# *Sun-Earth Connection; The Earth's Magnetosphere and the Importance of Space Weather*

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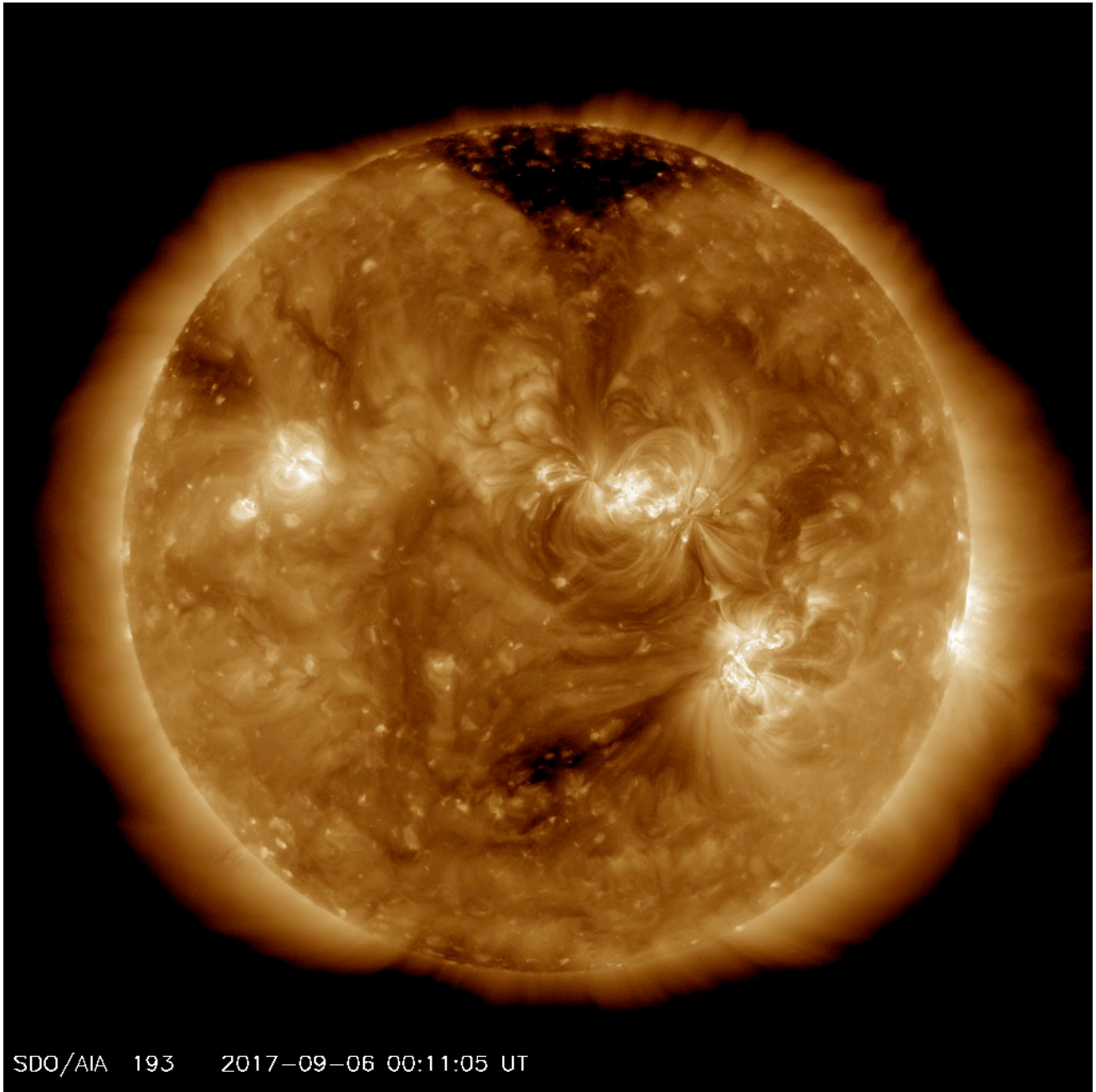
NASA Goddard Space Flight Center

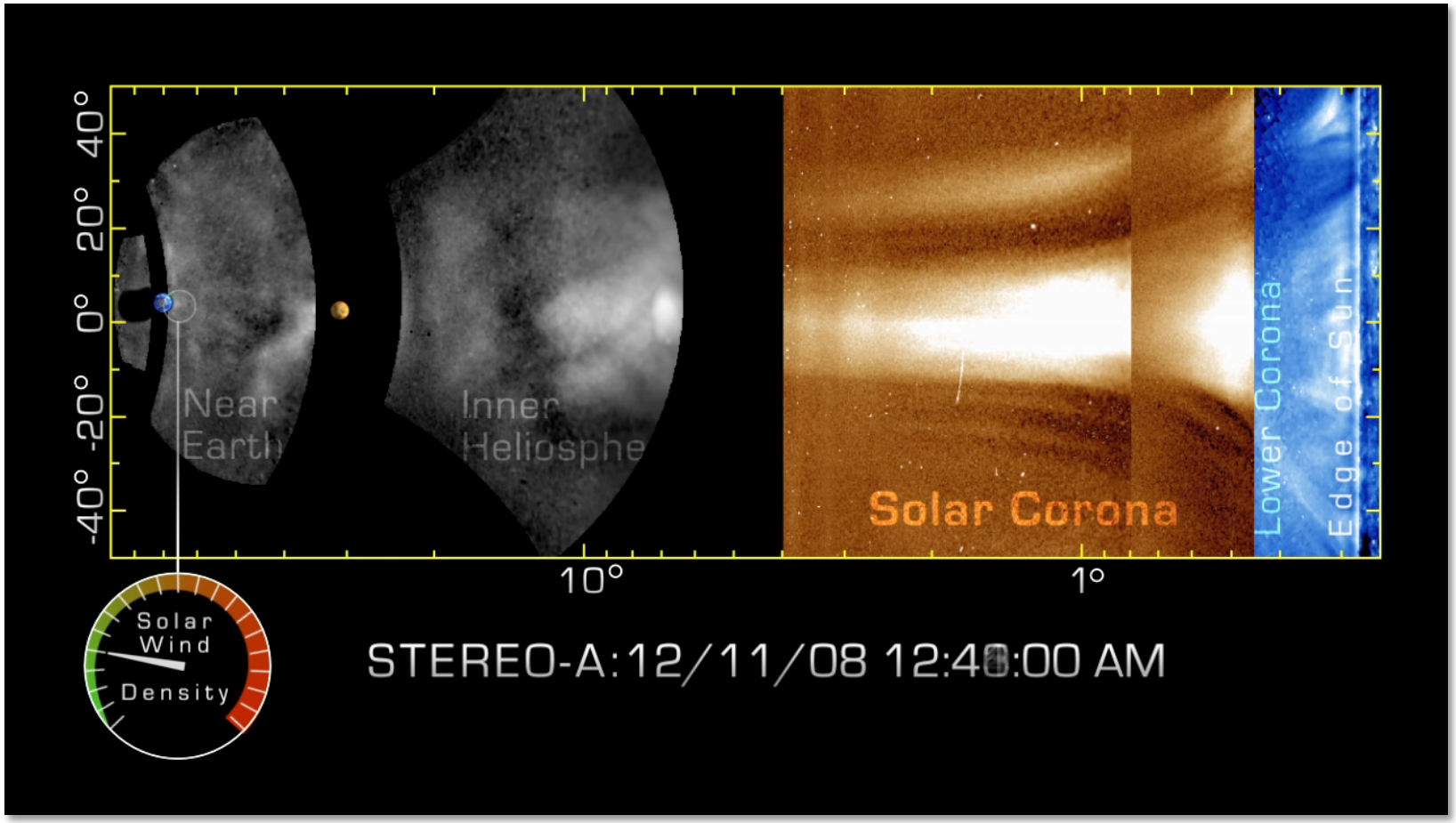
Thanks to the CCMC team

# The Sun

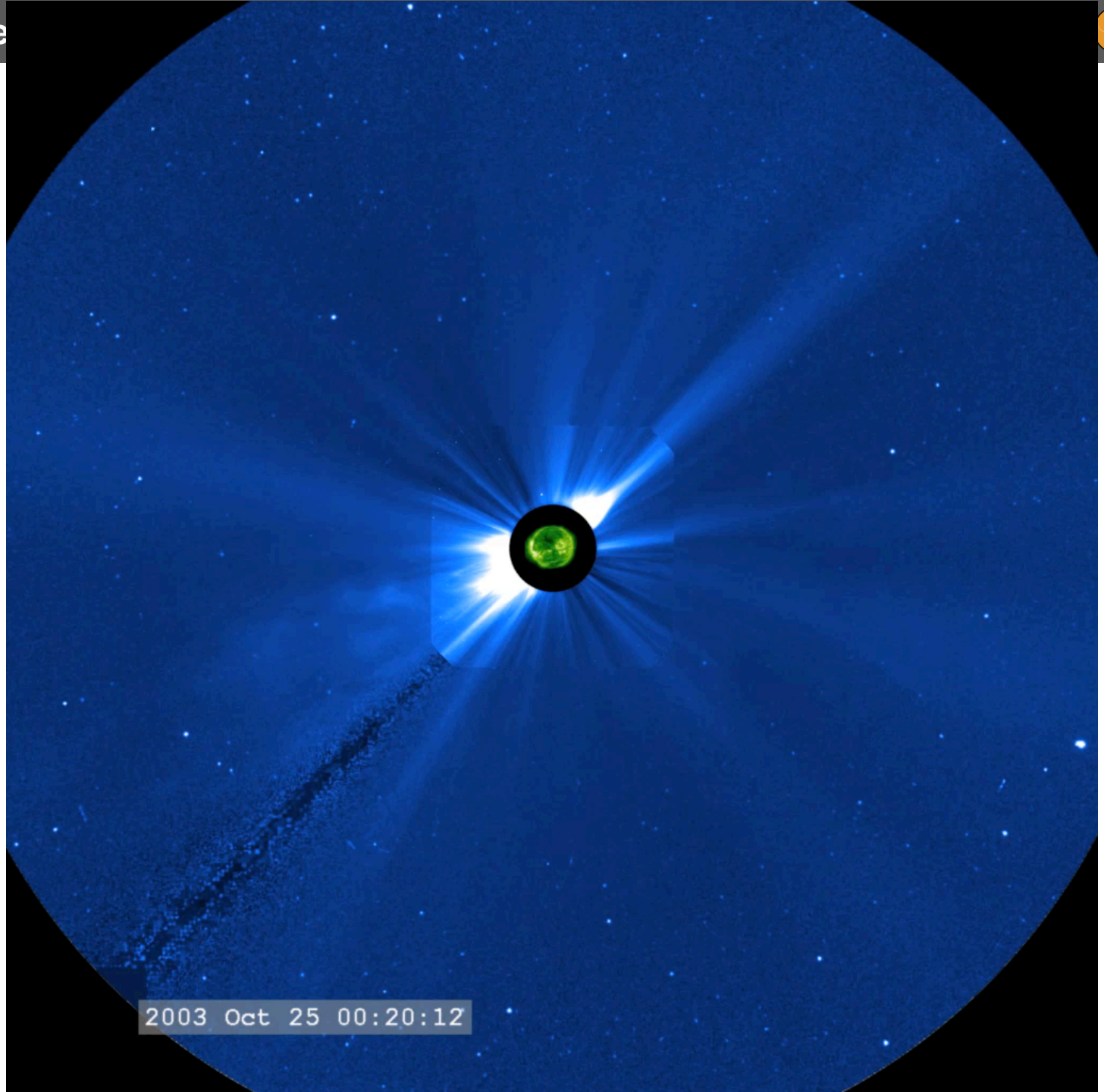


# The Sun's Rainbow

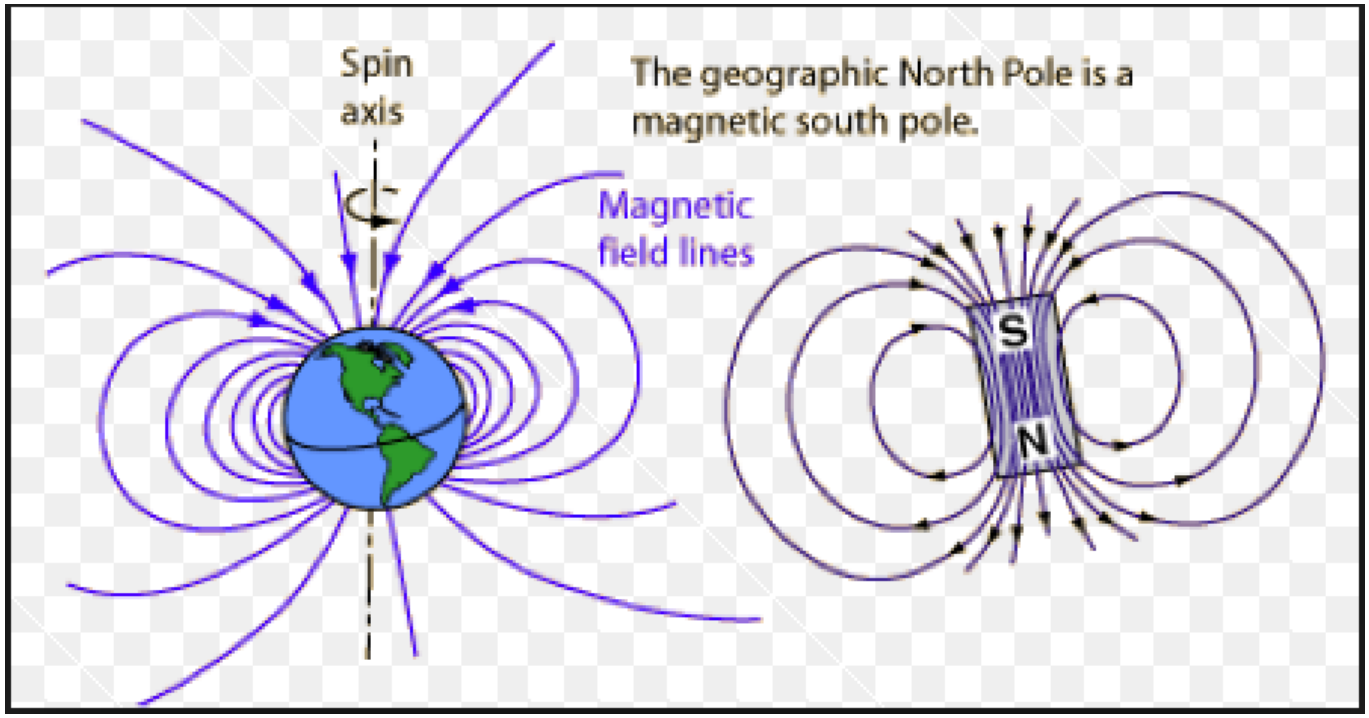
# CME propagation




CME propagation to the Earth takes typically 2-4 days.

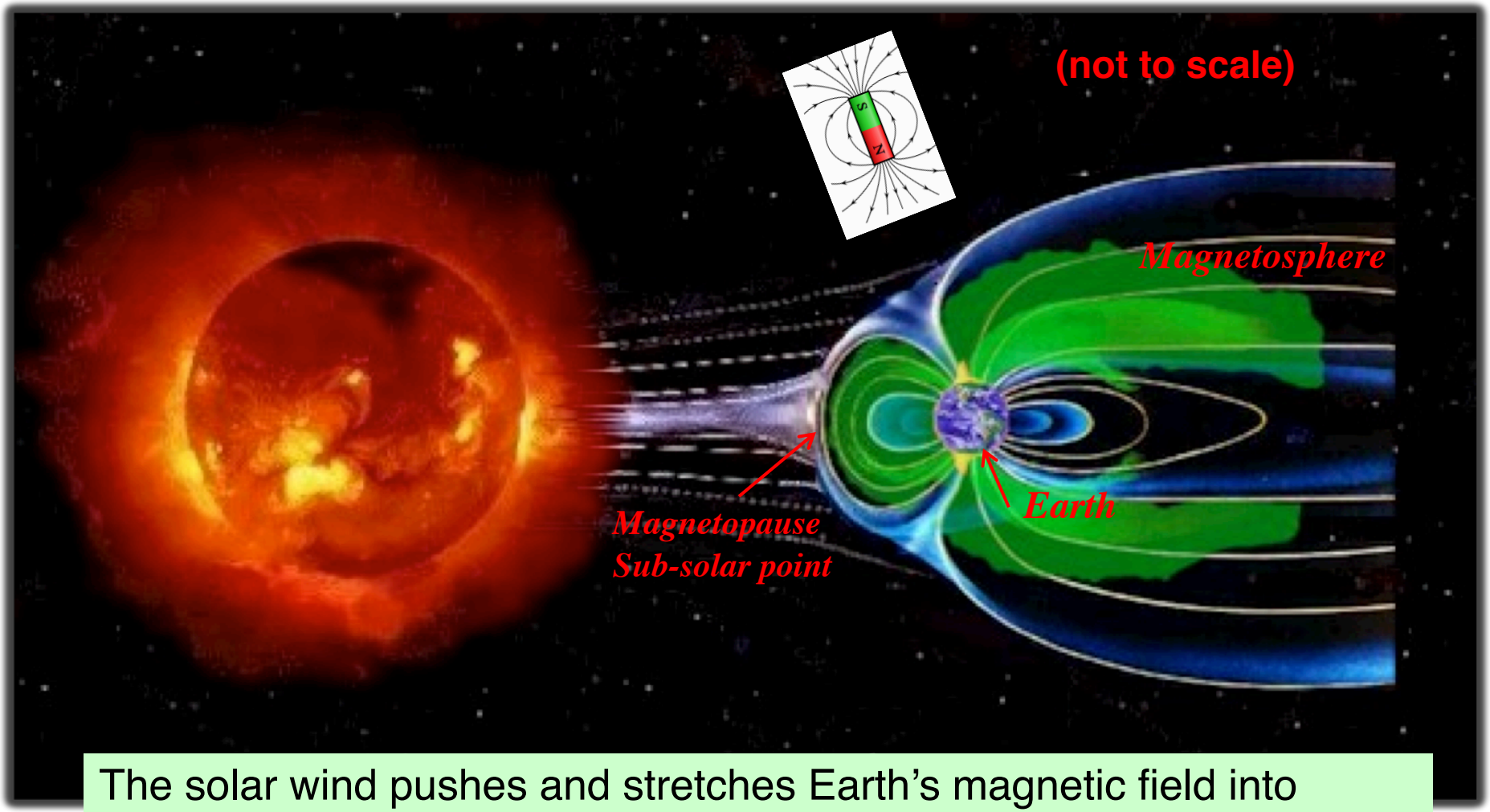

2003 Oct 25 00:20:12

# Magnetic Field of the Earth



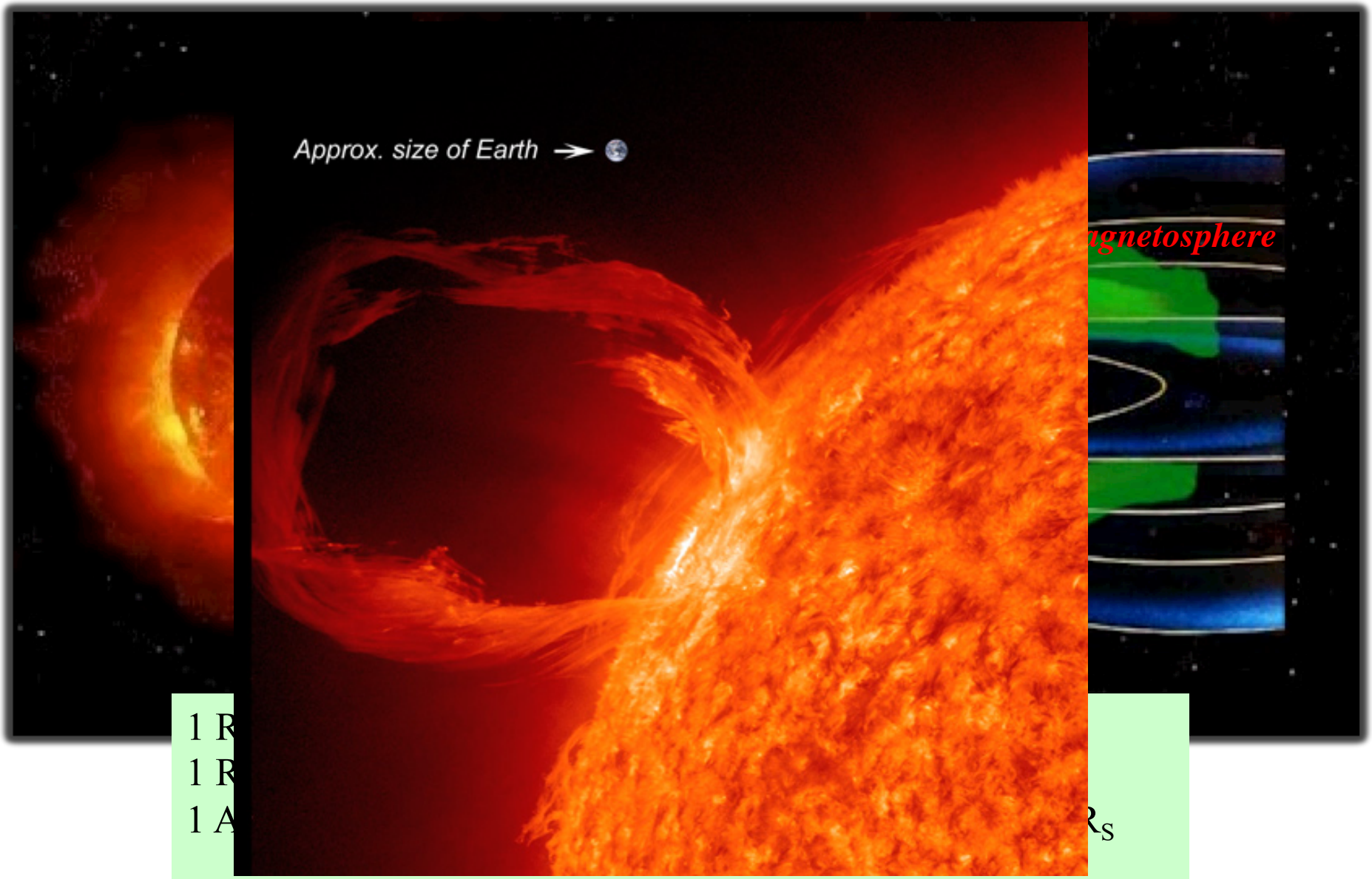

The Earth's magnetic field is similar to that of a bar magnet.

# Earth's Magnetic Field




The solar wind pushes and stretches Earth's magnetic field into comet-shaped region called the magnetosphere. The magnetosphere and Earth's atmosphere protect us from the solar wind and other kinds of solar and cosmic radiation.

# Spatial Scales



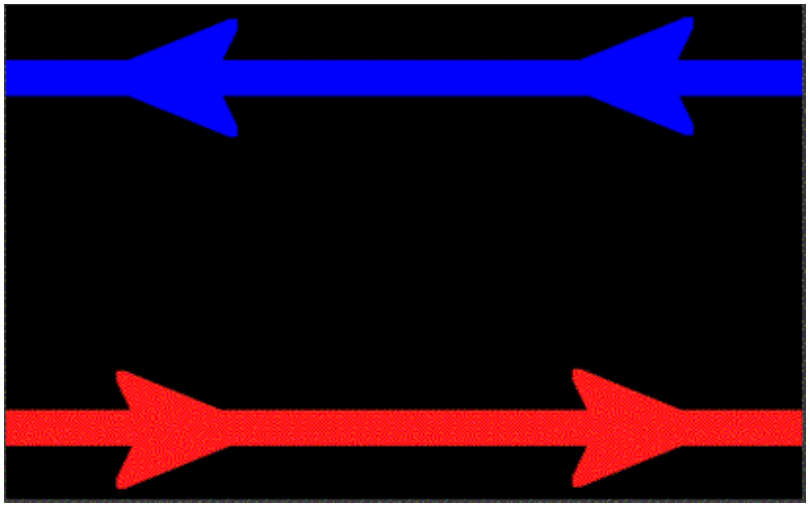

1 R

1 R

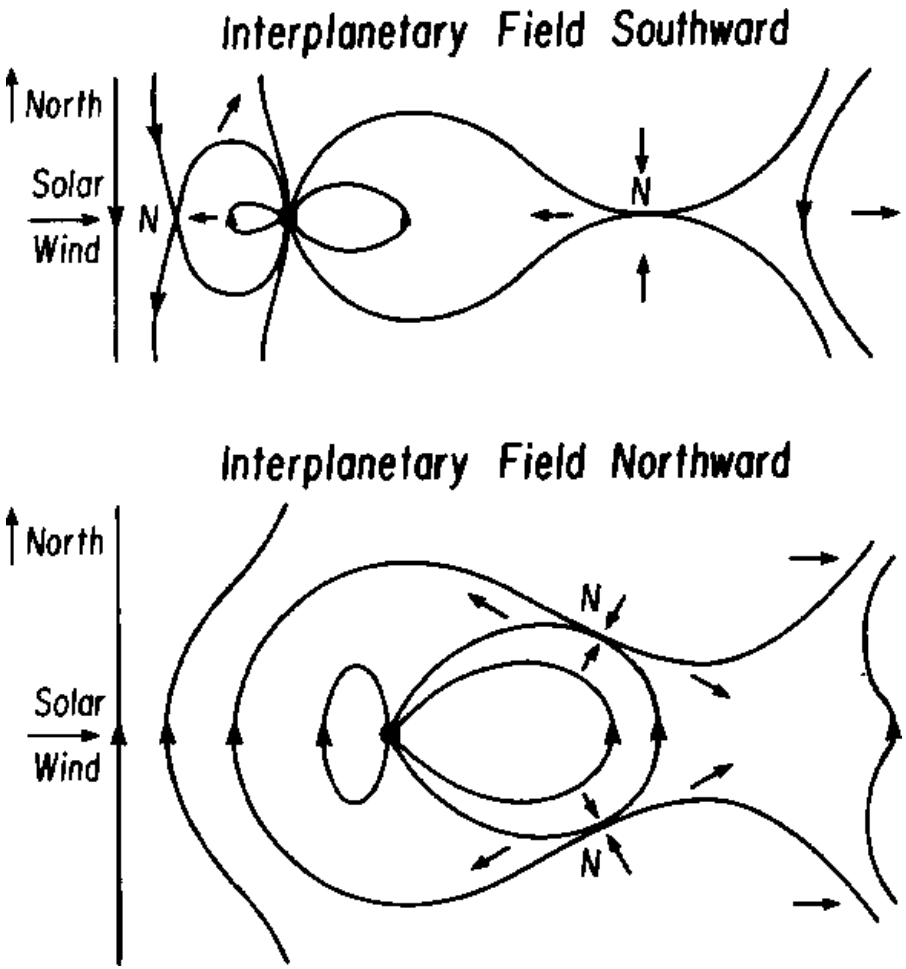
1 A

$R_S$

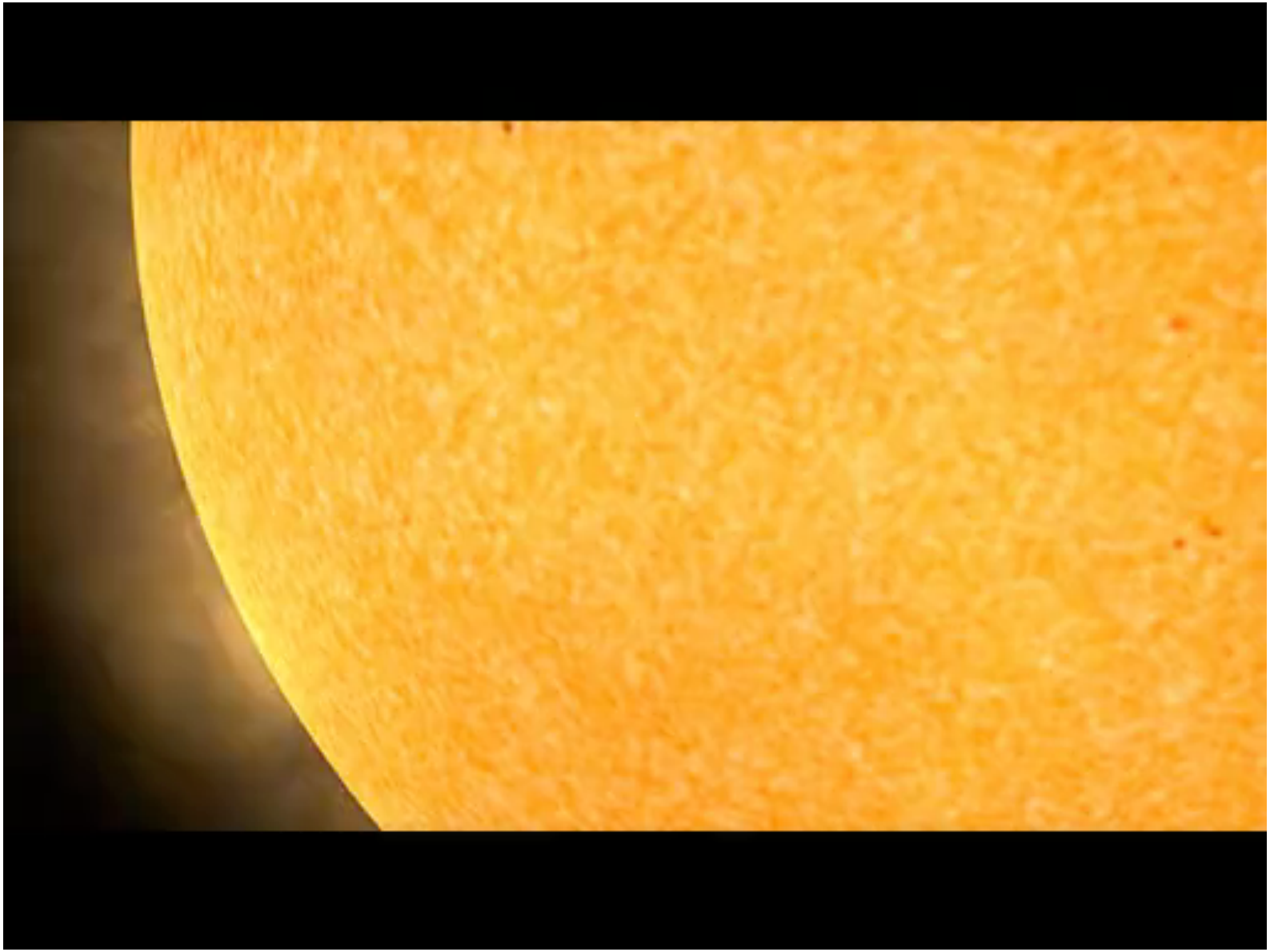
# Magnetosphere for Southward and Northward IMF Orientation



Magnetic Reconnection

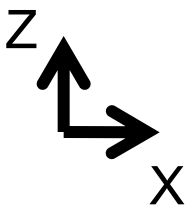


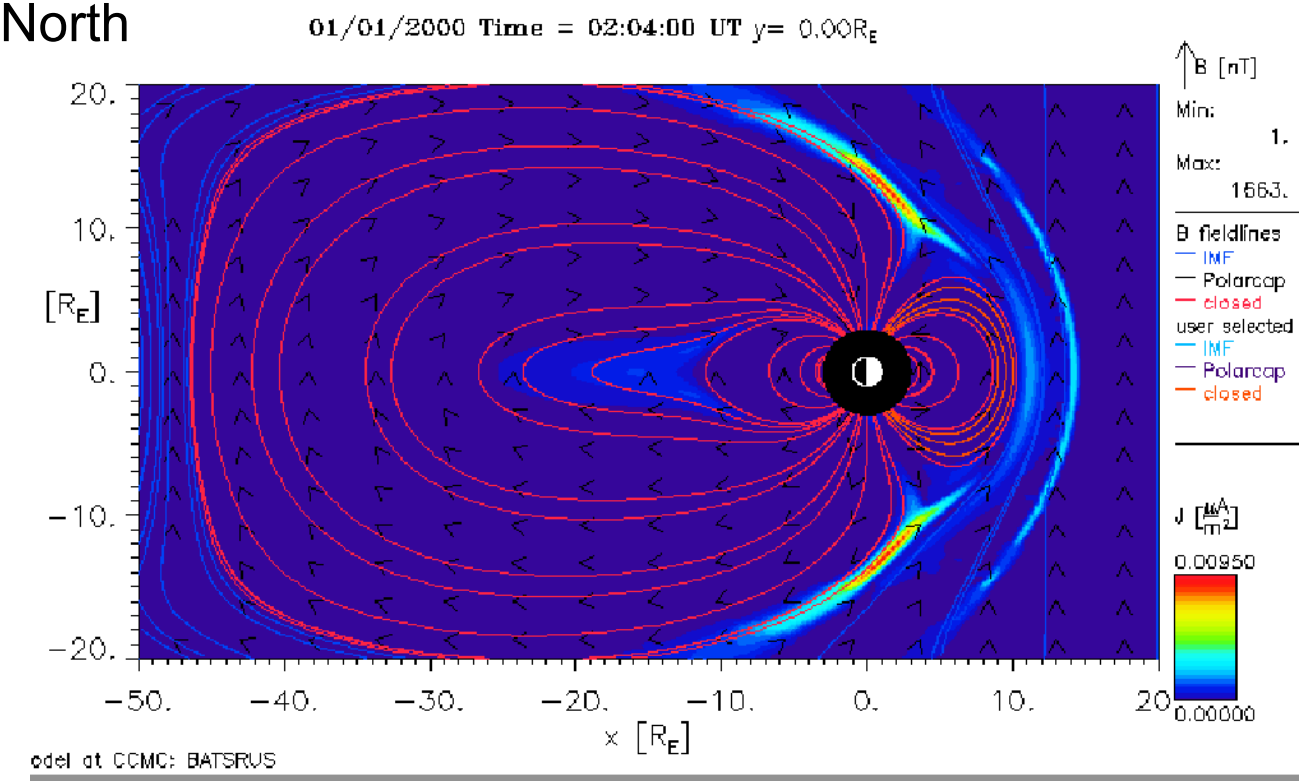

Dungey, 1961



# Magnetosphere:
# Northward IMF

X: Earth to Sun
Z: South to North



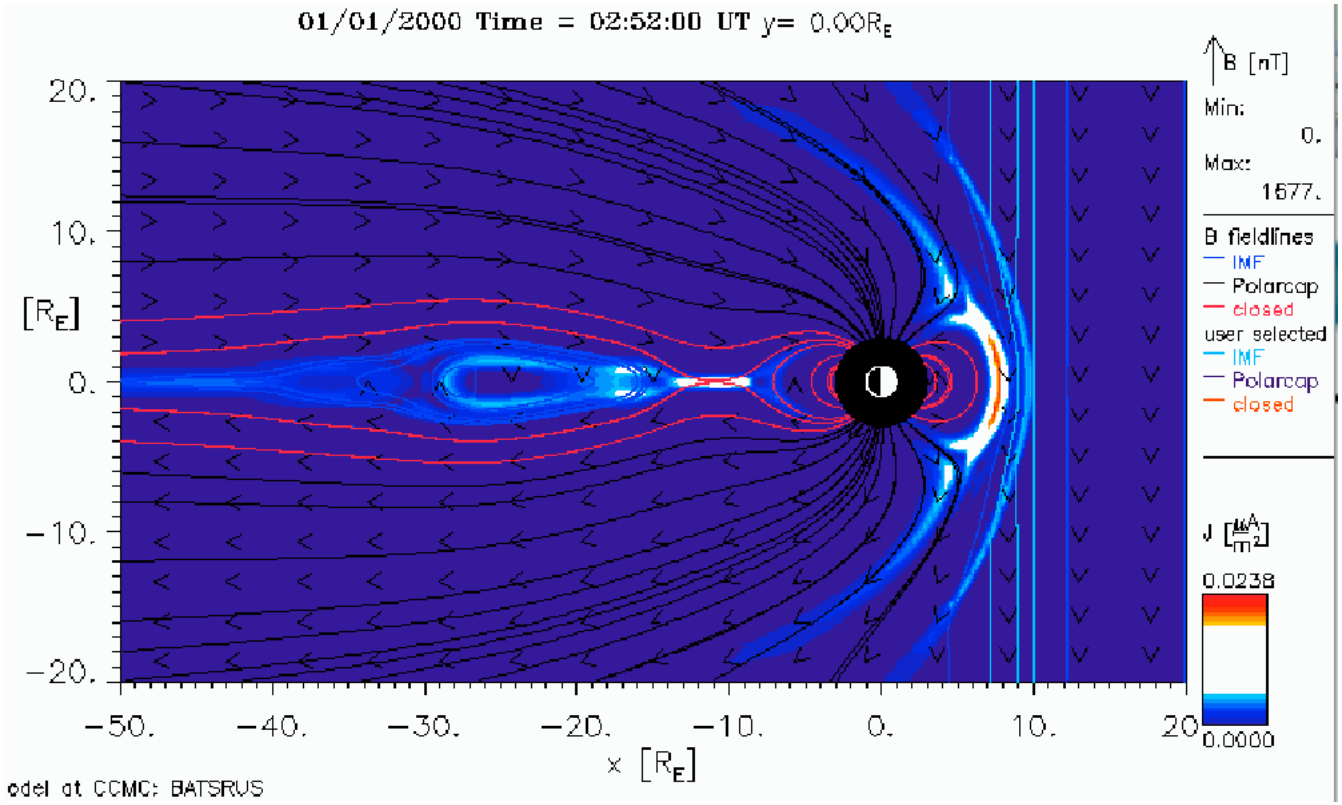

**Sun**

**Red lines** (closed): Magnetic field (MF) lines with both ends connected to the Earth

**Black lines** (open): MF lines with only one end a the Earth

**Blue lines** (interplanetary): MF lines with both ends in the interplanetary space

# Magnetosphere:
# Southward IMF



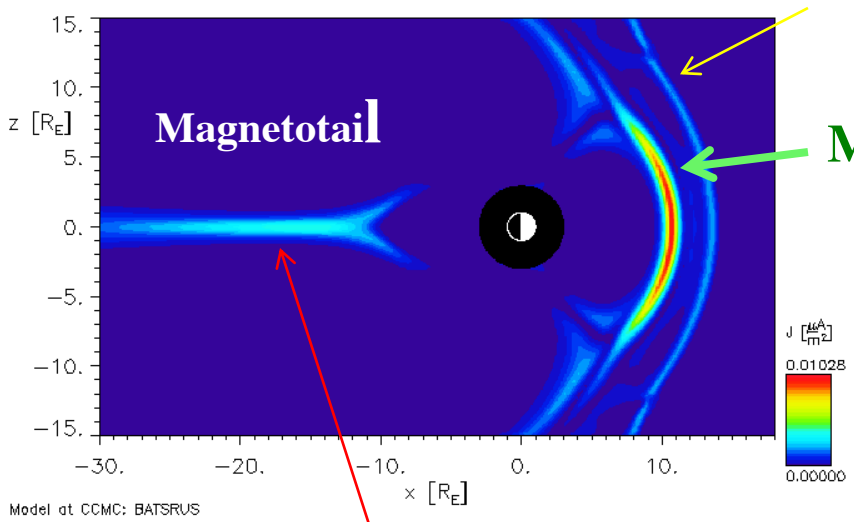

**Red lines** (closed): Magnetic field (MF) lines with both ends connected to the Earth

**Black lines** (open): MF lines with only one end a the Earth

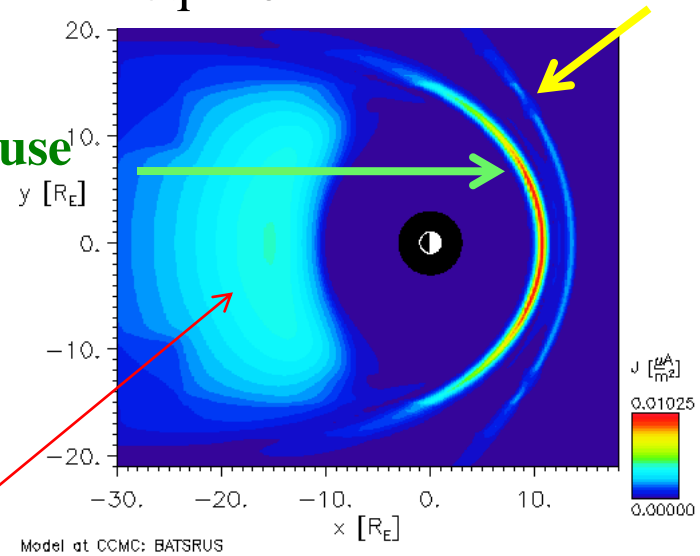
**Blue lines** (interplanetary): MF lines with both ends in the interplanetary space

# Magnetosphere in Different Cut Planes

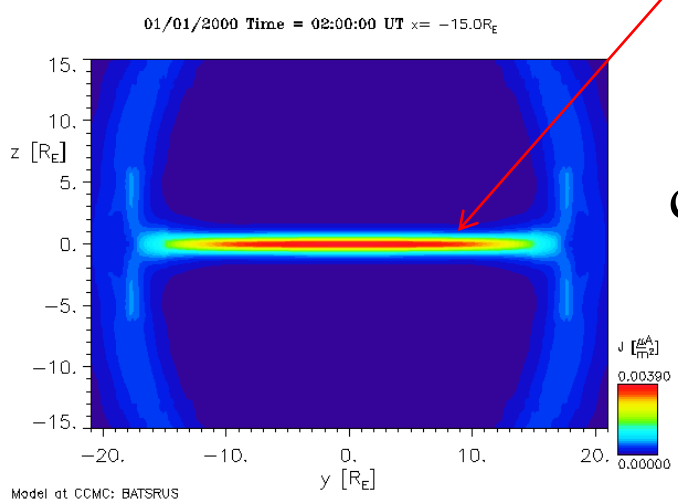
meridional cut Y=0




equatorial cut Z=0

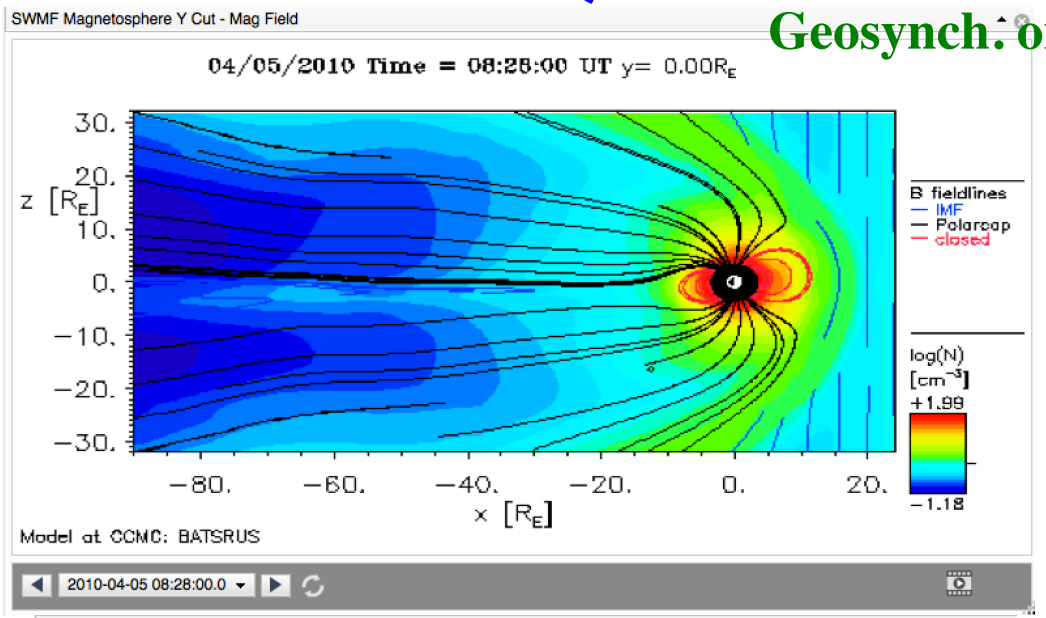



Magnetotail current sheet

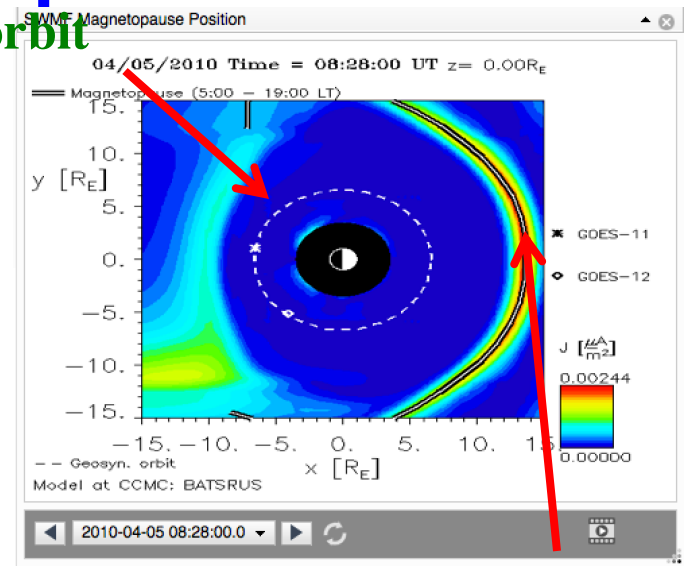



cross-tail cut X= -15 $R_E$

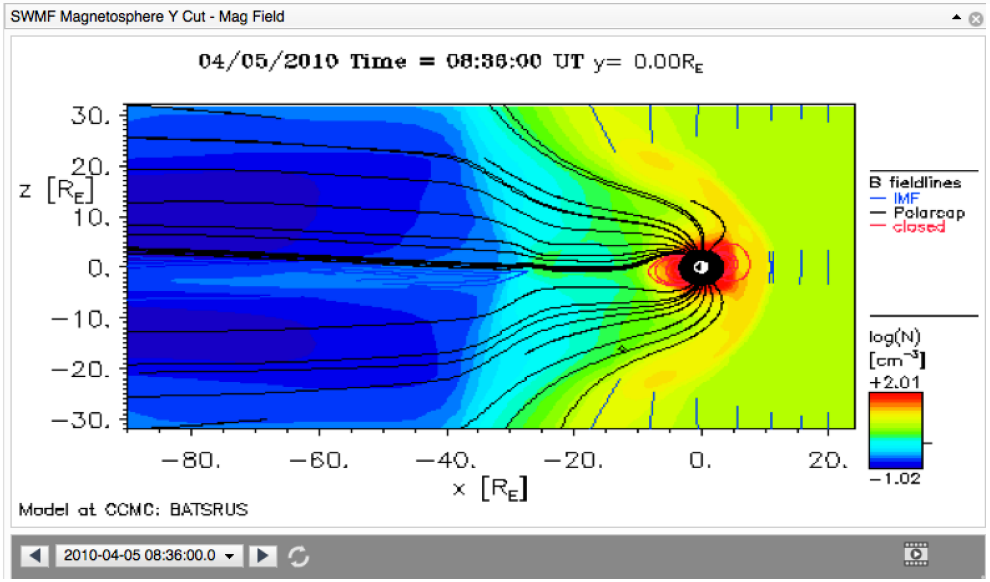
# Magnetosphere:
# Quiet vs. Compressed

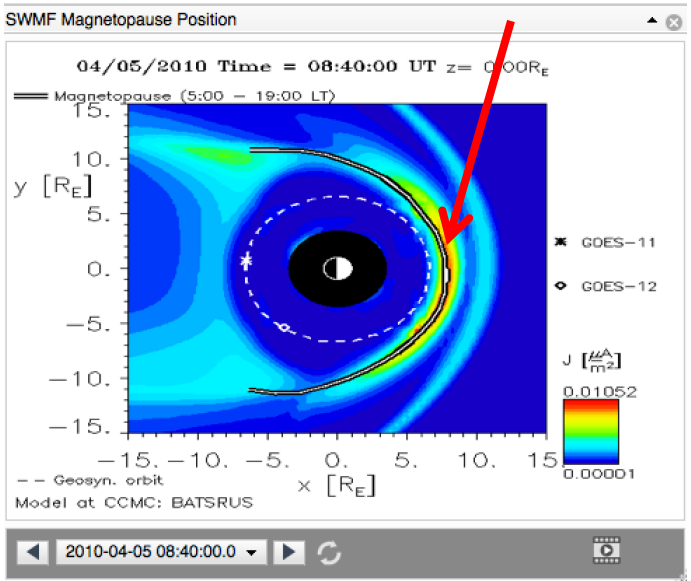



Geosynch. orbit

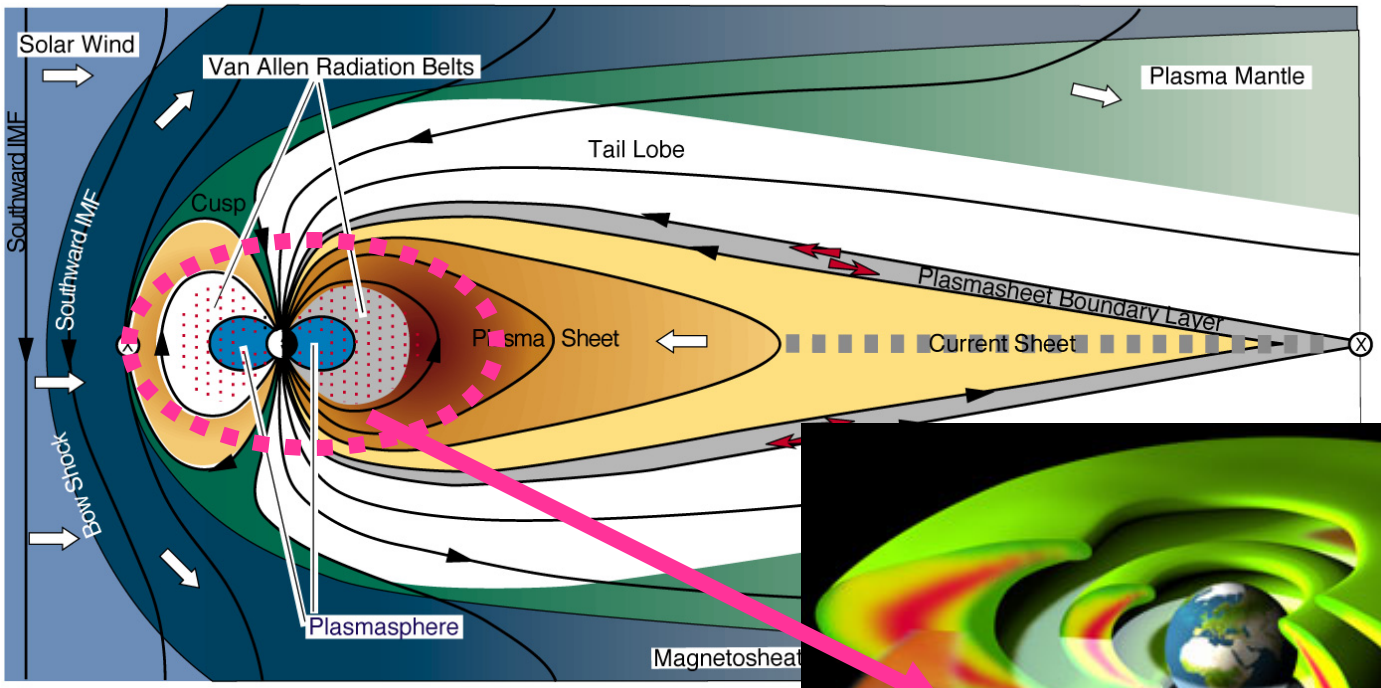


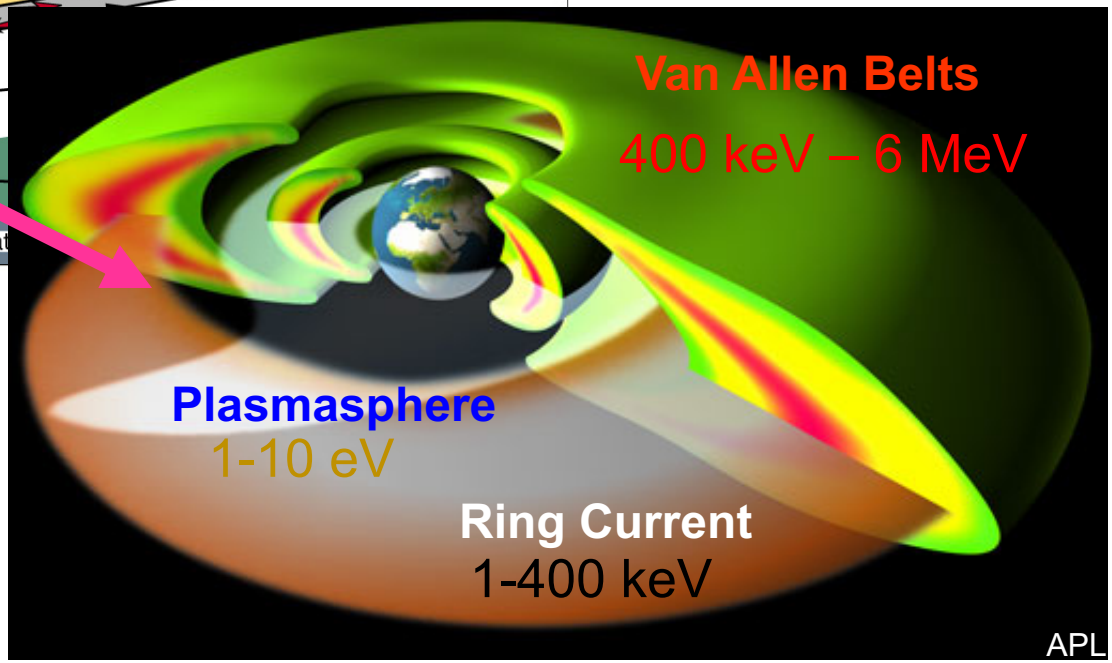

Magnetopause



# Inner Magnetosphere (up to ~ 10 RE)

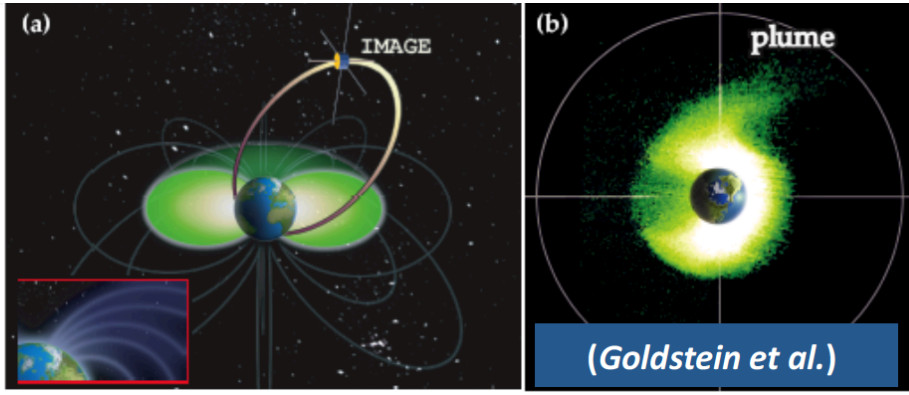


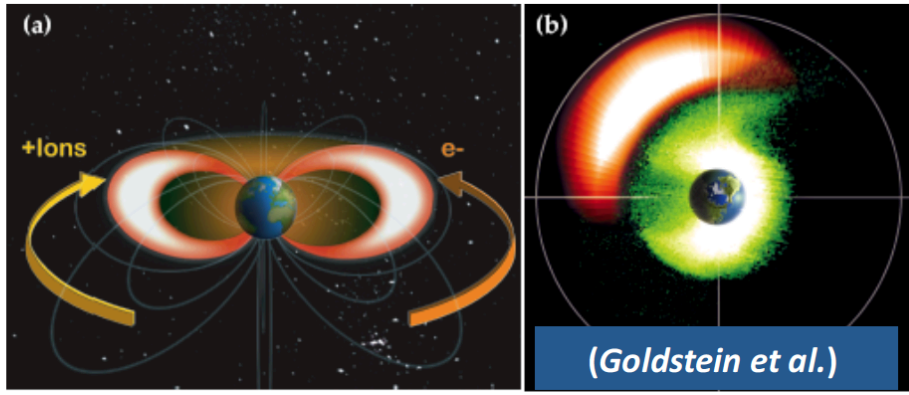



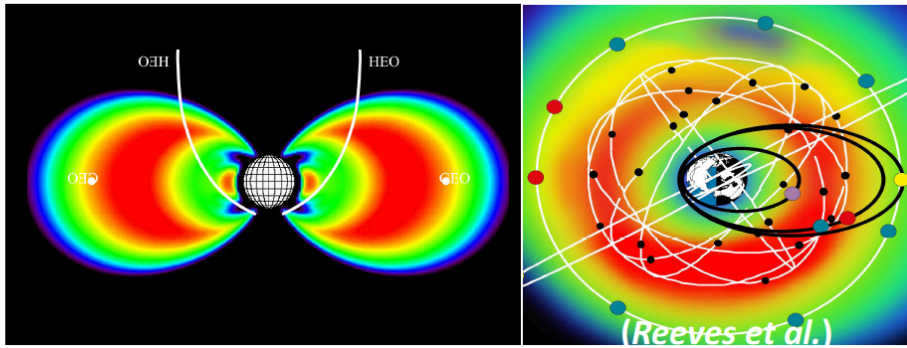
# Inner Magnetosphere Plasmas

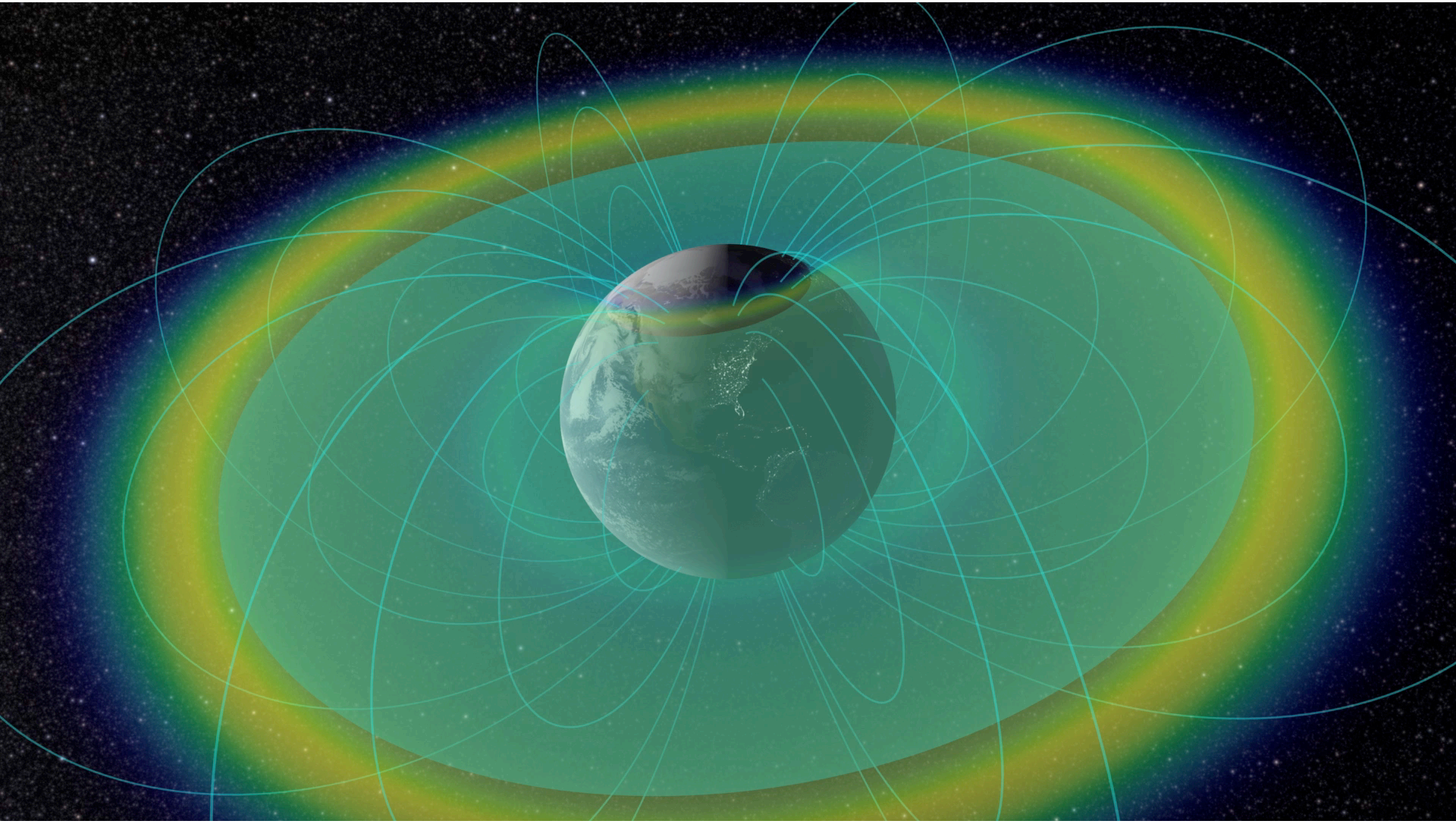
- Plasmasphere
  - 1-10 eV ions
  - ionospheric origin
- Ring current
  - 1-400 keV ions
  - both ionospheric and solar wind origin
- Outer radiation belt
  - 0.4-10 MeV electrons
  - magnetospheric origin

Inner magnetosphere: Gigantic Particle accelerator



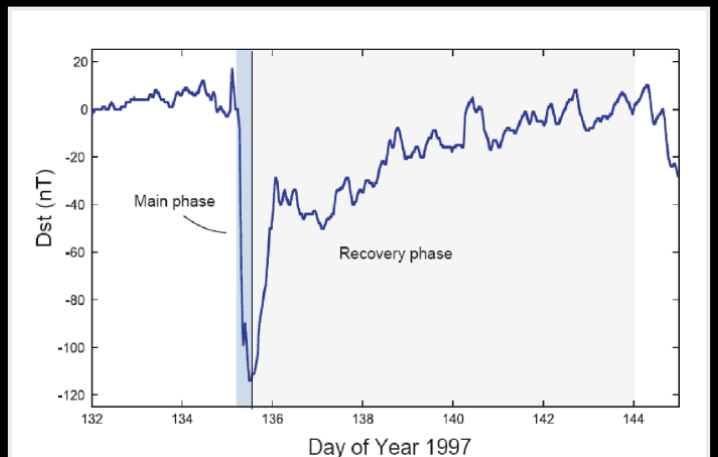





# Magnetic Storms

- Most intense solar wind-magnetosphere coupling
- Associated with solar coronal mass ejections (CME), coronal holes HSS
- IMF Bz southward, strong electric field in the tail
- Formation of ring current and other global effects

- Dst measures ring current development
  - Storm sudden commencement (SSC), main phase, and recovery phase
  - Duration: days

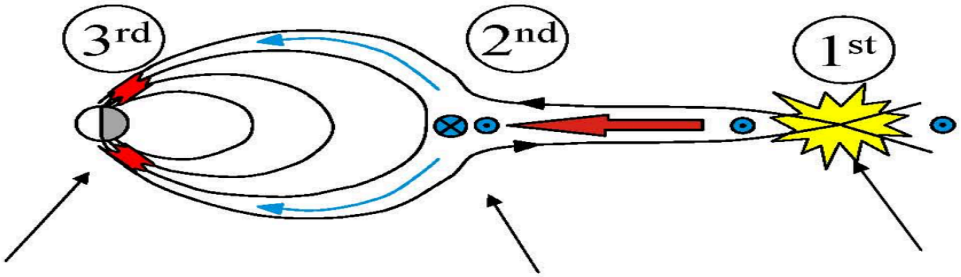


# Substorms

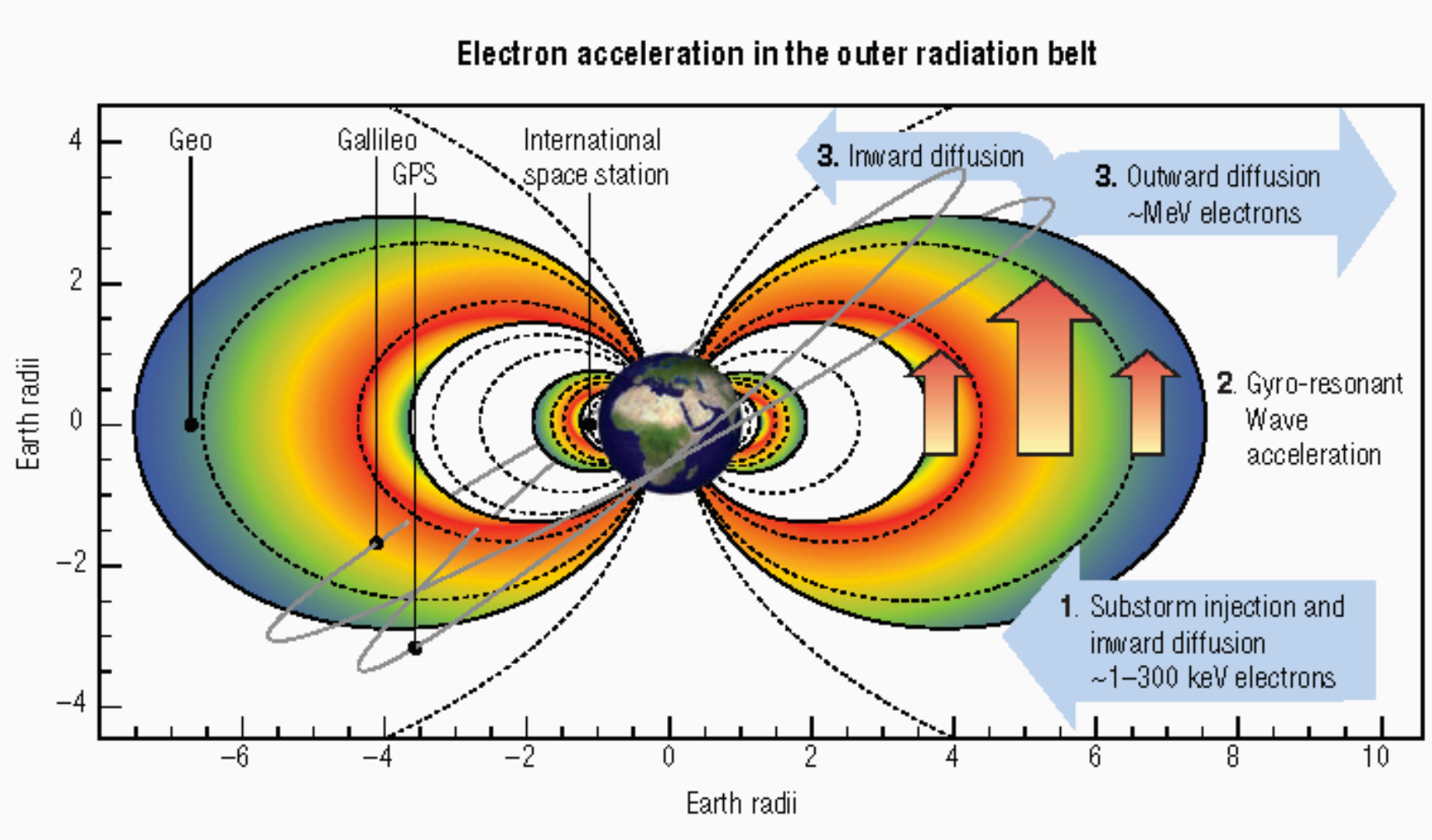
- Instabilities that abruptly and explosively release solar wind energy stored within the Earth's magnetotail.
- manifested most visually by a characteristic global development of auroras
- Last ~ hours

From 2008 THEMIS Science Nuggets
By Angelopoulos

Reconnection Model
(Explosion)

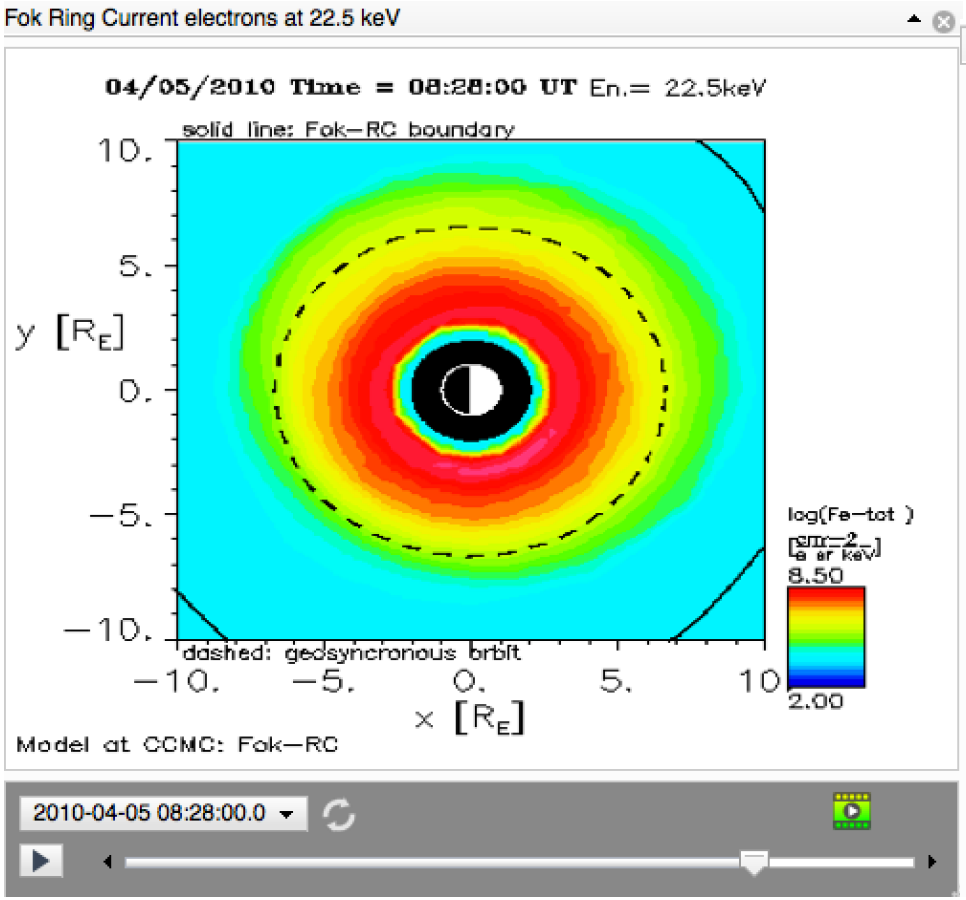


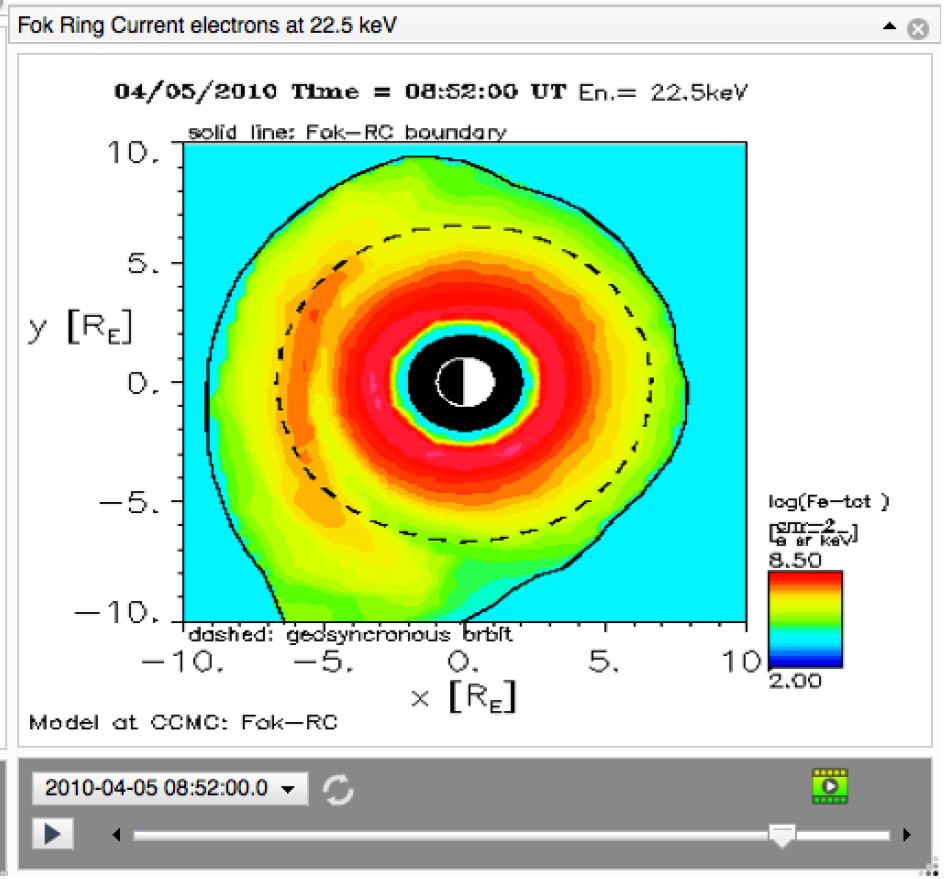

Key regions: Aurora Current Disruption Reconnection



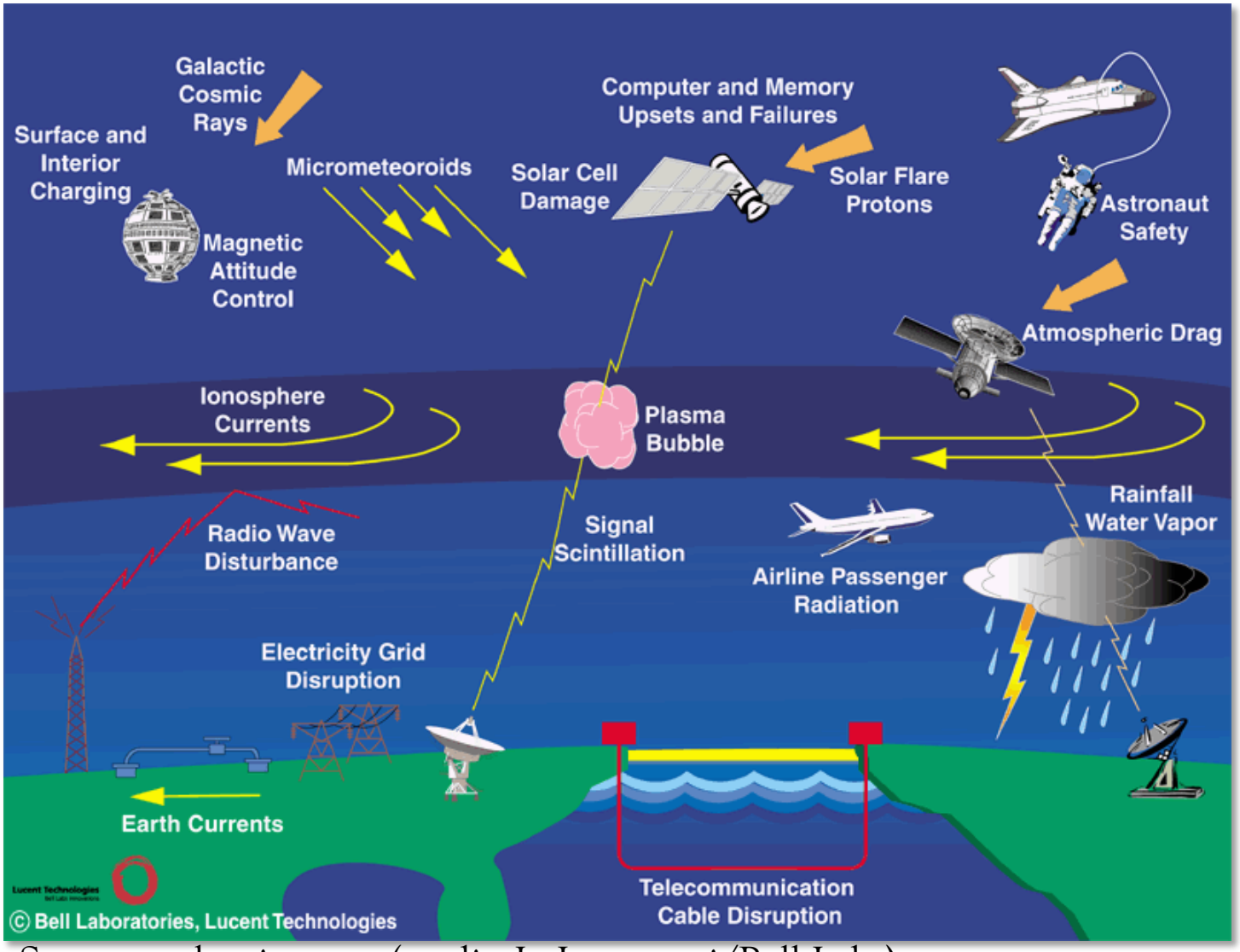

Horne et al., 2007, Nature Physics

# Ring Current:
# Quiet vs. Active



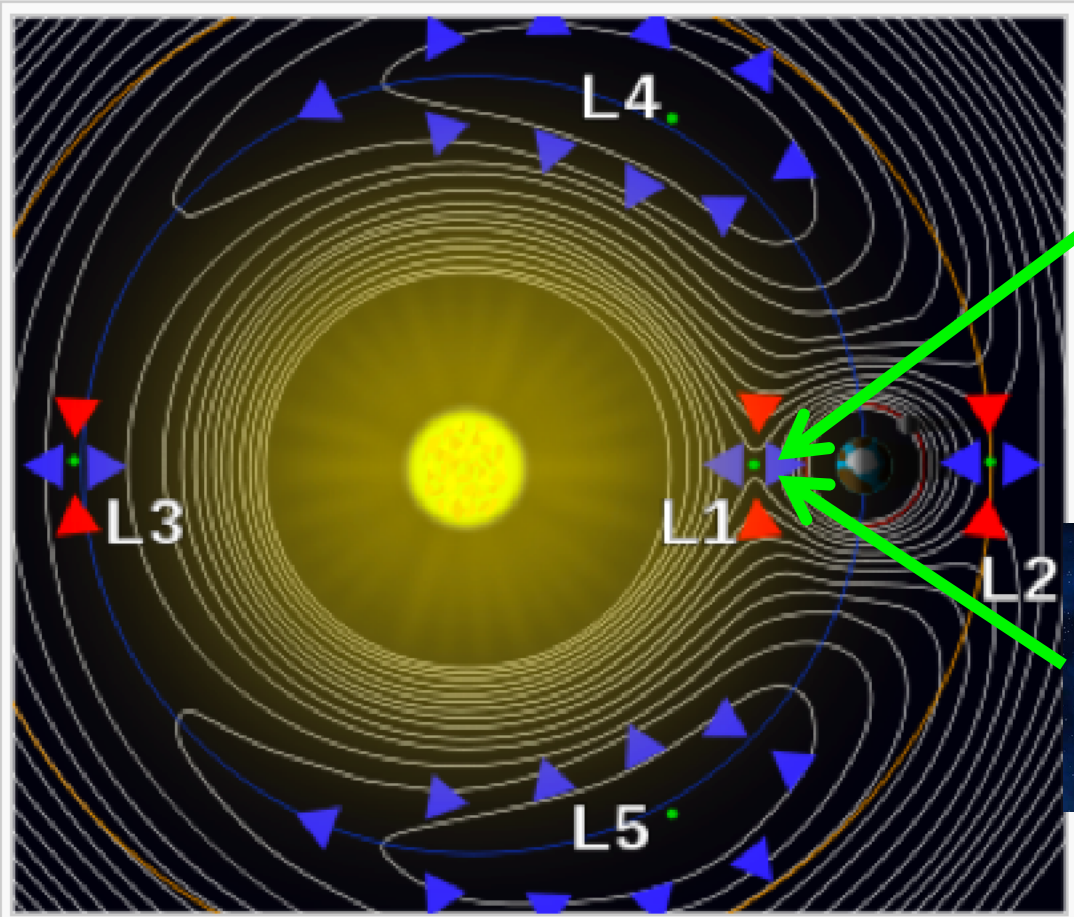



# Space Weather Impacts




Space weather impacts (credit: L. Lanzerotti/Bell Labs)

# Lagrange Point – L1




**A**dvanced
**C**omposition
**E**xplorer

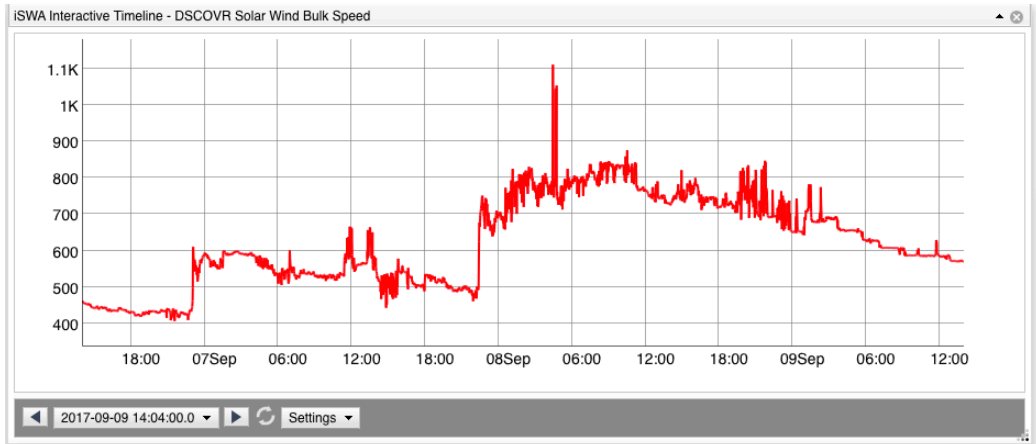
**DSCOVR**

**L1** (Solar Wind Monitor ACE/DSCOVR location): ~ 200 $R_E$ sunward
You can fit 1 Sun between the Earth and L1.
2 $R_S$ (Solar diameter) ~ 220 $R_E$

# Solar Wind Parameters at DSCOVR

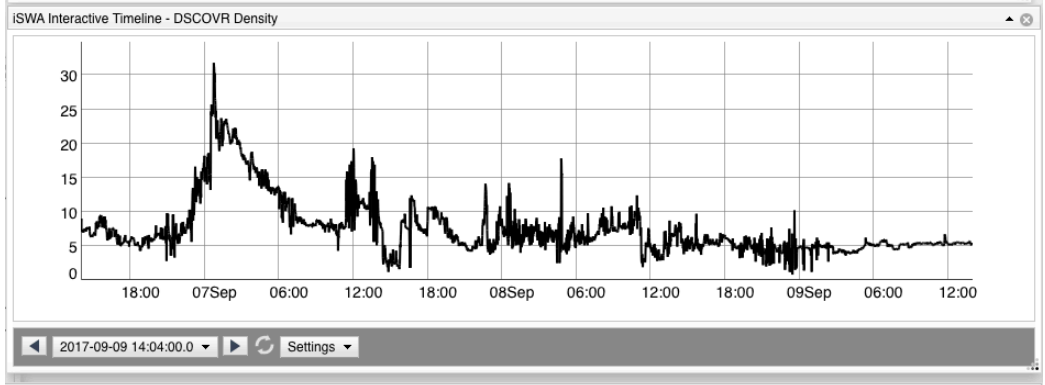
on 09/2017

km/s



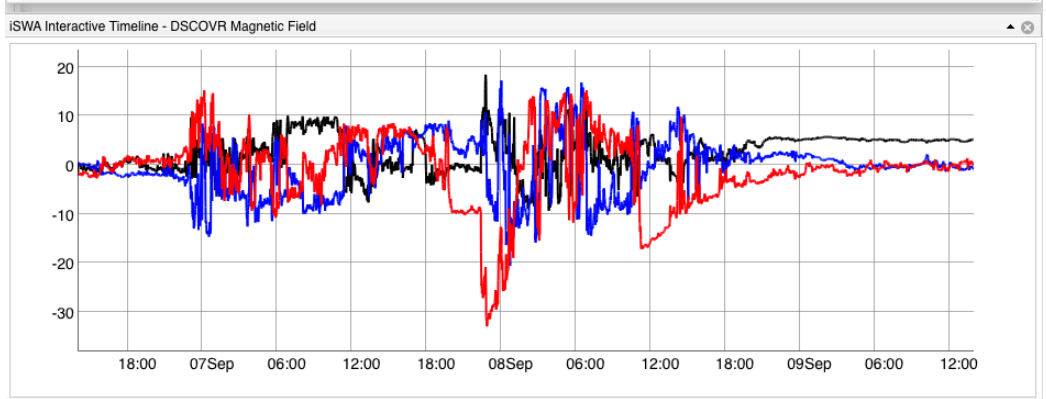

Velocity

part/cm$^3$




Density

nT




Magnetic field

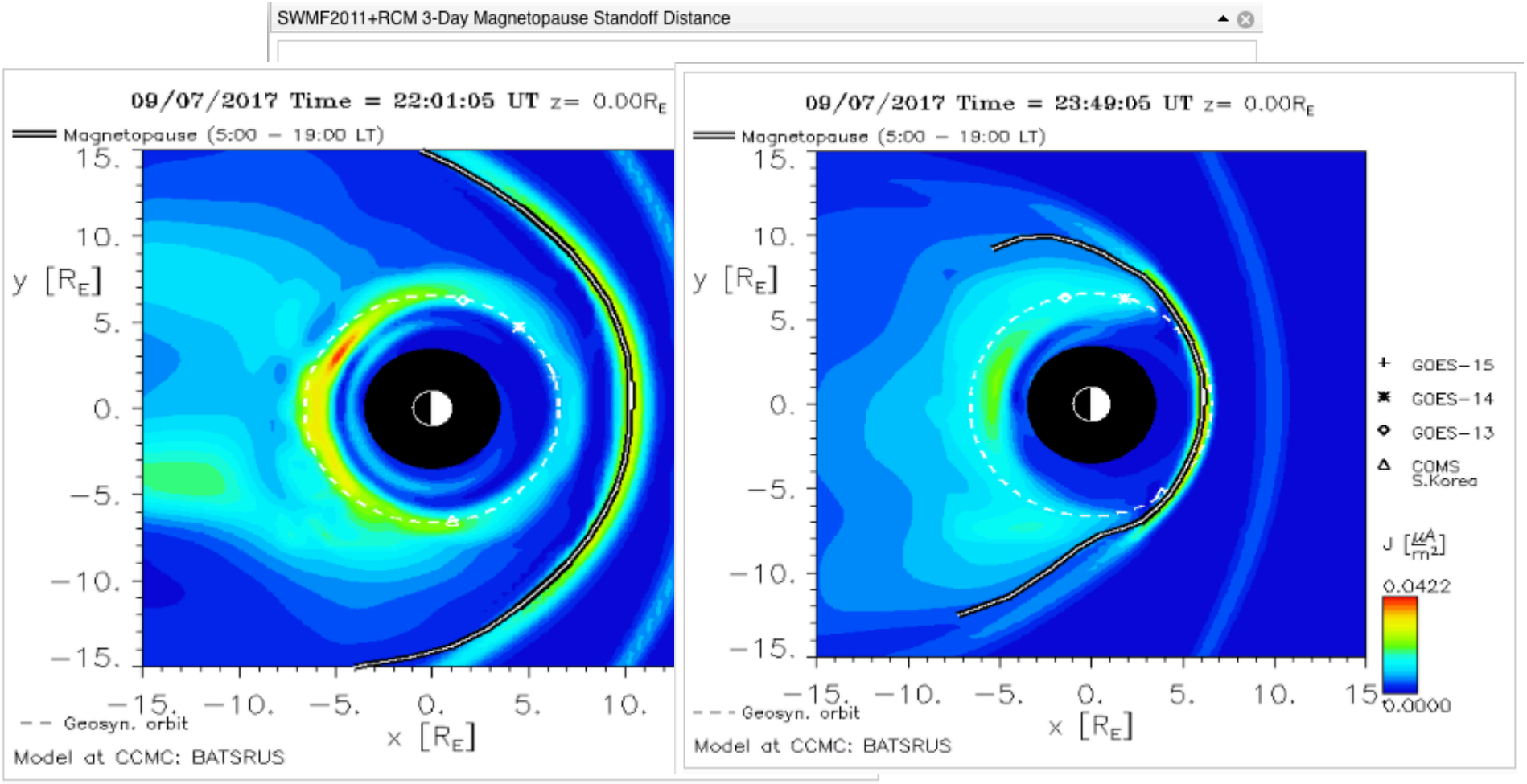
$B_x$, $B_y$, $B_z$

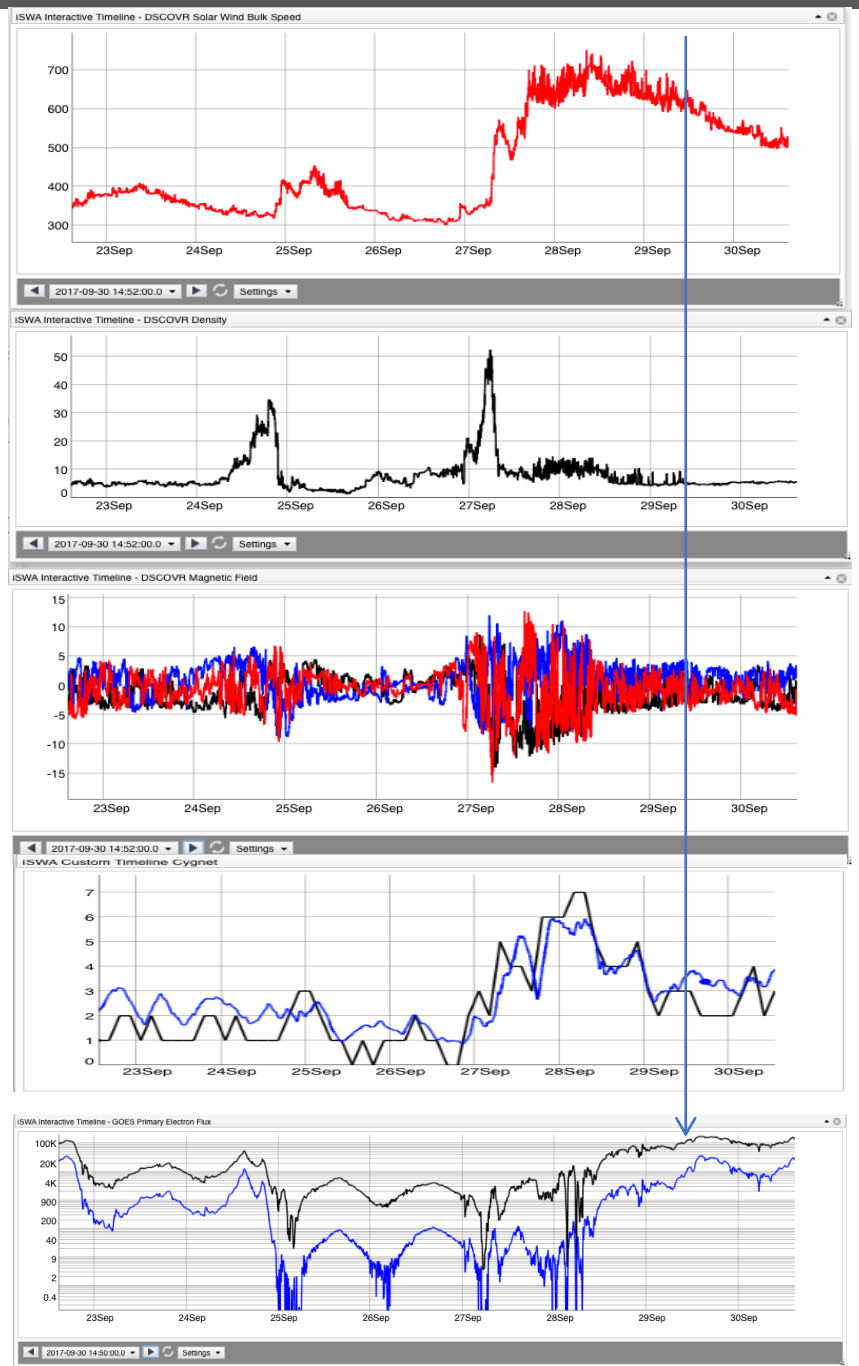
X: Earth to Sun

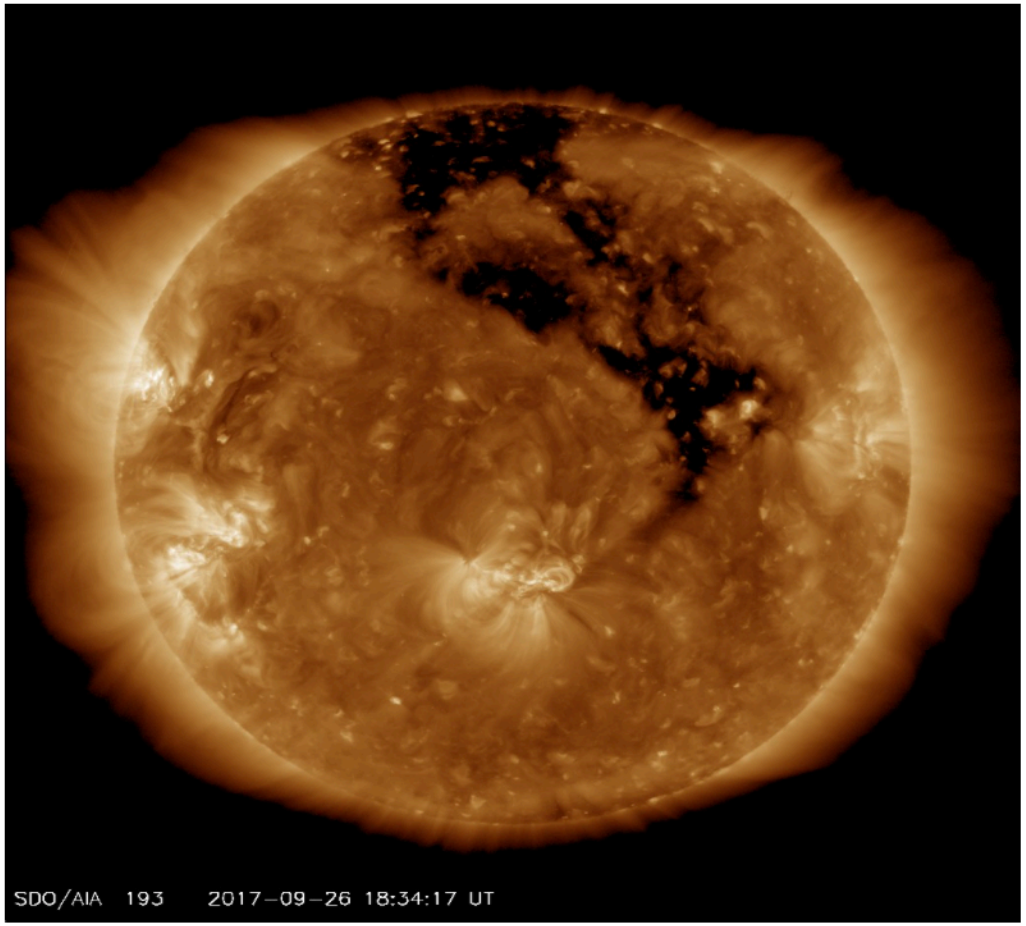
Z: North to South

# Magnetopause Stand-off Distance

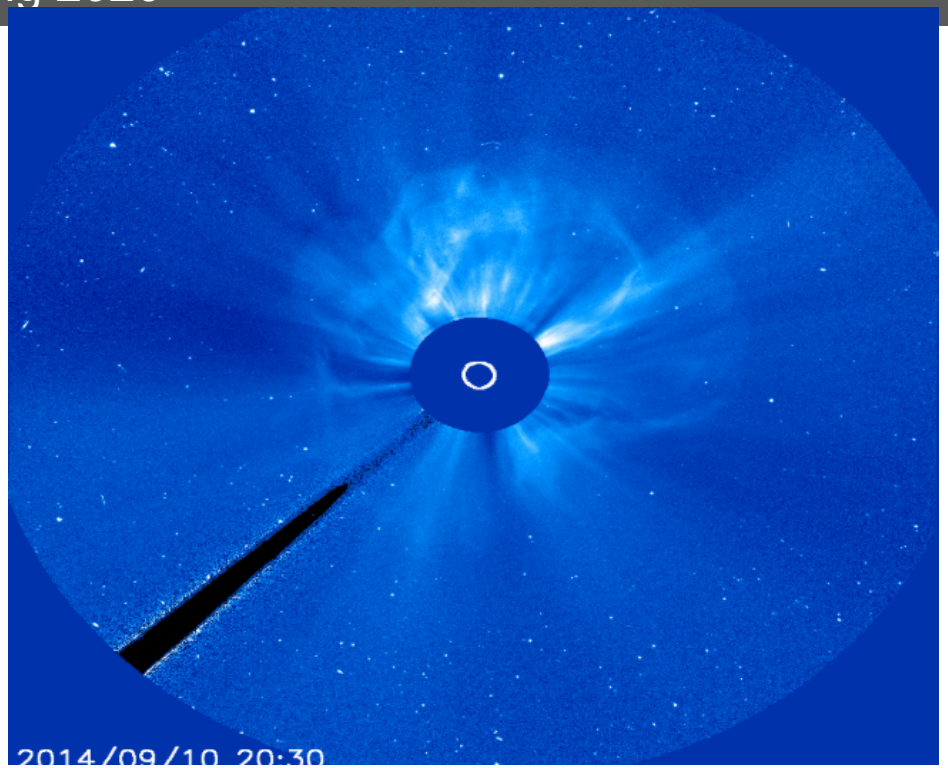
Degree of compression of MP due to dynamic pressure of solar wind






HSS and radiation belt electron flux enhancement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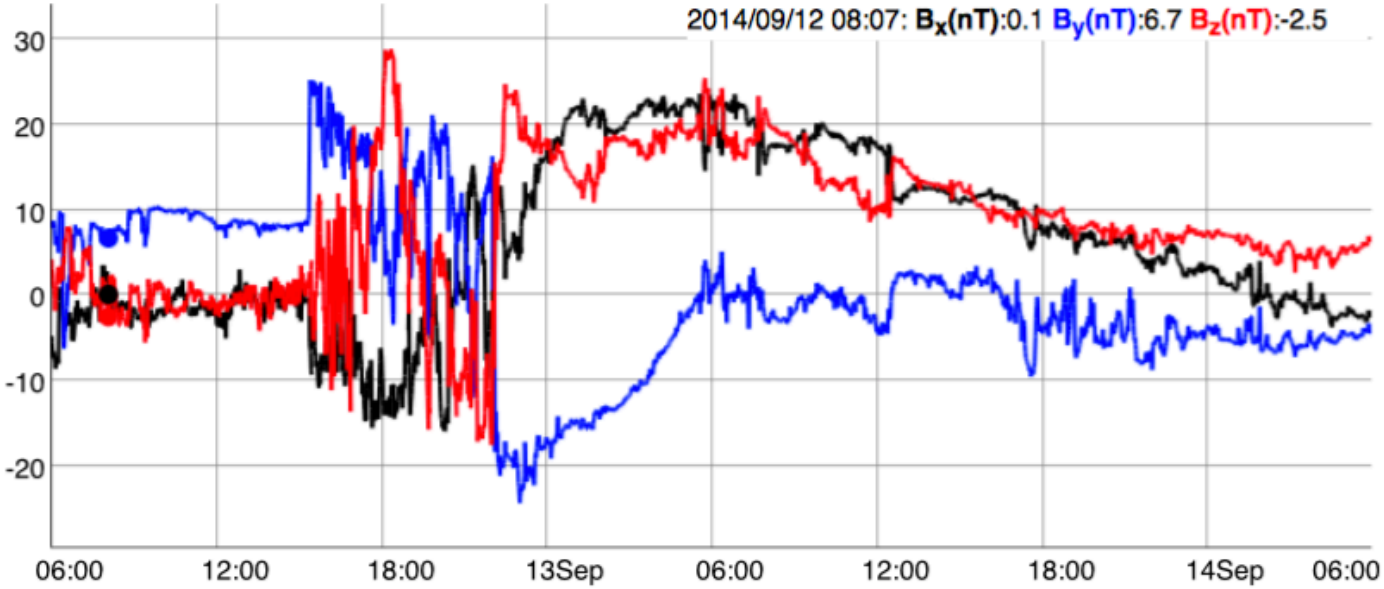
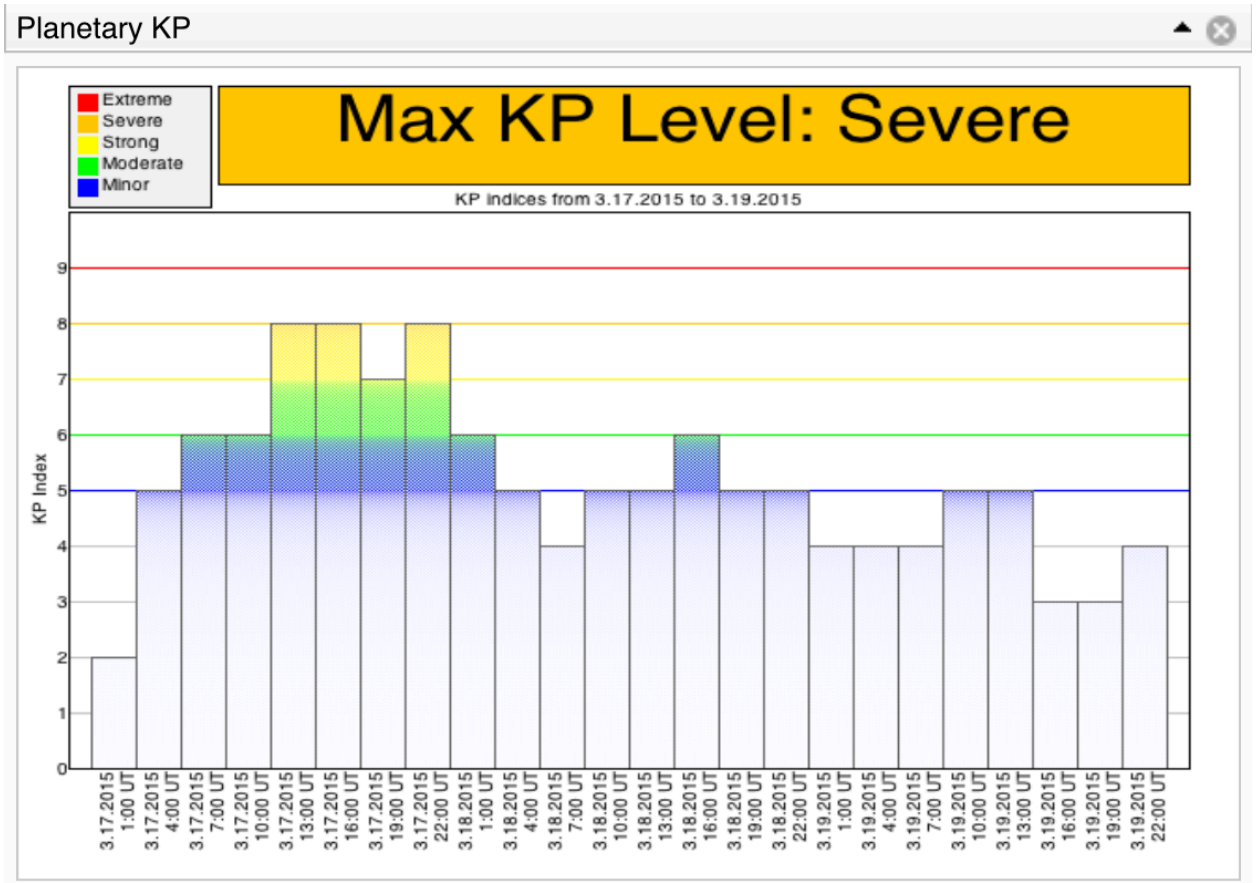

2014/09/12 08:07: $B_x$(nT):0.1 $B_y$(nT):6.7 $B_z$(nT):-2.5
30
20
10
0
-10
-20
06:00
12:00
18:00
13Sep
06:00
12:00
18:00
14Sep
06:00

# Kp index

"*p*lanetarische *K*ennziffer" ( = planetary index).

- Geomagnetic activity index - range from 0-9 disturbance levels of magnetic field on the ground – currents




Threshold Kp>=6

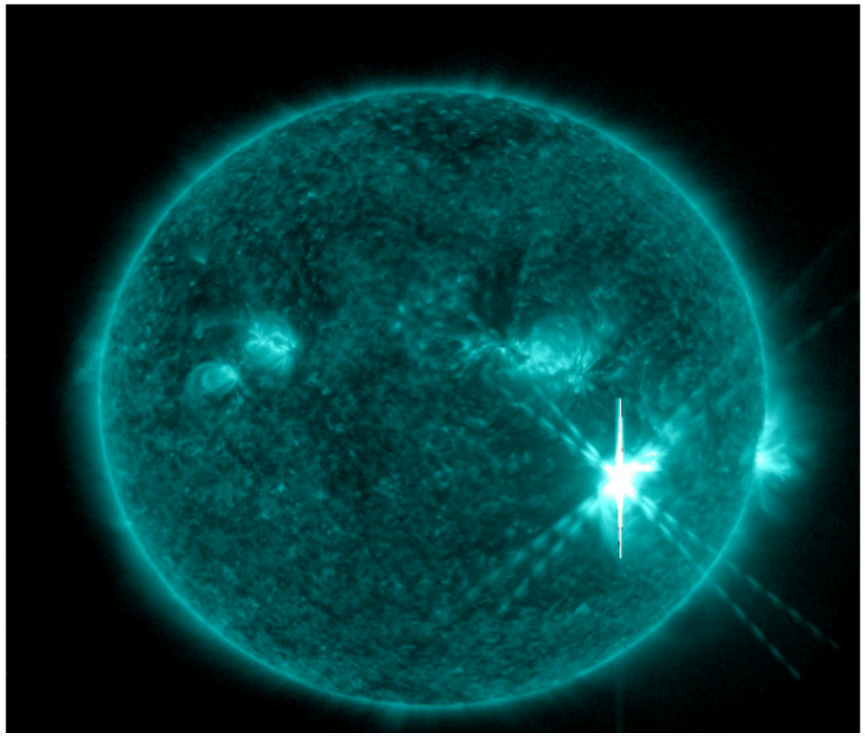
# Energetic Proton Flux

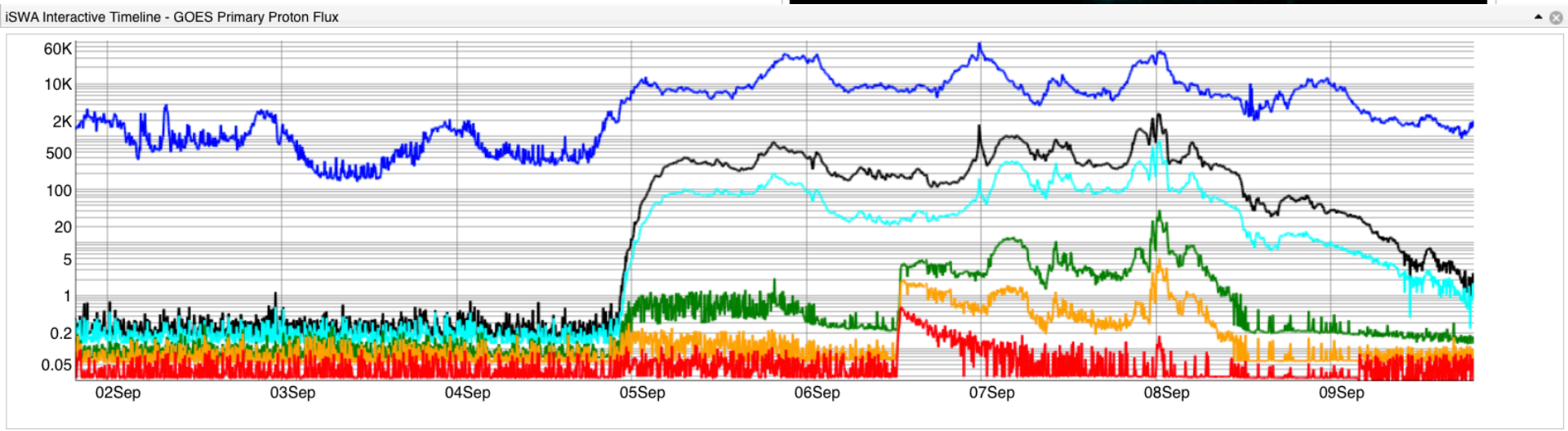
- >10 MeV flux by GOES spacecraft

Threshold: 10 pfu

- >100 MeV flux by GOES spacecraft

Threshold: 1 pfu





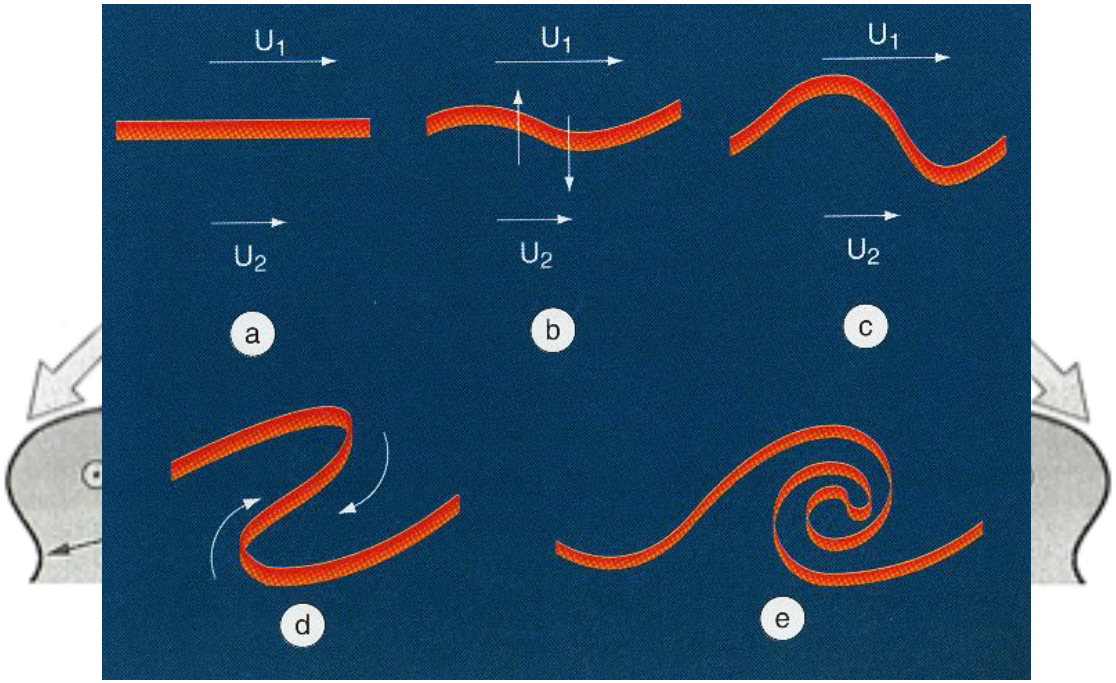
# Watch the video

# iSWA Layout:
# 07/12/2012

http://goo.gl/V0JjxV

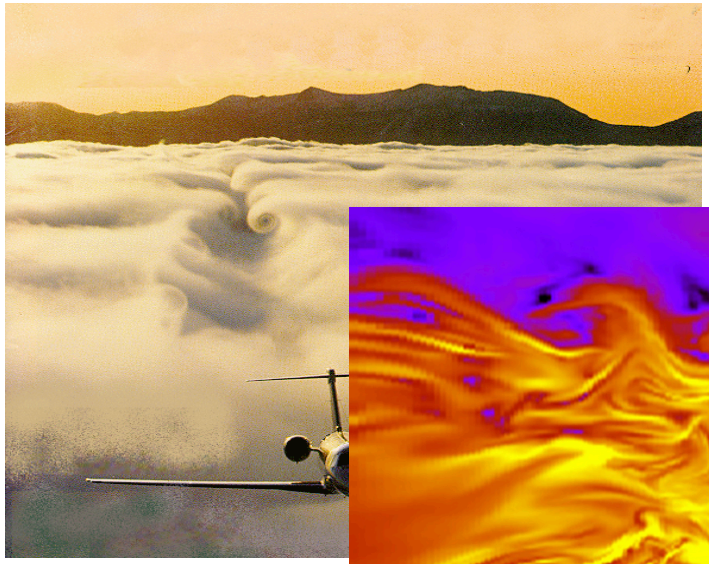
# Magnetosphere Physics Research

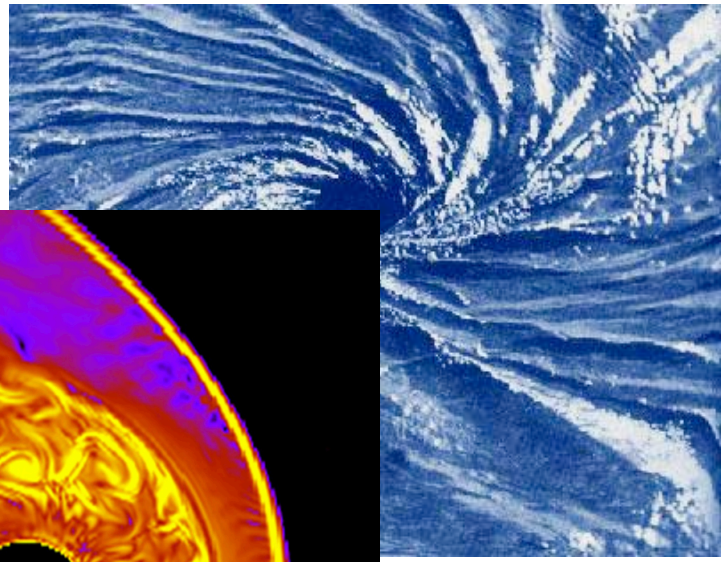
## Kelvin-Helmholtz Instability

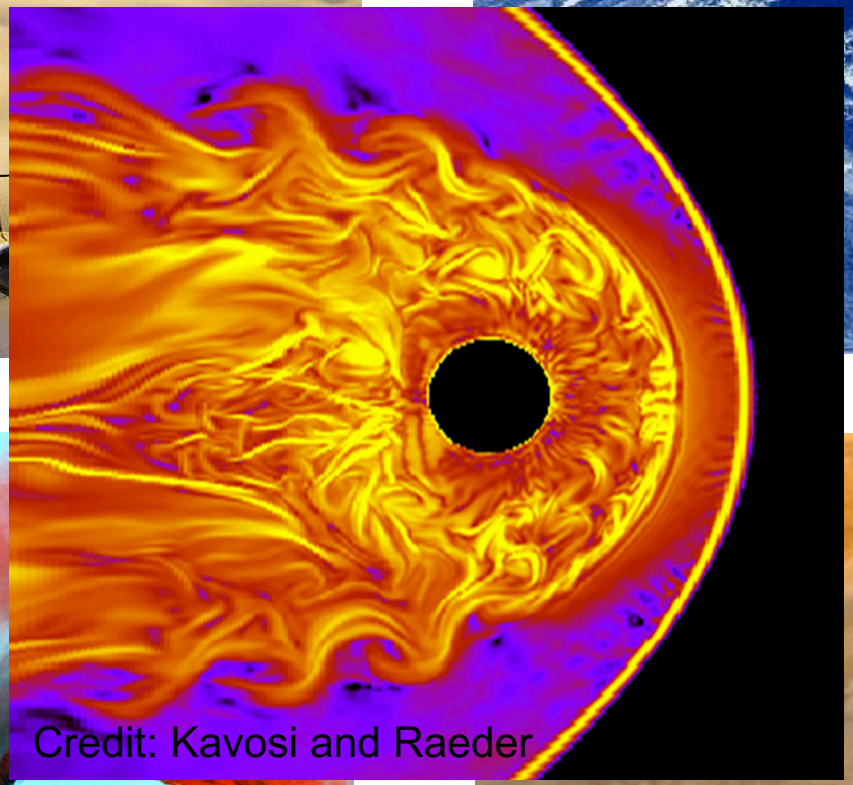



- Waves that occur between the velocity shear of two fluids.
- It creates vortices on the magnetopause, specially on the flanks.
- Predominantely at high solar wind velocities and northward IMF (positive Bz) component.
- Many scientific models have been created to study these two parameters: the flow velocity and the magnetic field.

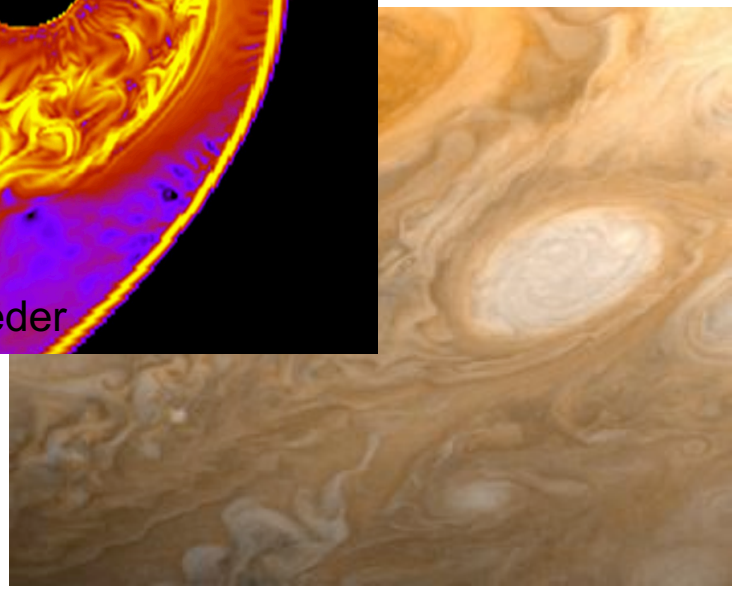
# Examples of Kelvin-Helmholtz Instability





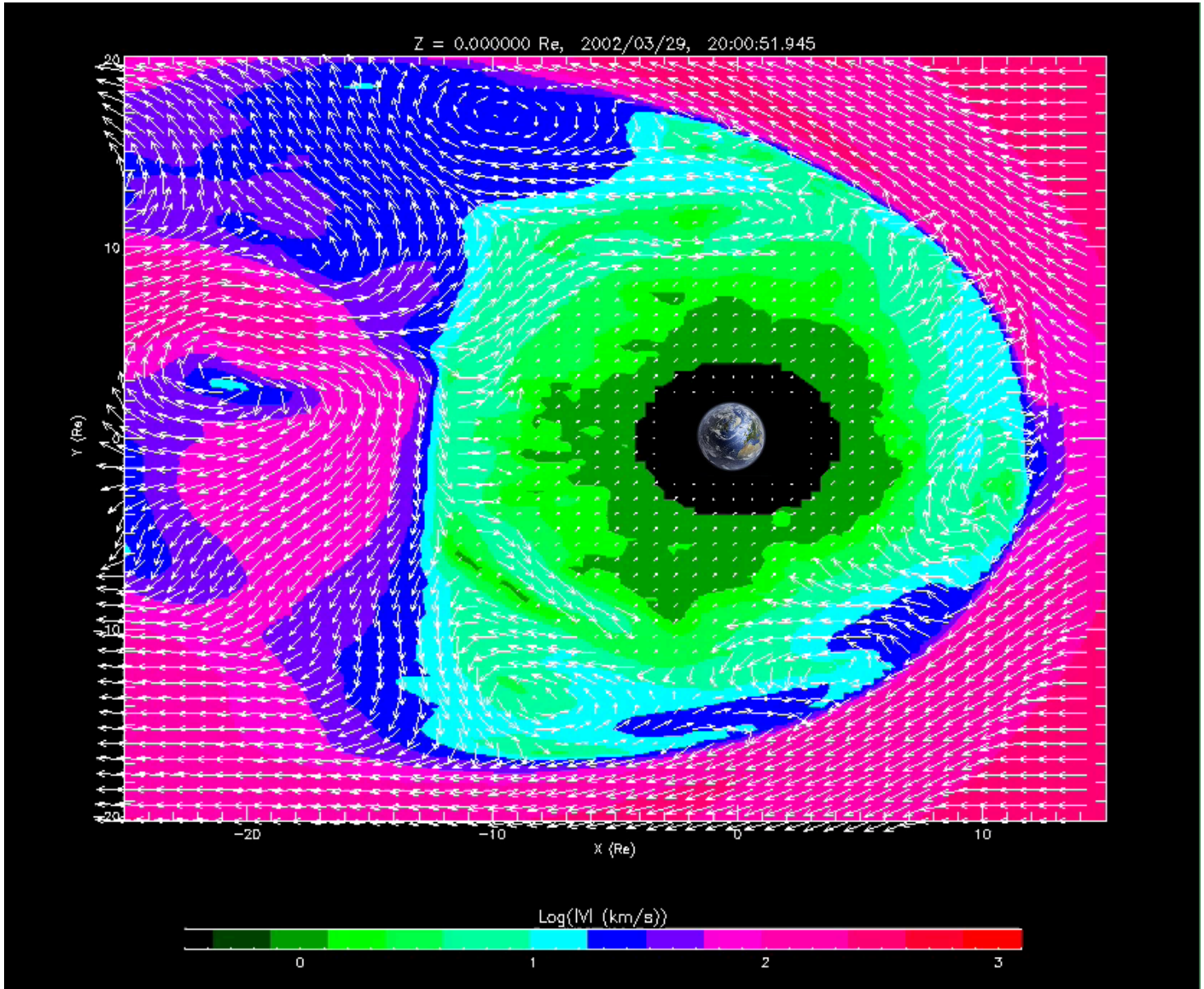


Credit: Kavosi and Raeder



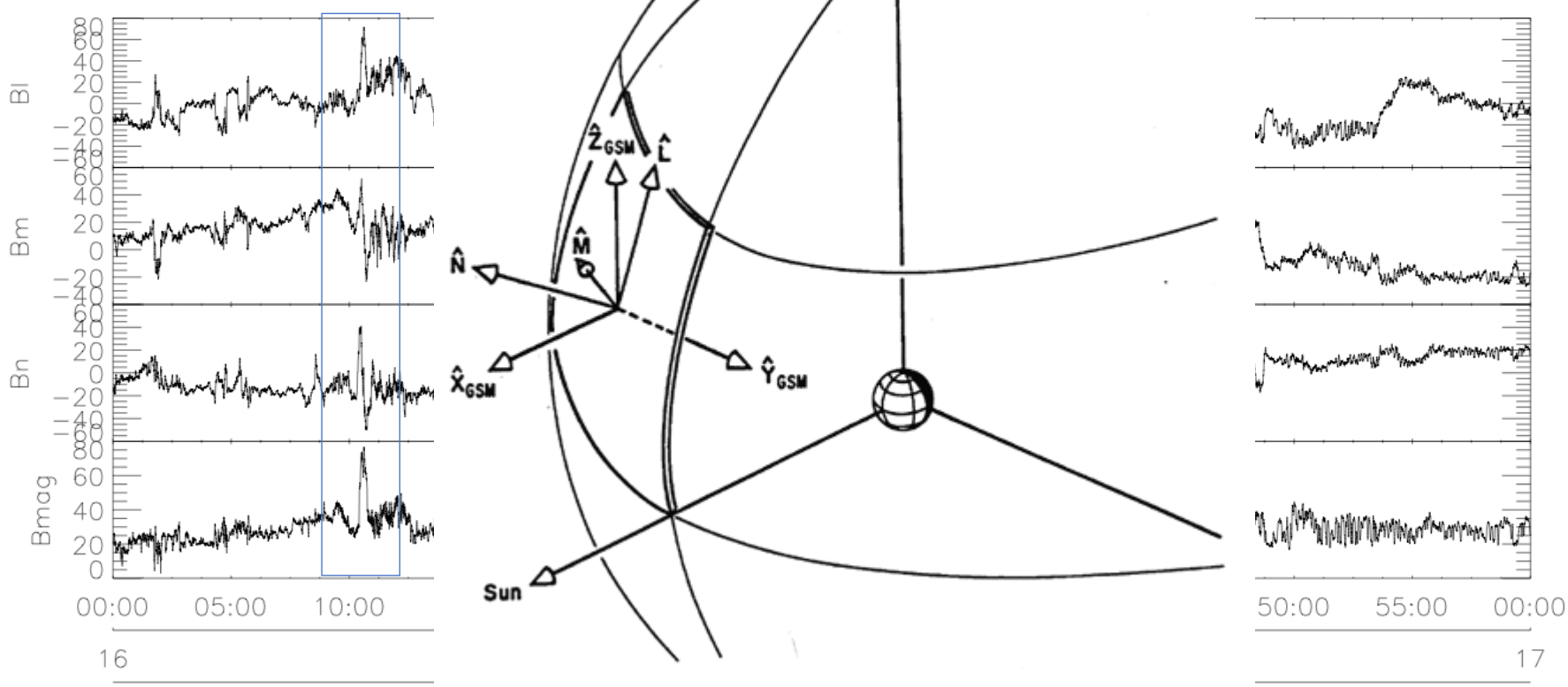
# Magnetosphere Physics Research

Collado-Vega, Y. M., et al., JGR, 2007 and 2013



# Flux Transfer Events (FTEs)

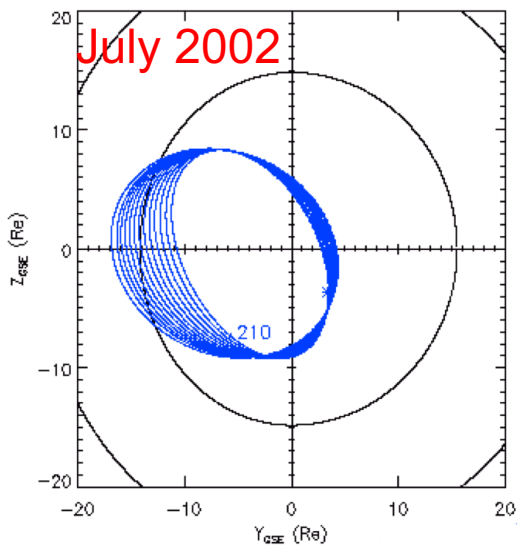
Flux Transfer Events (FTE's) are magnetopause signatures that result from the passage of flux ropes produced by reconnection.

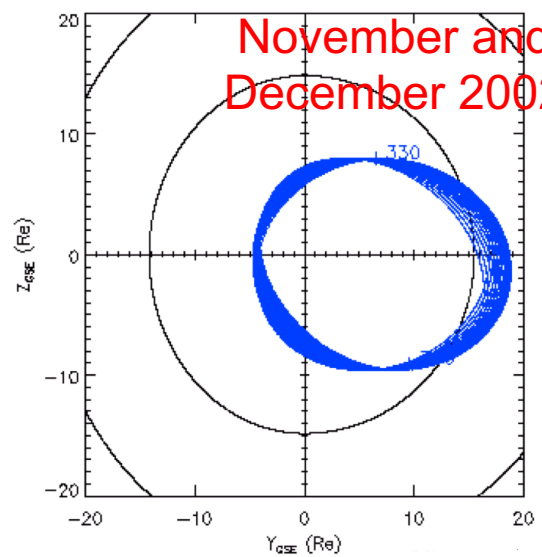


From Collado-Vega, Y. M., Ph.D. Thesis, 2013

Largest – 386 km/s

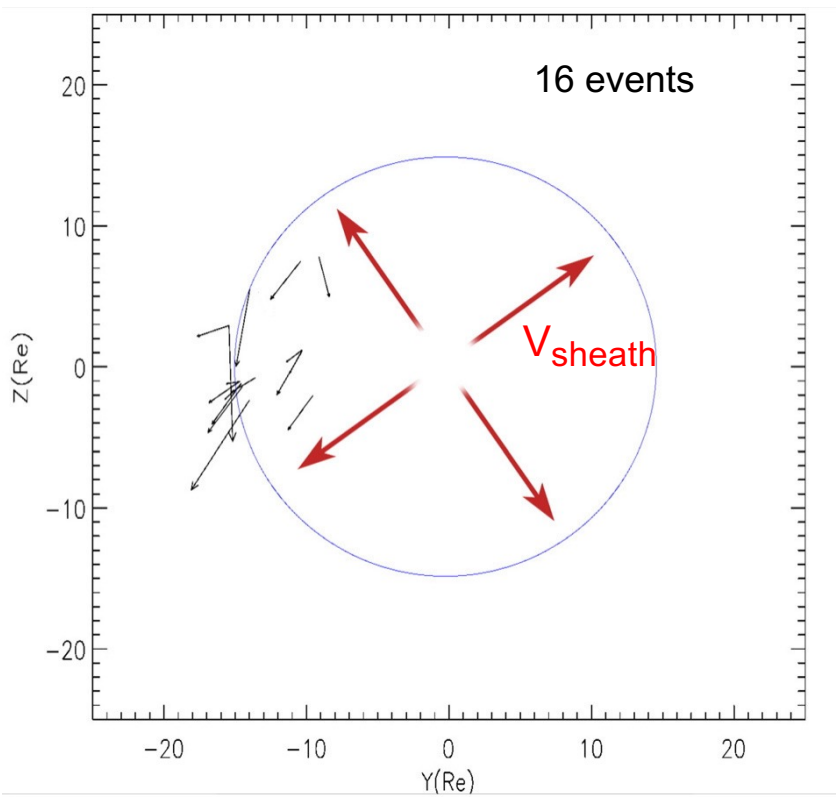
Smallest – 90 km/s

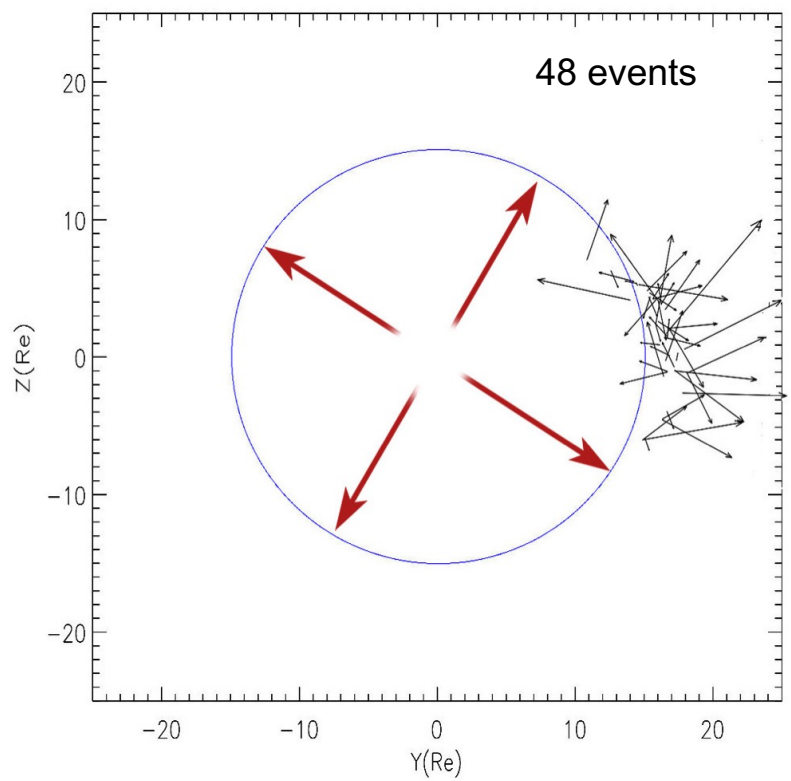


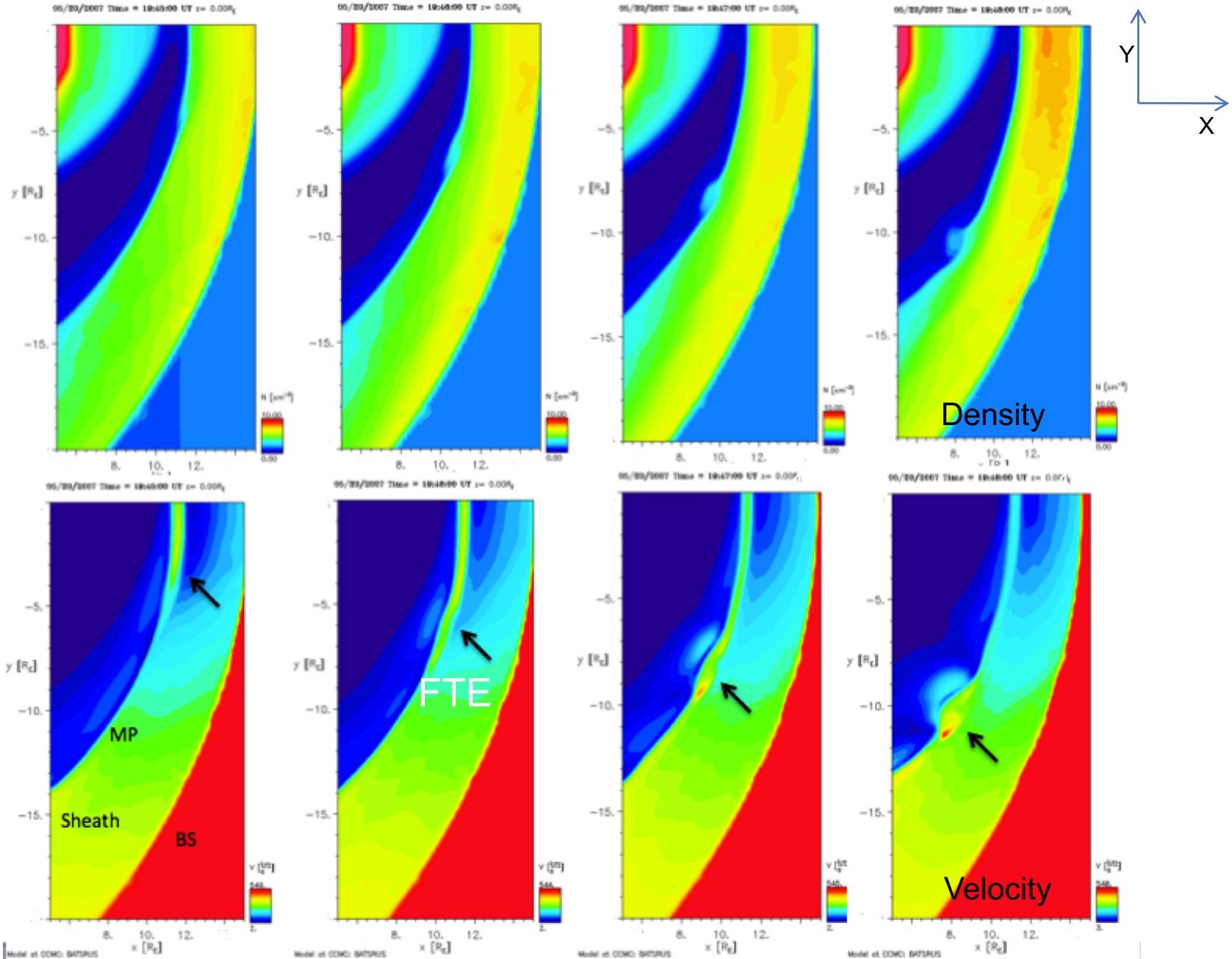

Largest – 412 km/s

Smallest – 92 km/s



# MHD Simulations (19:45-19:48 UT)



# Magnetopause Stand-off Position

From Collado-Vega, Y. M., et al., In progress