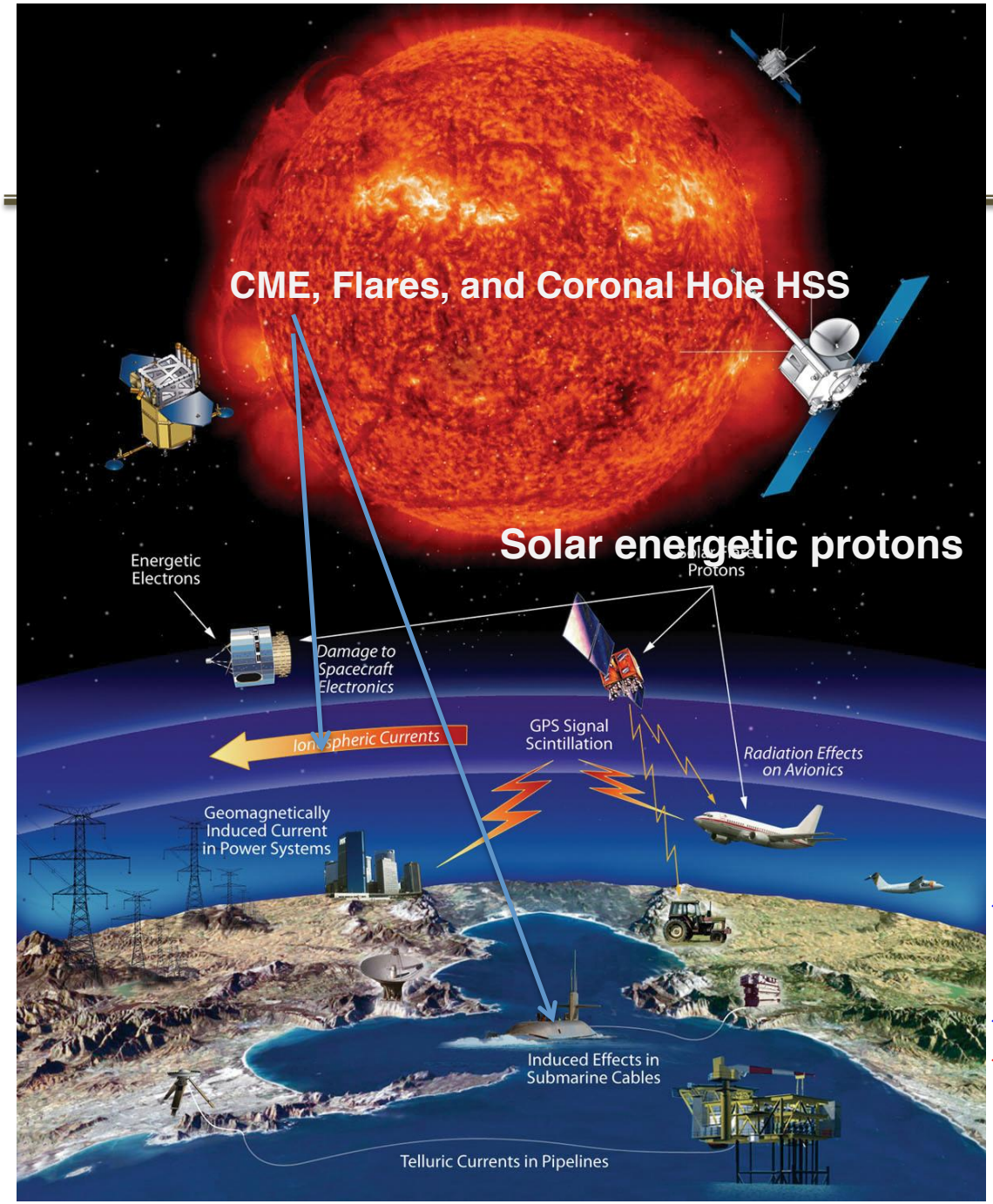
Space Weather
In the Magnetosphere

Yihua Zheng

SW REDI Engineers

Jan 28, 2014



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)**

Focus on geomagnetic storms and their impacts

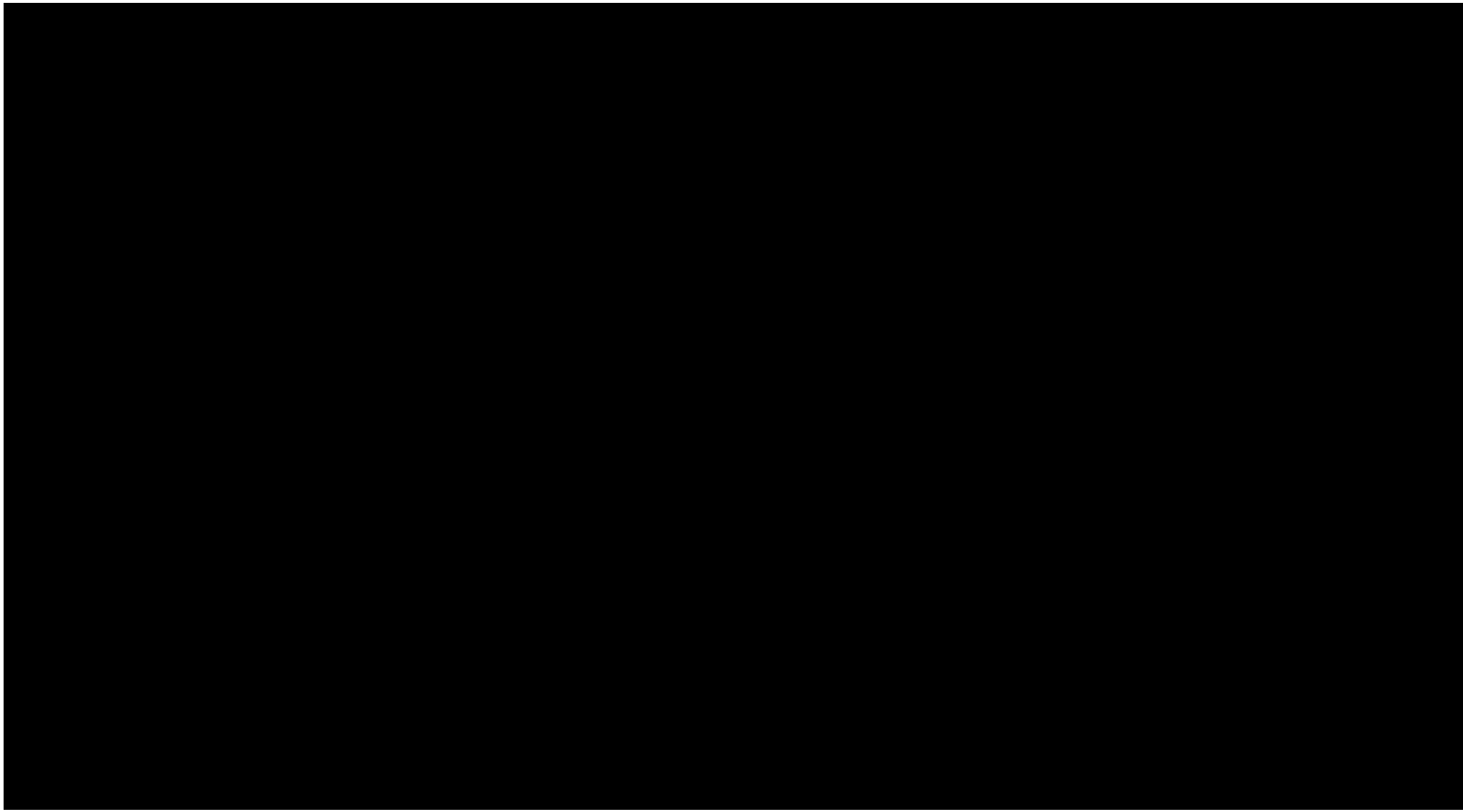
- Solar wind +magnetosphere interactions
- CIR/HSS and CME impacts on Earth
- Importance of magnetosphere in space weather

Geomagnetic storm

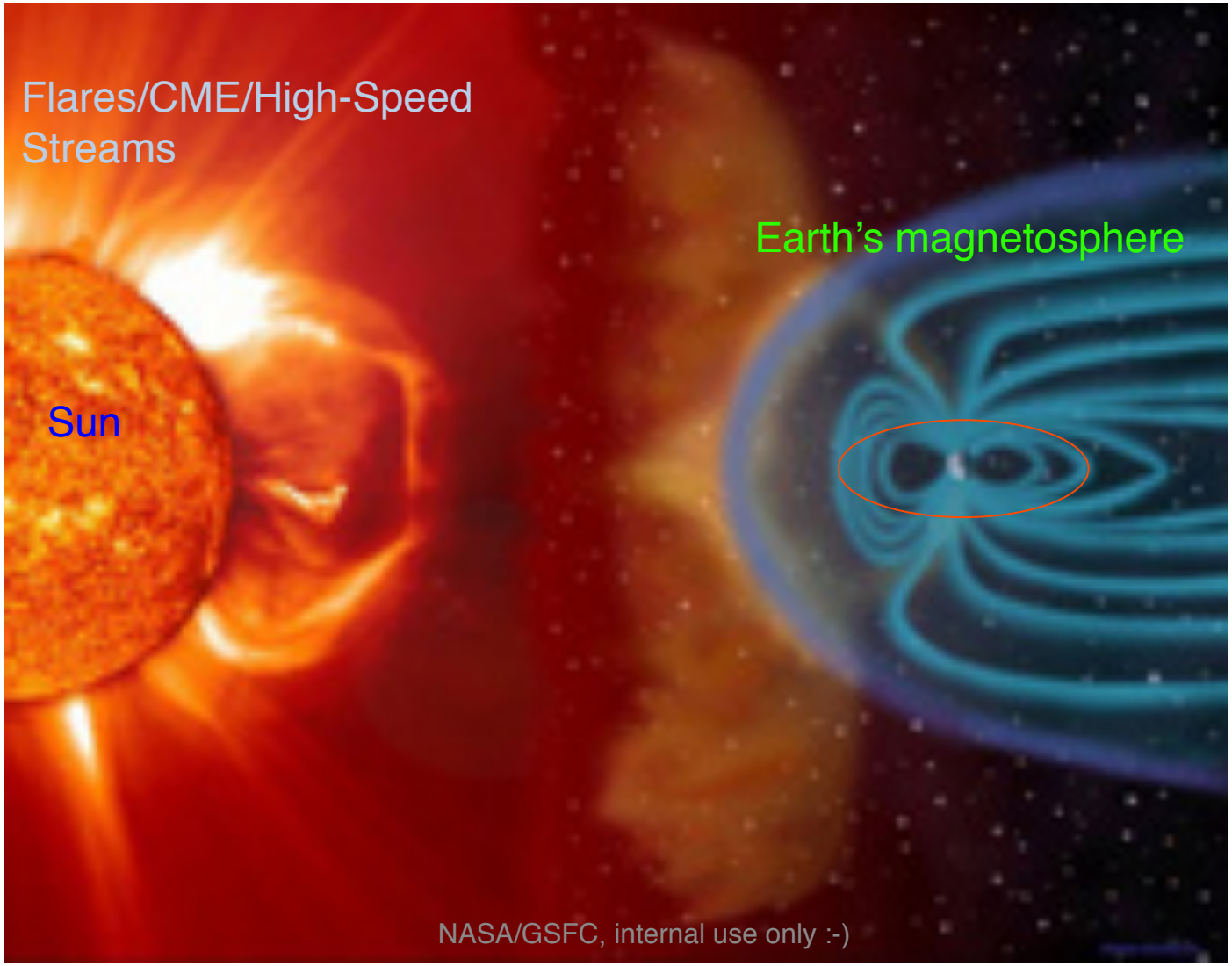
- **CME storm (can be severe)**
- **CIR storm (moderate)**

Earth's magnetosphere: home to many different plasma population of different energies – pose hazards to SC operation

A movie on Earth's magnetosphere



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.



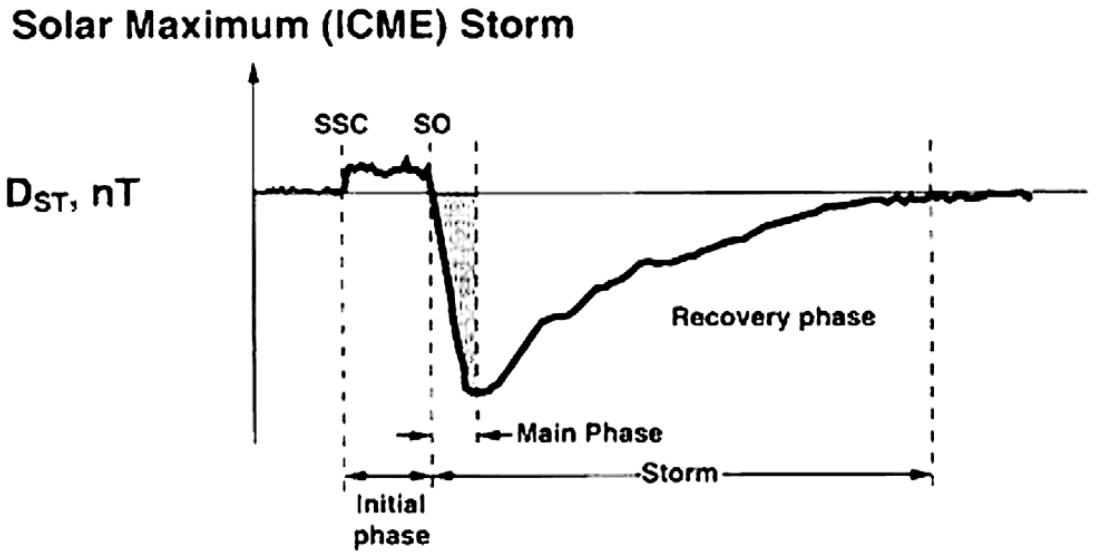
Two Main Drivers for the Magnetosphere

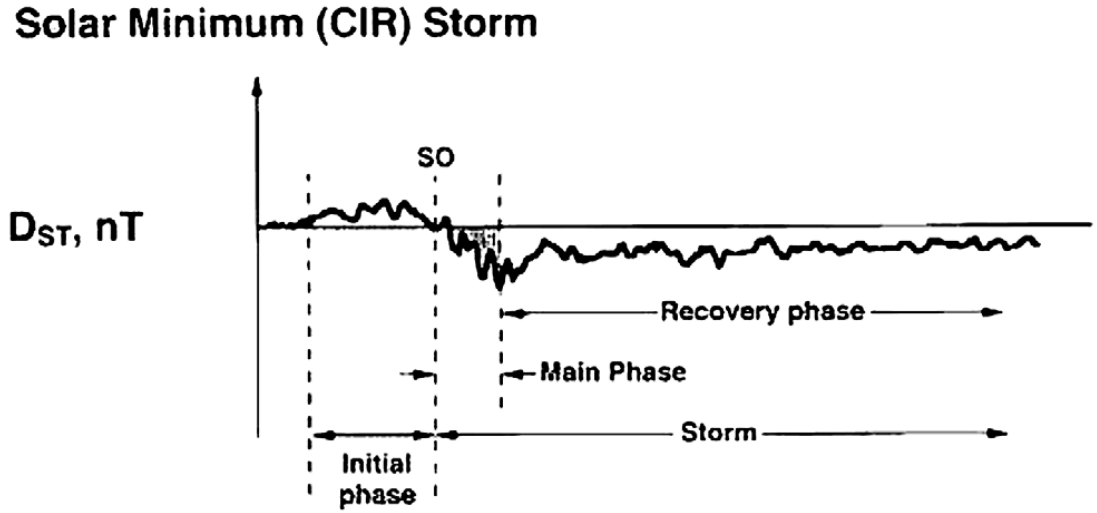
- CME (you have seen plenty of them already)
- CIR (Corotating Interaction Region) High Speed solar wind Stream (HSS)

Geomagnetic storm

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

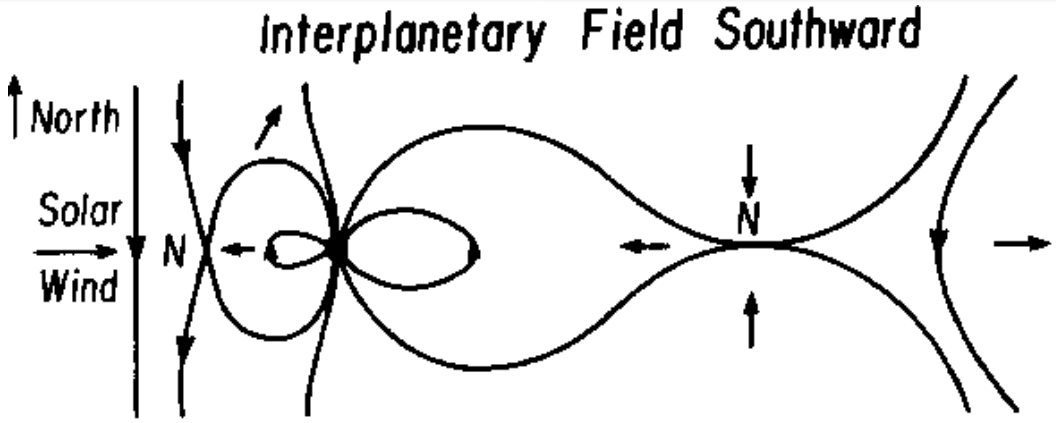
CME vs CIR storms



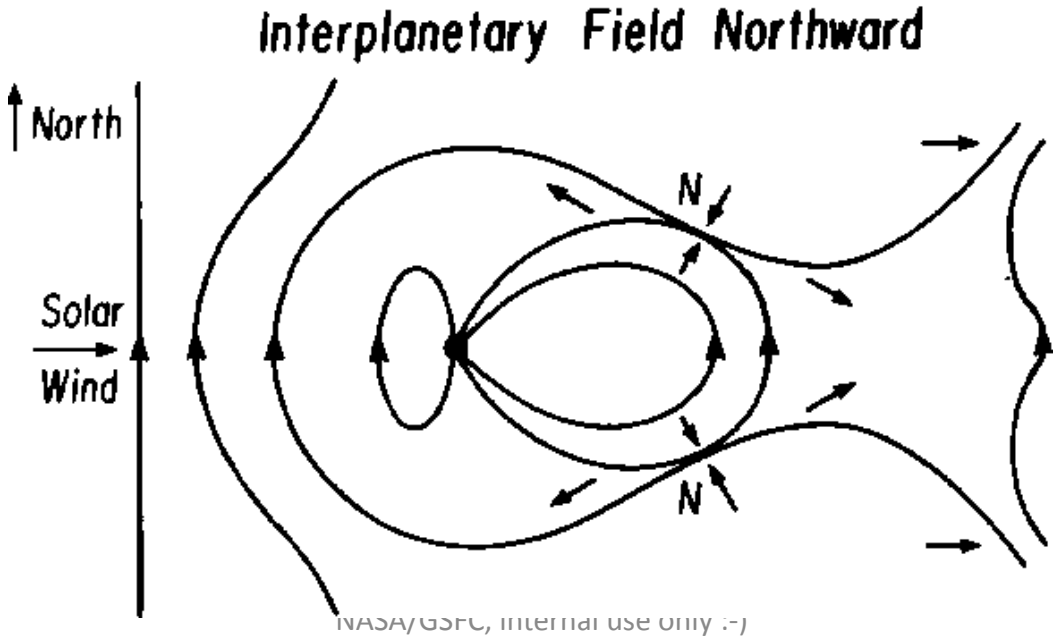


Two major types of solar wind-magnetosphere interactions

Southward IMF

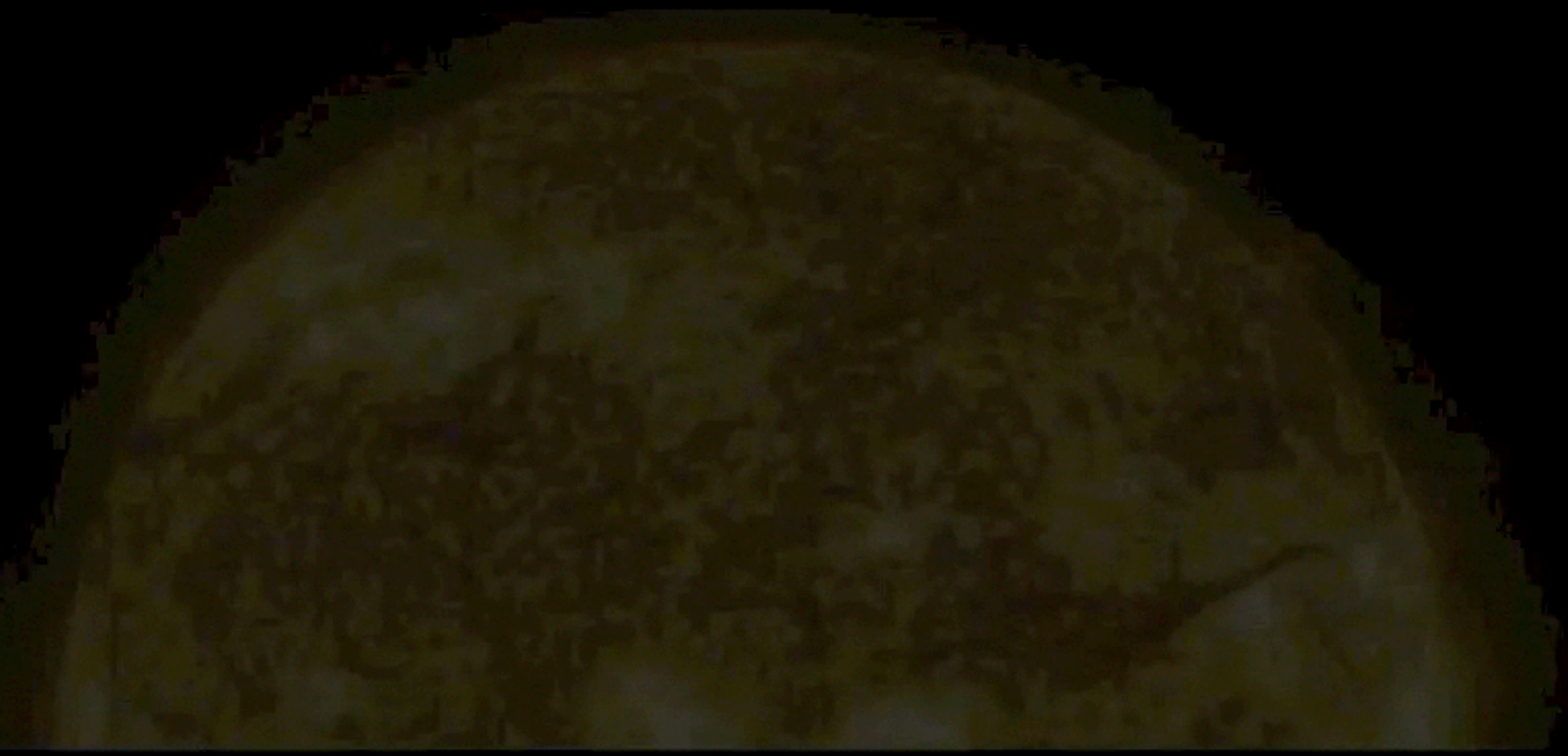


Northward IMF



Importance of IMF orientation

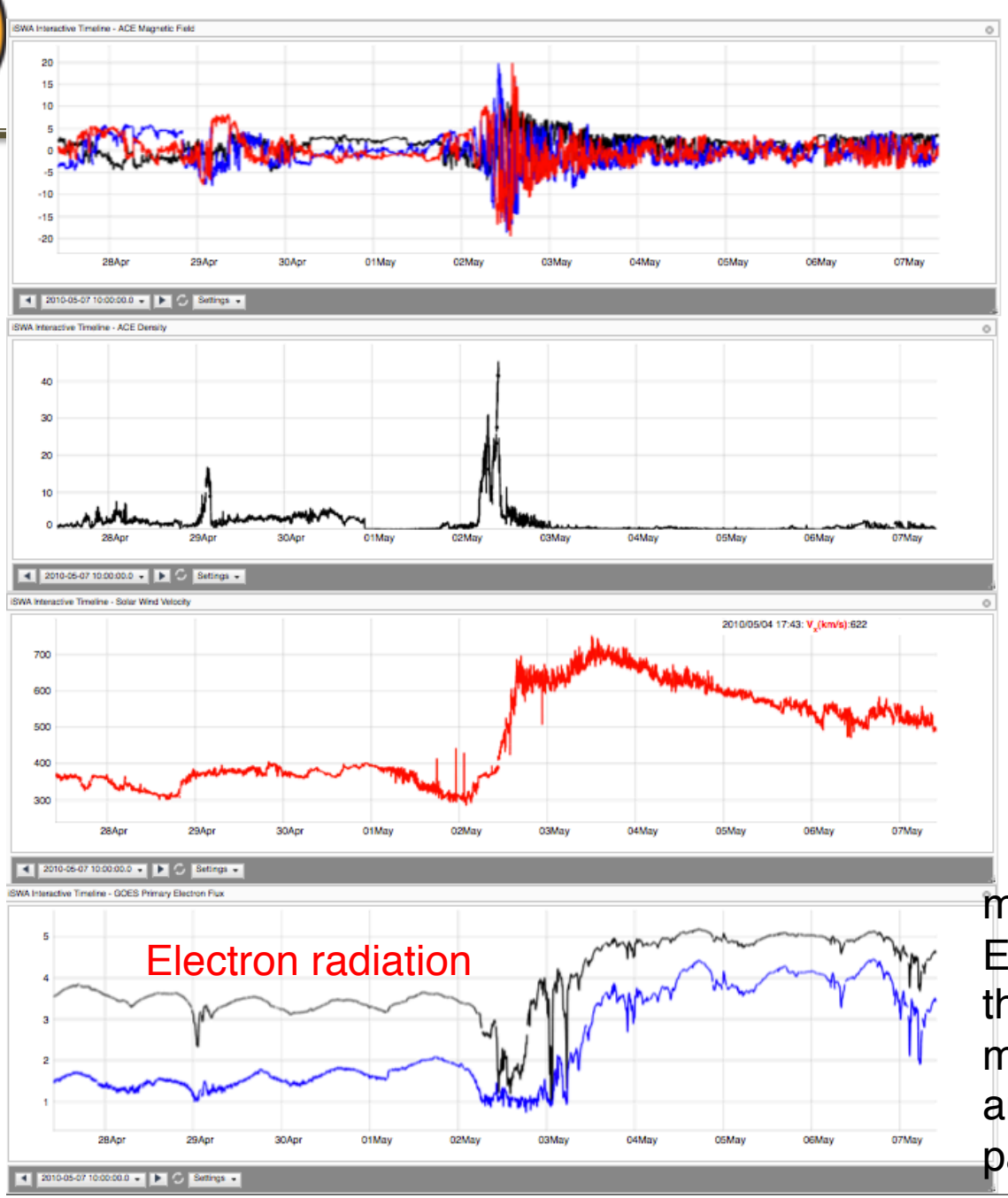
Illustration of Geomagnetic storms due to a CME



Geomagnetic storms due to CIRs are at most moderate

In-situ signatures of CME and CIR HSS at L1

ACE and WIND: important upstream solar wind monitor



Clean HSS

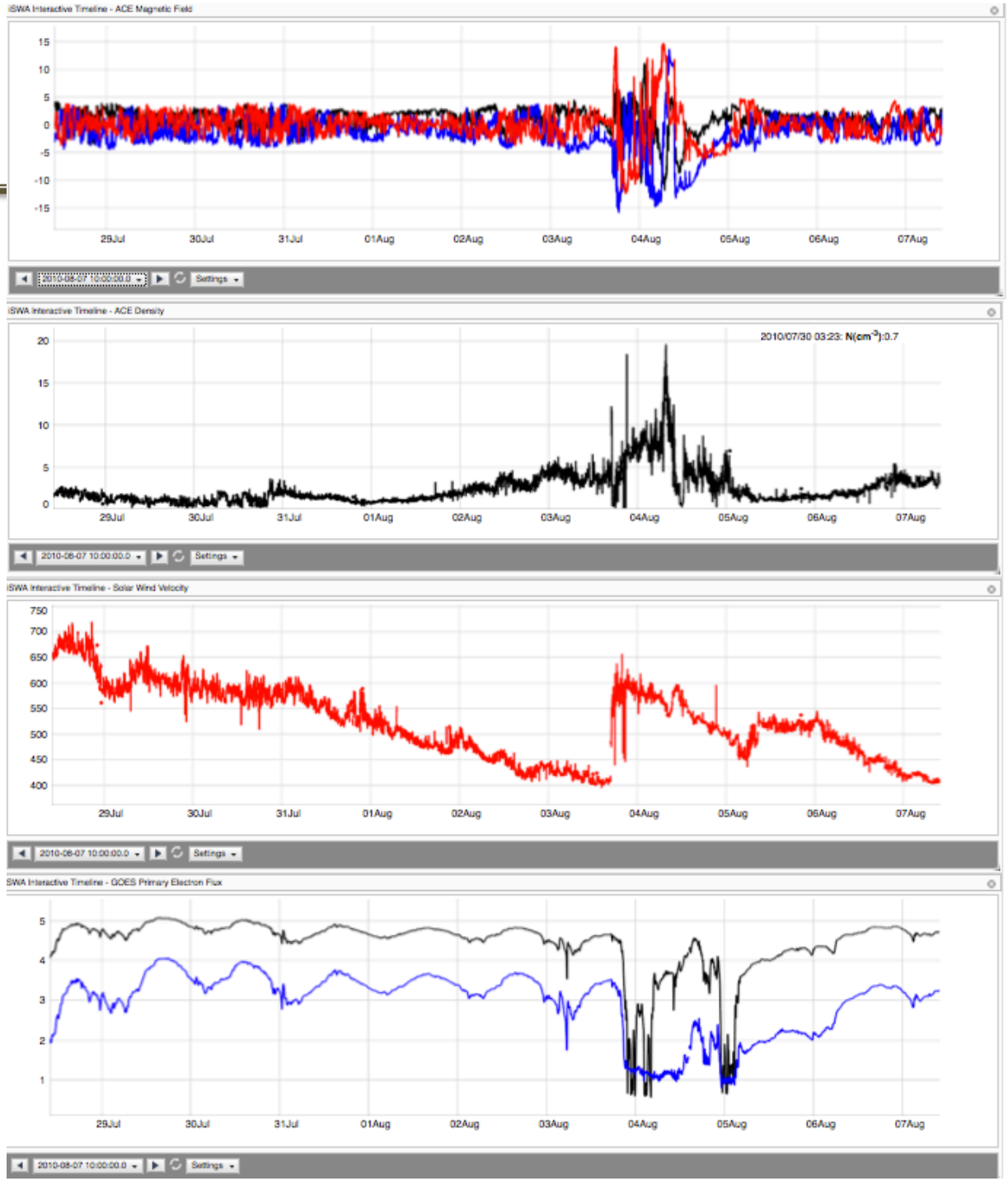
May 2, 2010

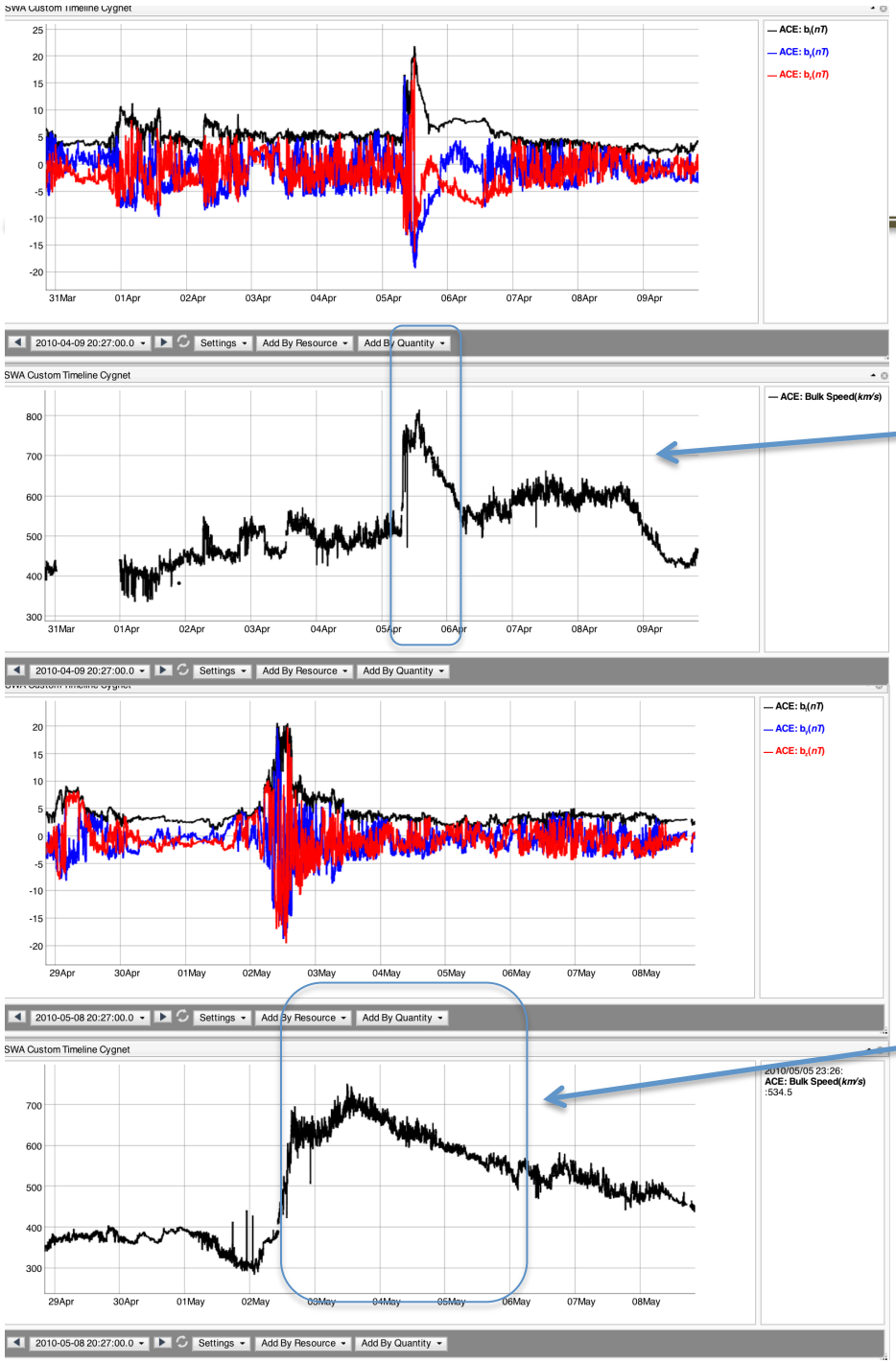
Dense (20-30 cc), HSS

IMFBz: -18 nT

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

Aug 3, 2010


ISWA Interactive Timeline - ACE Magnetic Field
15
10
5
0
-5
-10
-15
29Jul
30Jul
31Jul
01Aug
02Aug
03Aug
04Aug
05Aug
06Aug
07Aug
2010-08-07 10:00:00.0
Settings
ISWA Interactive Timeline - ACE Density
2010/07/30 03:23: N(cm-3):0.7
20
15
10
5
0
29Jul
30Jul
31Jul
01Aug
02Aug
03Aug
04Aug
05Aug
06Aug
07Aug
2010-08-07 10:00:00.0
Settings
ISWA Interactive Timeline - Solar Wind Velocity
750
700
650
600
550
500
450
400
29Jul
30Jul
31Jul
01Aug
02Aug
03Aug
04Aug
05Aug
06Aug
07Aug
2010-08-07 10:00:00.0
Settings
ISWA Interactive Timeline - GOES Primary Electron Flux
5
4
3
2
1
29Jul
30Jul
31Jul
01Aug
02Aug
03Aug
04Aug
05Aug
06Aug
07Aug
2010-08-07 10:00:00.0
Settings



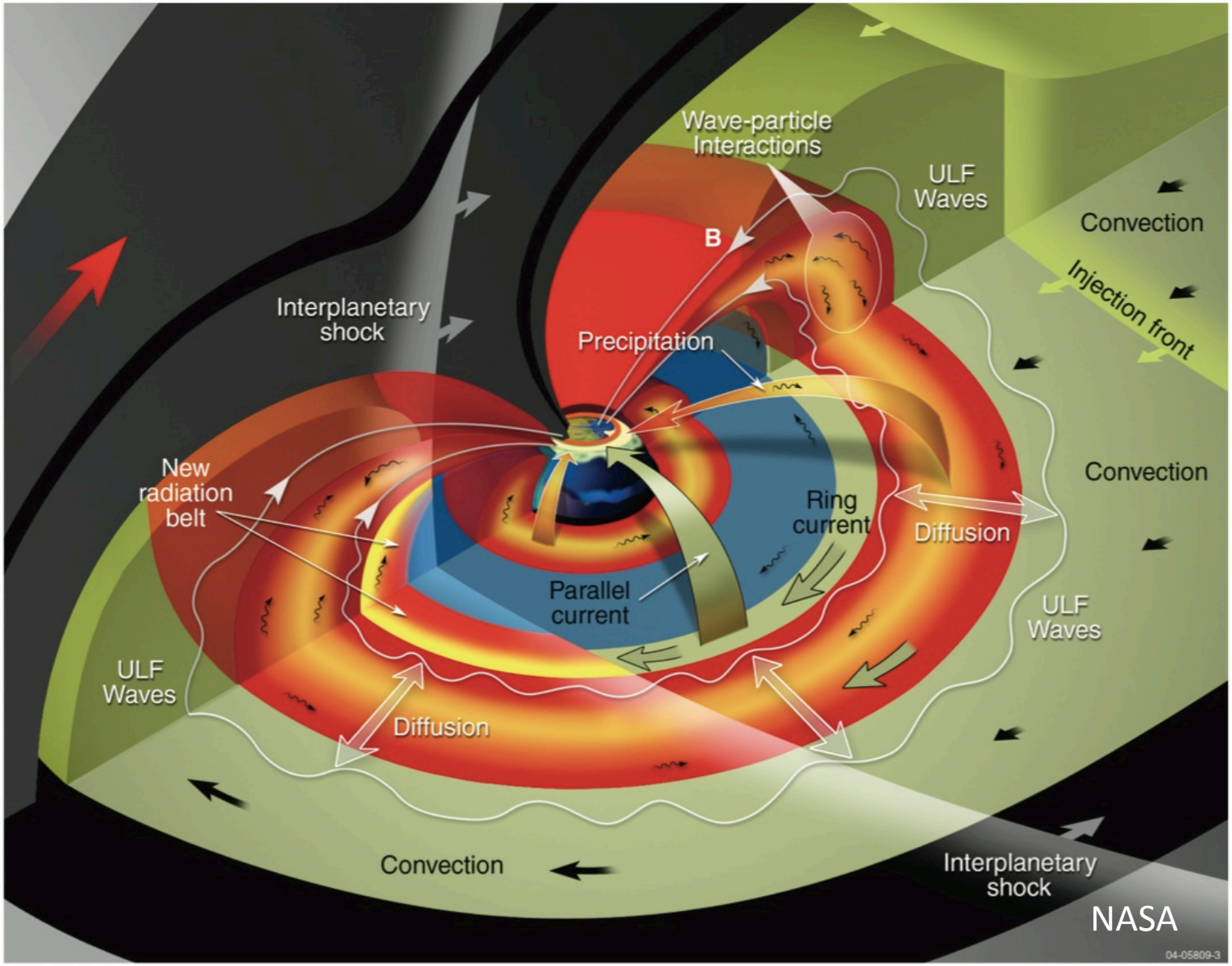
CME

High speed: last 1-2 days

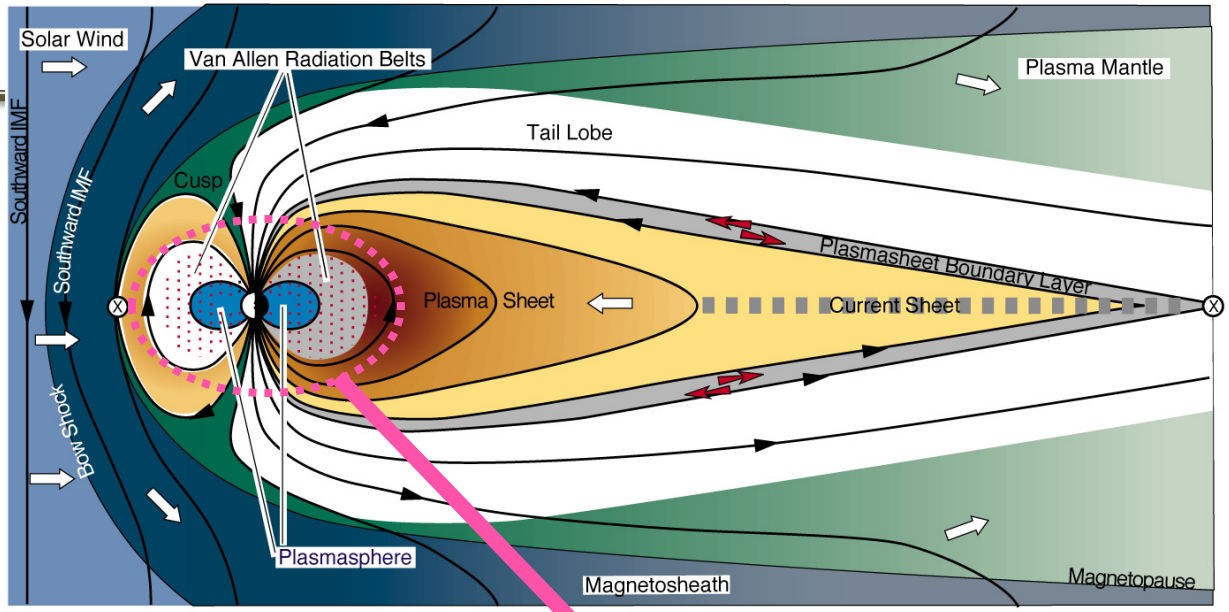
CIR

High speed: last 3-4 days

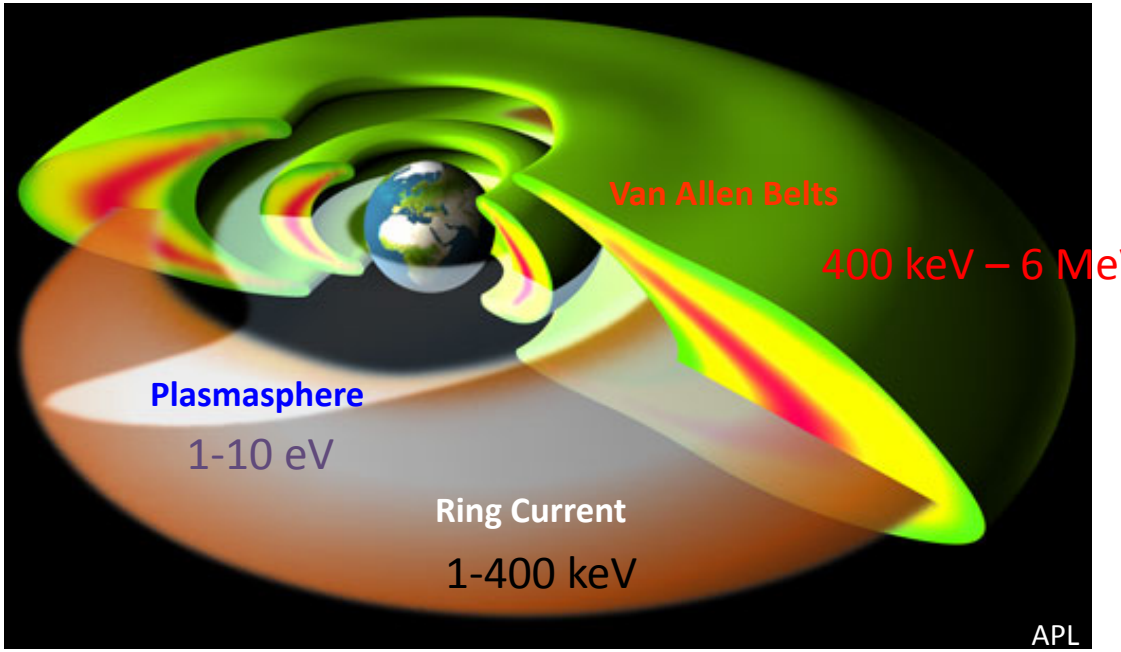
The Earth's Magnetosphere



The Earth's Magnetosphere



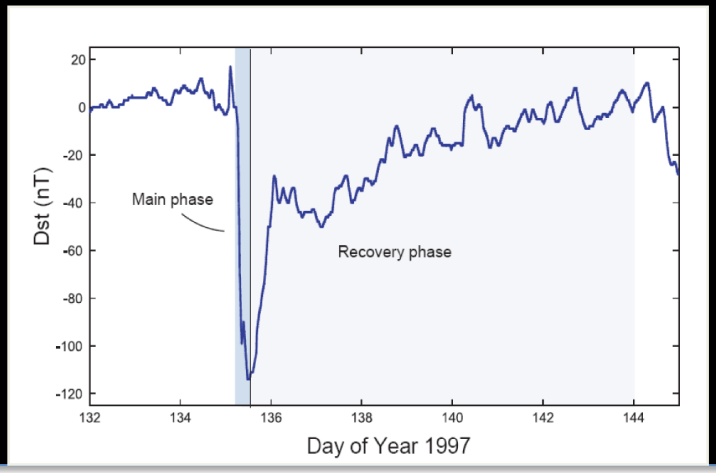
Inner Magnetosphere:
Up to ~ 10Re



Magnetic Storms

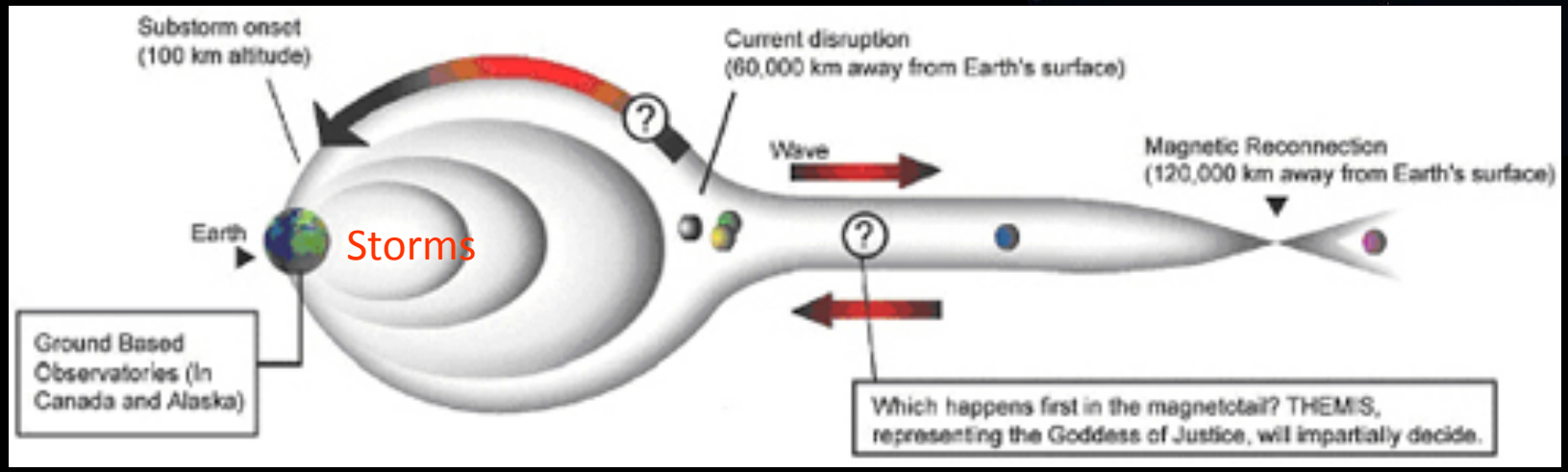
- Most intense solar wind-magnetosphere coupling
- Associated with solar coronal mass ejections (CME), coronal holes HSS
- IMF Bz southward, strong electric field in the tail
- Formation of ring current and other global effects

- 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



Kp: measure of storm intensity

"*p*lanetarische *K*ennziffer" (= 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>=6

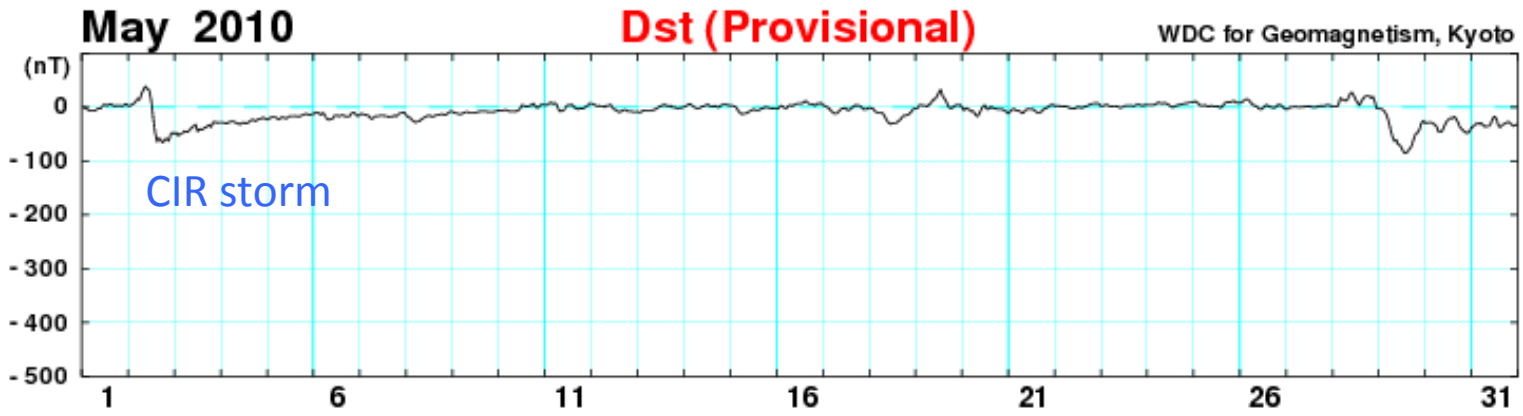
Geomagnetic Storm classification

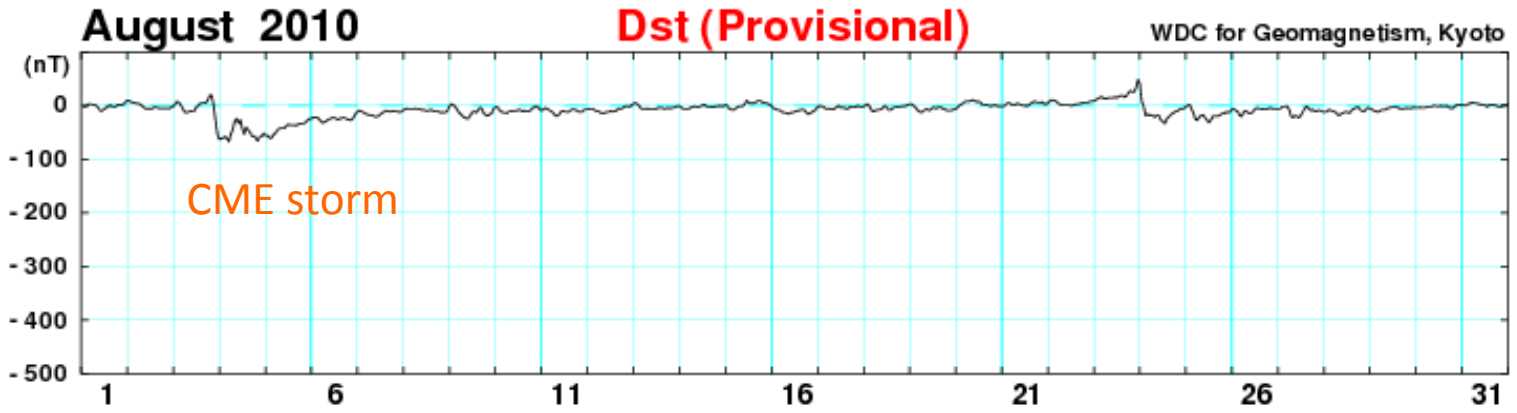
- http://www.swpc.noaa.gov/NOAAscales/index.html#GeomagneticStorms

- Operational world

Dst: Disturbance of Storm Time

Measure of Storm Intensity





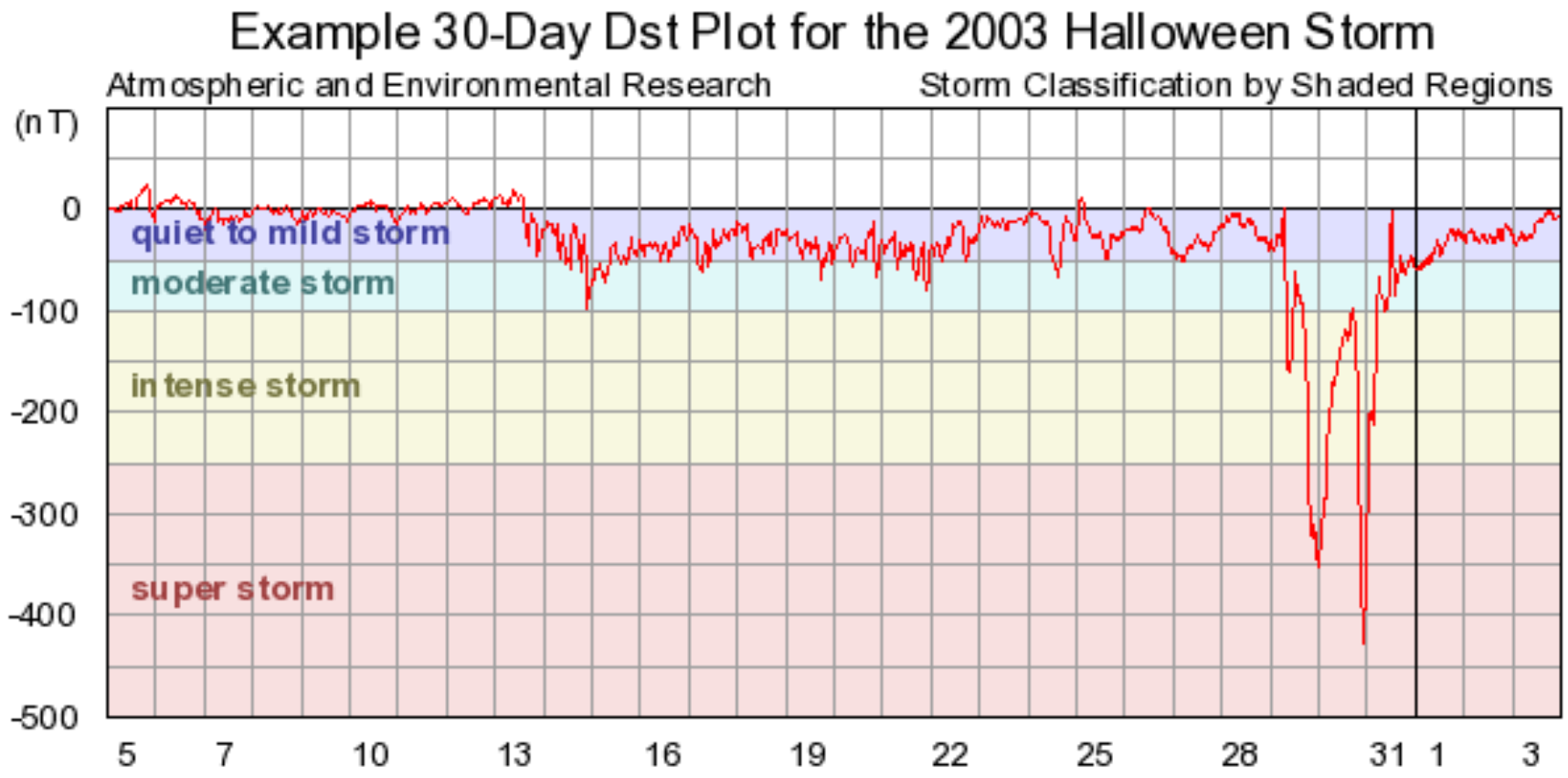
CIR storm at most: Dstmin ~ -130 nT

CME storm: Dstmin ~ -600 nT

1989 March 14 Dstmin= -589 nT

Geomagnetic Storm Classification

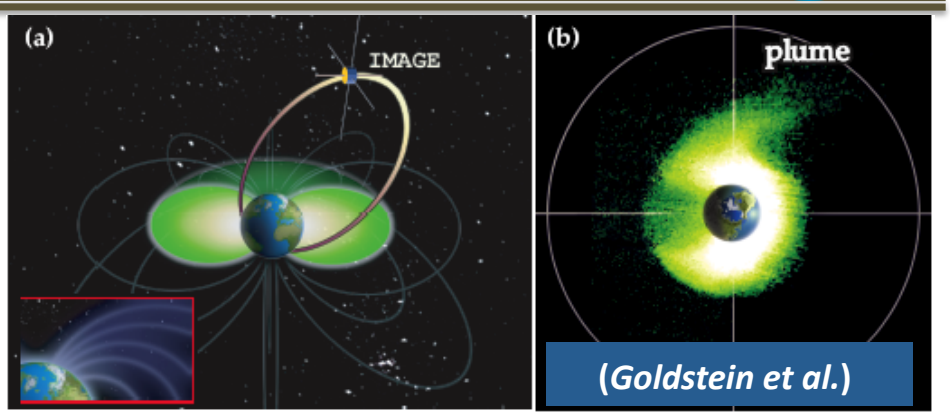
Research

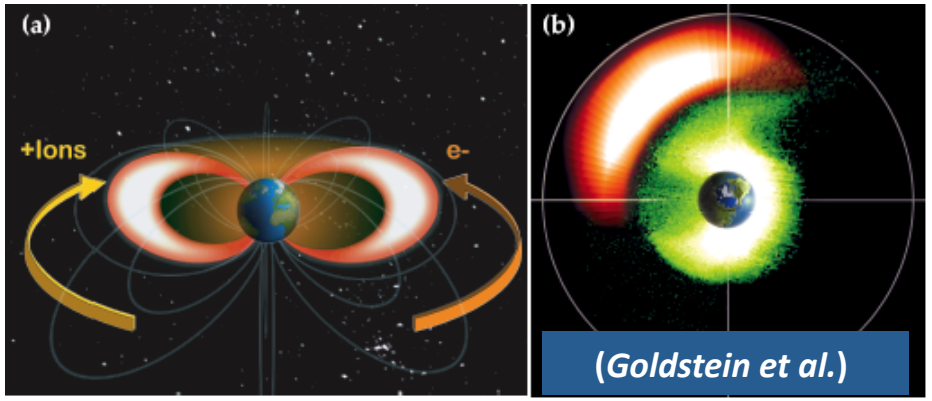


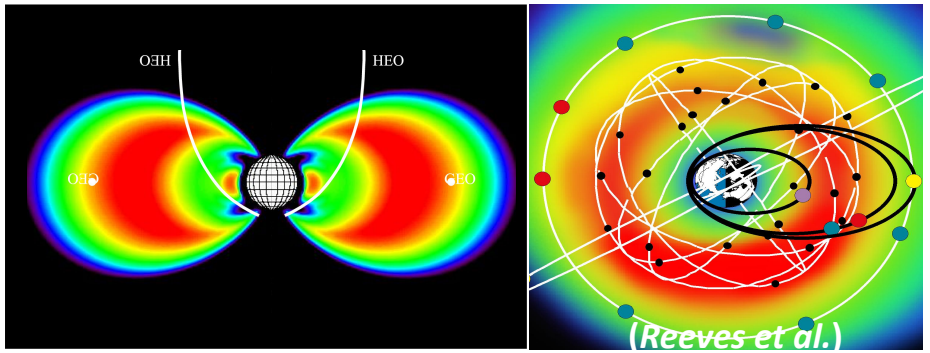
Inner magnetosphere plasmas

- 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

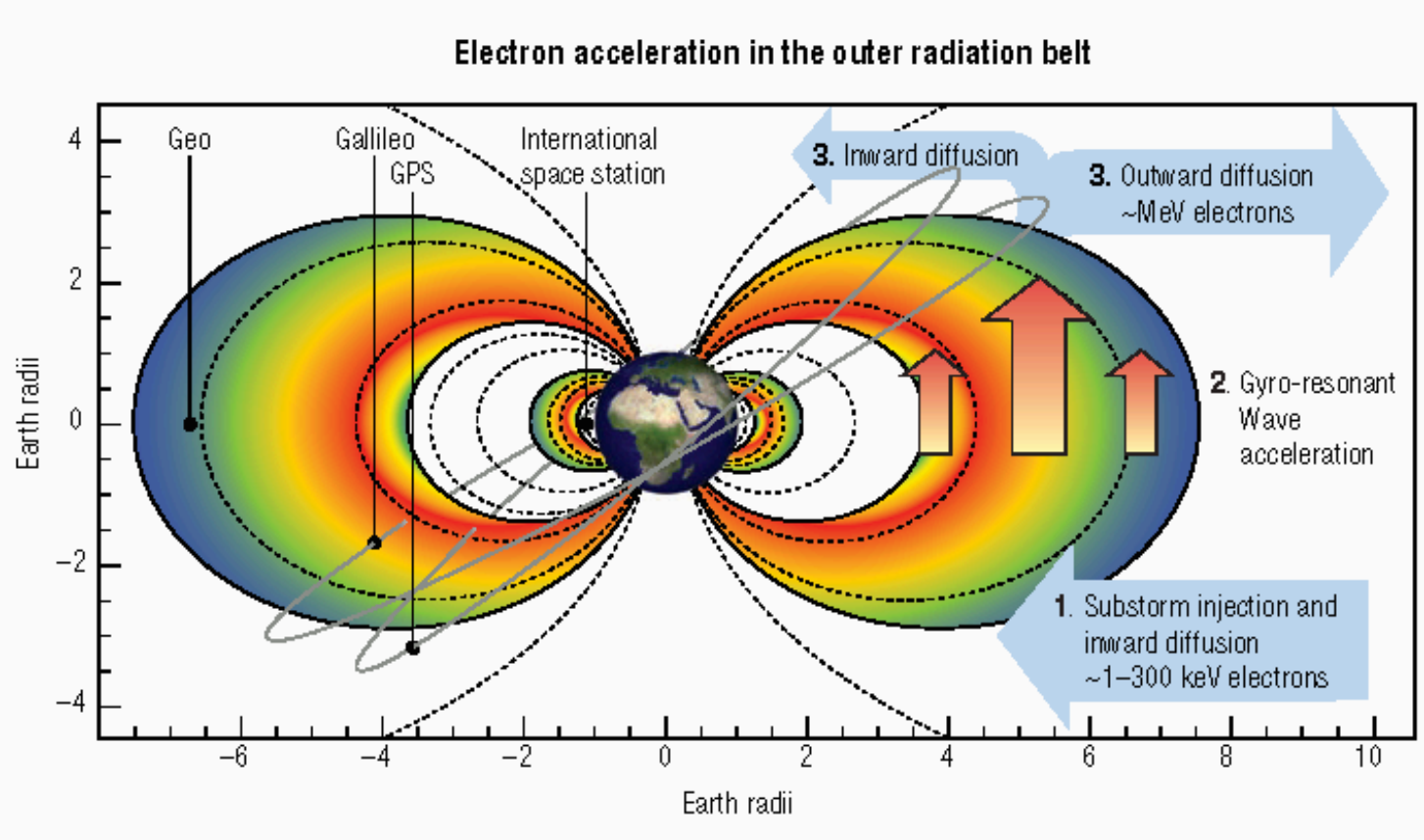
Inner magnetosphere: Gigantic Particle accelerator





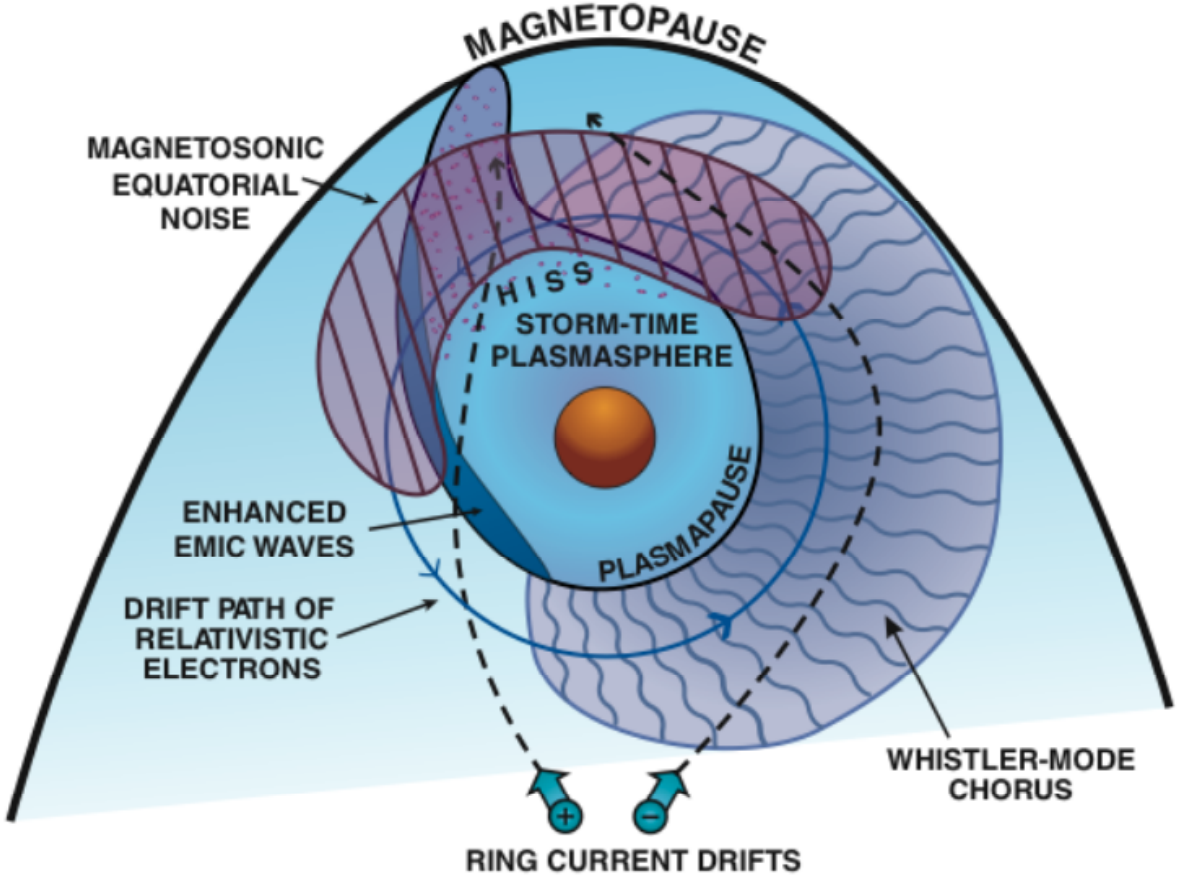


RB: Current understanding

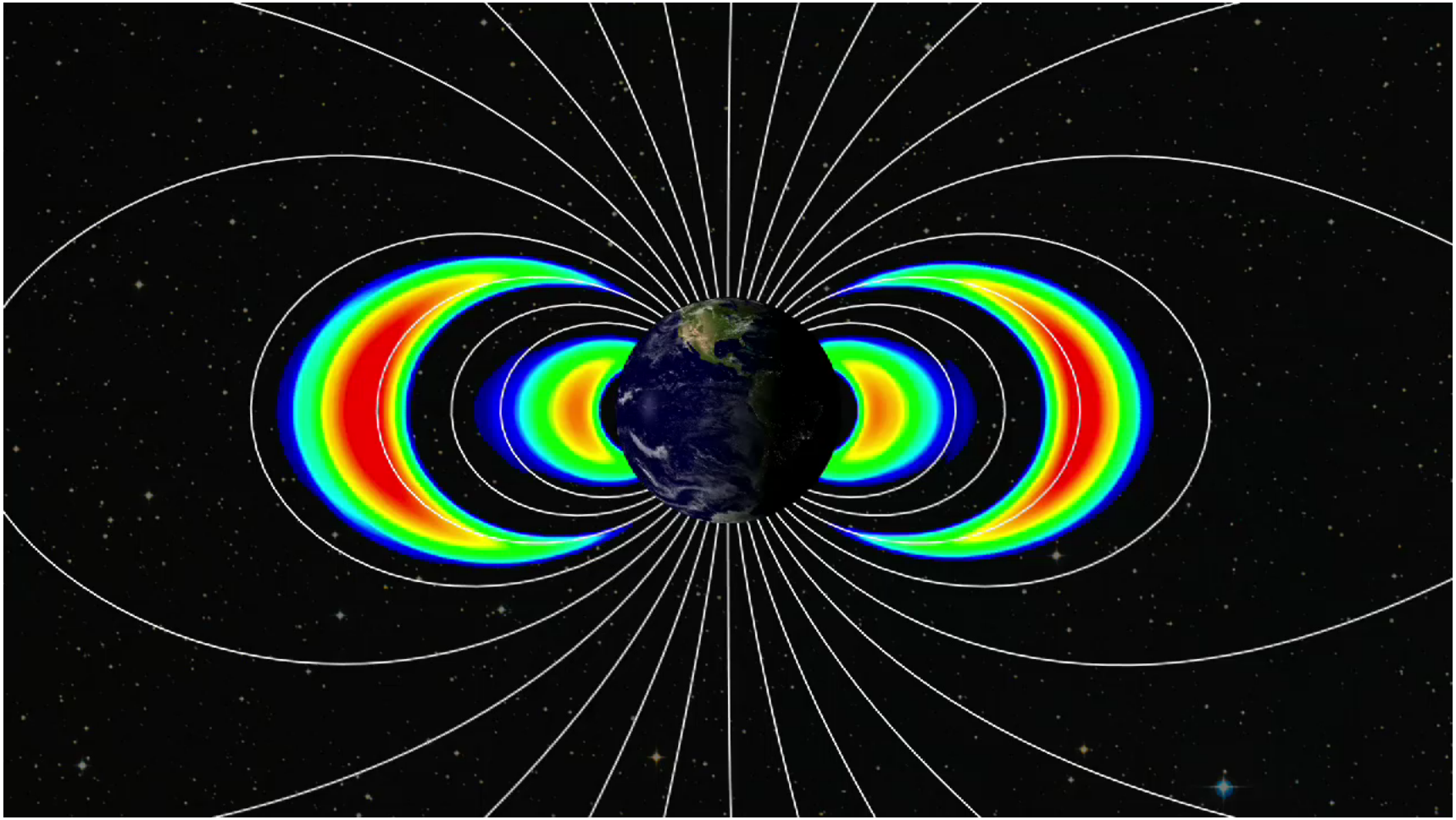


Horne et al., 2007, Nature Physics

Various types of waves that are important to RB dynamics

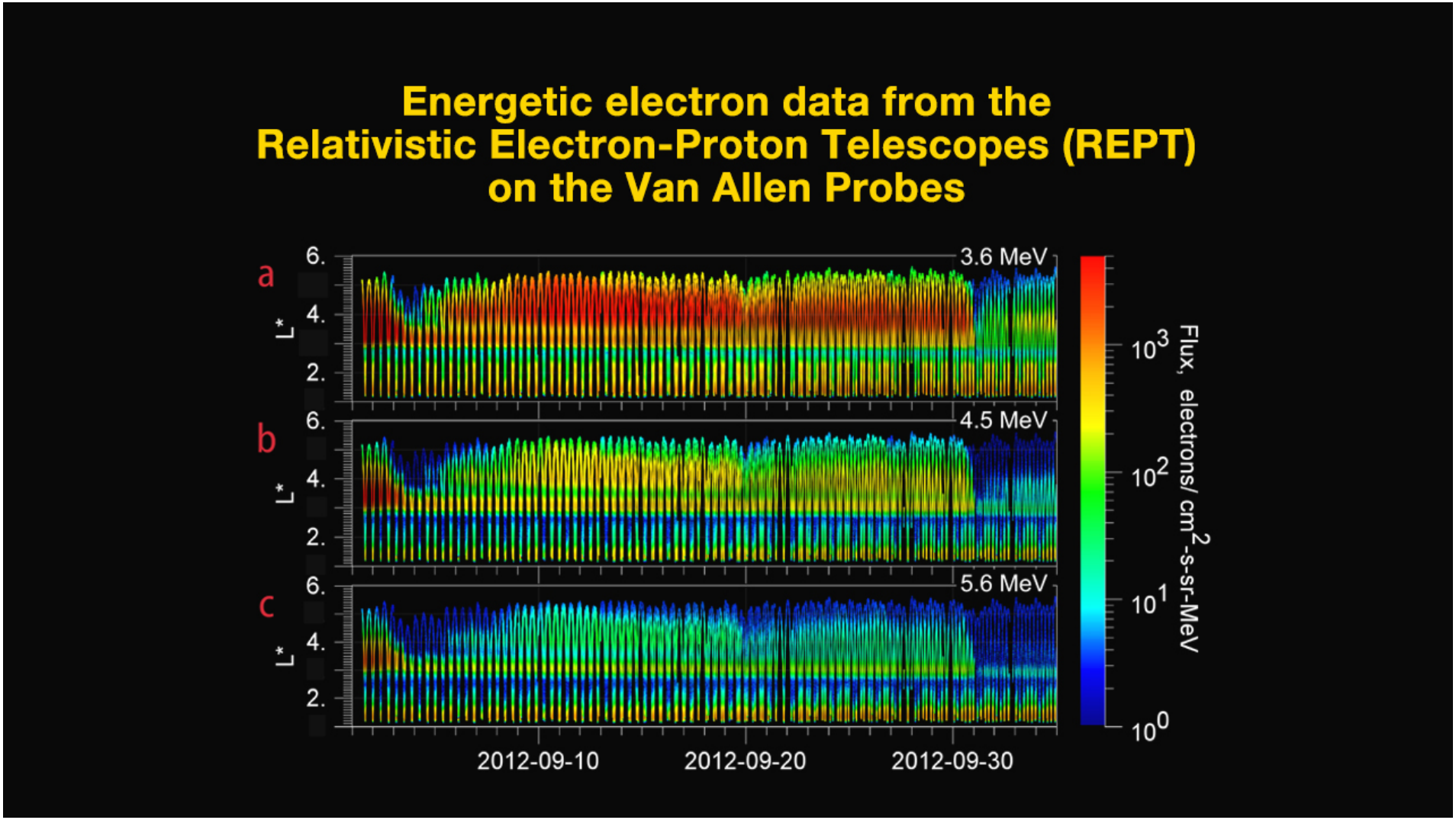


Van Allen Probes: current mission on radiation belt dynamics



Three-Belt Structure

Quiet-time phenomenon



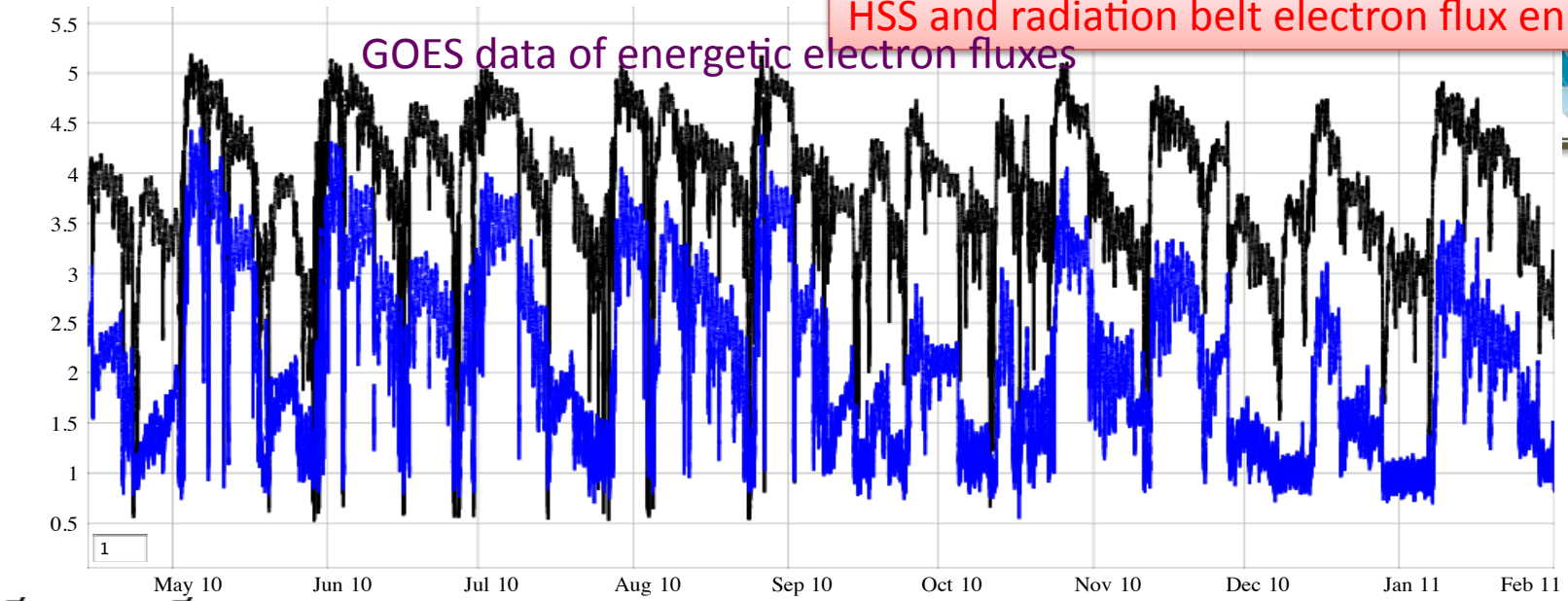
Different impacts on RB

CME vs CIR storms

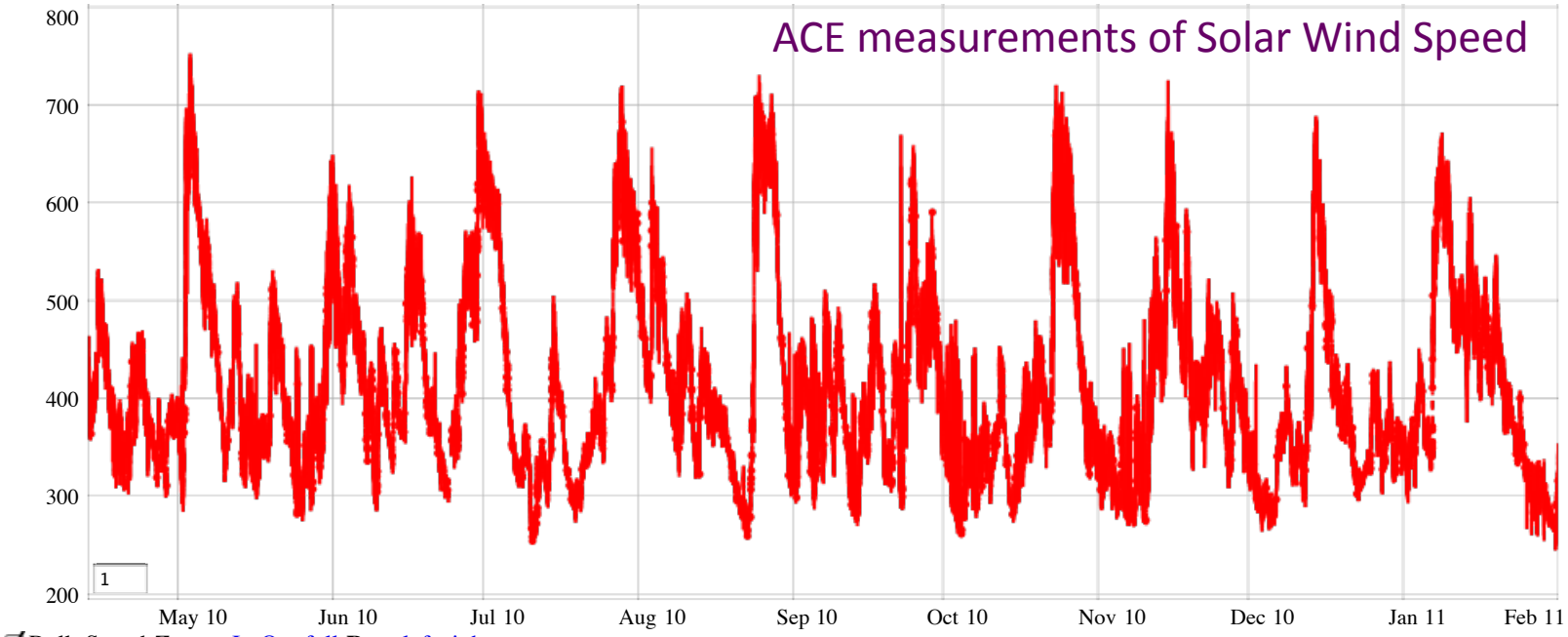
- CME geomagnetic storms: RB flux peak inside geosynchronous orbit. The peak locations moves inward as storm intensity increases
- CIR geomagnetic storms: More responsible for the electron radiation level enhancement at GEO orbit

HSS and radiation belt electron flux enhancement

Click the check boxes to toggle series visibility

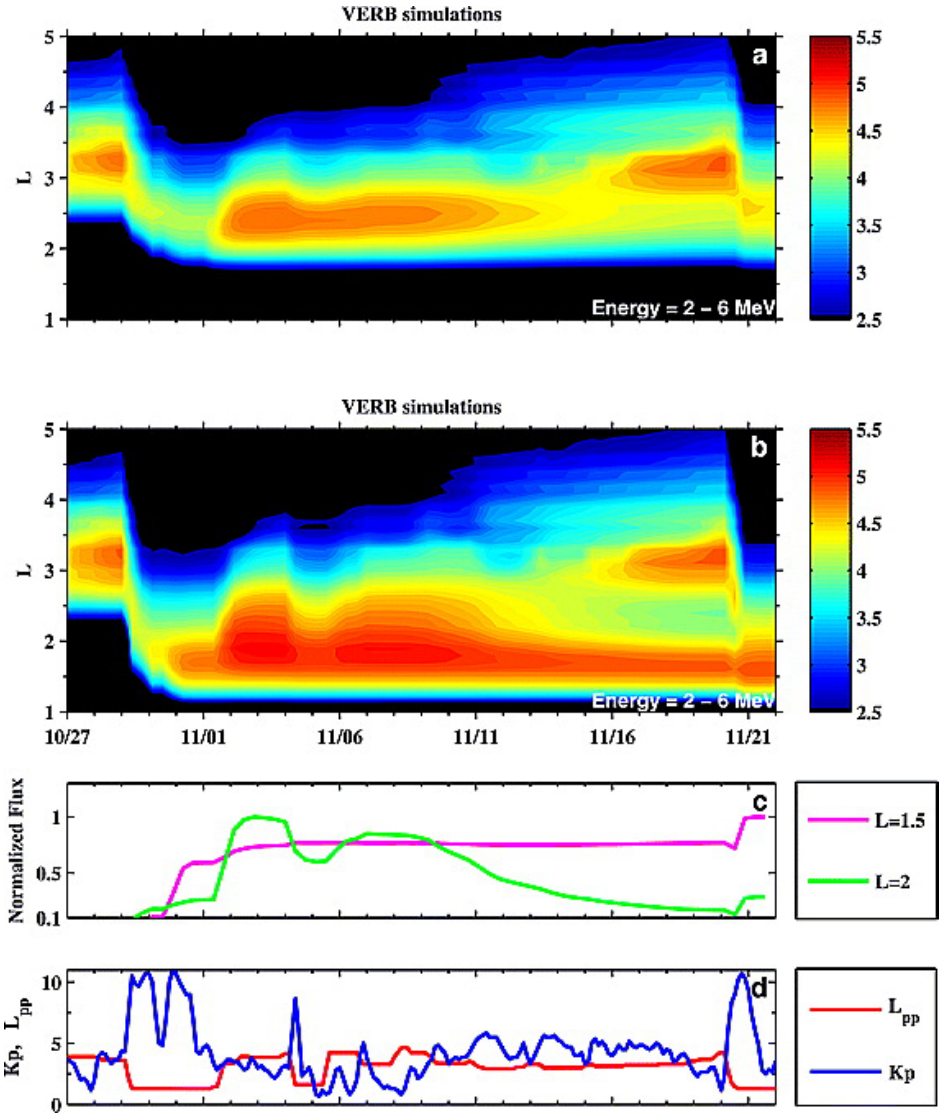


☑E > 0.8 MeV ☑E > 2.0 MeV **Zoom:** In Out full **Pan:** left right



☑Bulk Speed **Zoom:** In Out full **Pan:** left right

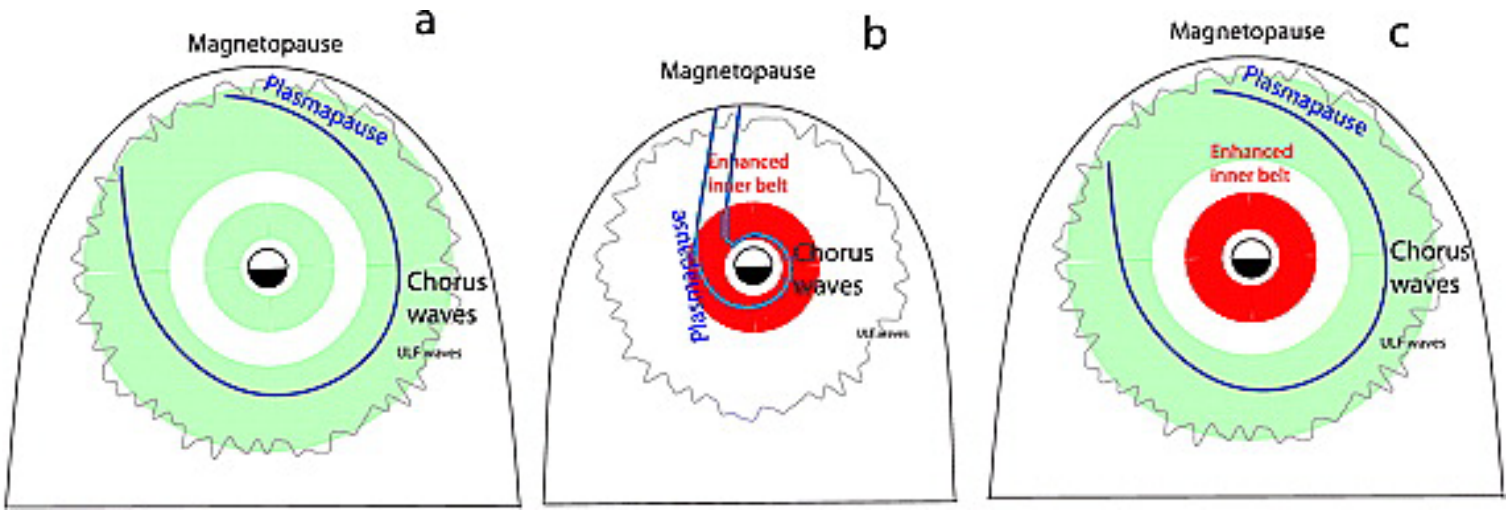
CME (superstorm condition) impact on RB



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!

Tsurutani et al., 2006

Magnetospsheric Products

Kp

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

- Geomagnetic activity index

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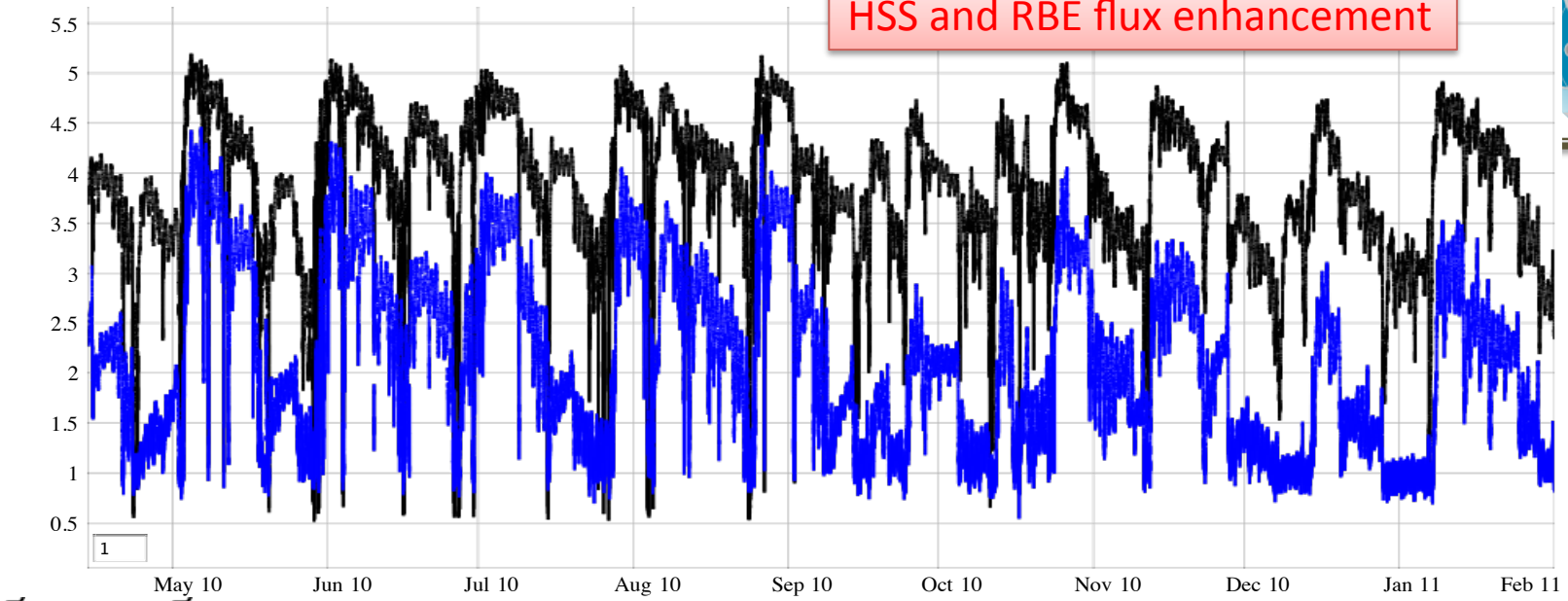
http://bit.ly/Kp_layout Threshold Kp>=6

Click the check boxes to toggle series visibility

HSS and RBE flux enhancement



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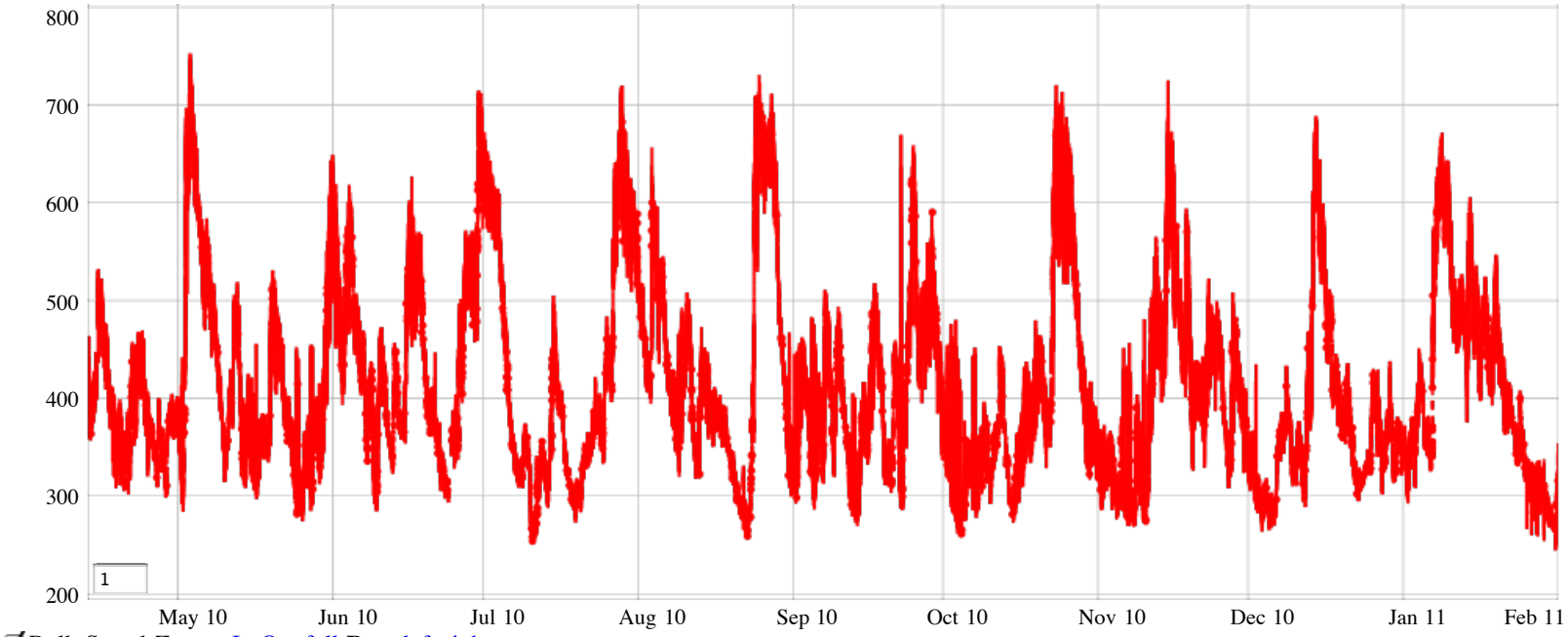


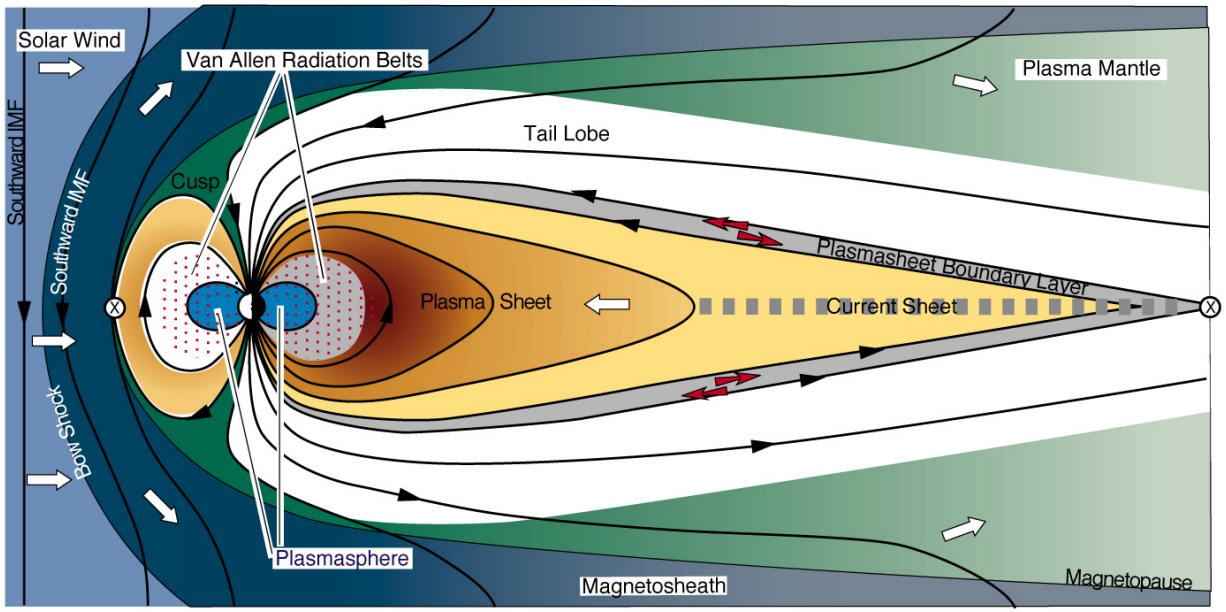
☑Bulk Speed **Zoom:** In Out full **Pan:** left right

Magnetopause stand-off distance

delineating the boundary between SW and Earth's magnetosphere

- r0 <=6.6 Re – model product
  - Events: Dec 28, 2010
  - Jan 7,2010 kp=5 at 22:30 UT on 1/6/2011
  - Non-event: Dec 1 – 7, 2010

Degree of compression of MP
Due to Pdyn of solar wind
(interplanetary shock /HSS)



An iSWA layout for magnetospheric products

http://bit.ly/iswa_mag

Challenges in forecasting geomagnetic storms

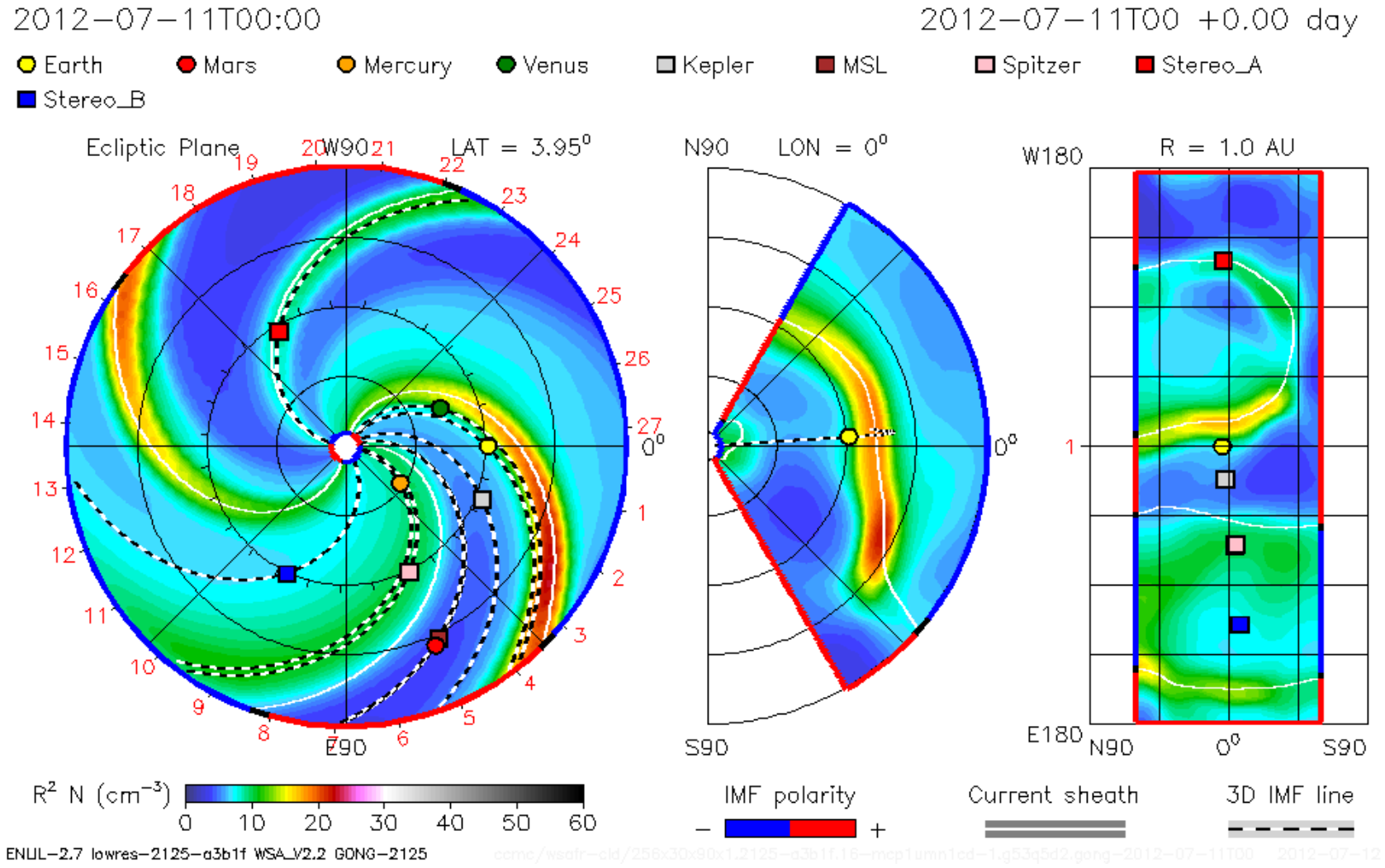
Forecasting Earth-Directed CME and its impact

a minor radiation storm (SEP)
But a major geomagnetic storm

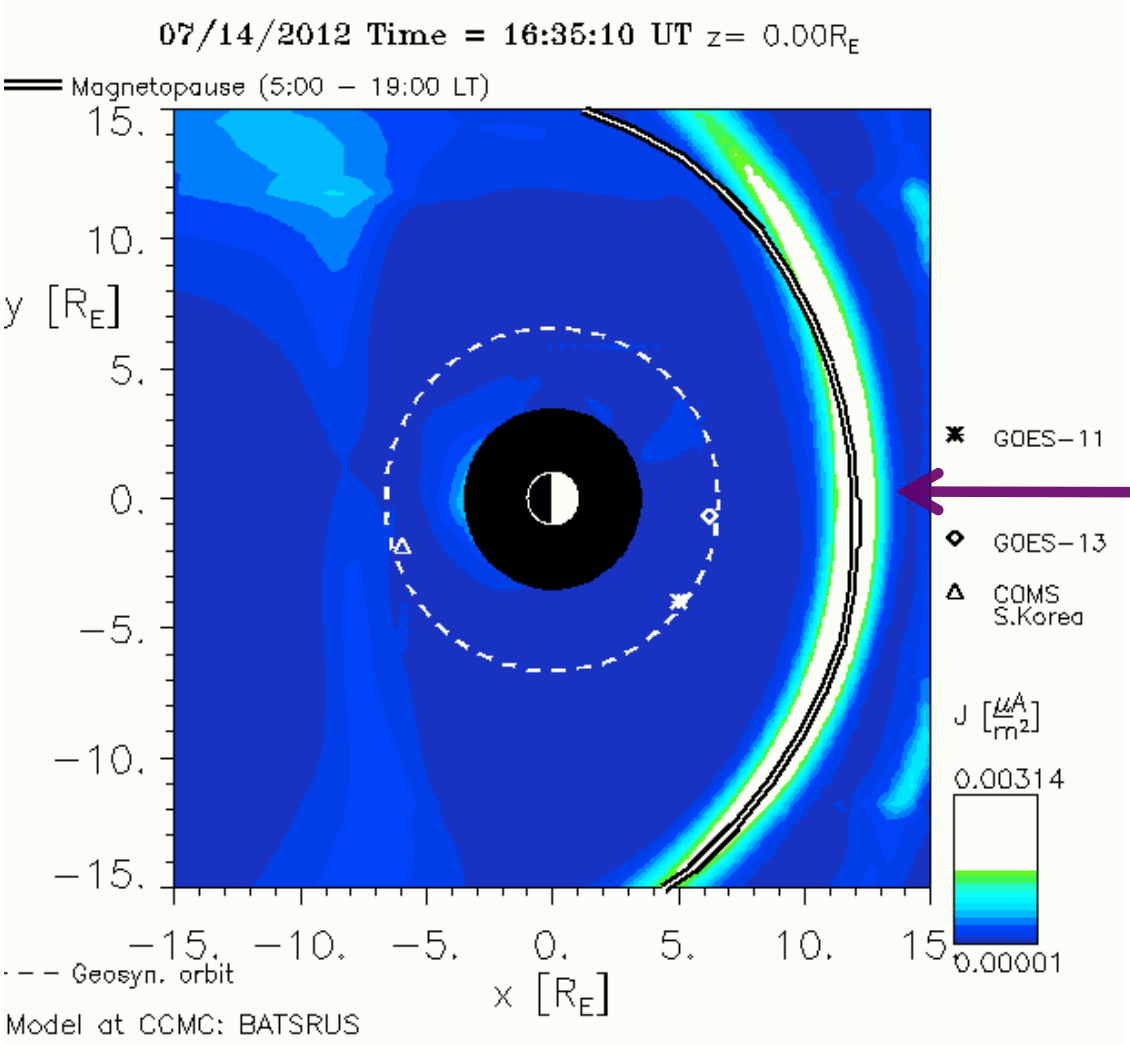
the 12 July 2012 solar eruption

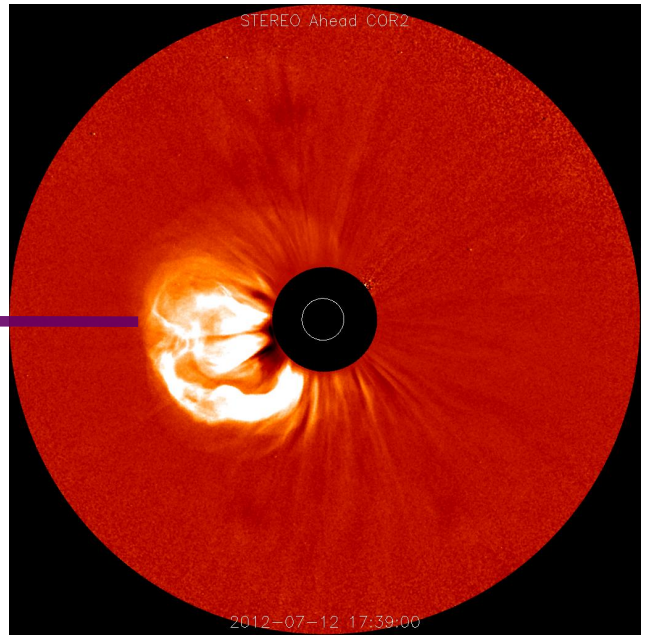
Modeling of the 12 July 2012 CME

V=1400 km/s, associated with an X1.4 class solar flare



Earth's Response to the CME's Arrival

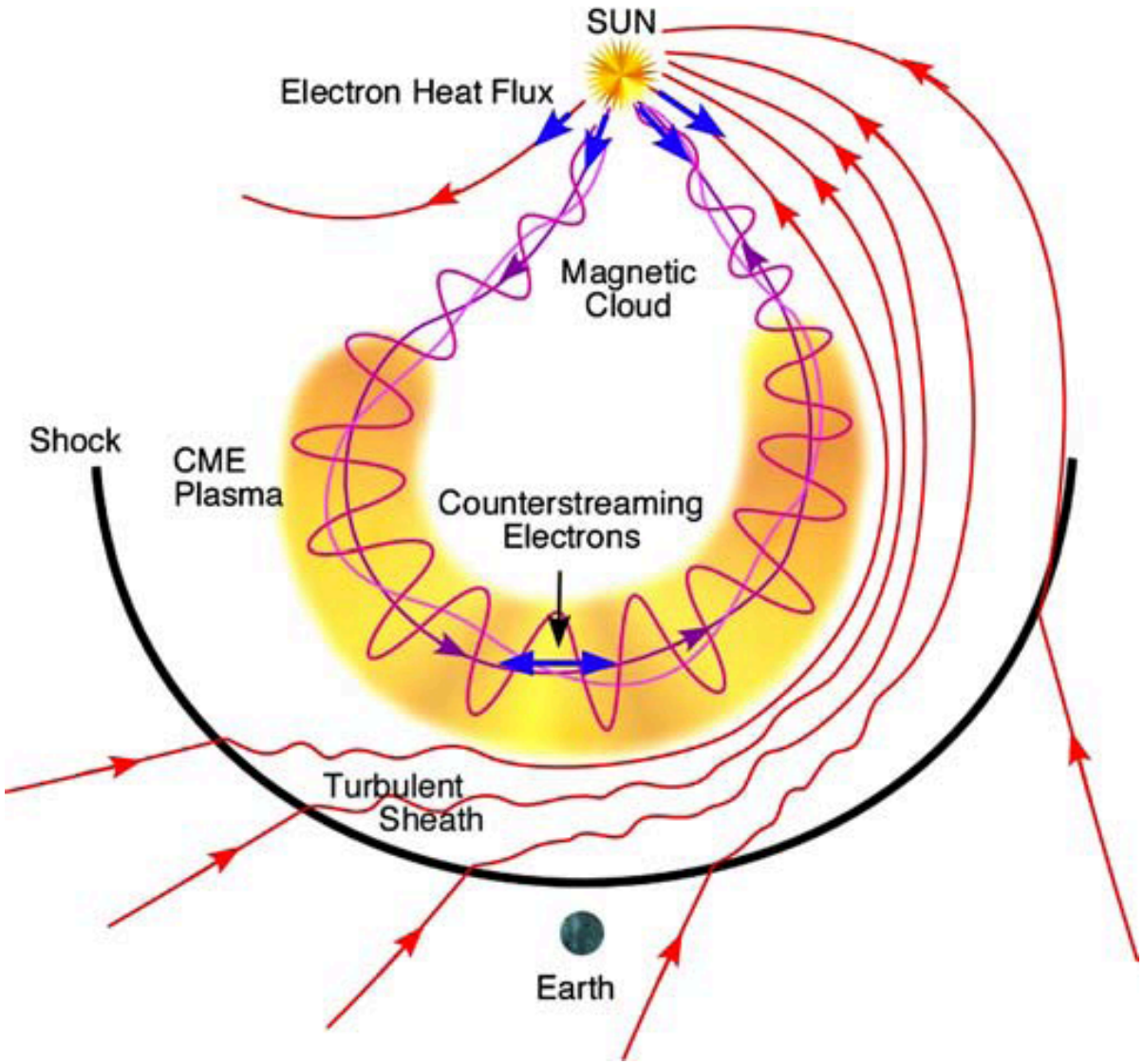




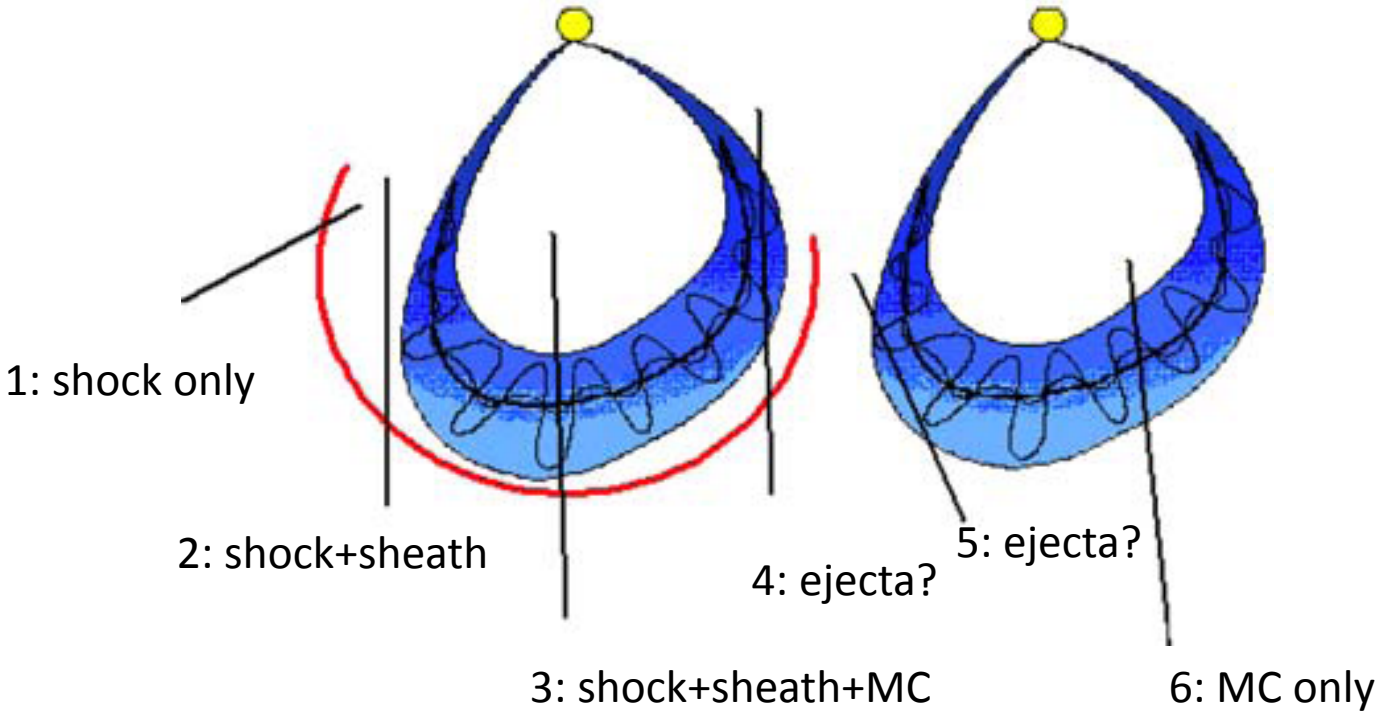
The CME seen by STEREO A

Resulting in a Kp = 7- on a scale from 0 – 9, Kp: a measure of geomagnetic disturbances

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



In-Situ signature can be quite complex



Space Weather Impacts on spacecraft in the magnetosphere

SWx Impacts on Satellites Electronics/ Components

hazards presented by the radiation and plasma environment in space

- Single Event Effects (affect all SC)
  - caused by protons and heavy ions with energies of 10s of MeV/amu
- Internal Charging (those in radiation belt)
  - caused by electrons with energies above about 100 keV that penetrate inside a vehicle
- Surface Charging (all in Earth's environment)
  - caused by electrons with energies of 10s of keV that interact with spacecraft surfaces
- Event Total Dose (all SC)
  - caused primarily by solar protons and possibly also by transient belts of trapped particles, typically protons with energies near 10 MeV

Effects on Satellite Orbit

- Orientation effects (spacecraft that use Earth's magnetic field for orientation)
- ~~Satellite drag (LEO)~~

Environment Hazards for different orbits

Space hazard	Spacecraft charging		Single-event effects			Total radiation dose		Surface degradation		Plasma interference with communications	
Specific cause	Surface	Internal	Cosmic rays	Trapped radiation	Solar particle	Trapped radiation	Solar particle	Ion sputtering	O^+ erosion	Scintillation	Wave refraction
LEO <60°											
LEO >60°											
MEO											
GPS											
GTO											
GEO											
HEO											
Inter-planetary											

Important Relevant Not applicable

Joe Mazur