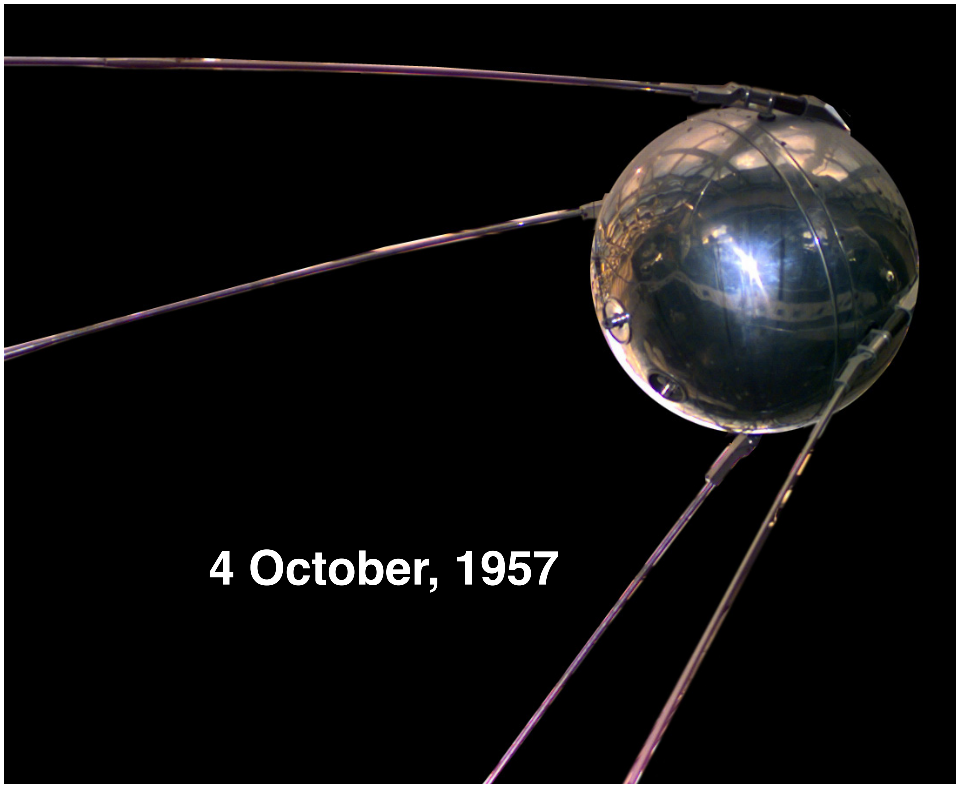
Space Weather impacts on satellites at different orbits

Outline

- ✓ Prelude
- ✓ Orbits
- ✓ Different types of SWx effects on satellites
- ✓ Satellite anomalies from the recent March 2012 SWx events

Yihua Zheng
June, 2014

1st satellite launched into space



The world's first artificial satellite, the **Sputnik 1**, was launched by the Soviet Union in 1957.

marking the start of the Space Age

International Geophysical Year: 1957

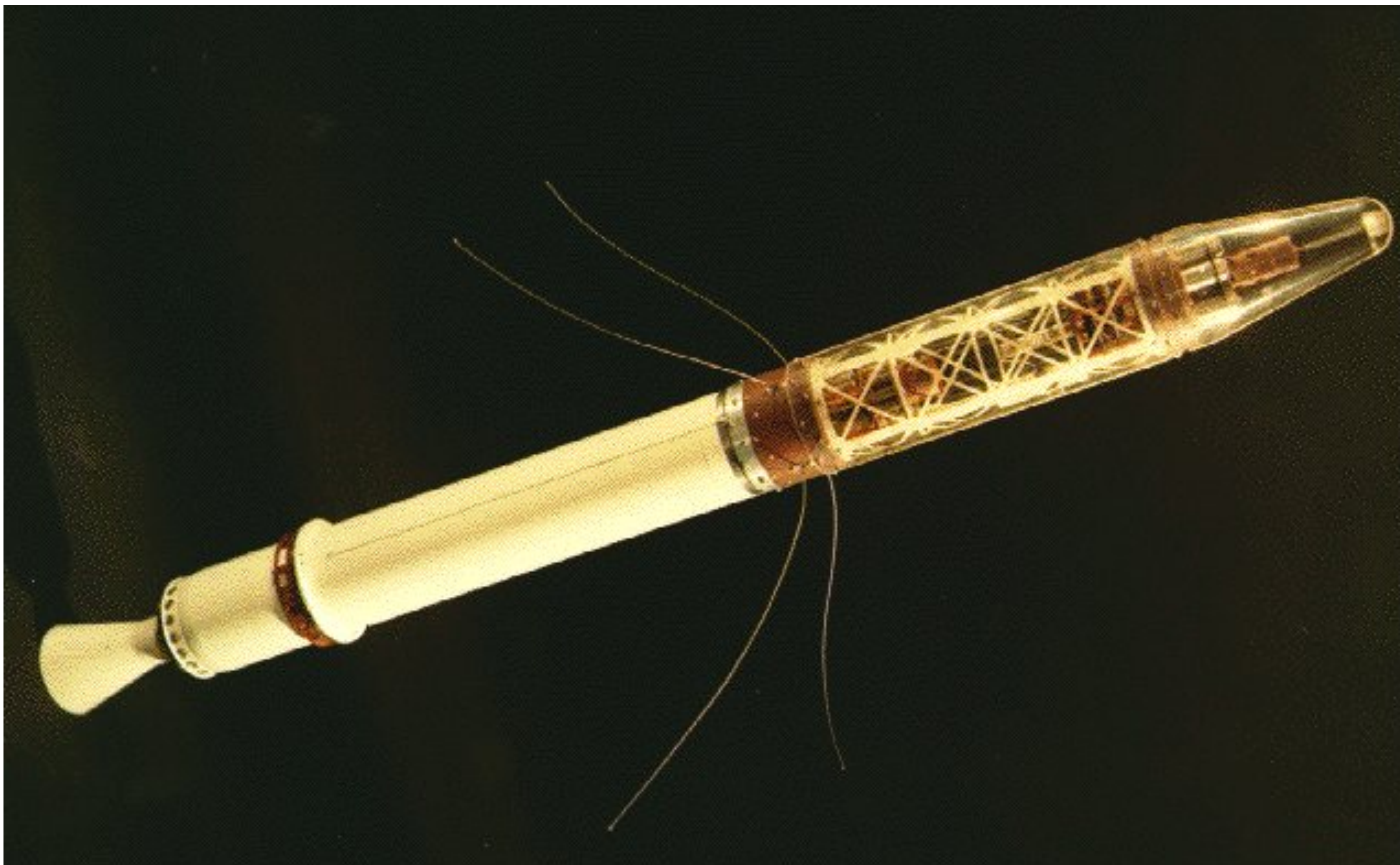
Space dog - Laika

the occupant of the Soviet spacecraft Sputnik 2 that was launched into outer space on November 3, 1957

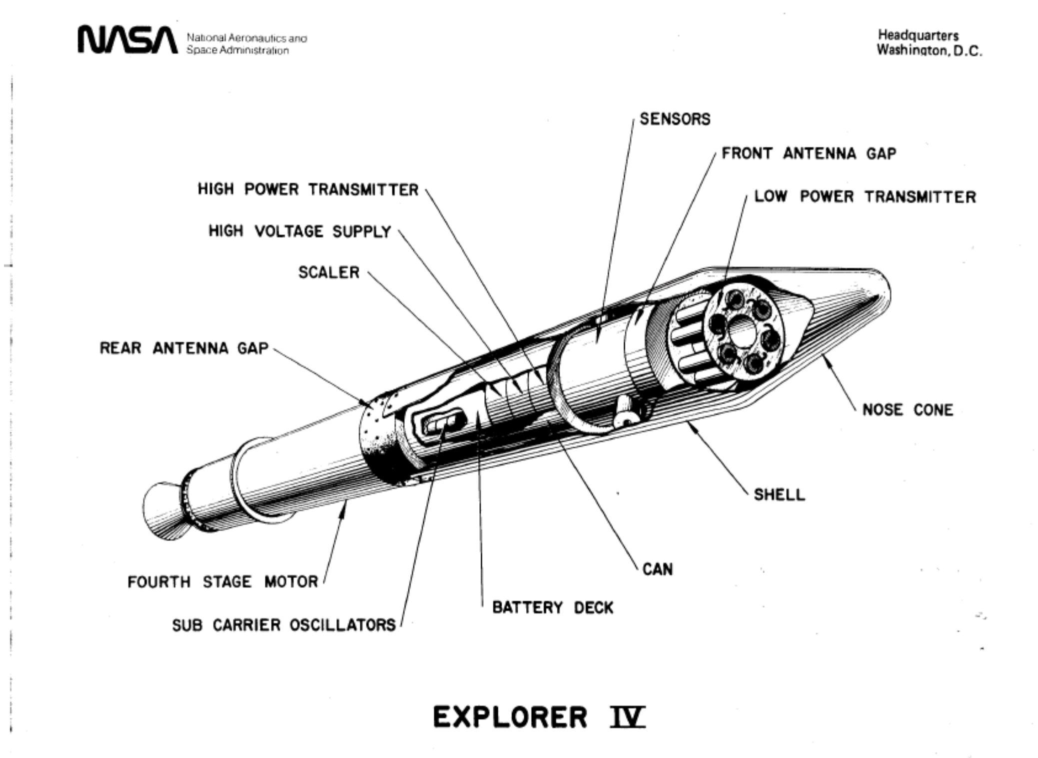
Paving the way for human missions

Explorer I – 1st U.S. Satellite

- Explorer 1, was launched into Earth's orbit on a Jupiter C missile from Cape Canaveral, Florida, on January 31, 1958

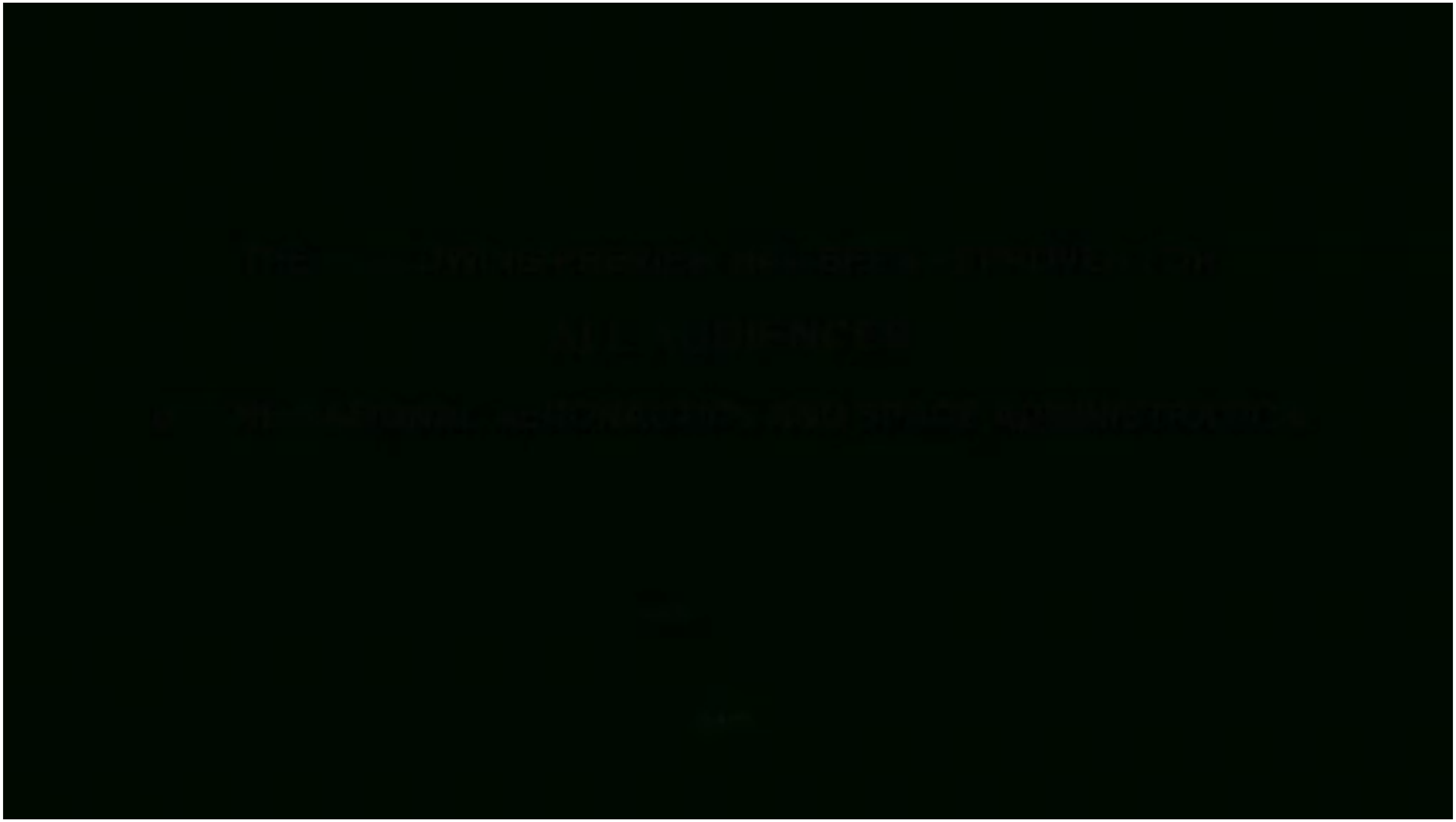


Discovery of the outer Van Allen RB

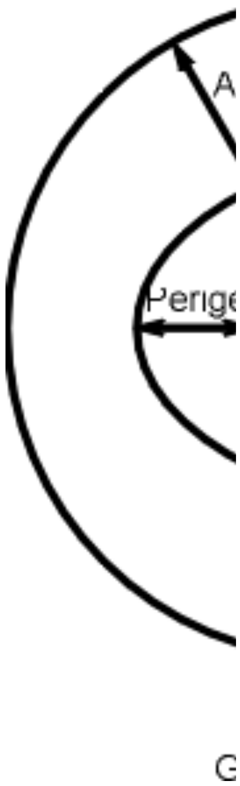


Pioneer 3 (launched 6 December 1958) and Explorer IV (launched July 26, 1958) both carried instruments designed and built by Dr. Van Allen. These spacecraft provided Van Allen additional data that led to discovery of a second radiation belt

RBSP – more than half-century later

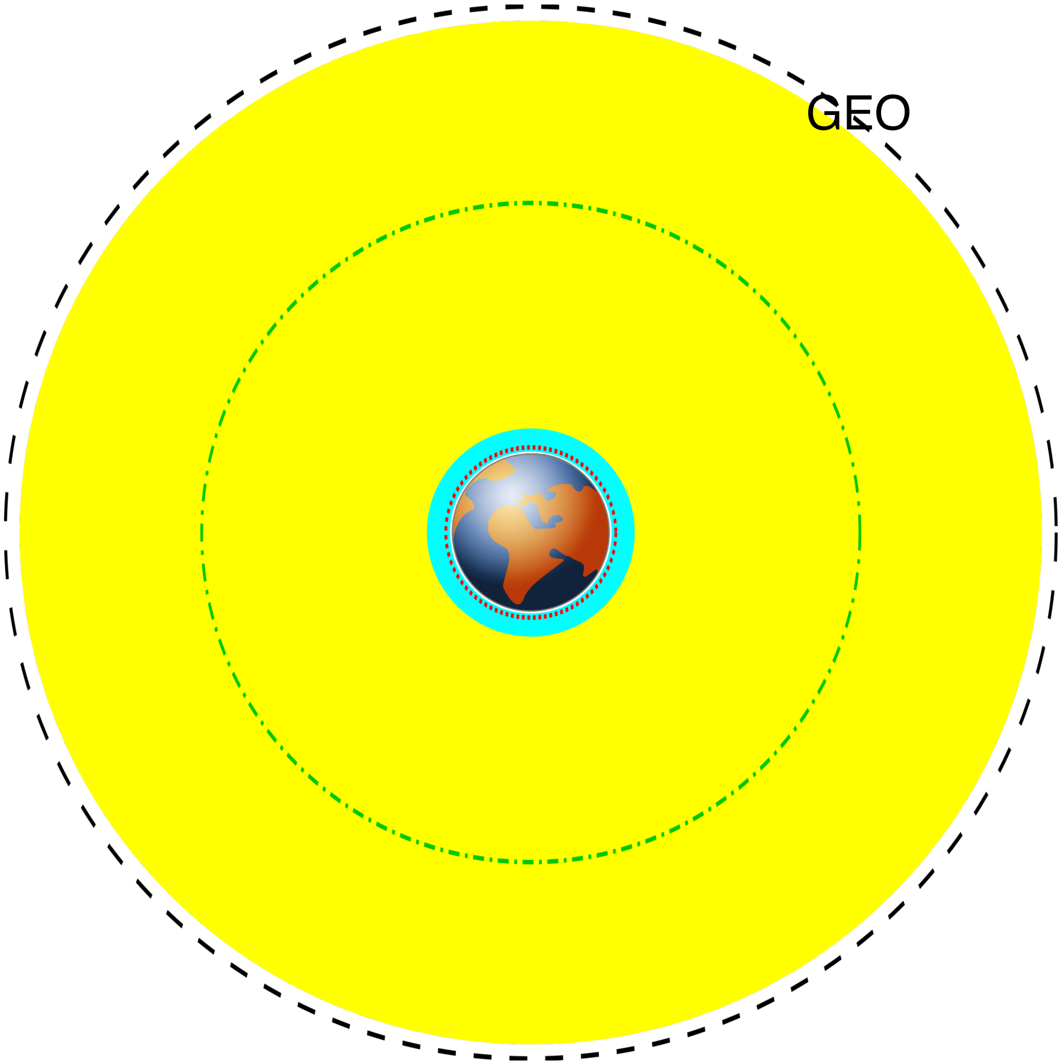


Orbits



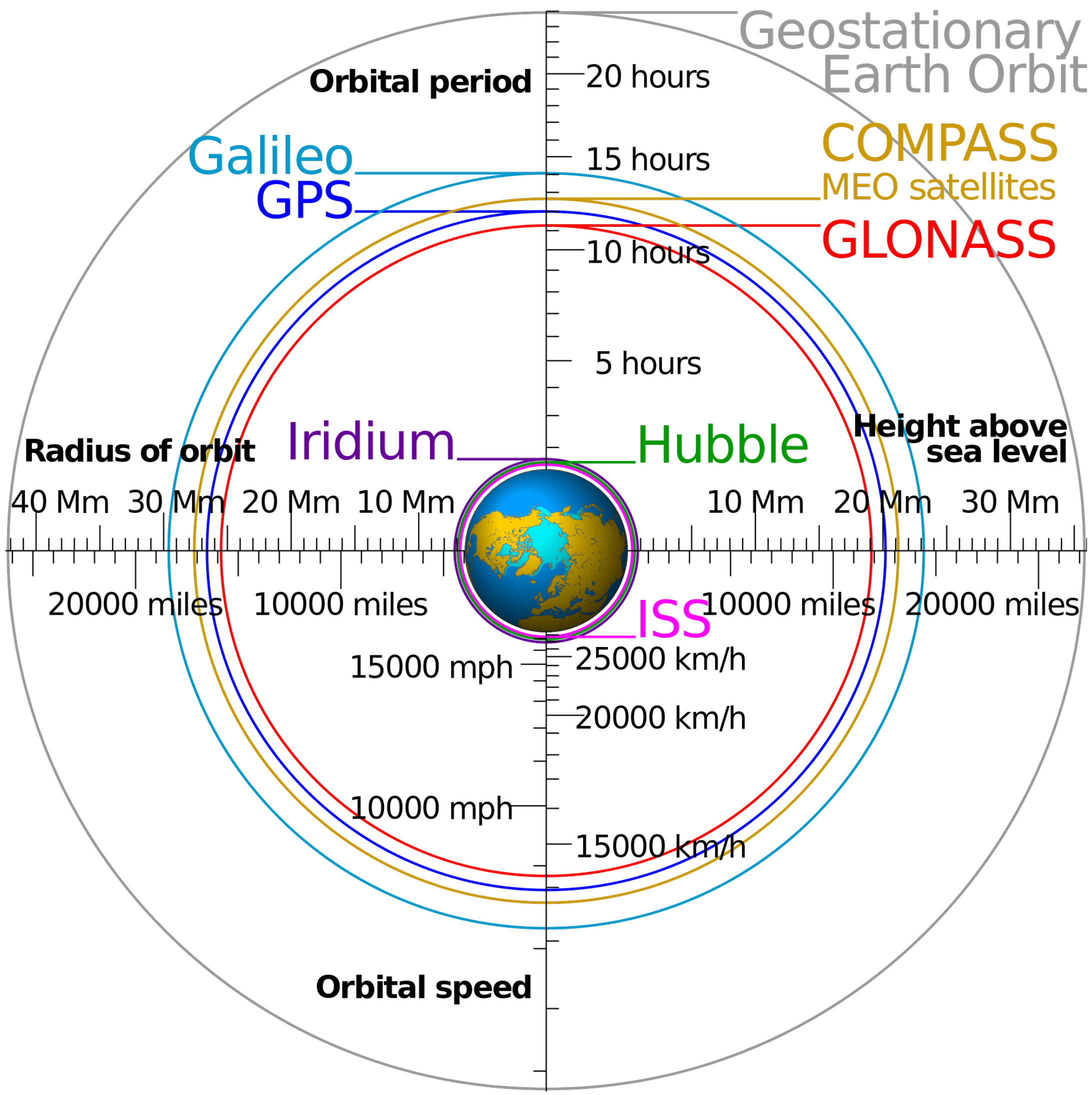
ORBIT NAME	ORBIT INITIALS	ORBIT ALTITUDE (KM ABOVE EARTH'S SURFACE)	DETAILS / COMMENTS
Low Earth Orbit	LEO	200 – 1200	
Medium Earth Orbit	MEO	1200 – 35790	
Geosynchronous Orbit	GSO	35790	Orbits once a day, but not necessarily in the same direction as the rotation of the Earth – not necessarily stationary
Geostationary Orbit	GEO	35790	Orbits once a day and moves in the same direction as the Earth and therefore appears stationary above the same point on the Earth's surface. Can only be above the Equator.
High Earth Orbit	HEO	Above 35790	

orbits



Yellow: MEO
Green-dash-dotted line: GPS
Cyan: LEO
Red dotted line: ISS

orbits


Geostationary
Earth Orbit
Orbital period
20 hours
15 hours
10 hours
5 hours
Galileo
GPS
COMPASS
MEO satellites
GLONASS
Iridium
Hubble
Radius of orbit
Height above
sea level
40 Mm
30 Mm
20 Mm
10 Mm
10 Mm
20 Mm
30 Mm
20000 miles
10000 miles
ISS
10000 miles
20000 miles
15000 mph
25000 km/h
20000 km/h
10000 mph
15000 km/h
Orbital speed

Orbits

- A **low Earth orbit** (**LEO**) is generally defined as an orbit below an altitude of 2,000 km. Given the rapid orbital decay of objects below approximately 200 km, the commonly accepted definition for LEO is between 160–2,000 km (100–1,240 miles) above the Earth's surface.
- **Medium Earth orbit (MEO)**, sometimes called **intermediate circular orbit (ICO)**, is the region of space around the Earth above low Earth orbit (altitude of 2,000 kilometres (1,243 mi)) and below geostationary orbit (altitude of 35,786 km (22,236 mi)).

Orbit classification based on inclination

- **Inclined orbit**: An orbit whose inclination in reference to the equatorial plane is not zero degrees.
  - **Polar orbit**: An orbit that passes above or nearly above both poles of the planet on each revolution. Therefore it has an inclination of (or very close to) 90 degrees.
  - **Polar sun synchronous orbit**: A nearly polar orbit that passes the equator at the same local time on every pass. Useful for image taking satellites because shadows will be nearly the same on every pass.

DMSP satellites

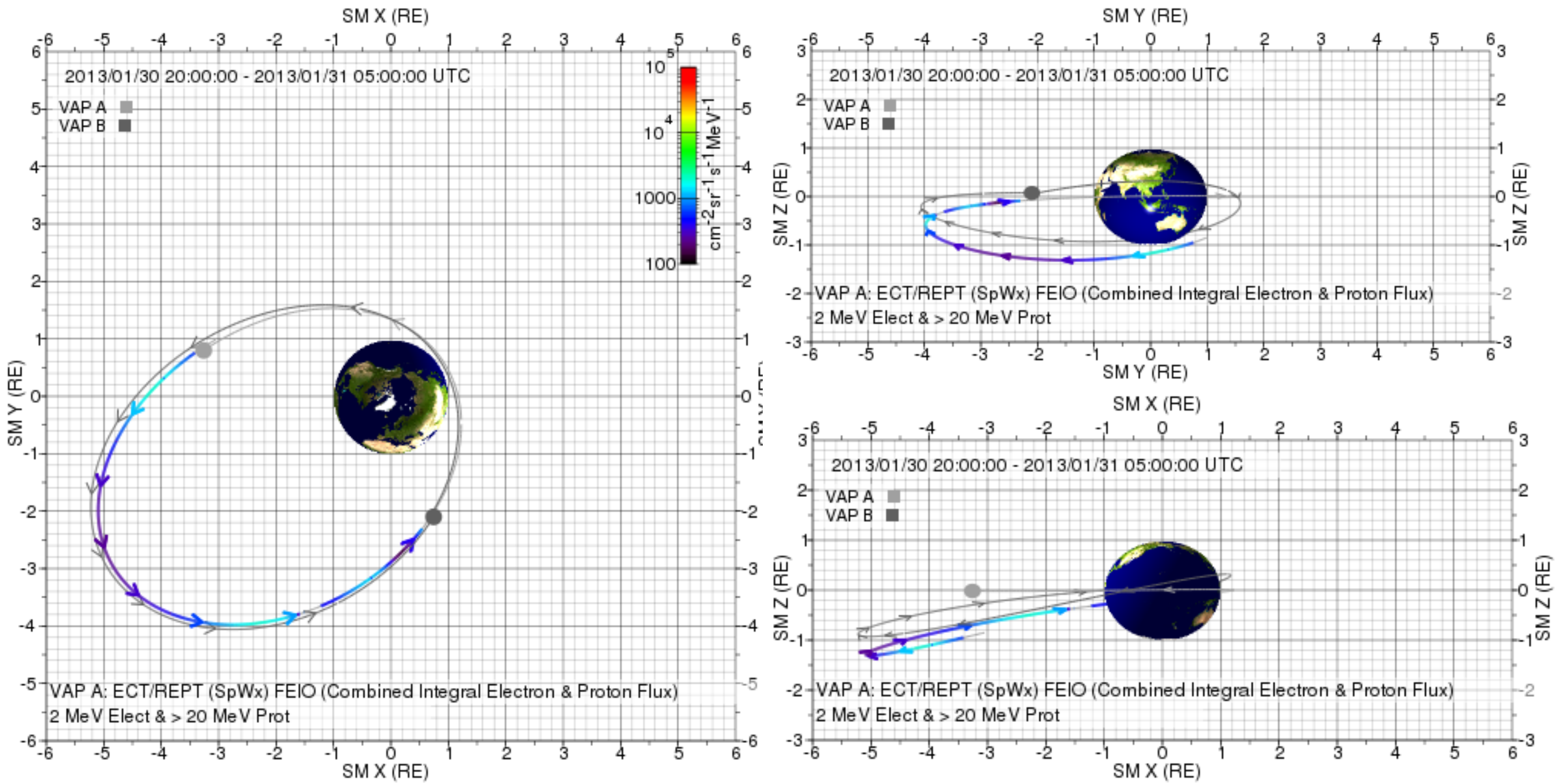
GTO

- A **geosynchronous transfer orbit** or **geostationary transfer orbit** (**GTO**) is a Hohmann transfer orbit used to reach geosynchronous or geostationary orbit.[1] It is a highly elliptical Earth orbit with apogee of 42,164 km (26,199 mi).[2] (geostationary (GEO) altitude, 35,786 km (22,000 mi) above sea level) and an argument of perigee such that apogee occurs on or near the equator. Perigee can be anywhere above the atmosphere, but is usually limited to only a few hundred km above the Earth's surface to reduce launcher delta-v (V) requirements and to limit the orbital lifetime of the spent booster.

SDO

The rapid cadence and continuous coverage required for SDO observations led to placing the satellite into an inclined geosynchronous orbit

Van Allen Probes



Other types of orbits

Heliocentric orbit: An orbit around the Sun.

STEREO A and STEREO B

Interplanetary space

At different planets

Orbit/Mission Design

- New Horizon to Pluto

http://www.jhu.edu/jhumag/1105web/pluto.html

Dr. Yanping Guo, a mission design specialist at APL

Reduce the journey by three years

Space Weather impacts on spacecraft operation

Yihua Zheng
NASA/GSFC Space Weather Center

For Earth System Science Pathfinder (ESSP) Program Office
May 15, 2012

Importance of SWx Services

RE: Staff Meeting Info — 2012_may

Delete | Junk | Reply | Reply All | Forward | Print | To Do

From: Regan, Curtis R. (LARC-D2) <curtis.r.regan@nasa.gov>
Subject: **RE: Staff Meeting Info**
Date: May 18, 2012 11:49:15 AM EDT
To: Yihua Zheng

Yihua,

Thank you for giving us a very informative presentation on how space weather can affect satellites. You helped explain some anomalies that I had seen before but did not fully understand the cause. I heard that a M5.1 solar flare occurred Weds. night and that we had to turn CALIPSO off again. We have a kickoff meeting today for the HEREOS project. MSFC will be flying their x-ray instrument to monitor the sun. That project now has more relevance to me after hearing your presentations. Please add me to the space weather mailing list.

Thanks,
Randy

Randy Regan
NASA LaRC
Earth System Science Pathfinder (ESSP) Program Office
Chief Engineer/Technical Authority
M/S 145, Org. Code: A5
B1195A, R161
Hampton, VA 23681-2199
(757) 864-1869
(757) 504-8506 cell#
Curtis.R.Regan@NASA.Gov
Building 1195A, Room 168.

Space Environment Model Use in Mission Life Cycle

Mission Concept

Mission Planning

Design

Launch

Operations

Anomaly Resolution

Space Climate
Minimize Risk

Space Weather
Manage Residual Risk

Both

+ in situ measurements

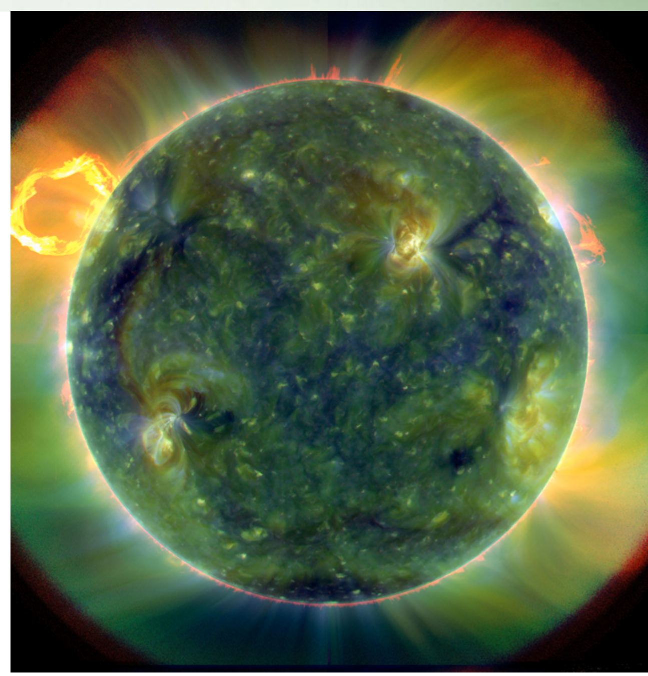
NASA SWx services

Acknowledge: Mike Xapsos

SWx Services provided by NASA/ SWC

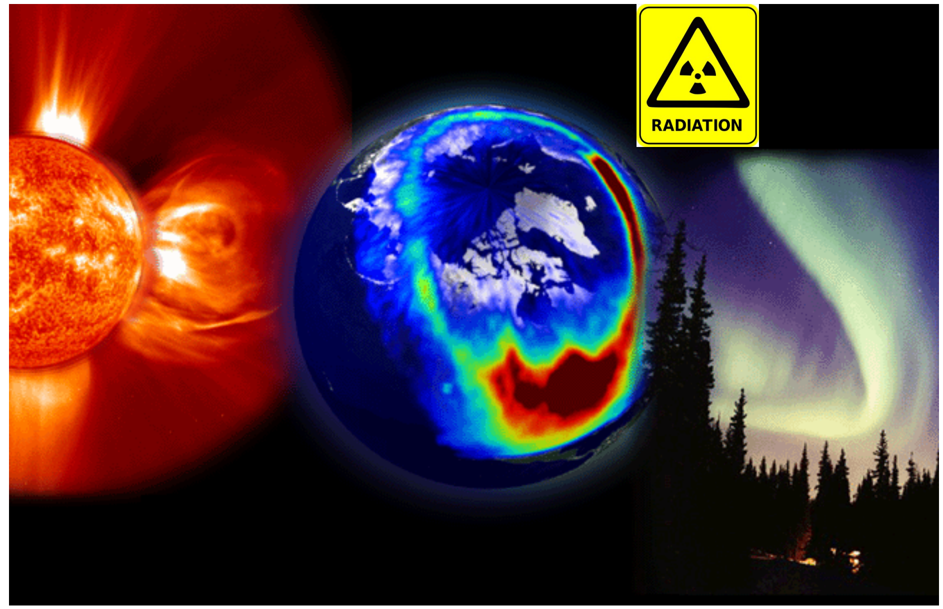
NASA SWC: Types of SWx Services

1. Providing assistance in spacecraft anomaly resolution by assessing whether space weather has any role in causing the observed anomaly/ anomalies.
2. Sending out weekly space weather reports/ summaries to NASA mission operators, NASA officials and involved personnel.



Types of SWx Services
- continued

3. Sending out timely space weather alerts/ forecasts regarding adverse conditions throughout the solar system, such as significant CME events, elevated radiation levels, etc.



4. Providing general space weather support for NASA customers.

Seven types SWx impacts for robotic missions

1. **Spacecraft surface charging caused by low-energy (< 100 keV)** electrons, which are abundant, for example, in the inner magnetosphere during magnetospheric substorms.
2. **Spacecraft internal electrostatic discharge caused by high-energy** electrons (> 100 keV) that exist, for example, in the dynamic outer radiation belt of the Earth.
3. **Single event effects due to high-energy (> 10 MeV) protons and heavier** ions generated, for example, in solar flares and in coronal mass ejection (CME) shock fronts.
4. **Total dosage effects caused by cumulative charged particle radiation** received by spacecraft.
5. **Increased spacecraft drag caused by the thermal expansion of the** Earth's upper atmosphere during space weather storms.
6. **Communication disruptions between ground stations and spacecraft due** to ionospheric irregularities
7. **Attitude control disruptions caused, for example, by large storm-time** magnetic field fluctuations in the geostationary orbit.

Feedback from our annual SWx workshop for robotic missions

SWx impacts on sc (cont'd)

- low-energy protons (< 10 MeV) pose a problem due to trapping into charge-coupled device (CCD) substrates.

➔ virtually any part of electron and ion spectra ranging from low to relativistic energies can impact spacecraft operations.

Space Environment Anomalies

- According to a study by the Aerospace Corporation the 2 most common types of spacecraft anomalies by far are due to electrostatic discharge (ESD) and single event effects (SEE)
- Reported results*:

Anomaly Type:	Number of Occurrences:
ESD	162
SEE	85
Total Dose and Damage	16
Miscellaneous	36

* H.C. Koons et al., 6th Spacecraft Technology Conference, AFRL-VS-TR-20001578, Sept. 2000

Surface Charging

surface charging: which can lead to electrostatic discharges (ESD),

ESD: can lead to a variety of problems,
including component failure and phantom commands in spacecraft electronics [Purvis et al., 1984].

Purvis, C. K., H. B. Garrett, A. C. Wittlesey, and N. J. Stevens (1984), Design guidelines for assessing and controlling spacecraft charging effects, NASA Tech. Pap. 2361

https://standards.nasa.gov/documents/detail/3314877

Surface Charging (SC)

Commercial satellite anomaly

Substorm injections (Aurora)

More often in the midnight to morning sector

<100 keV e- distribution: similar behavior as SC anomalies

=> Surface charging might be the main cause of the anomalies.

Choi, H.-S., J. Lee, K.-S. Cho, Y.-S. Kwak, I.-H. Cho, Y.-D. Park, Y.-H. Kim, D. N. Baker, G. D. Reeves, and D.-K. Lee (2011), Analysis of GEO spacecraft anomalies: Space weather relationships, Space Weather, 9, S06001,doi:10.1029/2010SW000597.

Surface Charging Hazards distribution

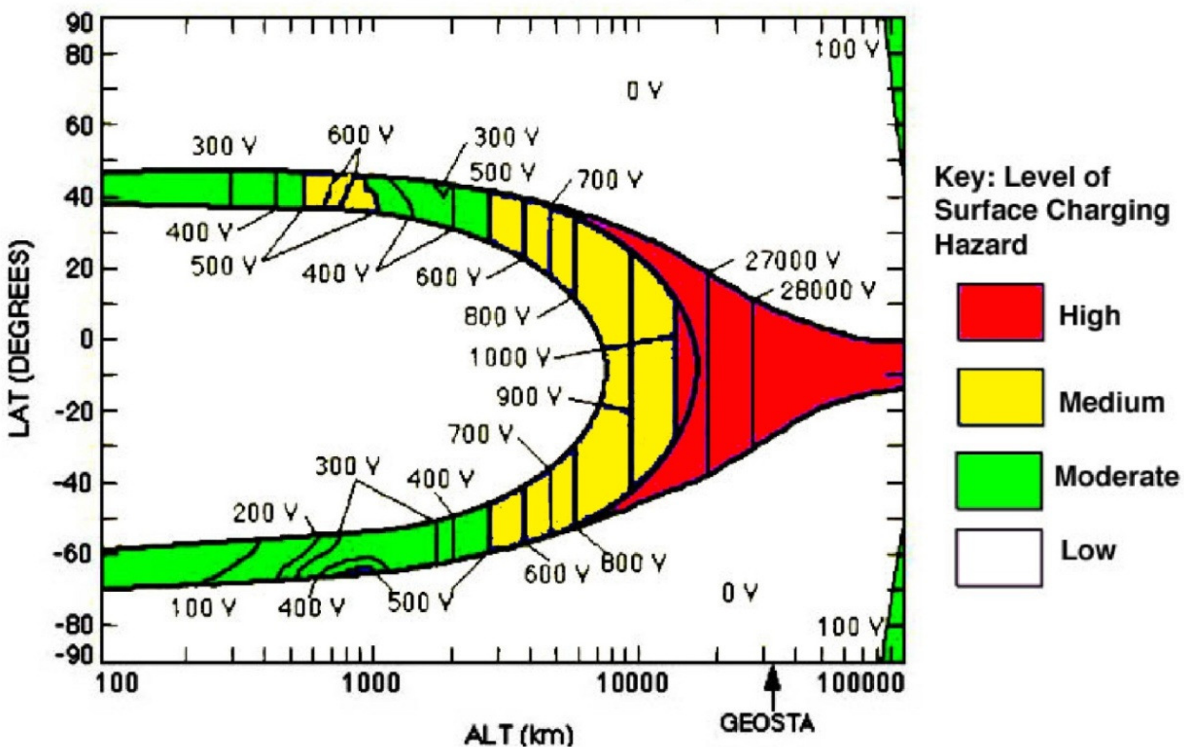


Figure 1—Earth Regimes of Concern for On-Orbit Surface Charging Hazards for Spacecraft Passing Through Indicated Latitude and Altitude (Evans and others (1989))

Title: Mitigating In-Space Charging Effects-A Guideline

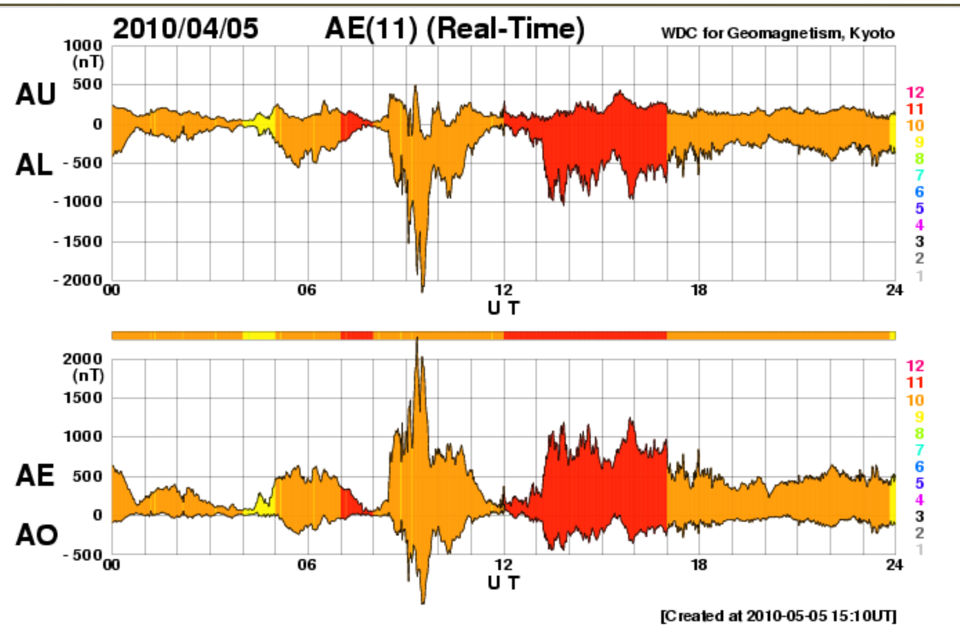
Document Date: 2011-03-03

Revalid and Reaffirmed Date: 2016-03-03

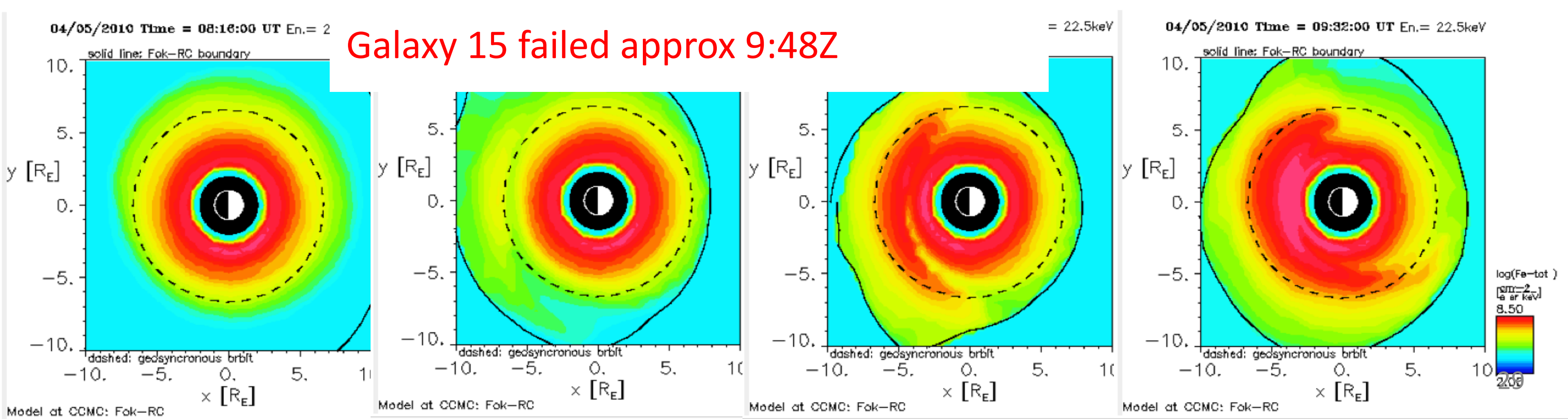
Revision: A

Organization: NASA

Galaxy 15 failure on April 5, 2010
- surface charging might play a role



22keV electrons 4/5, 8:16-9:32Z



Galaxy 15 failed approx 9:48Z

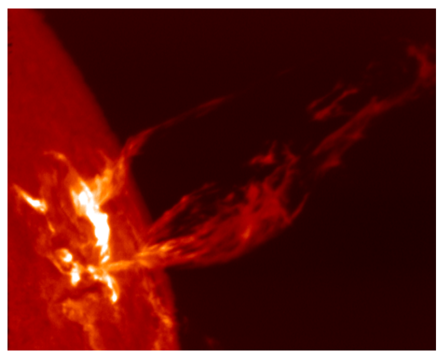
Environmental Source of SEEs

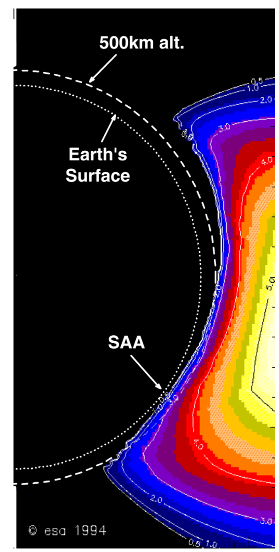
- Single Event Environments in Space
  - Galactic Cosmic Rays
  - Solar Particle Events (flare/CME)
  - Trapped Protons in the inner belt (1 – 3 RE)

SEE source in Space

High Energy Particle Radiation

- Galactic Cosmic Rays
- Solar Particle Events (flare/CME)
- Trapped Particles (SAA)





Most unpredictable

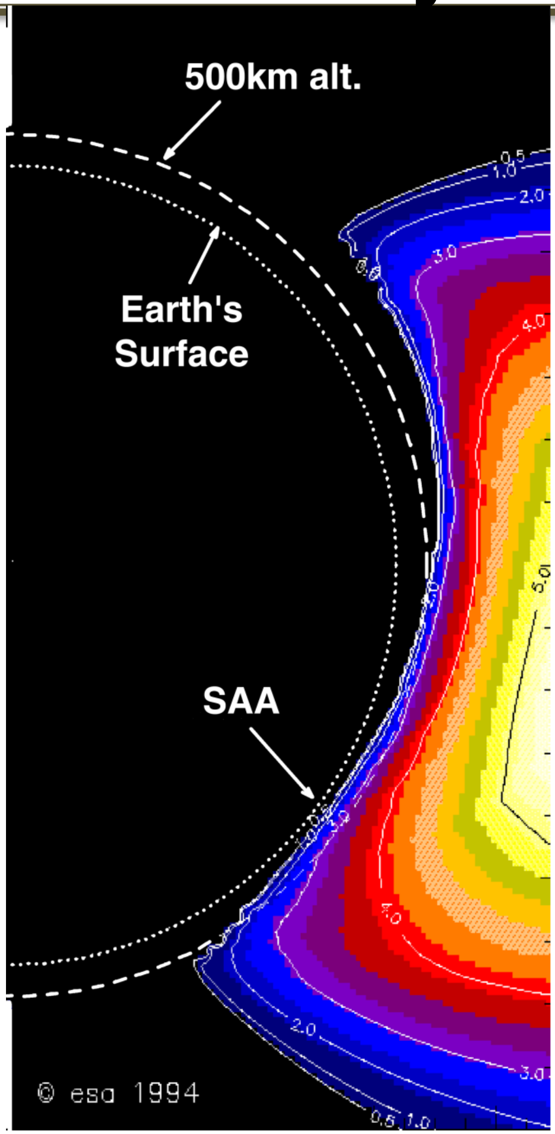
Galactic Cosmic Rays

- Galactic cosmic rays (GCR) are high-energy charged particles that originate outside our solar system.
- Supernova explosions are a significant source

Anticorrelation with solar activity
More pronounced/ intense during solar minimum

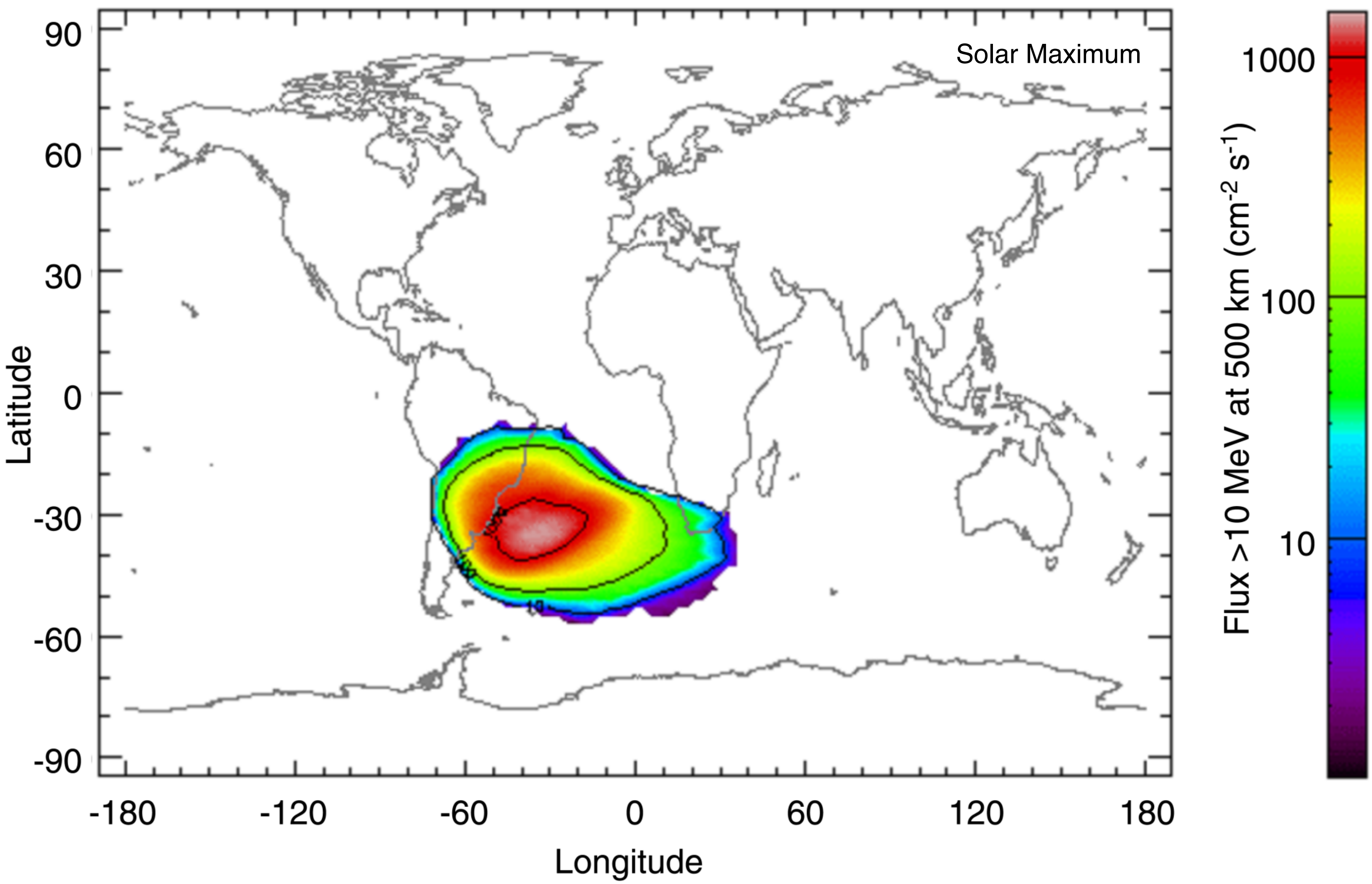
South Atlantic Anomaly

- Dominates the radiation environment for altitudes less than about 1000 km.
- Caused by tilt and shift of geomagnetic axis relative to rotational axis.
- Inner edge of proton belt is at lower altitudes south and east of Brazil.



E.J. Daly et al., IEEE TNS, April 1996

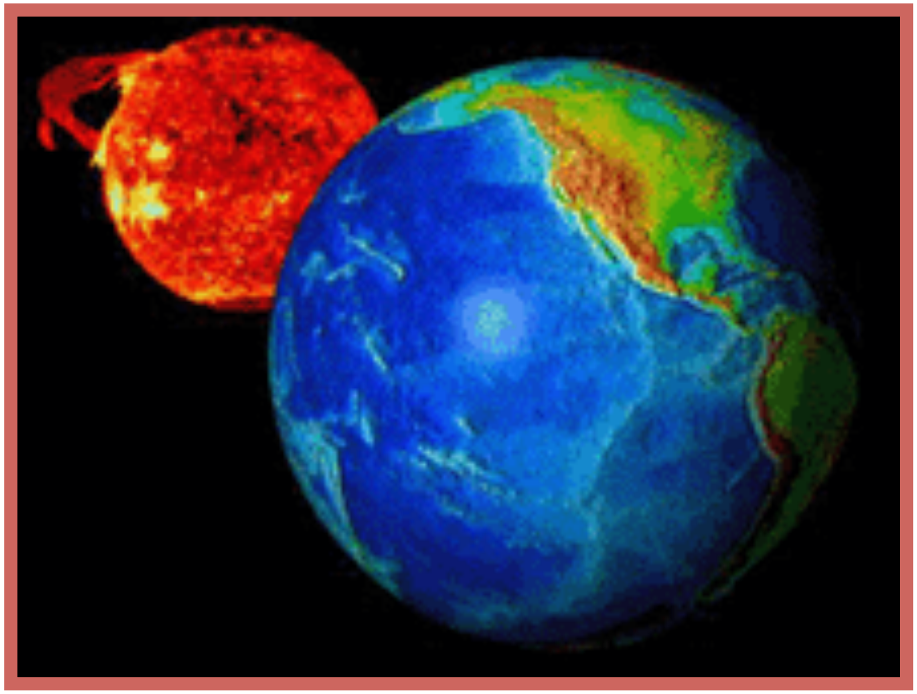
South Atlantic Anomaly



From SPENVIS, http://www.spenvis.oma.be/

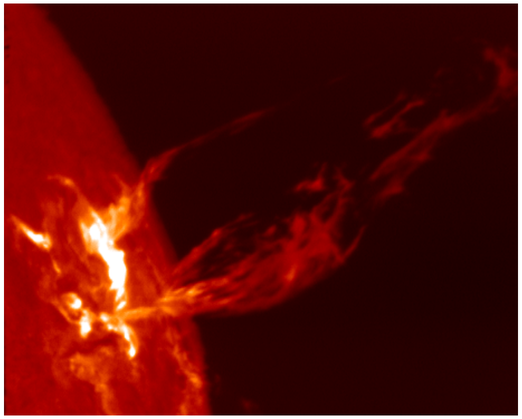
Solar Particle Events

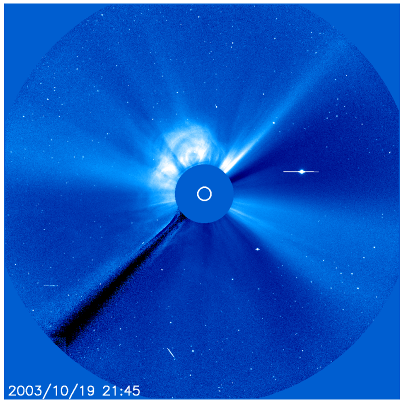
- Caused by flare/CME

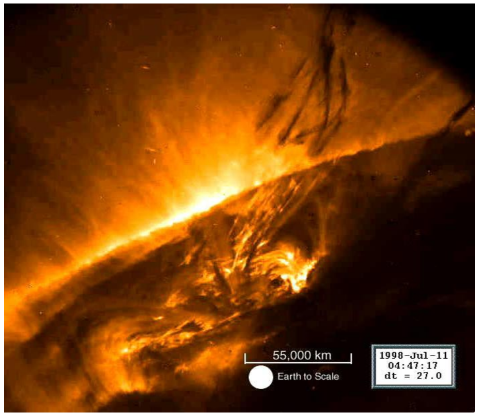


Characteristics of SEPs

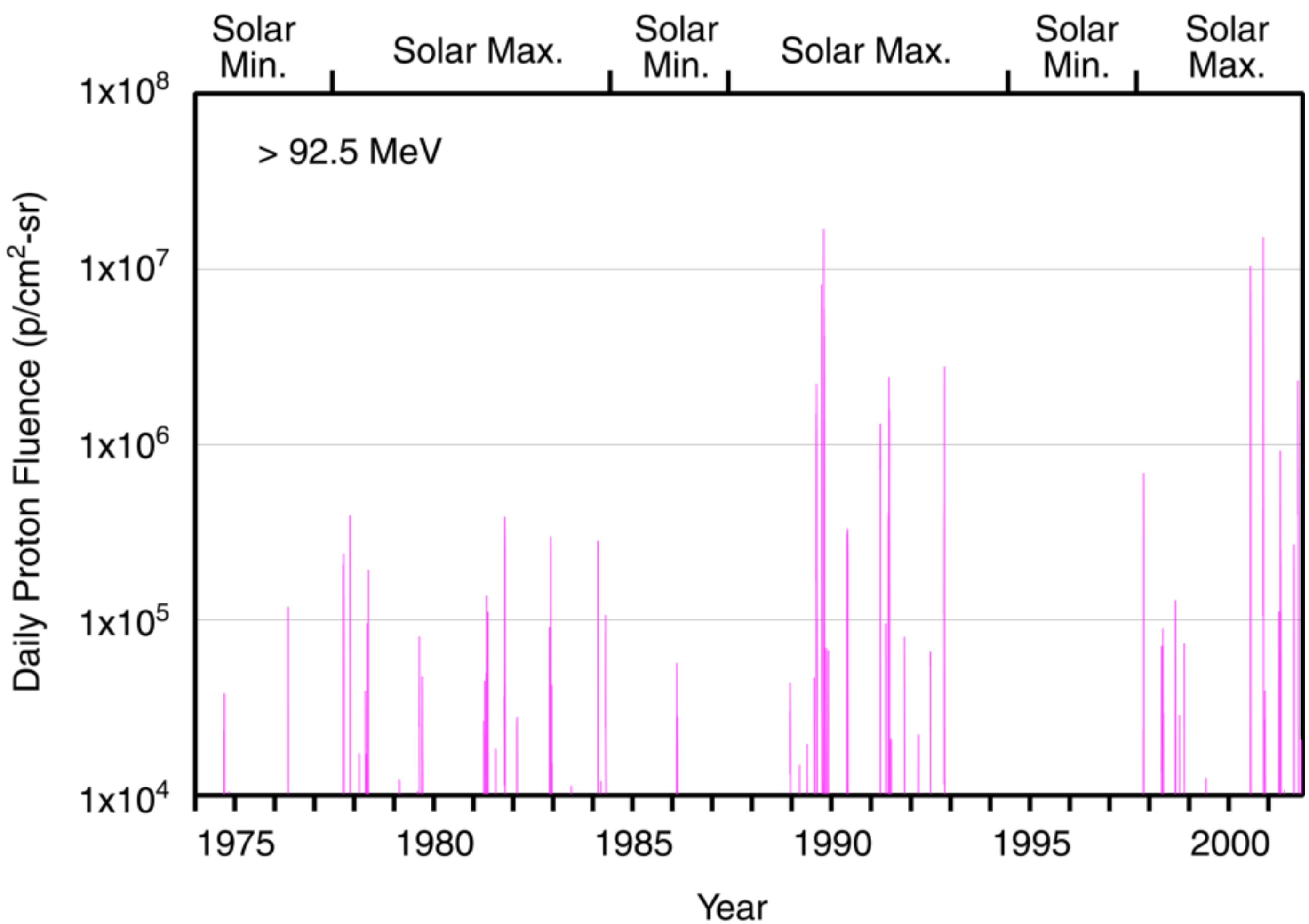
- Elemental composition* (may vary event by event)
  - 96.4% protons
  - 3.5% alpha particles
  - 0.1% heavier ions (not to be neglected!)
- Energies: up to ~ GeV/nucleon
- Event magnitudes:
  - > 10 MeV/nucleon integral fluence: can exceed 10^9 cm^{-2}
  - > 10 MeV/nucleon peak flux: can exceed 10^5 $cm^{-2}s^{-1}$







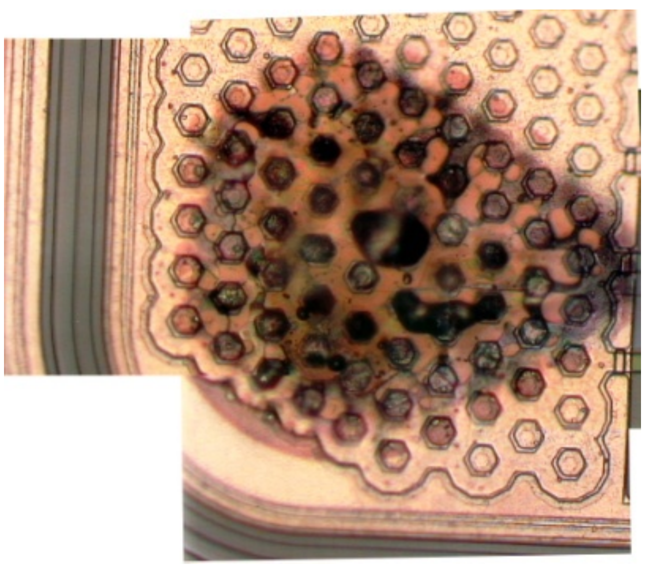
Solar Cycle Dependence



Most unpredictable

What is a Single Event Effect?

- Single Event Effect (SEE) – any measureable effect in a circuit caused by single incident ion
  - Non-destructive – SEU (Single Event Upset), SET (single event transients), MBU (Multiple Bit Upsets), SHE (single-event hard error)
  - Destructive – SEL (single event latchup), SEGR (single event gate rupture), SEB (single event burnout)



Destructive event in a COTS 120V DC-DC Converter

(credit: M.Xapsos)

Single Event Upsets

- SEUs: are soft errors, and non-destructive. They normally appear as transient pulses in logic or support circuitry, or as bitflips in memory cells or registers.

Destructive SEEs

- Several types of hard errors, potentially destructive, can appear:
- Single Event Latchup (SEL) results in a high operating current, above device specifications, and must be cleared by a power reset.
- Other hard errors include Burnout of power MOSFETS (Metal Oxide Semiconductor Field-Effect Transistor) , Gate Rupture, frozen bits, and noise in CCDs.

Anomalies March 2012 SWx events SEEs dominate

- Quite a few NASA spacecraft experienced anomalies, majority of which are SEEs. Some of them required reset/reboot.

Details to be discussed later.

Internal Charging
- energetic electrons in the outer radiation belt

CIR HSS geomagnetic storm
CME geomagnetic storms

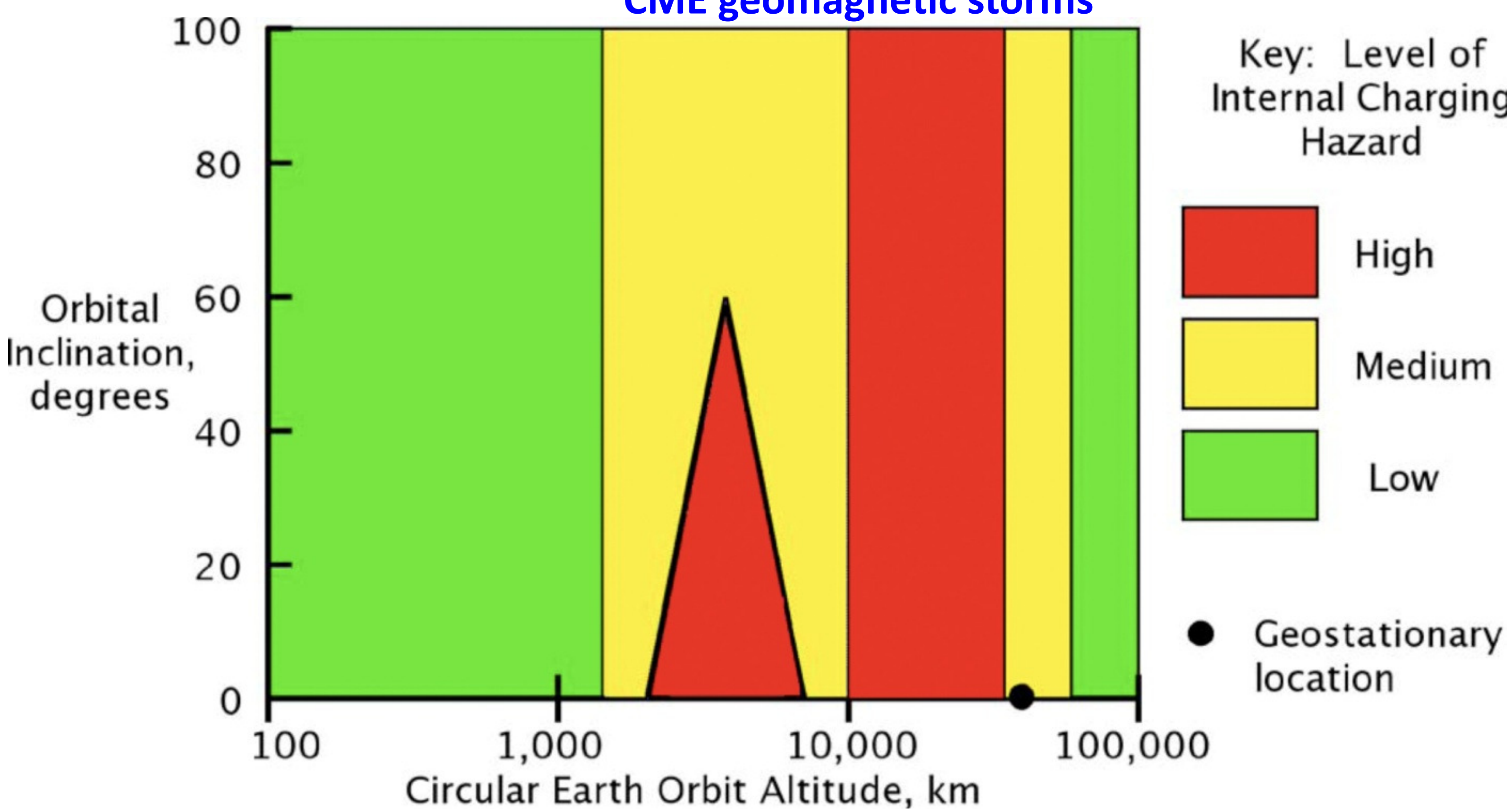


Figure 2—Earth Regimes of Concern for On-Orbit Internal Charging Hazards for Spacecraft with Circular Orbits

Operator response to SWx impacts

spacecraft specific/instrument specific

Human Safety in Space

- GCR
- **SEP**

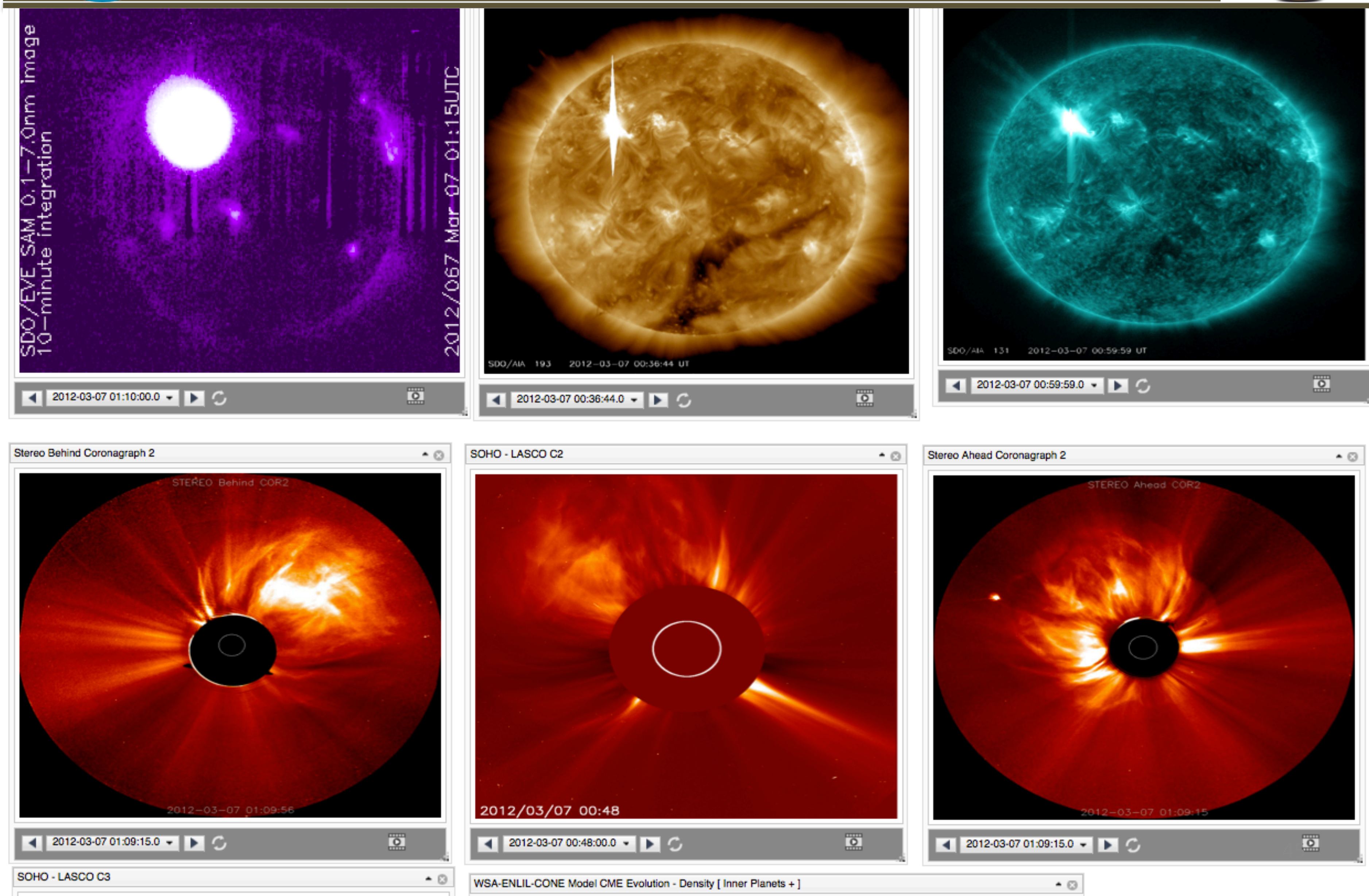
Johnson Space Center/Space Radiation Analysis Group (SRAG)

Limit: the > 100 MeV flux exceeding 1pfu

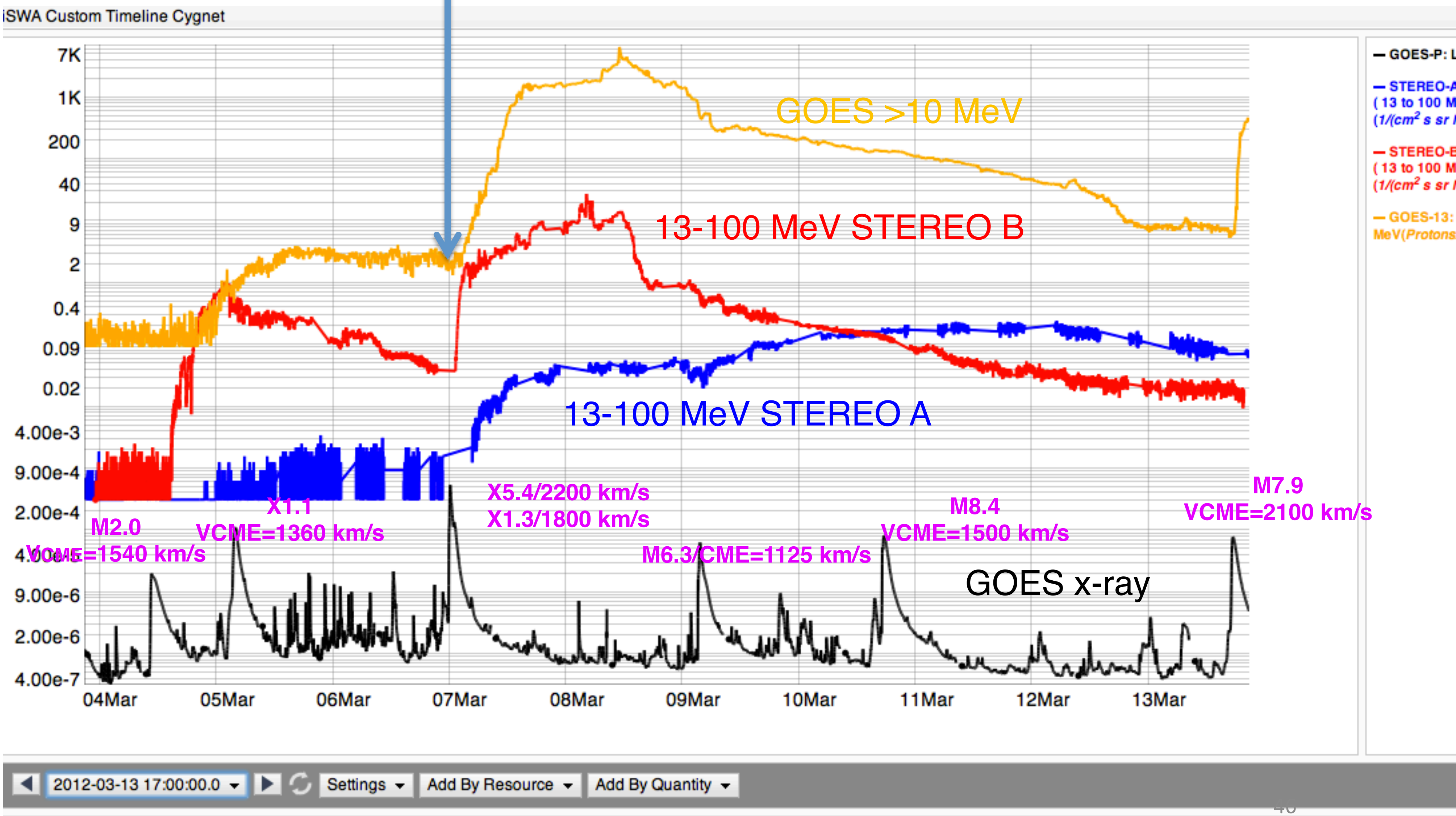
(1 pfu = 1 particle flux unit= 1/cm^2/sec/sr)

- All clear (EVA –extravehicular activity)

March 7 flares/CMEs



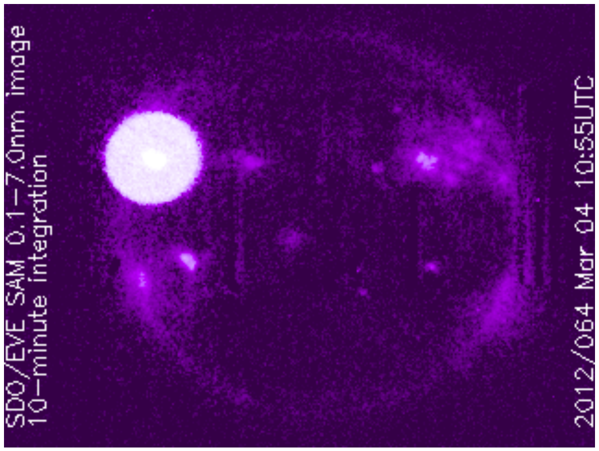
SEP: proton radiation (flare and CME)



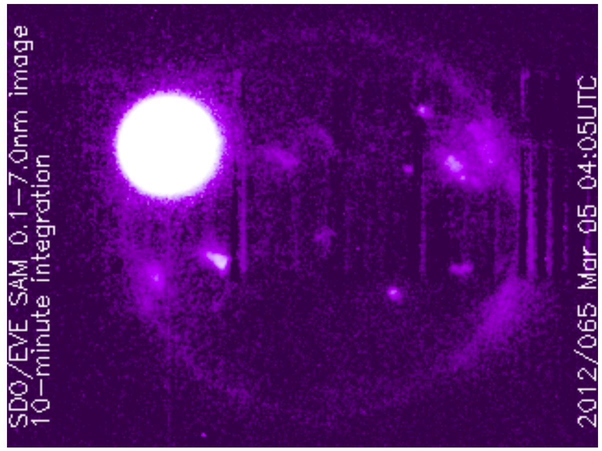
Major events from the long-lasting AR1429 during March 4 – 28, 2012

Flares of the Major Earth-Facing Events viewed by SDO EVE (x-ray)

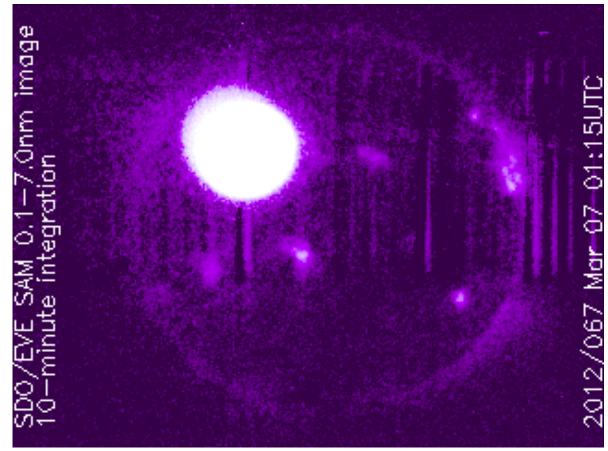
M2.0, 2012-03-04



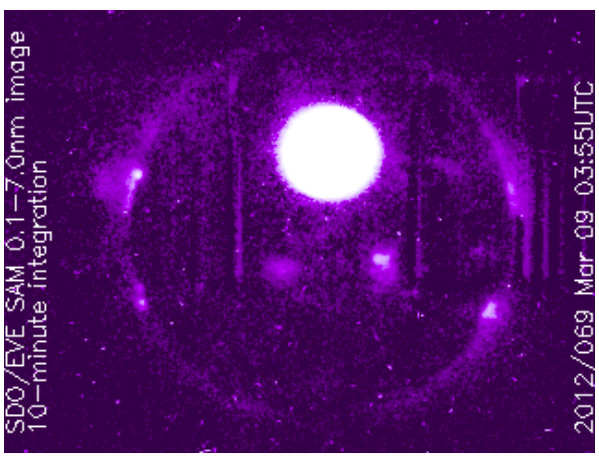
X1.1, 2012-03-05



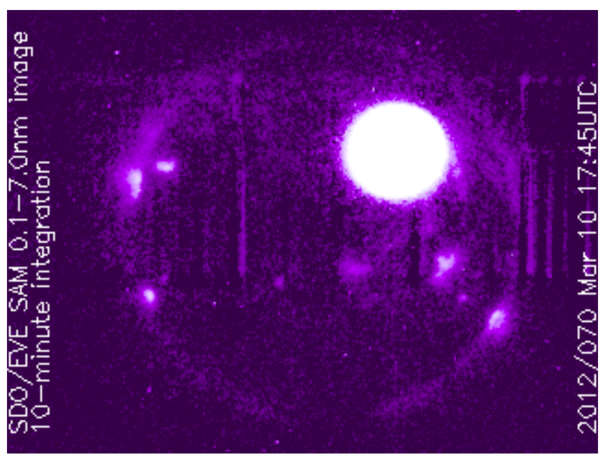
X5.4/X1.3 2012-03-07



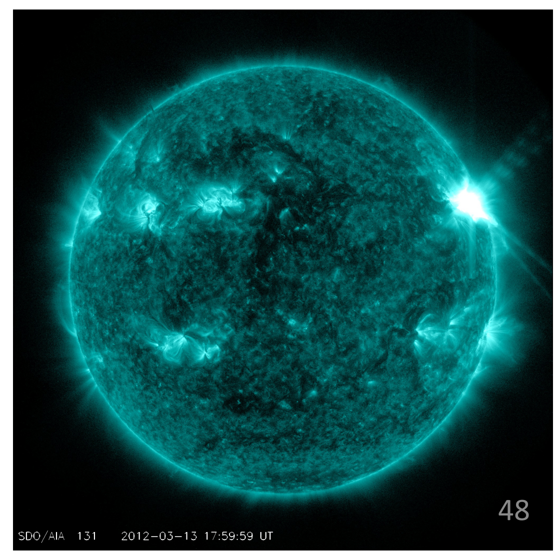
M6.3, 2012-03-09



M8.4, 2012-03-10

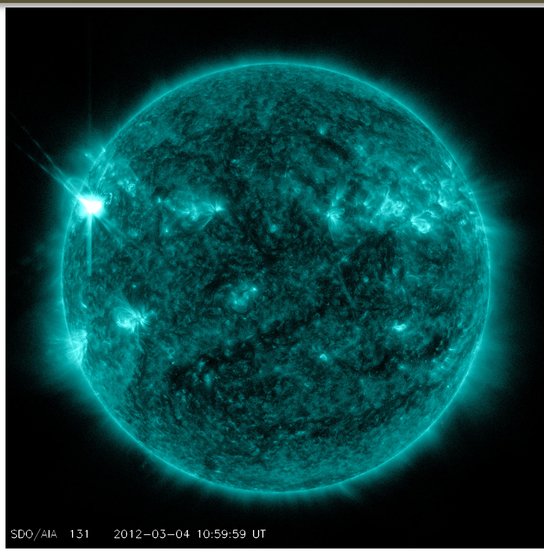


M7.9, 2012-03-13

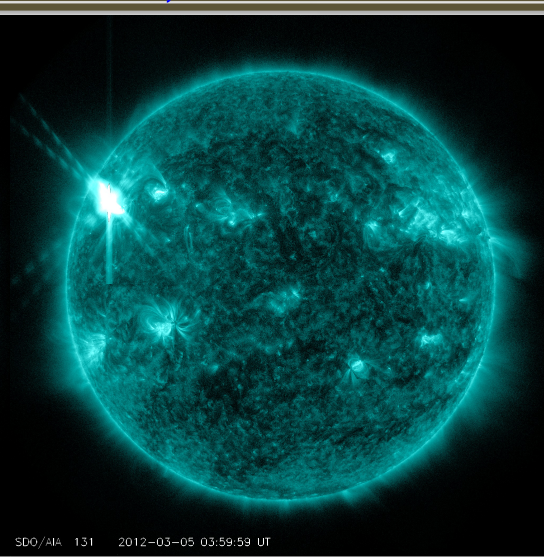


Flares of the Major Earth-Facing Events viewed by SDO AIA 131

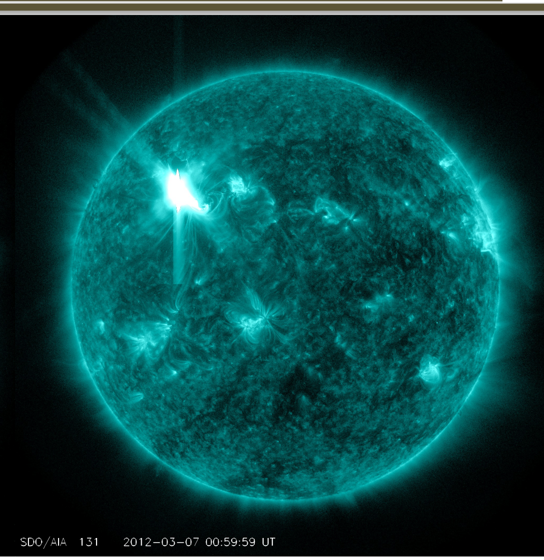
M2.0, 2012-03-04



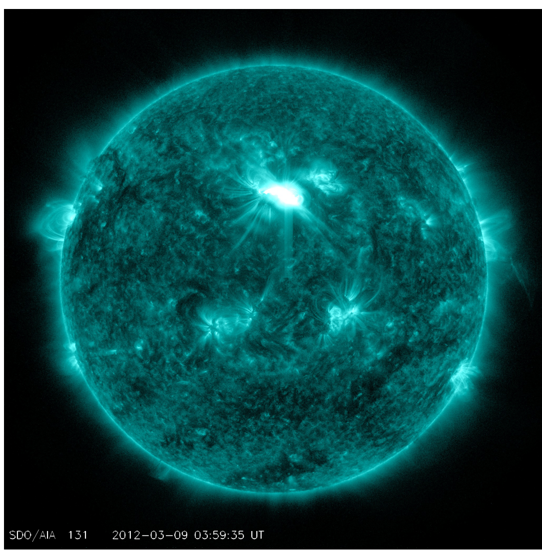
X1.1, 2012-03-05



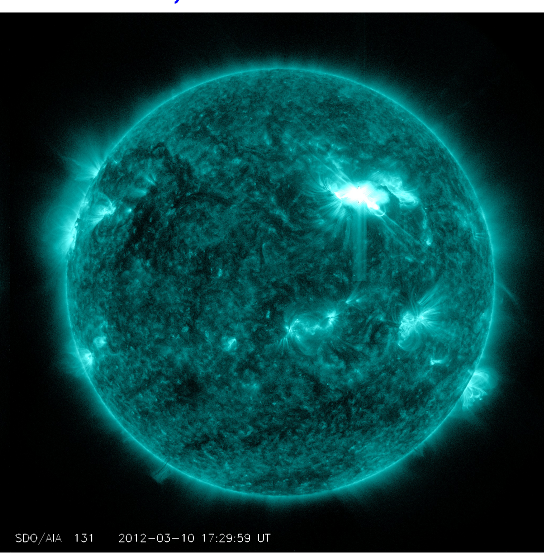
X5.4/X1.3 2012-03-07



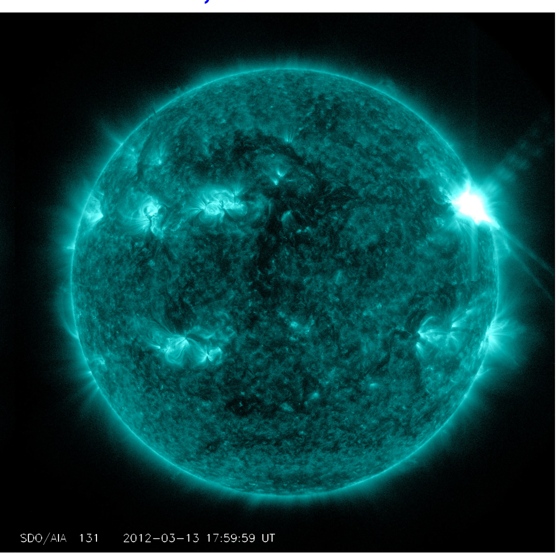
M6.3, 2012-03-09

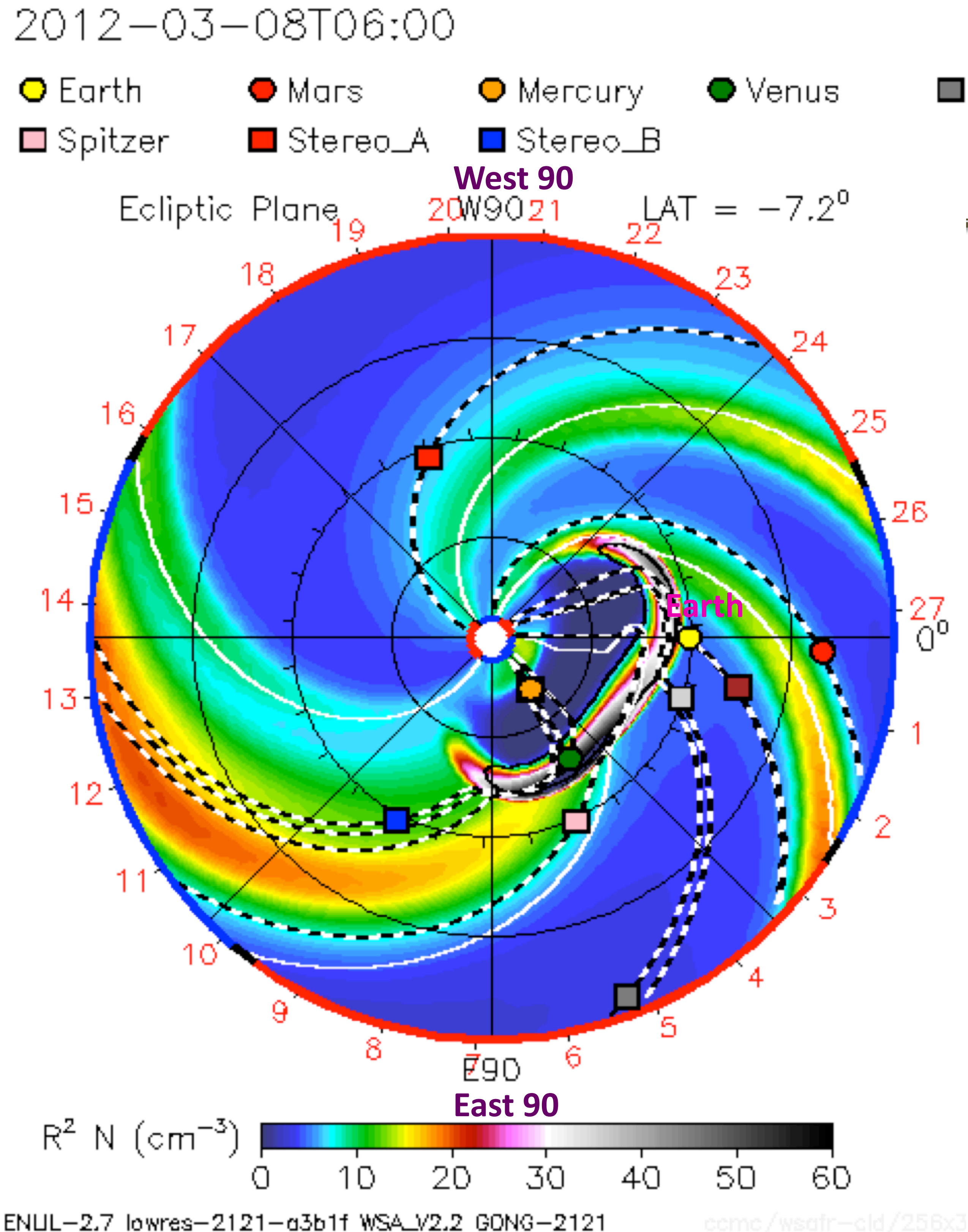


M8.4, 2012-03-10



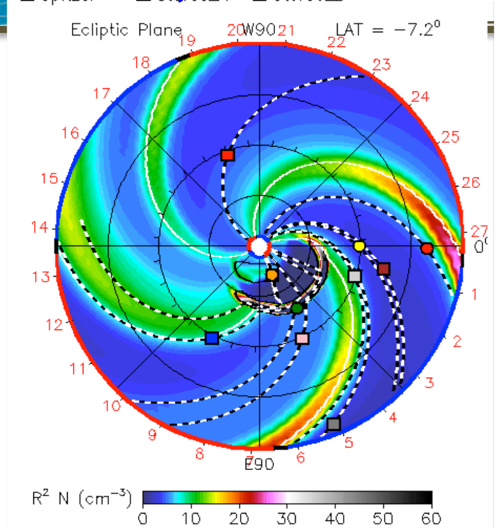
M7.9, 2012-03-13



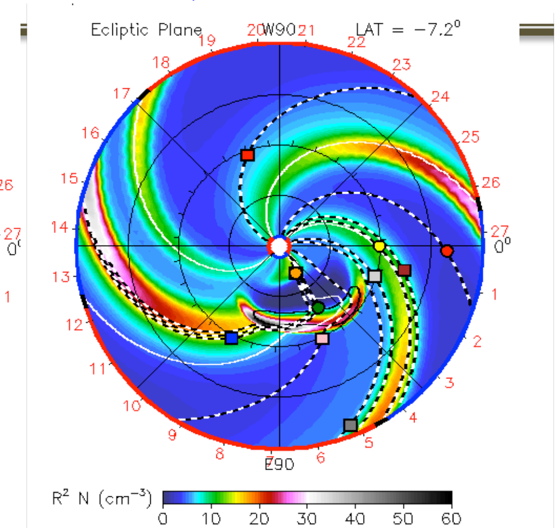

2012-03-08T06:00
Earth
Mars
Mercury
Venus
Spitzer
Stereo_A
Stereo_B
West 90
Ecliptic Plane
W90
LAT = −7.2°
Earth
0°
E90
East 90
R² N (cm⁻³)
0 10 20 30 40 50 60
ENLIL-2.7 lowres-2121-a3b1f WSA_V2.2 GONG-2121

The Corresponding CMEs Associated with the Flares

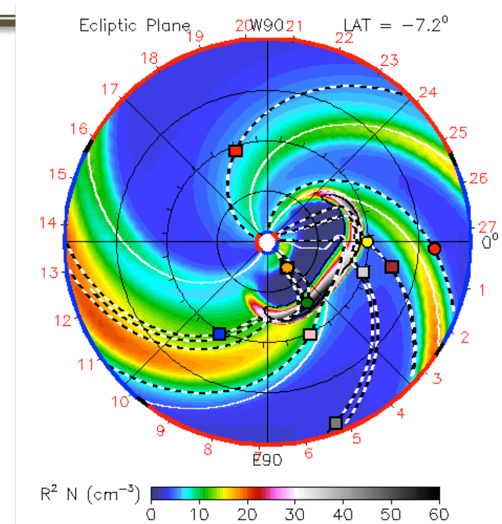
M2.0, 2012-03-04



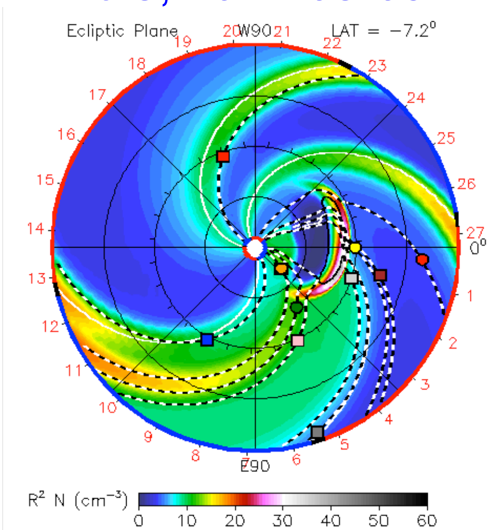
X1.1, 2012-03-05



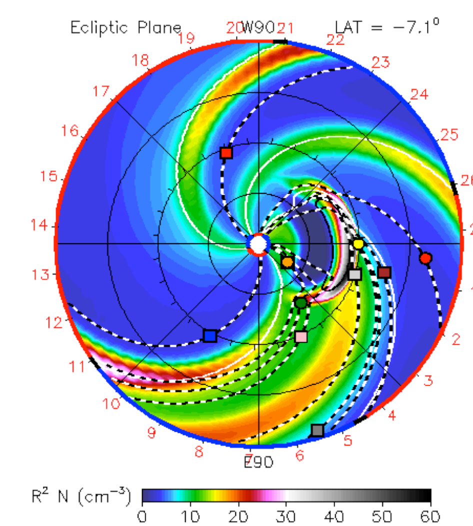
X5.4/X1.3 2012-03-07



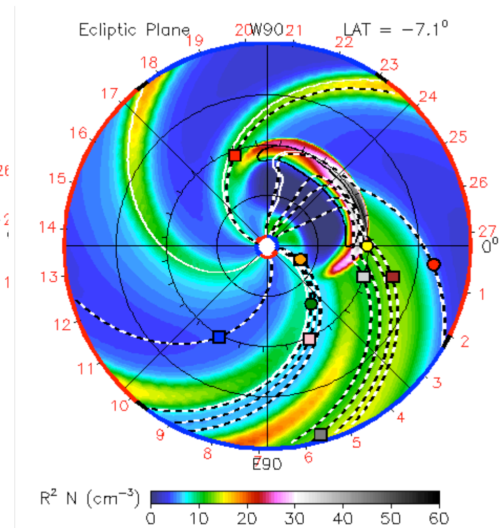
M6.3, 2012-03-09



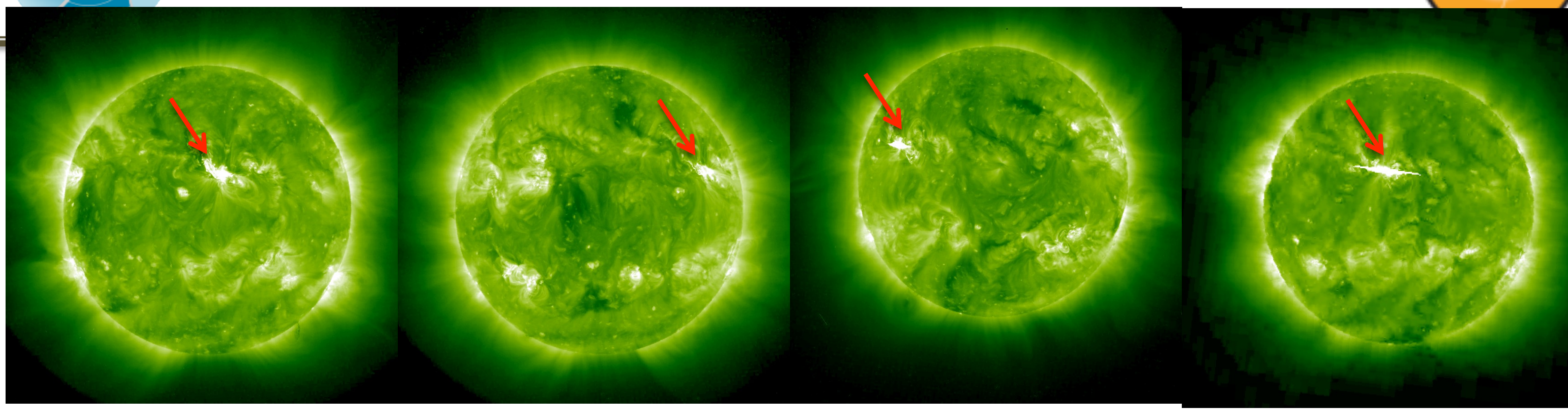
M8.4, 2012-03-10

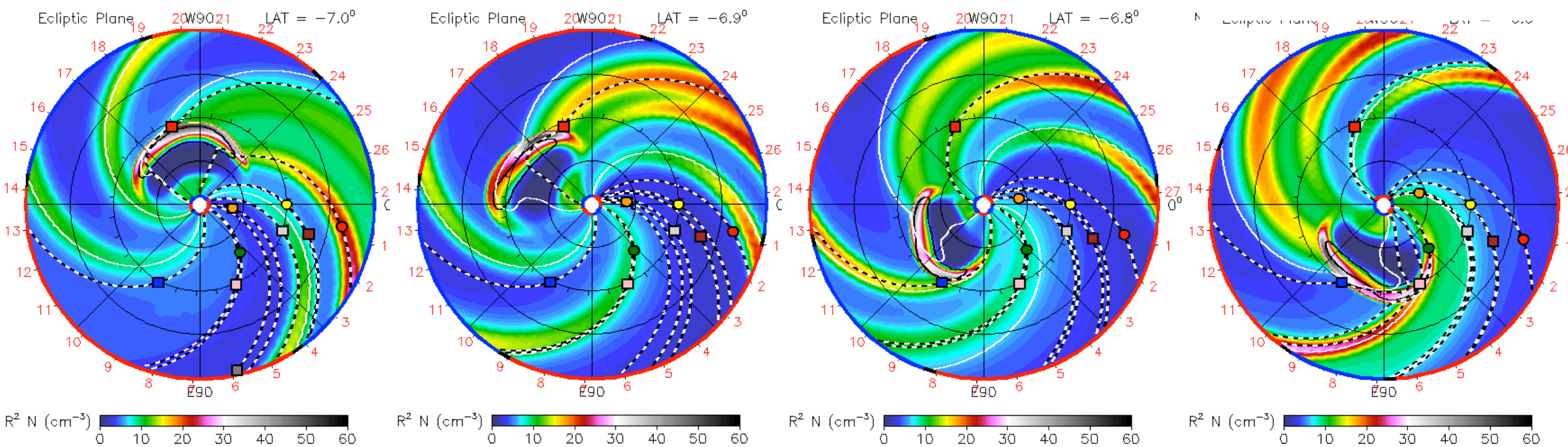


M7.9, 2012-03-13



STA: 2012-03-18 STA: 2012-03-21 STB: 2012-03-24 STB: 2012-03-26





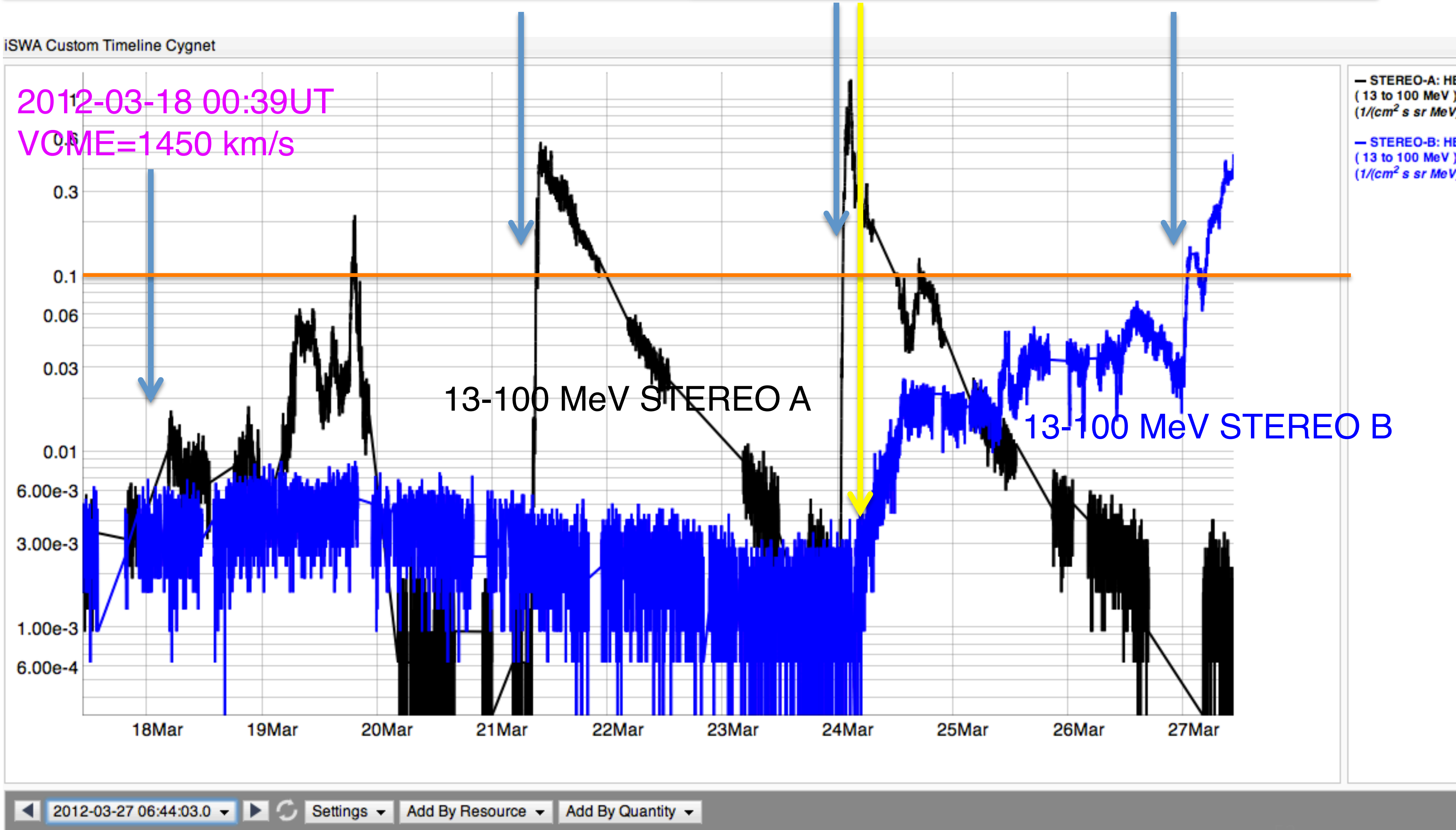
Backsided events in STEREO EUVI 195A (top) and CME model simulations (bottom)

Enhanced proton radiation at STEREO A and B from the backsided events.

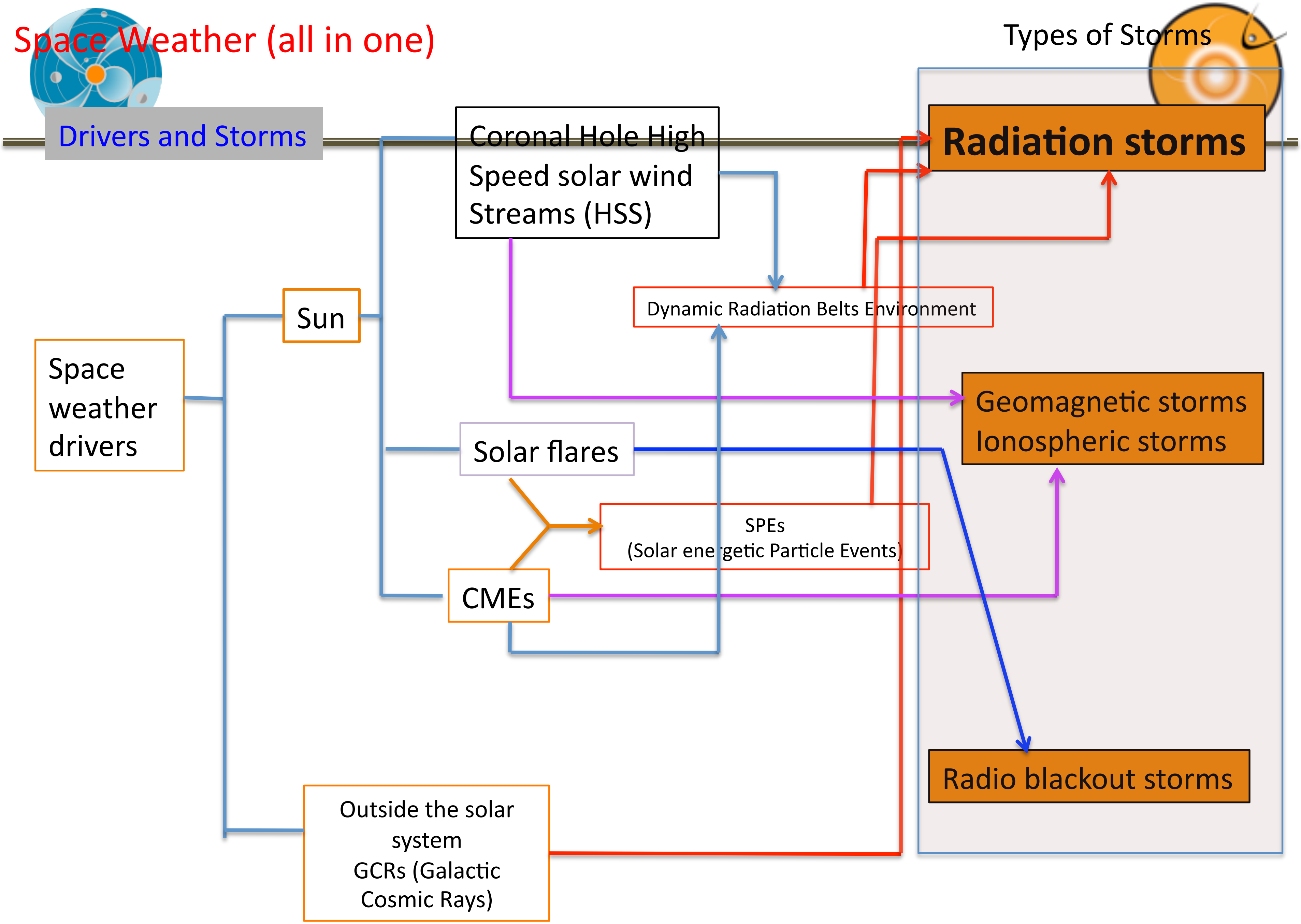
2012-03-21 07:39 UT
VCME=1550 km/s

2012-03-24 00:39UT
VCME=1600 km/s

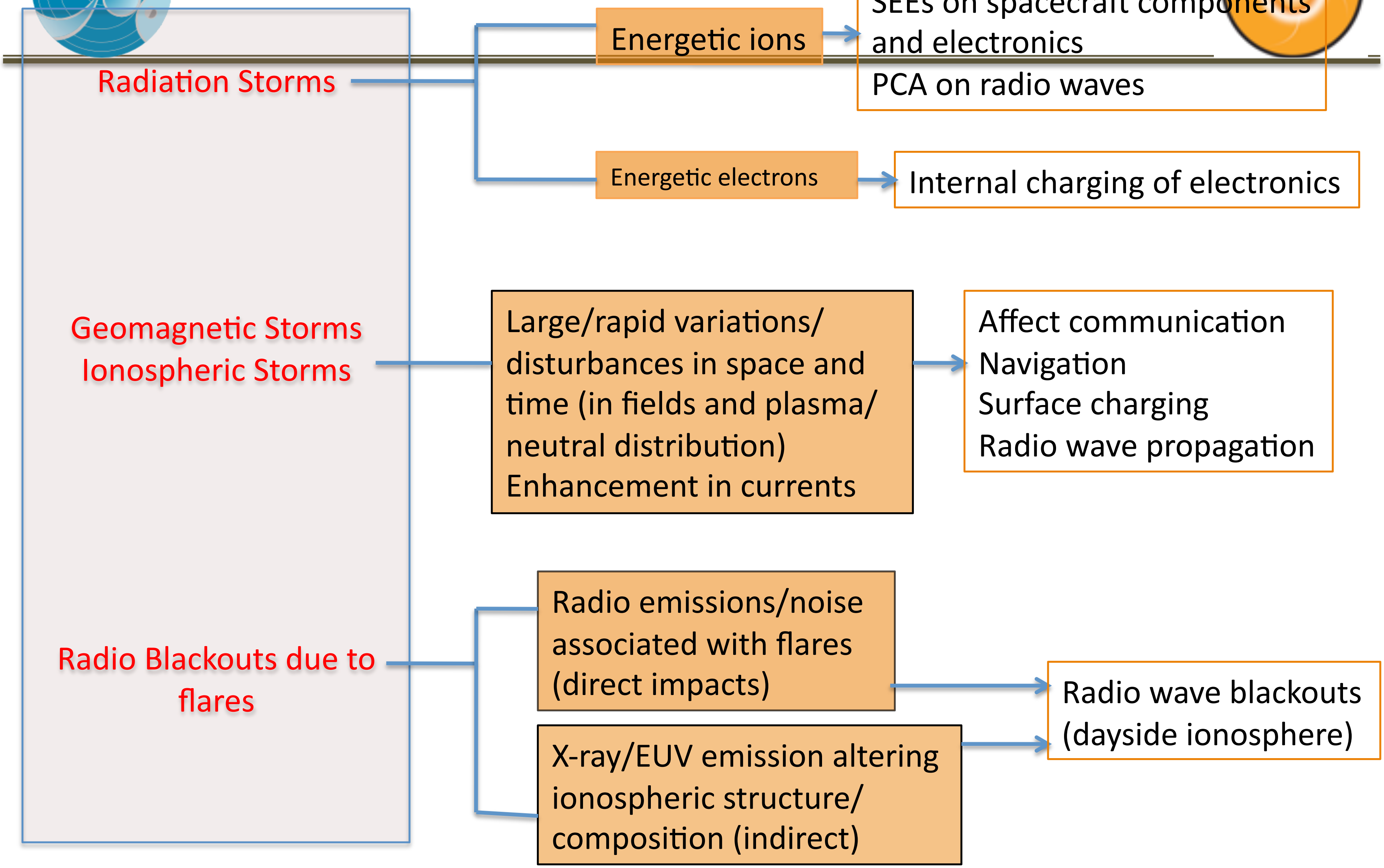
2012-03-26 23:12UT
VCME=1500 km/s



Space Weather (all in one)



Storms and Effects



Supplementary Material/contact info

- View our video, Incredible Active Region 1429: One for the record books, to learn more about the activities from this region from March 4 – March 28, 2012. http://youtu.be/PbyJswbX4VA
- This video has been updated at the following link: http://youtu.be/dxI5drPY8xQ
  (And also available on http://vimeo.com/nasaswc/ar1429)
- Summary Video of the March 7, 2012 event

  http://youtu.be/HeoKf6NfEJI

  Full text of event summary

  http://goo.gl/dTnfd

NASA Space Weather Center

http://swc.gsfc.nasa.gov/main/

homework

Name all types of space weather impacts on spacecraft and their potential causes

Types of spacecraft orbits

Go over the summary video of the 7 March 2012 event - can you give a 30 seconds – 1minute description of the event to a friend?

Go over the video of 'Incredible Active Region 1429' – can you give a 30s – 1min description in your own words?

Supplementary material

- Youtube video from Henry Garrett at JPL - http://www.youtube.com/watch?v=NarzGDuYYX4