Solar Wind and Magnetosphere Interactions

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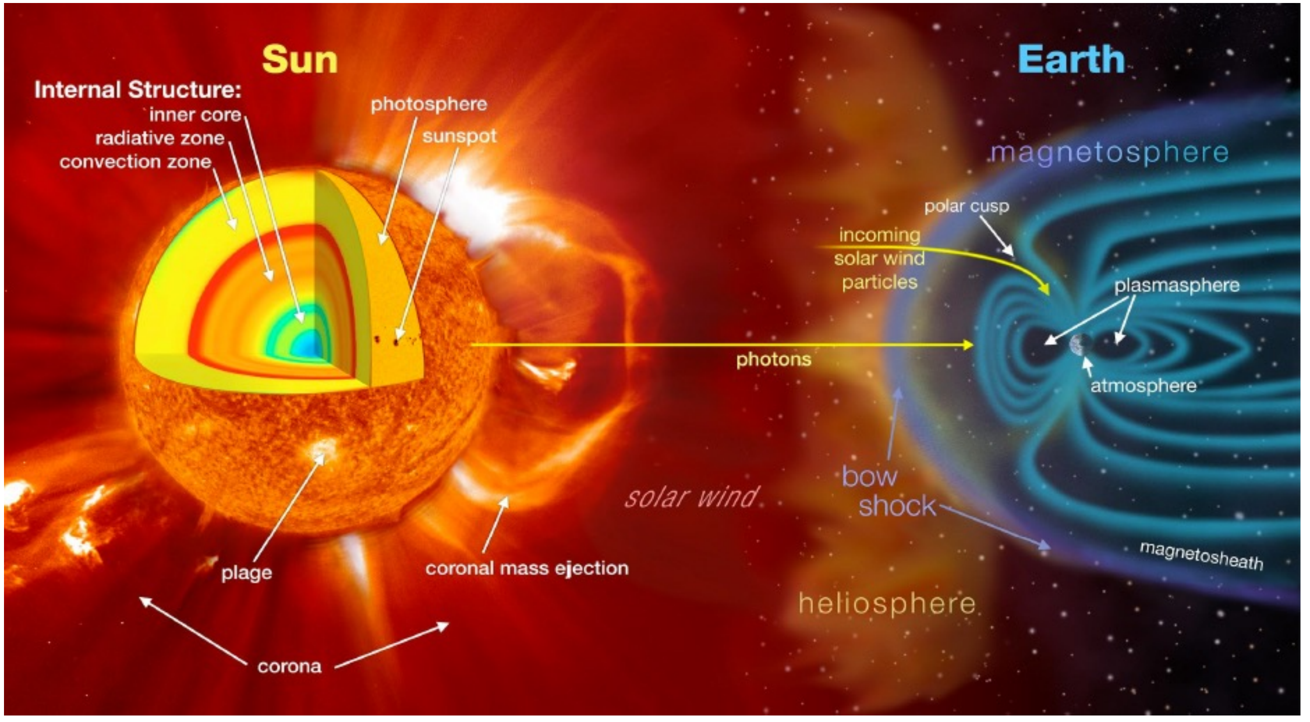
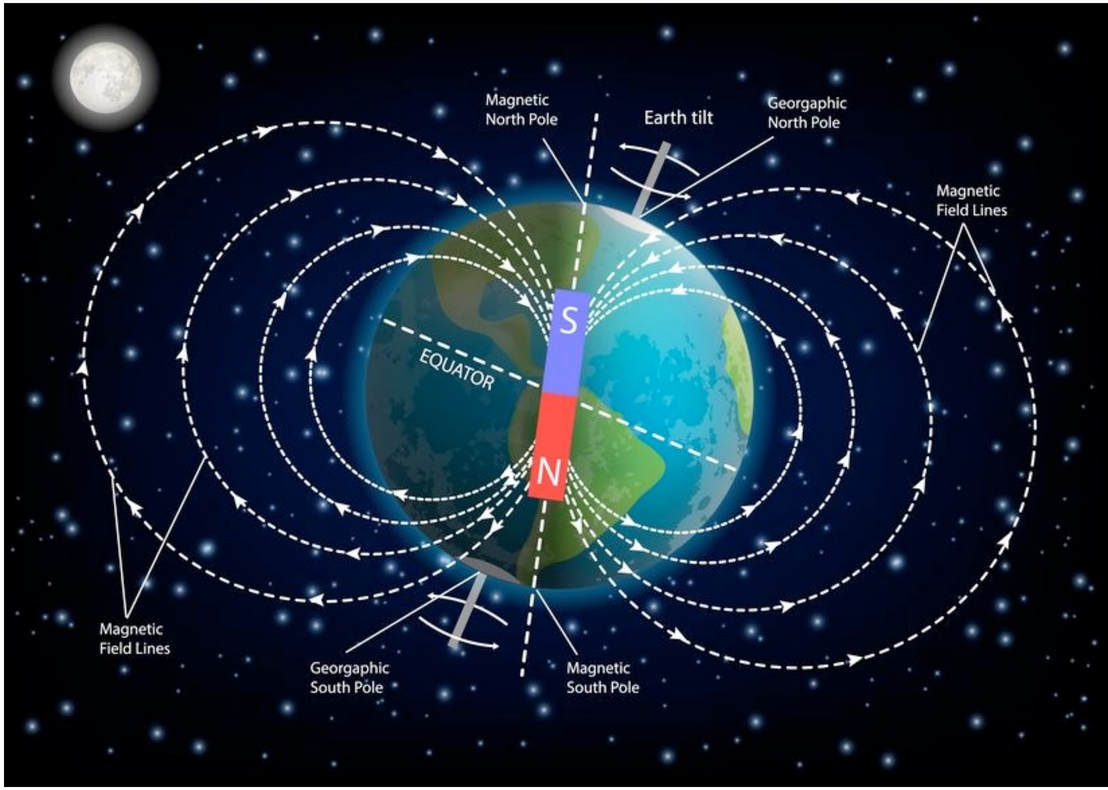
The Global Magnetosphere: Our Protective Magnetic Bubble



- Solar radiation and solar wind are the two ultimate energy sources provided by the Sun to the geospace system.
- The Earth's intrinsic magnetic field deflects much of the solar wind. The solar wind energy entering the magnetosphere drives the geospace dynamics.

The Earth is Approximately a Magnetic Dipole

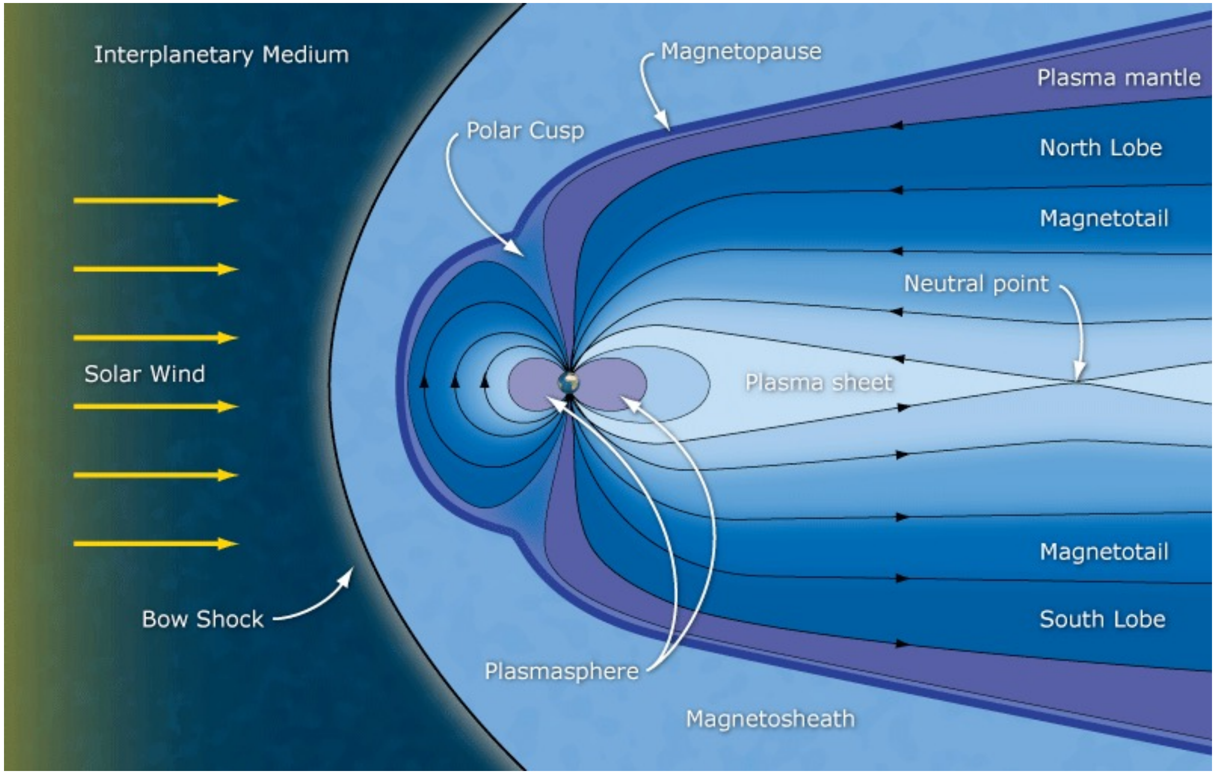
- Dipole tilted ~11^{o} from the rotational axis.
- Tilted dipole that has been displaced ~500 km from the center of the Earth toward the northern geographic pole (magnetic center of the Earth). So the southern hemisphere field strength is weaker.



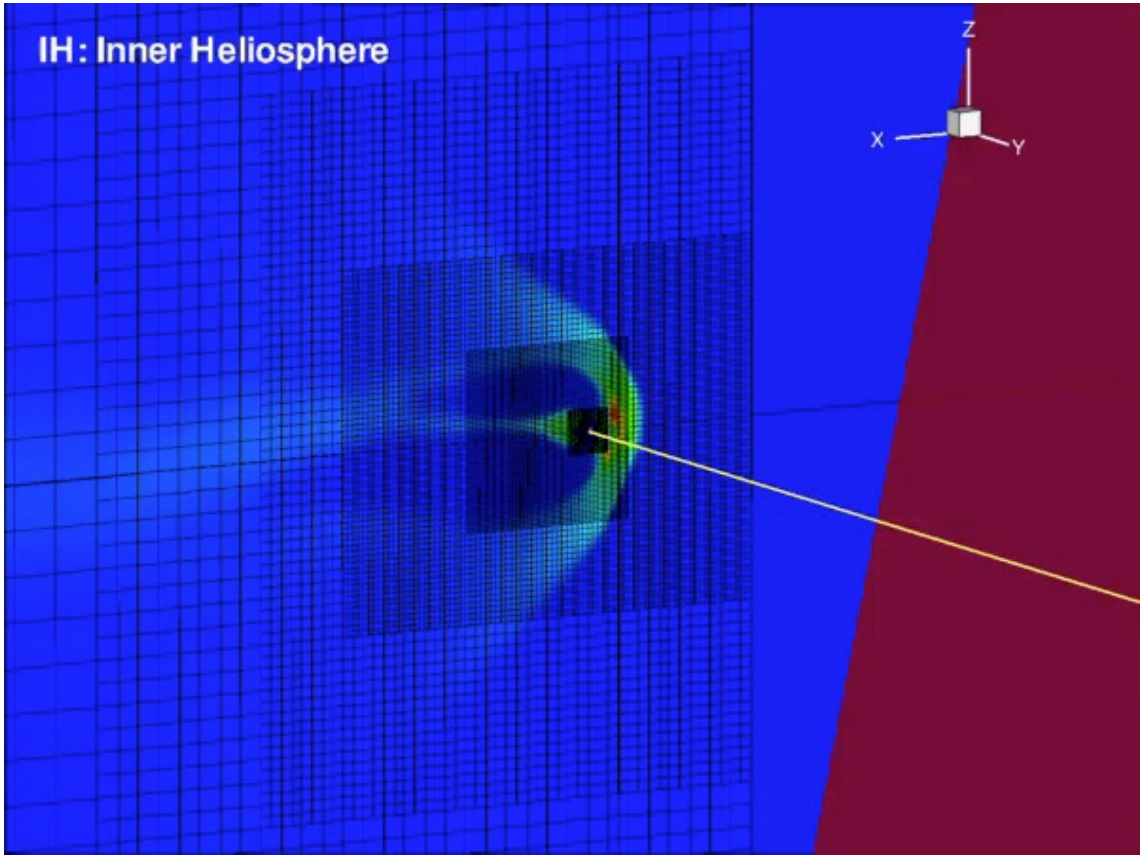
- The South Atlantic Anomaly (SAA) is the near-Earth region where the Earth's magnetic field is weakest relative to an idealized Earth-centered dipole field.

Geomagnetism and the Magnetosphere

- The Earth's magnetic field creates a magnetic bubble around Earth.
- The solar wind compresses the dayside and drags the nightside
- Basic shape: Bullet, with Earth close to the "front" end



Interaction between Solar Wind and the Earth

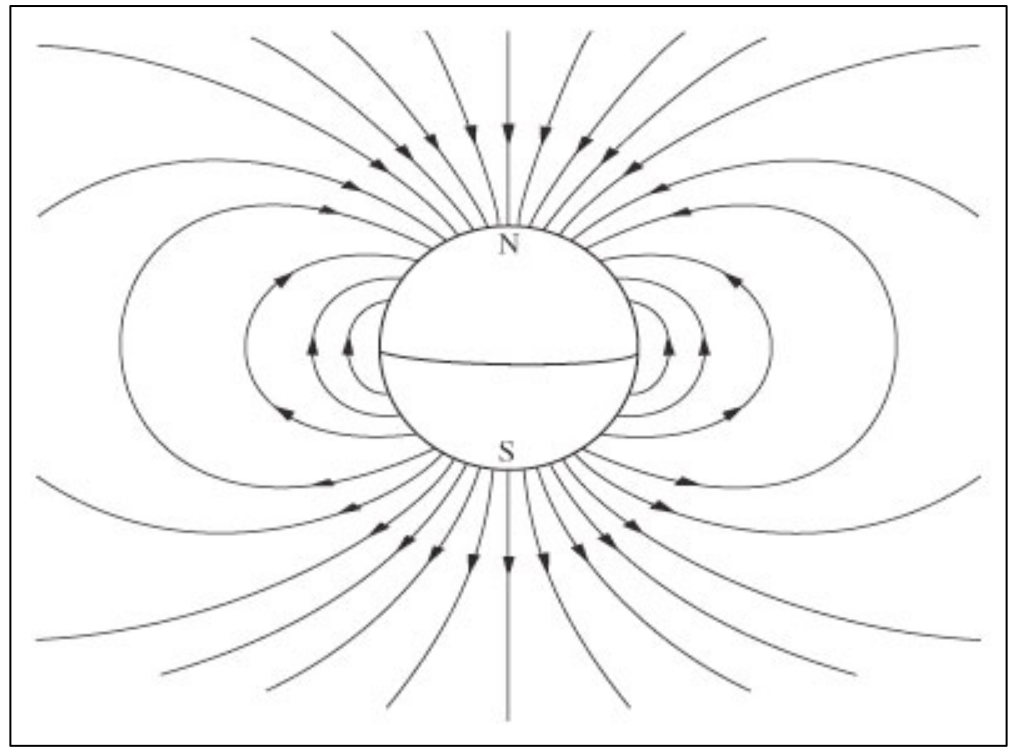


Plasma pressure and magnetic fields simulated using University of Michigan Space Weather Modeling Framework (SWMF)

- The geospace system dynamically respond to varying solar wind.

Simple Magnetosphere Shape

Chapman and Ferraro imaged the solar wind pushes the magnetopause as a superconducting plate approaching the Earth's dipole field.



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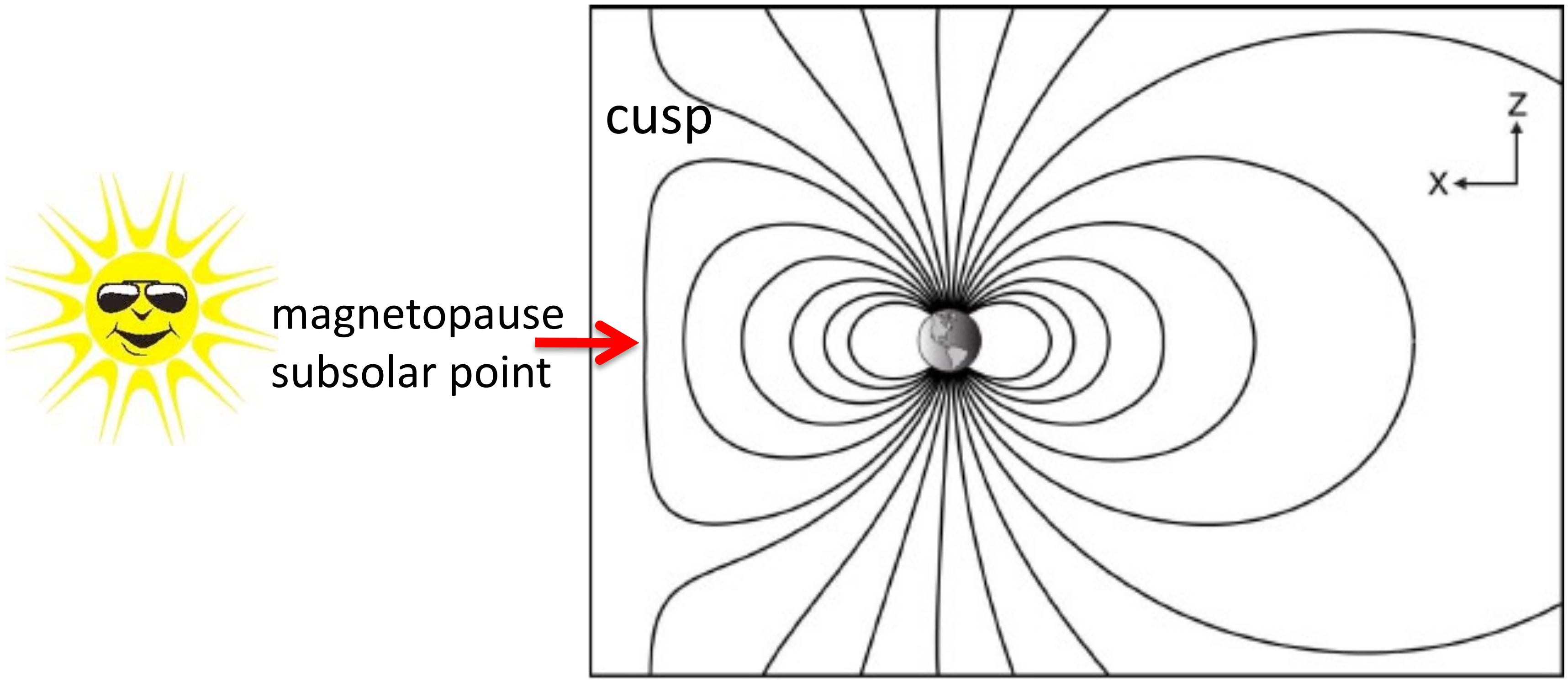
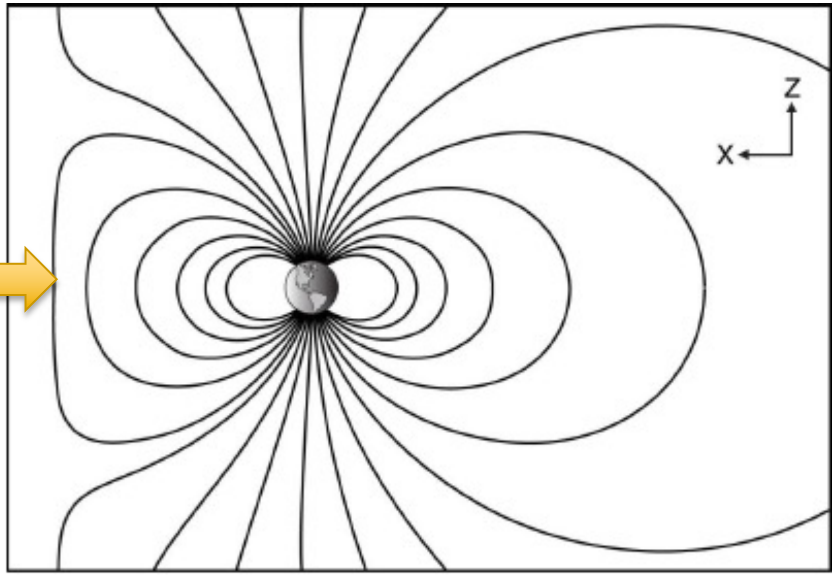


Pressure Balance at Magnetopause

Solar wind dynamic pressure P_{sw}



$$P_{sw} = \rho u^2$$

Solar wind dynamic pressure balances the magnetic pressure at magnetopause:

$$\rho u^2 = \frac{B_{mp}^2}{2\mu_0}$$

Subsolar standoff distance (r_{MP}, in units of Earth radii):

$$r_{MP} = \left(\frac{4B_E^2}{2\mu_0 \rho_{SW} u_{SW}^2} \right)^{\frac{1}{6}}$$

$B_{E:}$ dipole field strength at equator, ~3×10^{-5} T.

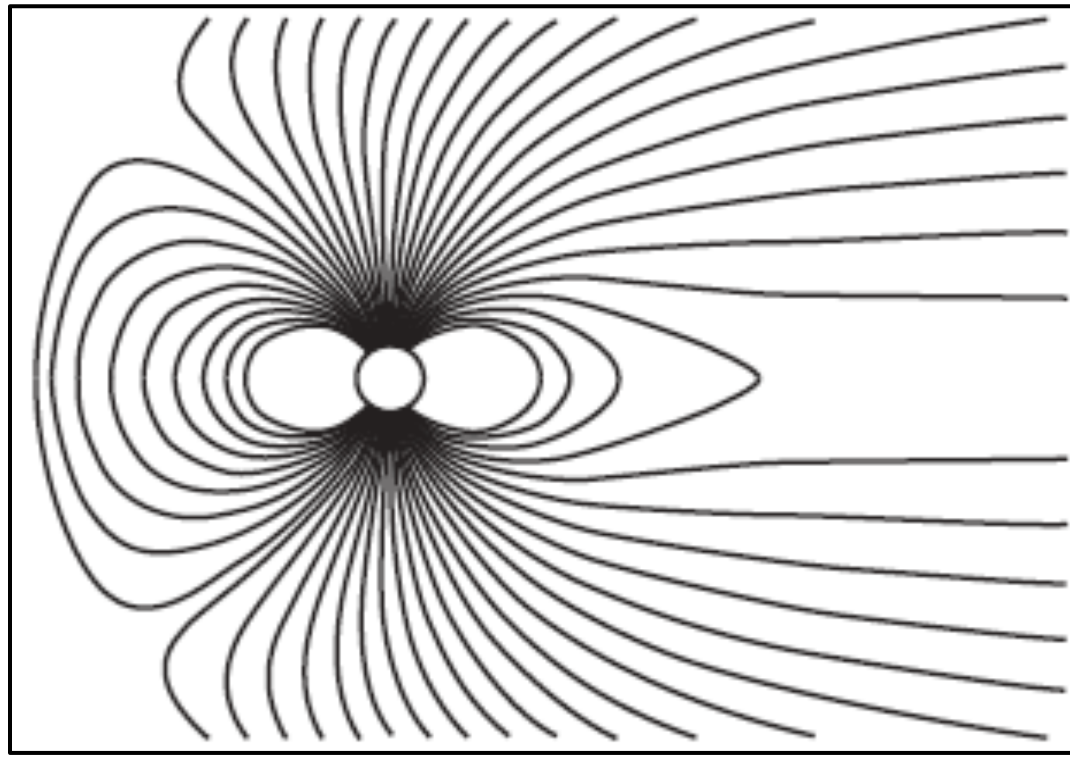
Magnetopause Standoff Distance

$$\rho u^2 = \frac{B_{mp}^2}{2\mu_0}$$

$$B_{mp} = \frac{aB_0}{r^3}$$

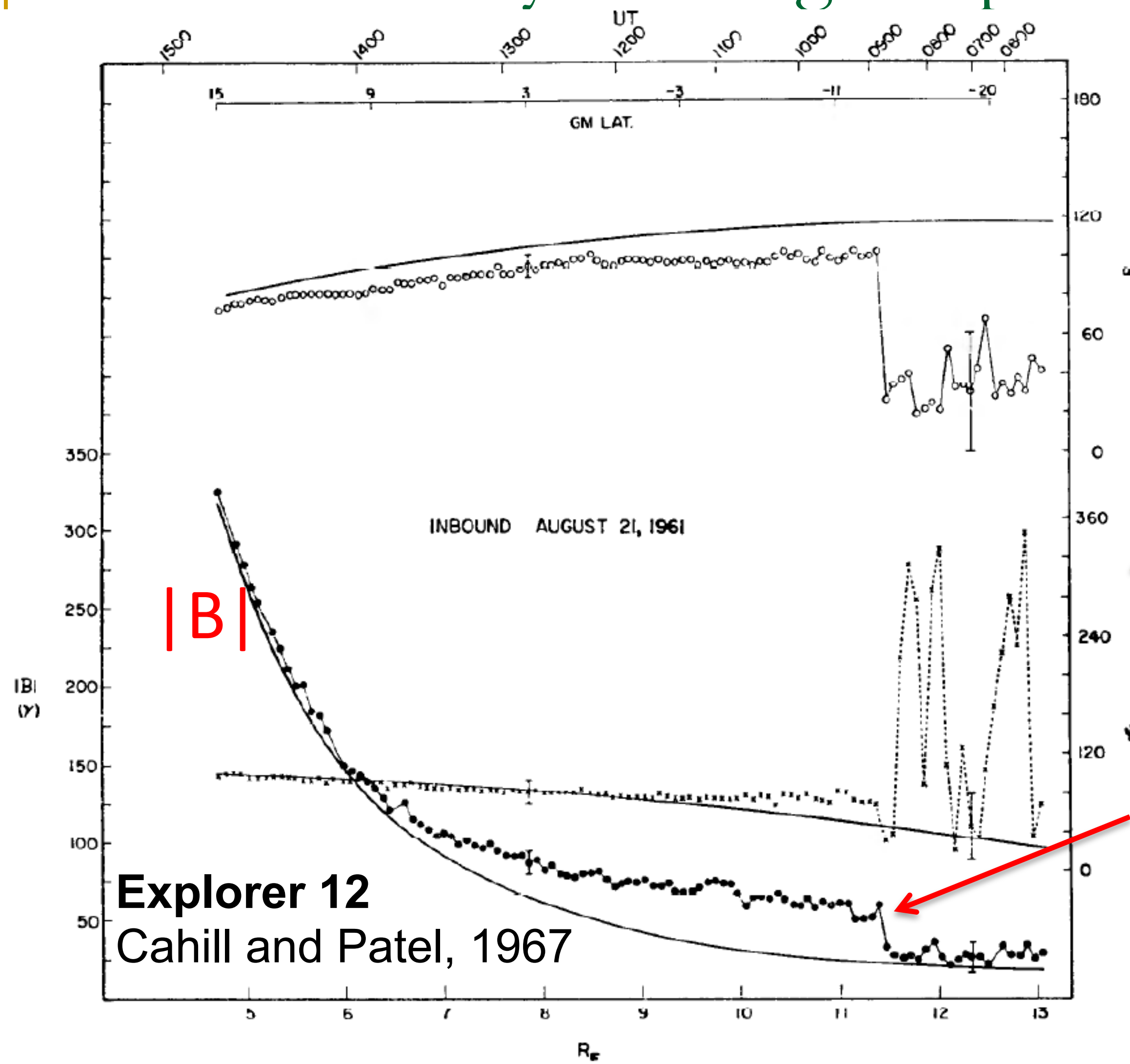
$$r = \left(\frac{a^2 B_0^2}{2\mu_0 \rho u^2}\right)^{\frac{1}{6}} \propto \left(\frac{1}{\rho u^2}\right)^{\frac{1}{6}}$$

a: compression factor depends on the shape of the magnetosphere

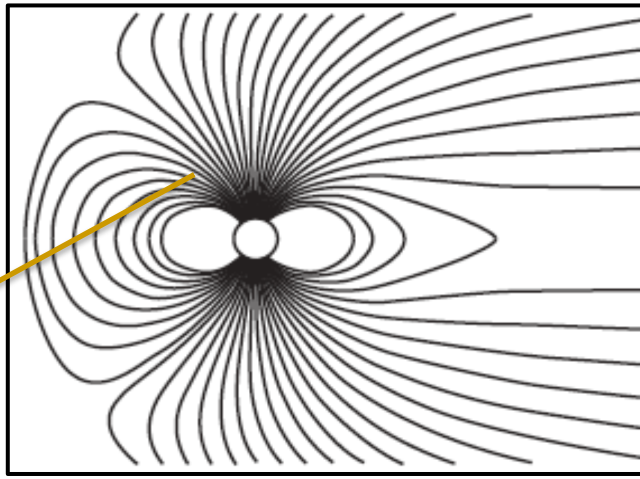


a=2.44

How to identify the magnetopause in satellite data?



Explorer 12
Cahill and Patel, 1967



magnetopause crossing

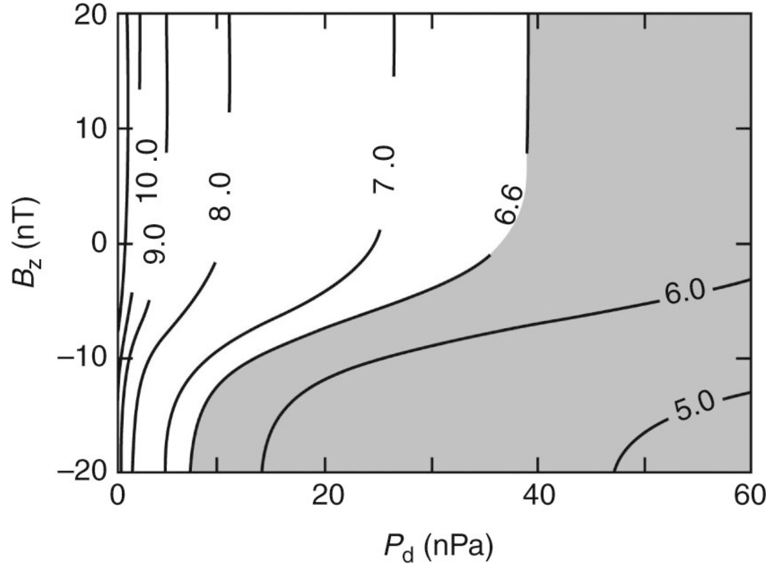
Empirical model for the magnetopause

- Shue et al. 1998 formula:

$$r = 2^{\alpha} r_0 (1+\cos\theta)^{-\alpha}$$

$$r_0 = \left\{10.22 + 1.29 \tanh\left[0.184\left(Bz + 8.14\right)\right]\right\}\left(\frac{1}{p_{SW}}\right)^{\frac{1}{6.6}}$$

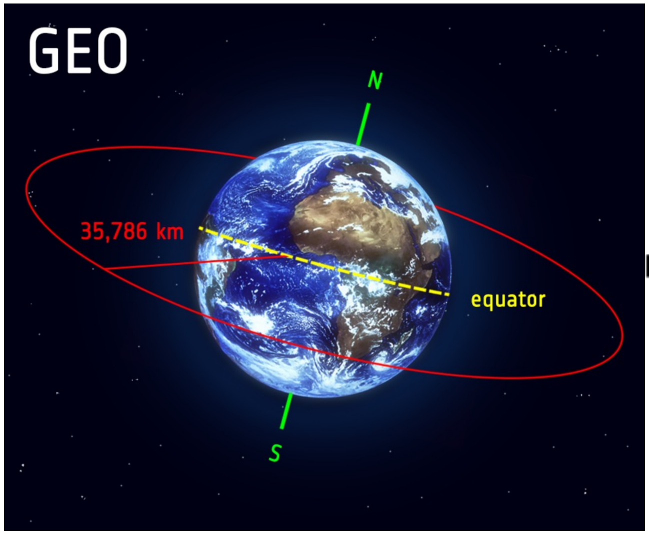
$$\alpha = (0.58 - 0.007 B_z)[1 + 0.024 \ln(P_d)]$$

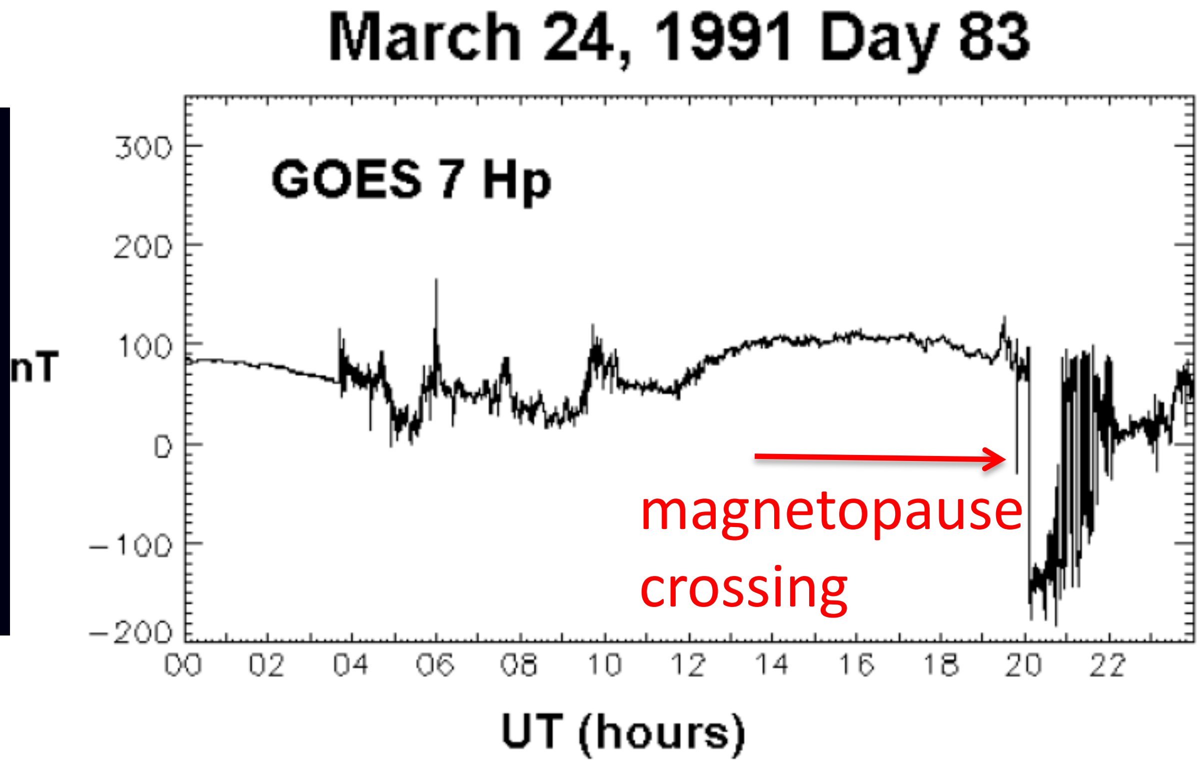


Subsolar standoff distance r_0 as functions of IMF Bz and solar wind dynamic pressure Pd derived from the Shue et al. 1998 model.

- r is the radial distance in Earth radii
- Θ is the solar zenith angle, 0°<Θ<180°
- R_E is in Earth radii
- P_d or P_{sw} is solar wind dynamic pressure in nPa
- B_z is IMF z component in nT in GSM coordinates

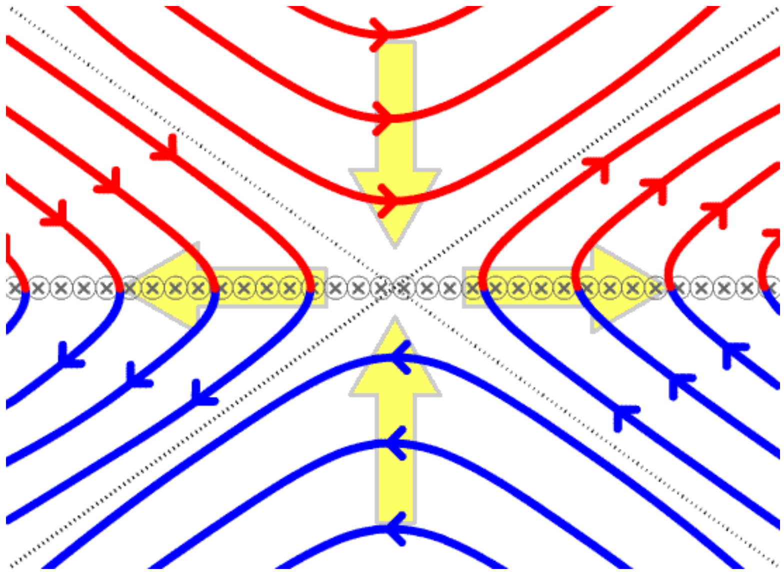
Extreme Compression Event





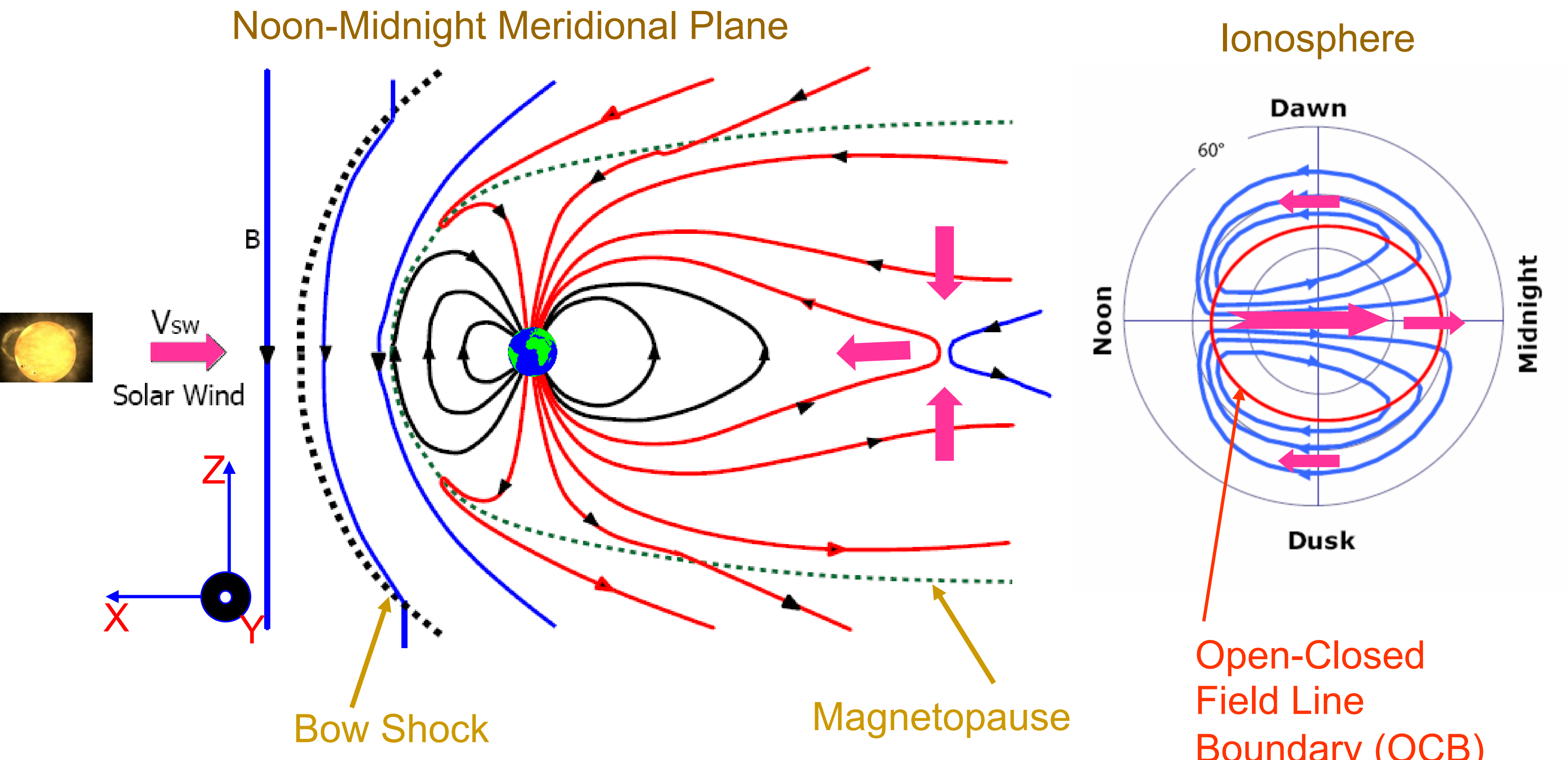
- Magnetopause pushed inside geosynchronous orbit
- Sudden B field change of a couple of hundred nT

Magnetic Reconnection



Magnetic reconnection: This view is a cross-section through four magnetic domains undergoing separator reconnection. Two separatrices (see text) divide space into four magnetic domains with a separator at the center of the figure. Field lines (and associated plasma) flow inward from above and below the separator, reconnect, and spring outward horizontally.

Reconnection Driven Convection



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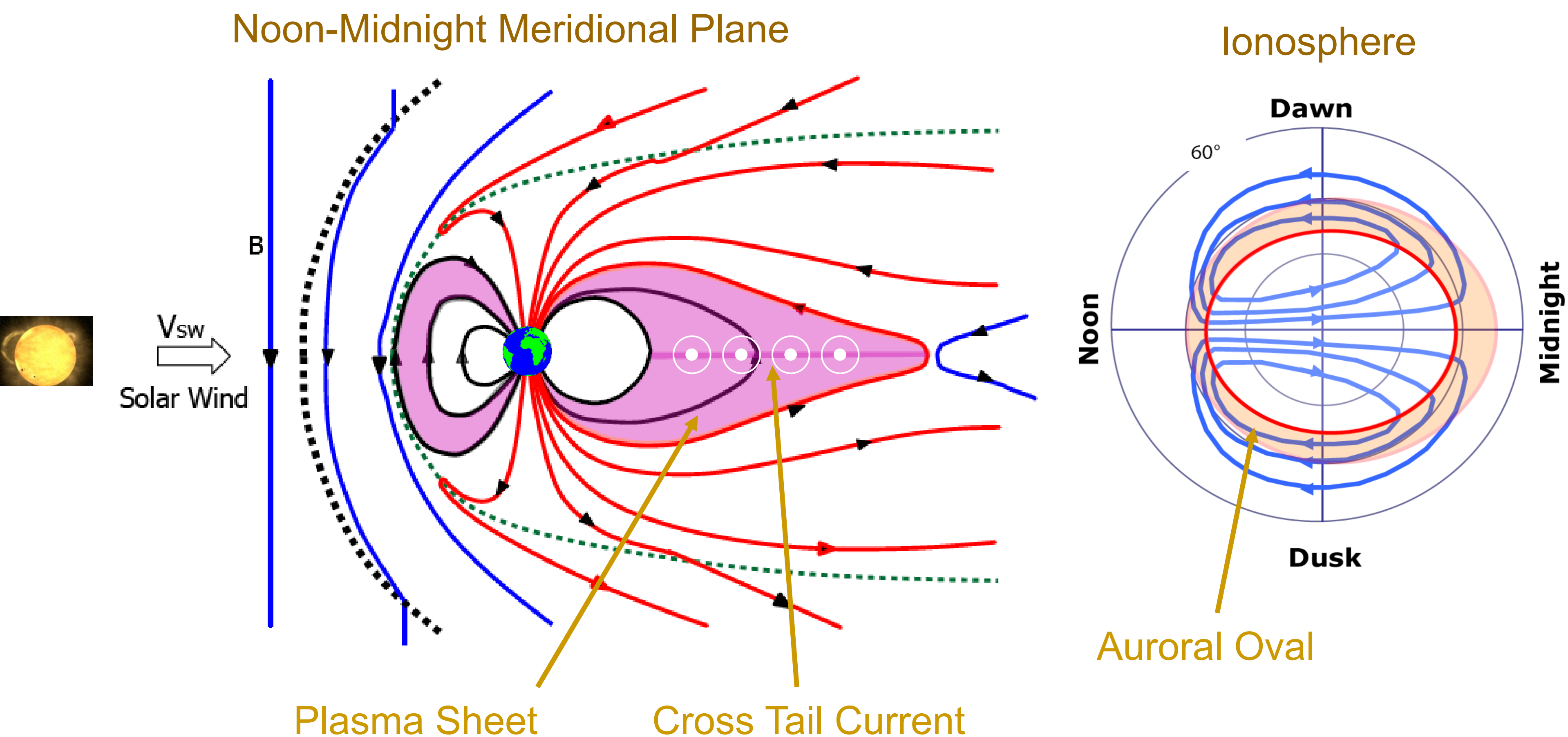


IMF dependence of convection pattern

The IMF 'clock angle' is the angle produced in the vertical plane from the vector addition of the "By" and "Bz" components of the interplanetary magnetic field.

Clock Angle in degrees:
Angle = 0 : IMF Bz north
Angle = 90 : IMF By +
Angle = 180 : IMF Bz south
Angle = 270 : IMF By -

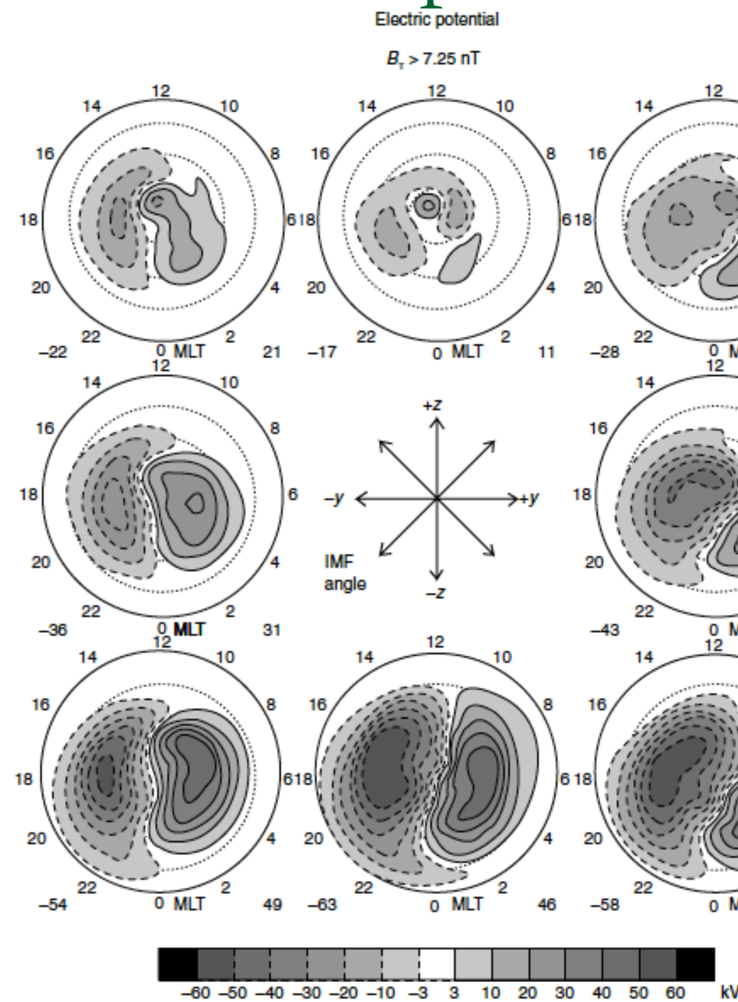
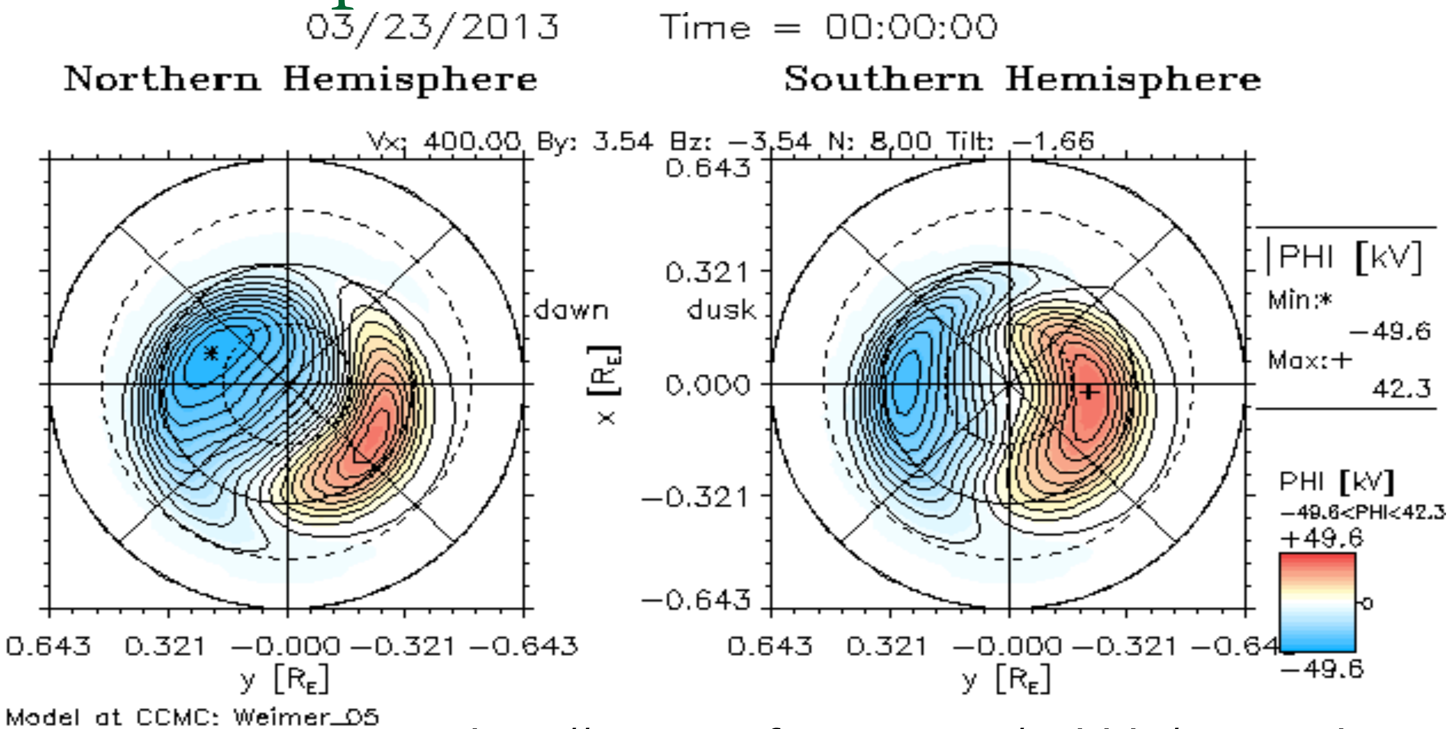


Figure 12.12 Contours of electric potential from an empirical convection model. The results are for the case when the magnitude of the IMF is greater than 7.25 nT. Co-rotation is not included.[10, 11]

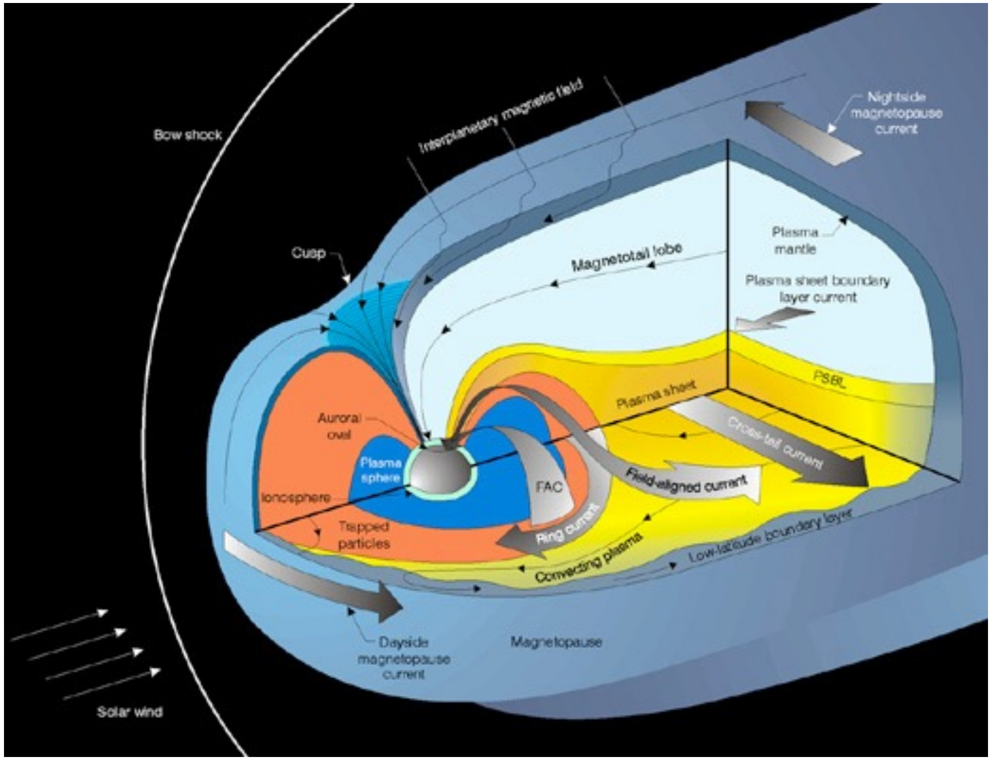
Weimer Ionosphere Model

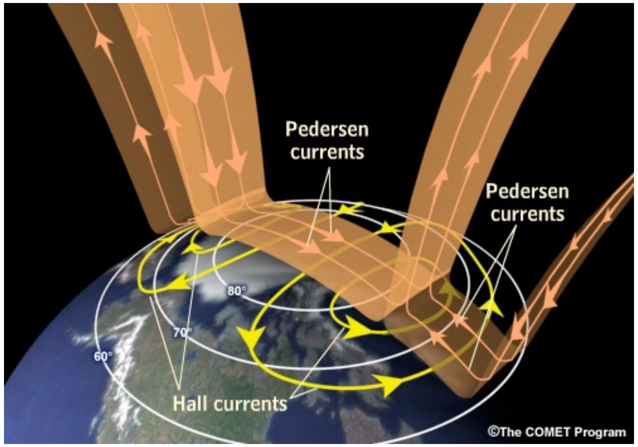


http://ccmc.gsfc.nasa.gov/cgi-bin/run_weimer.cgi

- Weimer models are statistical electric potential models for the high-latitude ionosphere.
- Past satellite measurements of ionospheric electric fields, and the simultaneous measurements of solar wind and IMF conditions, have been used.

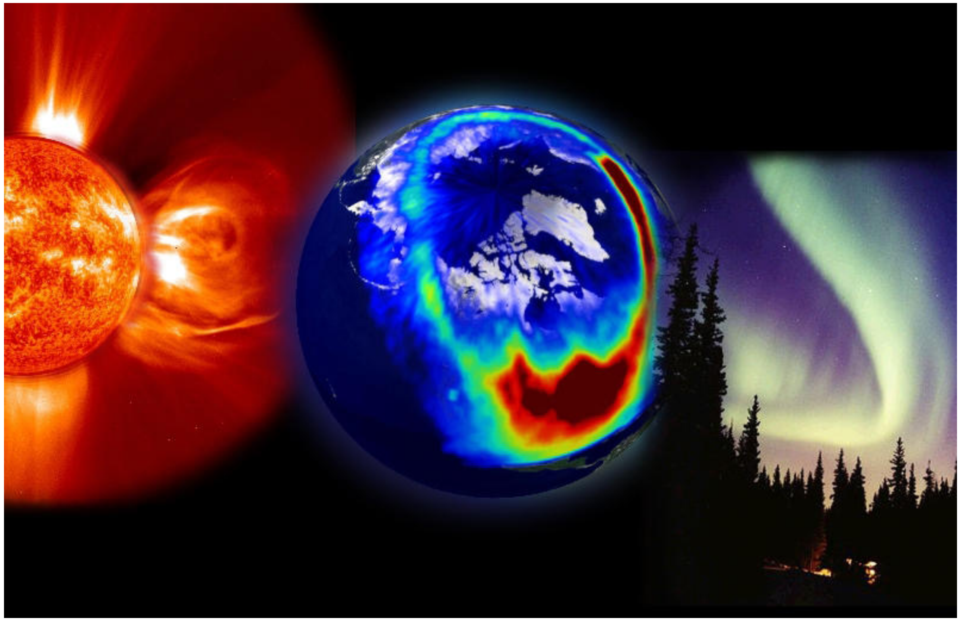
Currents in the Geospace System





- Energies entering the magnetopause are temporarily stored in the magnetosphere, powering several large-scale current systems.
- Field-aligned currents (FACs) communicate between the magnetosphere and ionosphere and vast majority of the energy deposition occurs in the FAC region.

Geomagnetic Disturbances



Geomagnetic disturbances are driven by transient solar wind and interplanetary magnetic field structures, such as Coronal Mass Ejection (CME) and Corotating Interaction Region (CIR).

Three major geomagnetic disturbances:

1. **Storm**: largest disturbance; global scale; last a couple of days
2. **Substorm**: nightside disturbance; last a couple of hours
3. **Shock compression**: transient but global disturbance; last several minutes