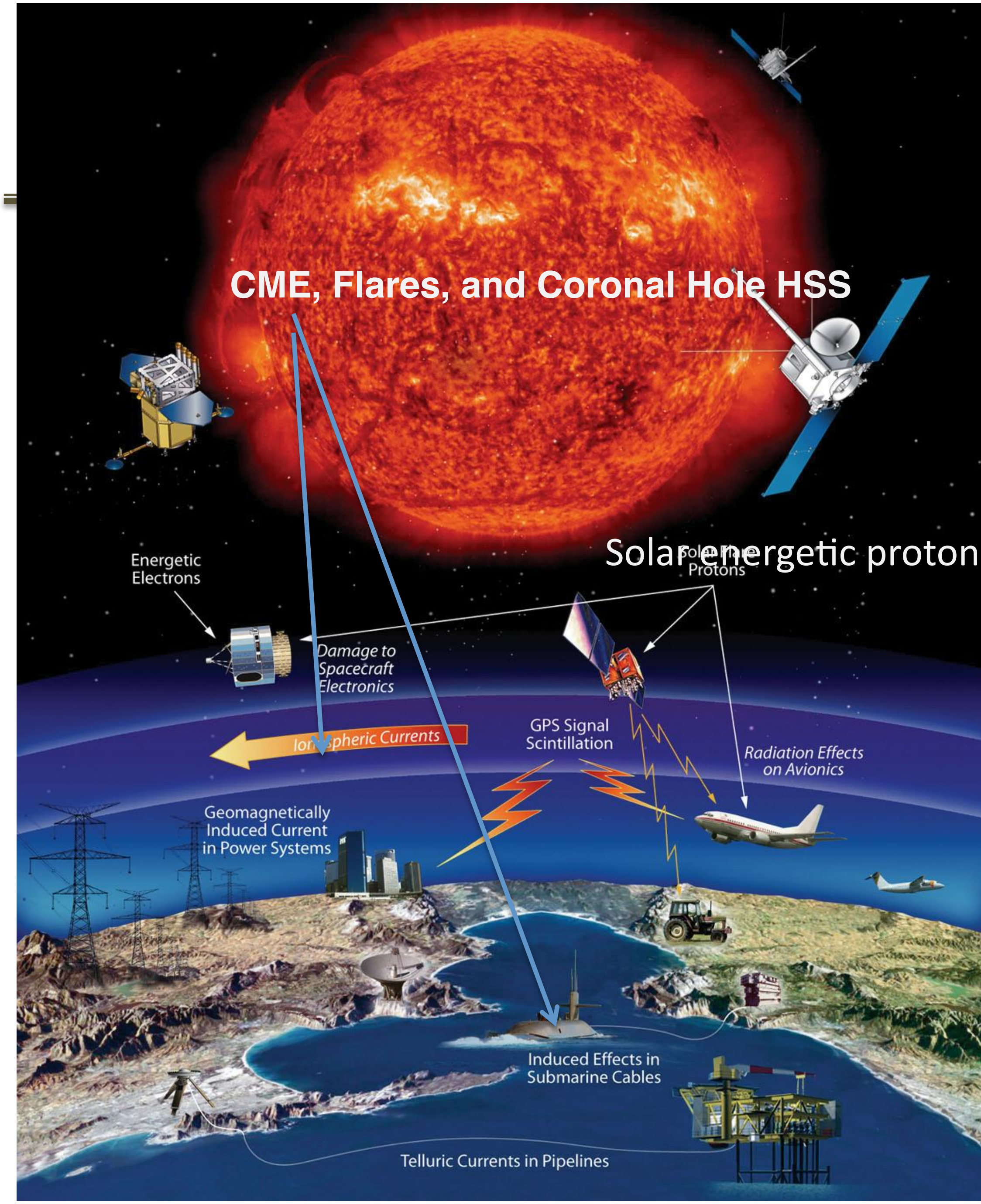
Introduction to Space Weather Part II

Yihua Zheng

Internal Use Only

June 12, 2012



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)**

Flare: SWx impacts

- Cause radio blackout through changing the structures/composition of the ionosphere (sudden ionospheric disturbances) – x ray and EUV emissions, lasting minutes to hours and dayside
- Affect radio comm., GPS, directly by its radio noises at different wavelengths
- Contribute to SEP – proton radiation, lasting a couple of days

Solar radio bursts can directly affect GPS operation

Solar radio bursts during December 2006 were sufficiently intense to be measurable with GPS receivers. The strongest event occurred on 6 December 2006 and affected the operation of many GPS receivers. This event exceeded 1,000,000 solar flux unit and was about 10 times larger than any previously reported event. The strength of the event was especially surprising since the solar radio bursts occurred near solar minimum. The strongest periods of solar radio burst activity lasted a few minutes to a few tens of minutes and, in some cases, exhibited large intensity differences between L1 (1575.42 MHz) and L2 (1227.60 MHz). Civilian dual frequency GPS receivers were the most severely affected, and these events suggest that continuous, precise positioning services should account for solar radio bursts in their operational plans. This investigation raises the possibility of even more intense solar radio bursts during the next solar maximum that will significantly impact the operation of GPS receivers.

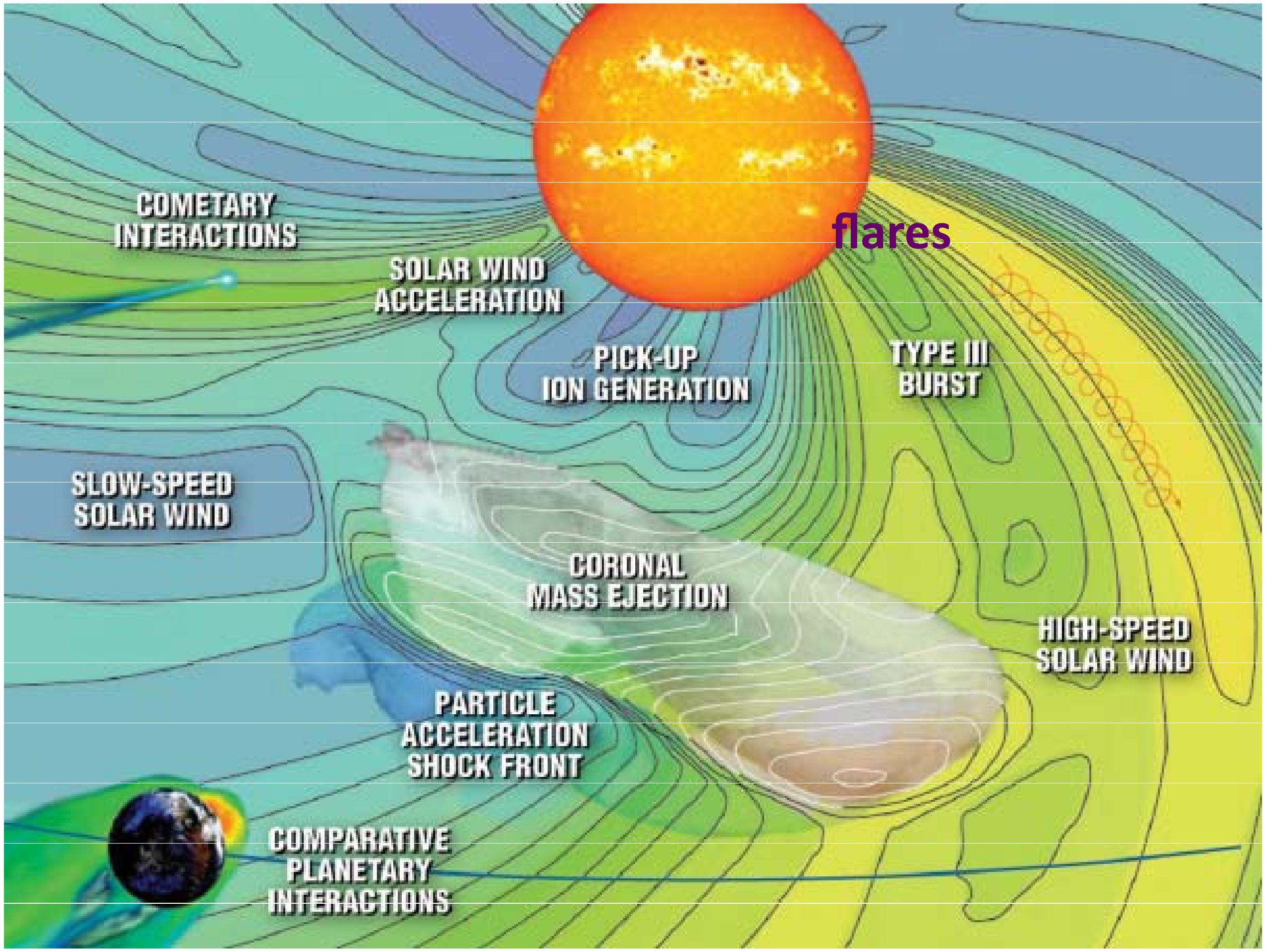
Cerruti, A. P., P. M. Kintner Jr., D. E. Gary, A. J. Mannucci, R. F. Meyer, P. Doherty, and A. J. Coster (2008), Effect of intense December 2006 solar radio bursts on GPS receivers, *Space Weather*, 6, S10D07, doi:10.1029/2007SW000375.

SWx impacts of CME

- Contribute to SEP (particle radiation): 20-30 minutes from the occurrence of the CME/flare
- Result in a geomagnetic storm: takes 1-2 days arriving at Earth
- Result in electron radiation enhancement in the near-Earth space (multiple CMEs): takes 1-3 days

Affecting spacecraft electronics – surfacing charging/internal charging, single event upsets
Radio communication, navigation
Power grid, pipelines, and so on

Flares/CMEs/HSS



Outline

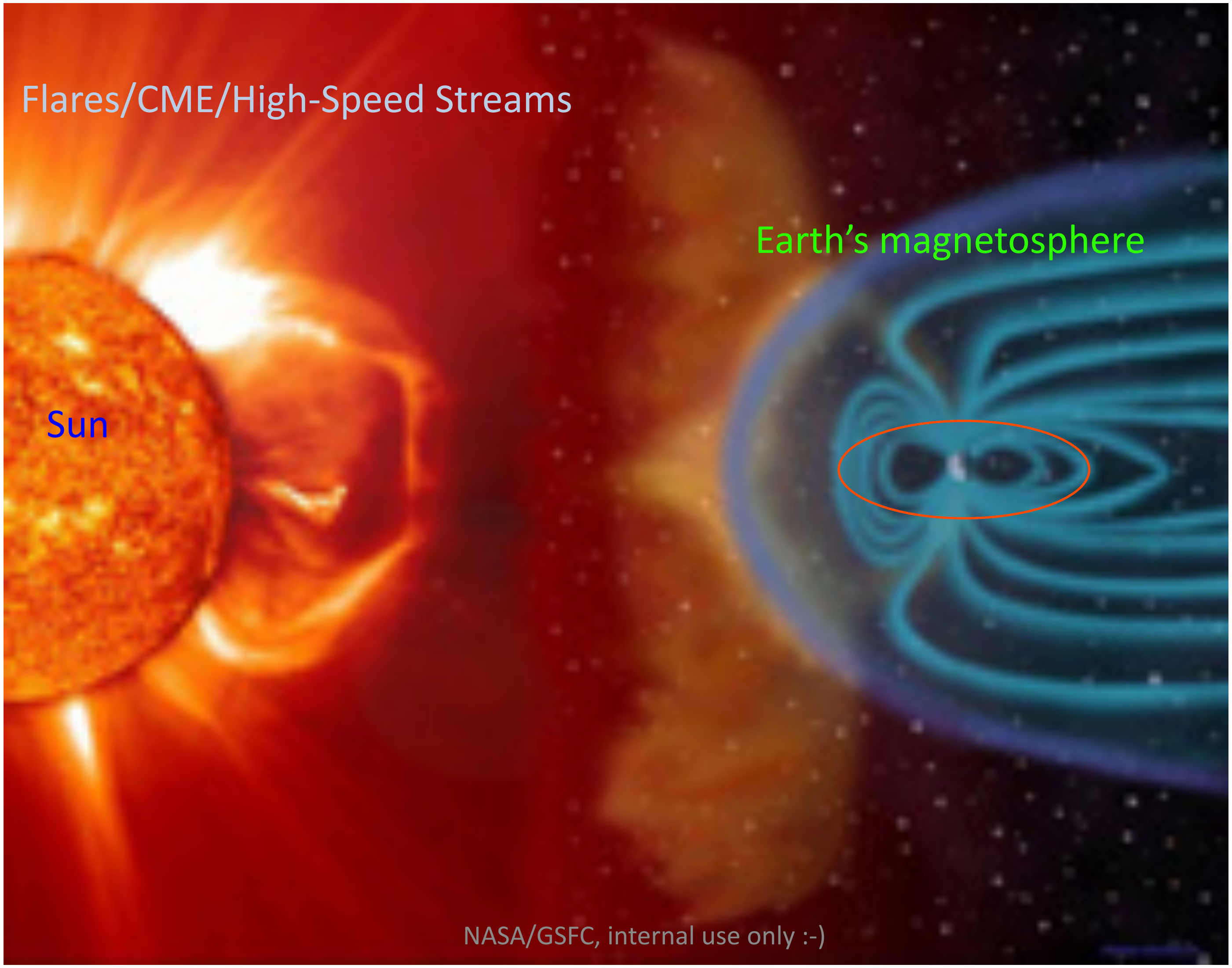
- Solar wind +magnetosphere interactions
- CIR and HSS impacts on Earth
- Importance of magnetosphere in space weather
- Importance of ionosphere in space weather

Videos

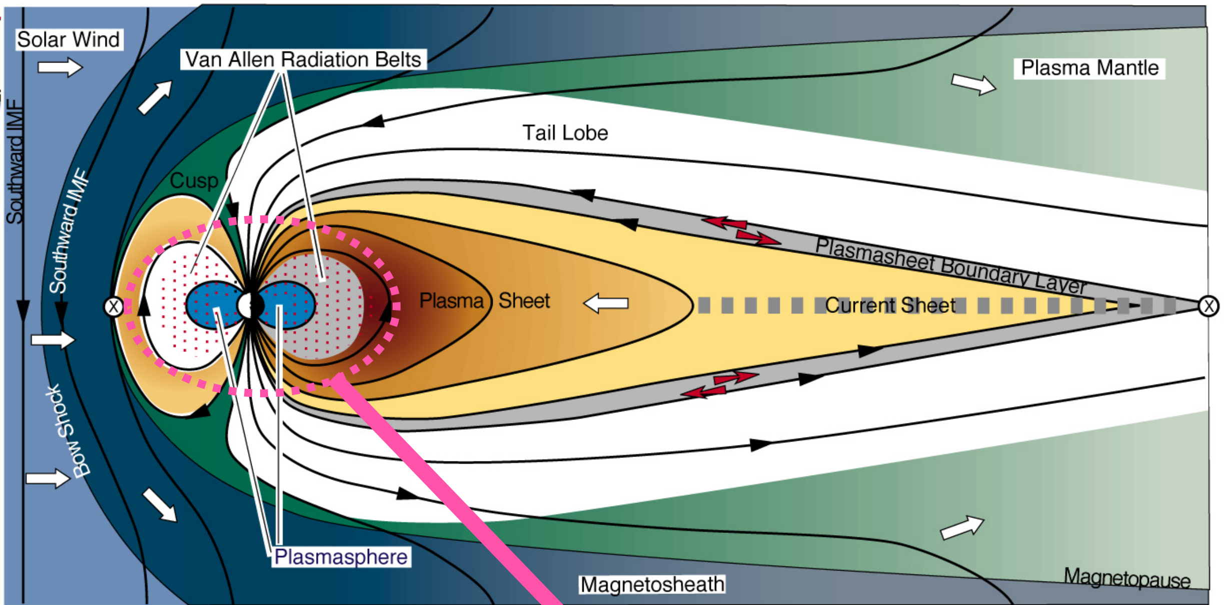
- Mysteries of the Sun
- Watch the video on ‘Earth’s magnetosphere’

- http://www.nasa.gov/mission_pages/sunearth/news/mystery-sun.html

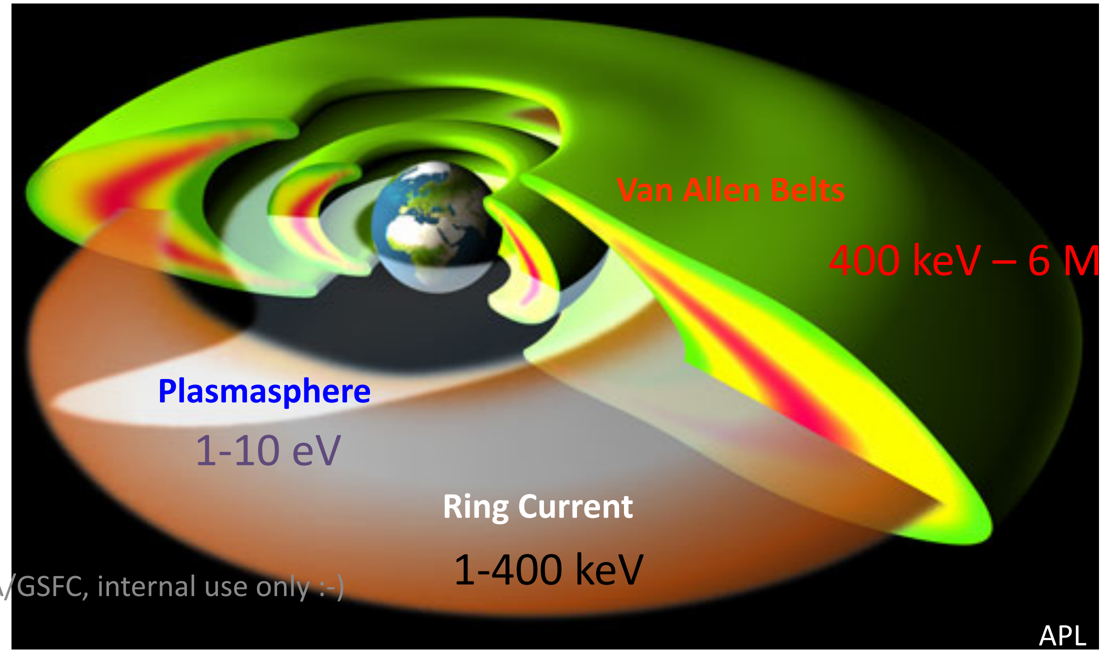
The solar wind pushes and stretches Earth's magnetic field into a vast, comet-shaped region called the magnetosphere. The magnetosphere and Earth's atmosphere protect us from the solar wind and other kinds of solar and cosmic radiation.



The Earth's Magnetosphere



Inner Magnetosphere:
Up to ~ 10Re



Kp

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

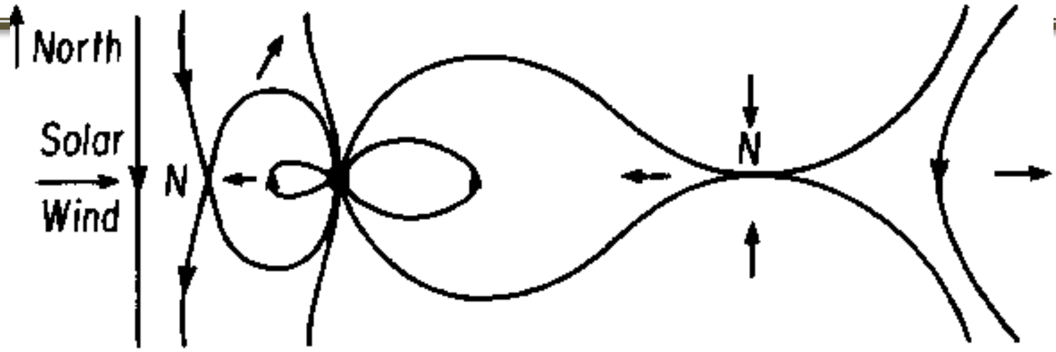
- Geomagnetic activity index

  range from 0-9   disturbance levels of magnetic field on the ground - currents

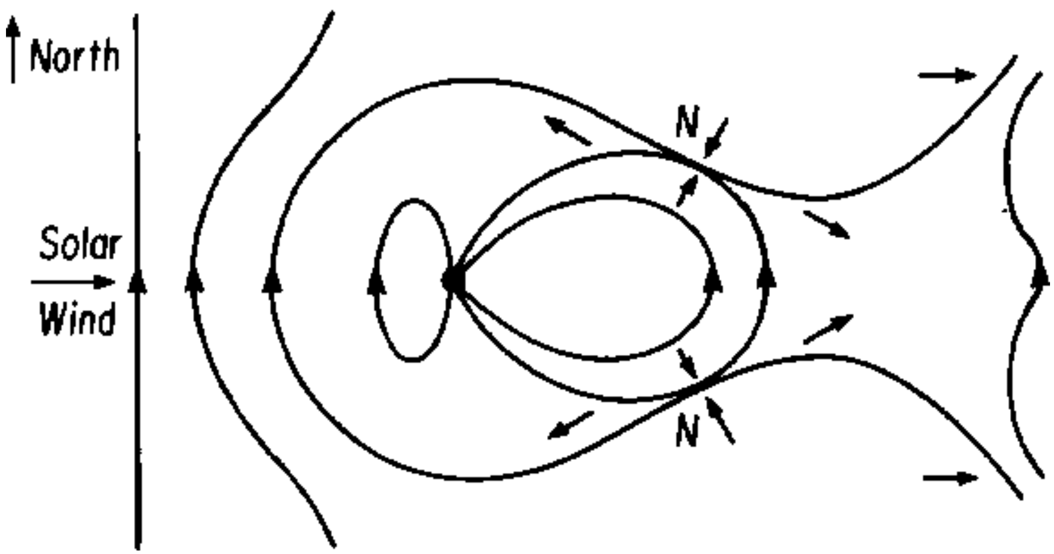
1. Non-event   - period of 12/01/2010 – 12/7/2010
2. Moderate event – April 5, 2010
3. Extreme event - Oct 29 – Oct 31, 2003

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

Interplanetary Field Southward



Interplanetary Field Northward



Coronal Hole HSS

Is one important space weather contributor too!

Particularly for its role in enhancing electron radiation levels in the near-Earth environment 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.

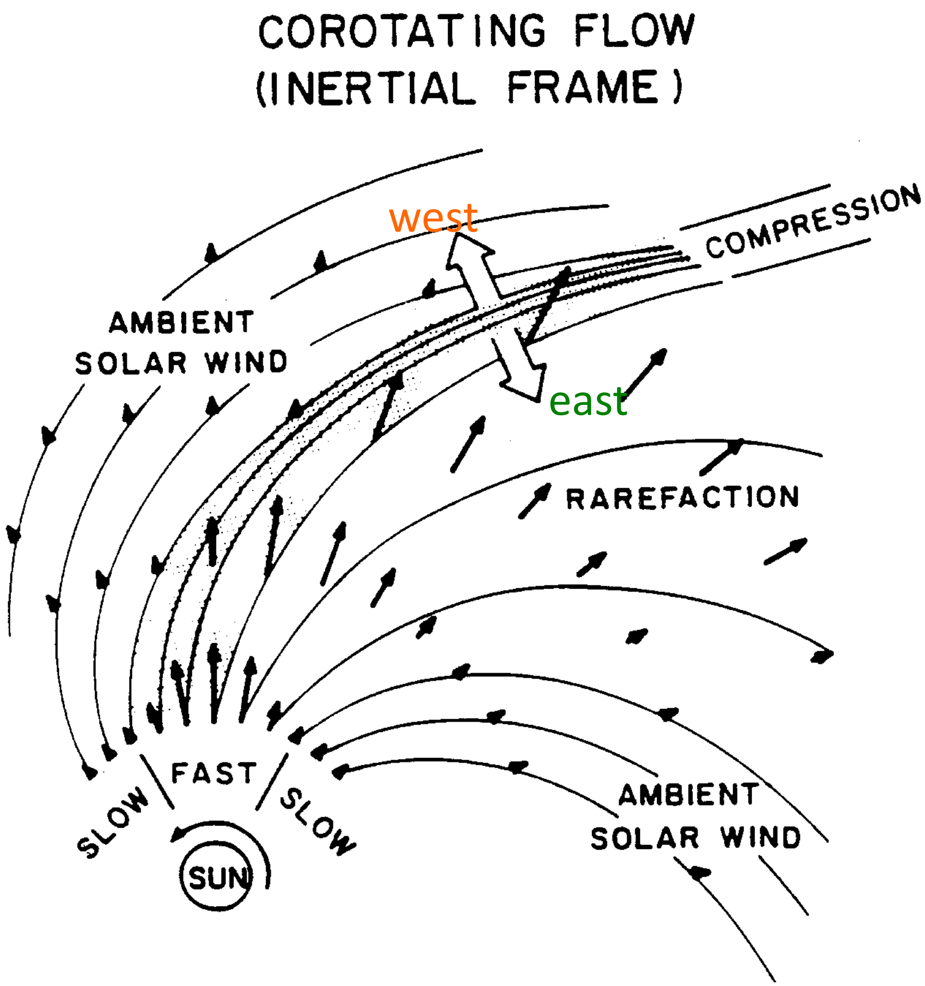
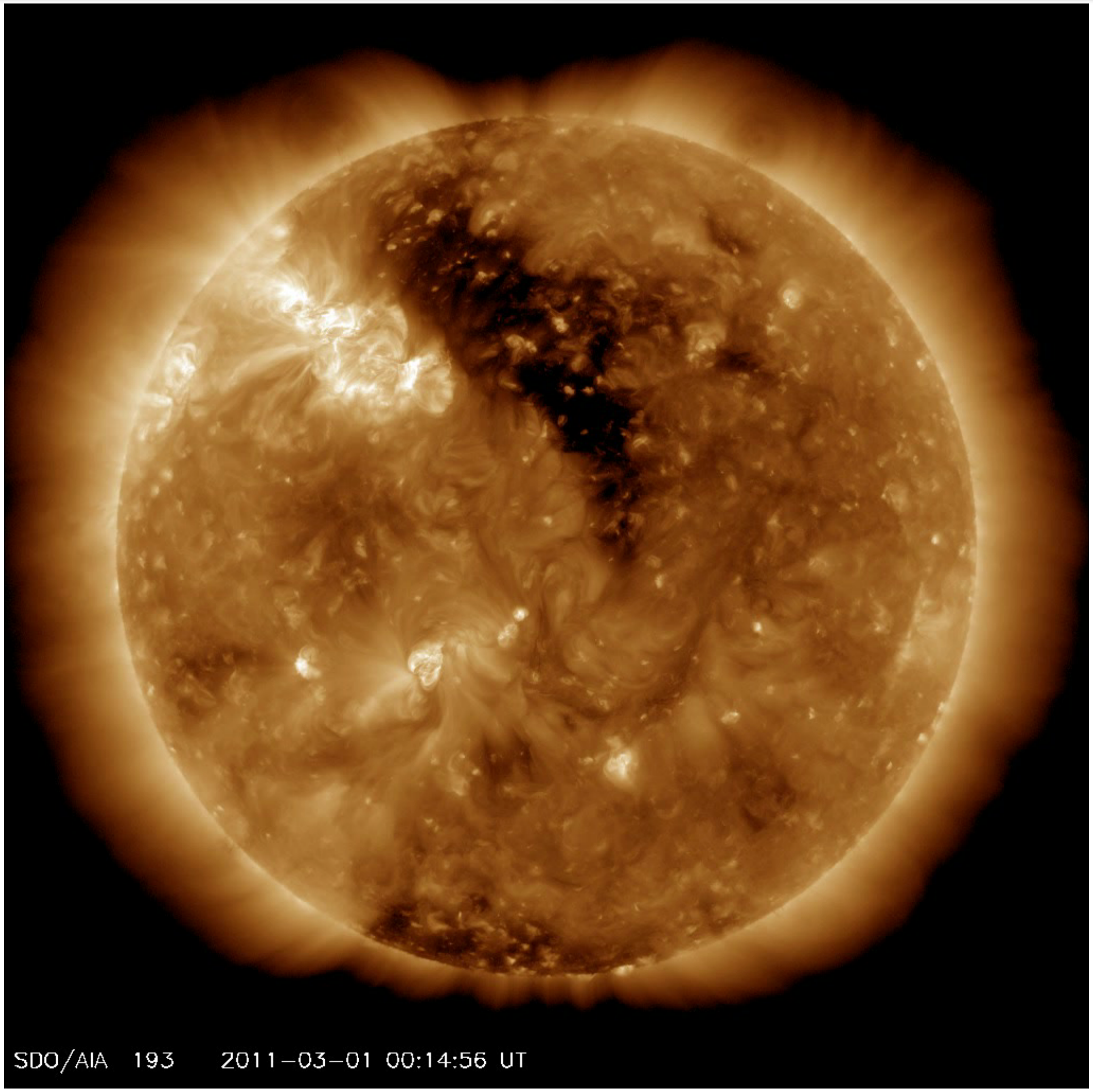


Figure 6. Schematic illustrating 2-D corotating stream structure in the solar equatorial plane in the inner heliosphere (from Pizzo, 1978).

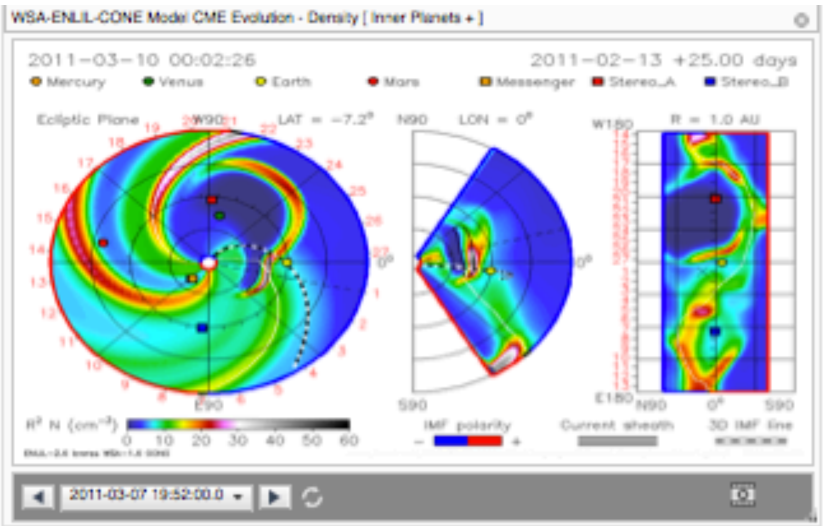
Coronal Hole HSS



Mar 1, 2011

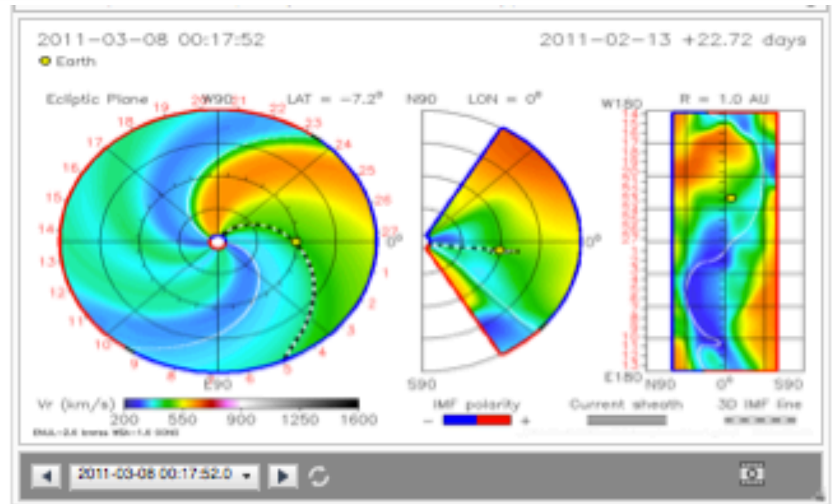
June 4, 2012

Forecasting capability enabled by ENLIL



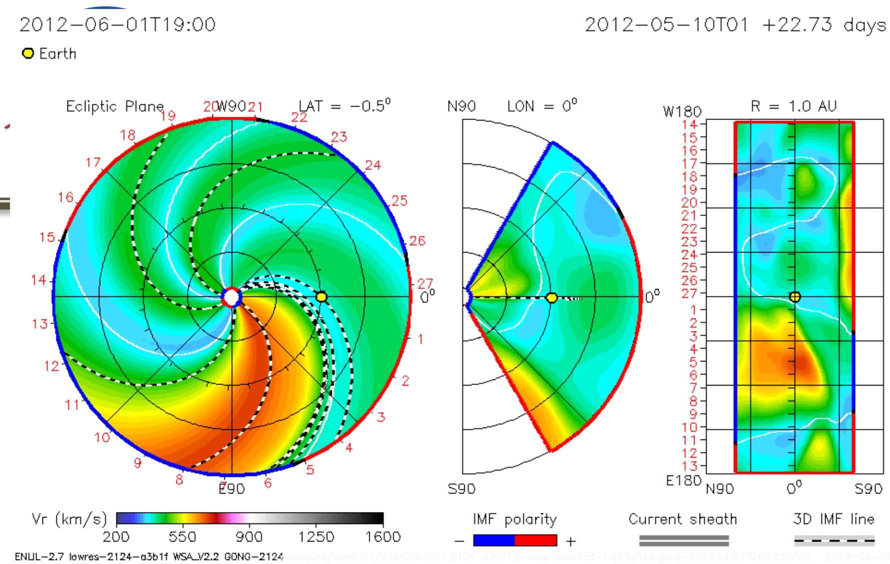
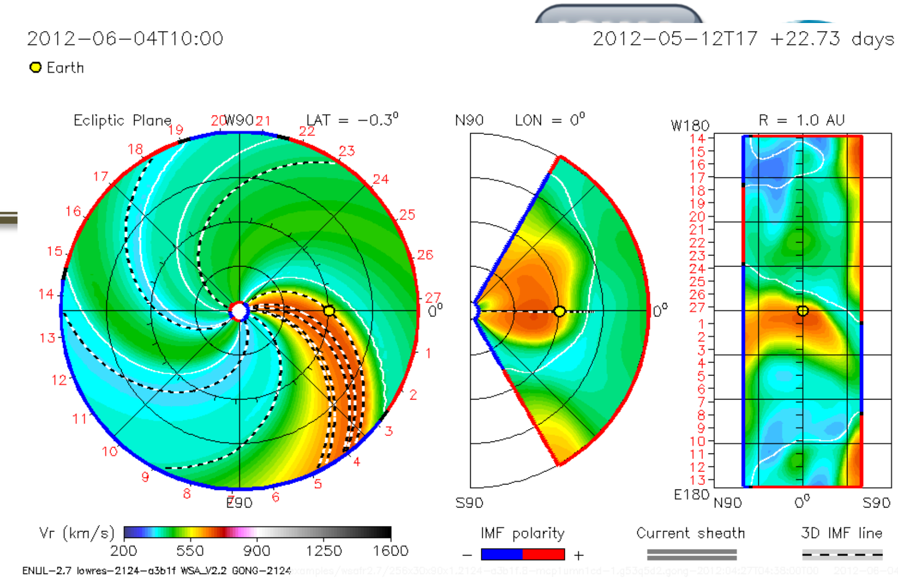
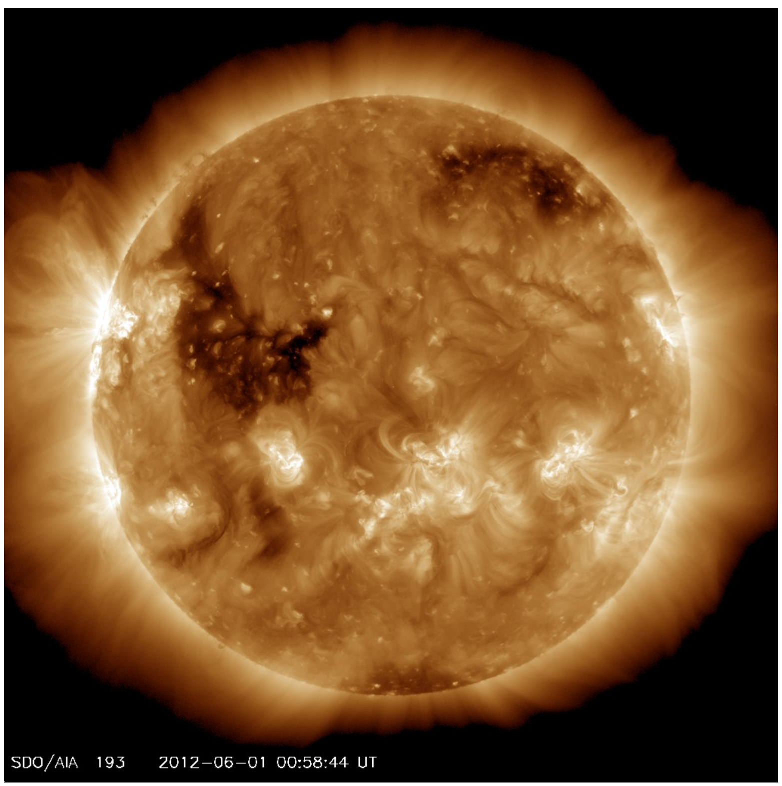
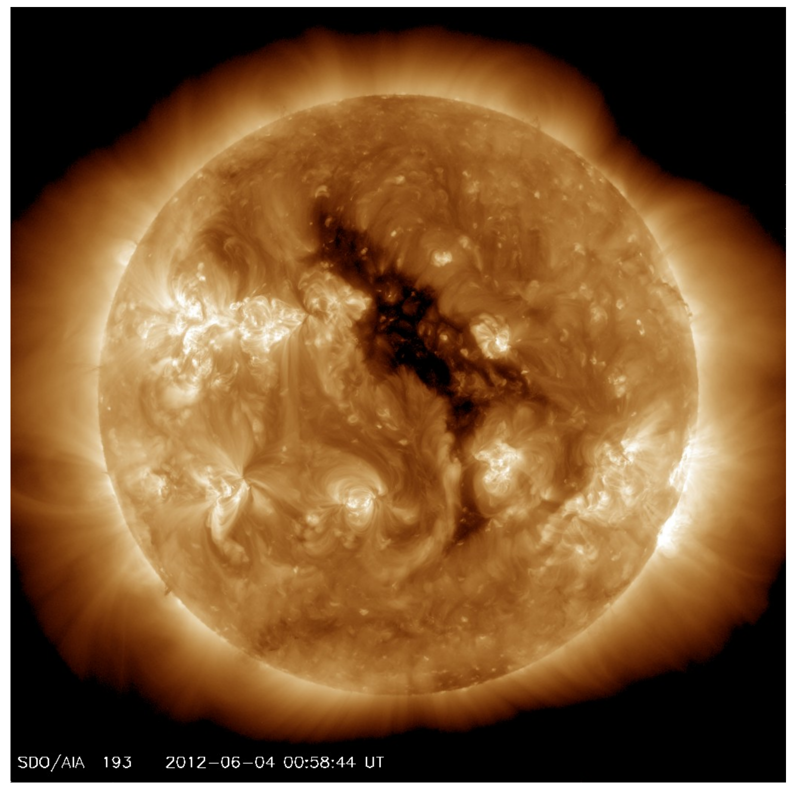
WSA+ENLIL+cone

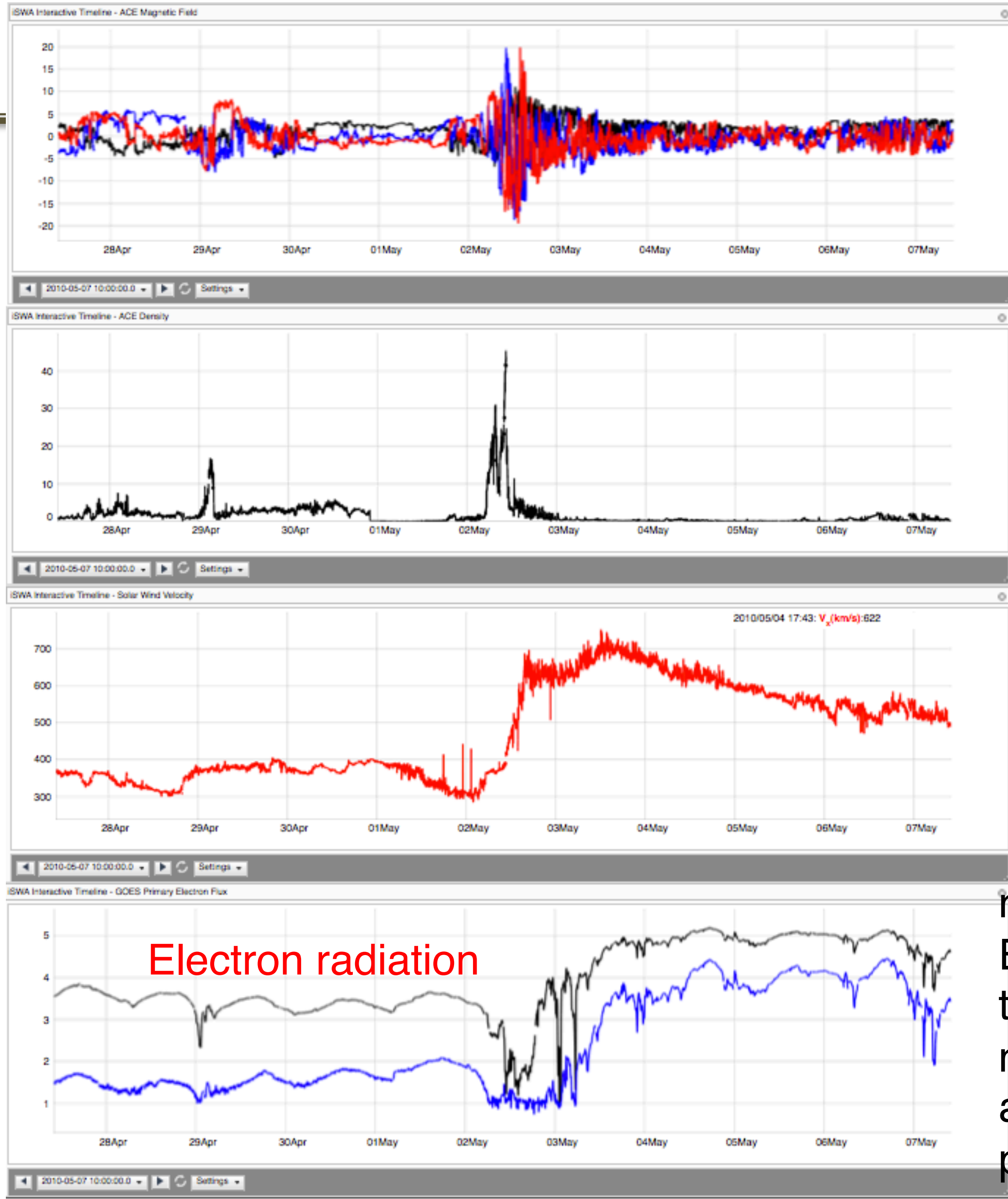
Predicting impacts of CMEs



WSA+ENLIL

Modeling and predicting the ambient solar wind


2012−06−01T19:00
2012−05−10T01 +22.73 days
Earth
Ecliptic Plane
LAT = −0.5°
N90
LON = 0°
W180
R = 1.0 AU
E90
S90
E180
Vr (km/s)
200 550 900 1250 1600
IMF polarity
Current sheath
3D IMF line
ENLIL−2.7 lowres−2124−a3b1f WSA_V2.2 GONG−2124

2012−06−04T10:00
2012−05−12T17 +22.73 days
Earth
Ecliptic Plane
LAT = −0.3°
N90
LON = 0°
W180
R = 1.0 AU
E90
S90
E180
Vr (km/s)
200 550 900 1250 1600
IMF polarity
Current sheath
3D IMF line
ENLIL−2.7 lowres−2124−a3b1f WSA_V2.2 GONG−2124

SDO/AIA 193 2012-06-01 00:58:44 UT

SDO/AIA 193 2012-06-04 00:58:44 UT



Clean HSS

May 2, 2010

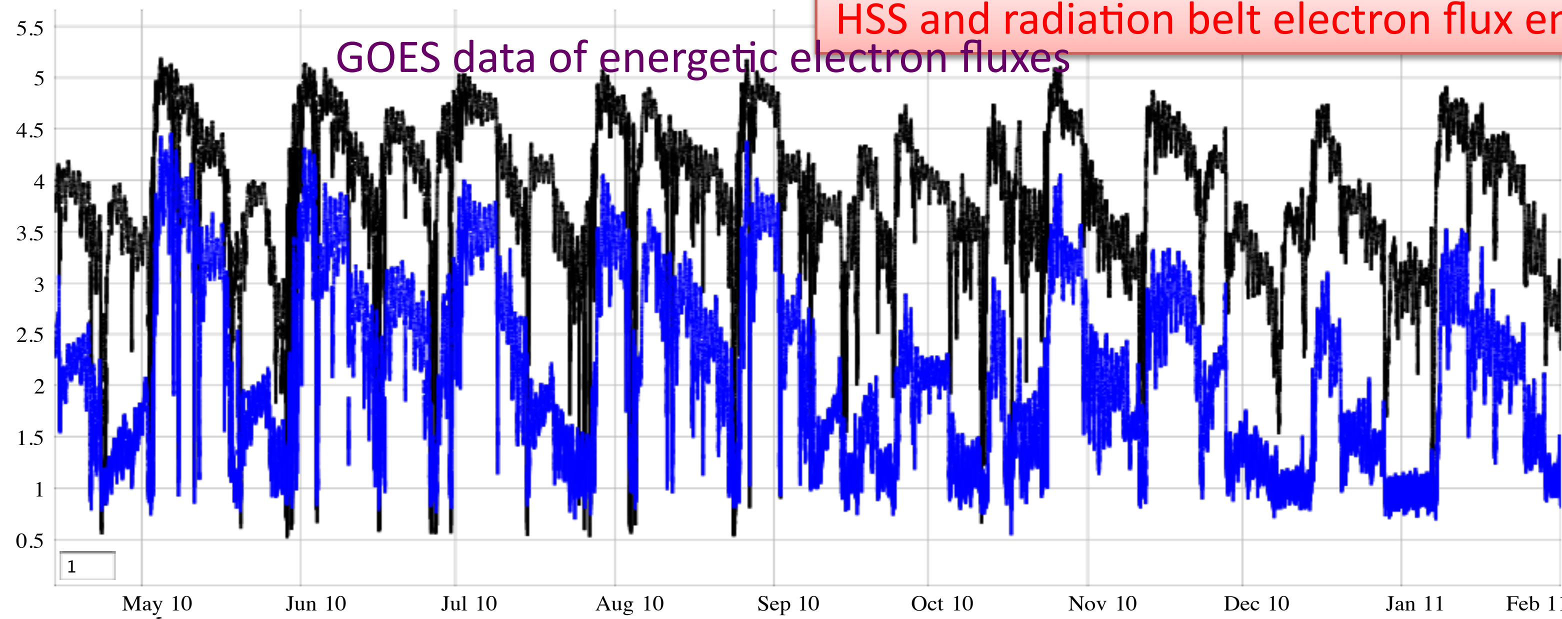
Dense (20-30 cc), HSS

IMFBz: -18 nT

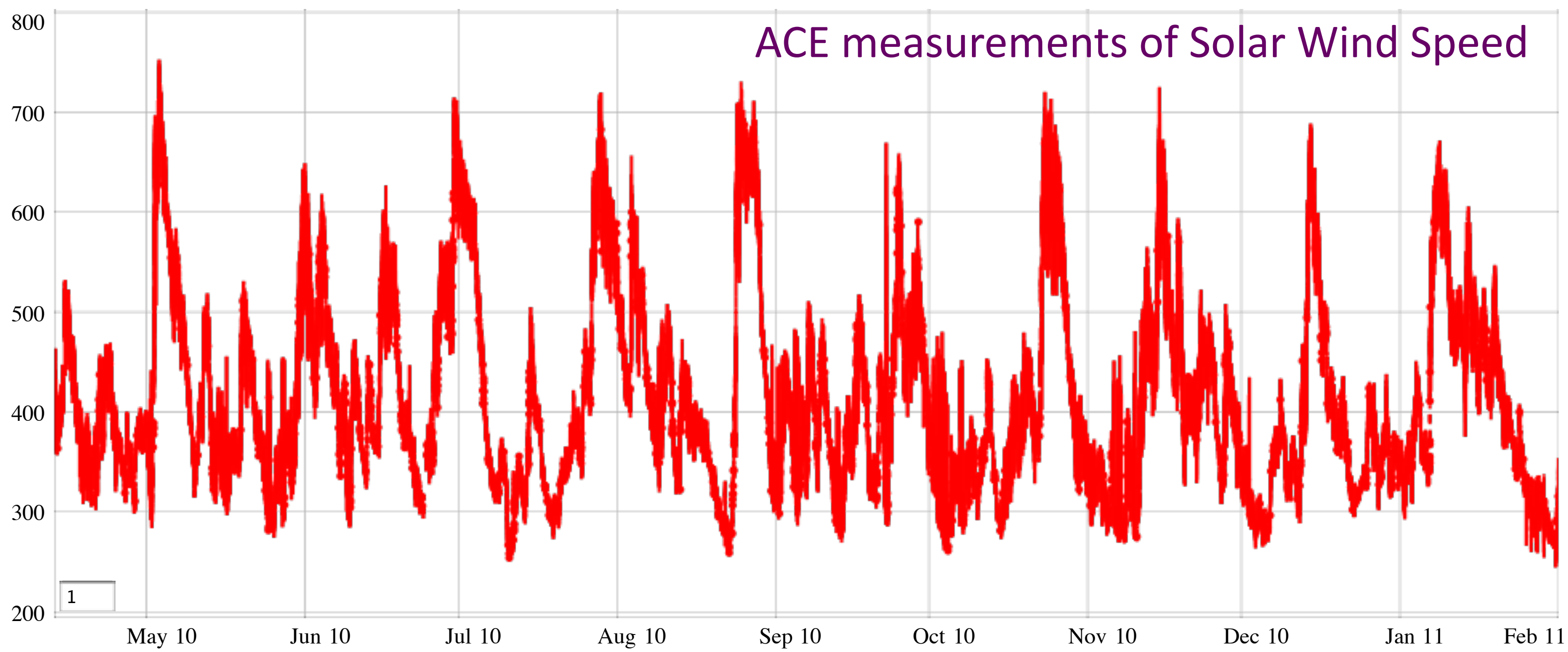
may be more hazardous to Earth-orbiting satellites than ICME-related magnetic storm particles and solar energetic particles

HSS and radiation belt electron flux enhancement

Click the check boxes to toggle series visibility

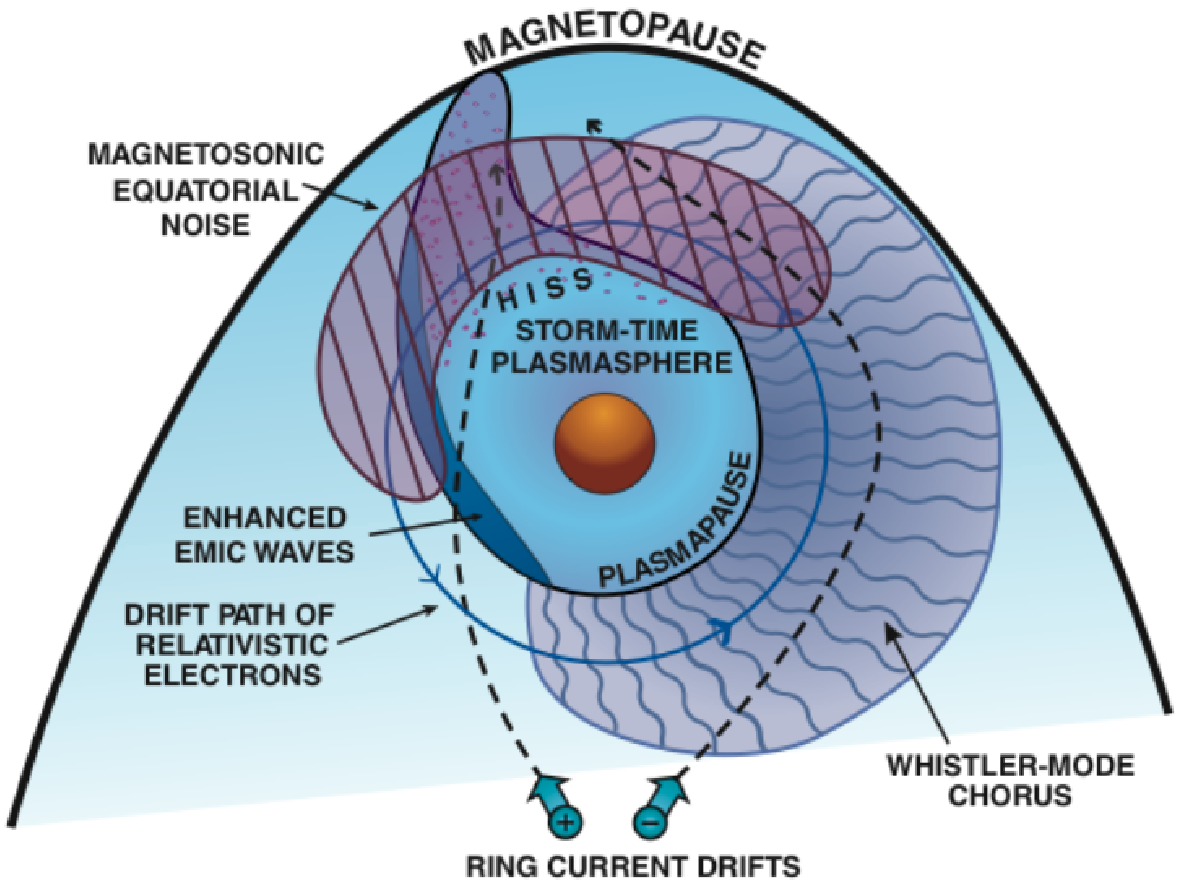


☑E > 0.8 MeV ☑E > 2.0 MeV **Zoom:** In Out full **Pan:** left right

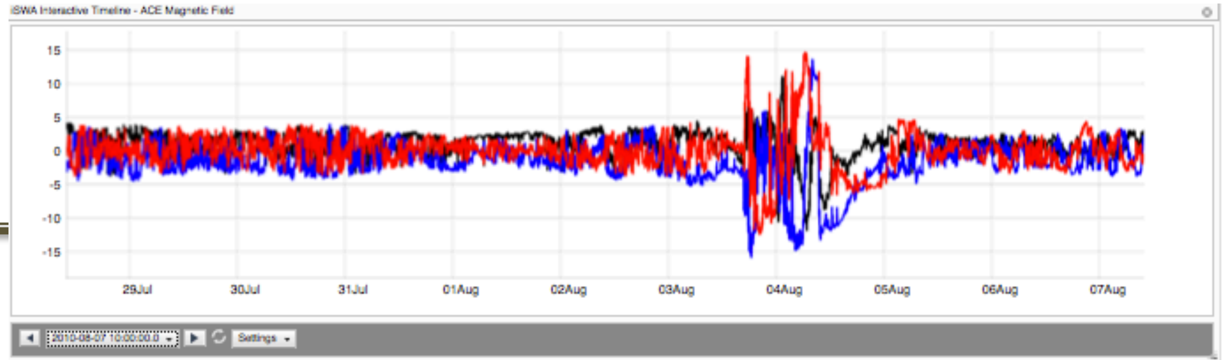


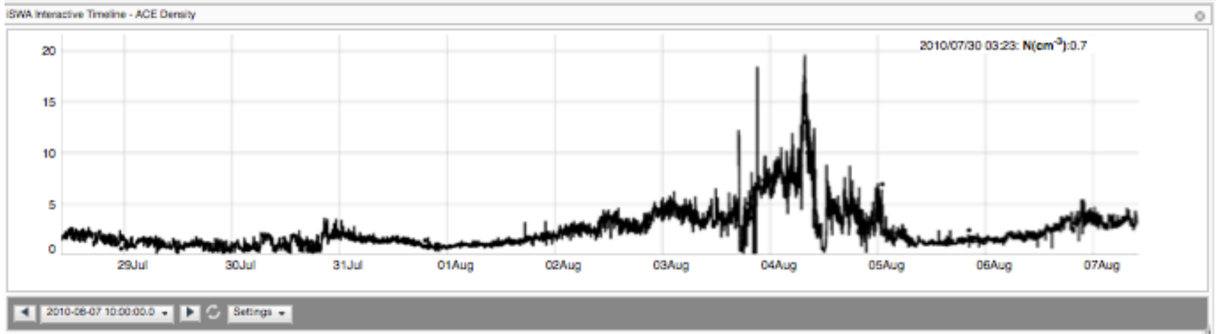
☑Bulk Speed **Zoom:** In Out full **Pan:** left right

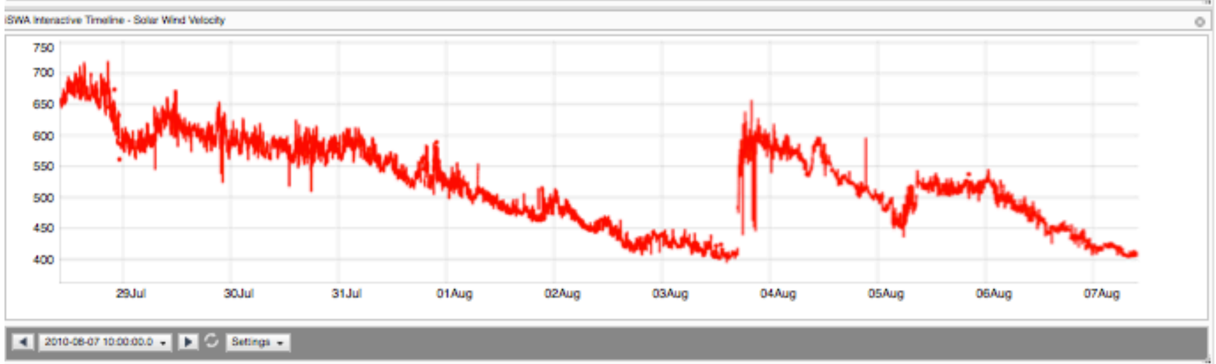
Various types of waves that are important to RB dynamics

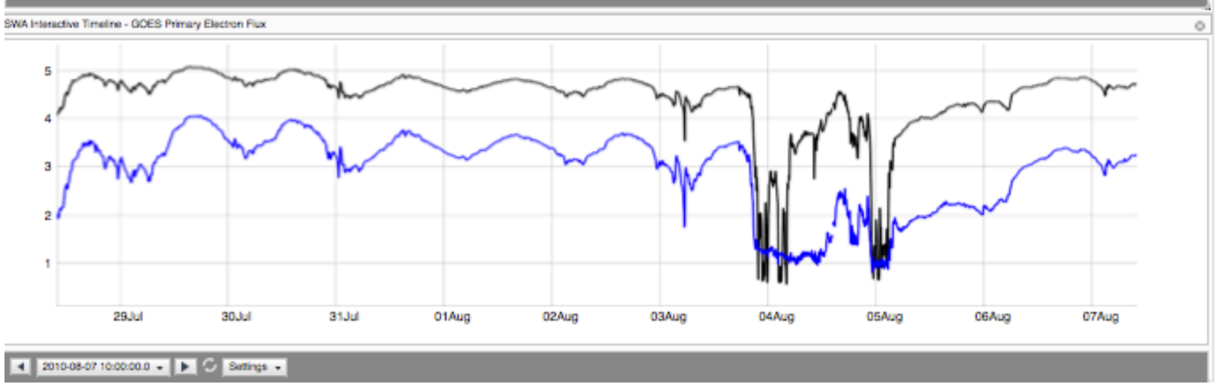


Aug 3, 2010


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

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

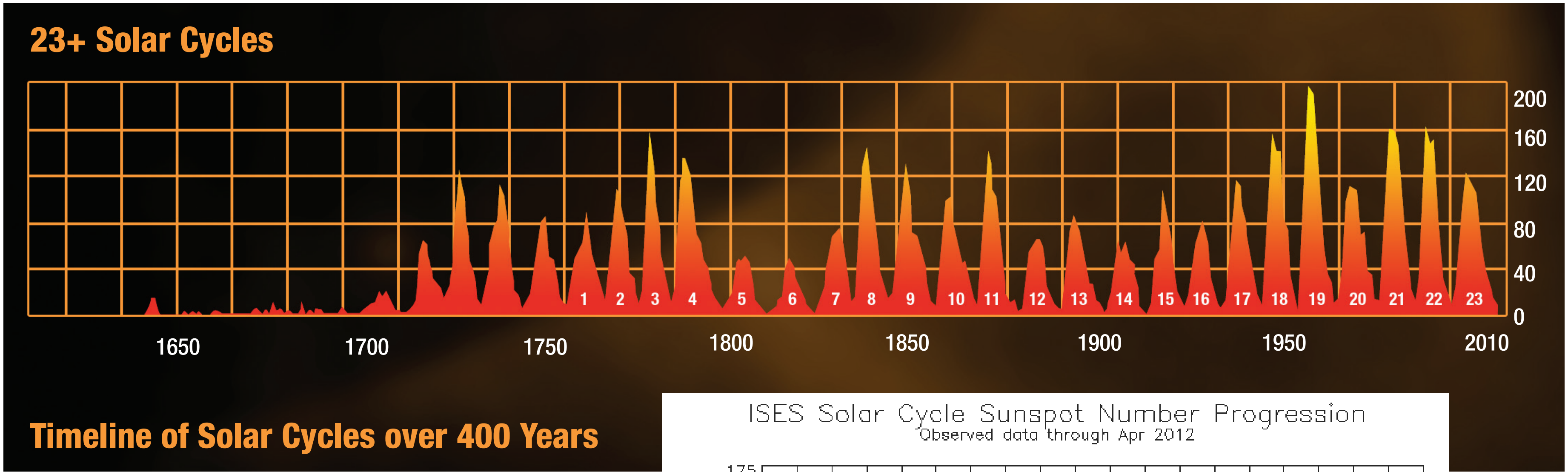
Table 1. A Summary of Some of the Important Differences Between CME-Driven Storms (Shock, Sheath, Ejecta, Cloud) and CIR-Driven Storms (CIR, High-Speed Stream)

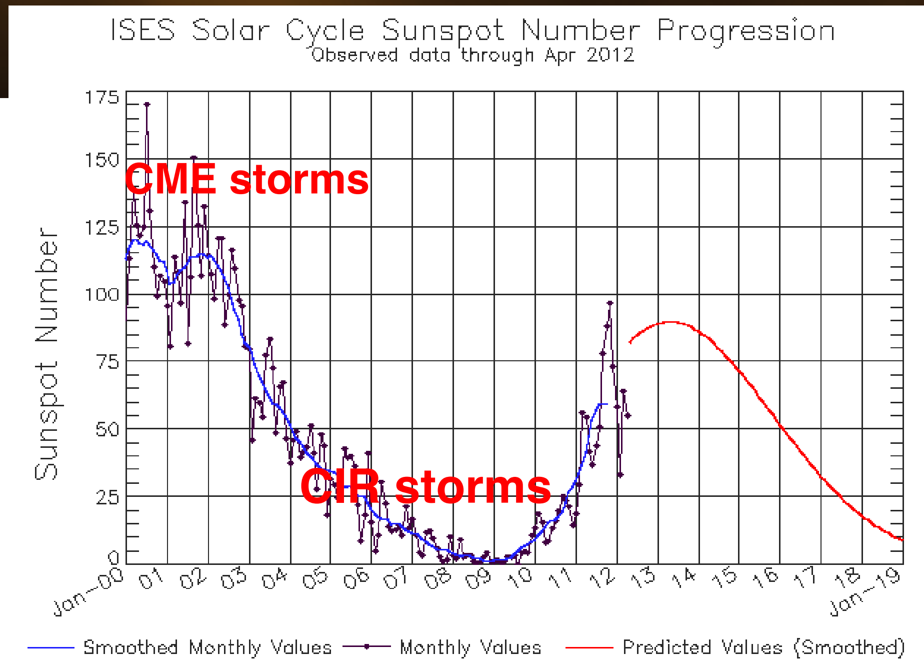
Phenomenon	CME-Driven Storms	CIR-Driven Storms
Phase of the solar cycle when dominant	solar maximum	declining phase
Occurrence pattern	irregular	27-day repeating
Calm before the storm	sometimes	usually
Solar energetic particles (SEP)	sometimes	none
Storm sudden commencement (SSC)	common	infrequent
Mach 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.

Solar Cycle

high and low sunspot activity that repeats about every 11 years





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!

Homework

March 1, 2011 high speed streams, find out the time of arrival and examine its behavior in terms of speed and density profile, IMF characteristics, when the >0.8 MeV energetic electron flux at GOES started to exceed 10^5 pfu?

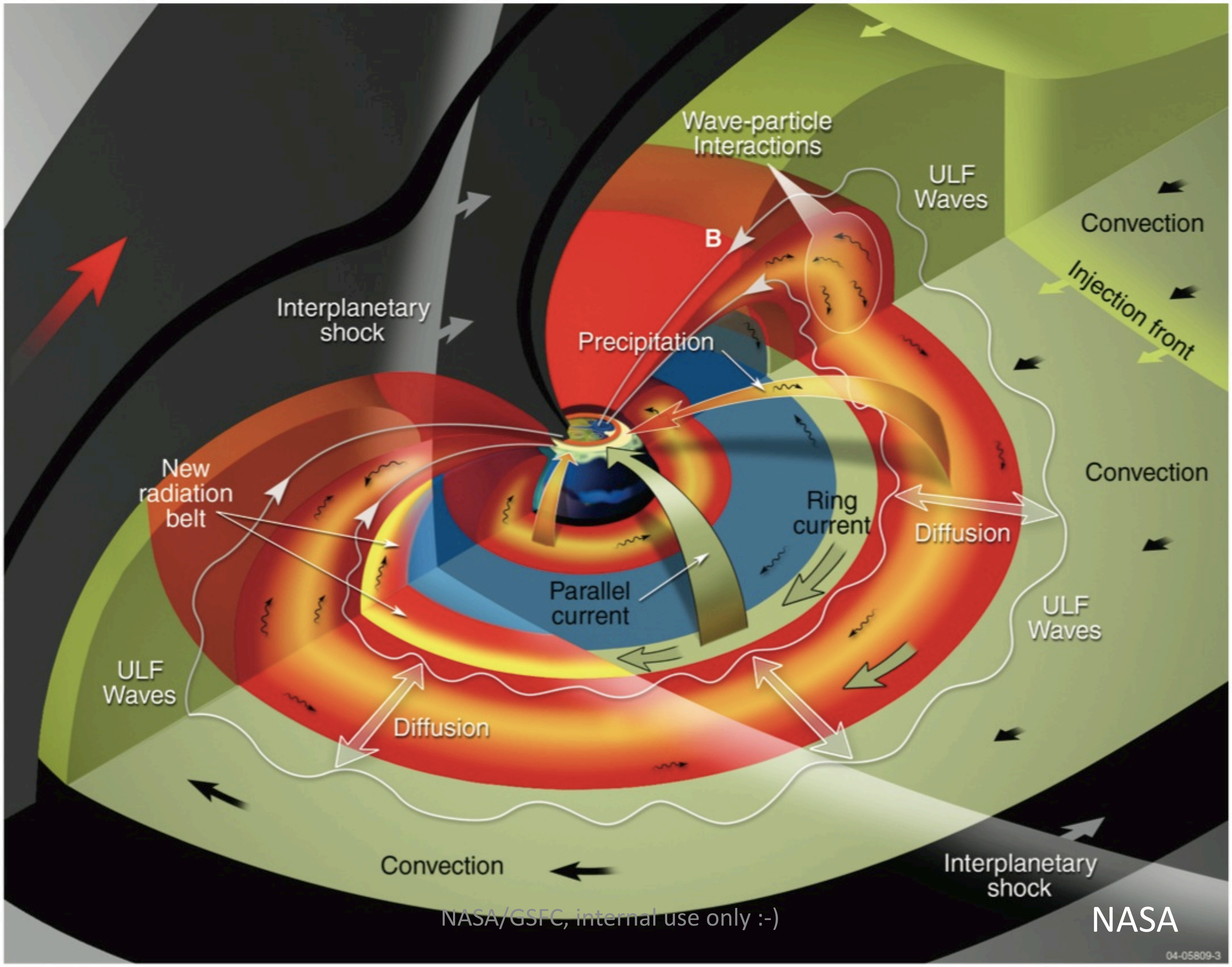
June 4, 2012 HSS

You can do the homework using this iSWA layout for HSS
http://bit.ly/HSS_layout_20110301

The importance of magnetosphere and ionosphere in SWx

Magnetosphere and magnetospspheric products

The Earth's Magnetosphere



NASA/GSFC, internal use only :-)

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- Geomagnetic activity index

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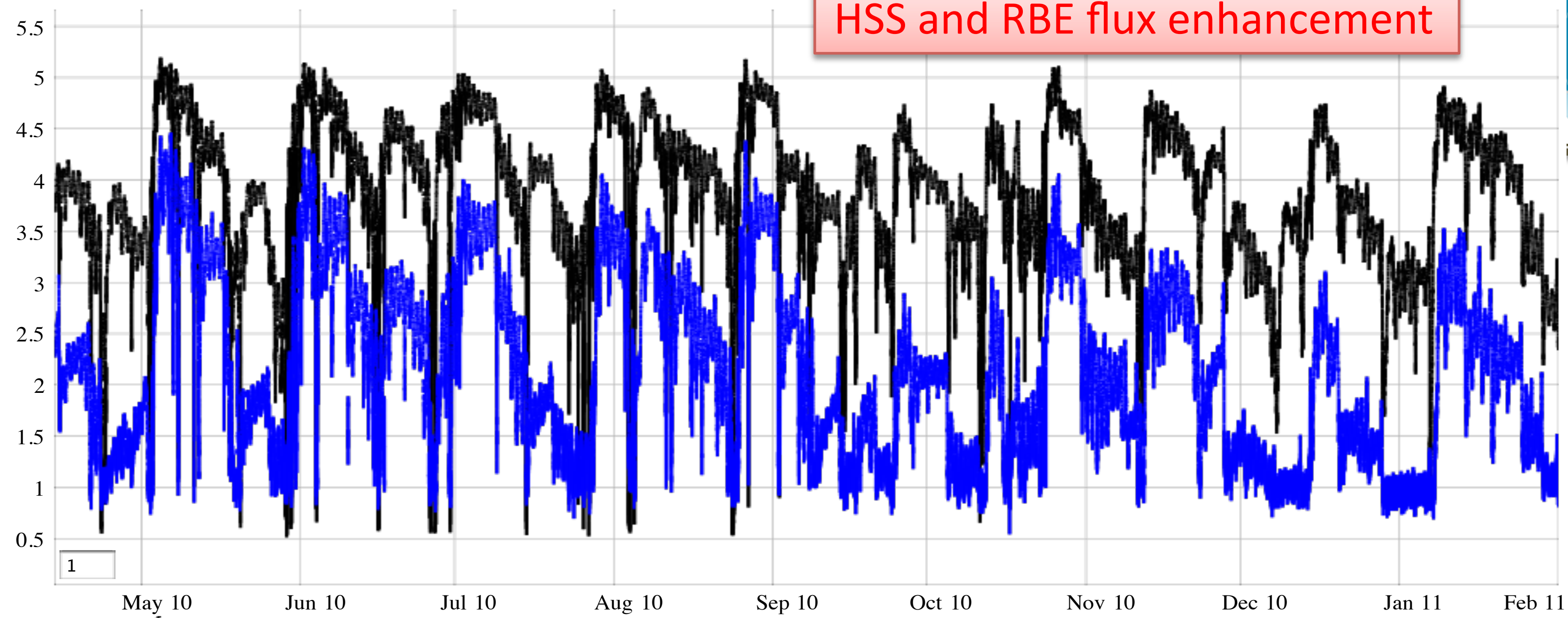
http://bit.ly/Kp_layout   Threshold Kp>=6

Click the check boxes to toggle series visibility

HSS and RBE flux enhancement



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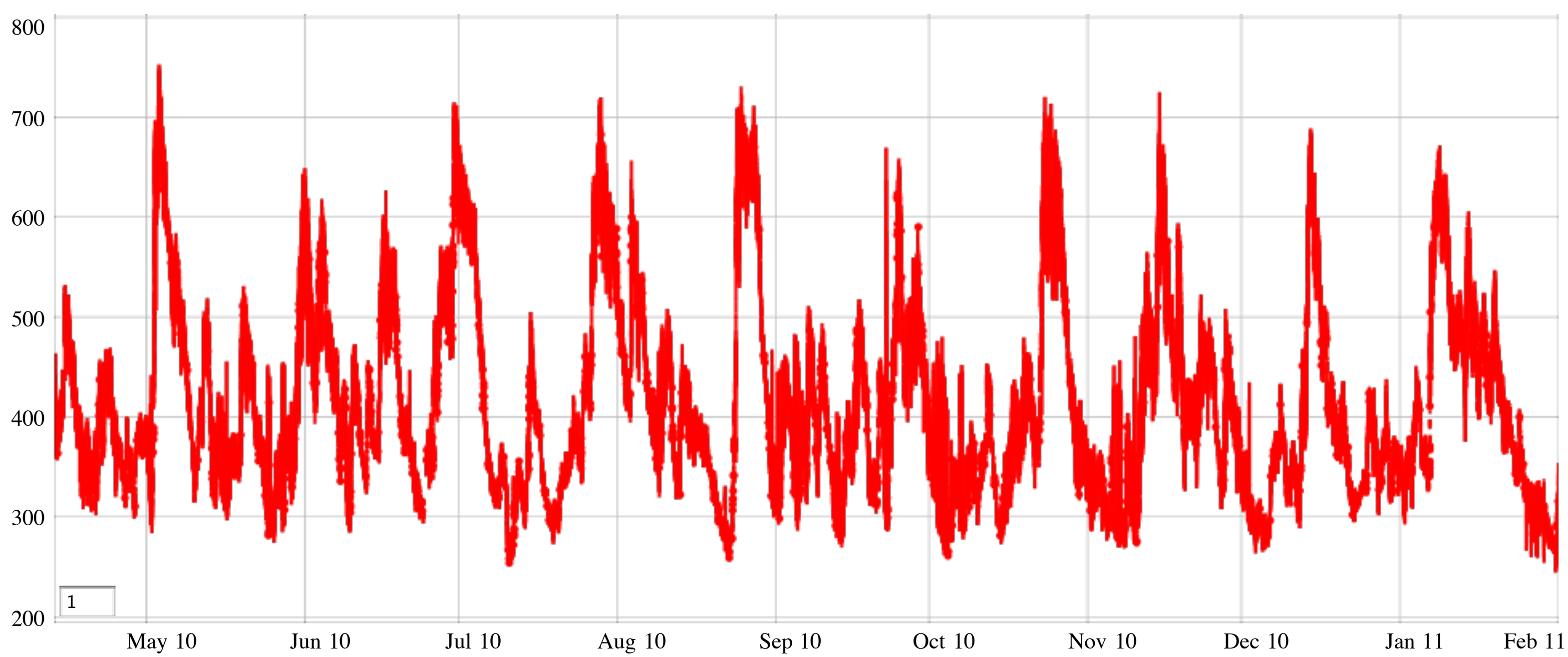


☑ Bulk Speed **Zoom:** In Out full **Pan:** left right

Energetic proton flux

- >10 MeV flux by GOES spacecraft

Threshold: 10 pfu

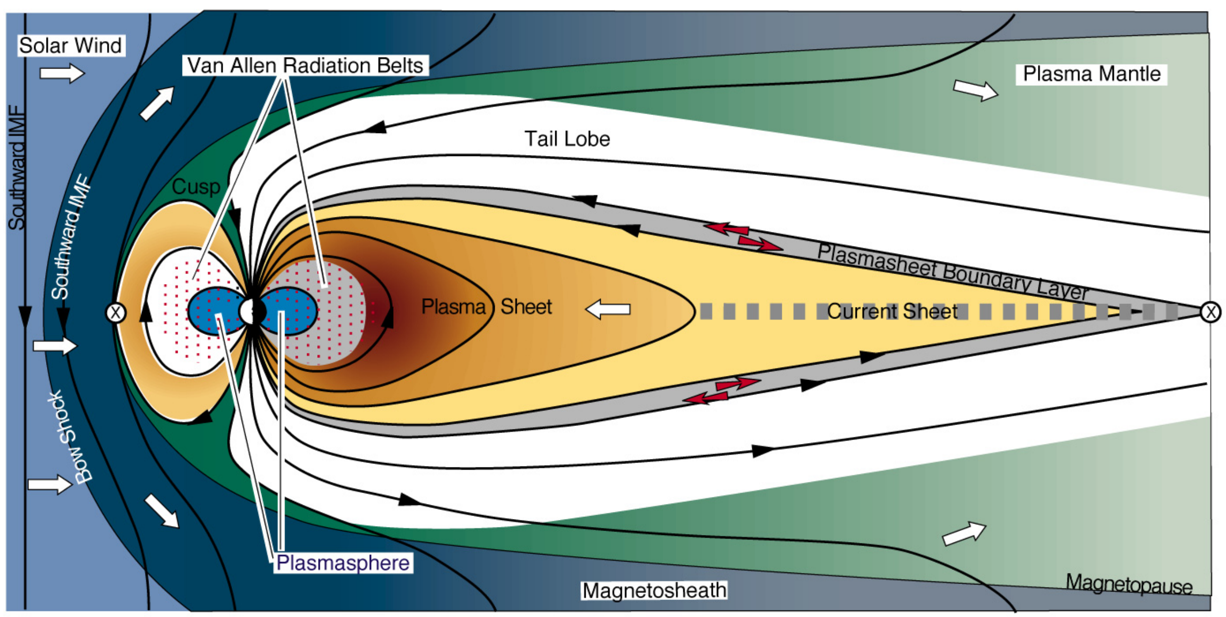
  - Non –event Dec 1 – 7, 2010
  - Event: Aug 14 – 18, 2010

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

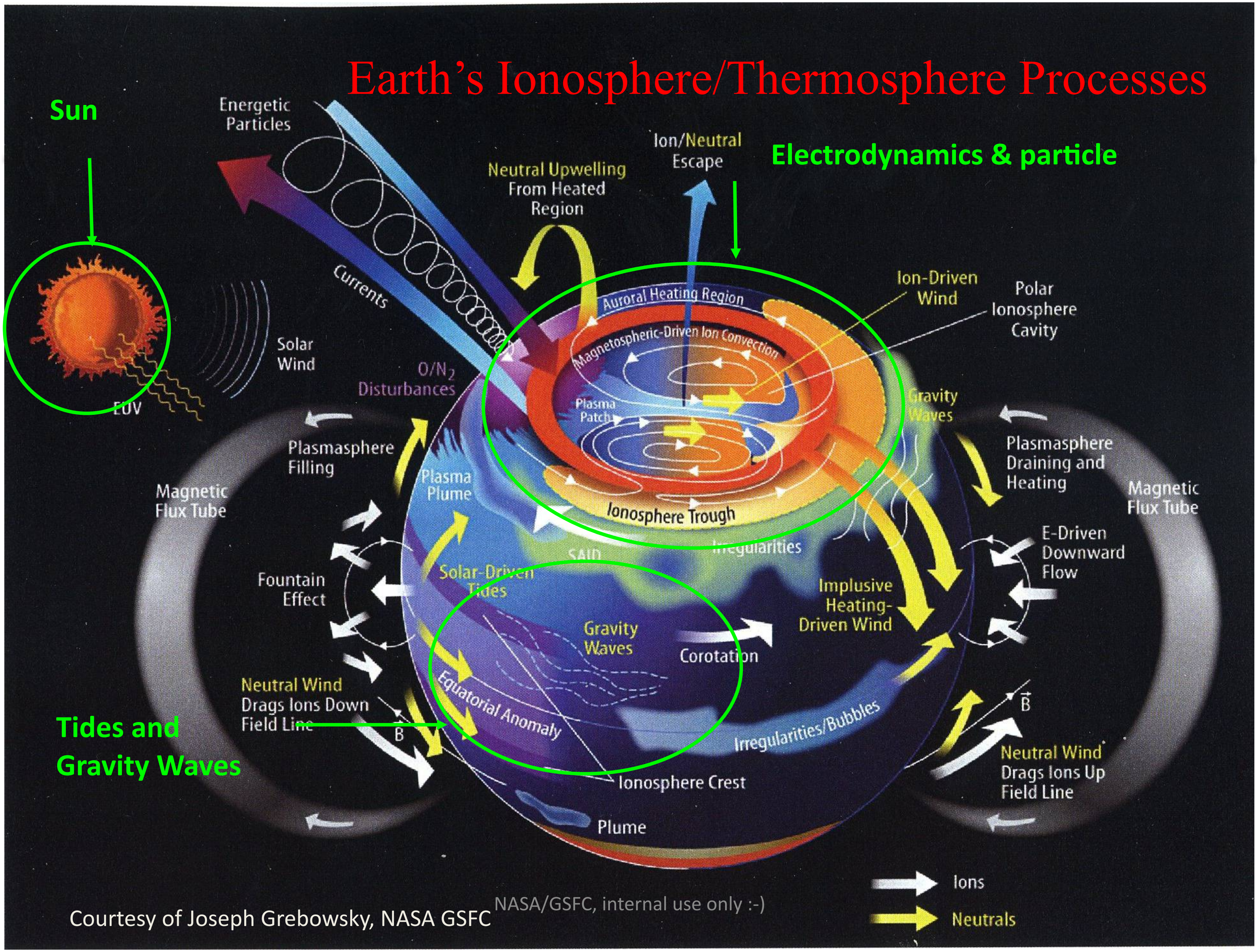
Degree of compression of MP
Due to Pdyn of solar wind
(interplanetary shock /HSS)



An iSWA layout for magnetospheric products

Videos

- Mysteries of the Sun
- Watch the video on ‘Earth’s upper atmosphere’


Earth's Ionosphere/Thermosphere Processes
Sun
Energetic Particles
Ion/Neutral Escape
Electrodynamics & particle
Neutral Upwelling From Heated Region
Currents
Solar Wind
EUV
O/N_2 Disturbances
Auroral Heating Region
Magnetospheric-Driven Ion Convection
Ion-Driven Wind
Polar Ionosphere Cavity
Plasma Patch
Gravity Waves
Plasmasphere Filling
Plasma Plume
Magnetic Flux Tube
Plasmasphere Draining and Heating
Magnetic Flux Tube
Ionosphere Trough
SAID
Irregularities
E-Driven Downward Flow
Fountain Effect
Solar-Driven Tides
Implusive Heating-Driven Wind
Gravity Waves
Corotation
Neutral Wind Drags Ions Down Field Line
B
Equatorial Anomaly
Irregularities/Bubbles
B
Neutral Wind Drags Ions Up Field Line
Tides and Gravity Waves
Ionosphere Crest
Plume
Ions
Neutrals
NASA/GSFC, internal use only :-)
Courtesy of Joseph Grebowsky, NASA GSFC

Ionosphere-Thermosphere

- Aurora – hemispheric power
- Satellite drag due to neutrals
- Equatorial bubbles/irregularities – scintillation, communication problems

http://bit.ly/iono_layout

Products demo

Auroral power
Auroral oval
TEC map
CTIPe products
HF absorption map

Scintillation index S4

An iSWA layout for ionosphere products

Ionosphere irregularities

- plasma bubbles: typical east–west dimensions of several hundred kilometers
  - contain irregularities with scale-lengths ranging from tens of kilometers to tens of centimeters (Woodman and Tsunoda). Basu et al. (1978) showed that between sunset and midnight, 3-m scale irregularities that cause radar backscatter at 50 MHz, co-exist with sub-kilometer scale irregularities that cause VHF and L-band scintillations. After midnight, however, the radar backscatter and L-band scintillations decay but VHF scintillations caused by km-scale irregularities persist for several hours.

Journal of Atmospheric and Solar-Terrestrial Physics Volume 61, Issue 16, 1 November 1999, Pages 1219-1226