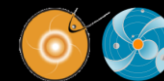




Space Weather

Emily Schomp
Dr. Ed DeLuca et al

Forecasting, Tracking, and Effects of
Earth Directed Solar Phenomena



Overview

- Phenomena
- Effects
- Forecasting
- Instrumentation
- Events



Phenomena

Phenomena

Anything powerful and Earth directed!

Events of interest to forecasters:

- Solar Flares
- Coronal Mass Ejections
- Ongoing Solar Wind

Solar Flares



- Explosive brightenings in magnetically active regions in chromosphere and corona
- Root cause of space weather
 - highly energetic electromagnetic radiation
 - solar energetic particles (SEPs)
 - Often initiate CMEs
- Energy of several hydrogen bombs and temperature of sun's core!

Coronal Mass Ejection (CME)

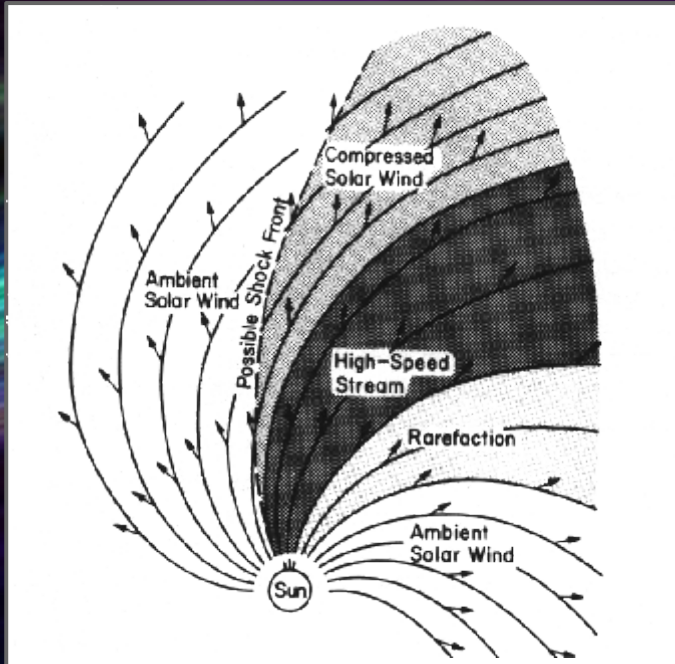
- Expulsions of large segments of outer corona
- Expand to be larger than sun itself
- Typical carries about a billion tons of plasma
- Typical speed 400 km per second
- 2-4 days to arrive at 1 AU

Photos:

Solar Wind junkdrome.org

Schematic illustration of a fast stream interacting with a slow stream *Hundhausen 1972*

Solar Wind



- Ambient solar wind always present, slow or fast
- Fast streams usually originate at poles and coronal holes
- Spiral towards Earth due to sun's rotation (called The Parker Spiral)
- *Fast and slow streams can interact and cause compression and rarefaction zones*

Incoming!

- Preceding CME material
 - SEPs and high speed electrons (MeV)
 - x-ray, EUV, and radio wave radiation
- ICMEs (plasma from sun)
 - Create shockwaves interacting with solar wind
 - Magnetic structures – you shall see!
 - dynamic pressure sheath
 - magnetic clouds/flux ropes
- *Varies every time*





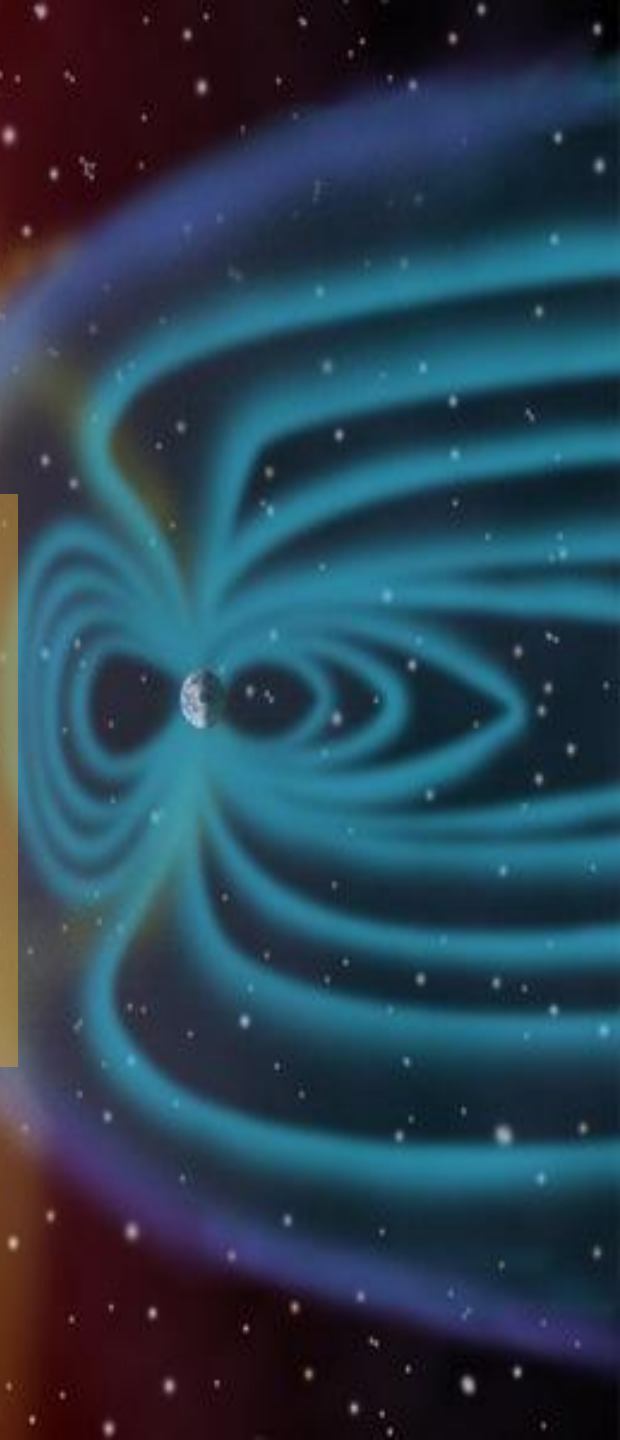
Effects



**That's probably not going to
happen though, in case I worried
you...**

Earth's Shield is Up

- Magnetosphere repels most charged matter
- Geomagnetic storms result from magnetic reconnection
- Plasma particles from ICME (protons/electrons) held in radiation belts
- Ionospheric O_2 and N_2 absorb far spectrum x-ray and EUV radiation
- Stratospheric ozone absorbs UV radiation



Results/Realistic Concerns

- Aurora Borealis! (and Australis)
- Compass fluxuations
- Expansion of thermosphere (atmospheric drag, ionization of atmosphere)
- Single Event Upsets (SEU)
- cumulative radiation and astronaut safety
 - Extra-vehicular activity for extended time
 - Mars or other space travel out of magnetosphere
- Flight delays over poles

Fund Us!

Our increasing dependence on microtechnology, satellite transmissions and electronics will make the effects of space weather a greater threat to our society and make heliophysics research of quintessential importance.



Forecasting and Instrumentation

Forecasting- What at Where?

Monitor sun for flares, CMEs, and SEP events

Measure parameters of events

Predict speed and direction of event based on sun's magnetic field

27 day cycle forecast of solar conditions

Monitor solar wind and plasma parameters

density, velocity, B field orientation

Spacecraft ahead to anticipate arrival times

Monitor Magnetosphere and radiation belt conditions

Predict expected onset, intensity and duration of geomagnetic storm

Programs and Facilities

National Space Weather Program (NSWP)

interagency initiative to speed improvement of space weather services
partnership among academia, industry, and government

National Science Foundation

National Oceanic and Atmospheric Administration (NOAA)

Departments of Defence, Energy, Transportation, and Interior

Space Radiation Analysis Group (SRAG)

Johnson's Space Center NASA

monitor space radiation environment for astronaut exposure

Track cumulative radiation

EVA planning

Space Weather Prediction Center (SWPC)

National Weather Service (NWS) and National Oceanic and Atmospheric Admin (NOAA)

occurrence of magnetic storms and auroral displays

Space Weather Modeling

Hosted by Community Coordinated Modeling Center (CCMC)

community access to modern space science simulations
situated at NASA Goddard Space Flight Center (GSFC)
slew of Agencies

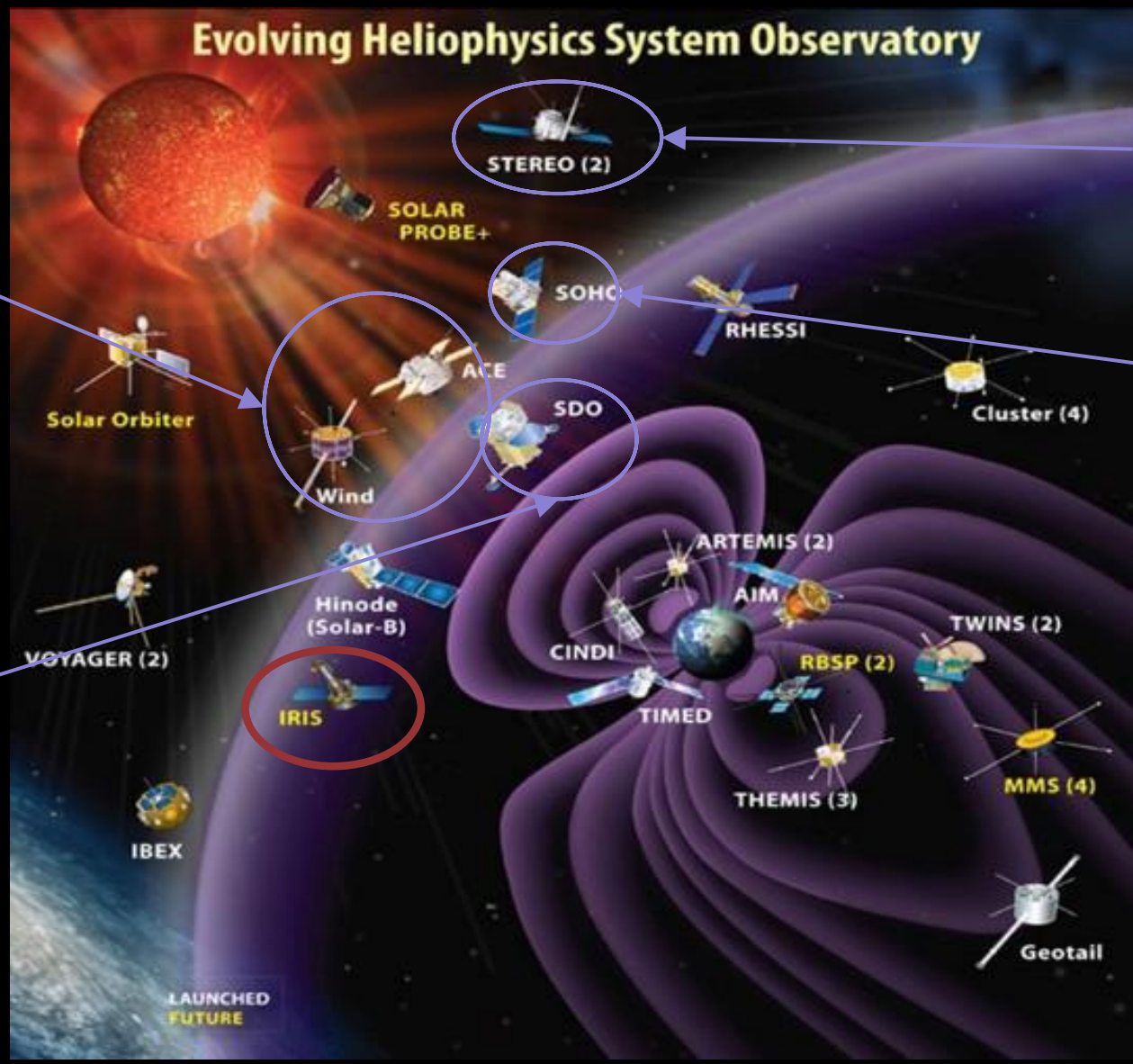
The integrated Space Weather Analysis System (iSWA)

web-based dissemination system for NASA
combines forecasts and observational data
specify and forecast space environment's and impacts for NASA missions
situated within CCMC

Magnetohydrodynamics (MHD) Codes used in Forecasting

Wang-Sheeley-Arge (WSA) model
ENLIL model
SWMF

Evolving Heliophysics System Observatory



solar wind

stereoscopic and "rear sun" data

LASCO CMEs

AIA solar imager

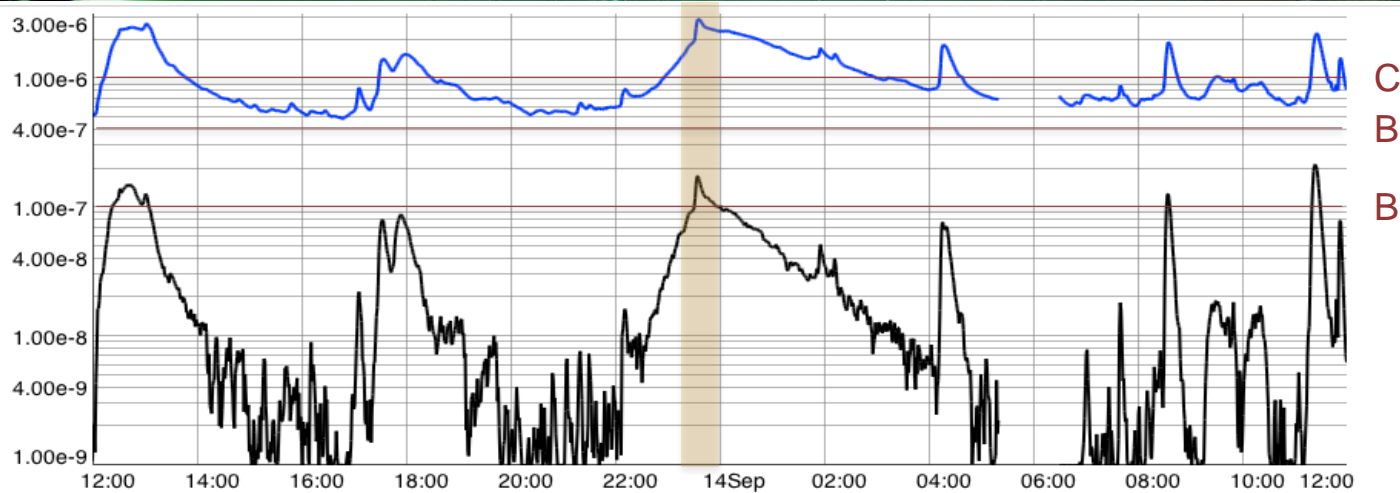
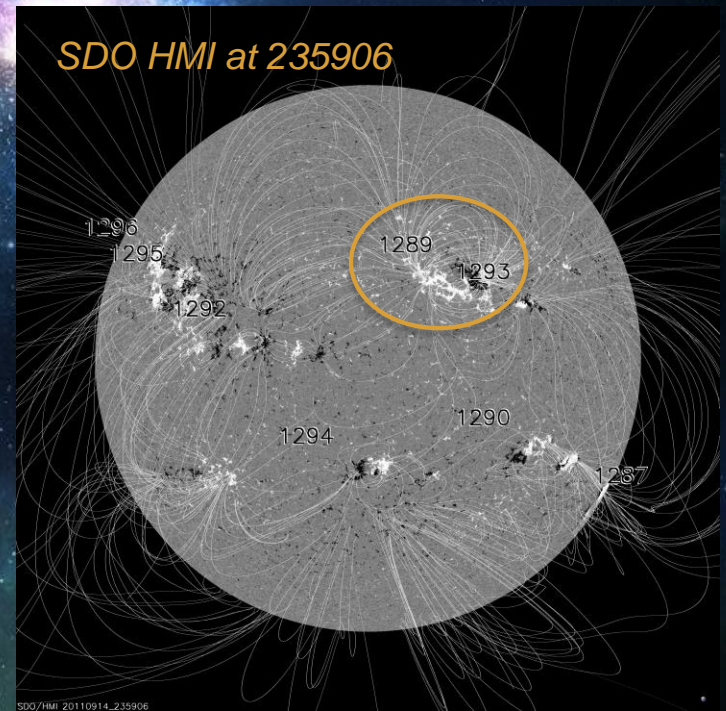
Solar Heliophysics Observatory

Tracking an Event



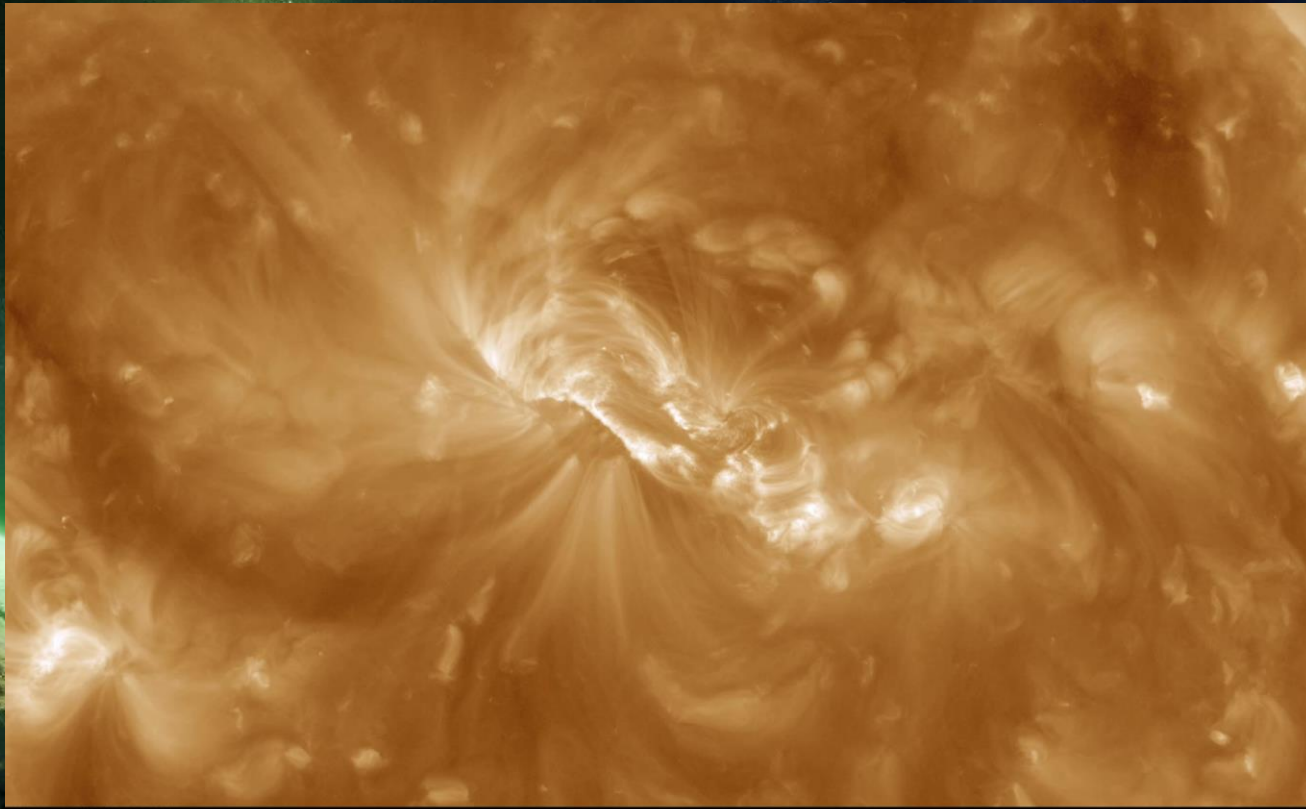
Event

- Detected by SDO AIA and HMI imagery
- Region 1289
- 9/13 23:32-23:46
- (max at 23:33)
- Potential Field Source Surface Model
- GOES spacecraft X-ray flux



SDO AIA 193 Å

2011 9/13 22:00 – 9/14 1:30



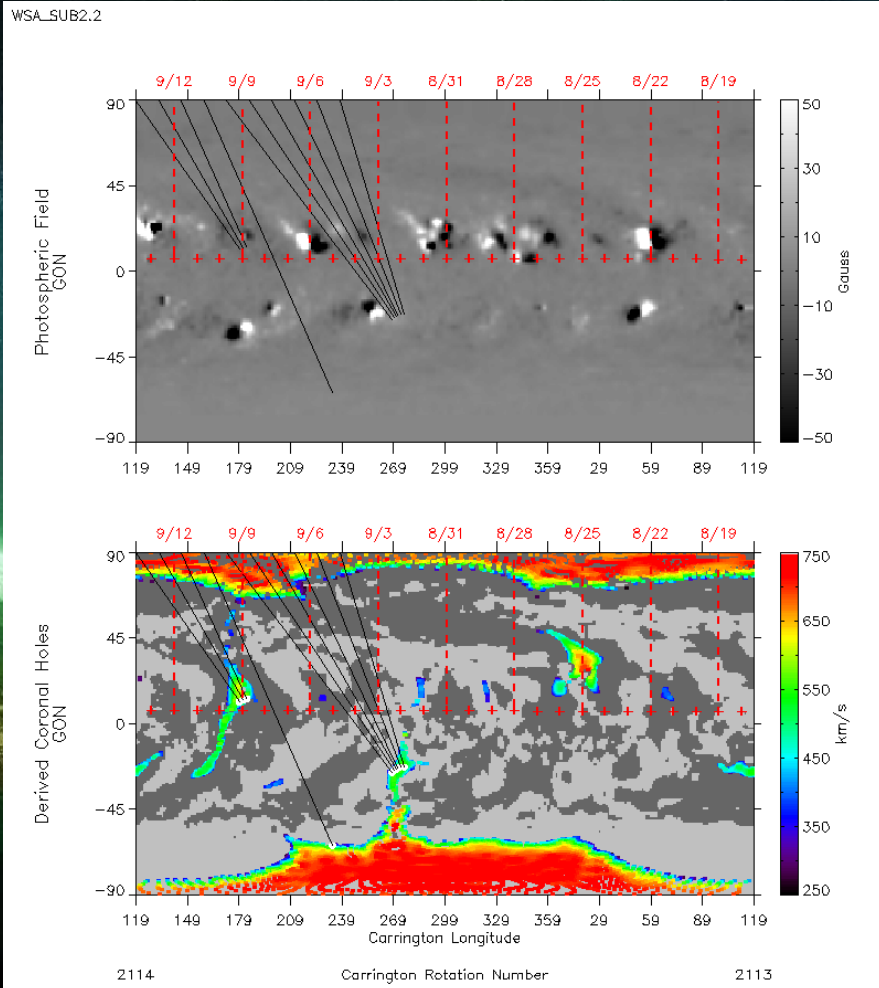
AIA 193 - 2011/09/13 - 22:00:31Z

Earth Directed Halo CME at 9/14 T000000



First detected by LASCO at 23:36

WSA-ENIL Forecast Model



Predicted Unremarkable Event

Wang-Sheeley-Arge (WSA)

- Nick Arge at Wright Patterson Air Force Base
- Semi empirical - approximates the outflow at the base of the solar wind
- Uses magnetogram data over solar rotation
- Creates synoptic map

Enlil

- D. Odstrcil at University of Colorado
- 3D MHD numerical model
- Computes ambient solar wind outflow

Storm Predictions

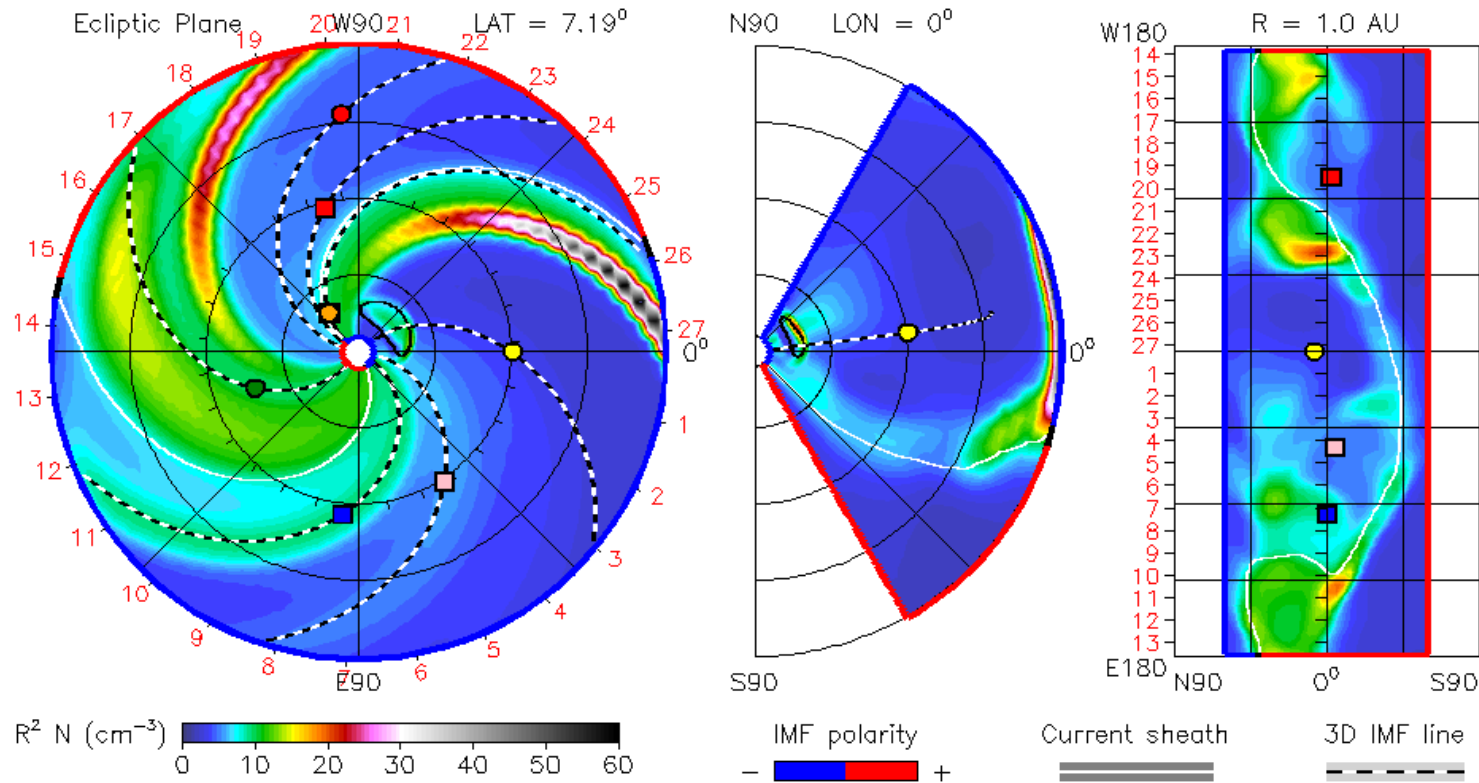
- Earth-directed CME is measured in coronagraph (speed, direction, and size)
- "cone" representation is injected into model
- basis for CME's arrival time at Earth, its intensity, and its duration

WSA-ENLIL Density Cone Model

2011-09-15T00:00

2011-09-15T00 +0.00 day

● Earth
 ● Mars
 ● Mercury
 ● Venus
 ■ Messenger
 ■ Spitzer
 ■ Stereo_A
 ■ Stereo_B



ENUL-2.7 lowres-2114-a3b1f WSA_V2.2 GONG-2114

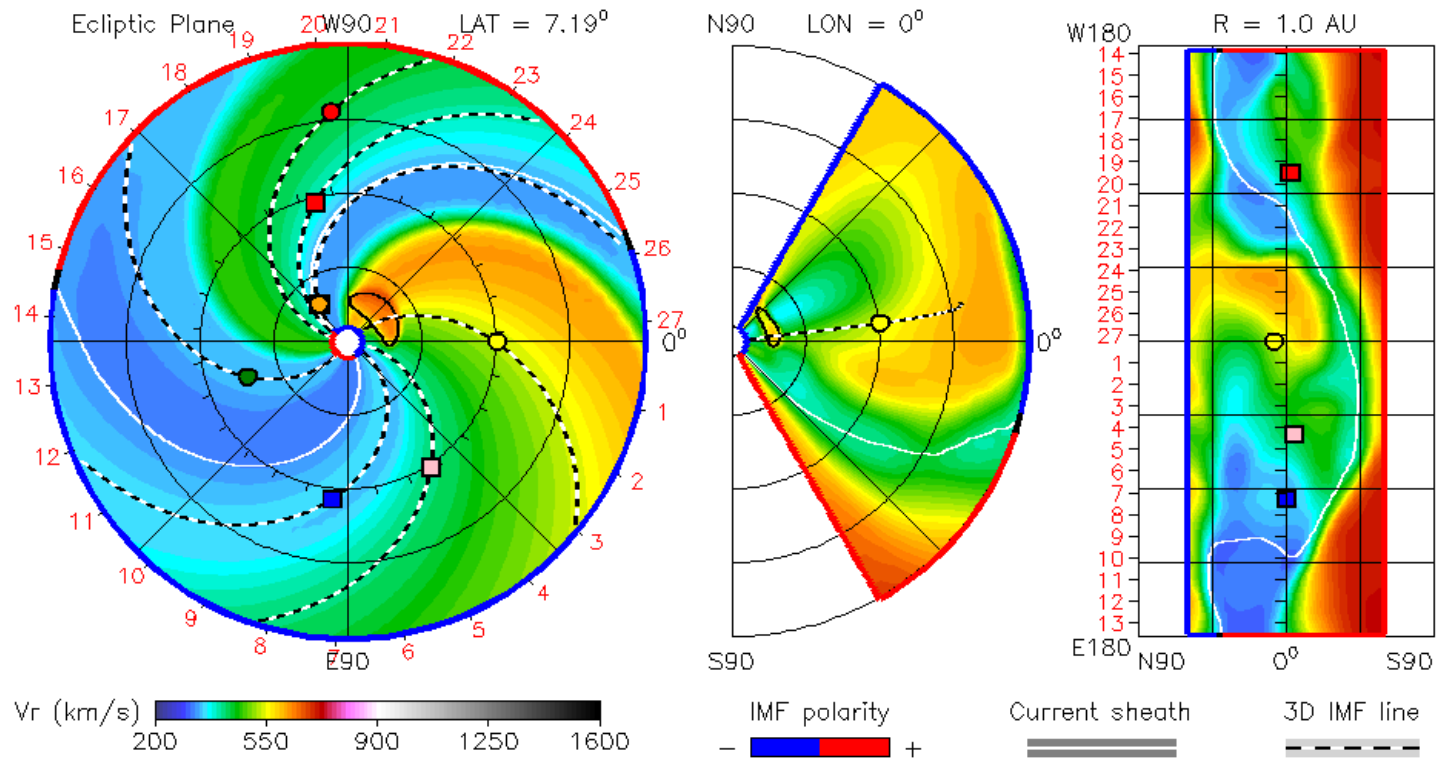
ccmc/wsafr-cd/256x30x90x1.2114-a3b1f.16-mcp1umh1ed-1a53a5d2.gong-2011-09-15T00_2011-09-15

WSA-ENLIL Velocity Cone Model

2011-09-15T00:00

2011-09-15T00 +0.00 day

● Earth
 ● Mars
 ● Mercury
 ● Venus
 ■ Messenger
 ■ Spitzer
 ■ Stereo_A
 ■ Stereo_B



ENLIL-2.7 lowres-2114-a3b1f WSA_V2.2 GONG-2114

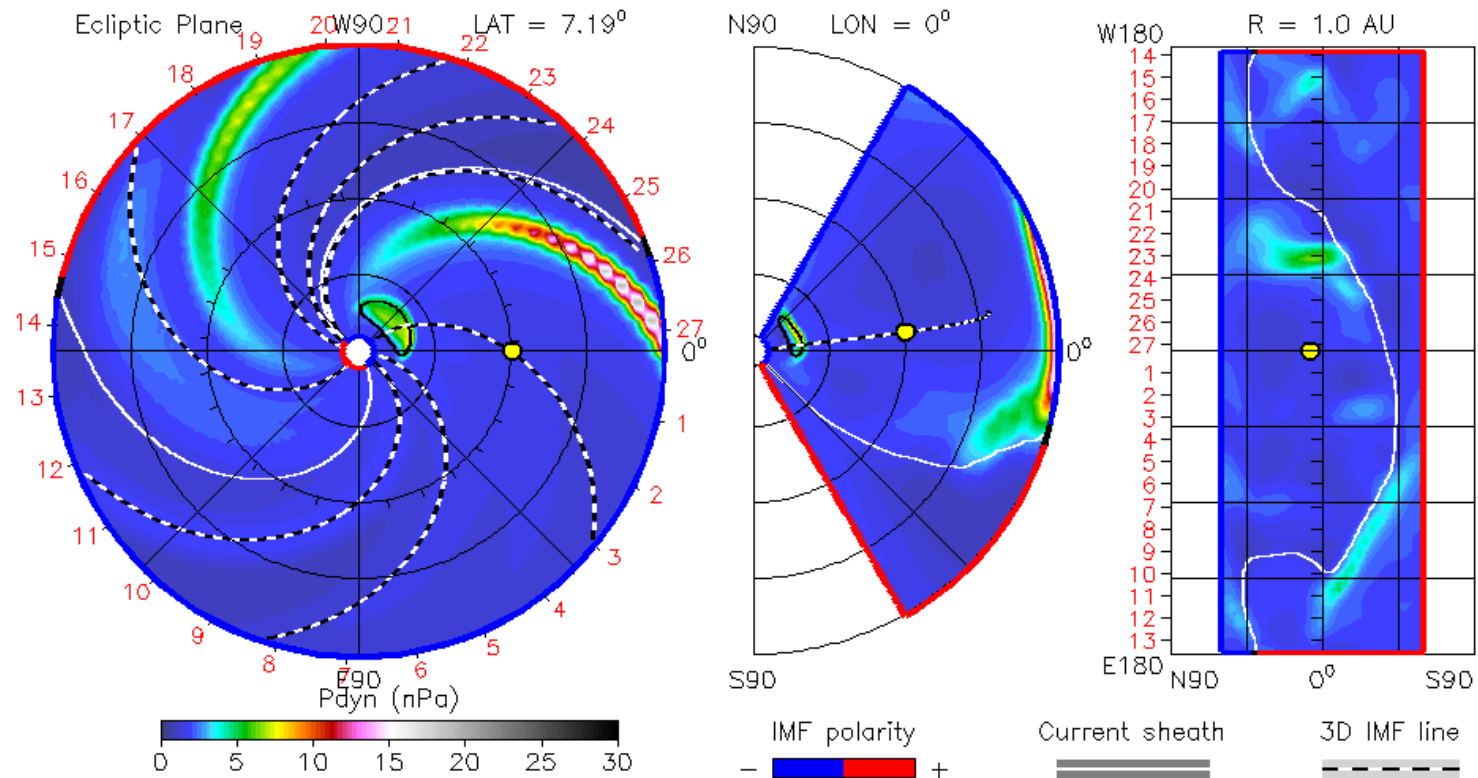
cmc/veofr-cid/258-30-90x1.2114-a3b1f-18-mcp1um1cd-1.053a502.gong-2011-09-15T00 2011-09-15

WSA-ENLIL Dynamic Pressure Cone Model

2011-09-15T00:00

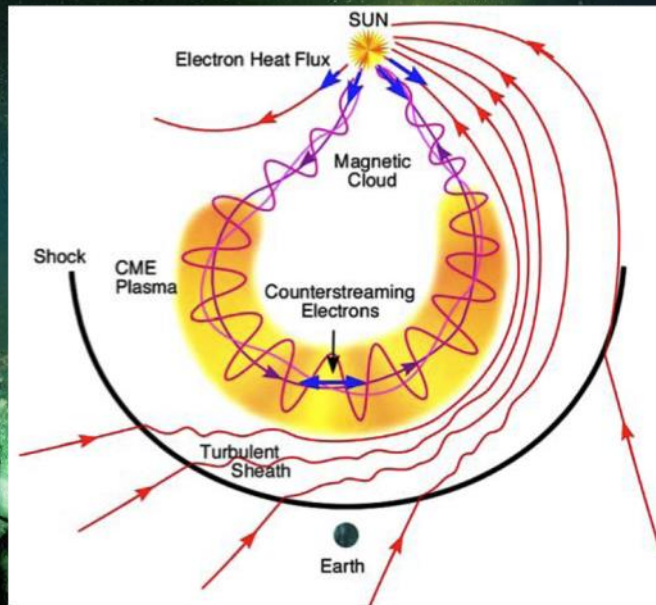
2011-09-15T00 +0.00 day

● Earth

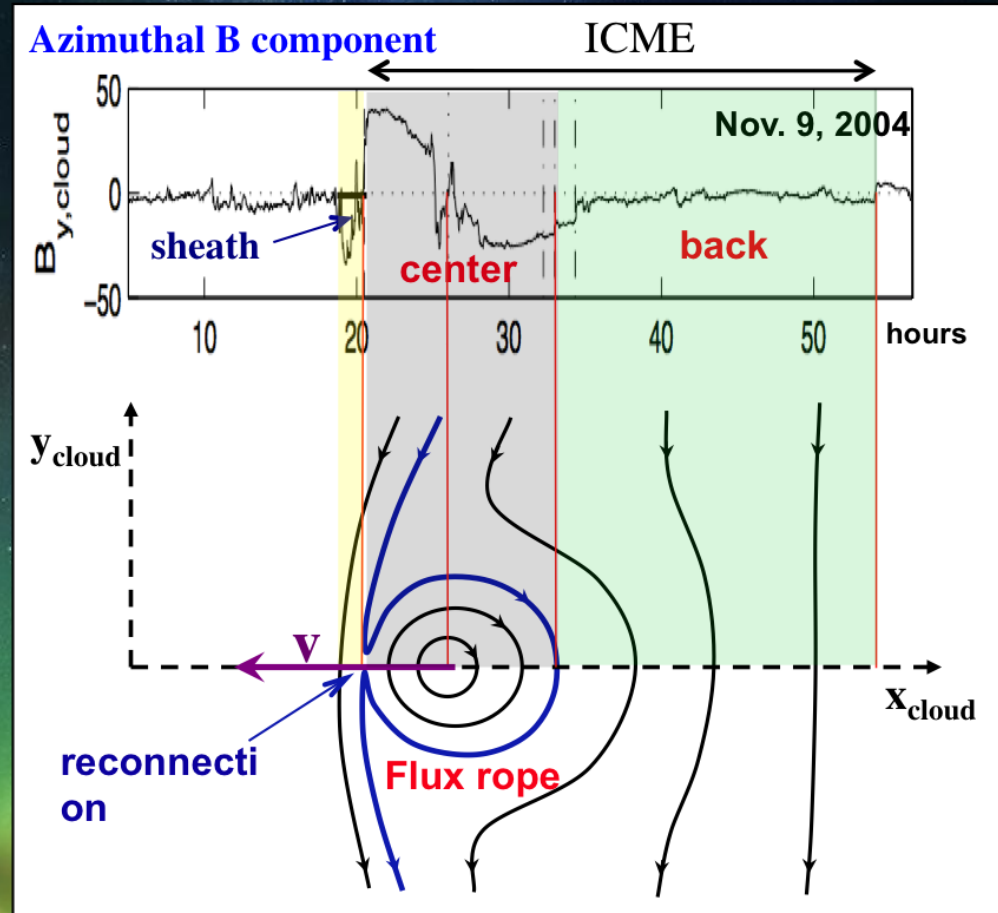


ENLIL-2.7 lowres-2114-a3b1f WSA_V2.2 GONG-2114

Evidence of Magnetic Cloud/Flux Rope?

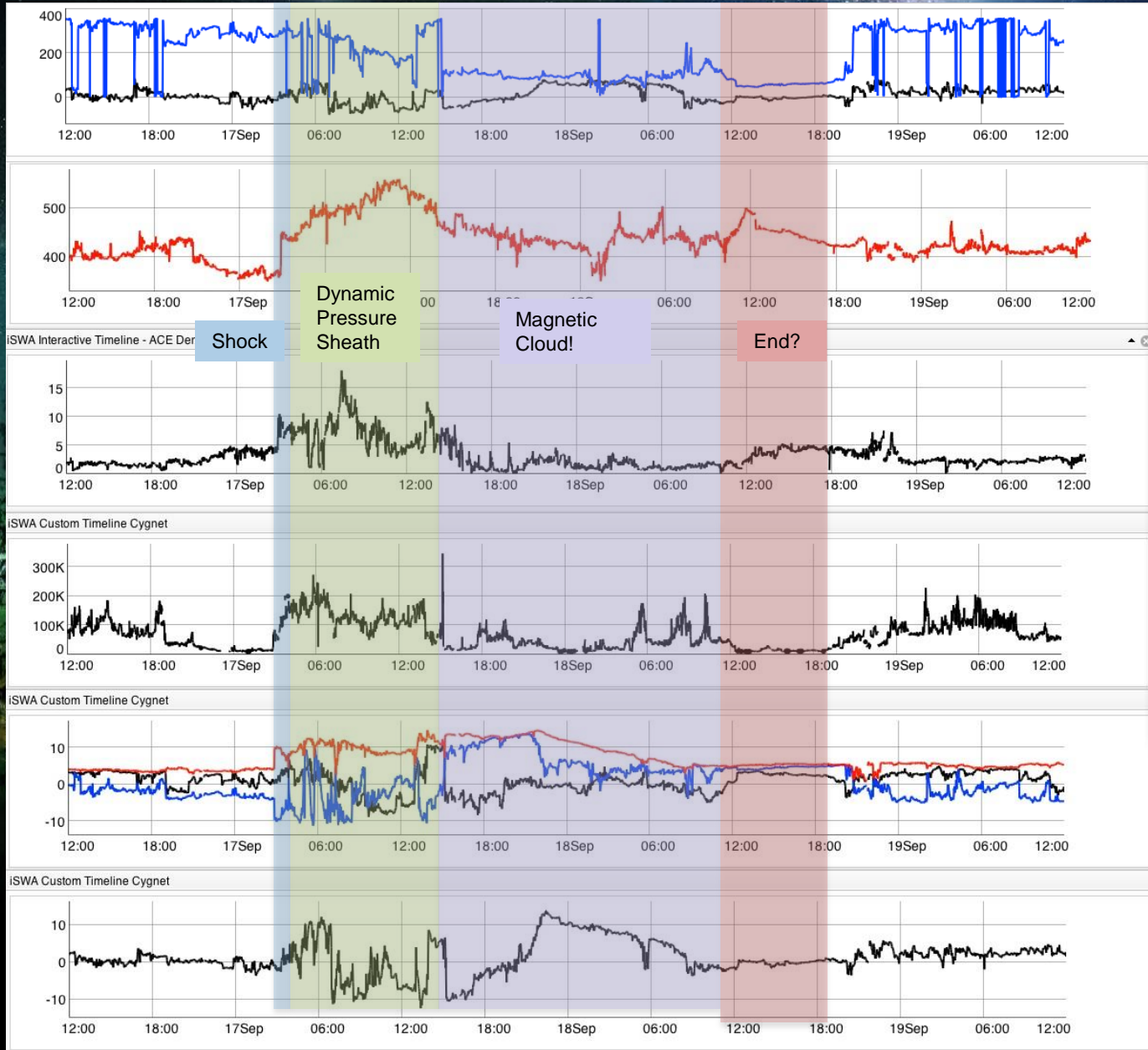


Zurbuchen & Richardson 2006



Dasso et al. 2006, 2007, Ruffenach et al. 2012

ACE Solar Wind Data Time Plot Sept 16-19th



Magnetic Field (°)
Latitude/Longitude

Velocity (km/s)

Density (N/cm³)

Temperature (K)

Magnetic Field Strength (nT)

Total B_T
Azimuthal B_y
Distance B_x

Elevation B_z

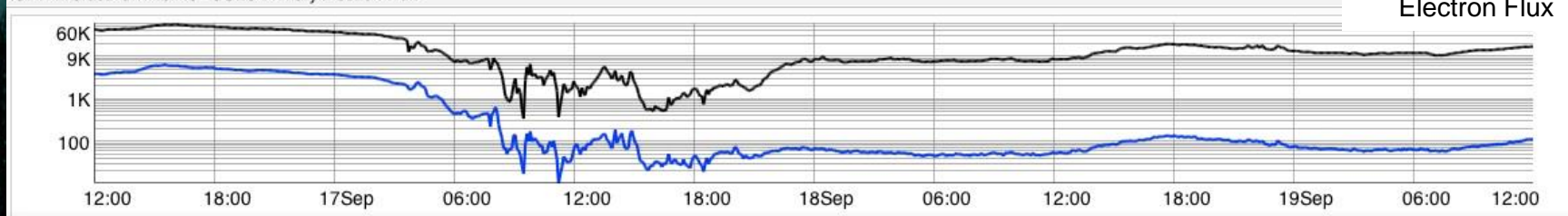
ICME Hits Magnetosphere

GOES spacecraft at geosynchronous orbit
rotate with Earth (35786 km)

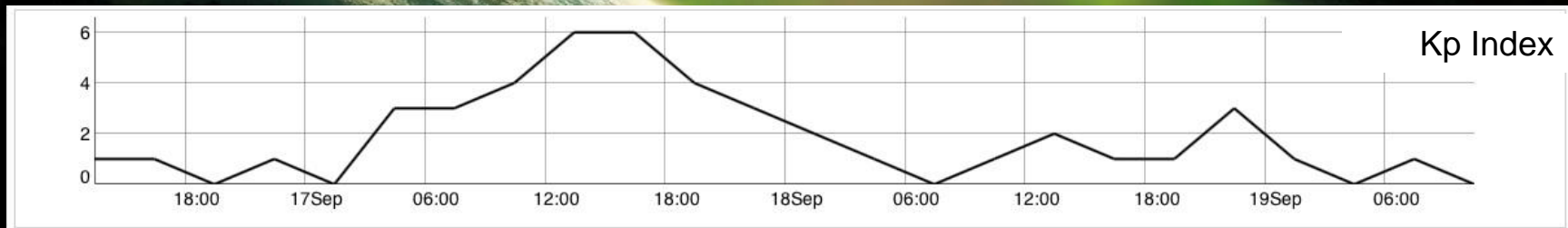
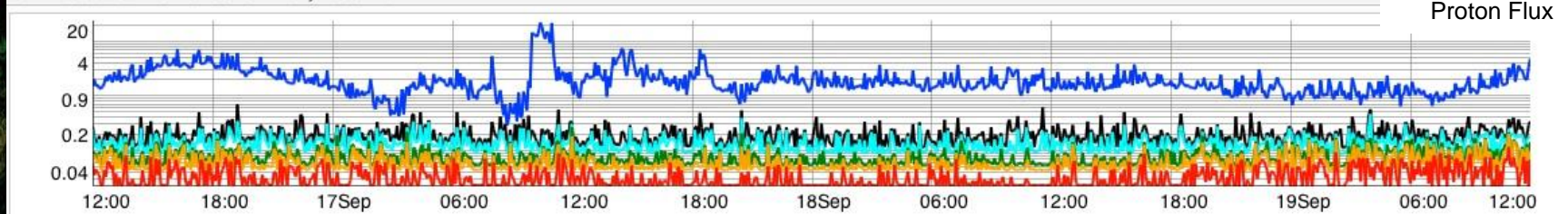
Major proton flux and electron emptying in radiation belts

Kp at high altitudes skyrocket

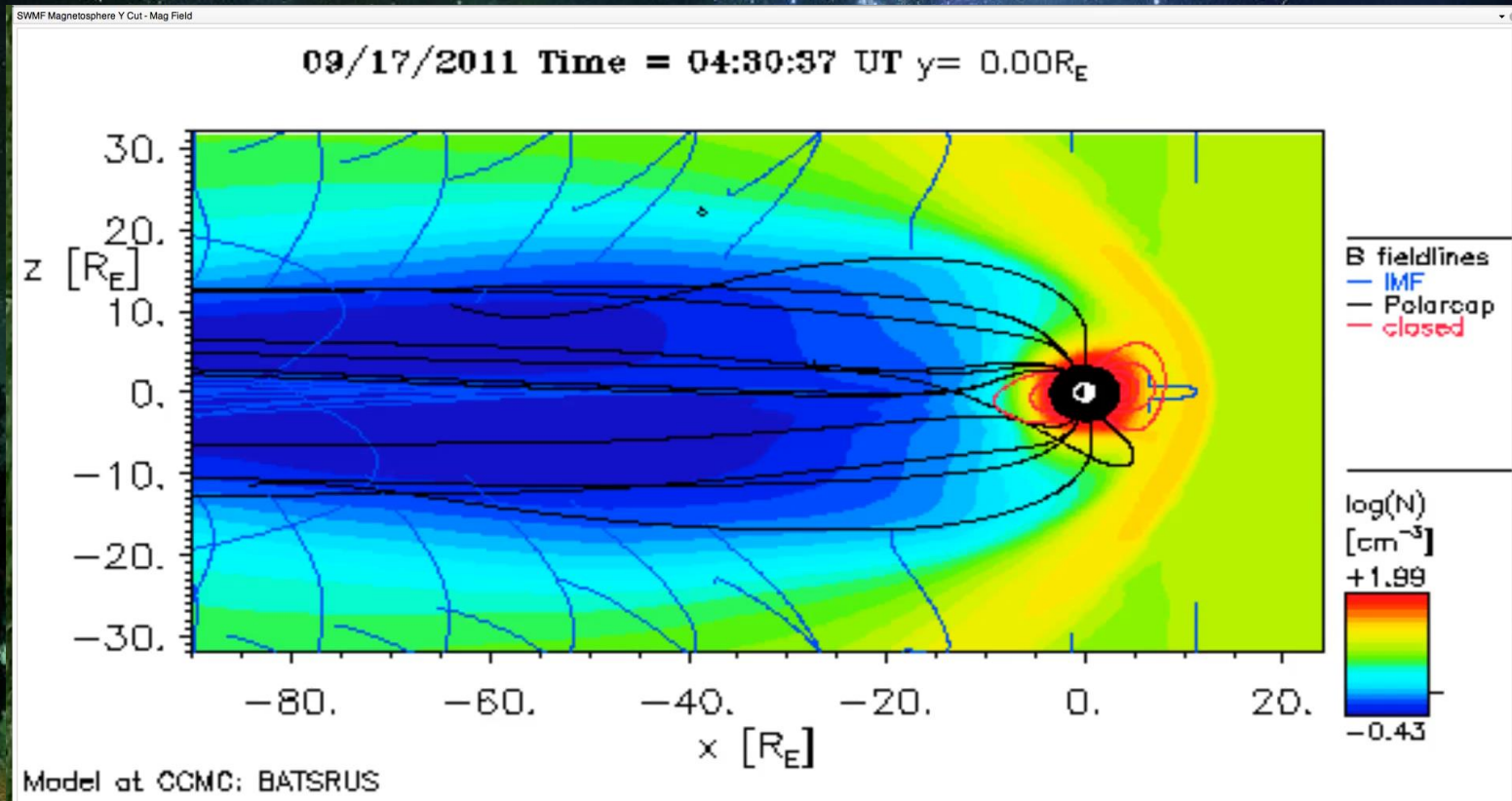
iSWA Interactive Timeline - GOES Primary Electron Flux



iSWA Interactive Timeline - GOES Primary Proton Flux

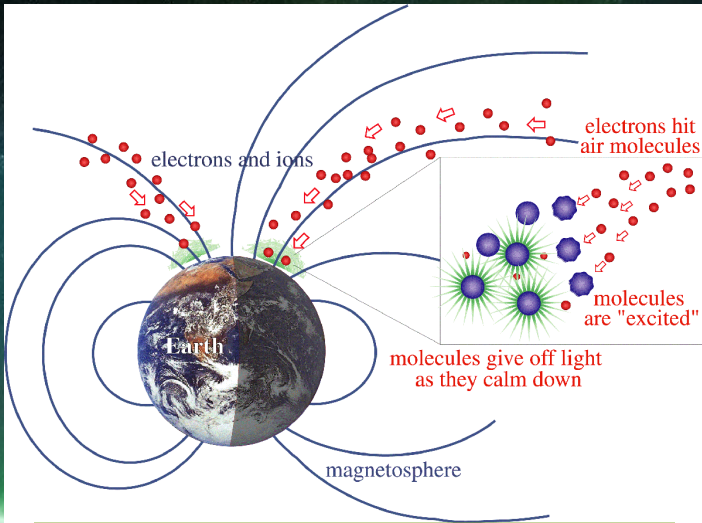


Block-Adaptive-Tree-Solar wind-Roe-Upwind-Scheme (BATS-R-US) Y-Cut SWMF Magnetosphere



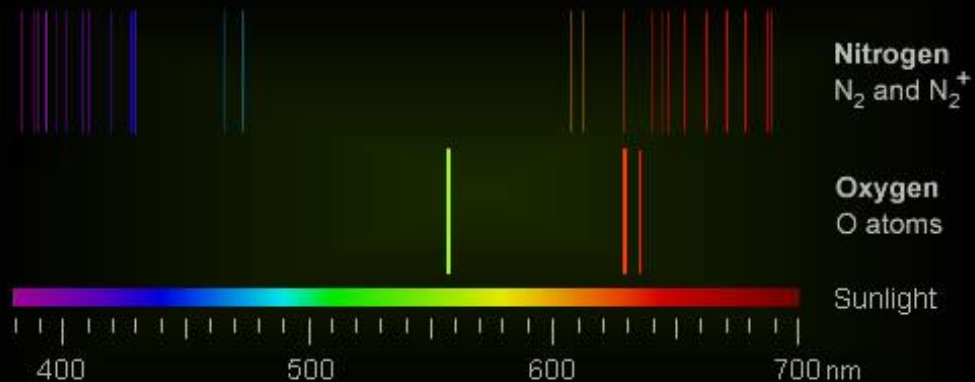
- Dr. Tamas Gombosi et al. At University of Michigan
- Models near-earth space environment (magnetosphere)
- 3D MHD Roe's Approximate Riemann Solver
- Input is solar wind plasma magnetic field measurement propagated from monitoring satellite's position
- Output is magnetospheric plasma parameters (density, pressure, velocity, magnetic field, electric currents) and ionospheric parameters
- Backbone of Space Weather Modeling Framework

Aurora



From Karen C. Fox at NASA Goddard Space Flight Center
Taken from international space station crossing over
southern Indian Ocean Sept 17th 12:22 to 12:45 ET

What Causes an Aurora? *Rachelle Oblack*



Auroral light *Atmospheric Optics*

Summary

- Comes from a variety of large scale, earth directed events
- Radiation, particles, and magnetic fields from plasma, and solar activity, affect earth's atmosphere, space environment, and technologies
- Ever increasing modeling, research, and instrumentation for monitoring solar activity, have improved our ability to predict and track solar phenomena's propagation and effects on earth



Questions?

Citations and References

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Richardson, Ian, and Hilary Cane. "Near-Earth Interplanetary Coronal Mass Ejections Since January 1996." *THE ACE SCIENCE CENTER*. N.p., 16 July 2013. Web. 31 July 2013.

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Space Weather Prediction Center, comp. *Space Weather Highlights, 12 September - 18 September 2011*. Rept. no. 1881. Boulder: Space Weather Prediction Center, 2011. Print.

Other Images

Radiation Effects *Children of the Atomic Bomb: UCLA School of Medicine*

Failed Russian Mars Probe Crashes into Pacific Ocean *Michael Carroll*

Sandy's Blackouts Pressure Utilities to Bury Power Lines *Tina Fineberg/AP Photo*

Saints of the Apocalypse *Matt Stewart*

Sci Fi – Post Apocalyptic Wallpaper *Alpha Coders*

BLT 3/2 TRAP exercise *vr033*

Space and Space Travel News *harsi*

Day space on surface effects: Photo of the damaged transformer windings *John Kappenman, Meta Tech.*

4g phones disrupting gps *webby*

Prevalent Pipeline Repair Methods and Their Drawbacks *Underground Solutions (UGSI)*

Re: Is it time to start prepping Twinkies? *majorhavoc*

Stock Photo - empty wallet - woman with no money in purse shopping. Female shopper in clothes store upset crying as she is out of money. Funny image of mixed race Caucasian / Asian woman. *ariwasabi*

Distress Signal *Jajasoon*