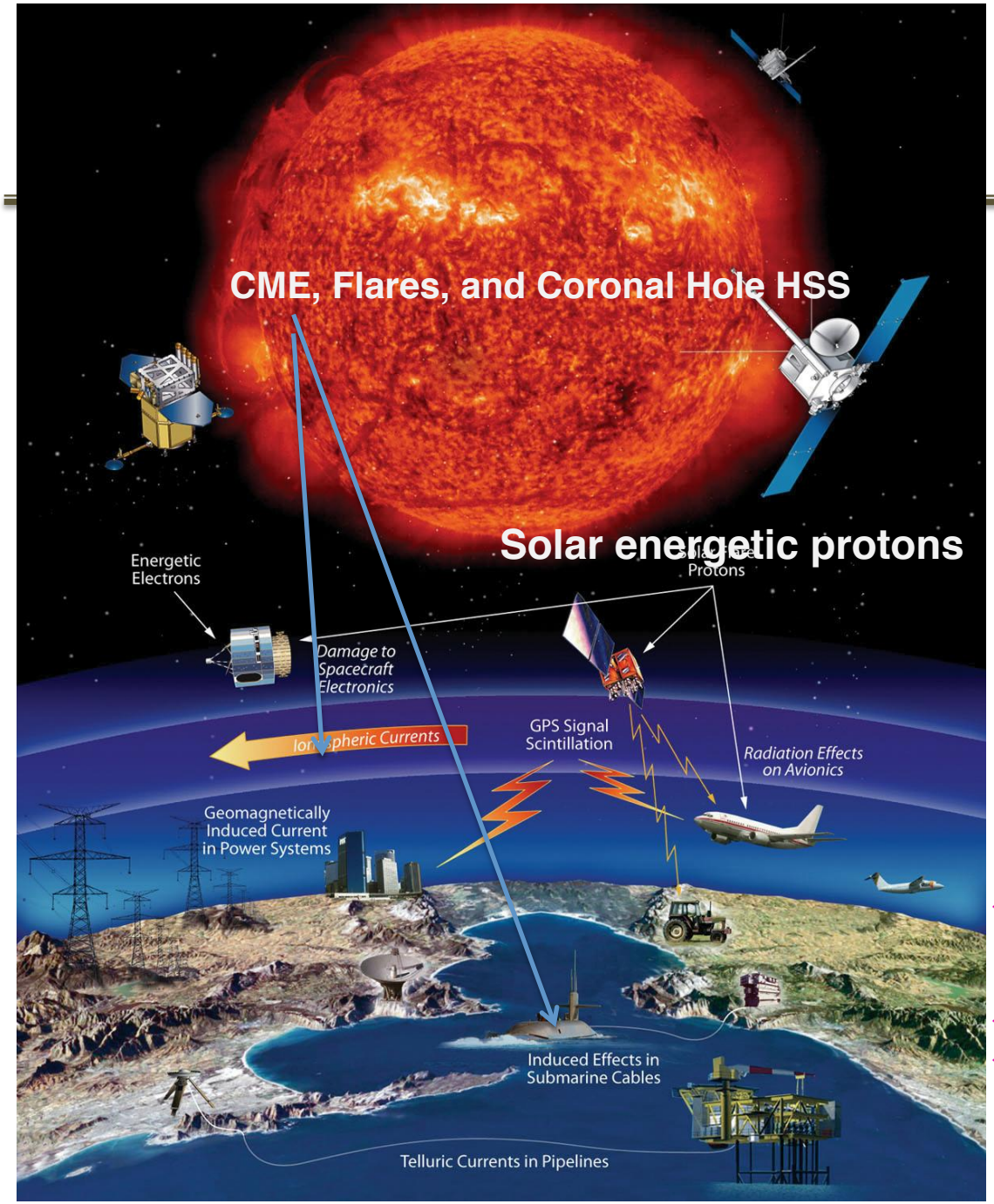
SW REDI Review

Yihua Zheng

SW REDI

June 9, 2014



The Sun
maker of space weather

CME, Flares, and Coronal Hole HSS

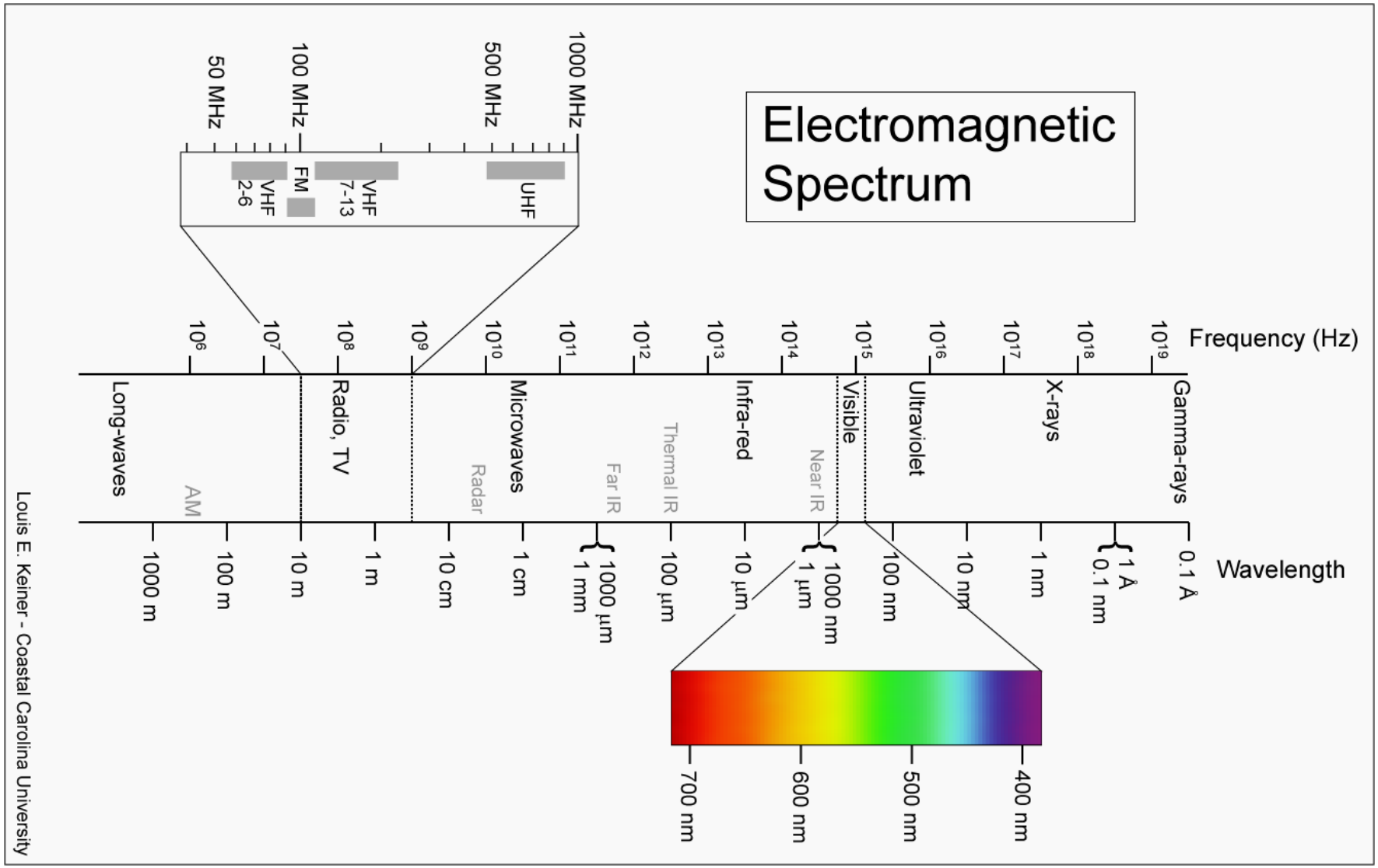
Three very important solar wind disturbances/structures for space weather

- ✓**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)**

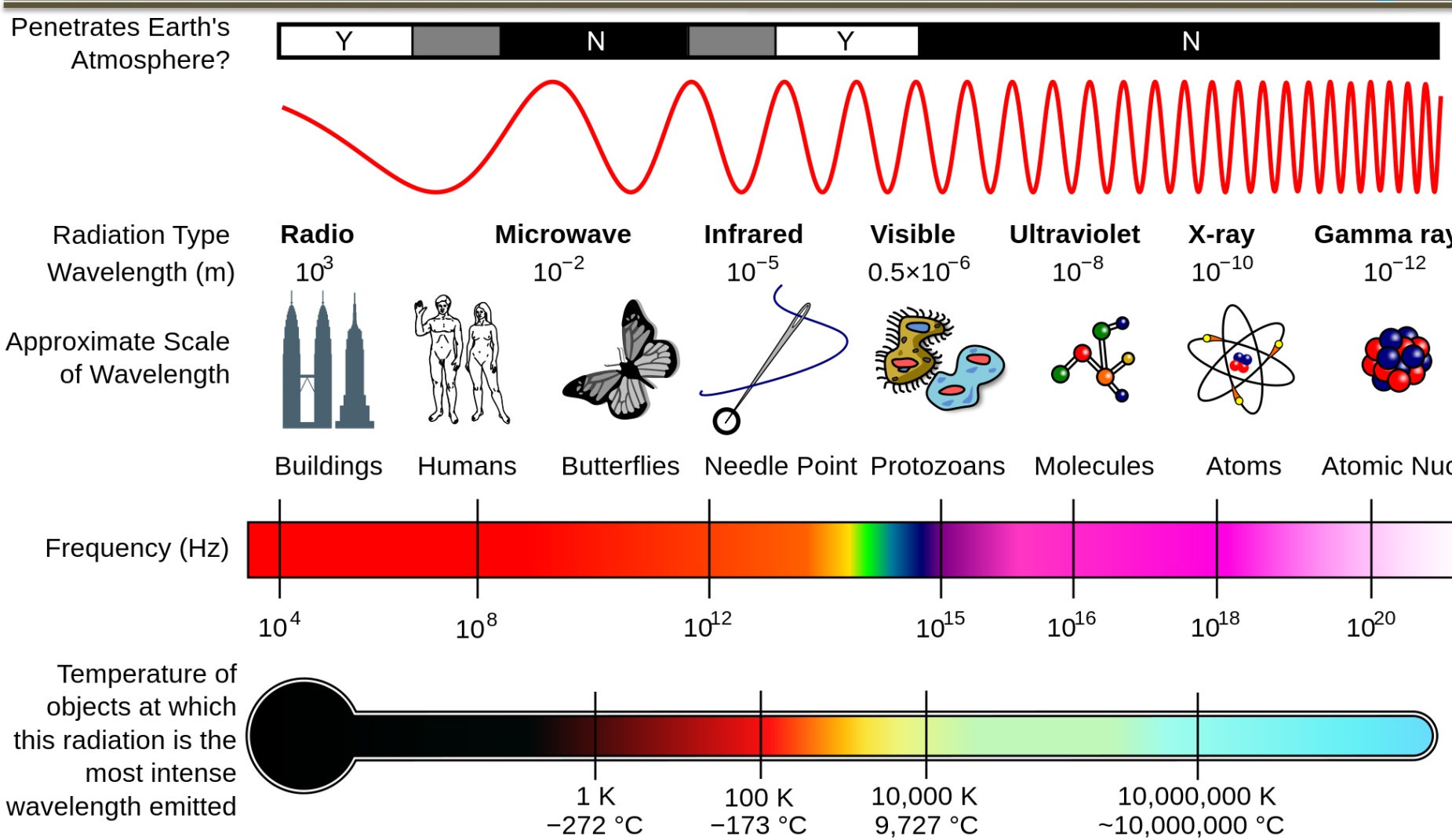
Flares

- Most pronounced in X-ray or Extreme Ultraviolet
- Flares occurring on the Earth-facing solar disk classified by GOES X-ray measurement in the 0.1-0.8 nm (1-8 A)
- Measured by SDO EUV wavelengths
- Farside flares – Can be seen in STEREO EUV images

Electromagnetic Spectrum



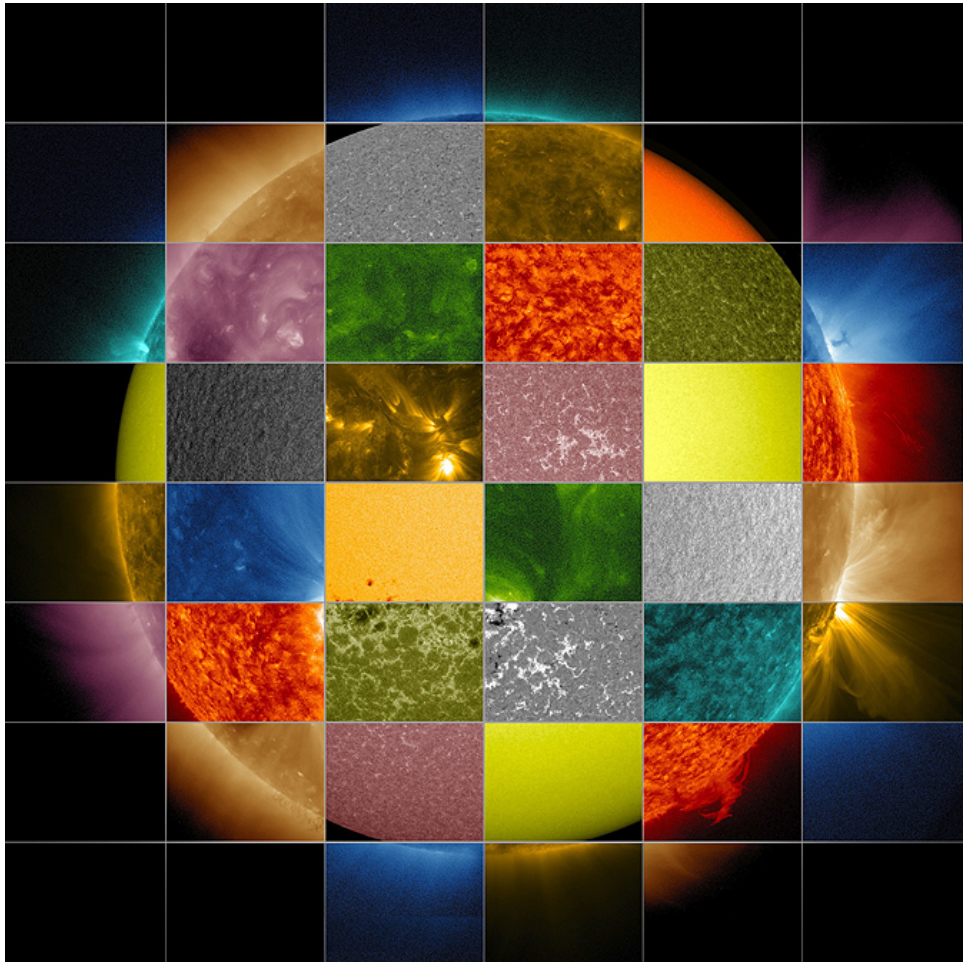
Electromagnetic Spectrum



Flares

Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths

http://www.nasa.gov/mission_pages/sunearth/news/light-wavelengths.html



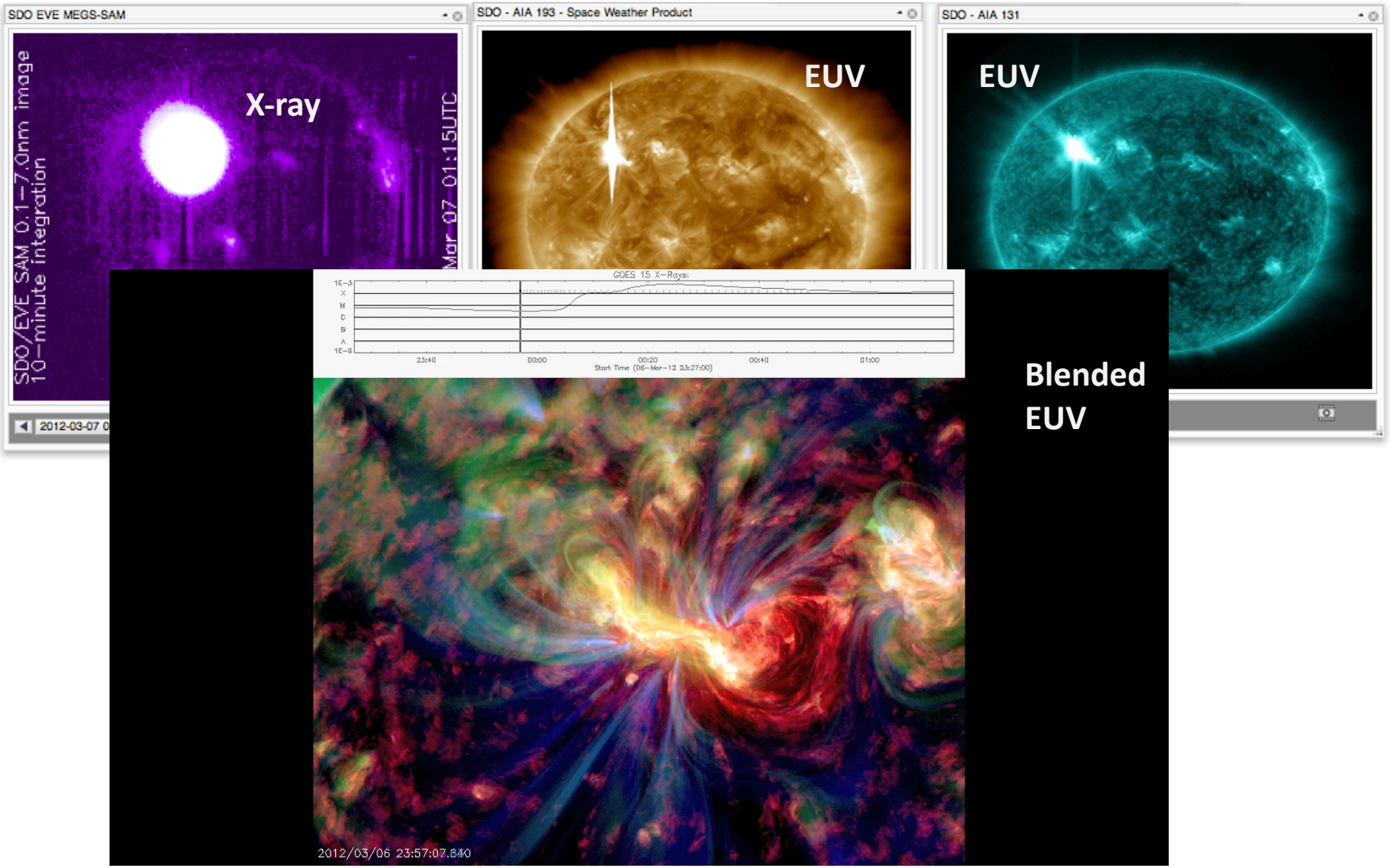
Different SDO Wavelengths

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

2012 March 7 X5.4/X1.3 flares

Most pronounced in x-ray and EUV



Solar Flare Consequences

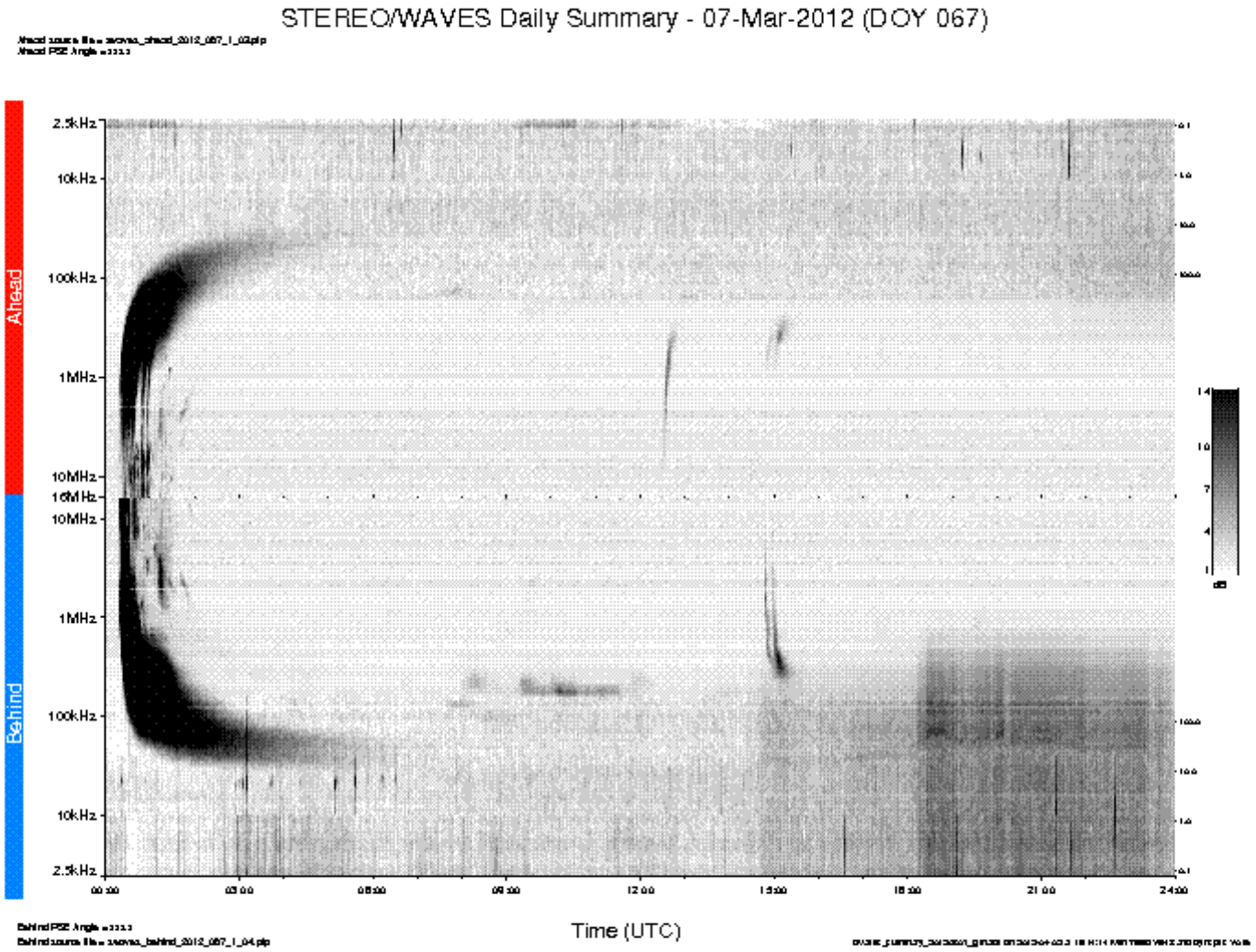
1: ionospheric dynamics

X-ray and EUV

- The extreme Halloween solar flares are shown to have extreme ionospheric effects. Enhancements in **ionospheric total electron content of 30% nominal values** were noted for the 28 October 2003 event. These changes occurred on timescales of 5 min. The enhanced ionospheric TEC lasts for hours after the flares.
- The **260–340 A °** portion of the flare spectra through photoionization creates electron-ion pairs at **altitudes >160 km**, where the recombination rates are long. **The x-ray portion** of the flare spectra, on the other hand, creates ionization at **95–110 km altitude**, where the recombination timescales are only approximately tens of seconds.
- There is a wide variation in **flare spectra** from event to event. It was shown that although the 4 November flare (X28) was almost double the intensity of the 28 October flare (X17) in 1–8 A ° x-rays. The 28 October flare was more than double the 4 November flare peak intensity in the 260–340 A ° EUV wavelength band.

Tsurutani, B. T., et al. (2006), Extreme solar EUV flares and ICMEs and resultant extreme ionospheric effects: Comparison of the Halloween 2003 and the Bastille Day events , *Radio Sci.* , 41 , RS5S07, doi: 10.1029/2005RS003331.

Type II Radio Emission

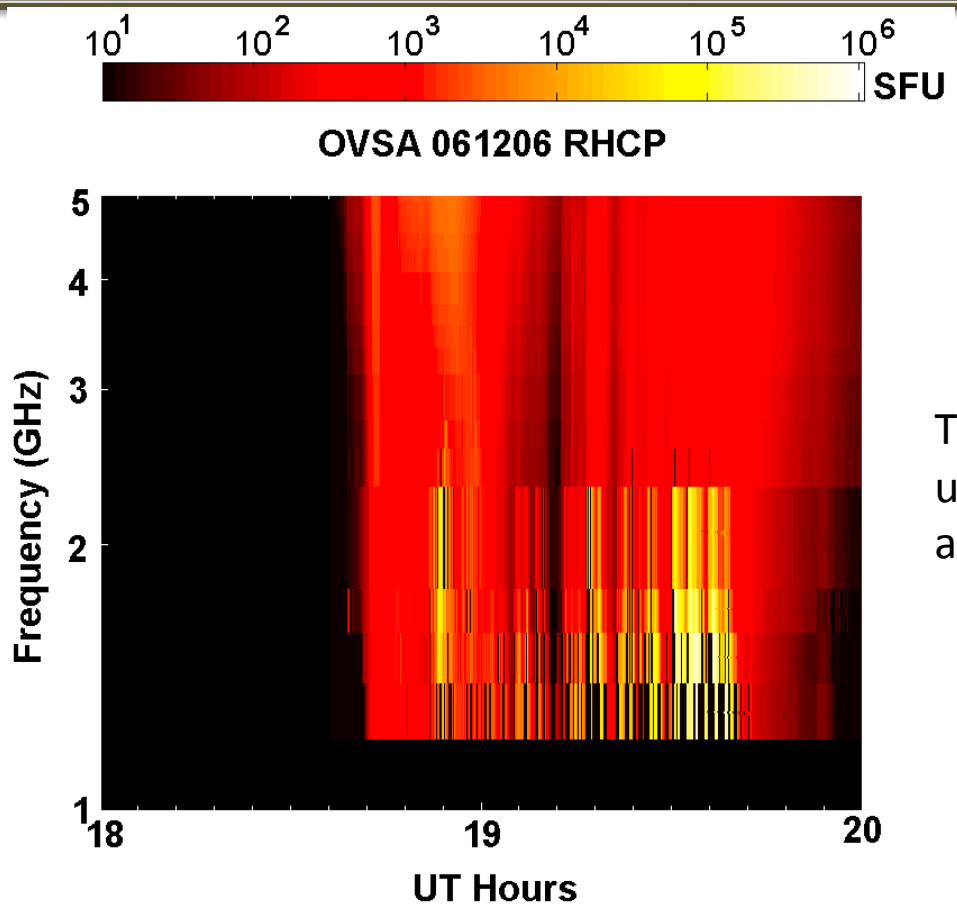


Solar Flare: radio noise

SUMMARY: 10cm Radio Burst
Begin Time: 2012 Mar 07 0007 UTC
Maximum Time: 2012 Mar 07 0117 UTC
End Time: 2012 Mar 07 0210 UTC
Duration: 123 minutes
Peak Flux: 7200 sfu
Latest Penticton Noon Flux: 138 sfu

This noise is generally short-lived but can cause interference for sensitive receivers including radar, GPS, and satellite communications.

Solar radio bursts affect GPS directly



This event exceeded 1,000,000 solar flux unit and was about 10 times larger than any previously reported event.

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.

Coronal Mass Ejection (CME)

SWx impacts of CME

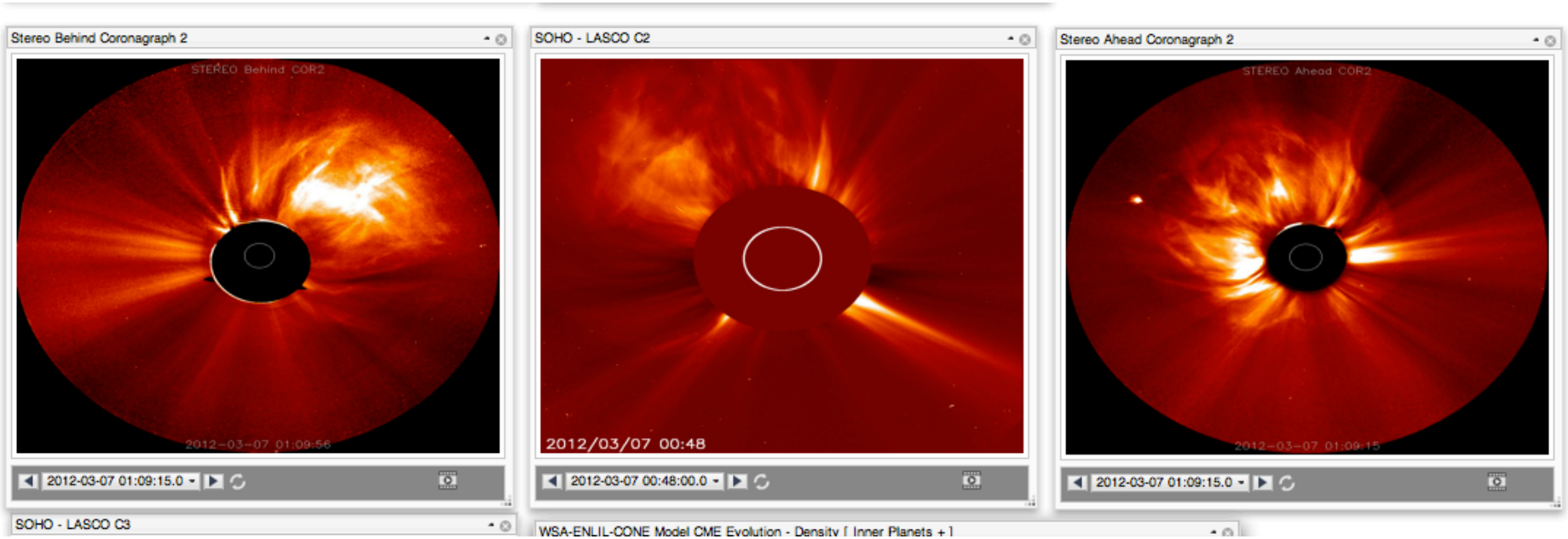
- Contribute to SEP (particle radiation): 20-30 minutes from the occurrence of the CME/flare
- Result in a geomagnetic storm: takes 1-2 days arriving at Earth
- Result in electron radiation enhancement in the near-Earth space (multiple CMEs): takes 1-3 days

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

CME

- Massive burst of solar materials into the interplanetary space: 10^15 g
- Kinetic energy 10^32 erg
- Yashiro et al. (2006) find that virtually all X-class flares have accompanying CMEs

CME viewed by coronagraph imagers



Eclipses allow corona to be better viewed
Does not happen often
Modern coronagraph imager is inspired by that
Occulting disk blocks the bright sun so we can observe corona features better

CME Example

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

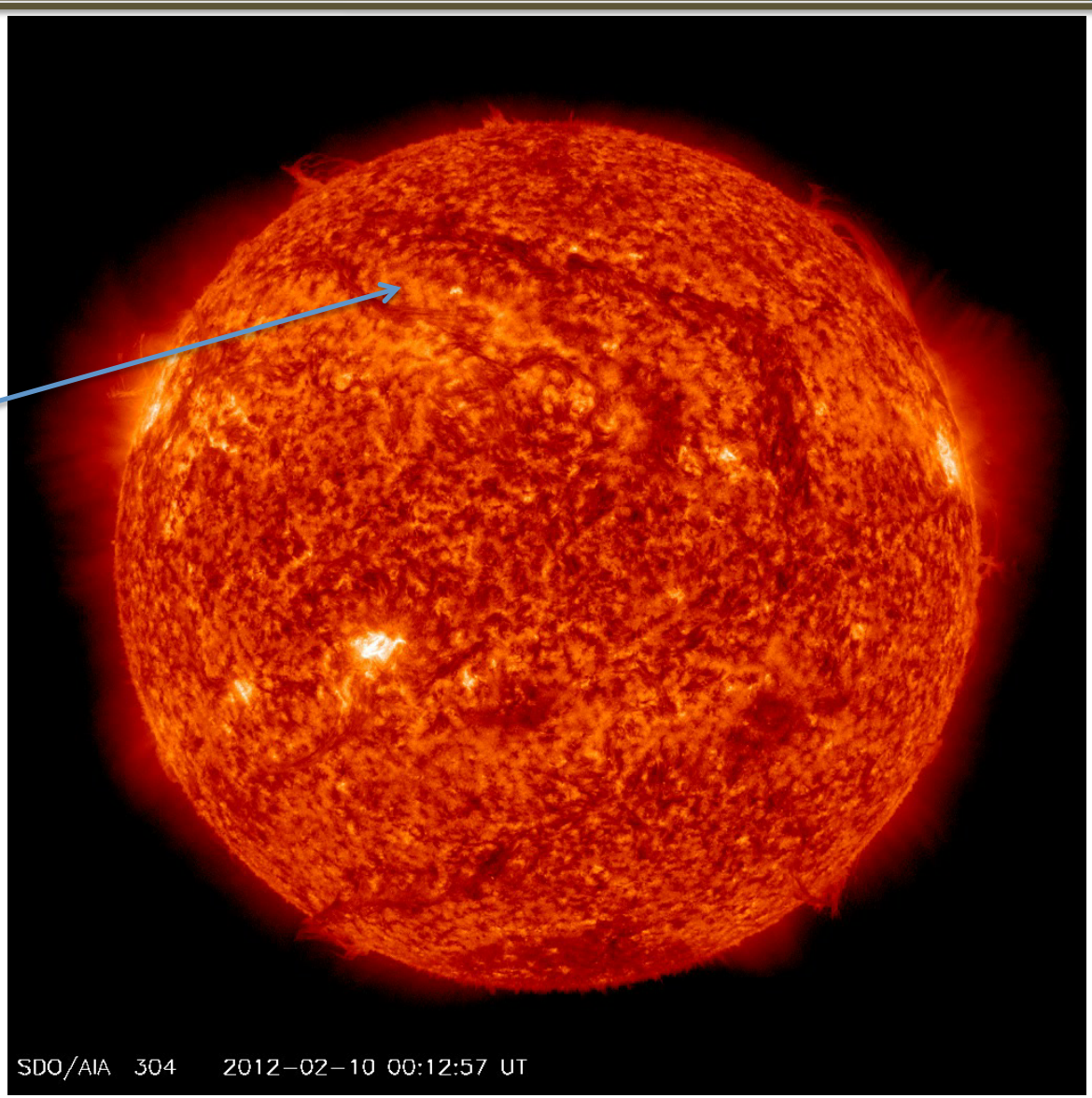
  iSWA layout

Associated with an Active Region

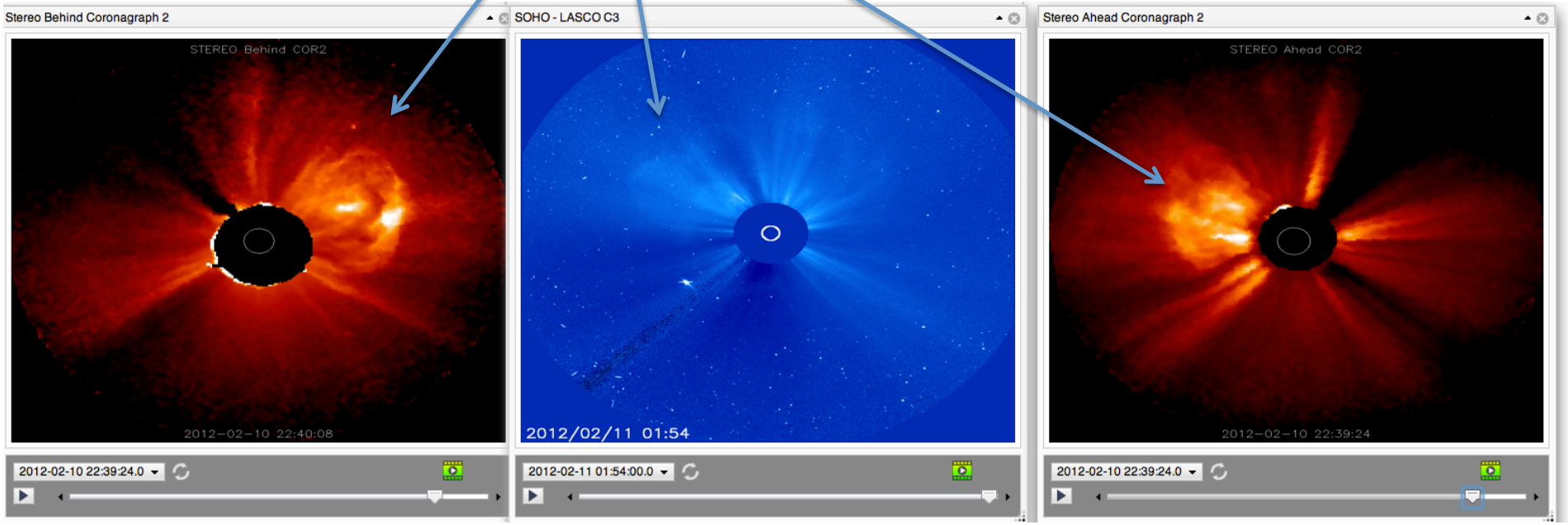
CME from Filament eruption

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).

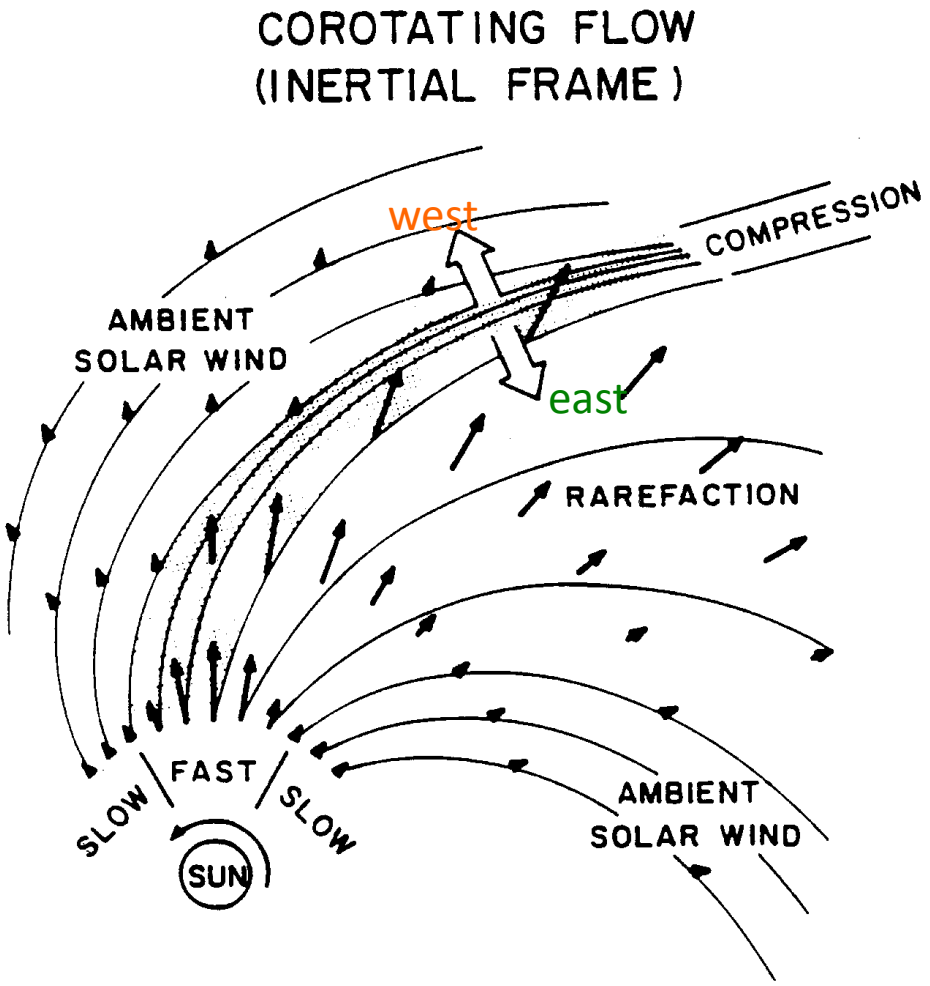
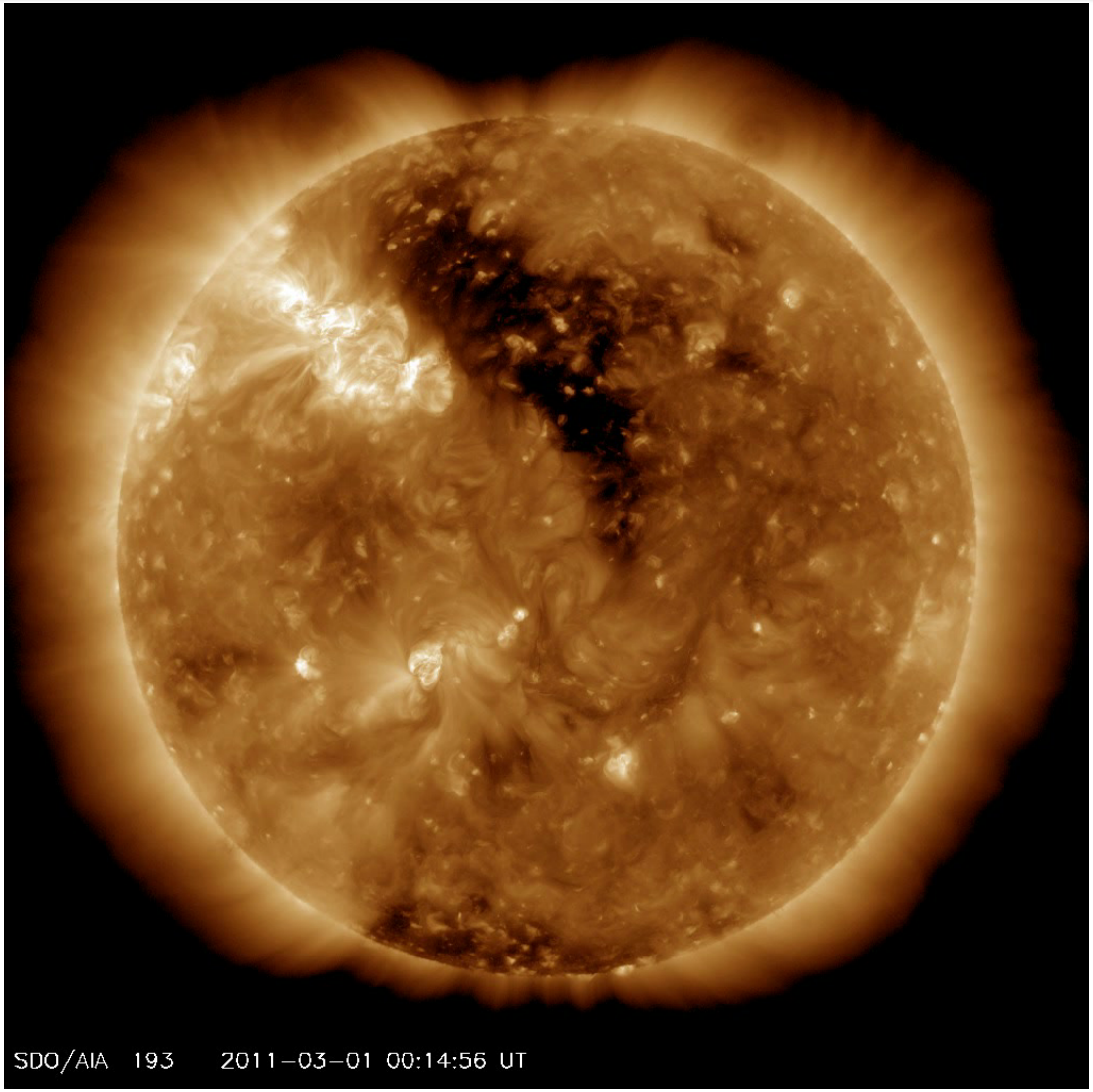


Figure 6. Schematic illustrating 2-D corotating stream structure in the solar equatorial plane in the inner heliosphere (from Pizzo, 1978).

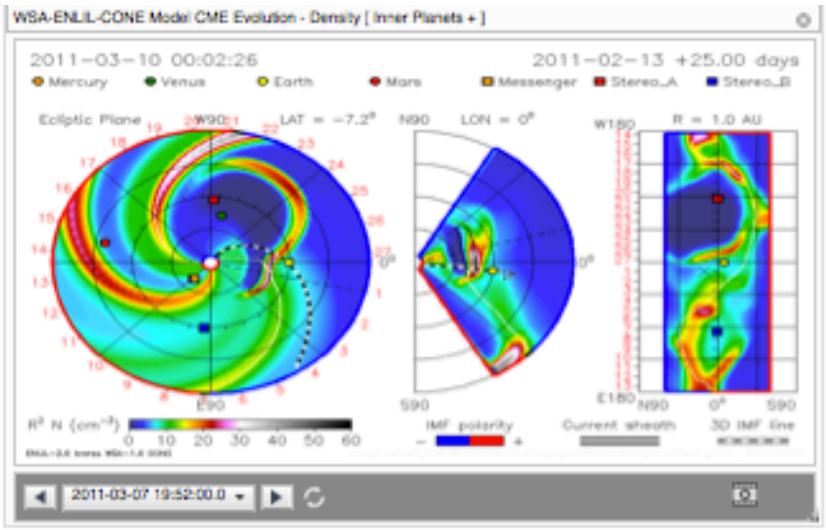
Coronal Hole HSS



Mar 1, 2011

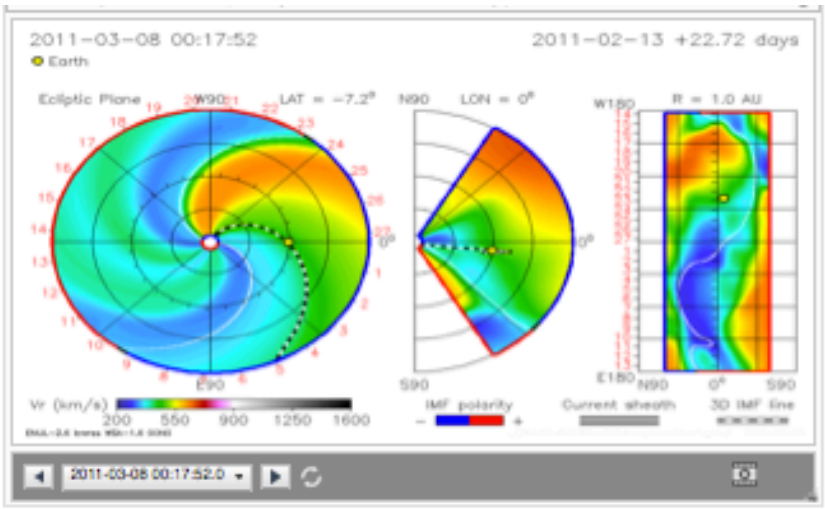
June 4, 2012

Forecasting capability enabled by ENLIL



WSA+ENLIL+cone

Predicting impacts of CMEs

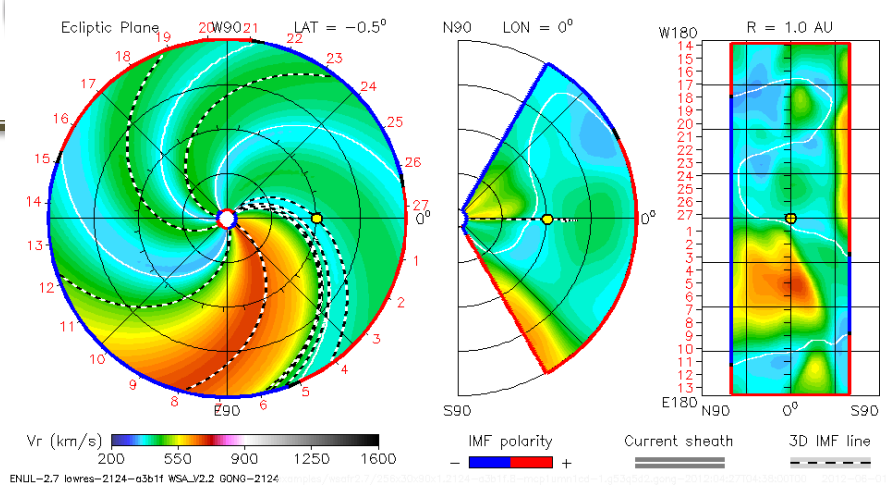


WSA+ENLIL

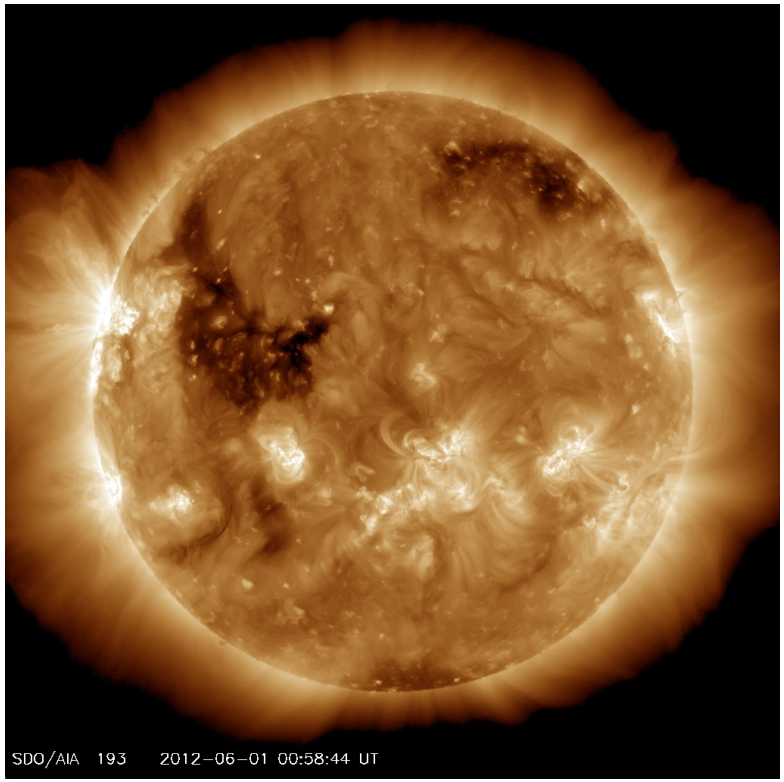
Modeling and predicting the ambient solar wind

2012-06-01T19:00 2012-05-10T01 +22.73 days

Earth

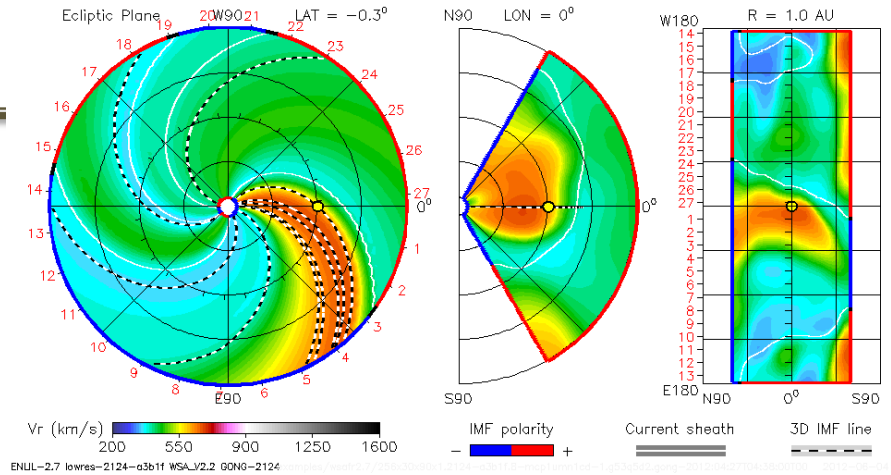


ENUL−2.7 lowres−2124−a3b1f WSA_V2.2 GONG−2124

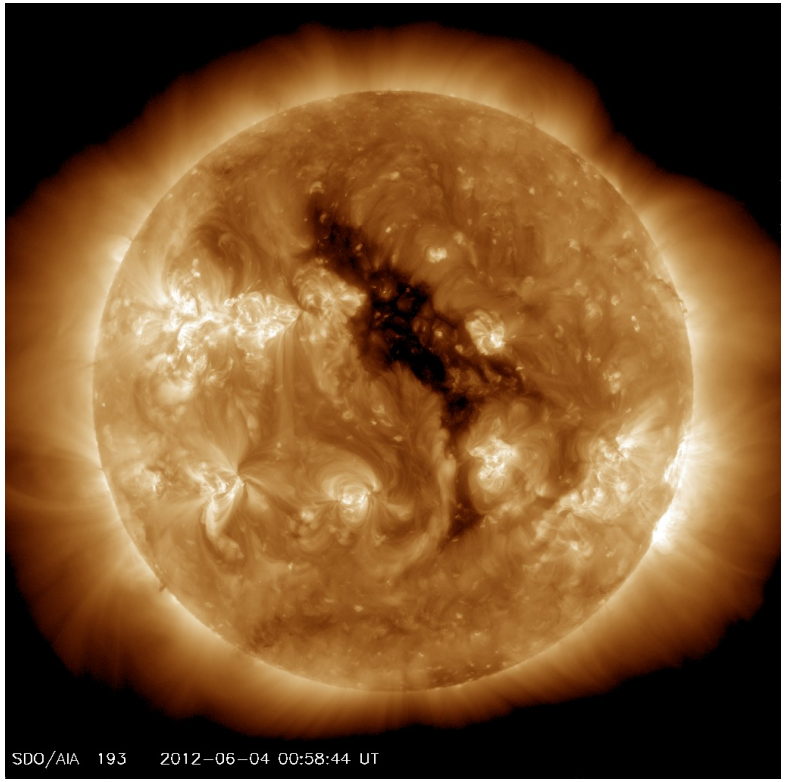


2012-06-04T10:00 2012-05-12T17 +22.73 days

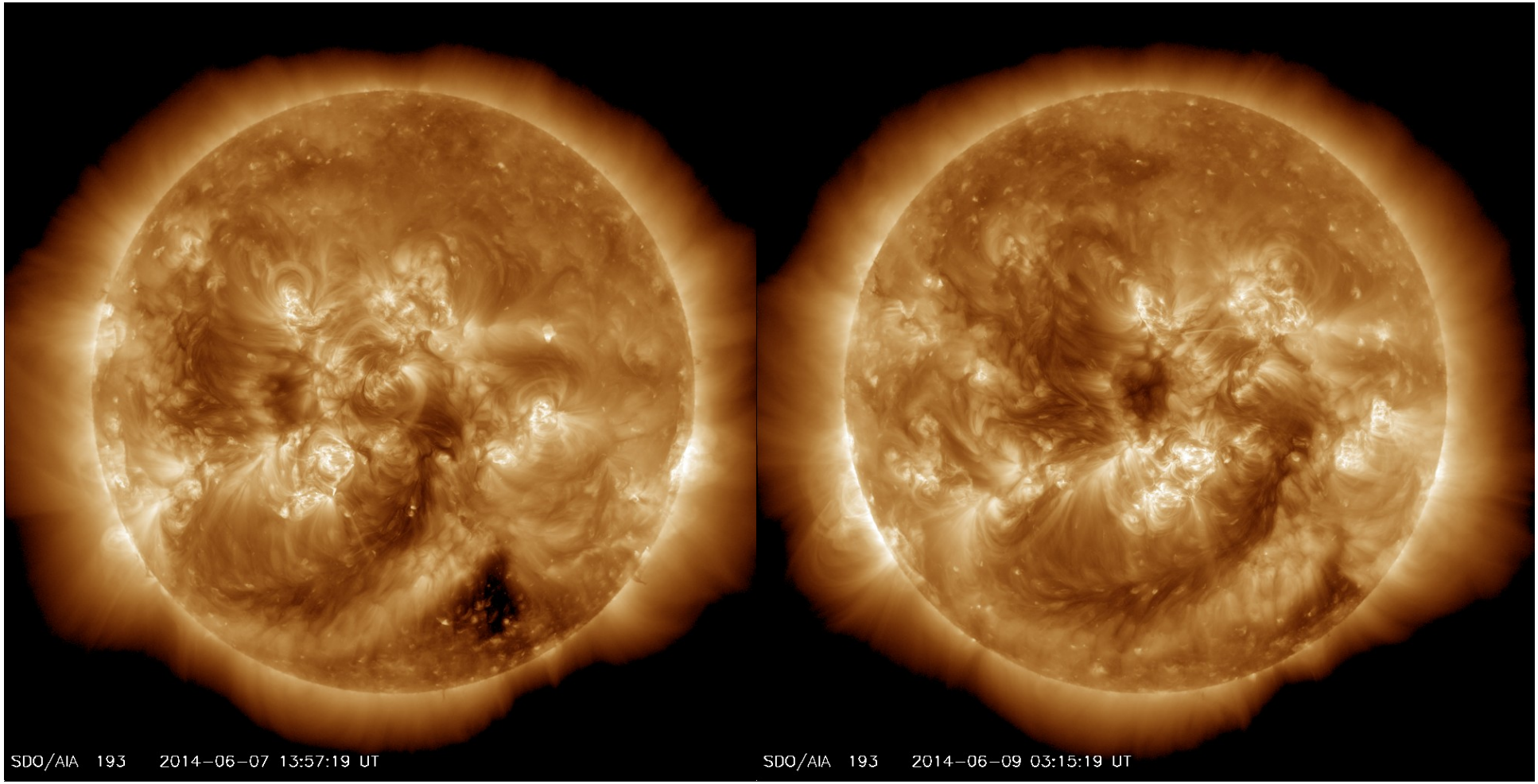
Earth



ENUL−2.7 lowres−2124−a3b1f WSA_V2.2 GONG−2124



Current coronal hole

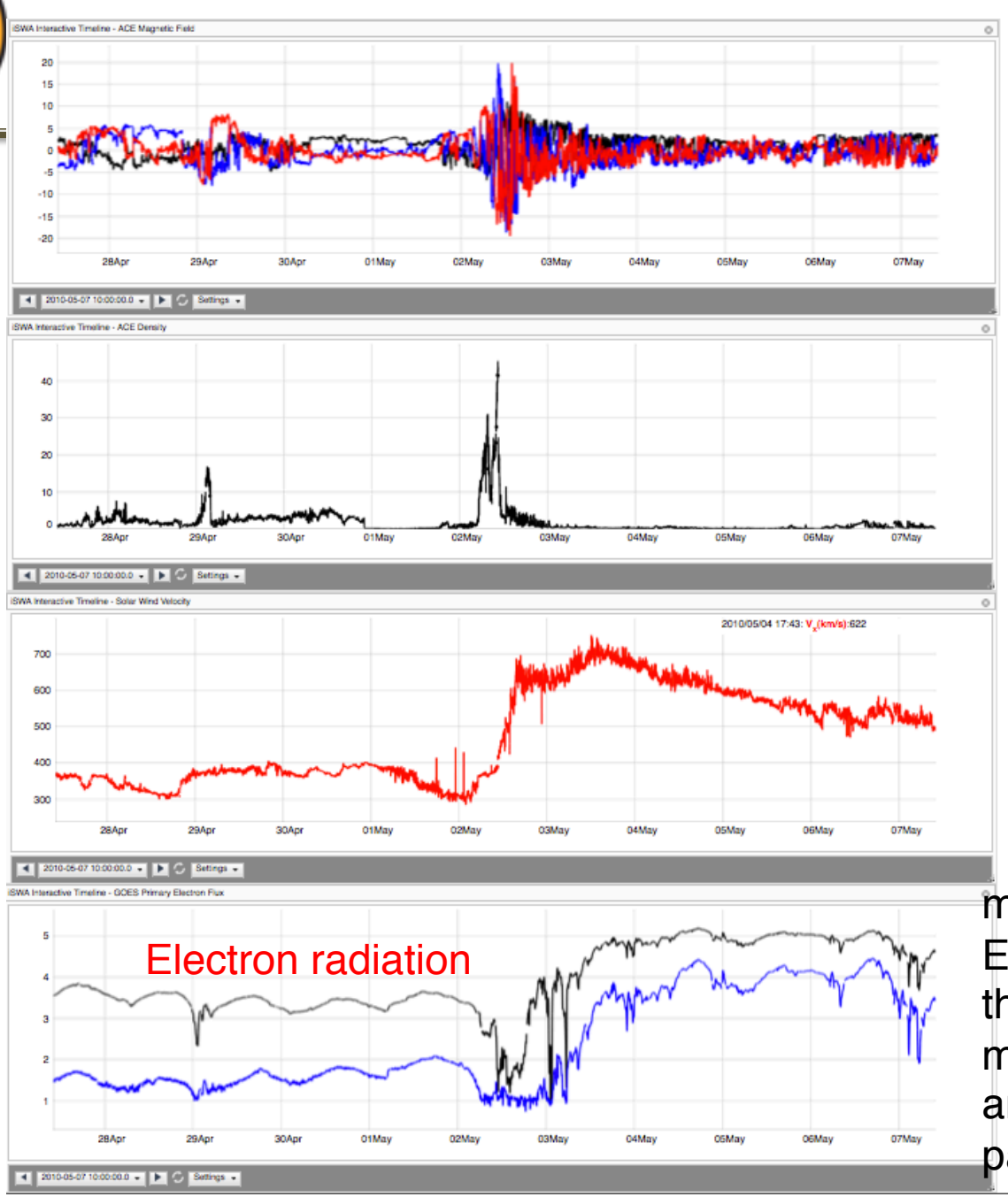


June 7, 2014

June 9, 2014

In-situ signatures of CME and CIR HSS at L1

ACE and WIND



Clean HSS

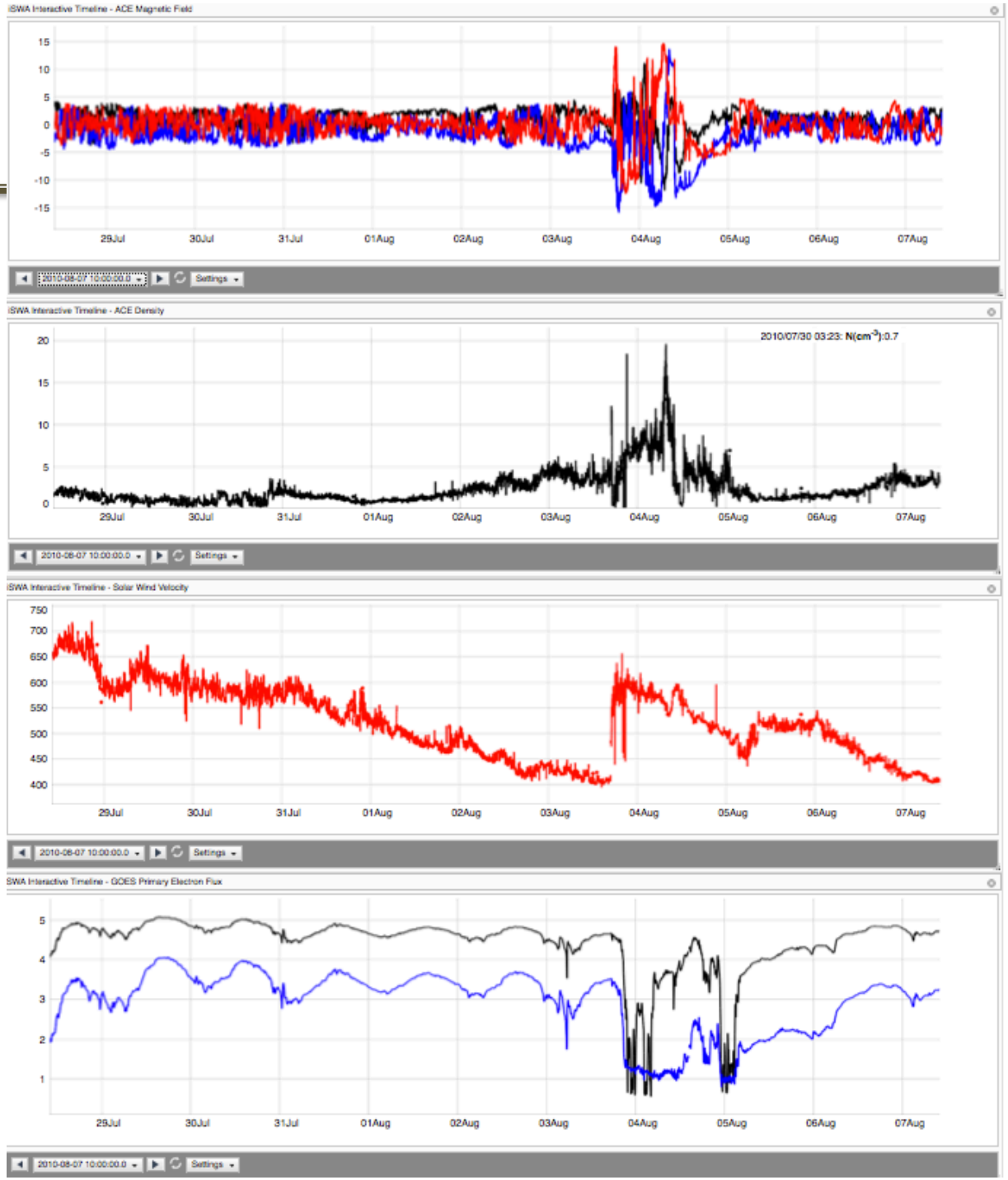
May 2, 2010

Dense (20-30 cc), HSS

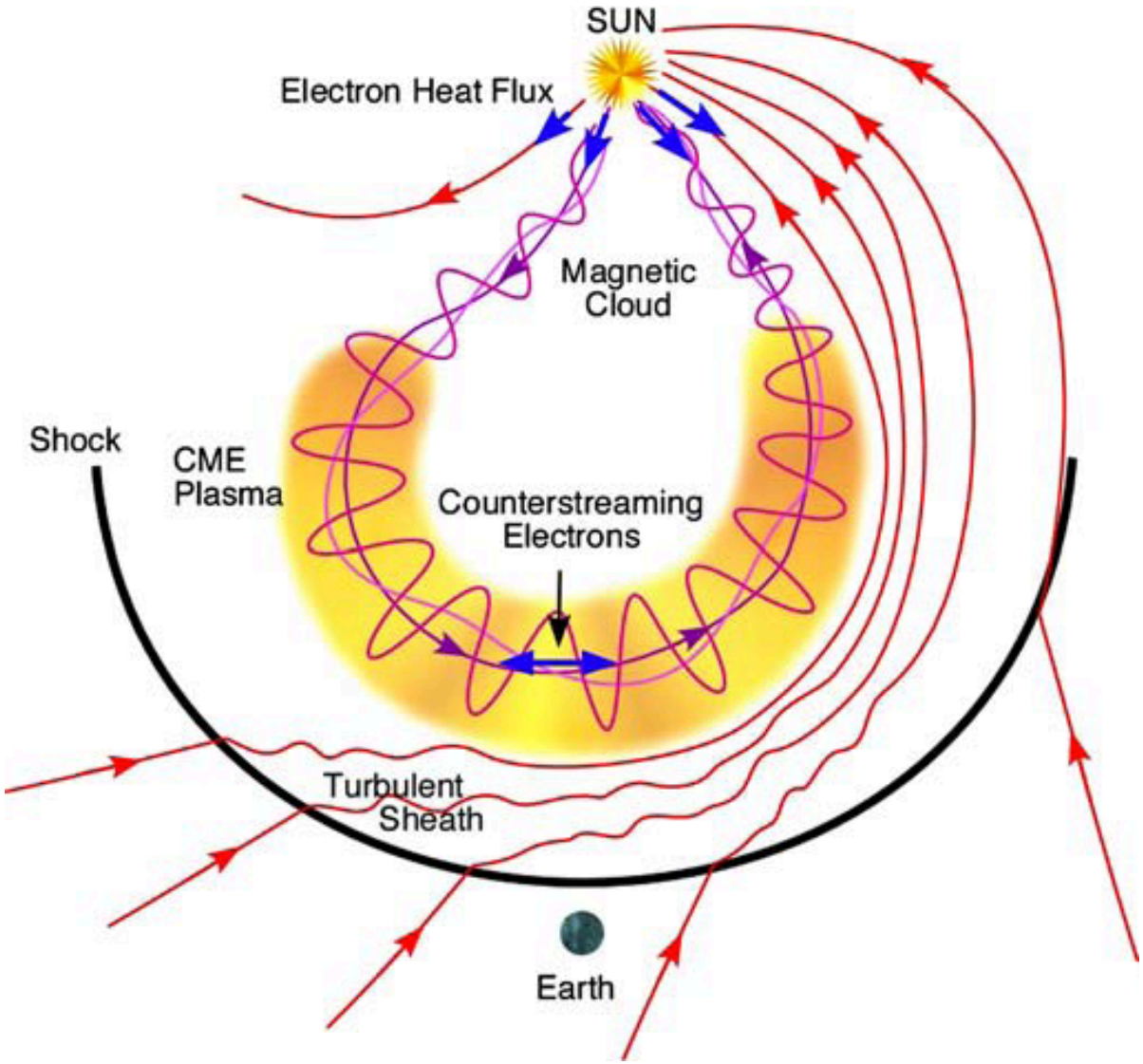
IMFBz: -18 nT

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

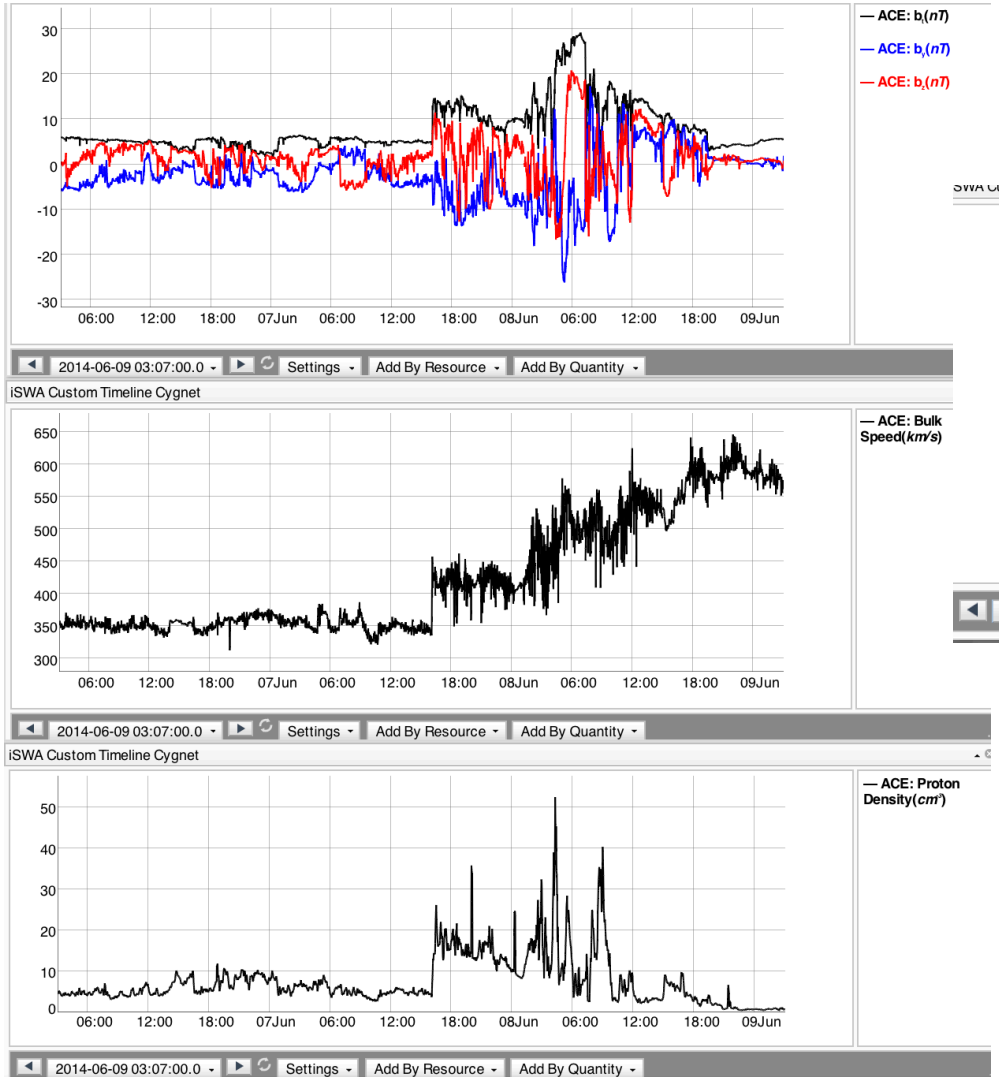
Aug 3, 2010


ISWA Interactive Timeline - ACE Magnetic Field
15
10
5
0
-5
-10
-15
29Jul
30Jul
31Jul
01Aug
02Aug
03Aug
04Aug
05Aug
06Aug
07Aug
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

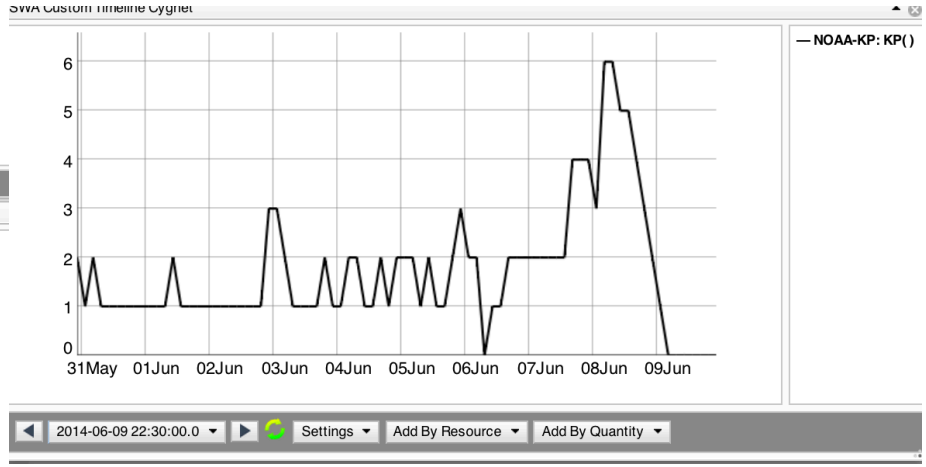
Schematic of the three-dimensional structure of an ICME and upstream shock



Current storm

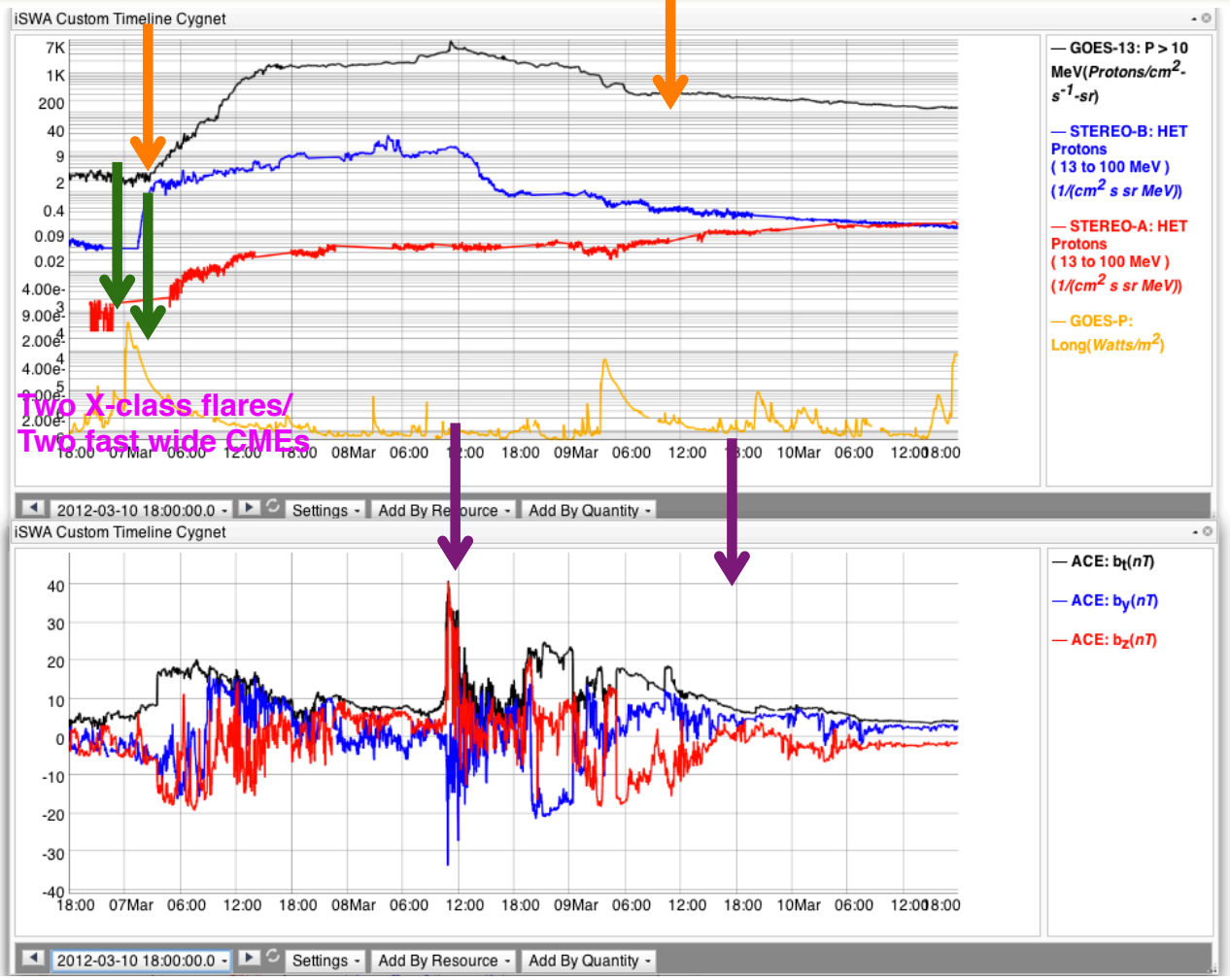


Kp=6



Space Weather Effects and Timeline

(Flare and CME)



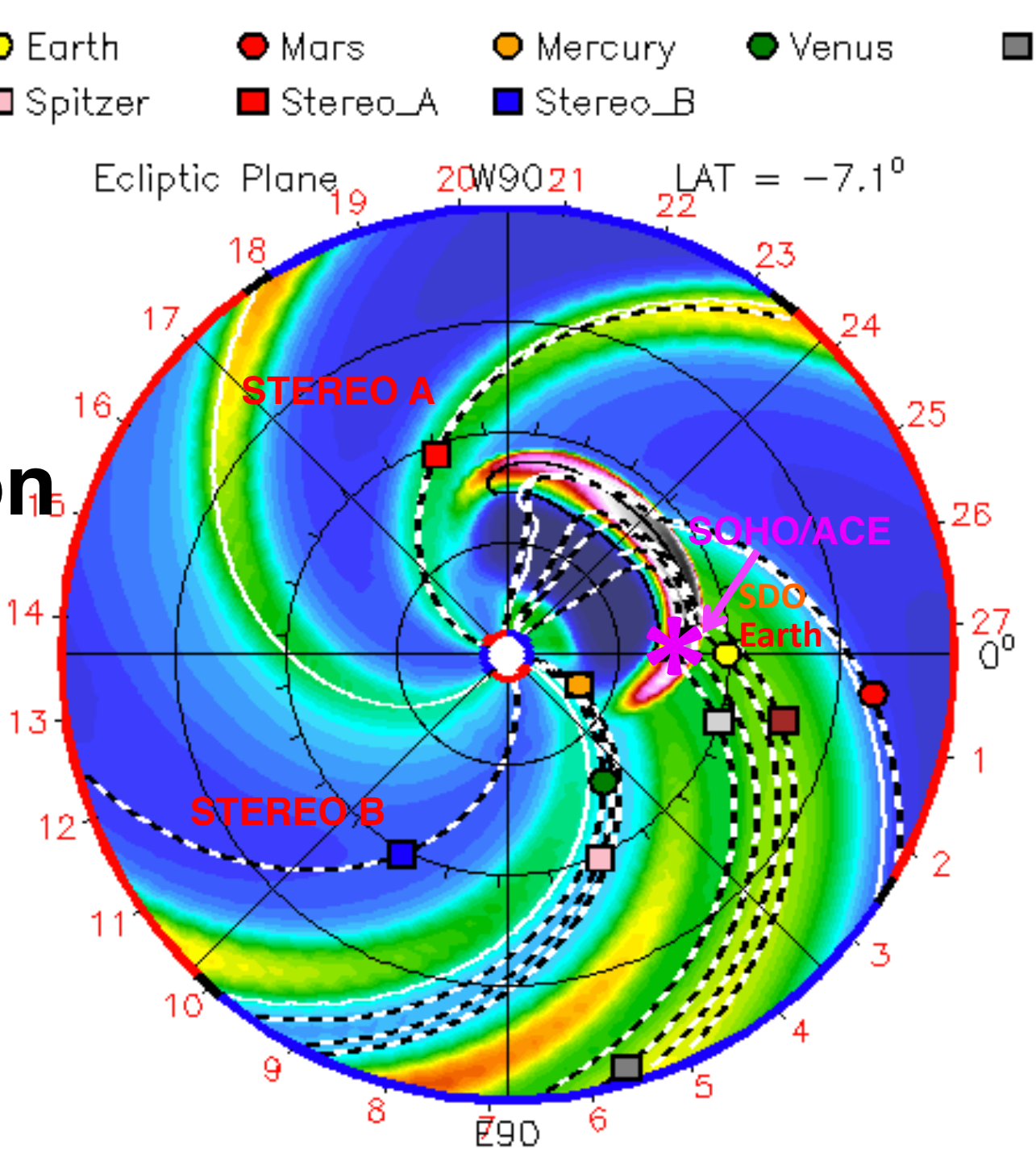
Flare effects at Earth:
~ 8 minutes (radio blackout storms)
Duration: minutes to hours

SEP radiation effects reaching Earth: 20 minutes – 1hour after the event onset
Duration: a few days

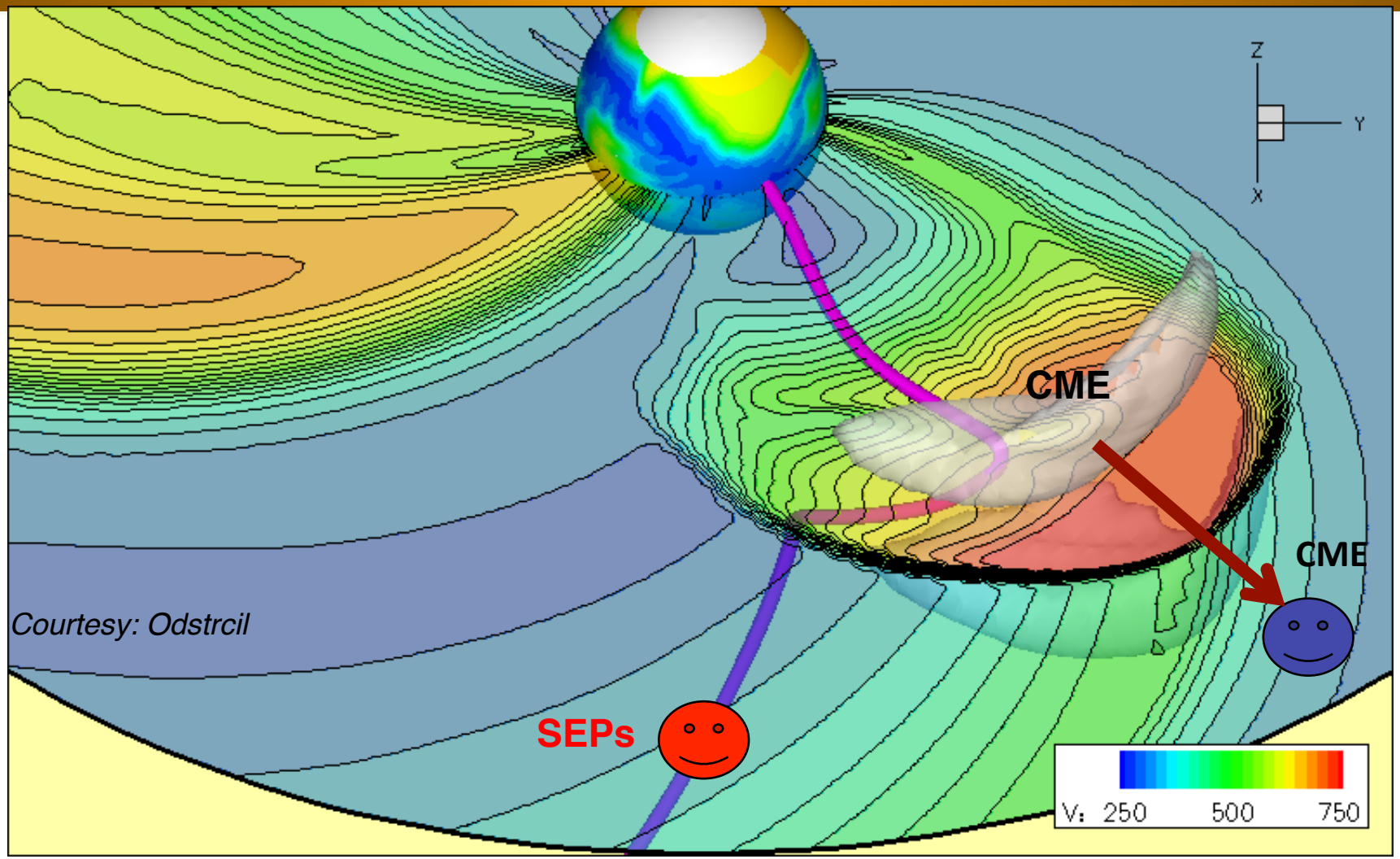
CME effects arrives @ Earth: 1-2 days (35 hours here)
Geomagnetic storms: a couple of days

Types of Storms

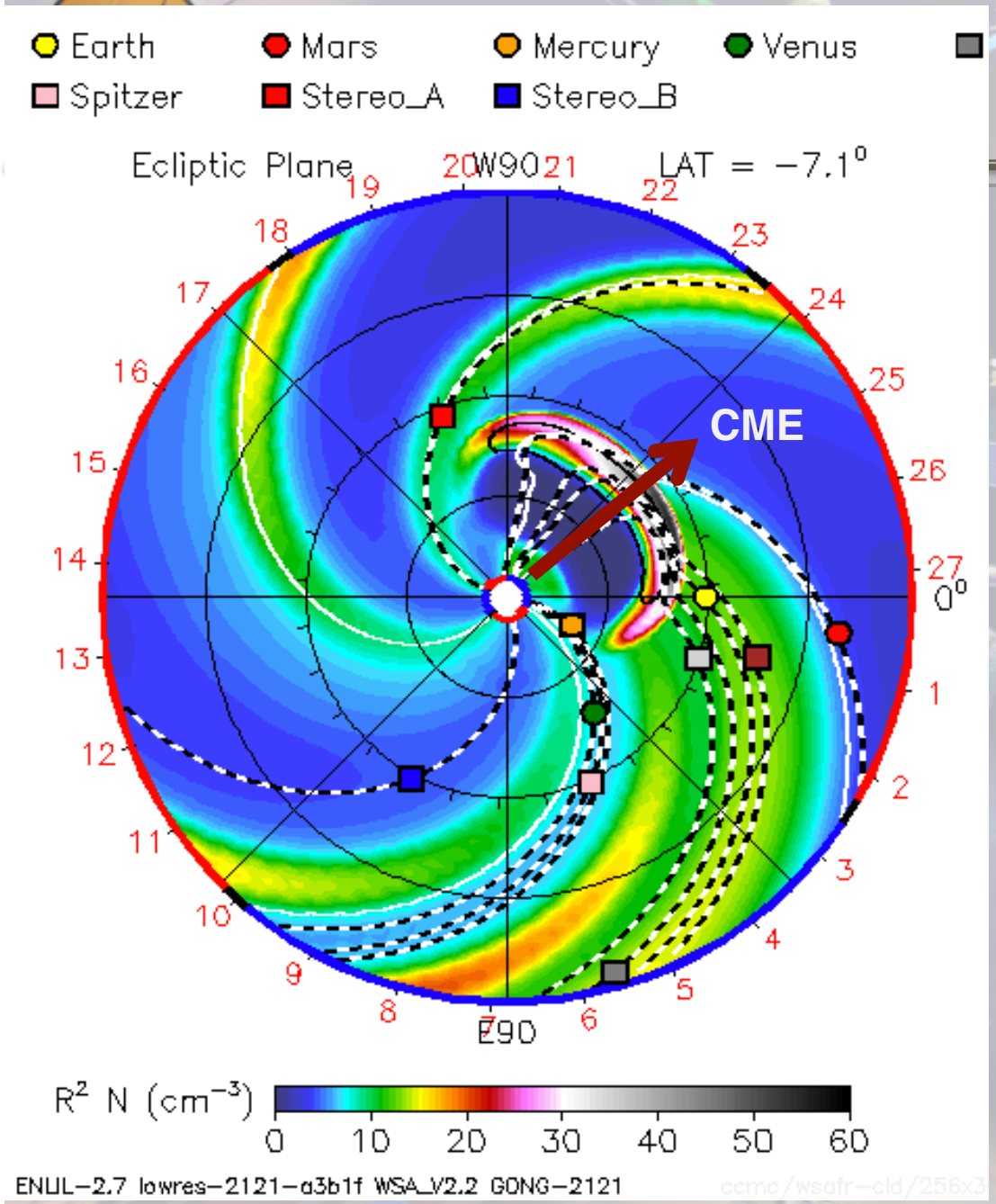
Orientation



CME and SEP path are different



CME: could get deflected, bended, but more or less in the radial direction



Important distinction

Ion Radiation storm vs
Geomagnetic storm

CME impact and SEP (Solar Energetic Particle) impact are different

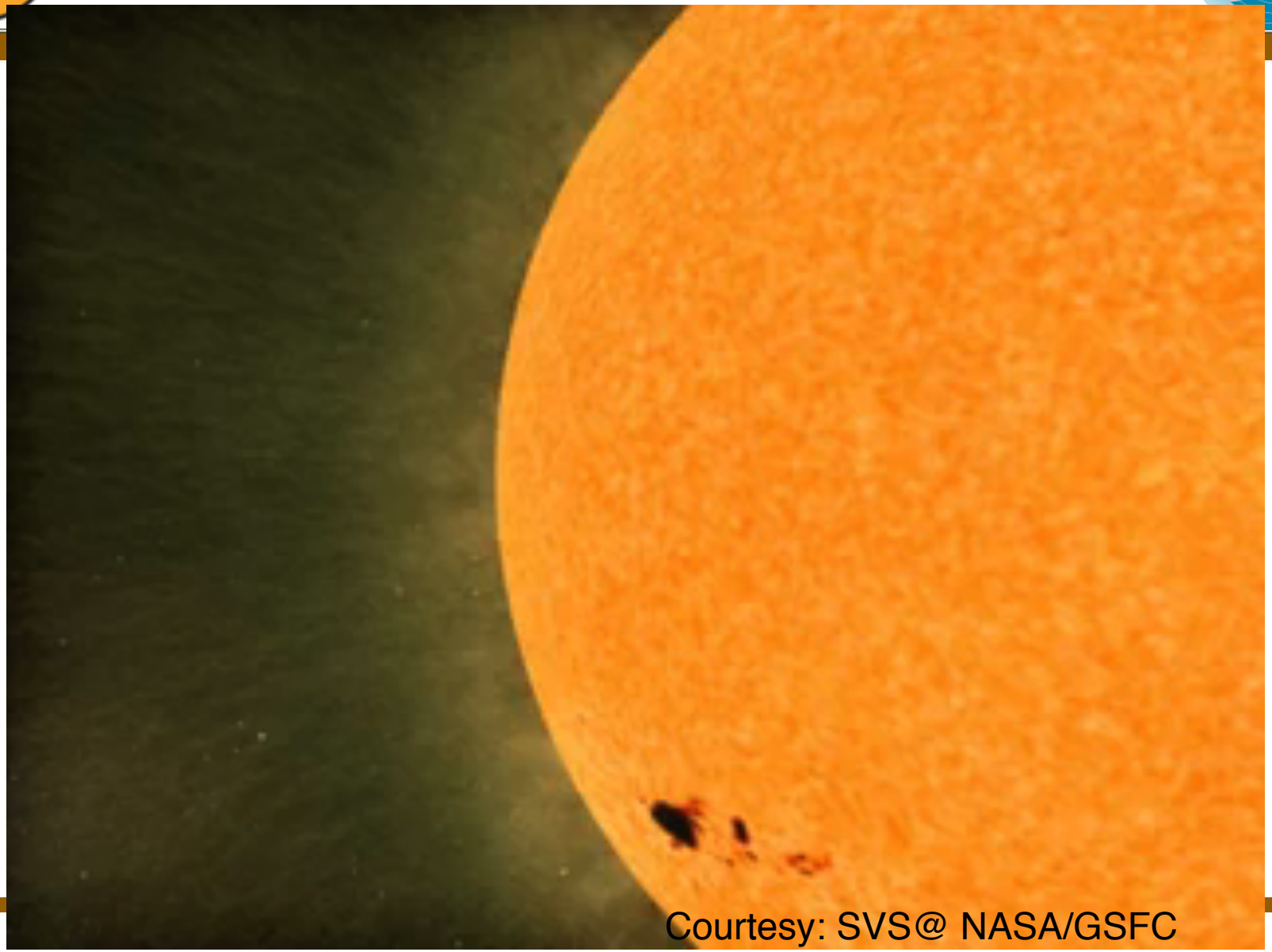
CME impact @ Earth: Geomagnetic Storm

Radiation storm @ Earth from SEPs

CME speed: 300 – 3500 km/s
SEPs: fraction of c
Light speed c: 3 x10^5 km/s

SEPs: ion radiation storms

Potentially affect everywhere in the solar system



Courtesy: SVS@ NASA/GSFC

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**

Geomagnetic Storms:

CME interaction with Earth (magnetic field)

Geomagnetic storms due to CIRs are at most moderate

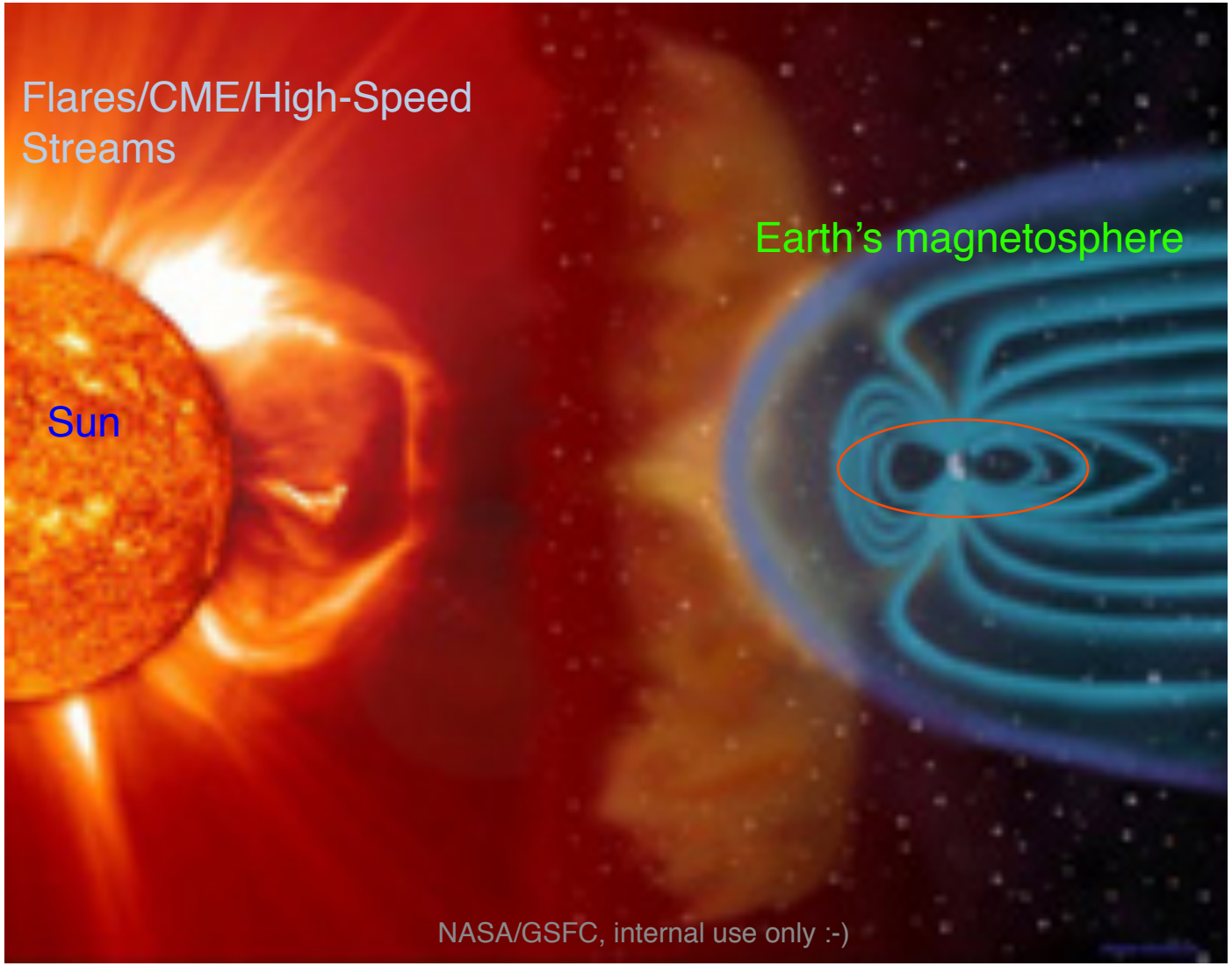
SWx in the near-Earth environment

- 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.



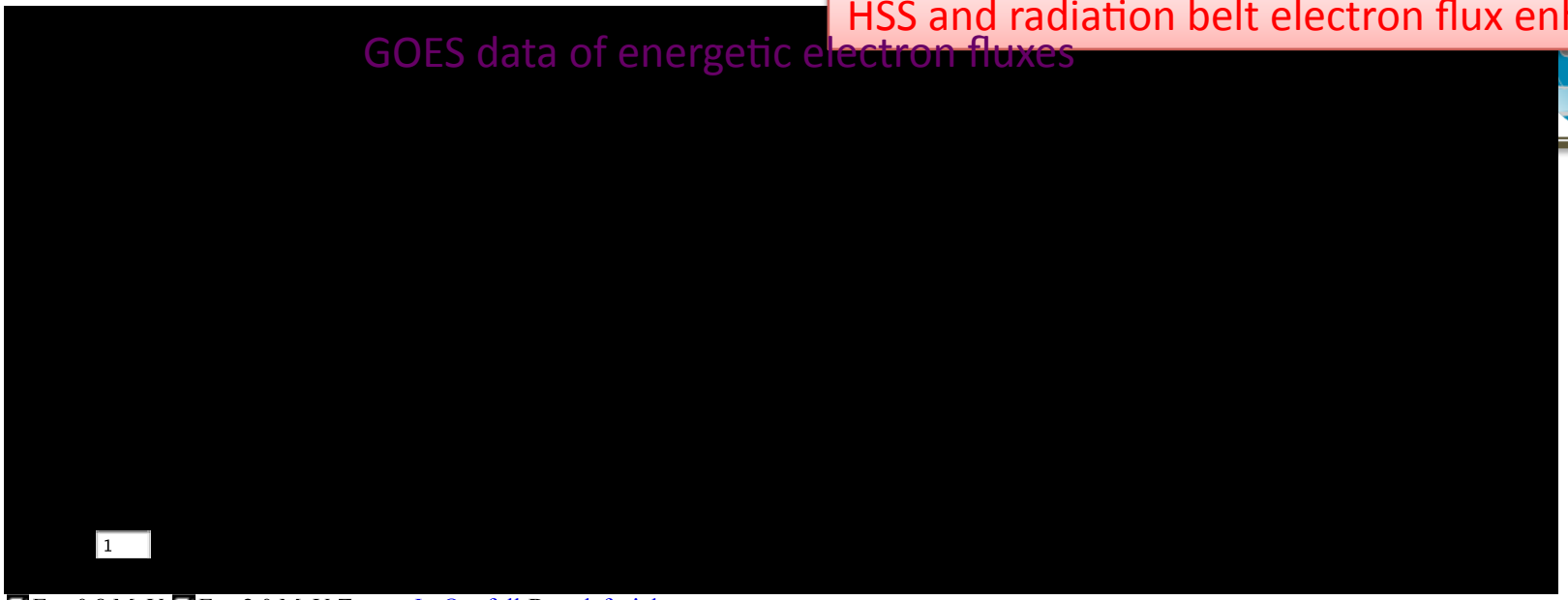
Different impacts on RB

CME vs CIR storms

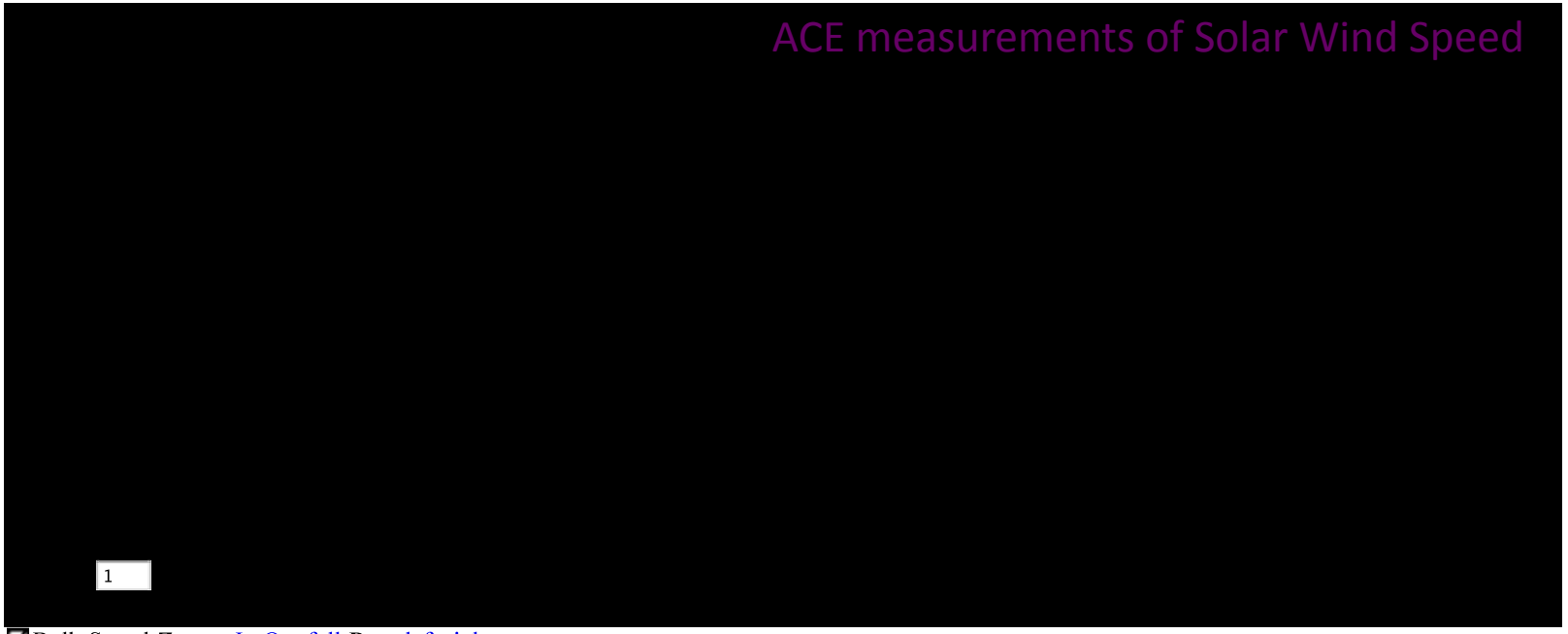
- CME geomagnetic storms: RB flux peak inside geosynchronous orbit. The peak locations moves inward as storm intensity increases
- CIR geomagnetic storms: More responsible for the electron radiation level enhancement at GEO orbit

Click the check boxes to toggle series visibility

HSS and radiation belt electron flux enhancement



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



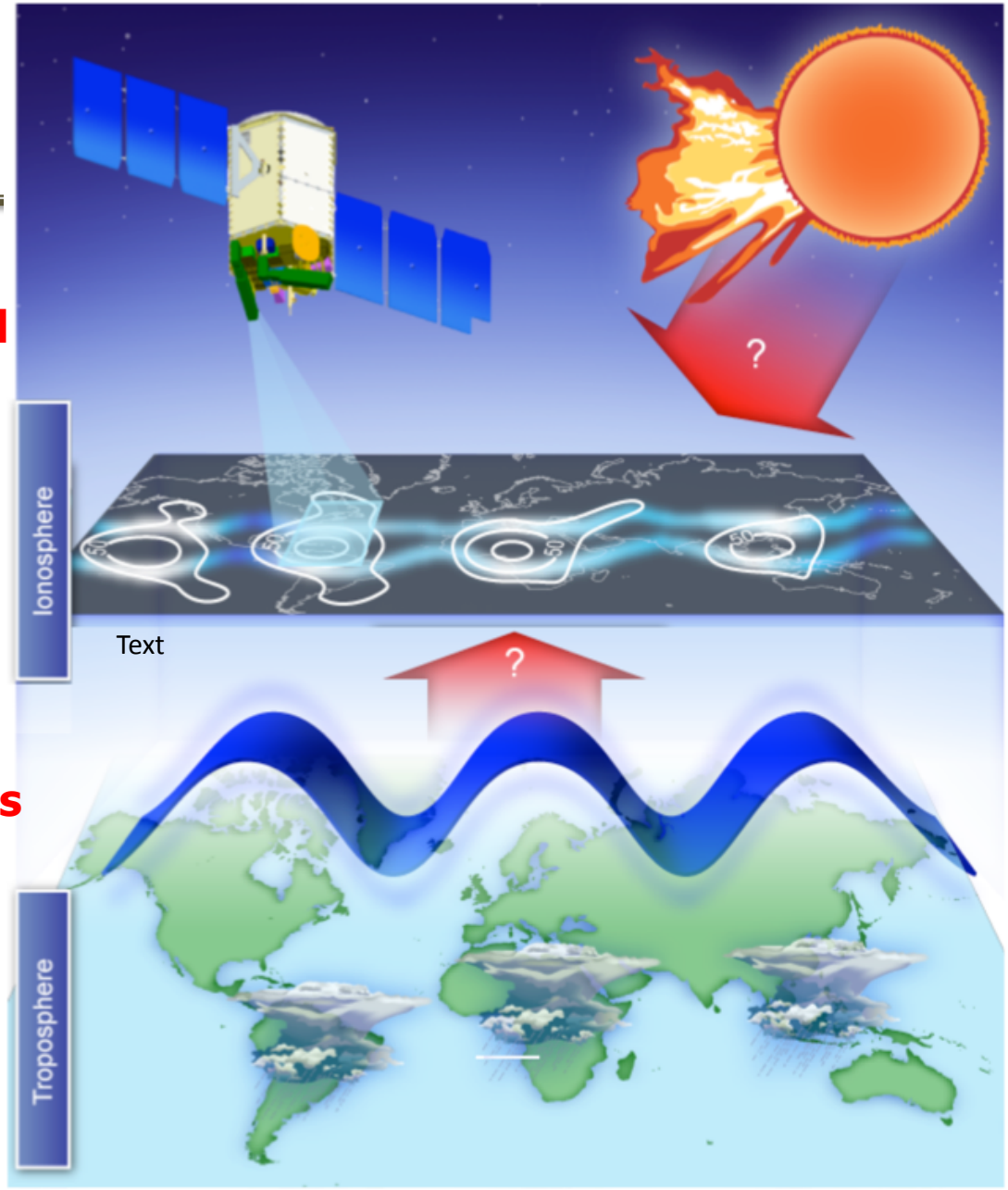
☑Bulk Speed **Zoom:** In Out full **Pan:** left right

Ionospheric Dynamics/Storms

The ionosphere is the densest plasma between the Earth and Sun, and is traditionally believed to be mainly influenced by forcing from above (solar radiation, solar wind/magnetosphere)

Recent scientific results show that the ionosphere is strongly influenced by forces acting from below.

Research remains to be done: How competing influences from above and below shape our space environment.



Courtesy: ICON

iSWA layouts

-

layouts

- Monitoring of space weather activities
- Events
- Anomaly
- Comparative study
- Weekly summary and highlights of specifics

Layouts - examples

- http://1.usa.gov/1rQXhWK - x1.4 flare on April 25, 2014
- http://1.usa.gov/1kr0842 - summary 20140430
- http://1.usa.gov/1i2Qemt scintillation with Kp
- http://1.usa.gov/1gPzEKM scintillation
- http://1.usa.gov/1deGdXC anomaly resolution
- http://1.usa.gov/1fk5Fv6 coronal hole responsible for Saturn aurora

Layouts - examples

- http://1.usa.gov/1e5ZBDW - march 7, 2012 event
- http://1.usa.gov/LSfnaC - evolution of March 2013 coronal hole in SDO, STA and STB
- http://1.usa.gov/1lZjWeD - SDO view of the coronal hole when it arrived at ACE
- http://1.usa.gov/1c51alC - layout of the 2013-09-29 CME and its impacts
- http://1.usa.gov/HUue2U - summary_20131113
- http://1.usa.gov/172TYTB - 20131107 CME highlight