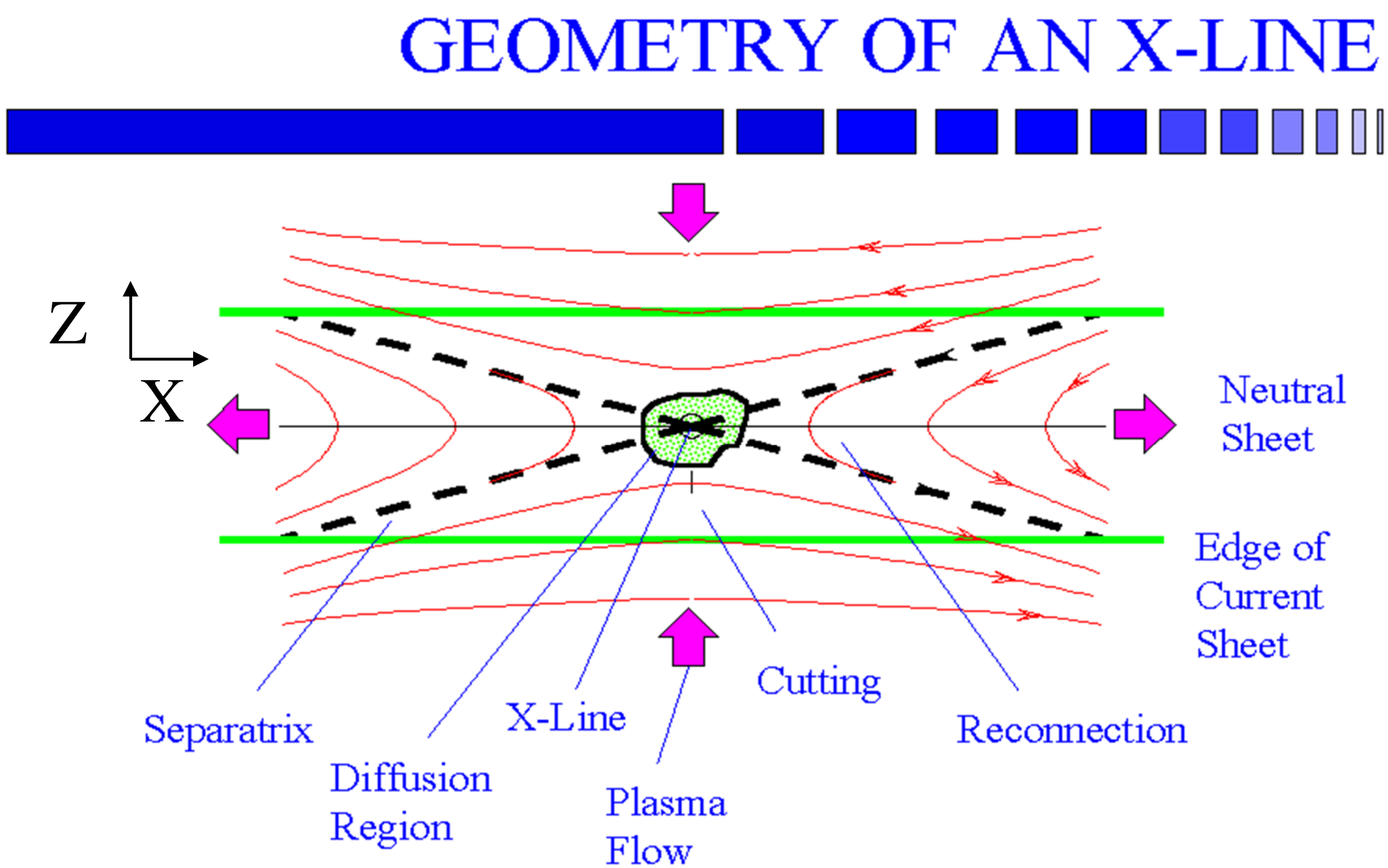
# The Magnetotail - Noon Midnight View



# Magnetic Reconnection

• The magnetotail is formed by the process of reconnection

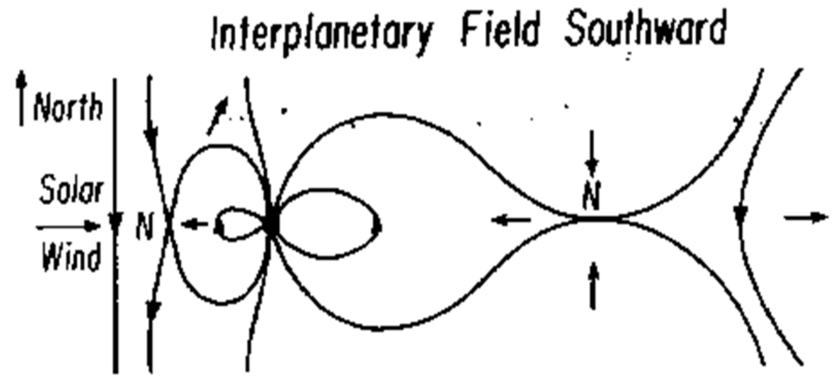
• Reconnection is thought to drive magnetospheric dynamics and the dynamics of the solar corona.

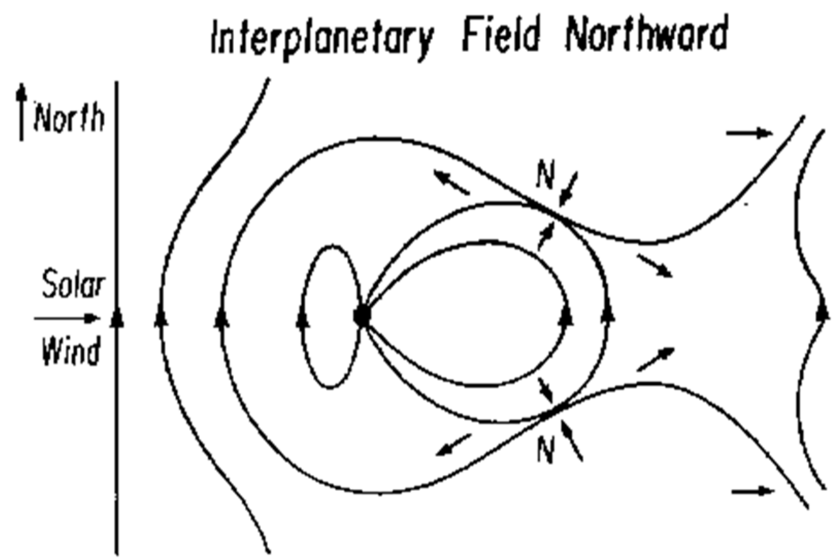


# Reconnection Driven Convection

- By the 1950's it was realized that plasma flows observed in the polar and auroral ionospheres must be driven by magnetospheric flows.
  - Flow in the polar regions was from noon toward midnight.
  - Return flow toward the Sun was at somewhat lower latitudes.
  - This flow pattern is called magnetospheric convection.
- Dungey in 1961 showed that if magnetic field lines reconnected in front of the magnetosphere the required pattern would result.
- This allows solar wind energy to be directly coupled into the magnetosphere.

The reconnection processes critically depend on the orientation of the solar wind magnetic field, "**Bz component**"



# Interaction between the IMF and magnetosphere.

The IMF is a vector quantity with three directional components, two of which ( $B_x$ and $B_y$ ) are oriented parallel to the ecliptic. The third component, $B_z$ , is perpendicular to the ecliptic and is created by waves and other disturbances in the solar wind.

When the IMF and geomagnetic field lines are oriented opposite or "antiparallel" to each other, they can "merge" or "reconnect," resulting in the transfer of energy, mass, and momentum from the solar wind flow to magnetosphere.

**The strongest coupling –with the most dramatic magnetospheric effects– occurs when the $B_z$ component is oriented southward.**

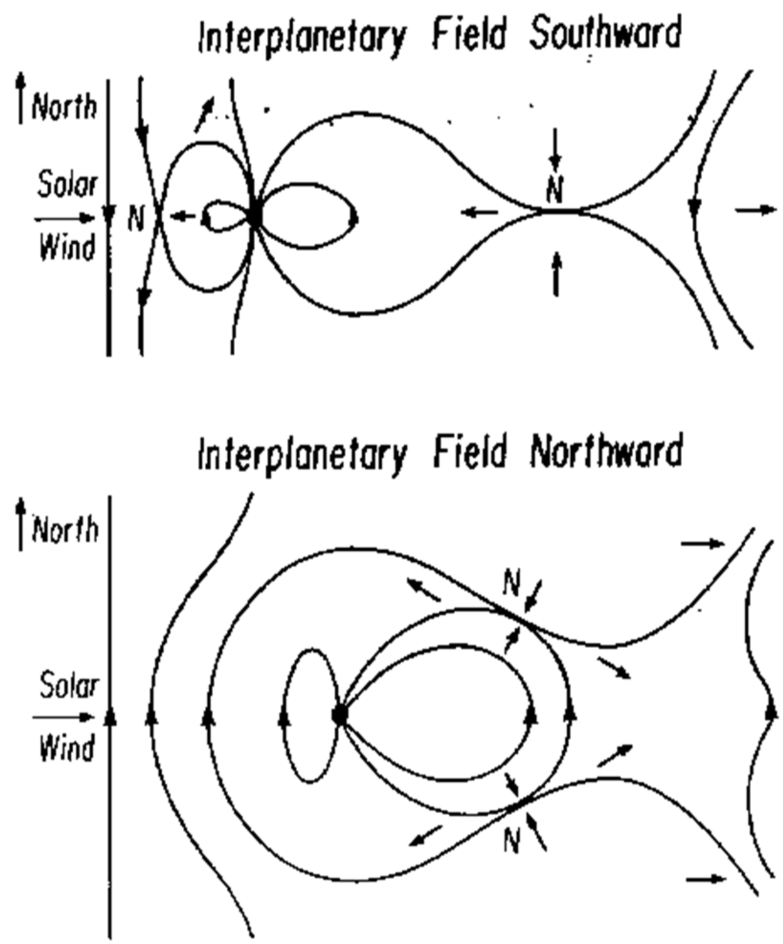


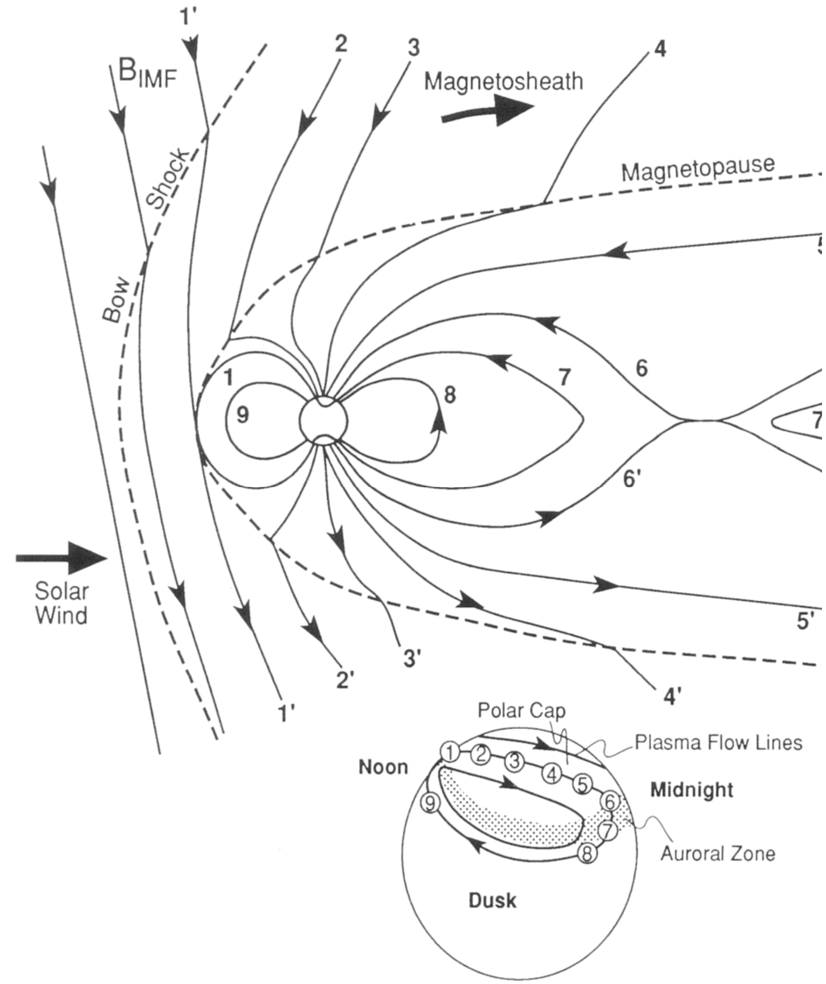

Figure 2

# The Formation of the Magnetotail and Flows in the Magnetosphere

- When IMF driven by the solar -wind has a southward $B_Z$ reconnection occurs between field lines 1 (closed with both ends at the Earth) and the IMF field line 1'
  - This forms two new field lines with one end at the Earth and one end in the solar wind (called open).
  - The solar wind will pull its end tailward

$$\vec{V}_{SW} = \frac{\vec{E}_{sw} \times \vec{B}_{sw}}{\left|\vec{B}\right|^2}$$

- The lower panel shows the motion of the flux tubes in the ionosphere.
- In the ionosphere tailward flow in the solar wind will drive flow tailward as well.

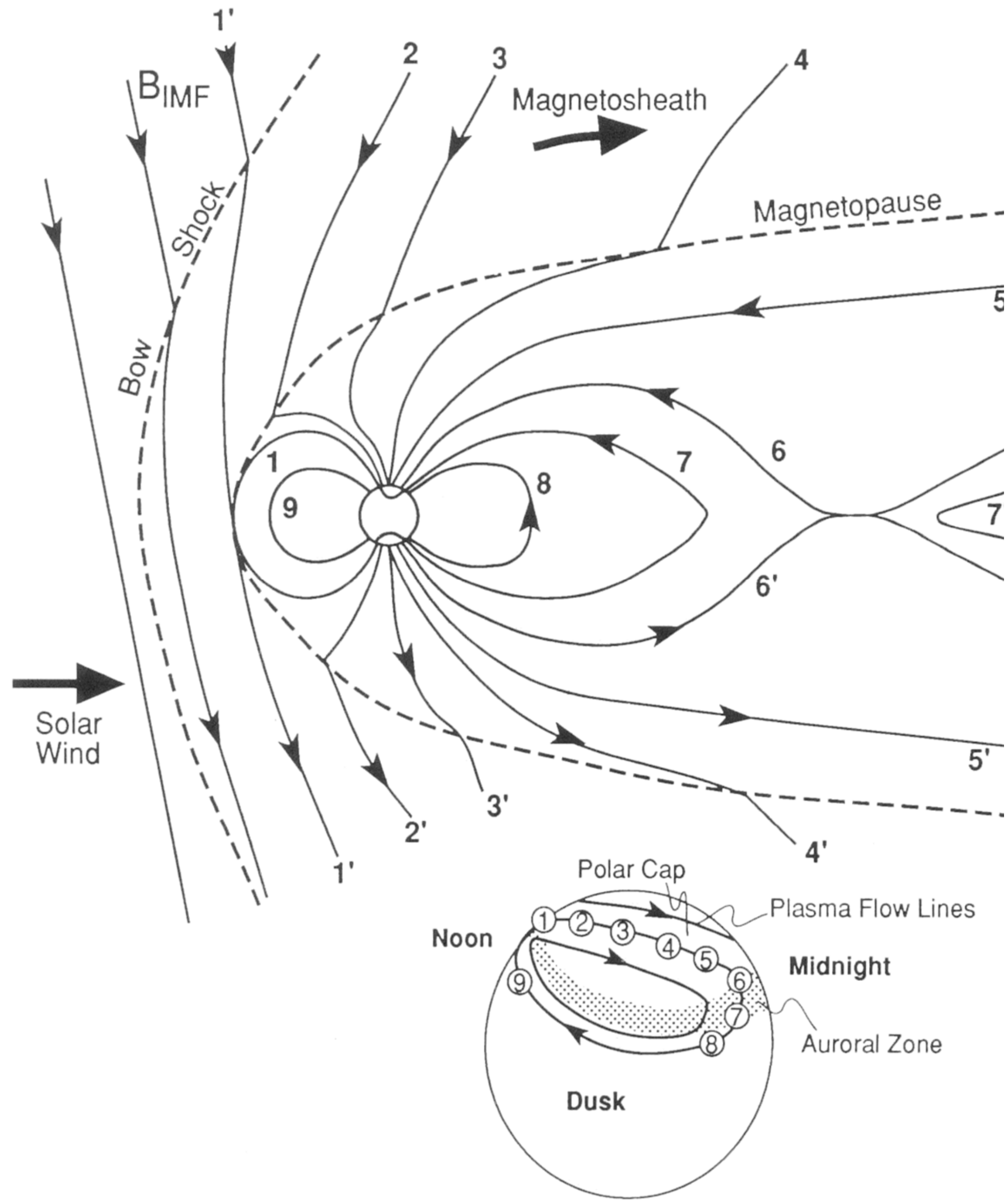


# Magnetospheric Convection – Steps 2, 3,4 and 5

• The newly reconnected flux tube will move be dragged tailward by the solar wind (steps 2, 3, 4 and 5).

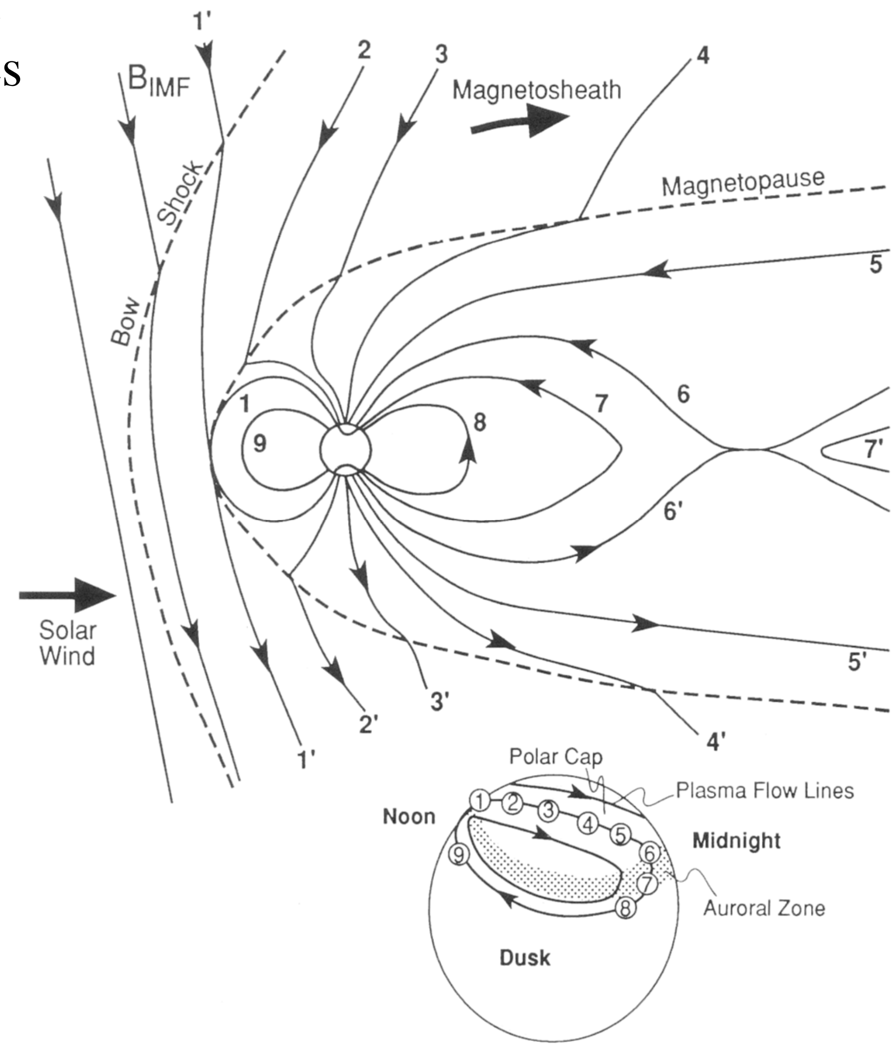
• The part of the flux tube above the ionosphere but inside the magnetopause forms the tail lobes.

• If the process of removing flux from the dayside continued indefinitely without returning some flux the Earth’s field would be lost.



# Returning Flux to the Dayside – Steps 6, 7, 8 and 9

- At a tail reconnection site (called an x-line) the lobe field lines (5 and 5’) reconnect at position (66’) to form new closed field lines 7 and new IMF field lines (7’).
- The new IMF field line 7’ is distorted and stressed and moves tailward.
- The new closed field line 7 is stressed and moves earthward.
- The flow circuit is finally closed when the newly closed field lines flow around either the dawn or dusk flanks of the magnetosphere to the dayside (8 and 9)
- The insert shows the flow pattern in the ionosphere that results. The return flow in the ionosphere is a lower latitudes than the tailward flow.



# The Electric Field Across the Magnetosphere

- The process of reconnection causes plasma to flow in the magnetosphere and therefore creates an electric field

$$\vec{E} = -\vec{v} \times \vec{B} / c$$

$$E = -\nabla \phi = \frac{\Delta \phi}{2R_{PC}} = v_{PC} B_{PC} / c$$

where $R_{PC}$ is the radius of the polar cap, $v_{PC}$ is the plasma flow speed and $B_{PC}$ is magnetic field strength in the polar cap. For typical ionospheric parameters

$$\Delta \phi \approx 53kV$$

and the electric field is directed from dawn to dusk.

- The solar wind electric field across a distance equal to one diameter of the tail ($50R_E$) is about 640 kV. Thus about 10% of the flux that impacts the magnetosphere interacts with it. The rest goes around the sides of the magnetosphere.

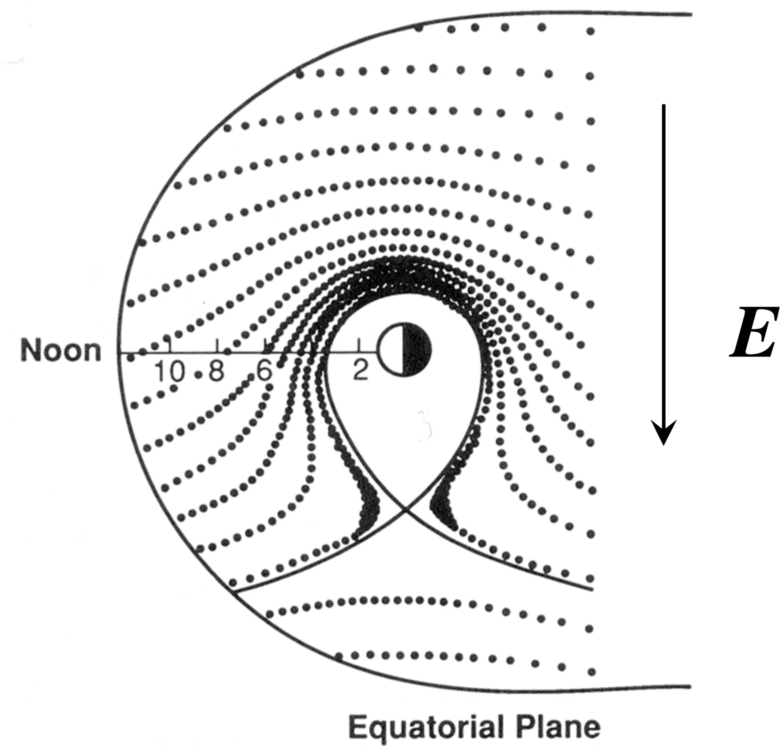
# The Convection in the Inner Magnetosphere

- The cross magnetosphere electric field drives flows toward the Sun in the equator. There is another electric field. It causes plasma close to the Earth to go around the planet once every 24 hours – corotation.
- When we include corotation the electric potential becomes

$$\phi = -E_0 r \sin\varphi - \frac{\omega_E B_0 R_E^3}{cr}$$

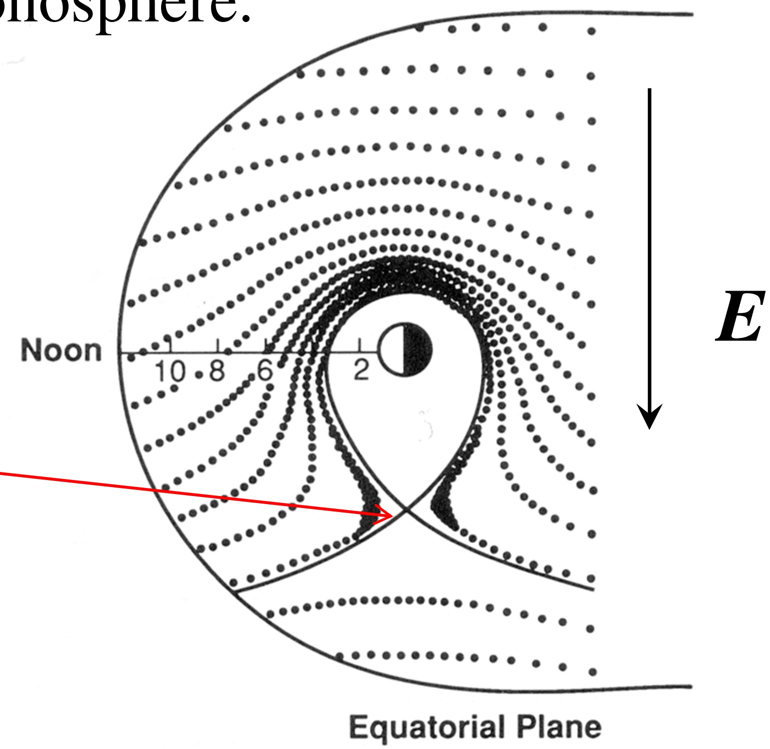
where $E_0$ is the cross tail electric field, $\phi$ is the azimuthal angle, r is the radial distance, $\omega_E$ is the angular frequency of the Earth, and $B_0$ is the magnetic field magnitude at the equator at $1R_E$.

•Contours of constant potential give the motion of the flux tube.

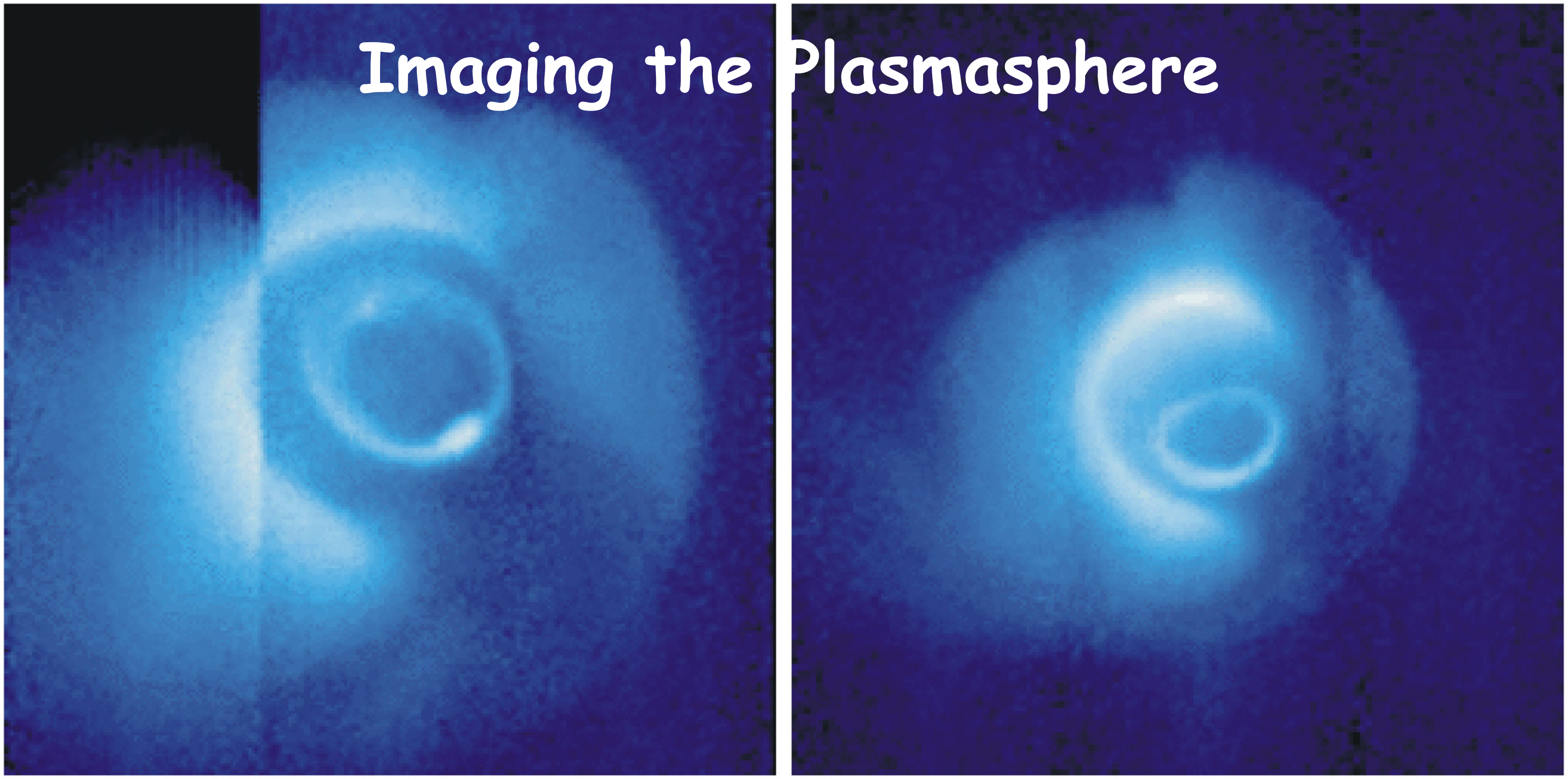


# The Plasmasphere

- Near the Earth the corotation term dominates the effective potential while far out in the tail the convection potential dominates.
- On the dusk side the two terms fight each other  and at one point the velocity is zero.
- The solid line shows a separatrix inside of which plasma from the tail can't enter.
- Cold particles that lie inside the separatrix go continuously around the Earth. They form the **plasmasphere**. It is filled with dense cold plasma from the ionosphere.



# Imaging the Plasmasphere



• Images in the EUV from the IMAGE spacecraft on May 24, 2000.

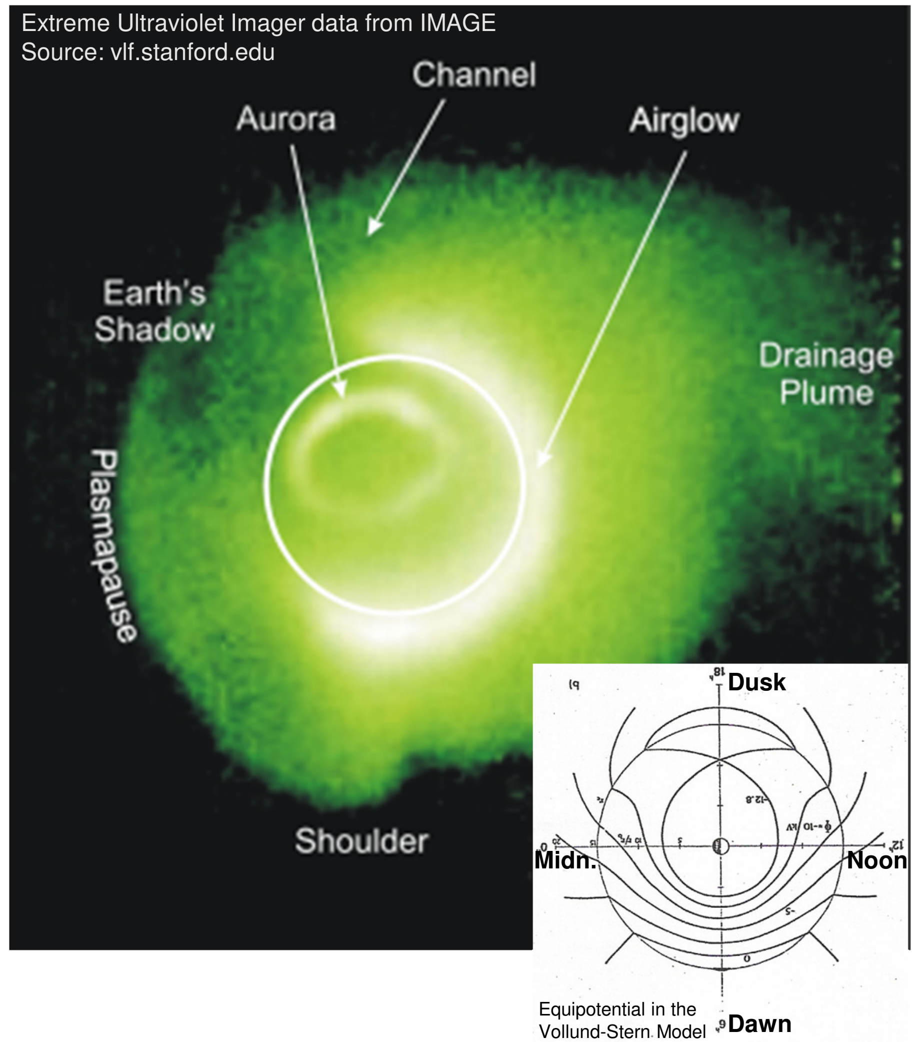
• The 30.4nm emission from helium ions appears as a pale blue cloud.

• The “bite out” in the lower right is caused by the Earth’s shadow. The helium is excited by sunlight.

• The emission at high latitudes is from aurora and is thought to be caused by 53.9nm emission from atomic oxygen.

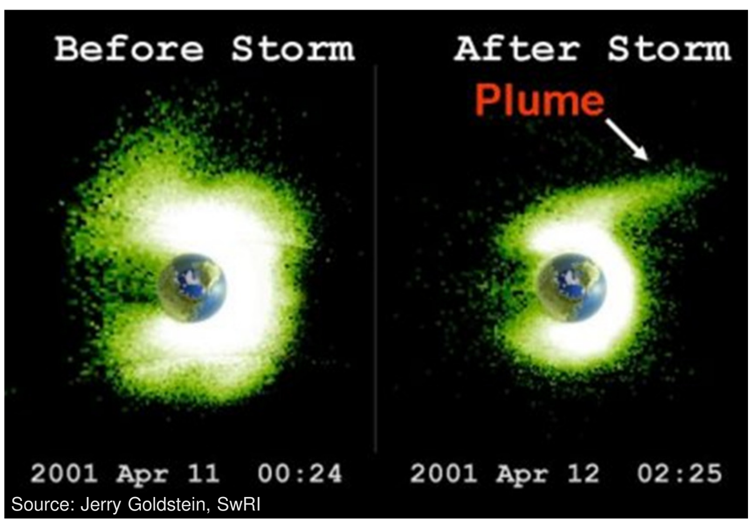
# The Plasmasphere

- Region of cold (~1-2 eV), dense (~100-1000 cm$^{-3}$) plasma, ions and electrons of ionospheric origin, in the inner magnetosphere
- Plasma co-rotates with Earth; plasmapause varies with changes in the convection electric field, and system has a "memory" of sorts…
- Variability and storm-time dynamics
- Difficult to observe in situ due to s/c potential, but plays an important role for waves affecting the ring current and radiation belts
- Some good references:
  - *Lemaire and Gringauz [Cambridge Univ. Press, 1998]*
  - *Kotova [Geomag. Aero., 2007]*
  - *Darouzet et al. [SSR, 2009]*



Extreme Ultraviolet Imager data from IMAGE
Source: vlf.stanford.edu

Equipotential in the Vollund-Stern Model



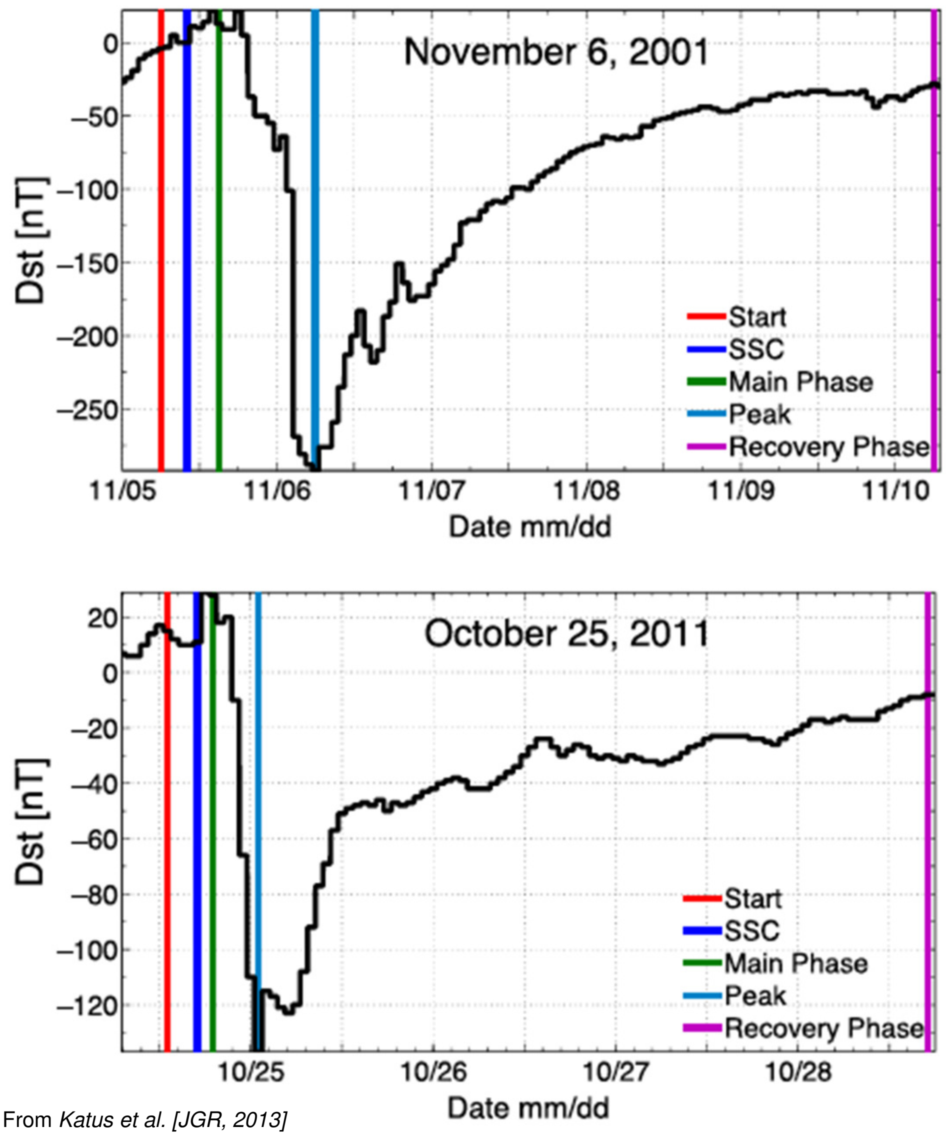
Source: Jerry Goldstein, SwRI

# Magnetic Storms Versus Substorms

- An isolated substorm is caused by a brief (30-60 min) pulse of southward IMF.
- Magnetospheric storms are large, prolonged disturbances of the magnetosphere caused by variations in the solar wind.
  - Many storms follow coronal mass ejections.
  - Storms also can be caused by high speed streams (interplanetary shocks).
- Storms are global disturbances of the magnetosphere while substorms tend to be localized in the magnetotail.
- During storms large amounts of energy are placed in the ring current – this does not happen in substorms.
- Substorms occur during storms but also at other times.

# Geomagnetic Storms

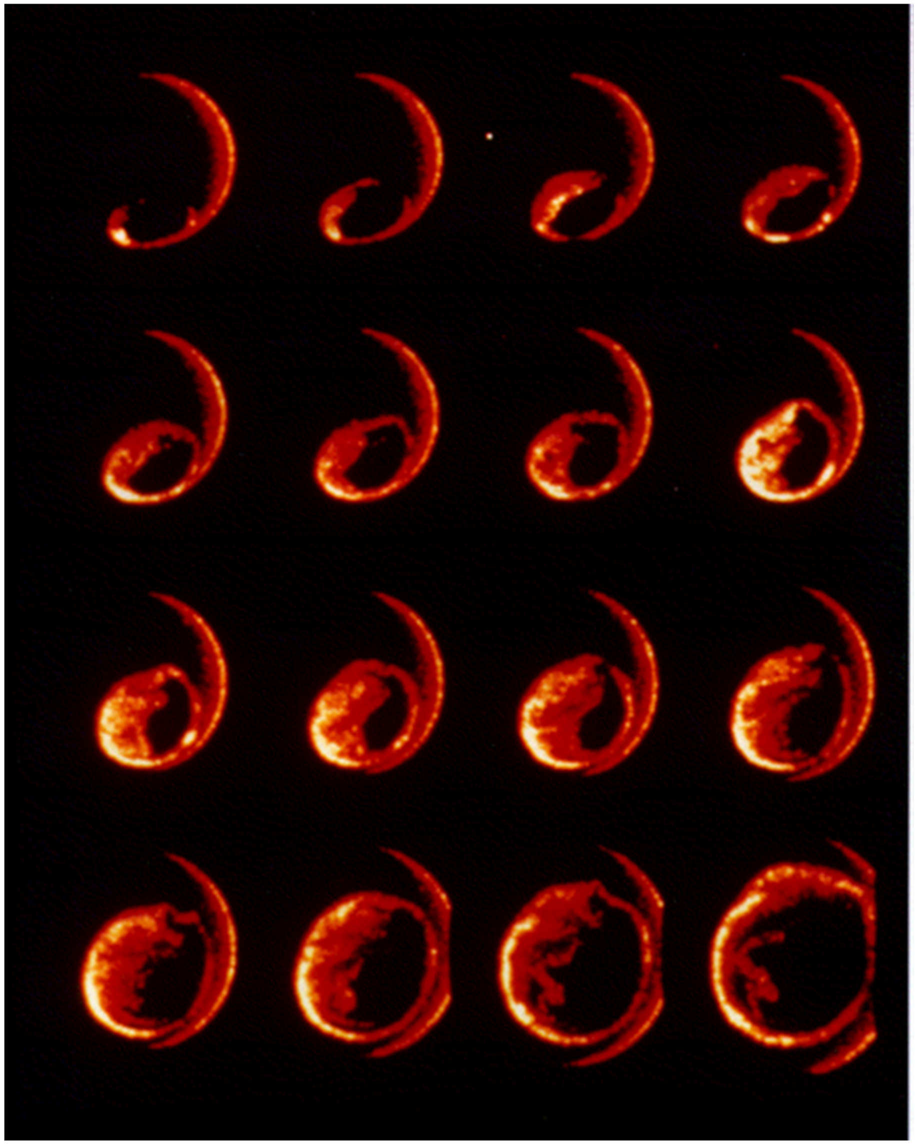
- Geomagnetic storms are periods of very strong activity in the inner magnetosphere***; storms affect all populations.***
- Storm intensity is characterized by the "Disturbance storm-time" (Dst) index, which is a measure of perturbations to the symmetric near-equatorial magnetic field that result from enhancements of the ring current
- Different drivers: CME shocks, sheaths, and magnetic clouds, SIs/CIRs, HSSs; prolonged periods of Bz south accompanied by high Vsw
- Slow decay during recovery: Charge exchange with exospheric neutrals *[Keika et al., JGR, 2006]*
- Rapid decay: ??? …unanswered question
- Some good references:
  - *Tsurutani et al., [Geo. Mono., 1997]*
  - *Katus et al. [JGR, 2013]*




From *Katus et al. [JGR, 2013]*

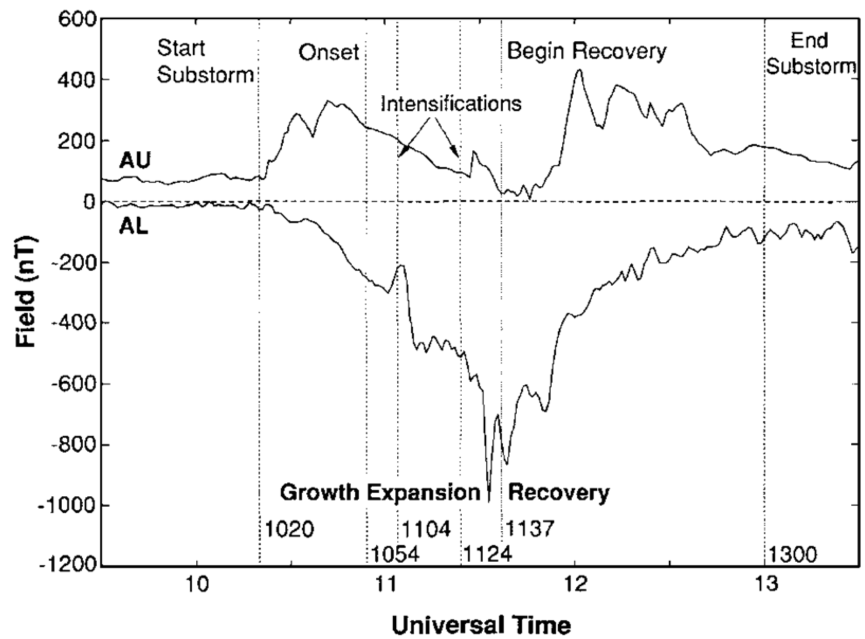
# Time Series of Images of the Auroral Substorm

- This set of images in the ultra-violet from the Polar satellite shows changes that occur during an auroral substorm.
- In aurora substorms go through a series of stages.
- They start with a brightening of an auroral arc nearest the equator.
- Moments later the aurora brightens more, and expands poleward and to the west.



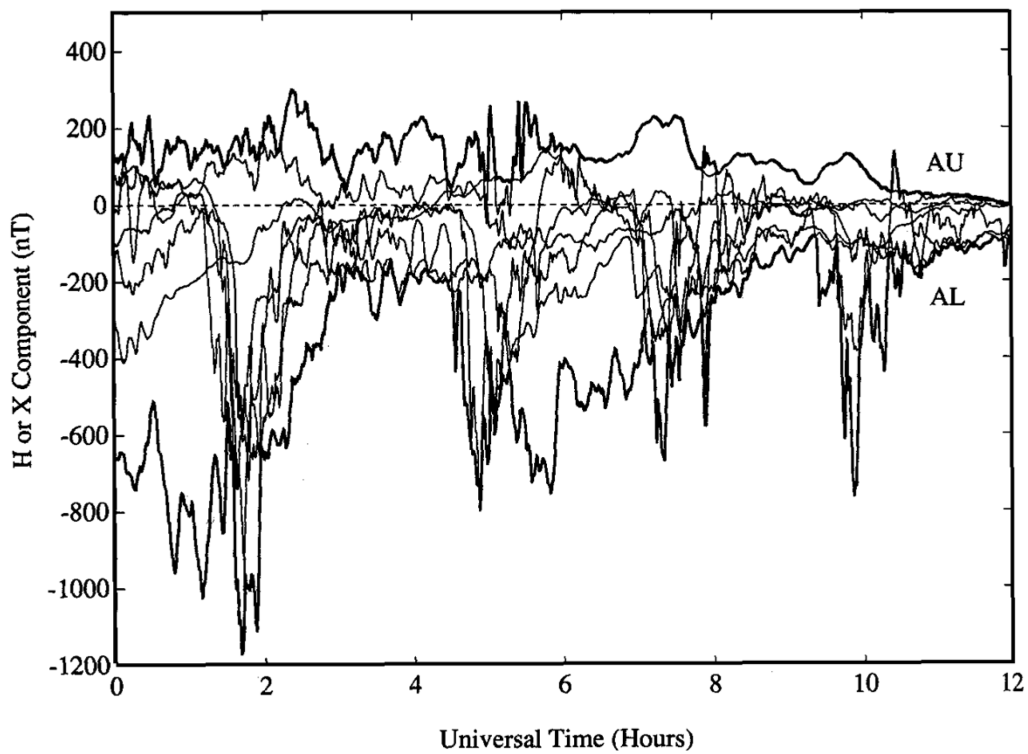
# Magnetospheric Substorms

- The phenomena associated with substorms in the magnetosphere start before the auroral signatures.
- McPherron interpreted these phenomena as the ***growth phase*** of the substorm.
  - Energy extracted from the solar wind is stored in the magnetosphere.
  - The initial interval of slowly growing AU and AL.
  - The growth phase usually lasts 30 minutes to one hour.
  - The magnetic perturbations during the growth phase results from increased ionospheric currents.
- The ***expansion phase*** corresponds to the release and unloading of the stored energy.
- The ***recovery phase*** is the return of the system to its ground state.



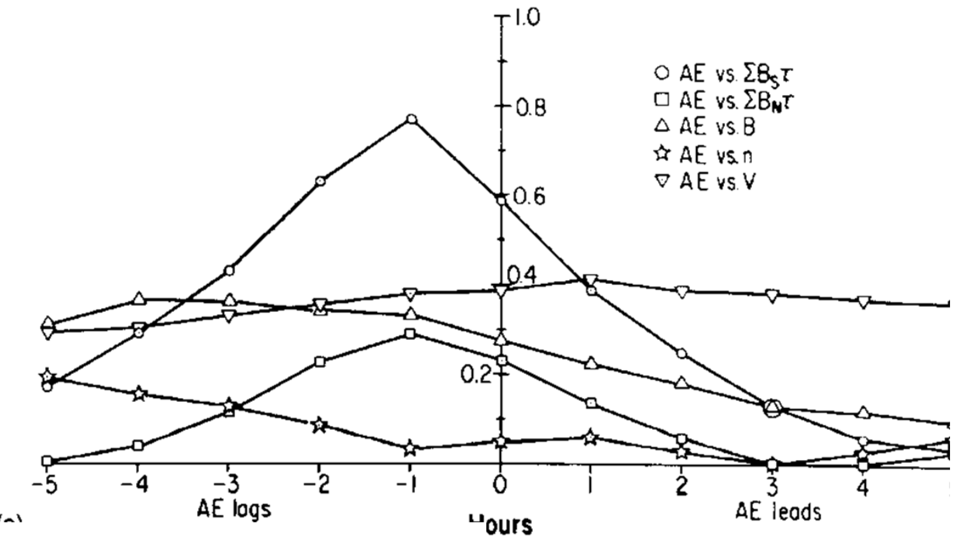
# Auroral Electrojet Indices

- Positive perturbations are produced by a concentrated current (called an auroral elecrojet) flowing eastward. They are observed by stations in the afternoon or evening.
- Negative perturbations are produced by a westward electrojet. They are observed near and past midnight.
- These currents flow at ~120km altitude and are carried by auroral particles.
- The positive and negative envelopes give the AU and AL indices.

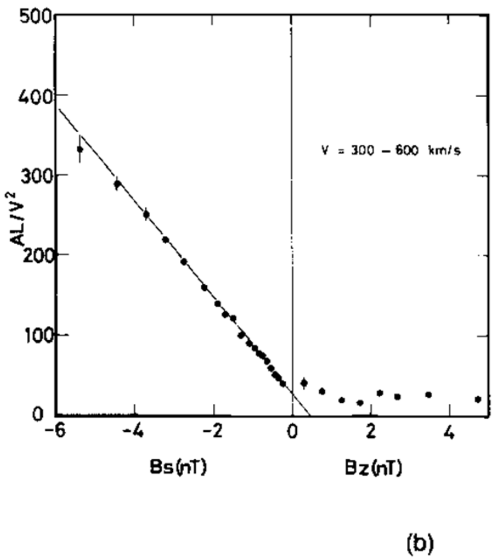


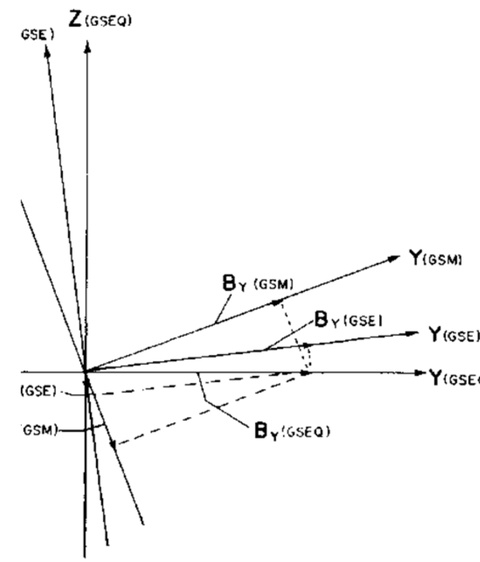
# Substorms Occur when the Interplanetary Magnetic is Southward

- Correlation analysis between the auroral-electrojet index AE (difference between the envelope of positive -AU- and negative -AL- magnetic perturbations at auroral latitudes) and five solar wind parameters (u, n, B, $B_n$, $B_s$)
  - $B_n$ is hourly average of the $B_{zGSM}$ magnetic field when $B_{zGSM}>0$.
  - $B_s$ is hourly average of the $B_{zGSM}$ magnetic field when $B_{zGSM}<0$.




- Activity peaks in $B_s$ for the hour prior to the hour when the activity was measured.




- $AL/v^2$ as a function of $B_s$ ($B_z<0$) and $B_n$ ($B_z>0$). No dependence on $B_n$ but strong dependence on $B_s$

# Magnetospheric Substorms

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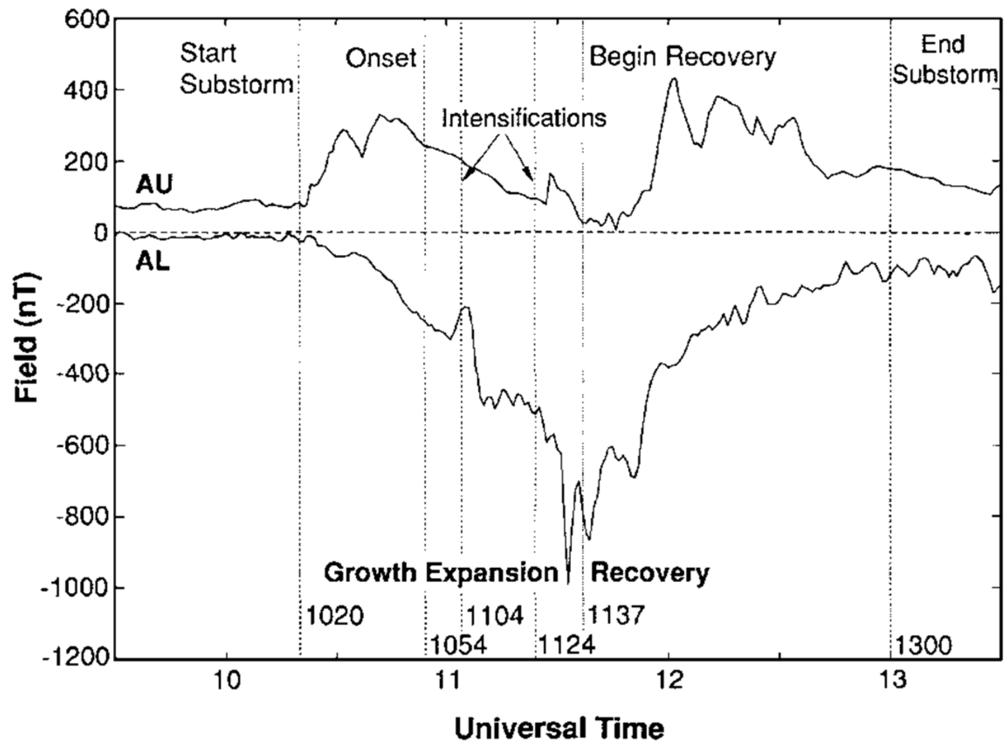
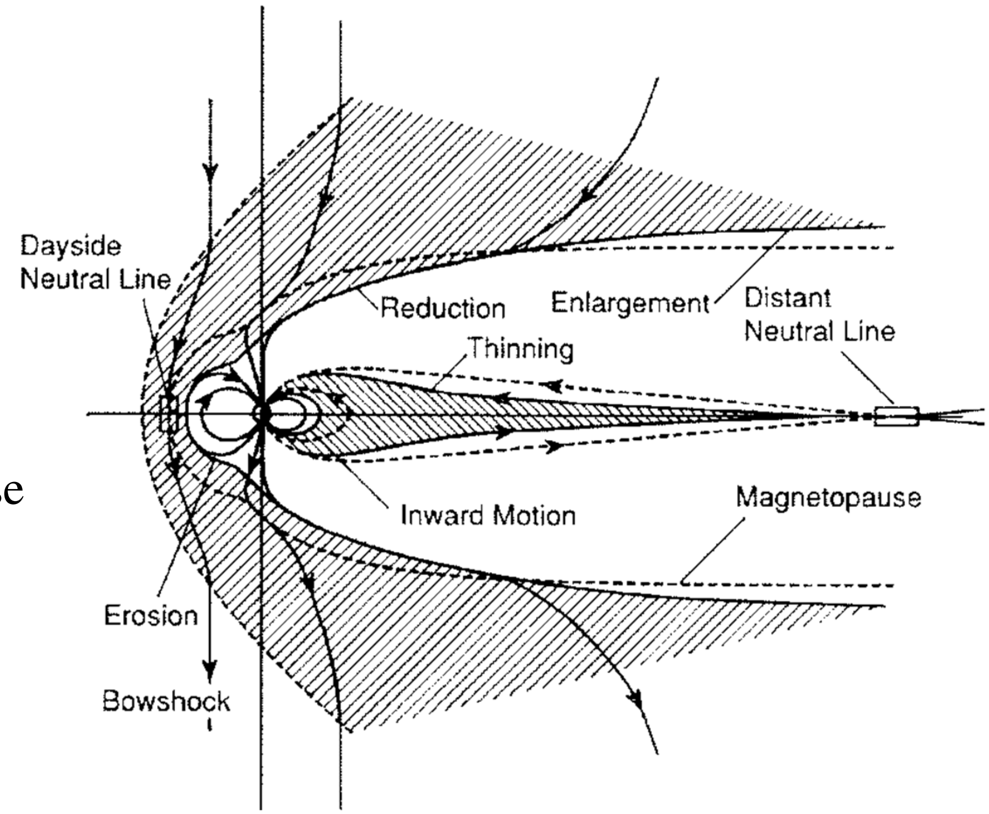


# The Events in the Magnetosphere During a Substorm – Growth Phase

- A southward turning of the IMF initiates or increases dayside reconnection.
  - Magnetic flux from the Earth connects to the IMF and is transported over the polar caps into the lobes.
  - The return flow in the magnetosphere is unable to return flux to the dayside as fast as it is removed. The dayside magnetopause is eroded.

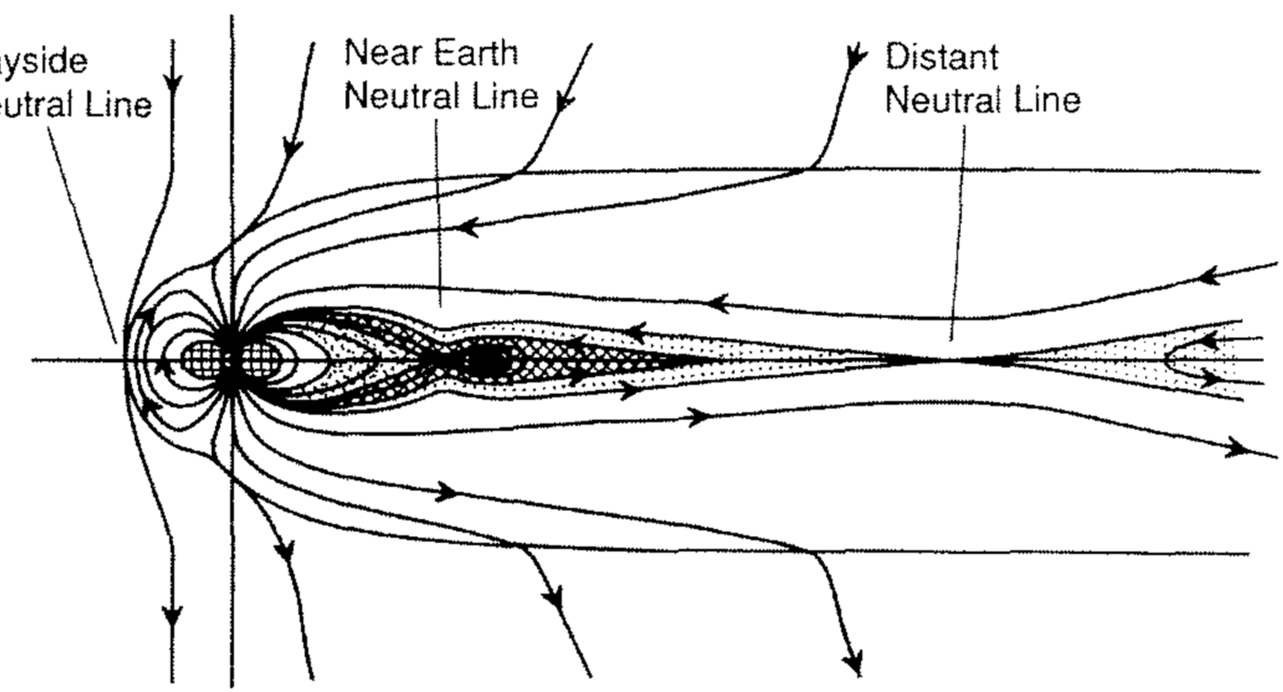



- The magnetic field in the tail lobes increases storing energy for later release.

- The plasma sheet thins.

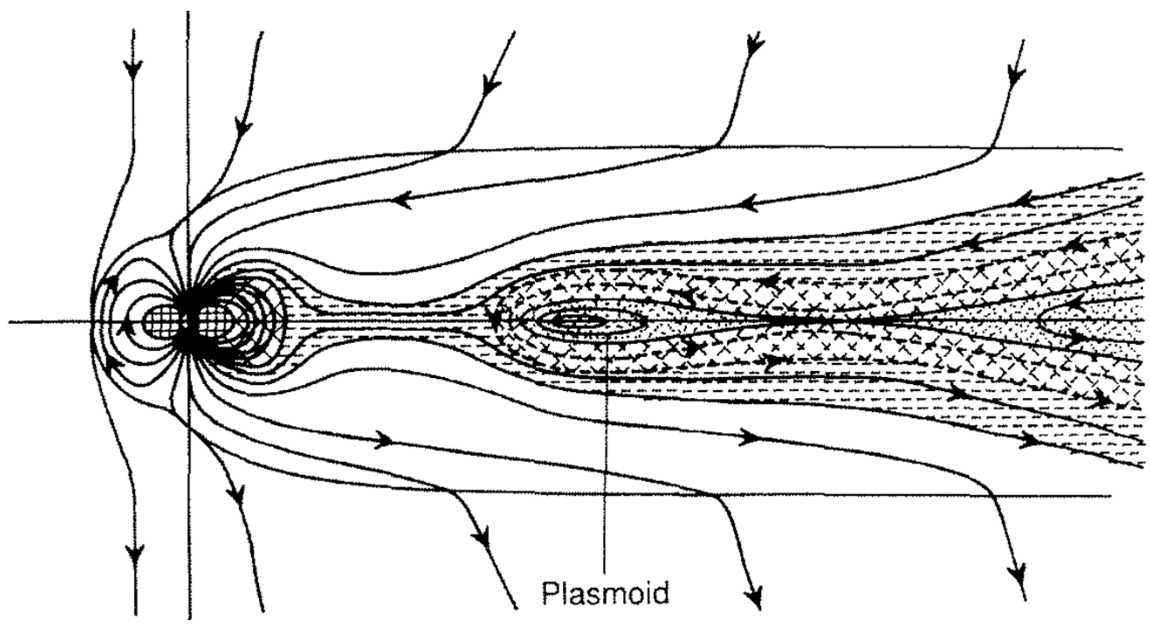
# Events in the Magnetosphere During a Substorm – The Late Growth Phase

- Some time during the late growth phase reconnection begins on closed field lines in the near-Earth plasma sheet.
  - The reconnection is slow at first.
  - As closed field lines are cut they reconnect to form a magnetic O region called a plasmoid (technically a magnetic flux rope).
  - This stage of the substorm continues until the last closed field line is severed by the reconnection process.
  - The reconnection rate increases during the late growth phase.



# Events in the Magnetosphere During Substorms – The Expansion Phase

- When the last closed field line is severed the reconnection rate becomes explosive. This is the onset of the expansion phase of the substorm.
  - The current “wedge” may occur at this time.
  - 20%-30% of the open magnetic flux stored in the tail lobes is rapidly reconnected.
  - This is the principal energy conversion process during substorms.
- The severed plasmoid leaves the magnetotail.
- If the reconnection fails to reach the lobe field lines the disturbance is quenched. This is called a pseudo-breakup.



# Magnetospheric Multiscale Mission

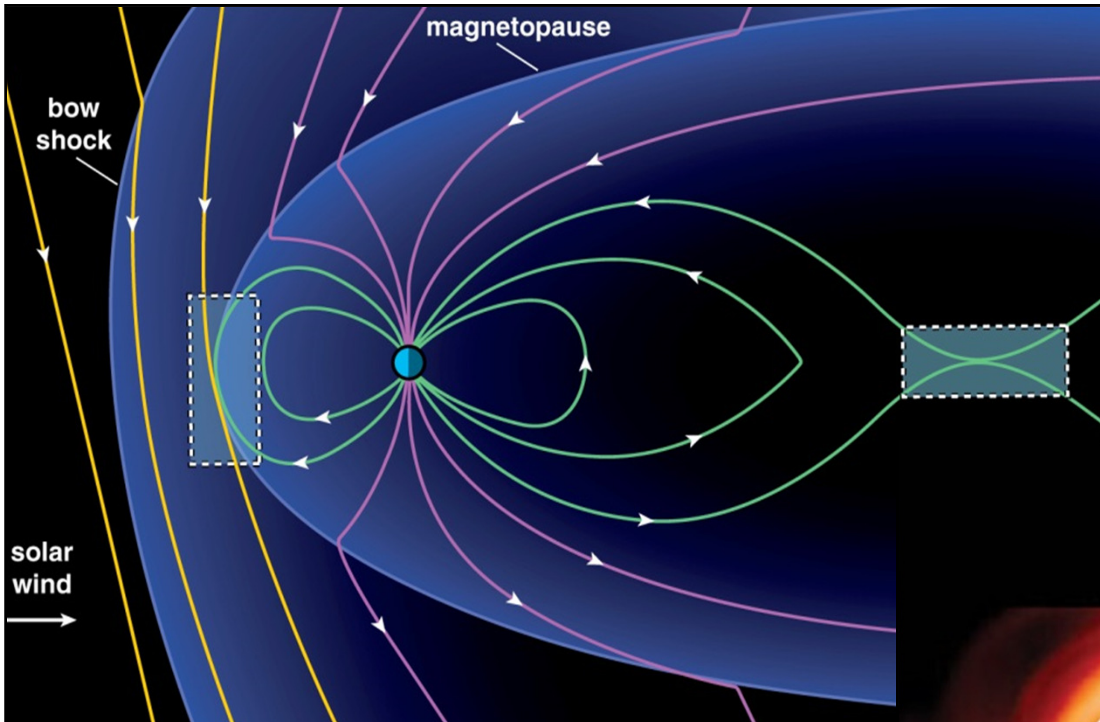
Understand the microphysics of magnetic reconnection by determining the kinetic processes occurring in the electron diffusion region that are responsible for collisionless magnetic reconnection, especially how reconnection is initiated.

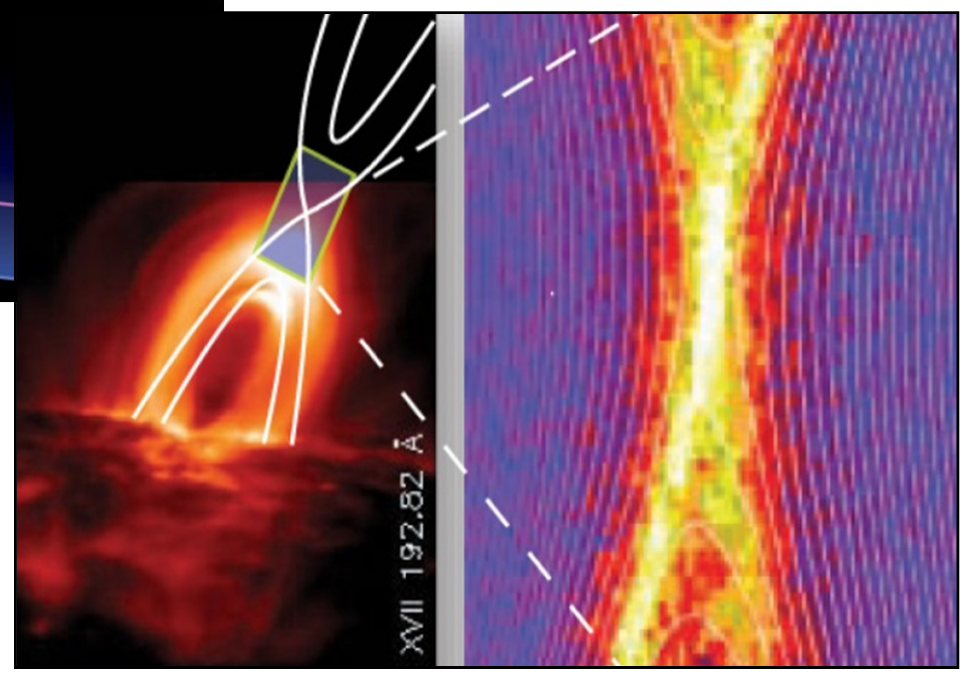
•Determine the role played by electron inertia and turbulence in regulating magnetic reconnection.

•Determine the rate of magnetic reconnection and the parameters that control it.

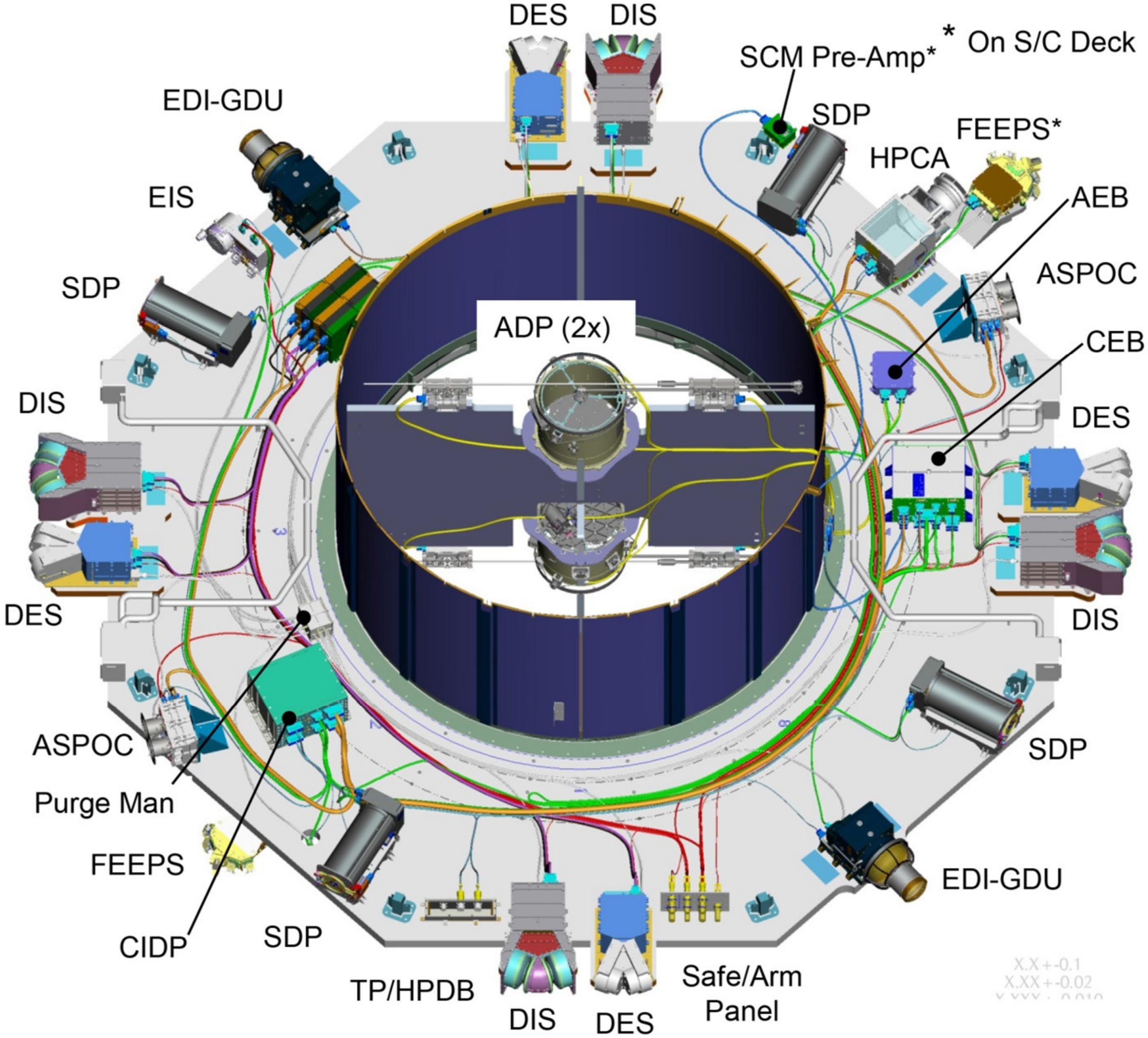
•Determine the role played by ion inertia and turbulence in magnetic reconnection.

# Magnetic Reconnection is a Fundamental Universal Process



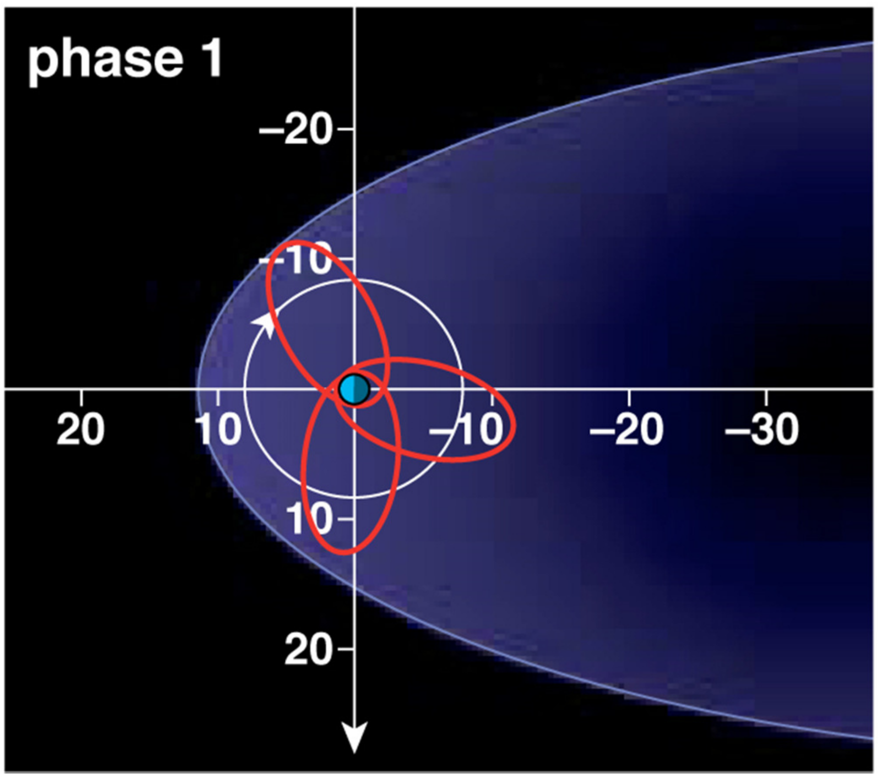
# MMS Instrument Suite

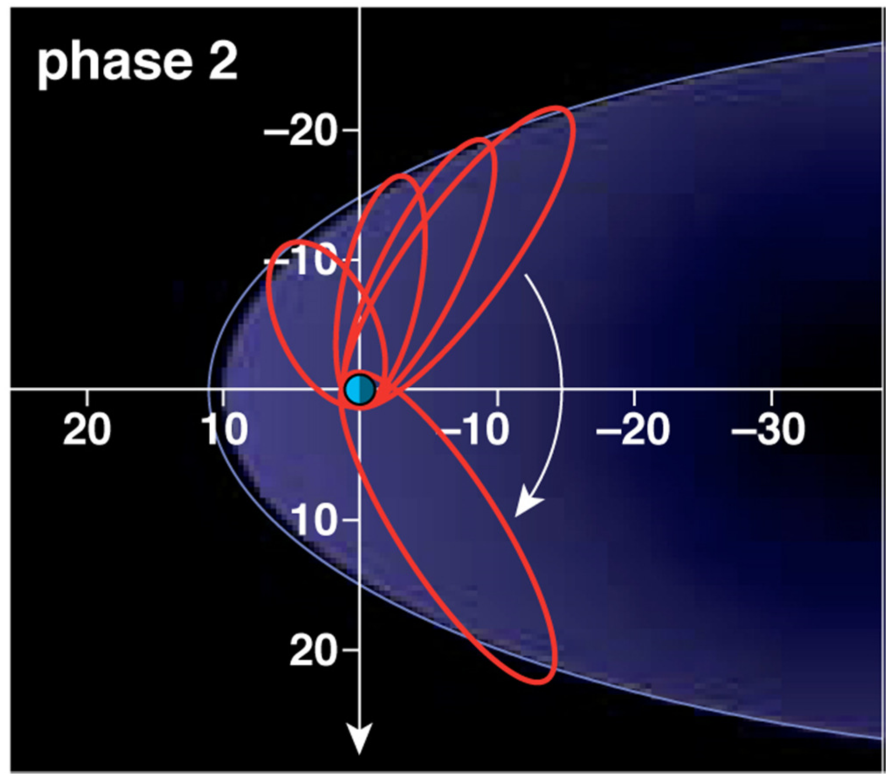



**ADP** - **Axial Double Probe**
**AFG** - **Analog Flux Gate Magnetometer (mounted on boom)**
**ASPOC** - **Active Spacecraft Potential Control**
**CEB** - **Central Electronics Box (Fields)**
**CIDP** - **Central Instrument Data Processor**
**DES** - **Dual Electron Spectrometer**
**DFG** - **Digital Flux Gate Magnetometer (mounted on boom)**
**DIS** - **Dual Ion Spectrometer**
**EDI/GDU** - **Electron Drift Instrument/ Gun Detector Unit**
**EIS** - **Energetic Ion Spectrometer**
**FEEPS** - **Fly's Eye Energetic Particle Sensors**
**HPCA** - **Hot Plasma Composition Analyzer**
**IDPU** - **Instrument Data Processing Unit (FPI)**
**SCM** - **Search-Coil Magnetometer (mounted on boom)**
**SDP** - **Spin-Plane Double Probe**
**TP/HPDB** – **Test Panel Heater Power Distribution Box**

# Orbital Phases

MMS employs two mission phases with inclination of 28 deg. to optimize encounters with both dayside and nightside reconnection regions.



# Animation of reconnection and MMS orbit