

Recap and Space Weather In the Magnetosphere (II)

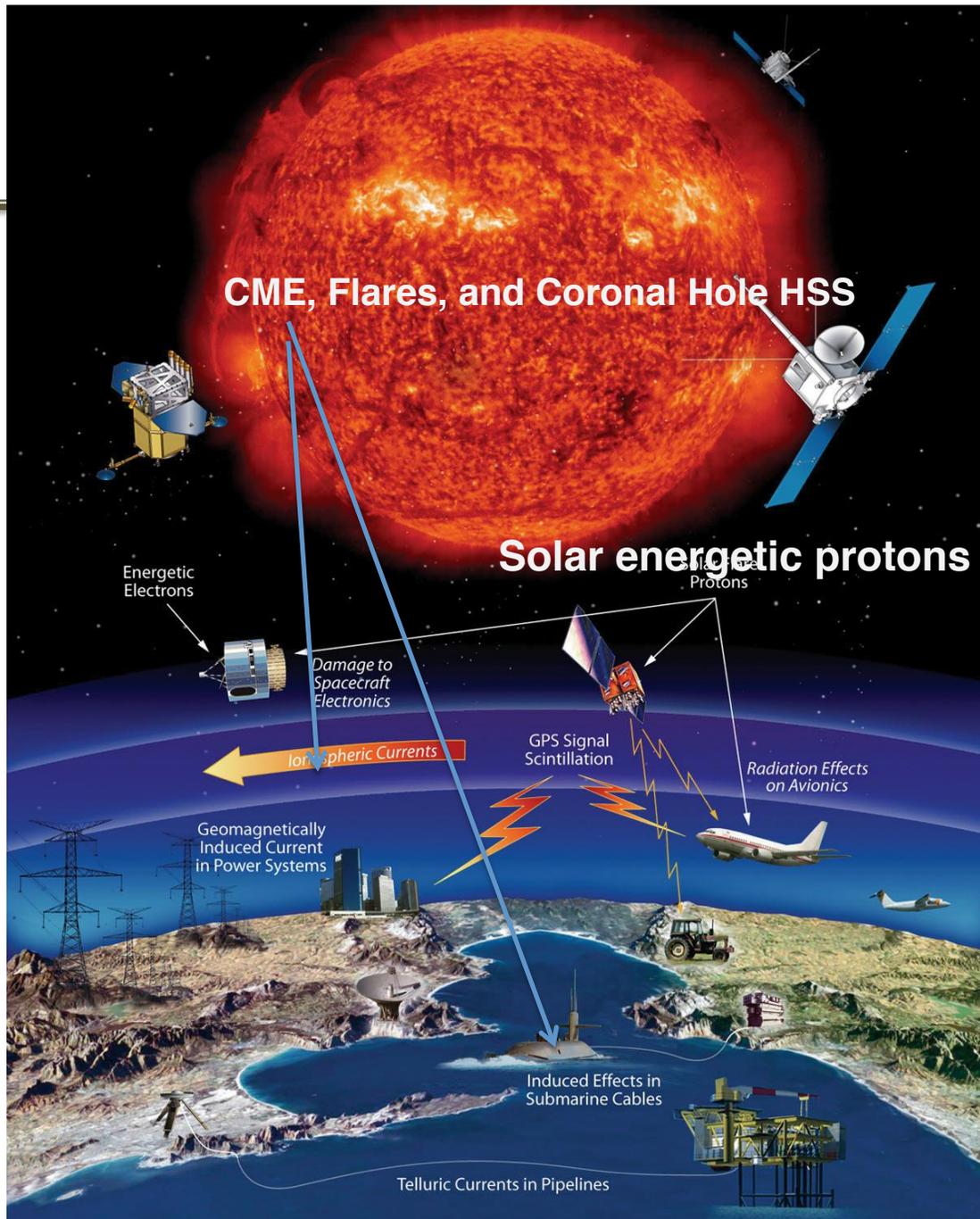
Yihua Zheng

SW REDI

June 5, 2014



Recap



The Sun maker of space weather

CME, Flares, and Coronal Hole HSS

Three very important solar wind
disturbances/structures for space
weather

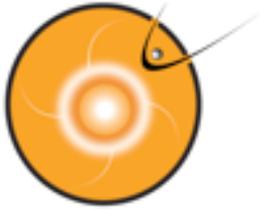
✓ Radiation storm

- proton radiation (SEP) <flare/CME>
- electron radiation <CIR HSS/CME>

✓ Radio blackout storm <flare>

✓ Geomagnetic storm

- CME storm (can be severe)
- CIR storm (moderate)



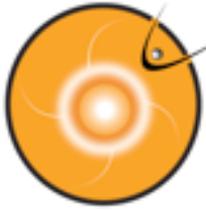
Outline



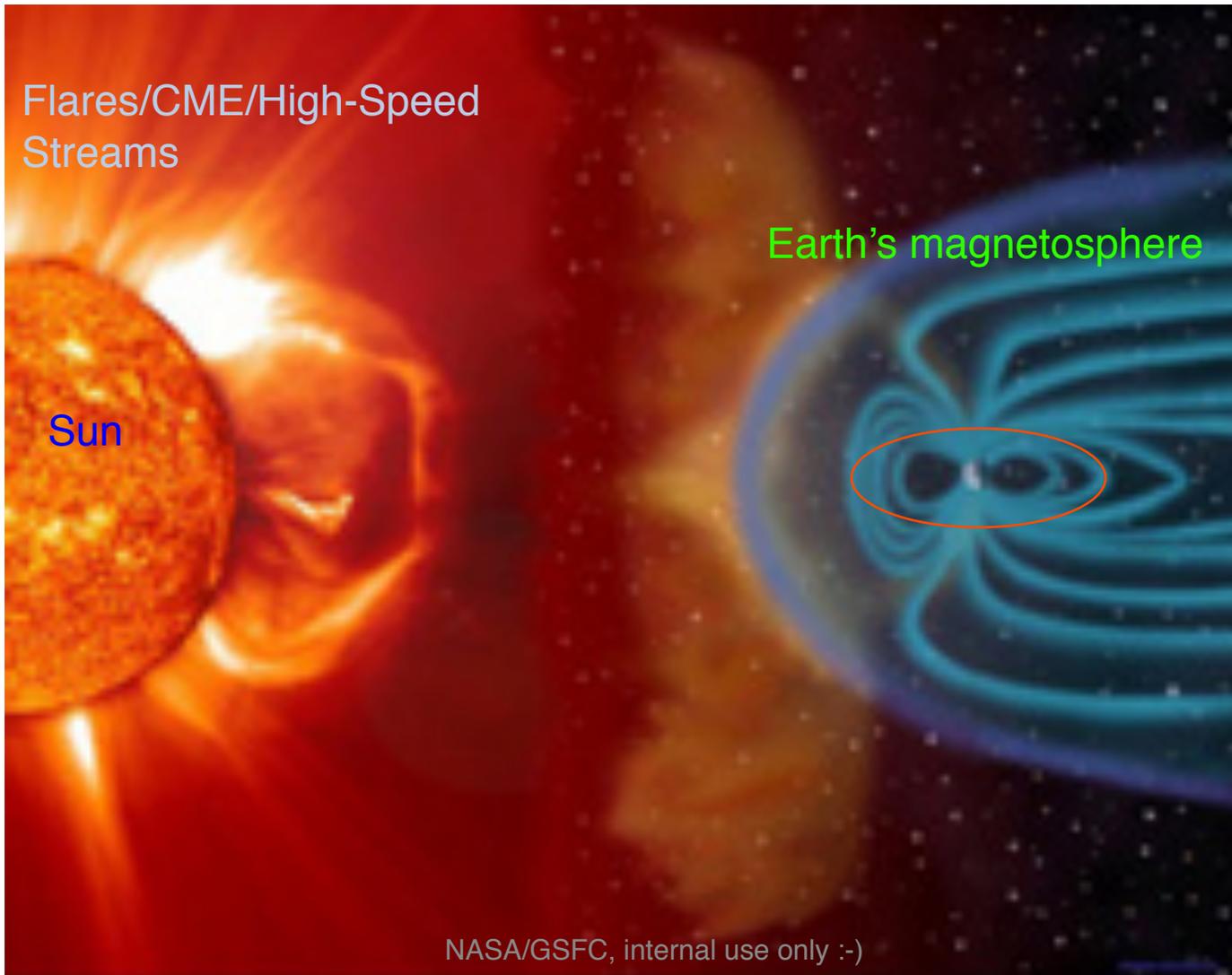
- Solar wind +magnetosphere interactions
- CIR/HSS and CME impacts on Earth
- Importance of magnetosphere in space weather

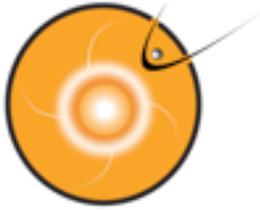
Geomagnetic storm

- **CME storm (can be severe)**
- **CIR storm (moderate)**



The solar wind pushes and stretches Earth's magnetic field into a vast, 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.





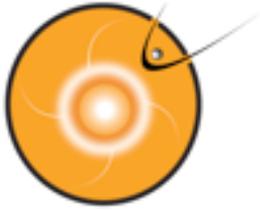
Two Main Drivers for the Magnetosphere



- CME (you have seen plenty of them already)
- CIR (Corotating Interaction Region) High Speed solar wind Stream (HSS)

Geomagnetic storm

- **CME storm (can be severe) Kp can reach 9**
- **CIR storm (moderate) Kp at most 6**



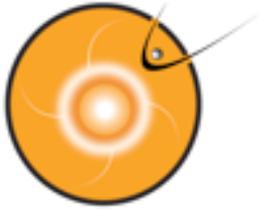
CME Example



- March 7, 2012 CMEs associated with two x-class flares

[iSWA layout](#)

Associated with an Active Region

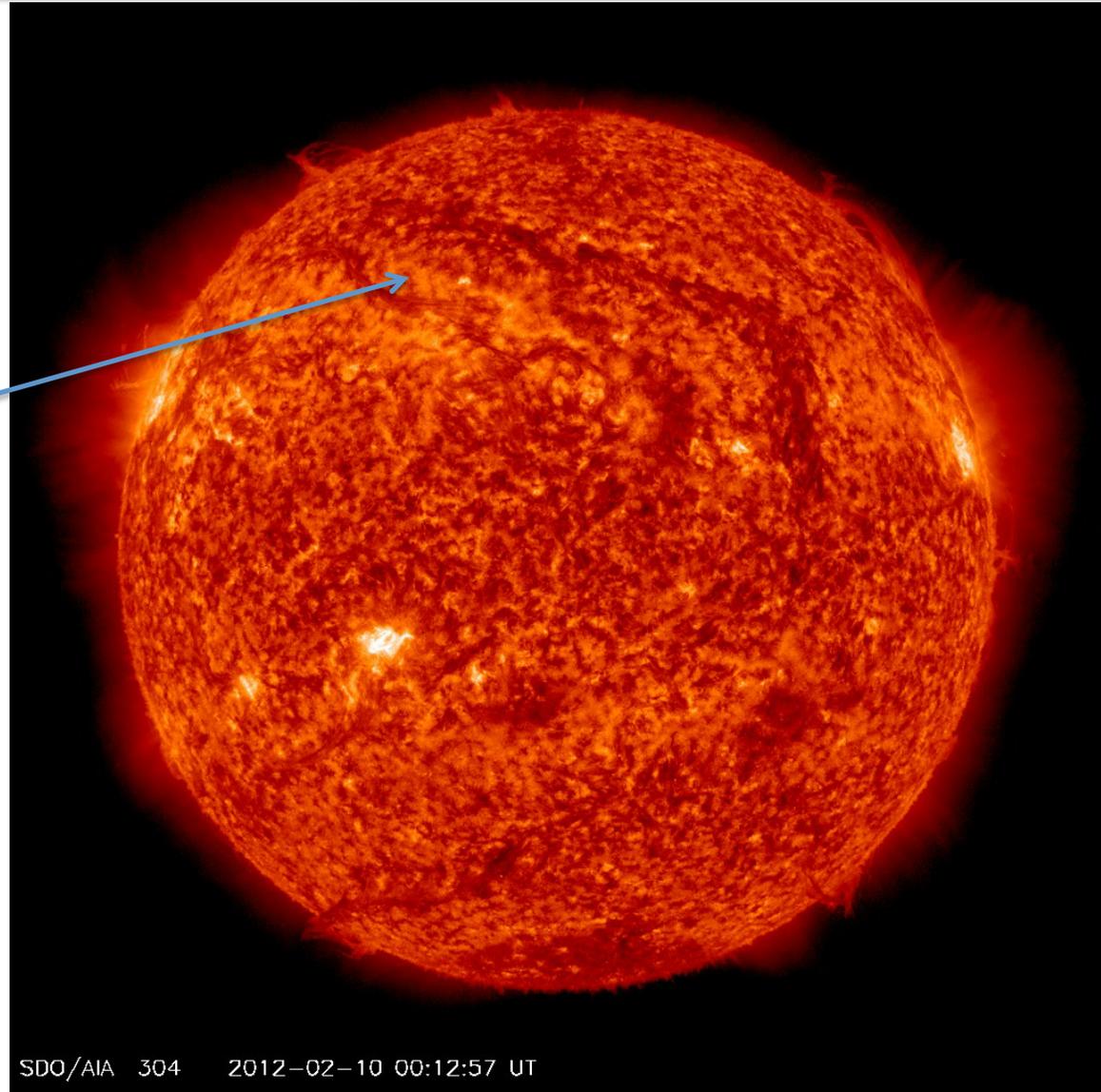


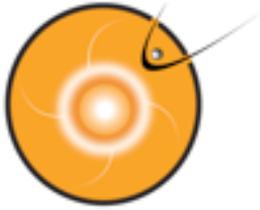
CME from Filament eruption



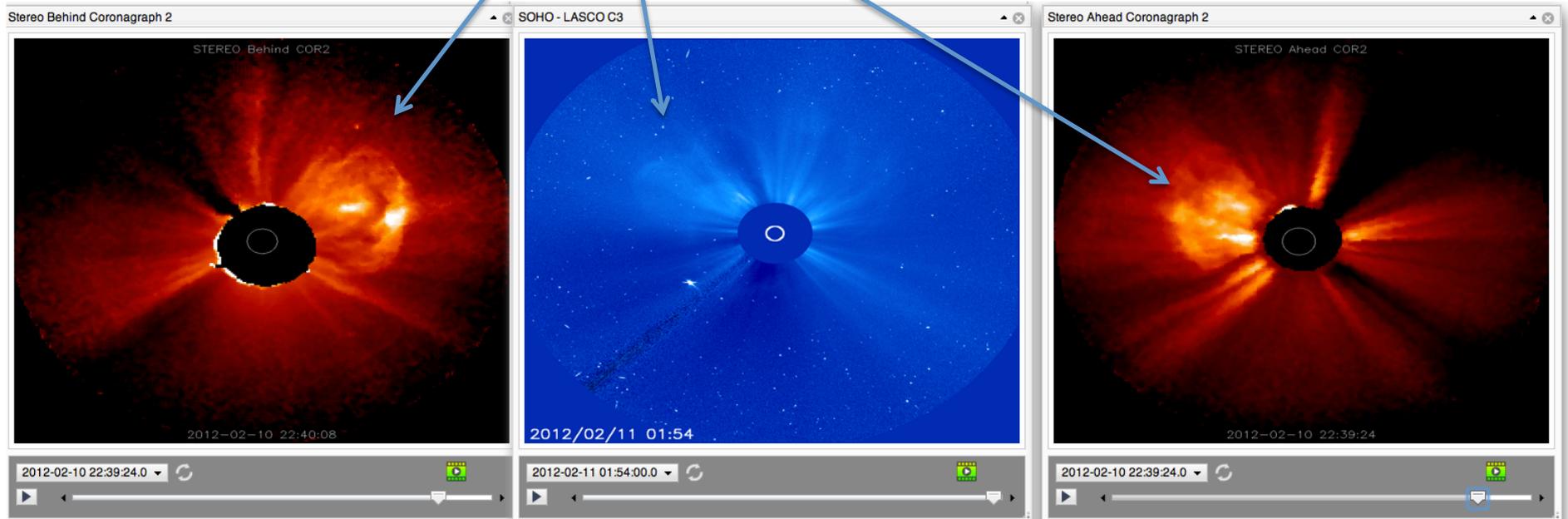
A movie

Northeast (upper left) quadrant starting around 19:00 UT on Feb 10, 2012





The associated CME

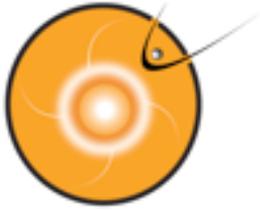


STEREO B

SOHO

STEREO A

Heart-shaped



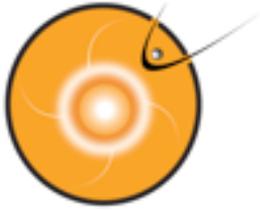
Coronal Hole HSS



Is one important space weather contributor too!

Particularly **for its role in enhancing electron radiation levels near GEO orbit** and for substantial energy input into the Earth's upper atmosphere

May be more hazardous to Earth-orbiting satellites than CME-related magnetic storm particles and solar energetic particles (SEP)

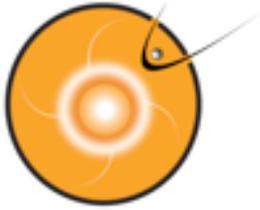


CIR and HSS



Co-rotating Interactive Regions (CIRs) are regions within the solar wind where streams of material moving at different speeds collide and interact with each other. The speed of the solar wind varies from less than 300 km/s (about half a million miles per hour) to over 800 km/s depending upon the conditions in the corona where the solar wind has its source. Low speed winds come from the regions above [helmet streamers](#) while high speed winds come from [coronal holes](#).

As the Sun rotates these various streams rotate as well (co-rotation) and produce a pattern in the solar wind much like that of a rotating lawn sprinkler. However, if a slow moving stream is followed by a fast moving stream the faster moving material will catch-up to the slower material and plow into it. This interaction produces shock waves that can accelerate particles to very high speeds (energies).



COROTATING FLOW (INERTIAL FRAME)

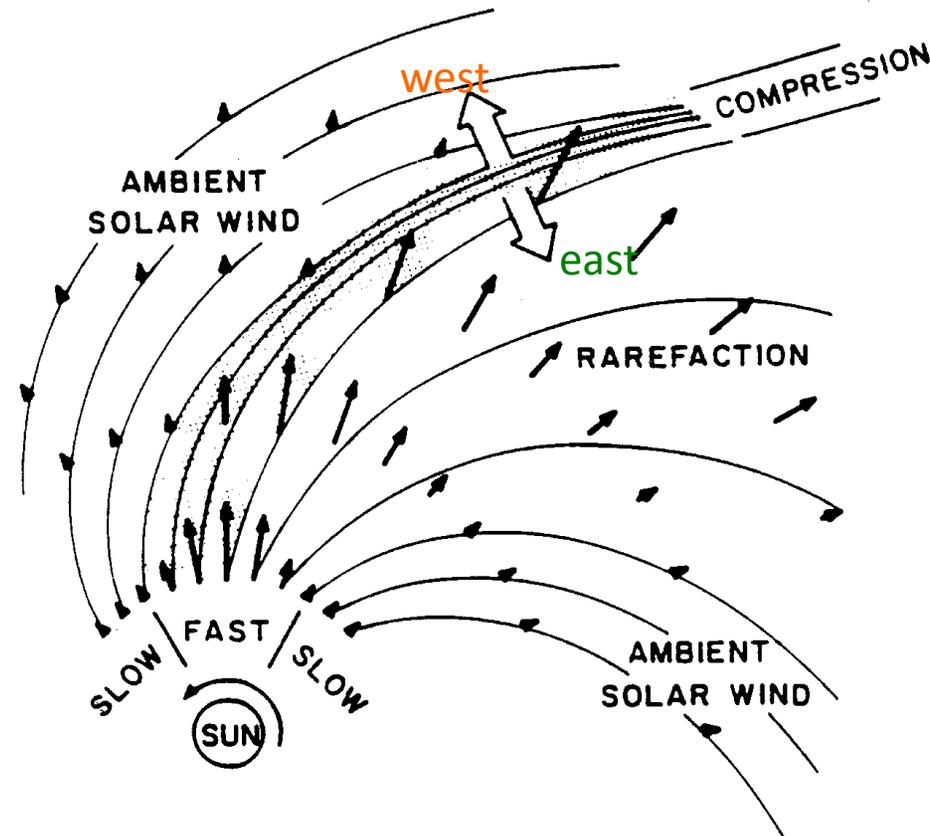
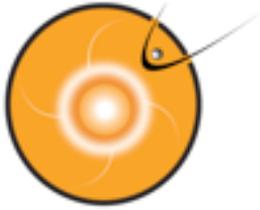
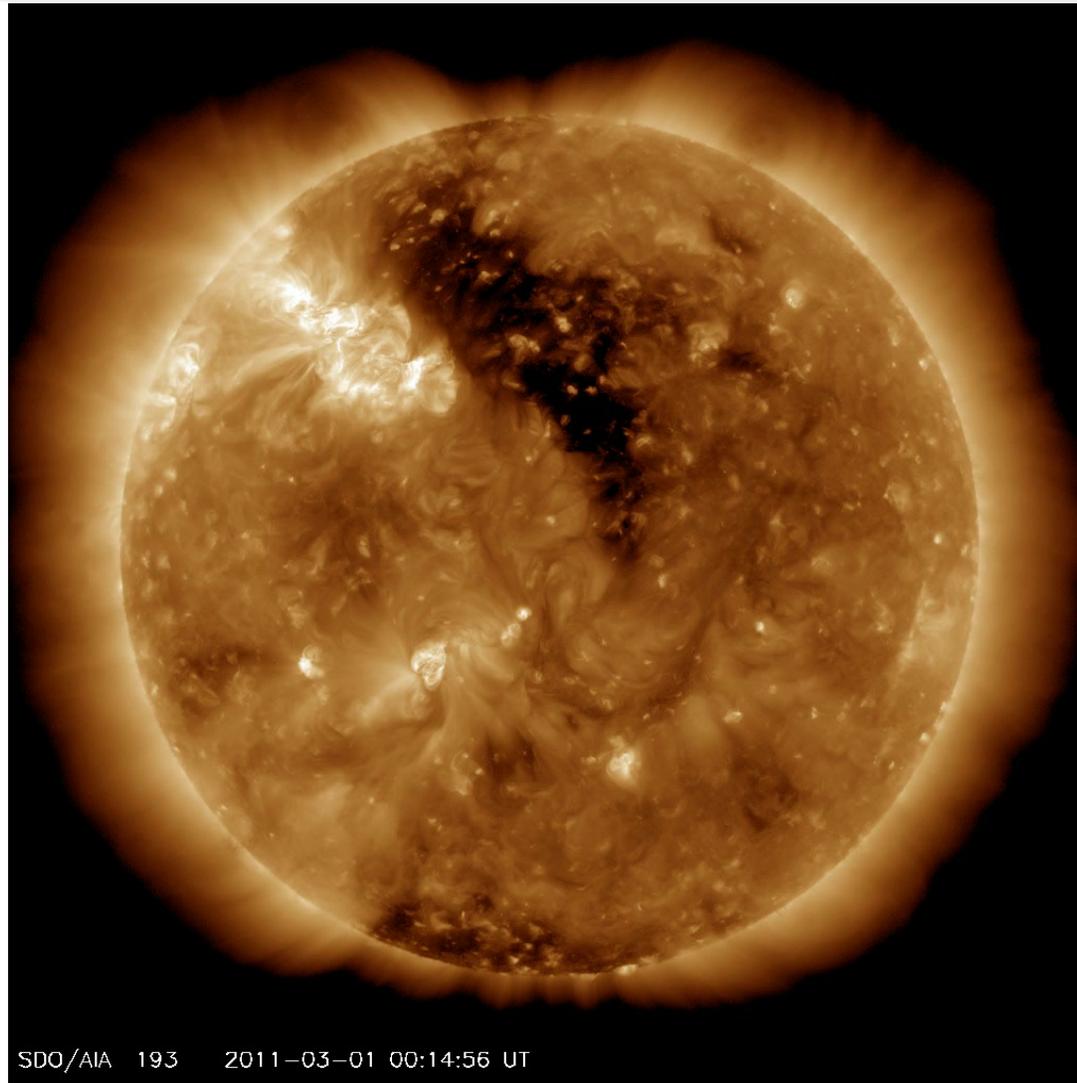


Figure 6. Schematic illustrating 2-D corotating stream structure in the solar equatorial plane in the inner heliosphere (from Pizzo, 1978).

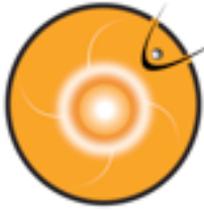


Coronal Hole HSS

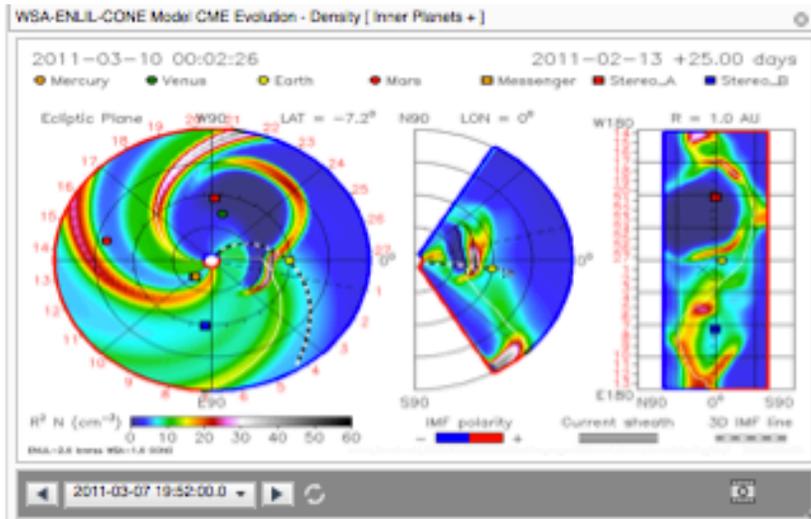


Mar 1, 2011

June 4, 2012

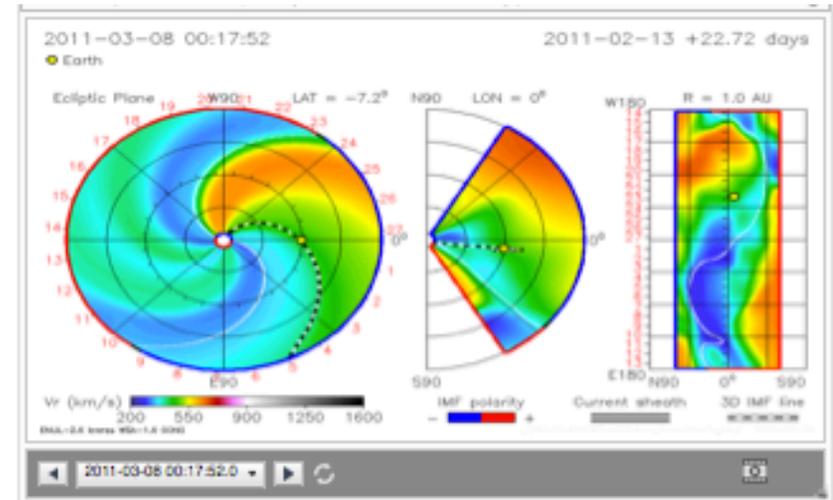


Forecasting capability enabled by ENLIL



WSA+ENLIL+cone

Predicting impacts of CMEs



WSA+ENLIL

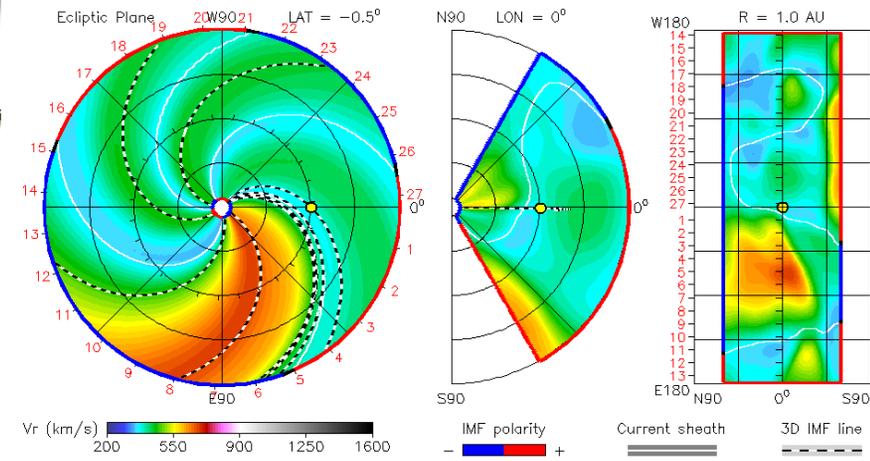
Modeling and predicting the ambient solar wind

2012-06-01T19:00
 ● Earth

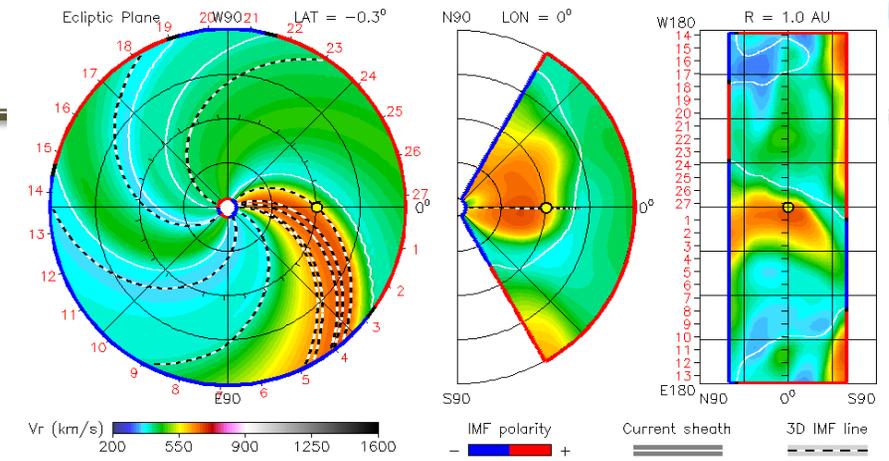
2012-05-10T01 +22.73 days

2012-06-04T10:00
 ● Earth

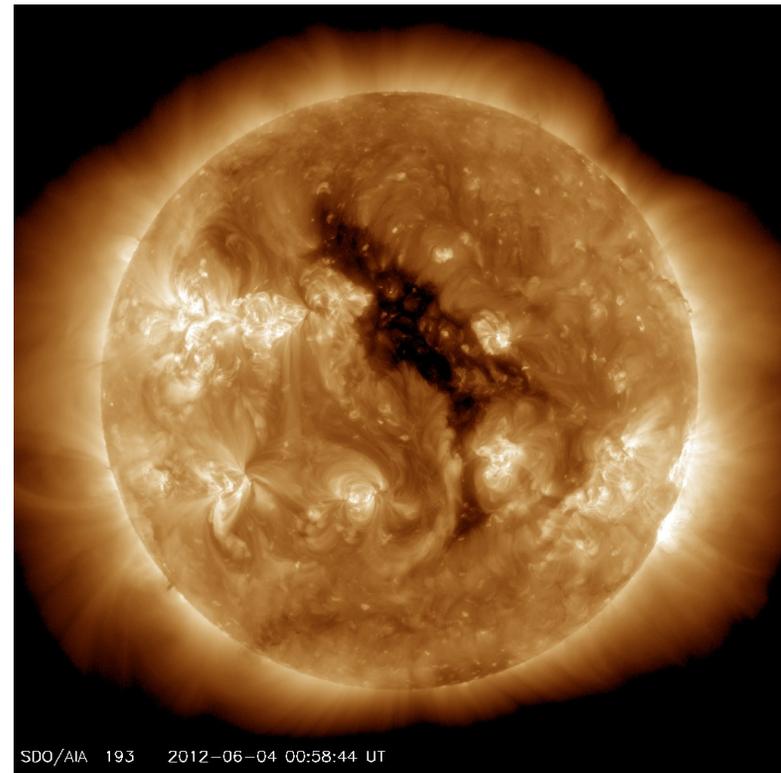
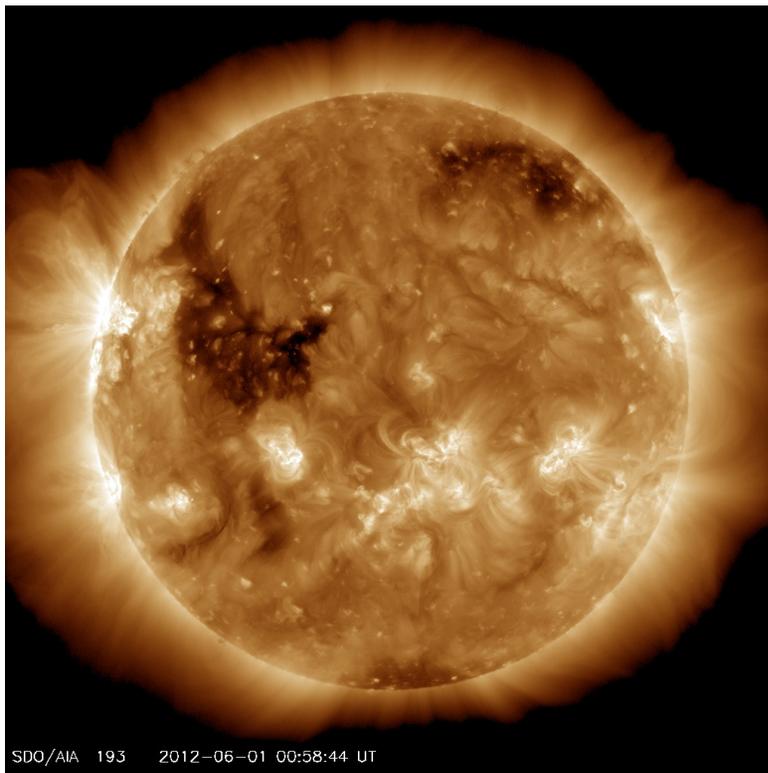
2012-05-12T17 +22.73 days

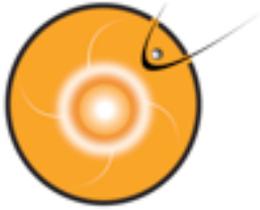


ENUL-2.7 lowres-2124-a3b11 WSA_V2.2 GONG-2124



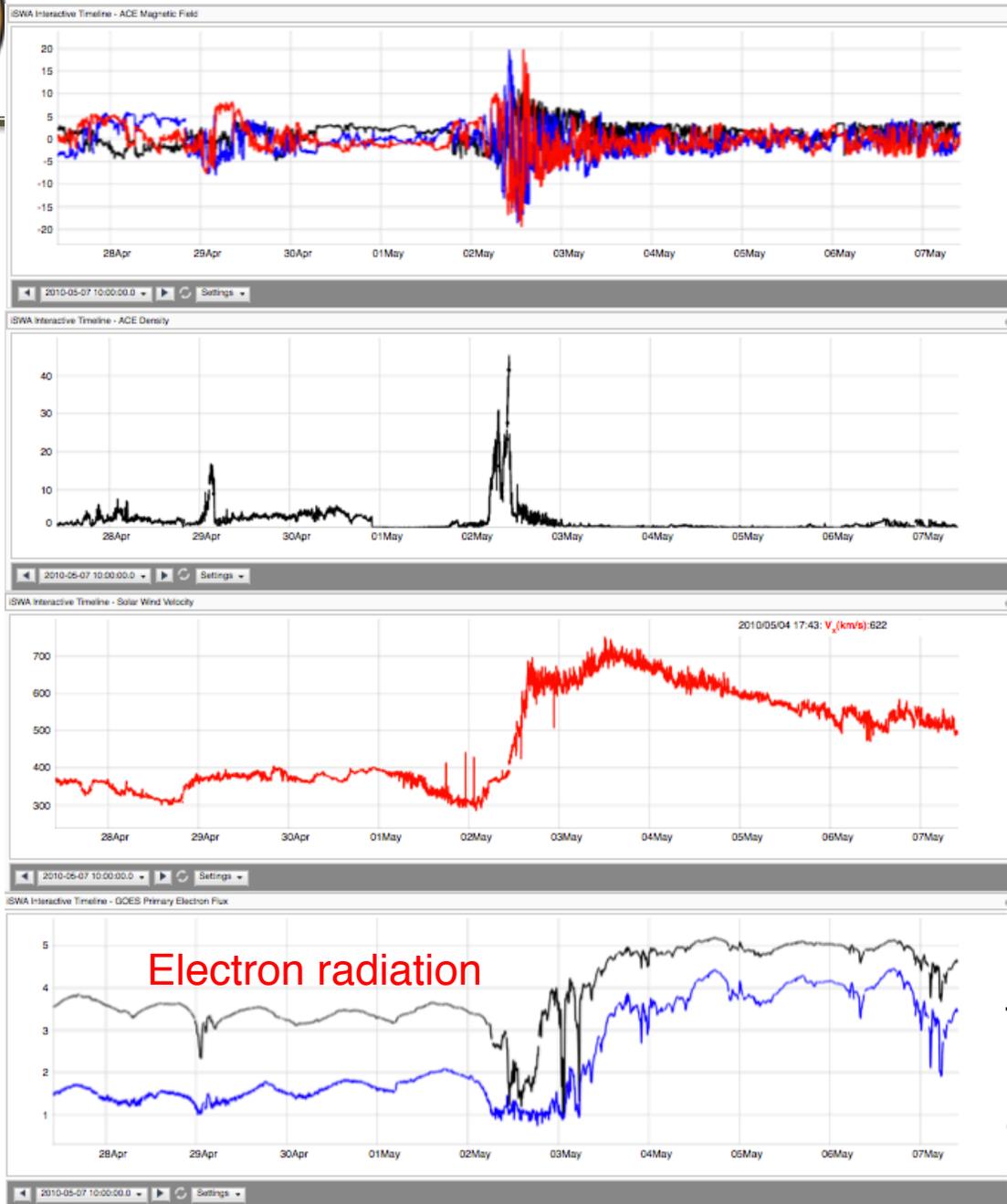
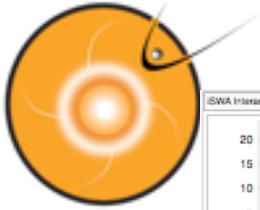
ENUL-2.7 lowres-2124-a3b11 WSA_V2.2 GONG-2124





In-situ signatures of CME and CIR HSS at L1

ACE and WIND



Electron radiation

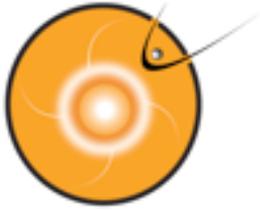
Clean HSS

May 2, 2010

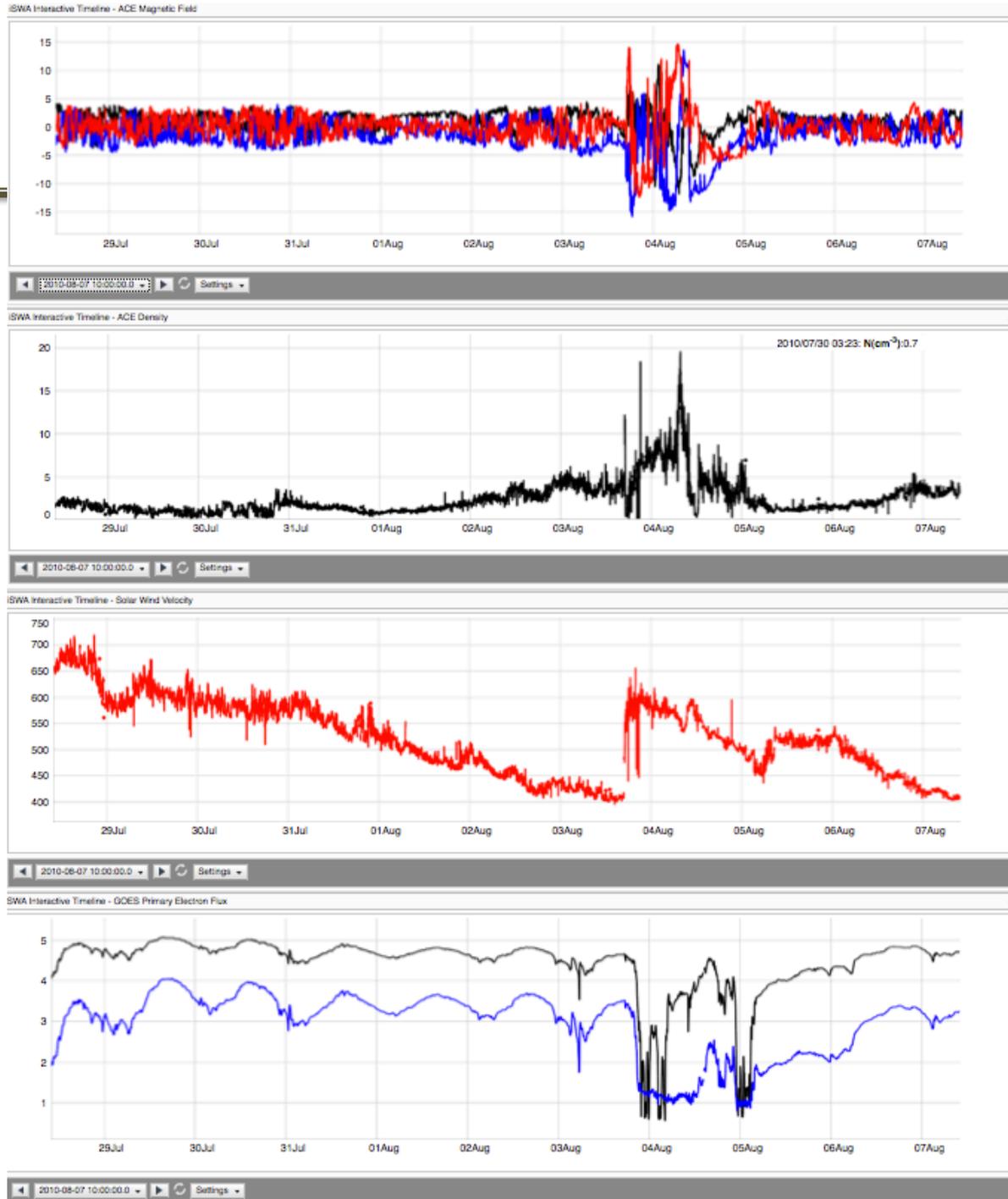
Dense (20-30 cc), HSS

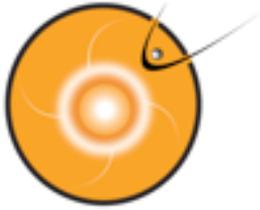
IMFBz: -18 nT

may be more hazardous to Earth-orbiting satellites than ICME-related magnetic storm particles and solar energetic particles

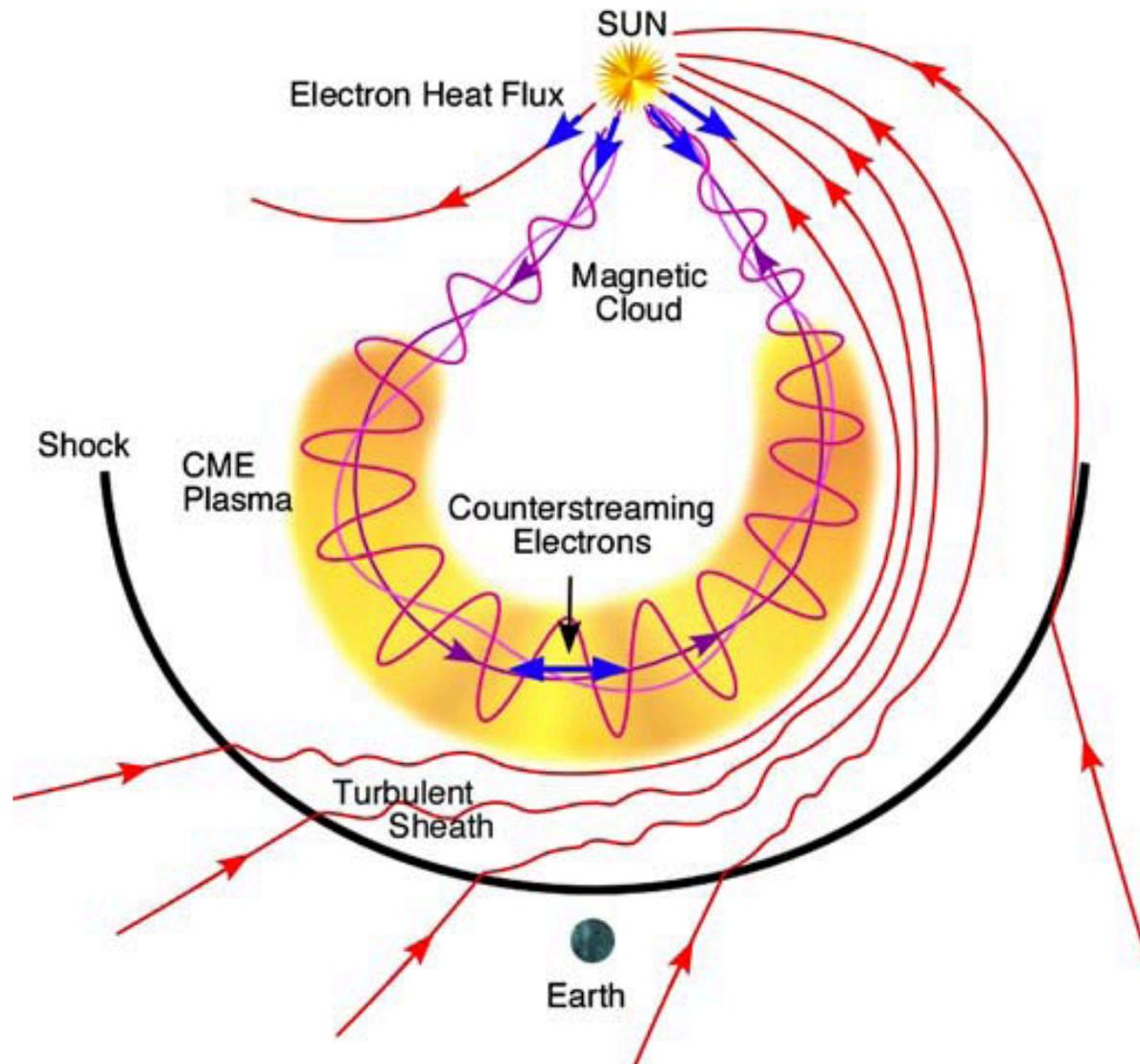


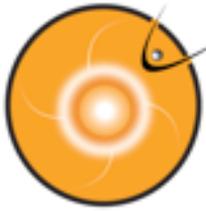
Aug 3, 2010





Schematic of the three-dimensional structure of an ICME and upstream shock



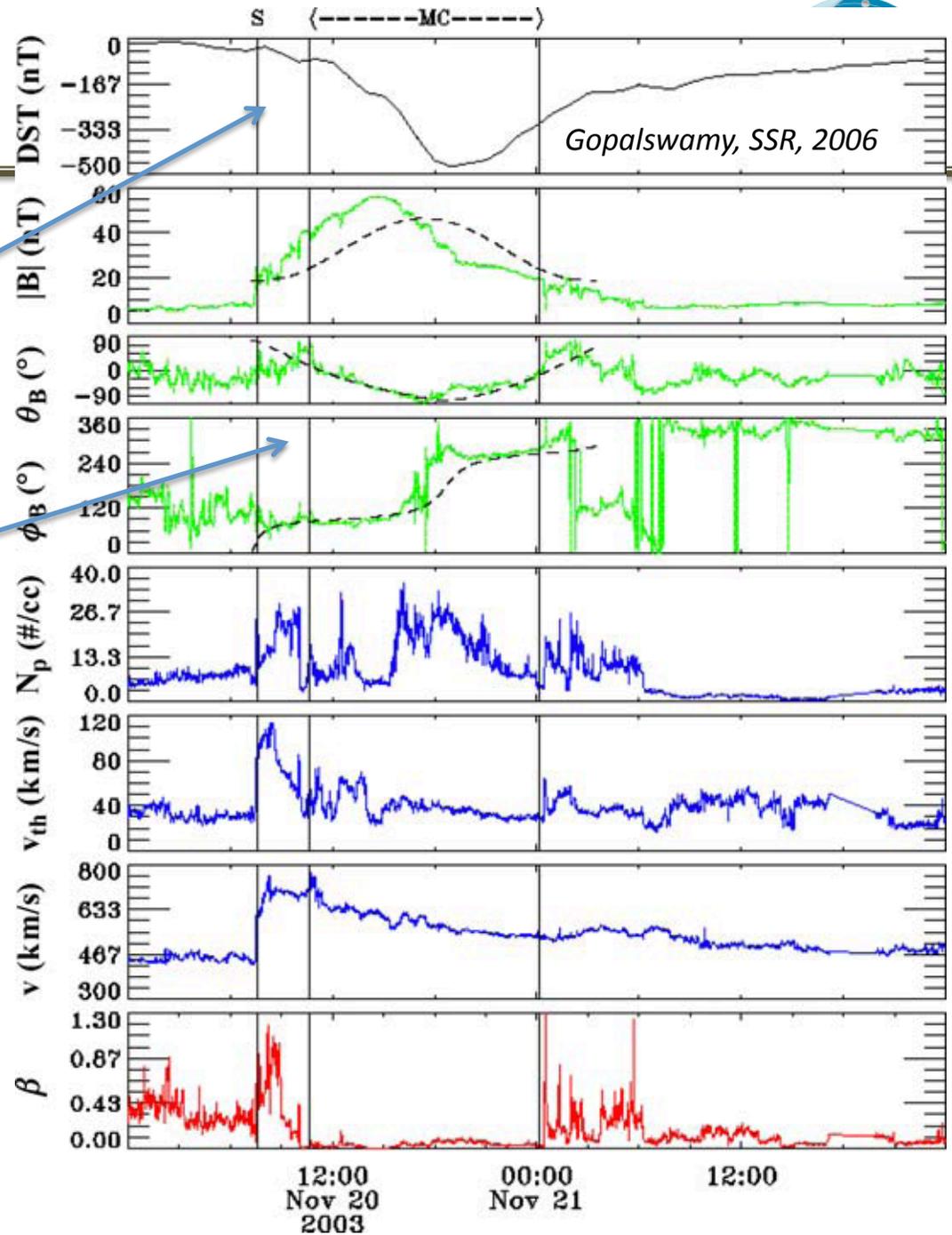


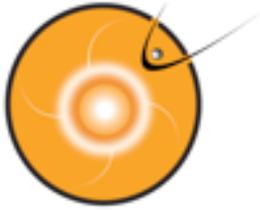
Textbook
example of ICME
in-situ signature

shock

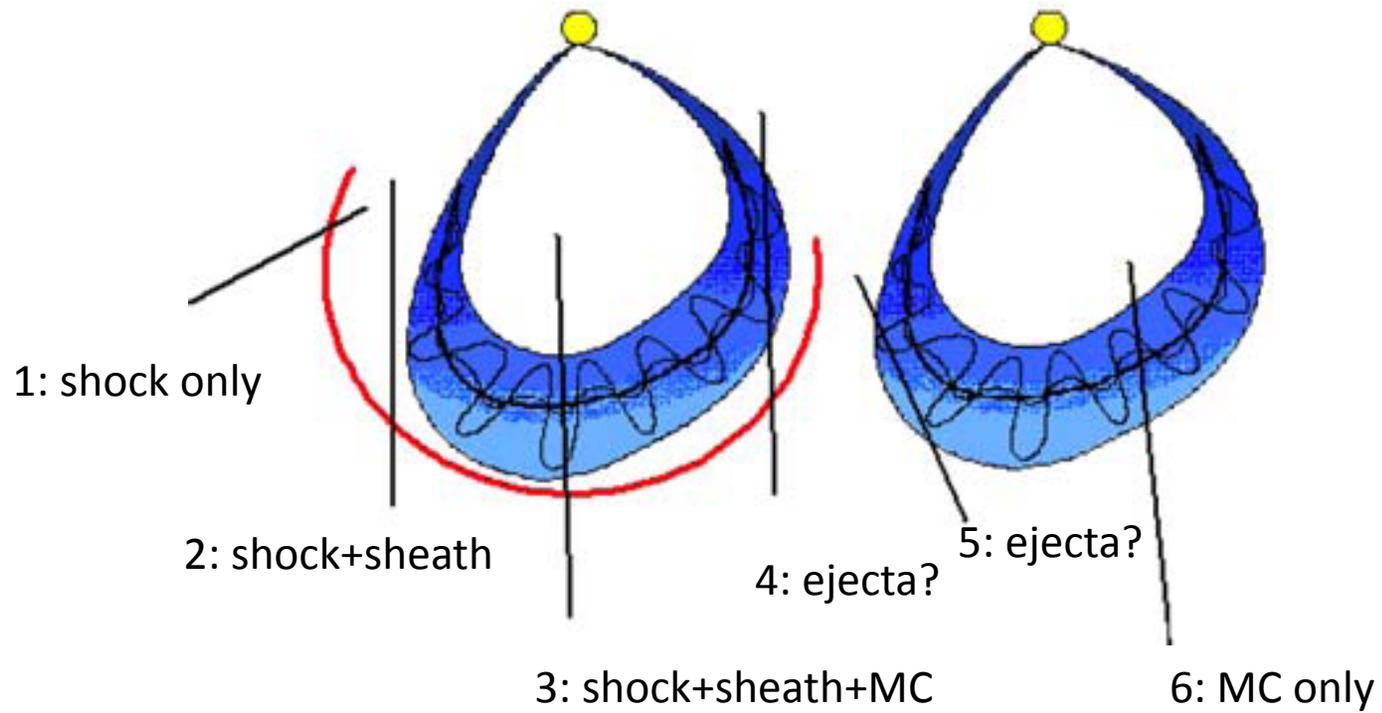
sheath

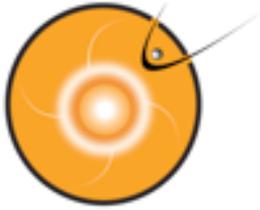
Magnetic cloud





In-Situ signature can be quite complex





Locating the CIR interface



- increase of solar wind speed
- pile-up of total perpendicular pressure (P_t) with gradual decreases at both sides from the P_t peak to the edges of the interaction region
- velocity deflections
- increase of proton number density
- enhancement of proton temperature
- increase of entropy,
- compression of magnetic field.

Jian et al., 2006 Solar physics
McPherron et al., 2009, JASTP

Typical behavior of CIRs

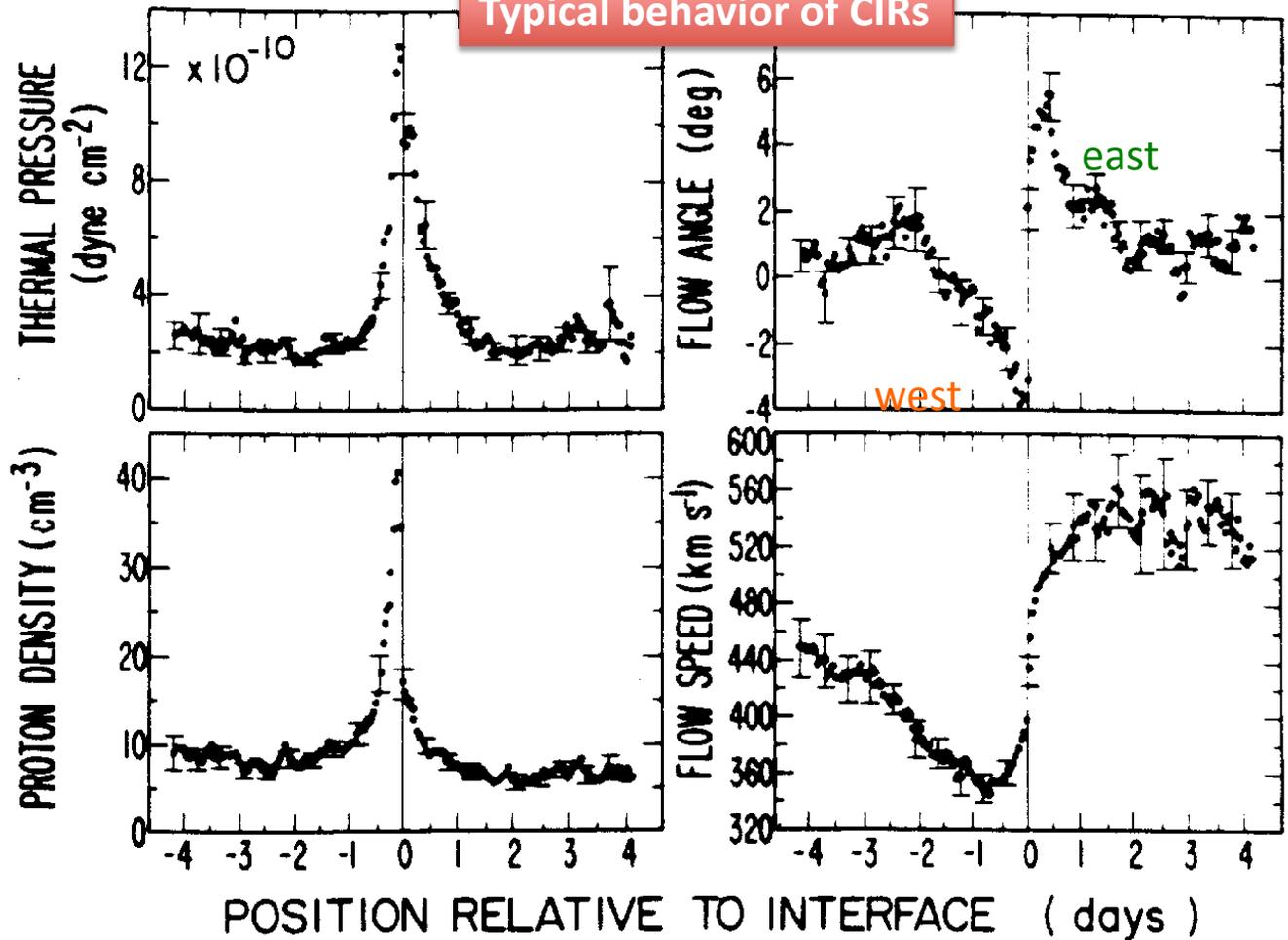


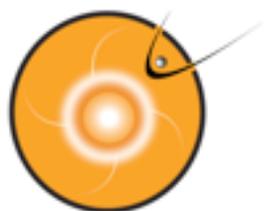
Figure 3. Superposed epoch plots of selected 1-hour averaged solar wind parameters for 23 CIRs containing abrupt stream interfaces. The flow angle is the azimuthal (east-west) flow angle and the sign convention is that negative flow angles correspond to flow in the direction of planetary motion about the Sun (westward) (from Gosling *et al.*, 1978).

Another example

394 stream interfaces in the interval 1995–2006



McPherron, R. L., D. N. Baker, and N. U. Crooker (2009), Role of the Russell-McPherron effect in the acceleration of relativistic electrons, *J. Atmos. Sol. Terr. Phys.*, 71(10–11), 1032–1044



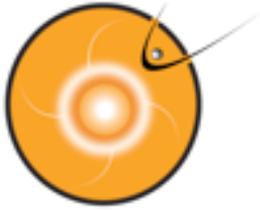
Both CME and CIRs are capable of generating geomagnetic storms. Differs in



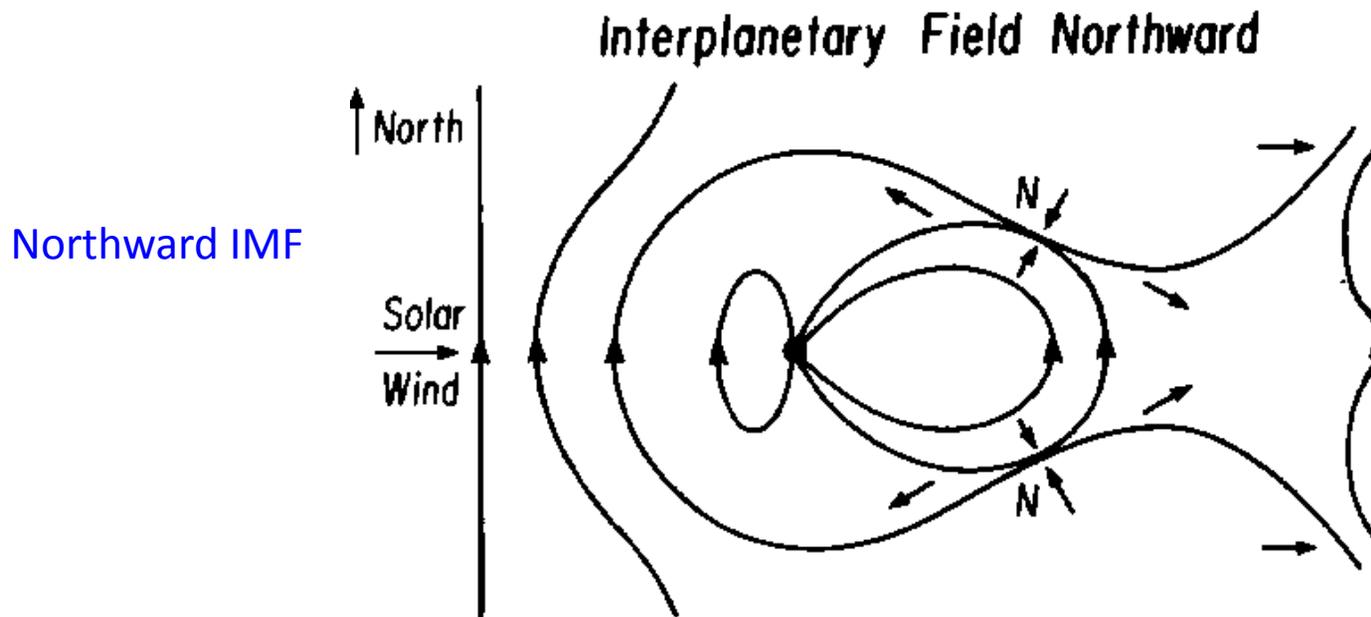
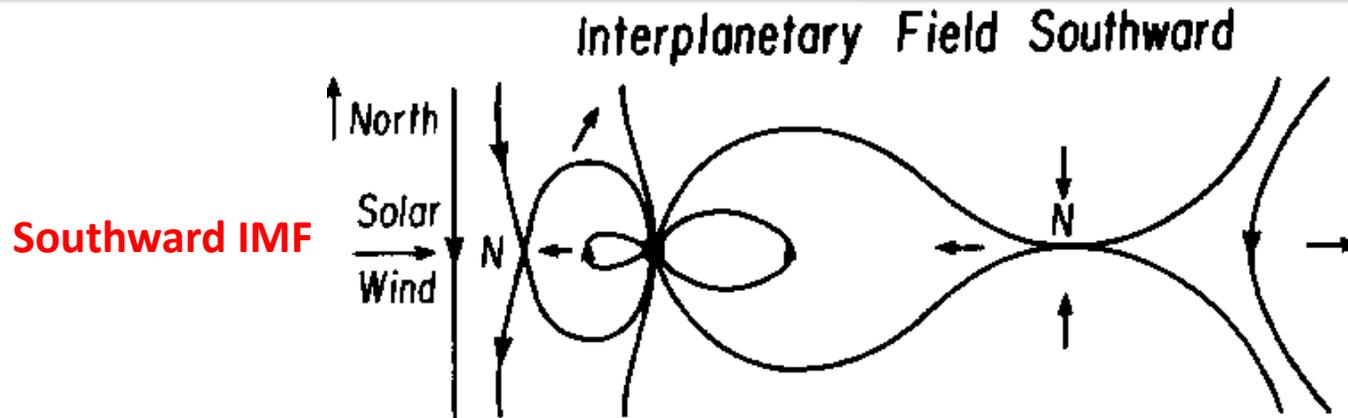
Table 1. A Summary of Some of the Important Differences Between CME-Driven Storms (Shock, Sheath, Ejecta, Cloud) and CIR-Driven Storms (CIR, High-Speed Stream)

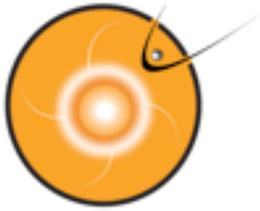
Phenomenon	CME-Driven Storms	CIR-Driven Storms
Phase of the solar cycle when dominant	solar maximum	declining phase
Occurrence pattern	irregular	27-day repeating
Calm before the storm	sometimes	usually
Solar energetic particles (SEP)	sometimes	none
Storm sudden commencement (SSC)	common	infrequent
Mach number of the bow shock	moderate	high
β of magnetosheath flow	low	high
Plasma-sheet density	very superdense	superdense
Plasma-sheet temperature	hot	hotter
Plasma-sheet O ⁺ /H ⁺ ratio	extremely high	elevated
Spacecraft surface charging	less severe	more severe
Ring current (Dst)	stronger	weaker
Global sawtooth oscillations	sometimes	no
ULF pulsations	shorter duration	longer duration
Dipole distortion	very strong	strong
Saturation of polar-cap potential	sometimes	no
Fluxes of relativistic electrons	less severe	more severe
Formation of new radiation belts	sometimes	no
Convection interval	shorter	longer
Great aurora	sometimes	rare
Geomagnetically induced current (GIC)	sometimes	no

Borovsky, J. E. and M. H. Denton (2006), Differences between CME-driven storms and CIR-driven storms , *J. Geophys. Res.* , 111 , A07S08, doi:10.1029/2005JA011447.

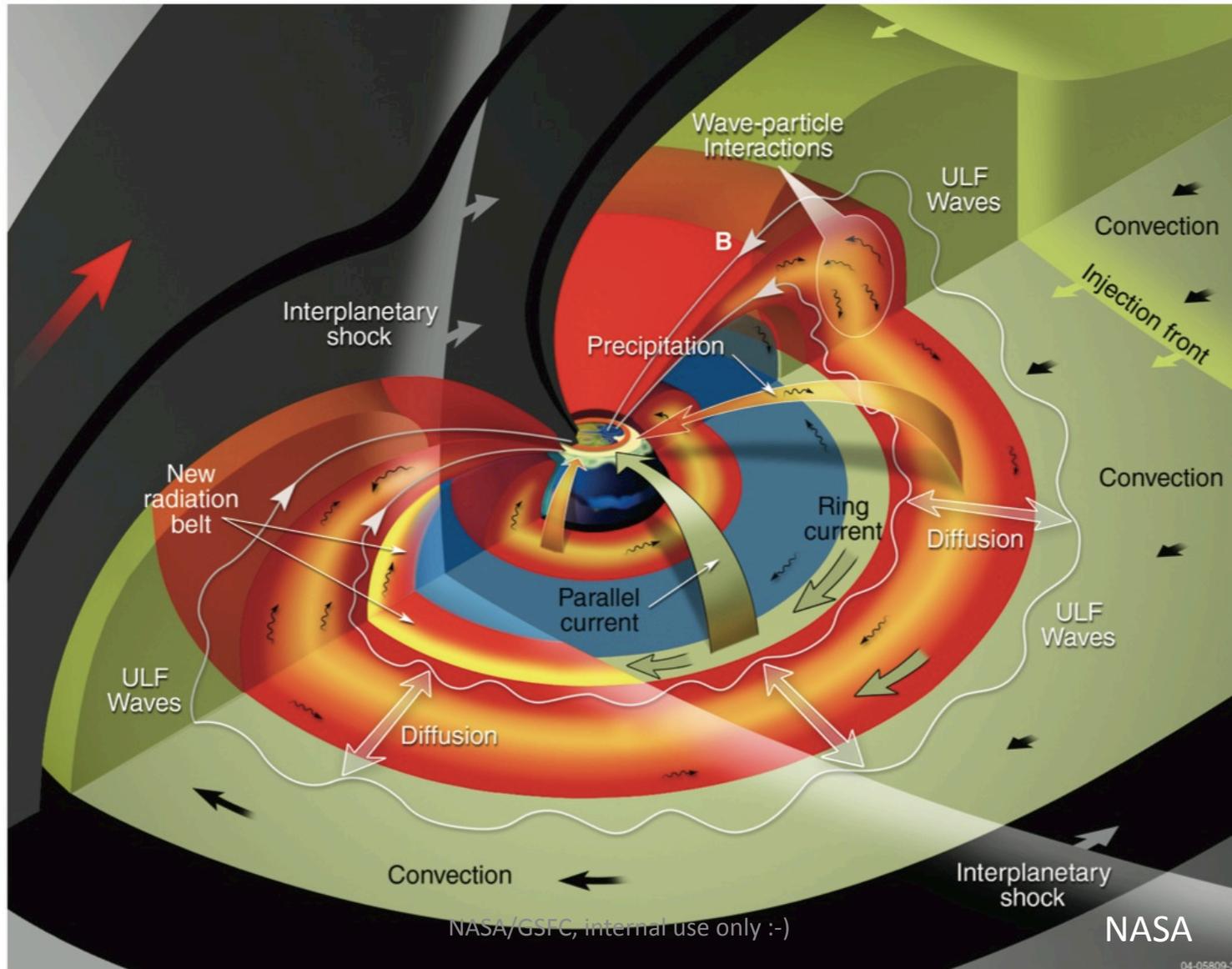


Two major types of solar wind-magnetosphere interactions

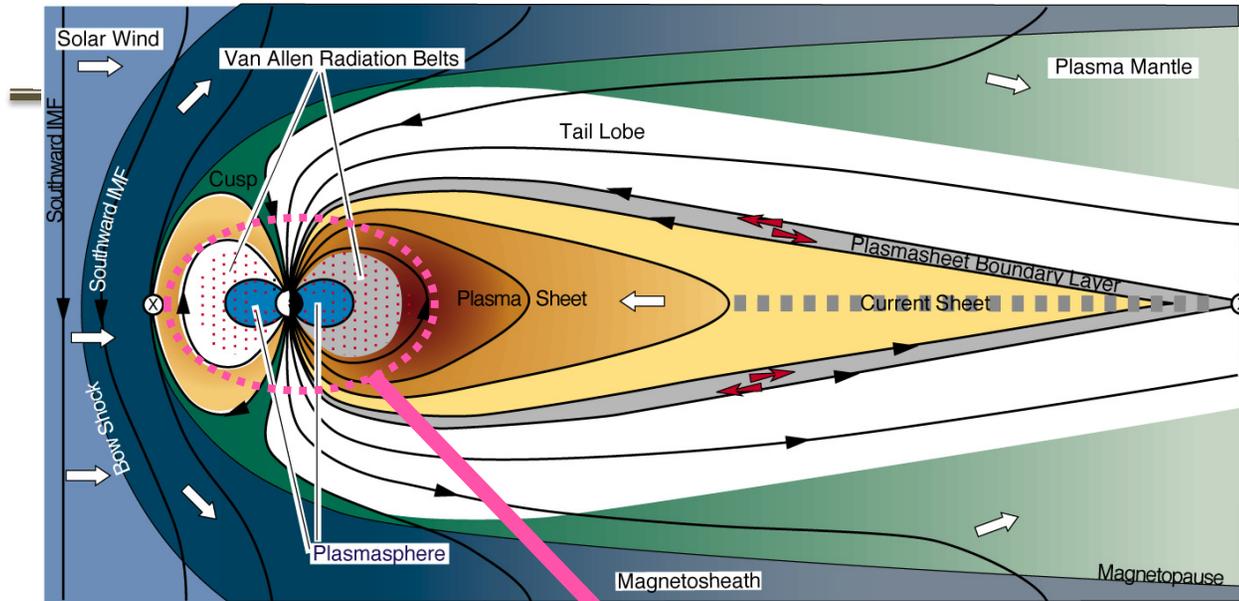




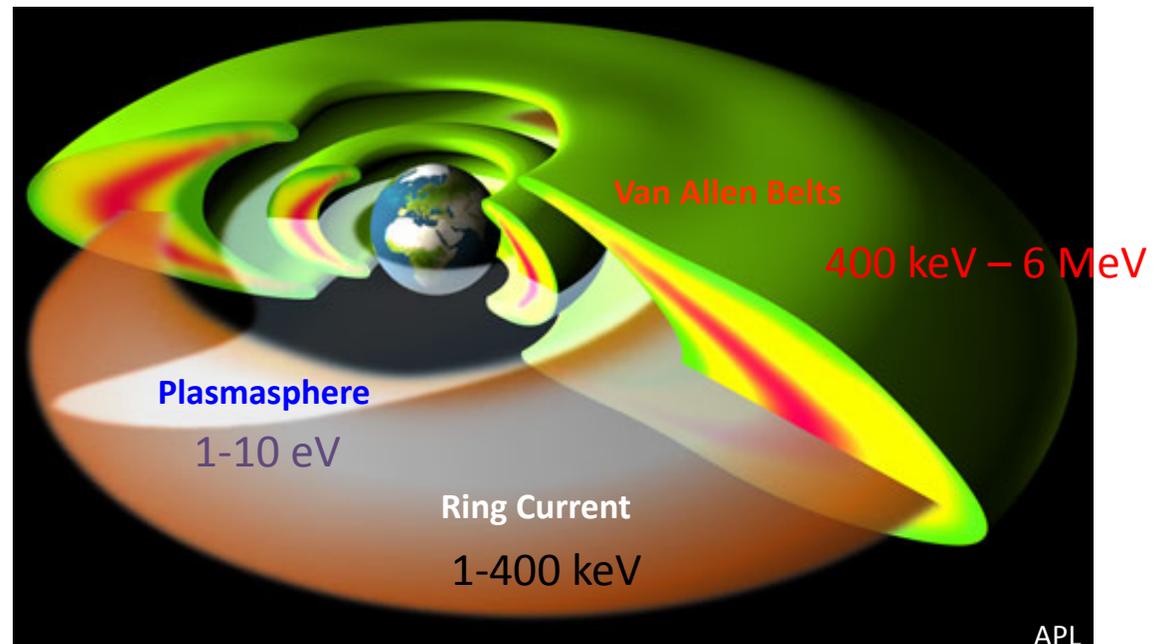
The Earth's Magnetosphere



The Earth's Magnetosphere



Inner Magnetosphere:
Up to $\sim 10R_e$

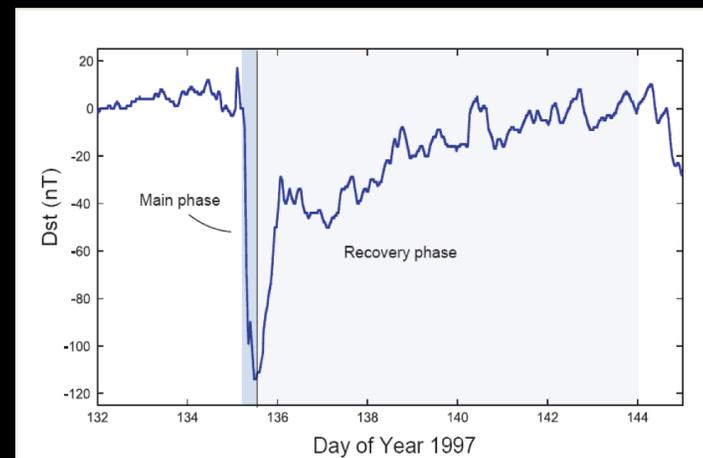


Magnetic Storms



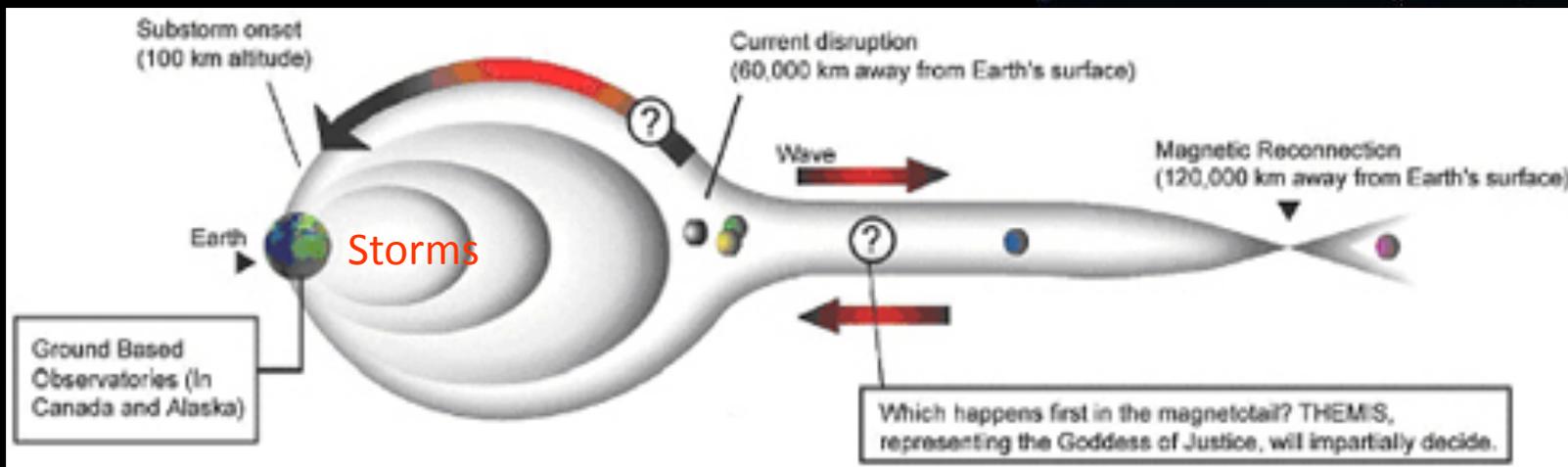
- Dst measures ring current development
 - Storm sudden commencement (SSC), main phase, and recovery phase
 - Duration: days

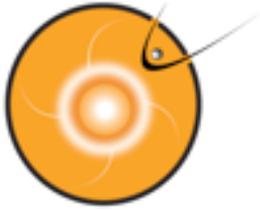
- Most intense solar wind-magnetosphere coupling
- Associated with solar coronal mass ejections (CME), coronal holes HSS
- IMF Bz southward, strong electric field in the tail
- Formation of ring current and other global effects



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





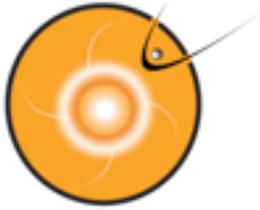
Kp: measure of storm intensity



"planetarische Kennziffer" (= planetary index).

- Geomagnetic activity index
range from 0-9 disturbance levels of
magnetic field on the ground - currents
1. Non-event - period of 12/01/2010 – 12/7/2010
 2. Moderate event – April 5, 2010
 3. Extreme event - Oct 29 – Oct 31, 2003

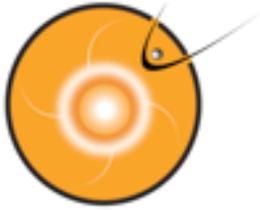
http://bit.ly/Kp_layout Threshold $K_p \geq 6$



Geomagnetic Storm classification



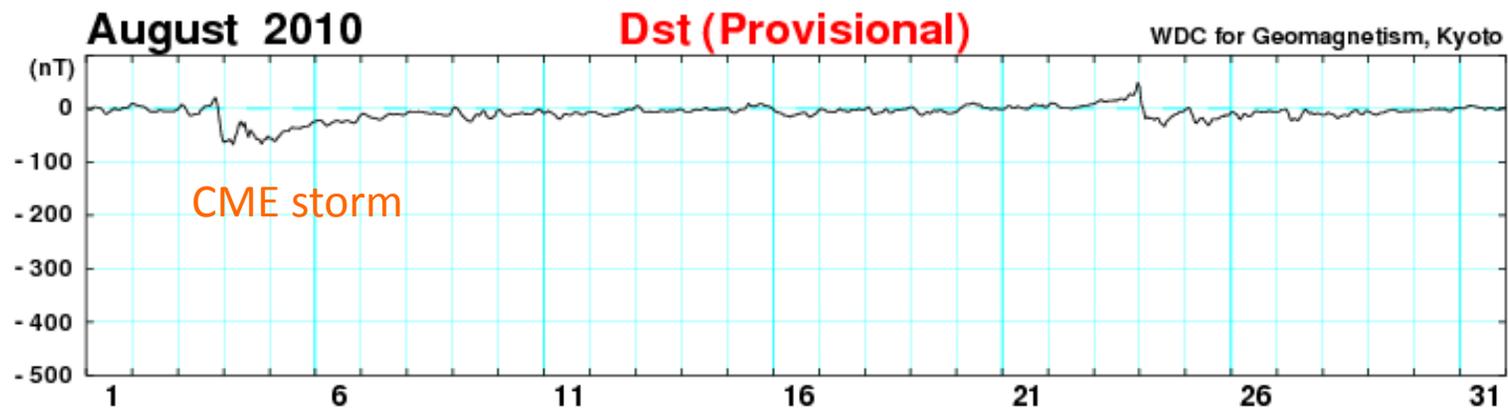
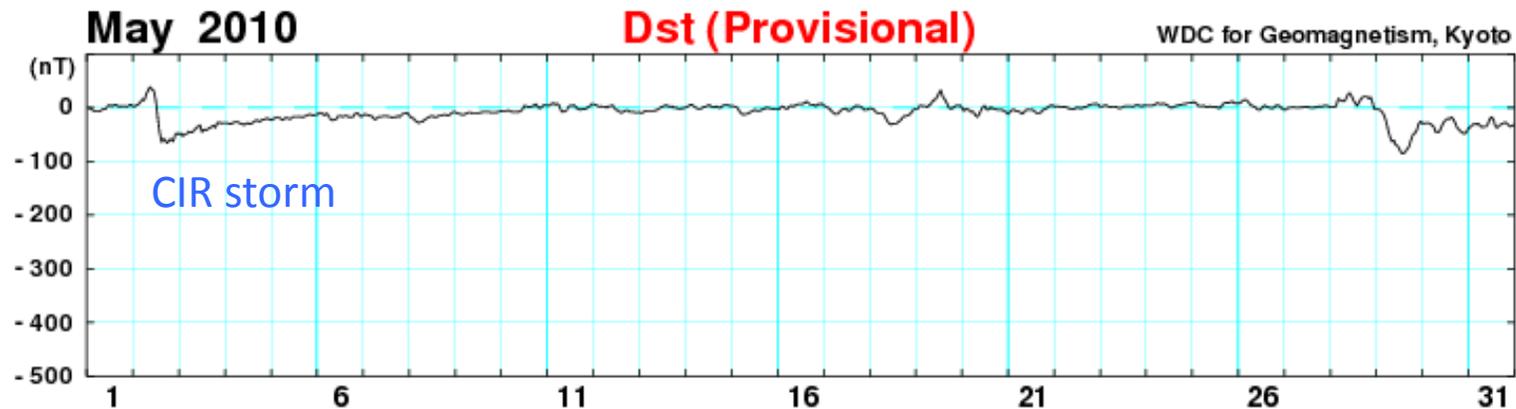
- http://www.swpc.noaa.gov/NOAA_scales/index.html#GeomagneticStorms
- Operational world



Dst: Disturbance of Storm Time



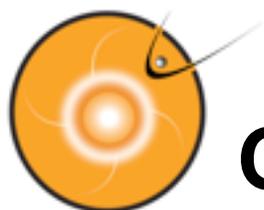
Measure of Storm Intensity



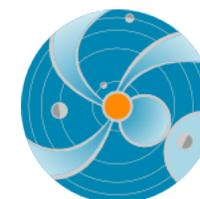
CIR storm at most: Dstmin \sim -130 nT

CME storm: Dstmin \sim -600 nT

1989 March 14 Dstmin = -589 nT

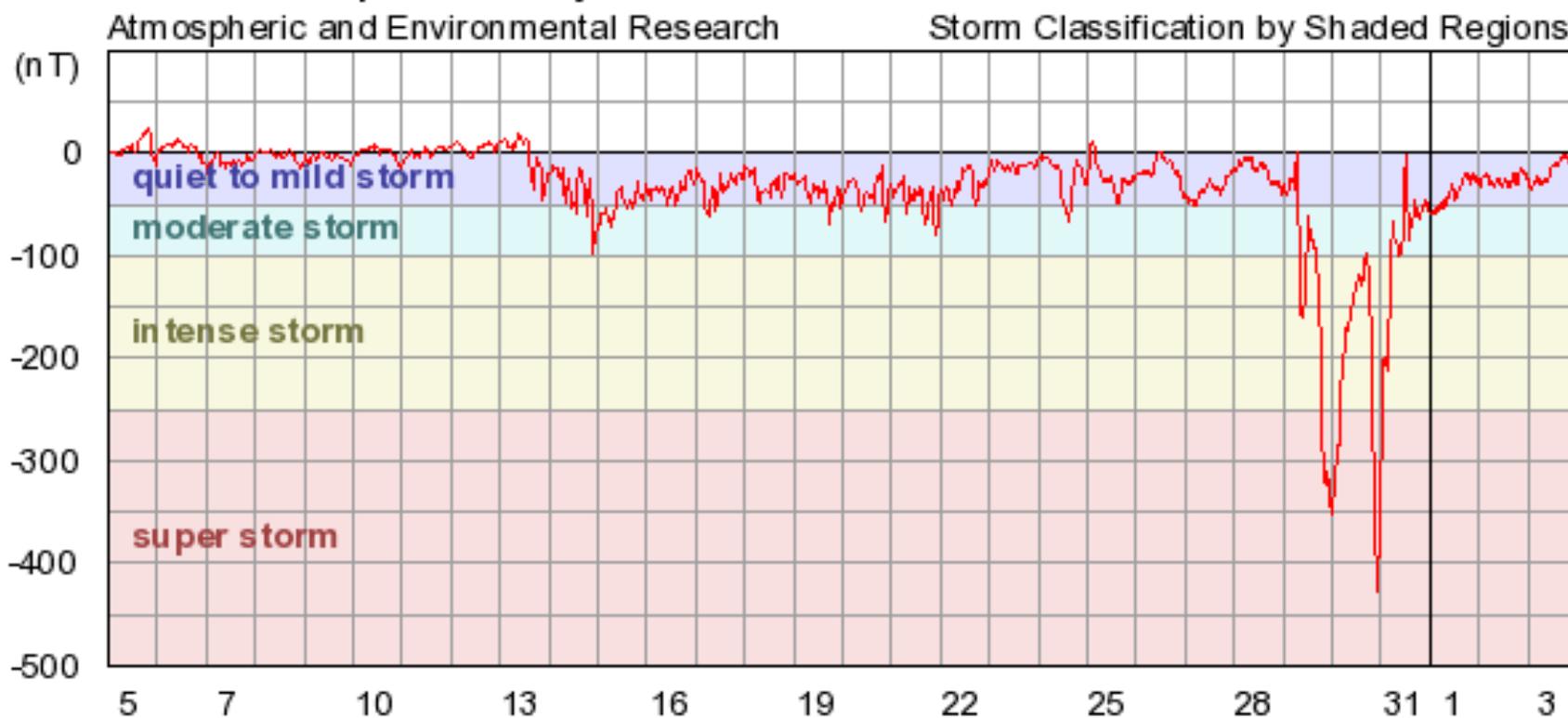


Geomagnetic Storm Classification

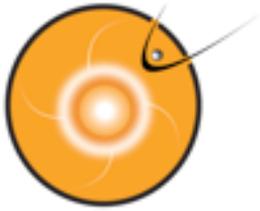


Research

Example 30-Day Dst Plot for the 2033 Halloween Storm





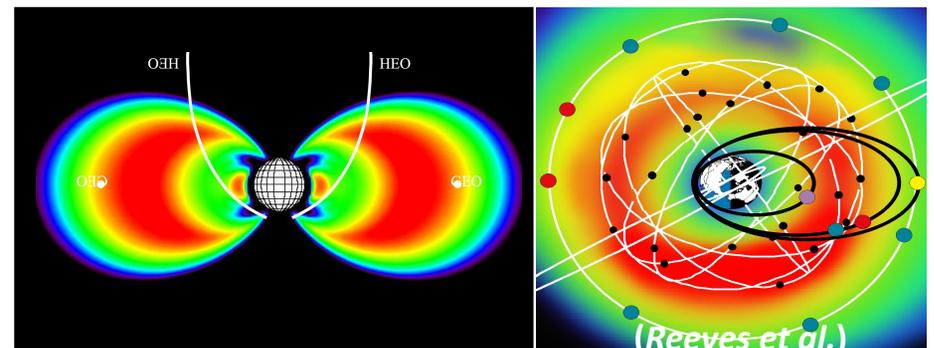
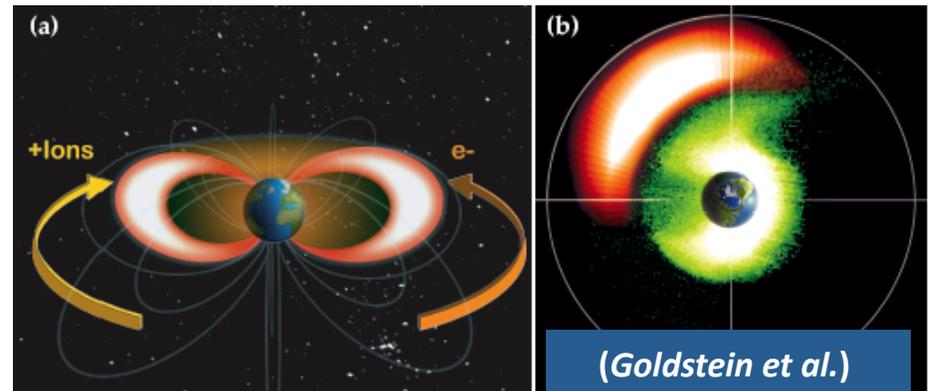
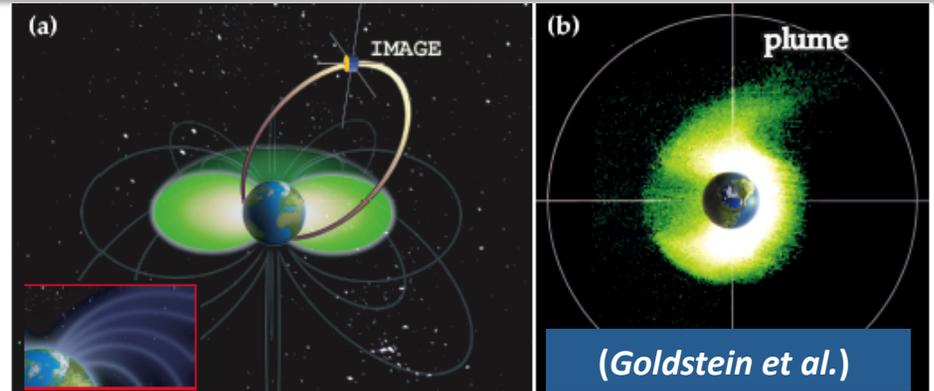


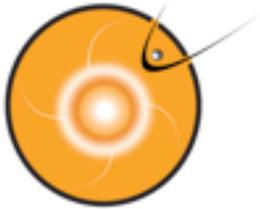
Inner magnetosphere plasmas



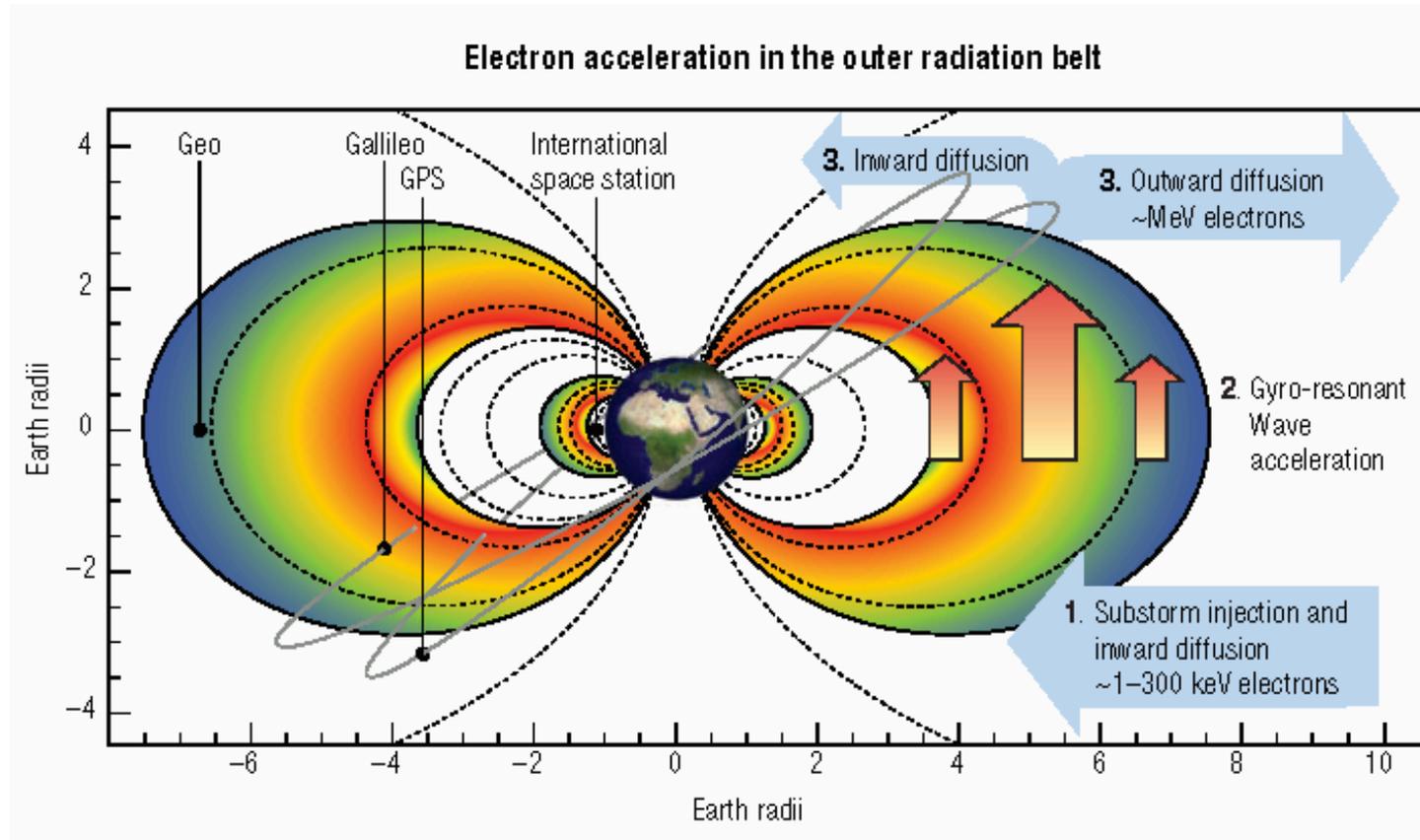
- Plasmasphere
 - 1-10 eV ions
 - ionospheric origin
- Ring current
 - 1-400 keV ions
 - both ionospheric and solar wind origin
- Outer radiation belt
 - 0.4-10 MeV electrons
 - magnetospheric origin

Inner magnetosphere: Gigantic Particle accelerator

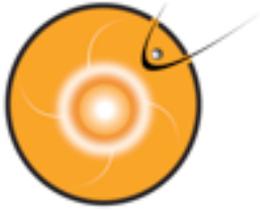




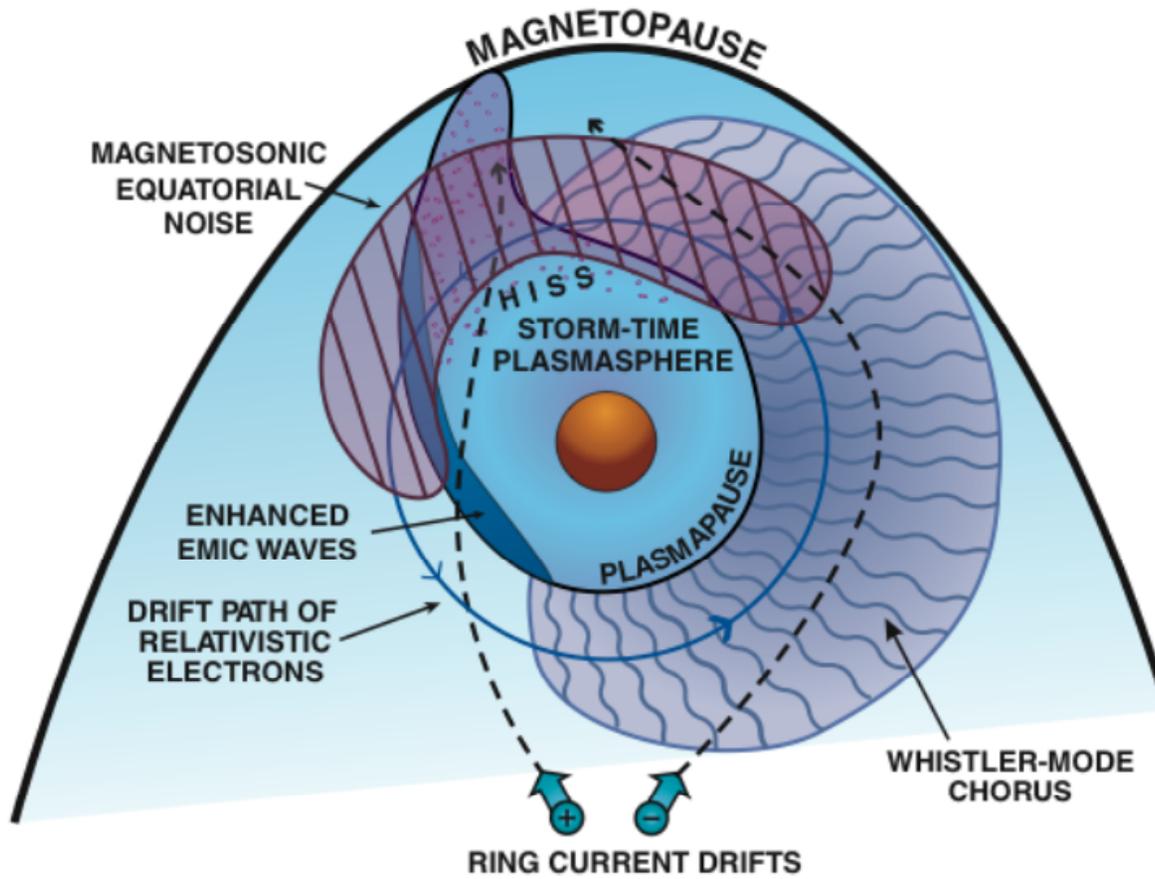
RB: Current understanding

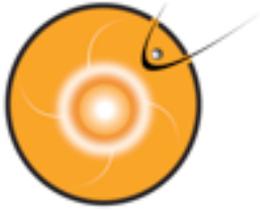


Horne et al., 2007, Nature Physics

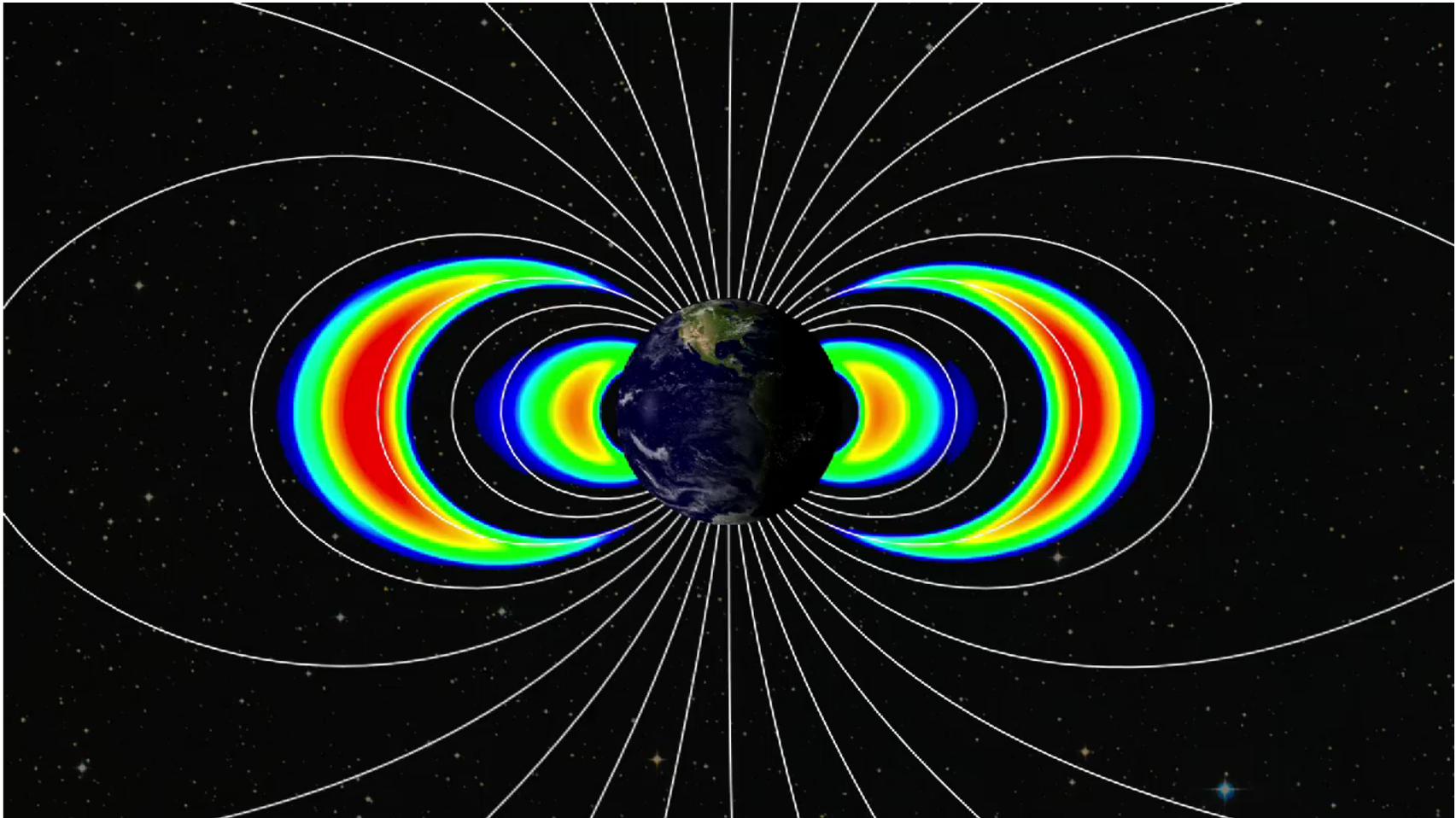


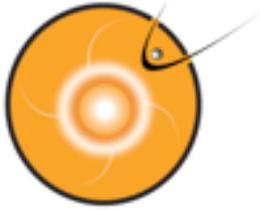
Various types of waves that are important to RB dynamics





Van Allen Probes: current mission on radiation belt dynamics



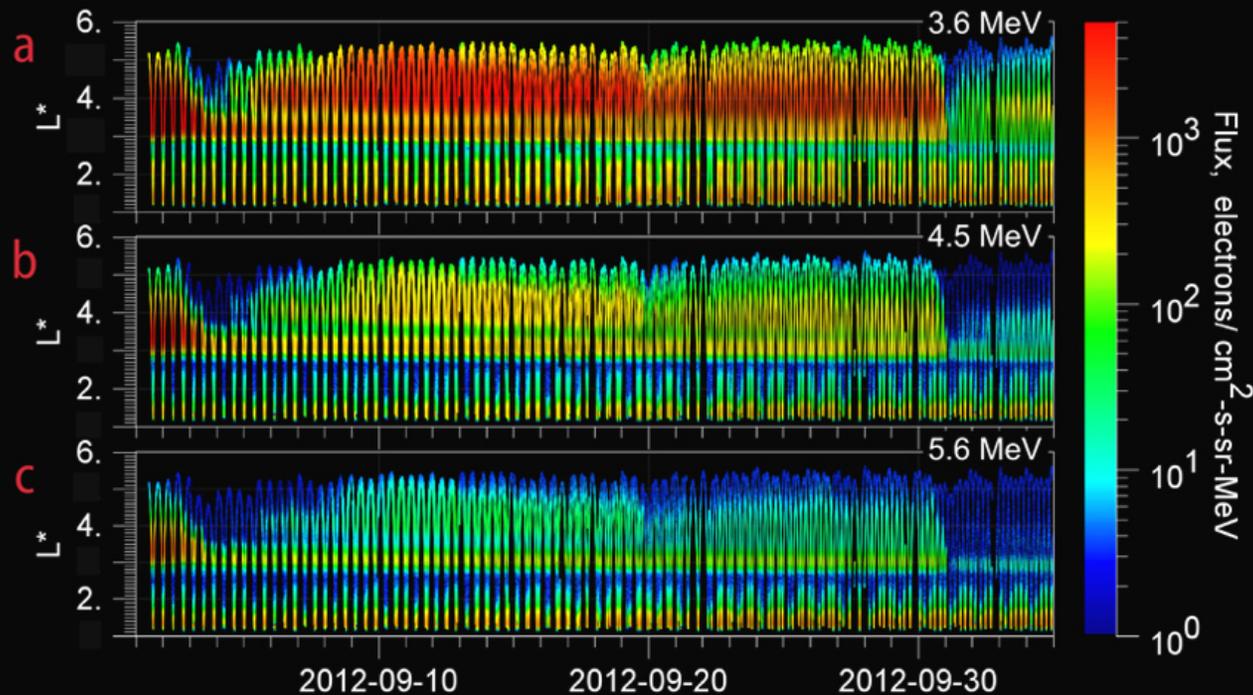


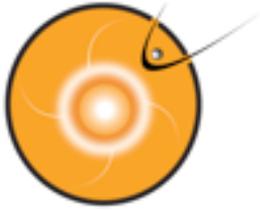
Three-Belt Structure



Quiet-time phenomenon

Energetic electron data from the Relativistic Electron-Proton Telescopes (REPT) on the Van Allen Probes





Different impacts on RB



CME vs CIR storms

- CME geomagnetic storms: RB flux peak inside geosynchronous orbit. The peak locations moves inward as storm intensity increases
- CIR geomagnetic storms: More responsible for the electron radiation level enhancement at GEO orbit

Click the check boxes to toggle series visibility

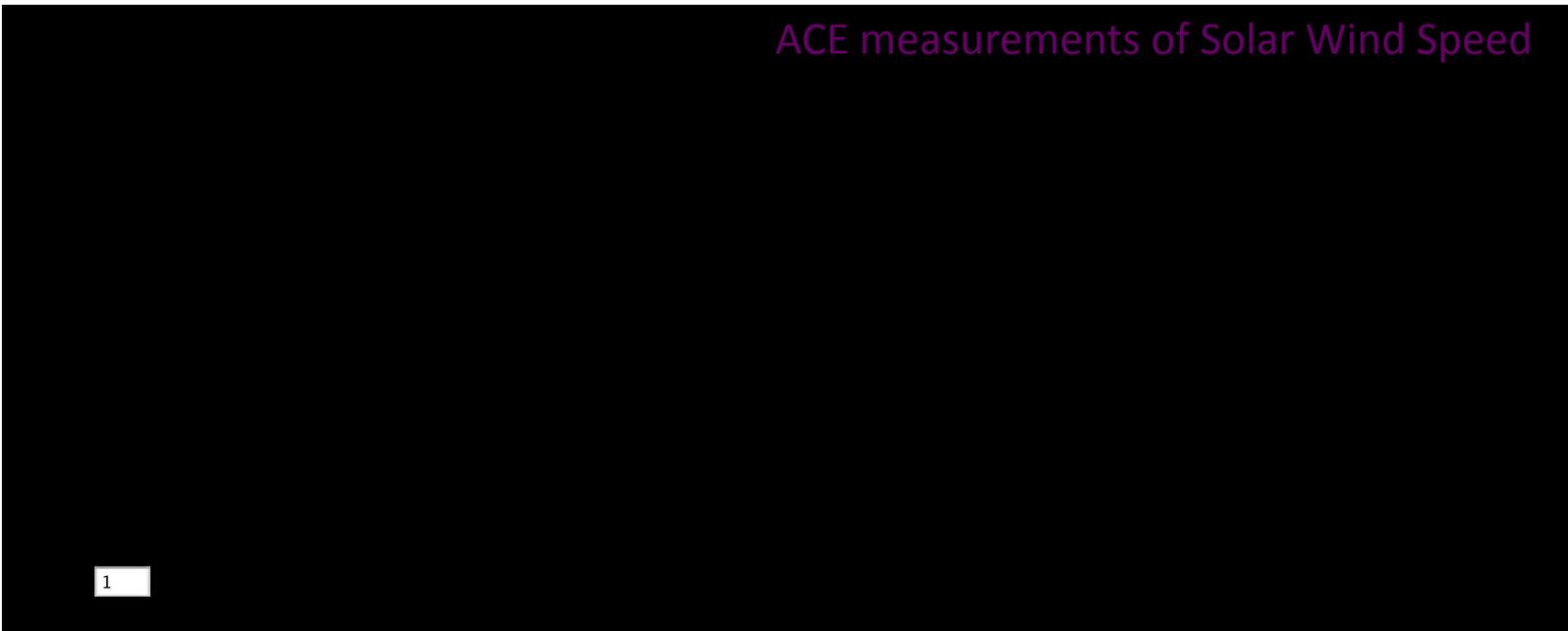
HSS and radiation belt electron flux enhancement

GOES data of energetic electron fluxes

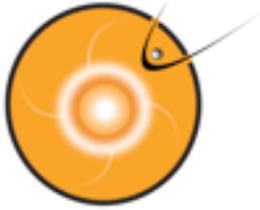


E > 0.8 MeV E > 2.0 MeV Zoom: [In](#) [Out](#) [full](#) Pan: [left](#) [right](#)

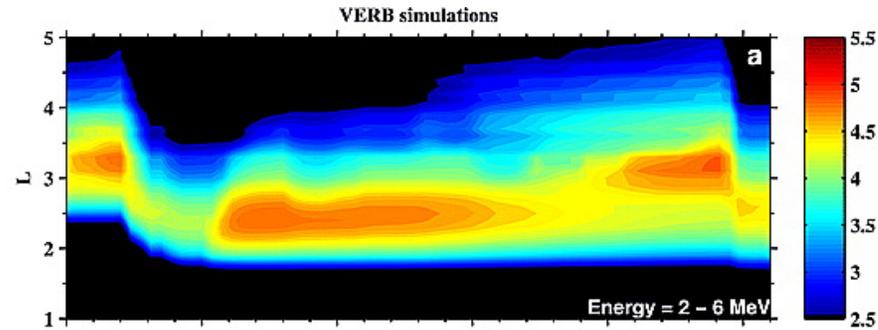
ACE measurements of Solar Wind Speed



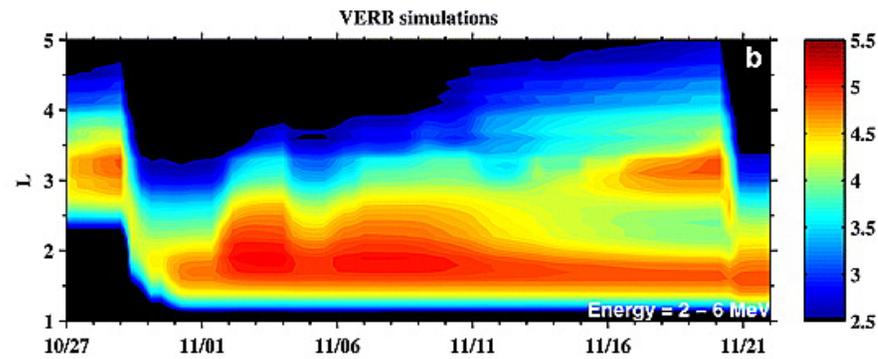
Bulk Speed Zoom: [In](#) [Out](#) [full](#) Pan: [left](#) [right](#)



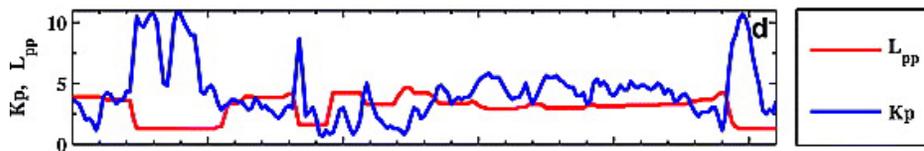
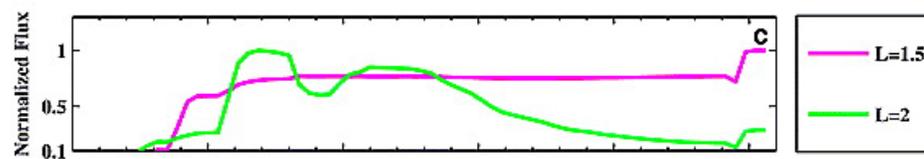
CME (superstorm condition) impact on RB

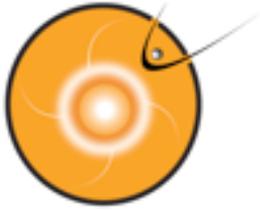


Halloween storm

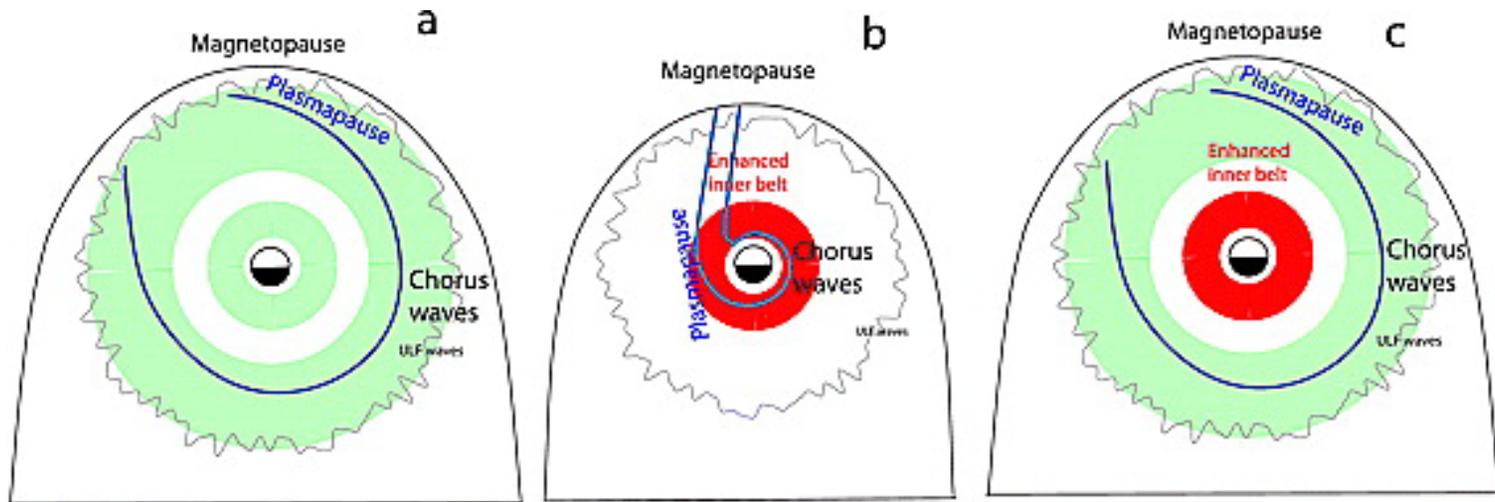


Carrington-like superstorm

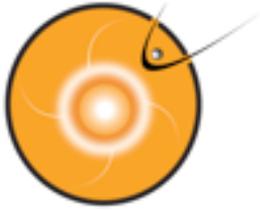




CME (superstorm condition) impact on RB



Shprits et al., 2011, Space Weather



SWx consequences of CIR HSS



CIR HSS: usually long-duration (3-4 days)

Radiation belt electron flux enhancement

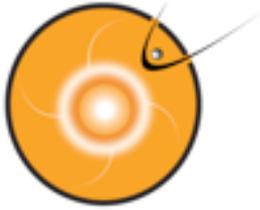
Surface charging

Geomagnetic disturbances (moderate at most)

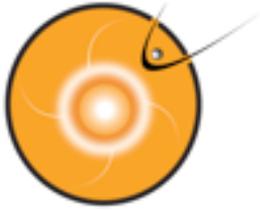
heating of upper atmosphere: satellite drag

Energetic electron radiation: (the >0.8 MeV electron flux exceeding 10^5 pfu alert threshold): takes 2-3 days from the CIR interface

Although geomagnetic activity (due to CIR HSS) during the declining and minimum phases of the solar cycle appears to be relatively benign (especially in comparison to the dramatic and very intense magnetic storms caused by interplanetary coronal mass ejections (ICMEs) that predominate during solar maximum), this is misleading. Research has shown that the time-averaged, accumulated energy input into the magnetosphere and ionosphere due to high speed streams can be greater during these solar phases than due to ICMEs during solar maximum!



magnetospheric products



Kp



"planetarische Kennziffer" (= planetary index).

- Geomagnetic activity index
range from 0-9 disturbance levels of
magnetic field on the ground - currents
1. Non-event - period of 12/01/2010 – 12/7/2010
 2. Moderate event – April 5, 2010
 3. Extreme event - Oct 29 – Oct 31, 2003

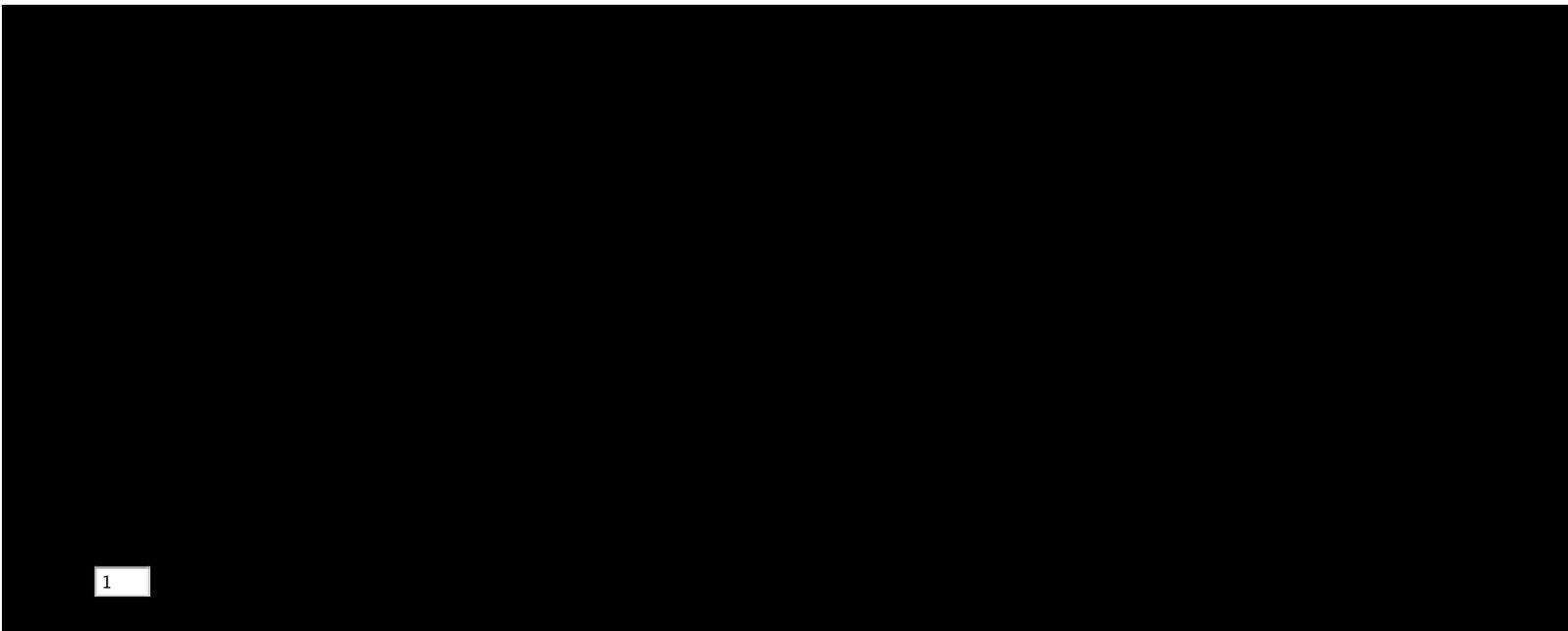
http://bit.ly/Kp_layout Threshold $Kp \geq 6$

Click the check boxes to toggle series visibility

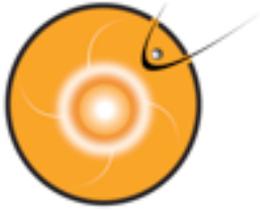
HSS and RBE flux enhancement



E > 0.8 MeV E > 2.0 MeV Zoom: [In](#) [Out](#) [full](#) Pan: [left](#) [right](#)



Bulk Speed Zoom: [In](#) [Out](#) [full](#) Pan: [left](#) [right](#)

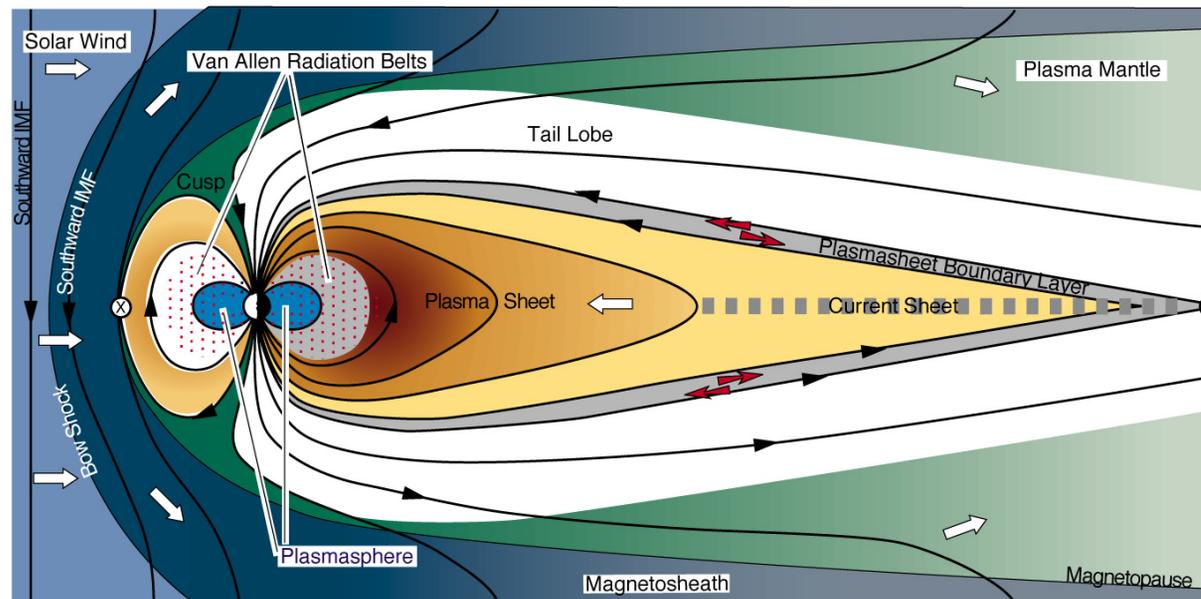


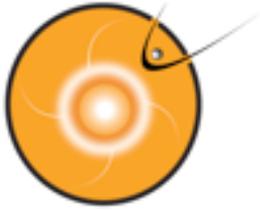
Magnetopause stand-off distance



delineating the boundary between SW and Earth's magnetosphere

- $r_0 \leq 6.6 R_E$ – model product
 - **Events: Dec 28, 2010** Degree of compression of MP Due to P_{dyn} of solar wind
 - **Jan 7, 2010** $k_p=5$ at 22:30 UT on 1/6/2011 (interplanetary shock /HSS)
 - **Non-event: Dec 1 – 7, 2010**





An iSWA layout for magnetospheric products

http://bit.ly/iswa_mag