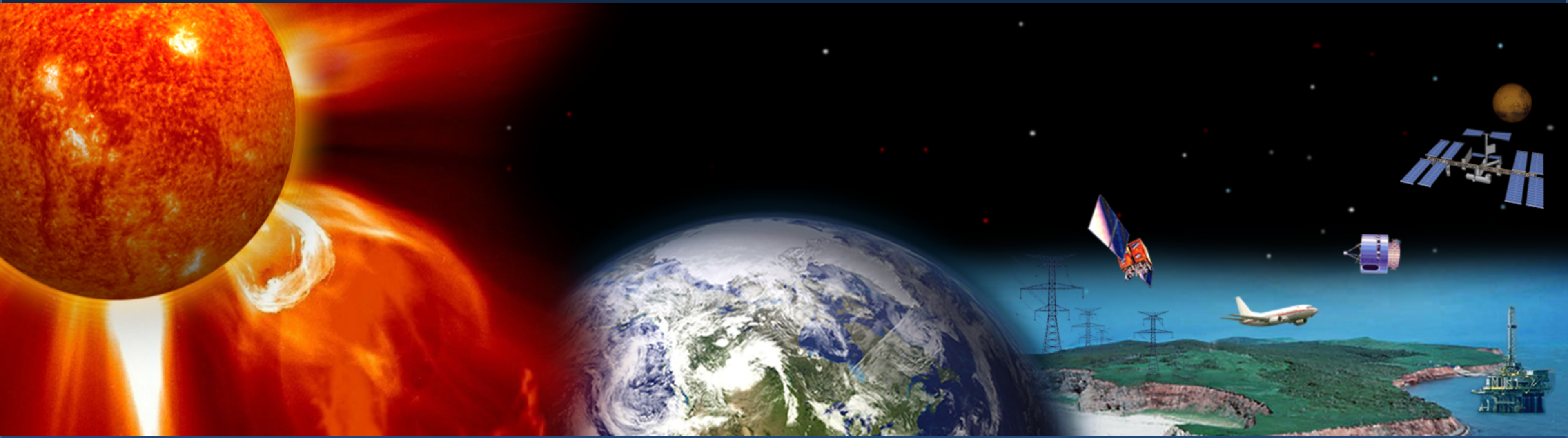
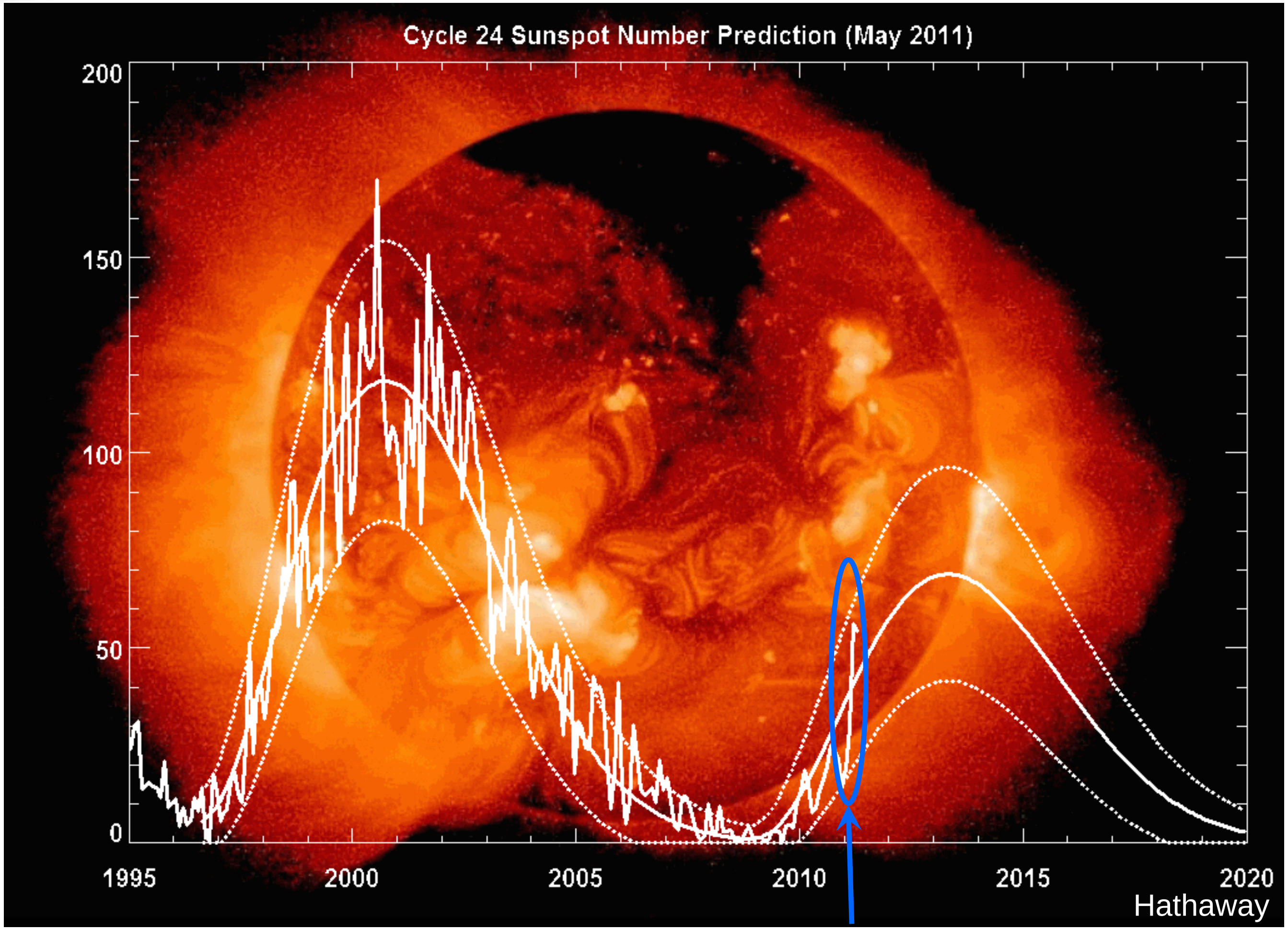
Space Weather Threats, Detection, Warning, and Sharing



Terrance G Onsager
National Oceanic and Atmospheric Administration
Space Weather Prediction Center

Solar Activity Increasing to Solar Maximum



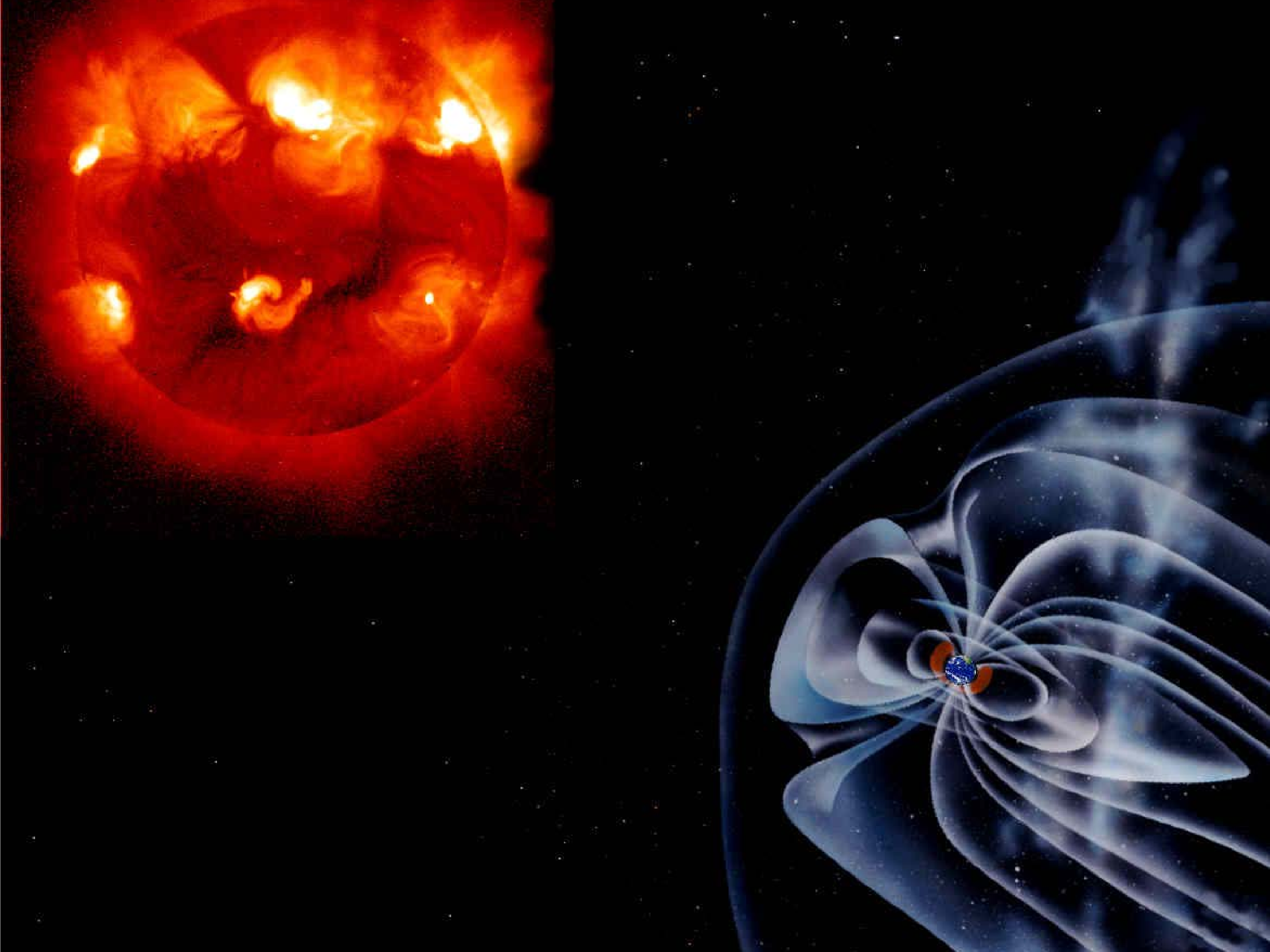
Recent Increase in Solar Activity

Increasing Vulnerabilities to Space Weather

- Satellite-based applications:
  - Navigation and communication
  - Environmental monitoring and research
  - Broadcast television and radio
  - Business and finance
- HF communication – wireless technology
- Electric power grid
- Airline safety
  - Navigation and communication
  - Radiation
- Marine applications

Space Weather Impacts on Space Sustainability

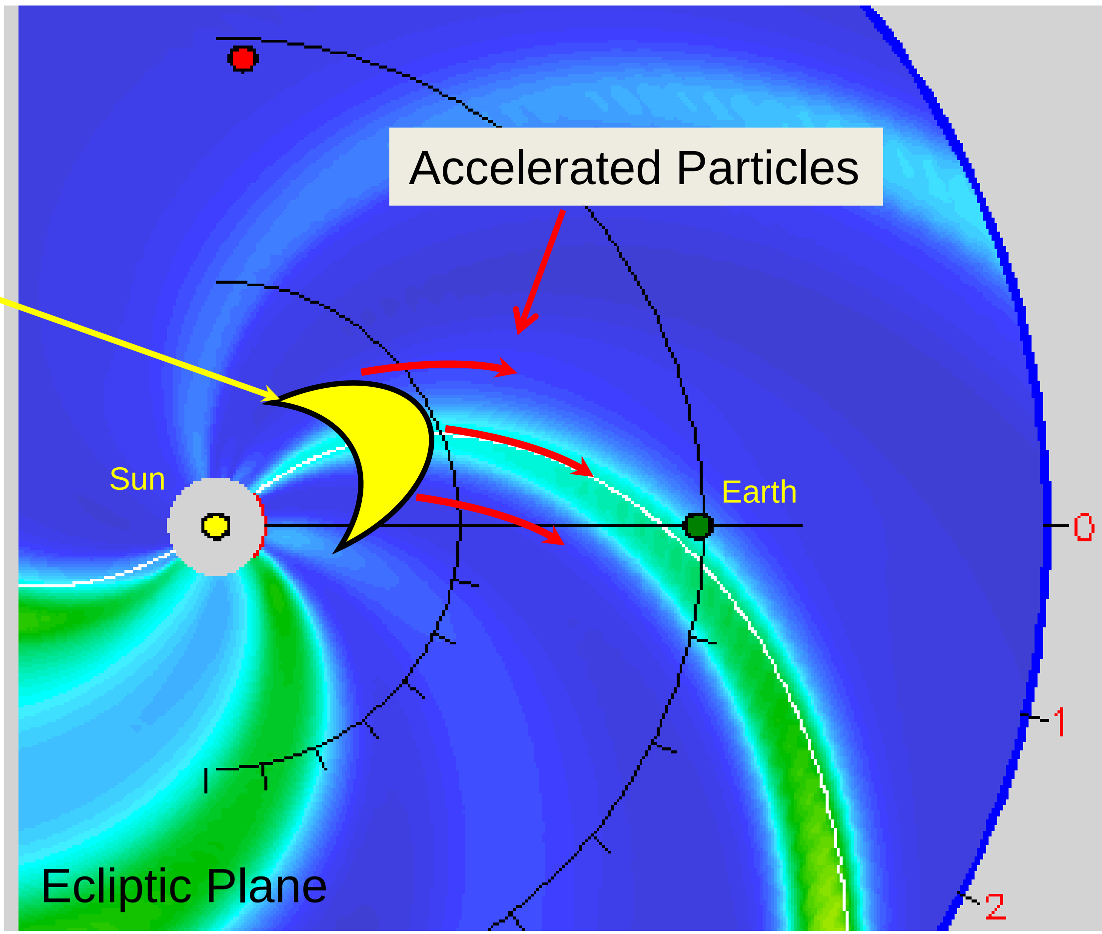
1. Satellite Electronics
    - Single event upsets (energetic protons, heavy ions)
    - Deep dielectric charging (energetic electrons)
    - Surface charging (low energy electrons)
    - Surface corrosion (low energy oxygen)
2. Satellite Orientation
    - Star tracker anomalies (energetic protons)
    - Magnetic field variability (magnetopause crossings)
3. Satellite Communication
    - Ionospheric disturbances, solar radio interference
4. Satellite and Debris Orbit Determination
    - Neutral density variability
5. Human Health
    - Radiation impacts (energetic protons, ions, and electrons)



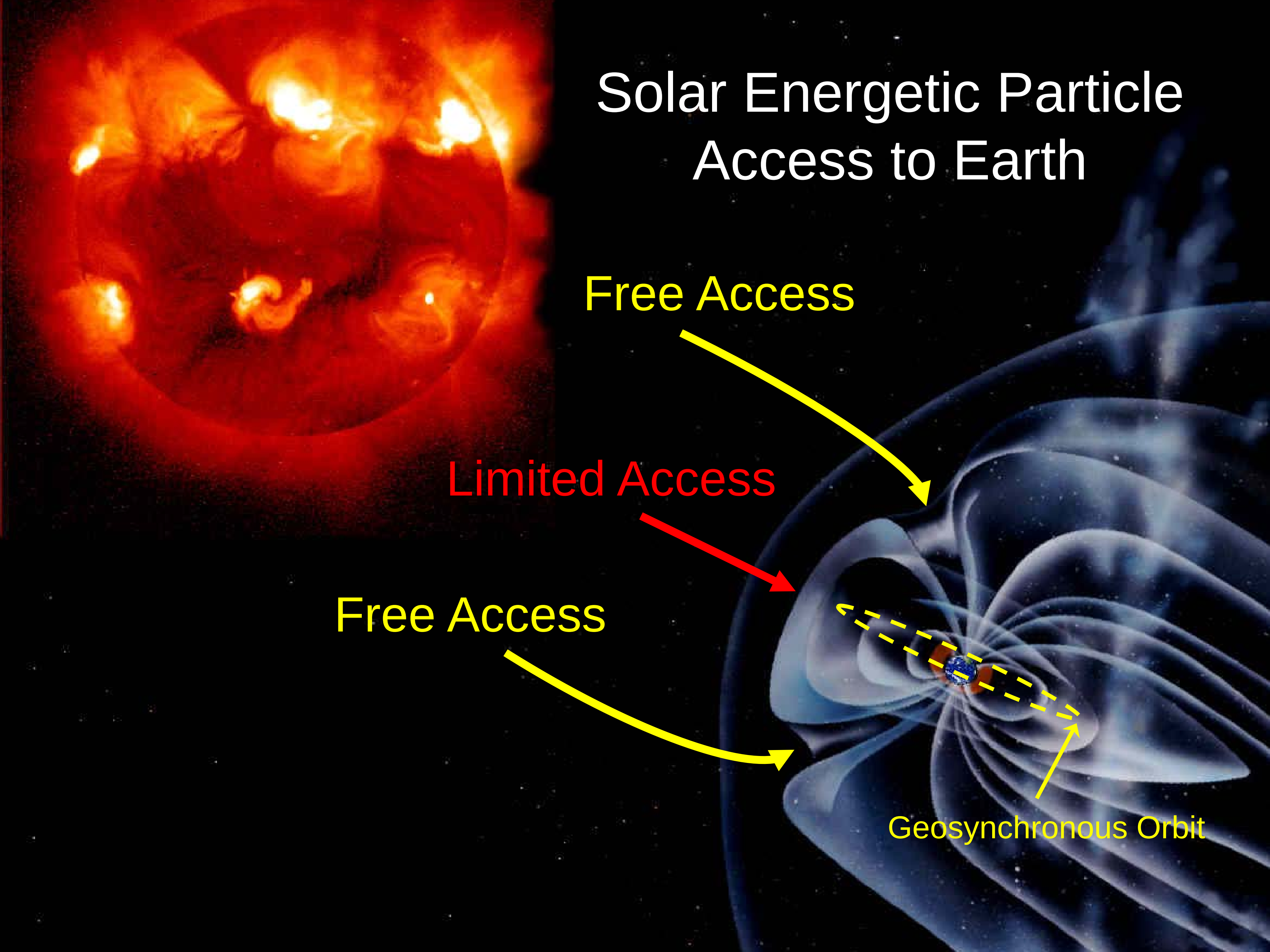
Energetic Particle Acceleration by Coronal Mass Ejections

Fast Coronal Mass Ejections create shock waves that accelerate particles to relativistic energies

Coronal Mass Ejection

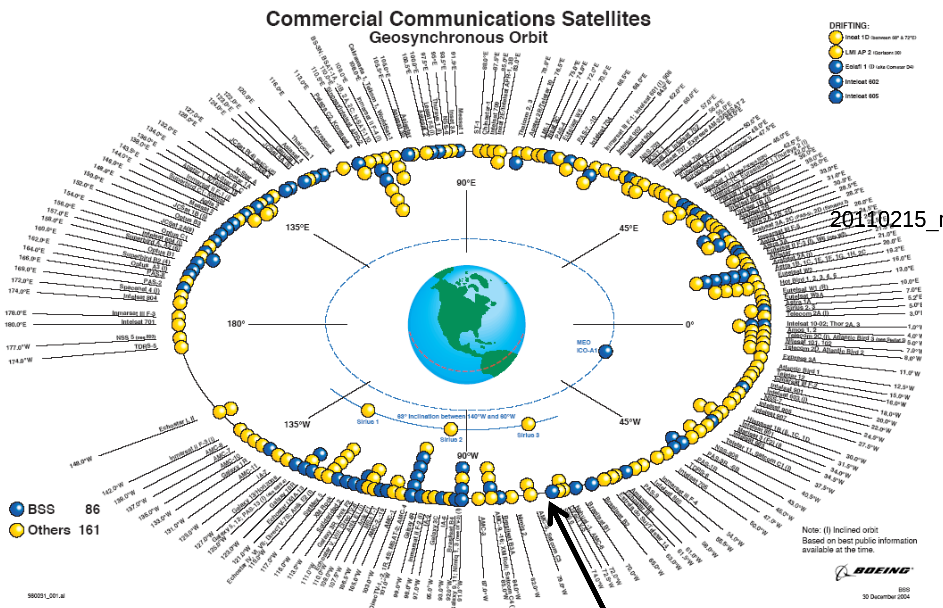


View from above plane of Earth's orbit


Solar Energetic Particle
Access to Earth
Free Access
Limited Access
Free Access
Geosynchronous Orbit

Solar Energetic Particles Impact On-Orbit Satellites

Satellites in Geostationary Orbit



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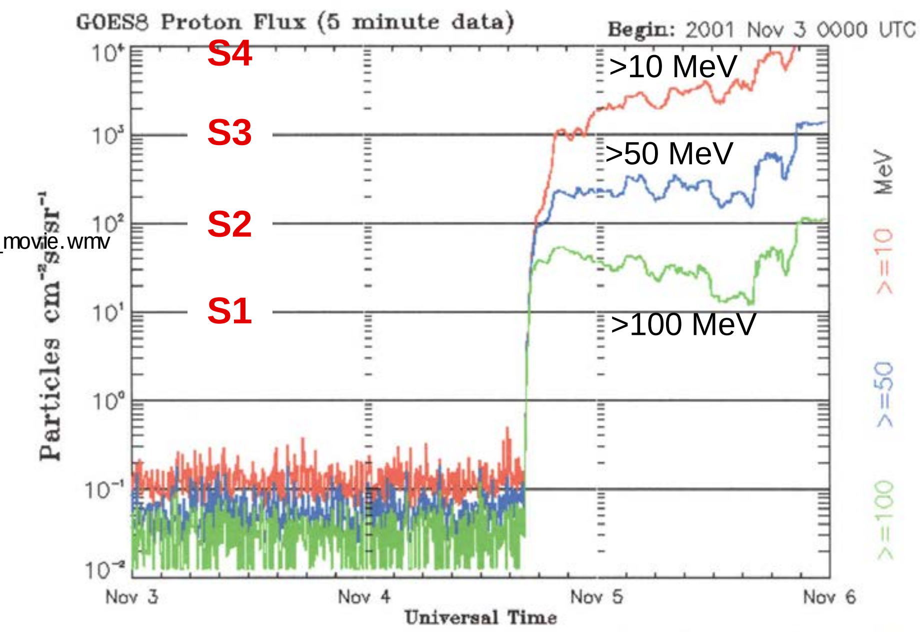
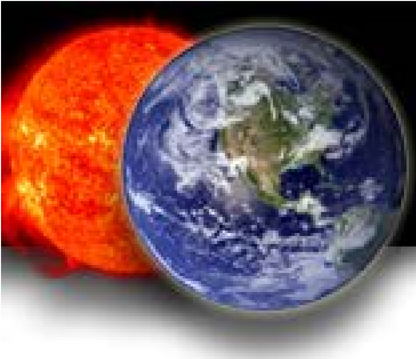
Solar Radiation Storm

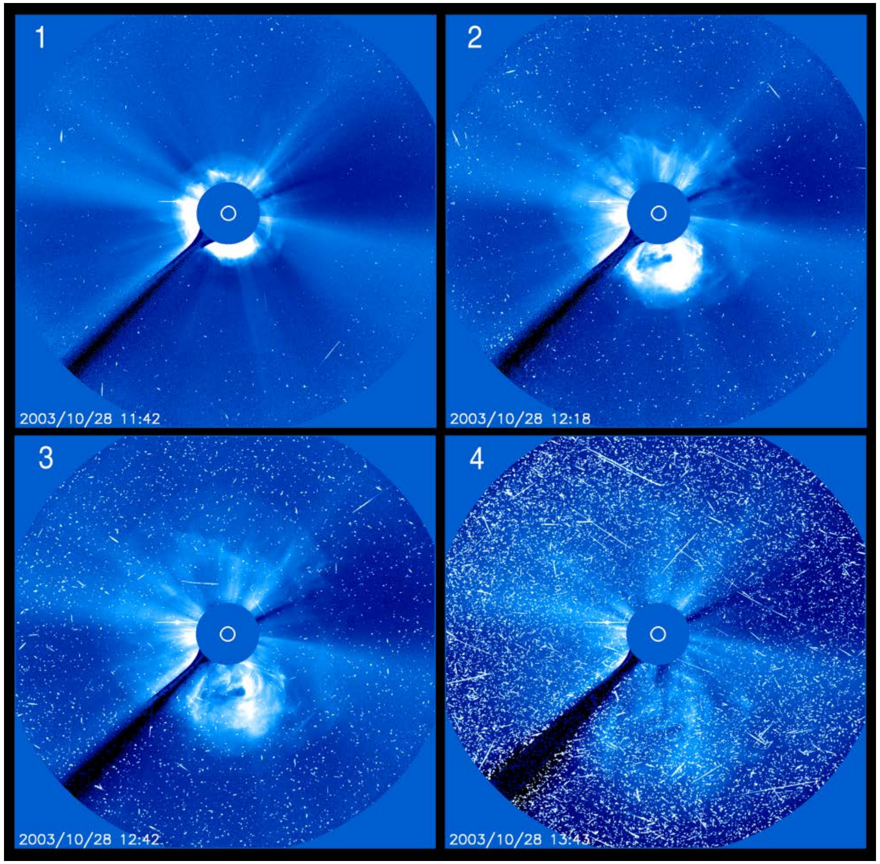


NOAA GOES Satellite Measurements

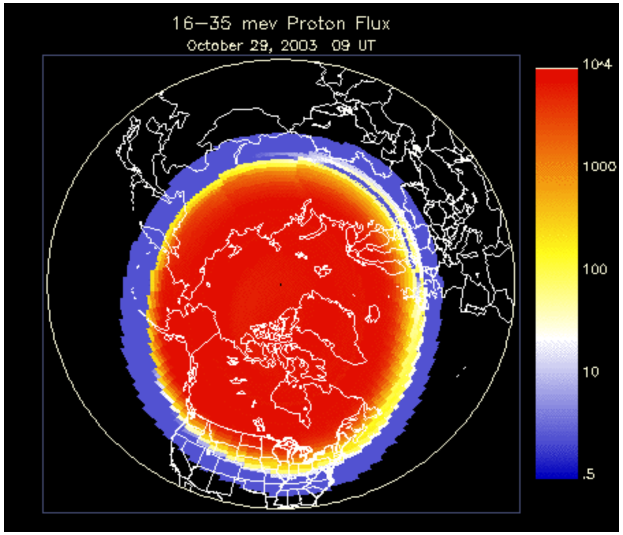


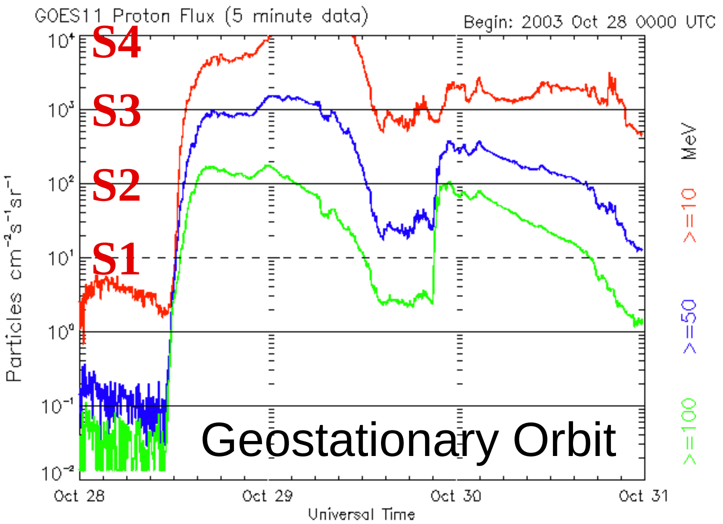
Solar Energetic Particles in Interplanetary Space, Polar Regions, and Geostationary Orbit

Interplanetary Space



Polar Ionosphere

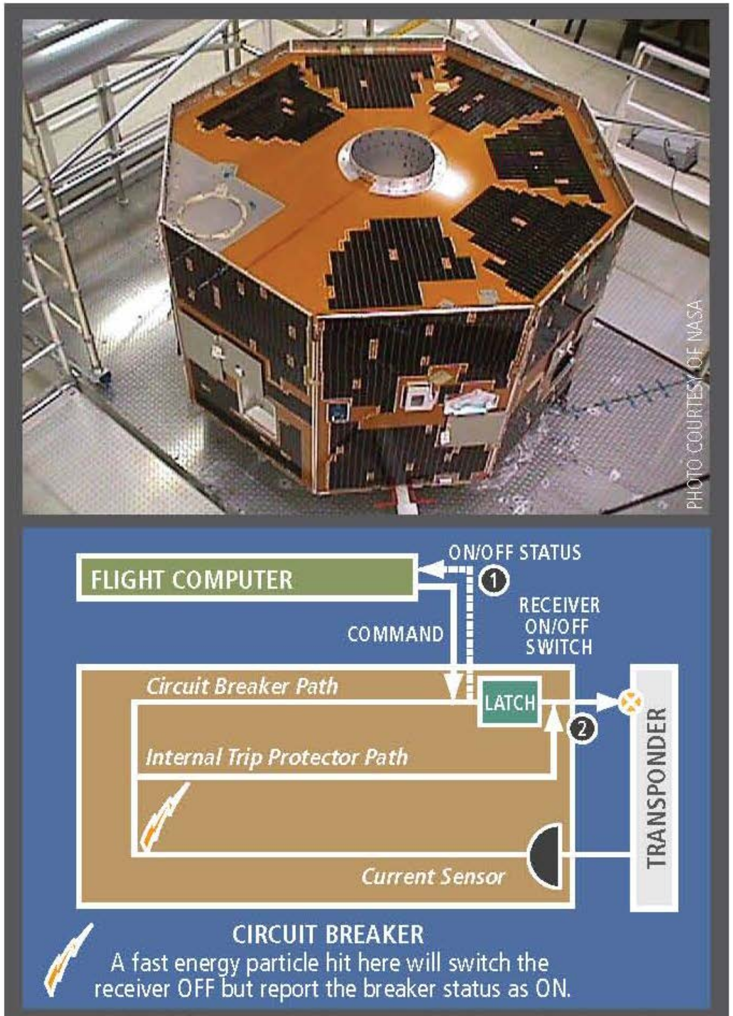




Example of Single Event Upset Caused by Energetic Proton or Heavy Ion

- NASA/IMAGE satellite – 2000-2006
- Anomalous circuit break trip caused by energetic particle
- Circuit design did not allow recovery
- Two other satellites experienced similar issues, but were reset from ground

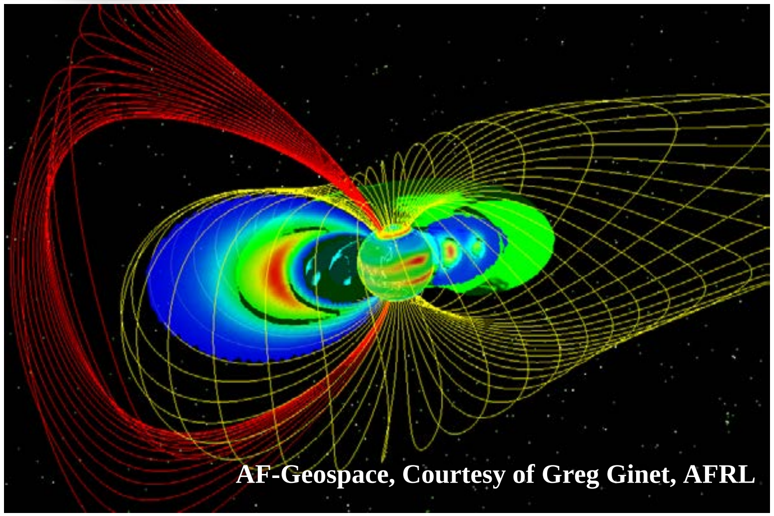
Even with careful design, it is difficult to protect against all contingencies.

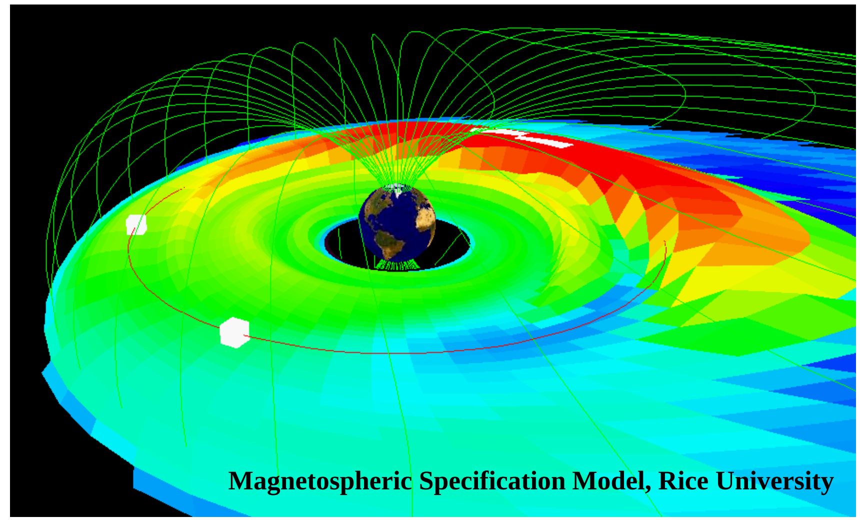


Above: The IMAGE spacecraft; below: simplified circuit breaker schematic

Getting it Right, Aerospace Corp., June 6, 2011

Electron Environment and Spacecraft Charging


AF-Geospace, Courtesy of Greg Ginet, AFRL

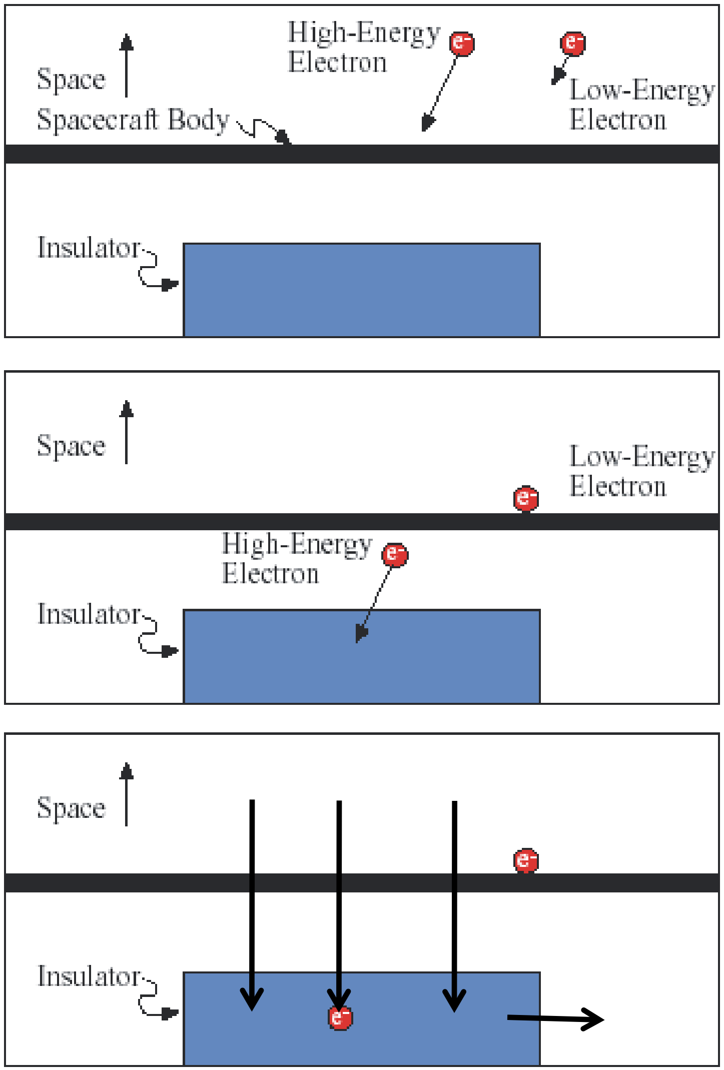

Magnetospheric Specification Model, Rice University

Radiation belt electrons:	> 500 keV	Deep dielectric charging
Ring current electrons:	< 500 keV	Surface charging

Radiation belt dynamics: diffusion and magnetic drifts

Ring current dynamics: electric and magnetic drifts

Surface and Deep-Dielectric Charging Result in Electrical Discharge



Low-energy electrons “stick” to the spacecraft surface.

High-energy electrons penetrate the satellite and can get embedded in insulating materials.

If electrons enter insulator faster than they can dissipate, internal charging and discharging will occur.

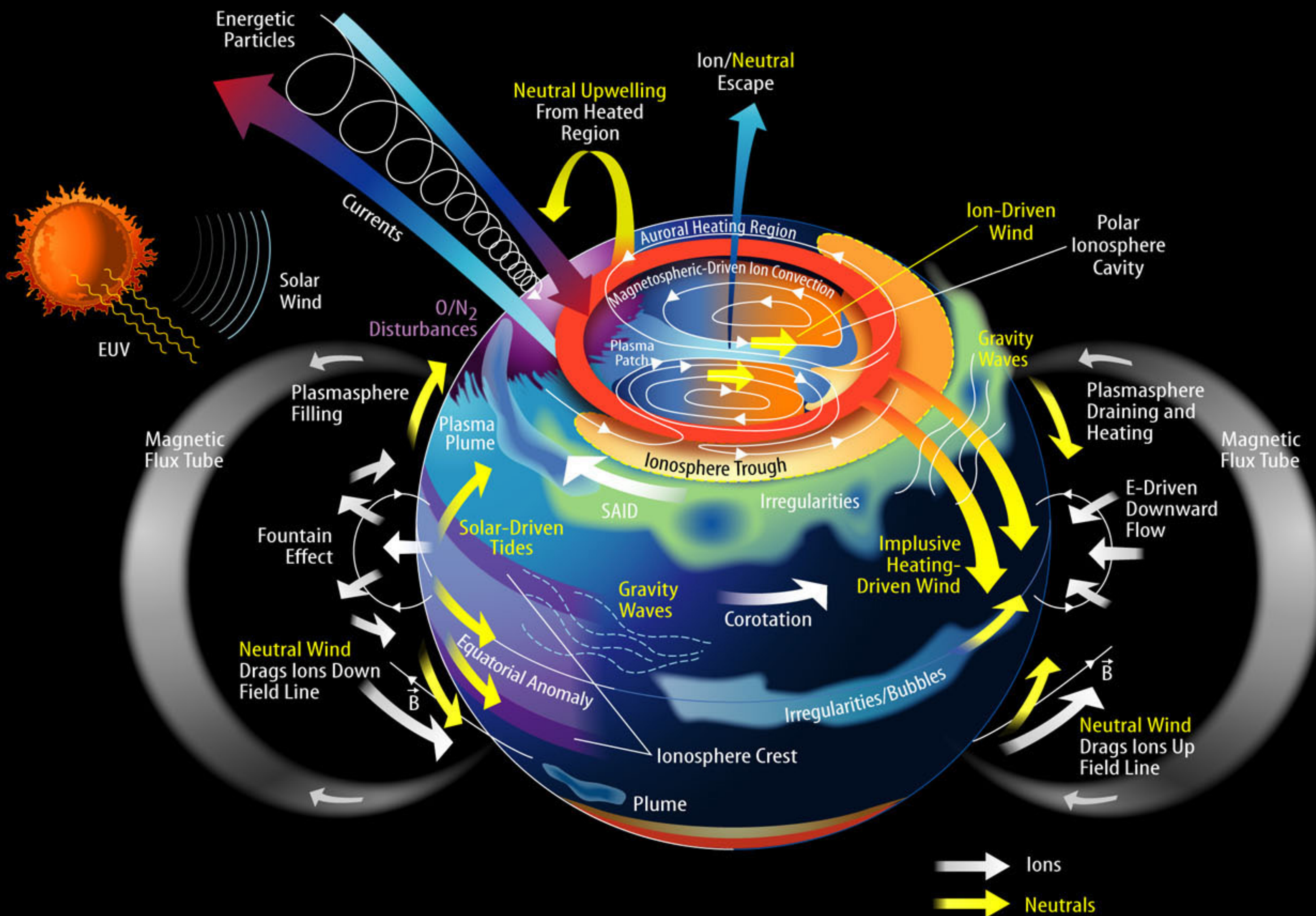
Satellite Impacts During Storm Period: October 19 – November 7, 2003

Approximately 53% of Earth and Space science missions were impacted (NASA/GSFC)

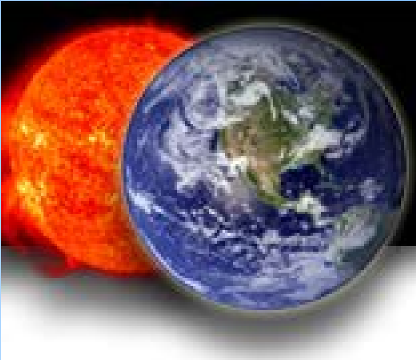
Examples include:

Mars Odyssey Probe :	Spacecraft entered safe mode; MARIE instrument failed
Stardust Mission:	Spacecraft entered safe mode
SMART-1:	Three auto shut-downs of engines in lunar transfer orbit
Mars Explorer Rover:	Entered idle mode due to excessive star tracker events
Microwave Anisotropy Probe:	Star tracker resets
Mars Express:	Star tracker unusable – relied on gyroscopes
ADEOS-2:	Total loss

Ionosphere is Impacted from Space and from the Atmosphere

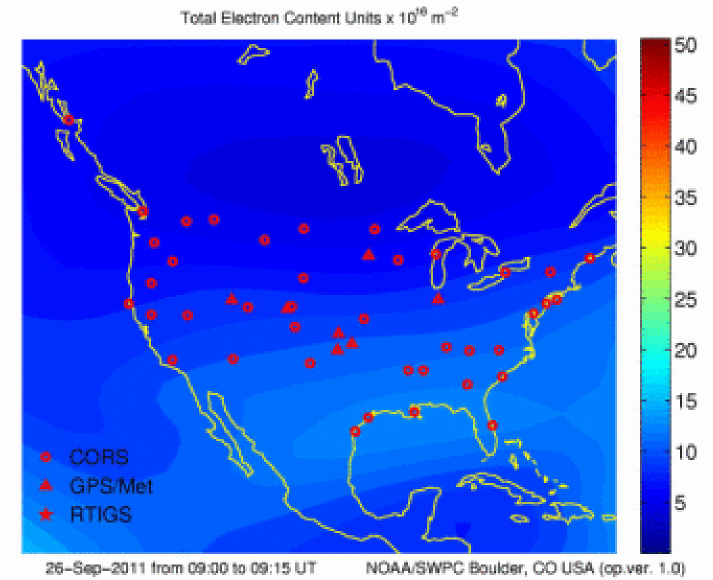


J. Grebowsky / NASA GSFC

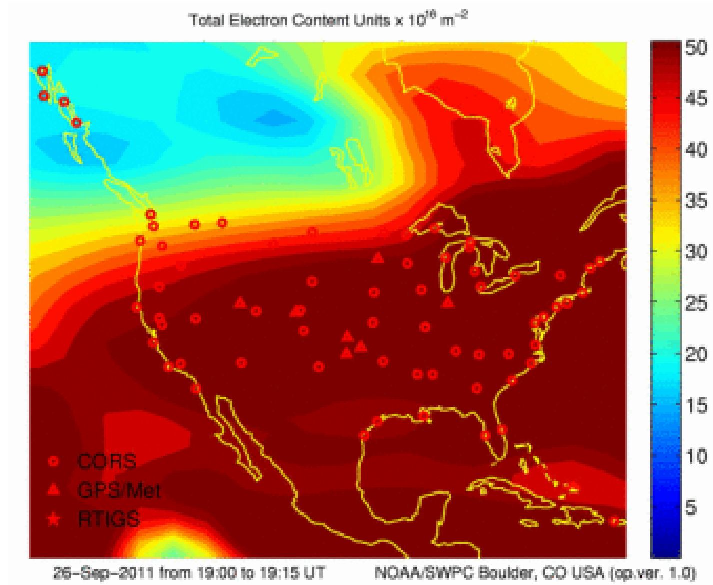


Ionospheric Total Electron Content (TEC) Variability Impacts GPS Accuracy

September 26, 2011 Geomagnetic Storm



0900 UT



1900 UT

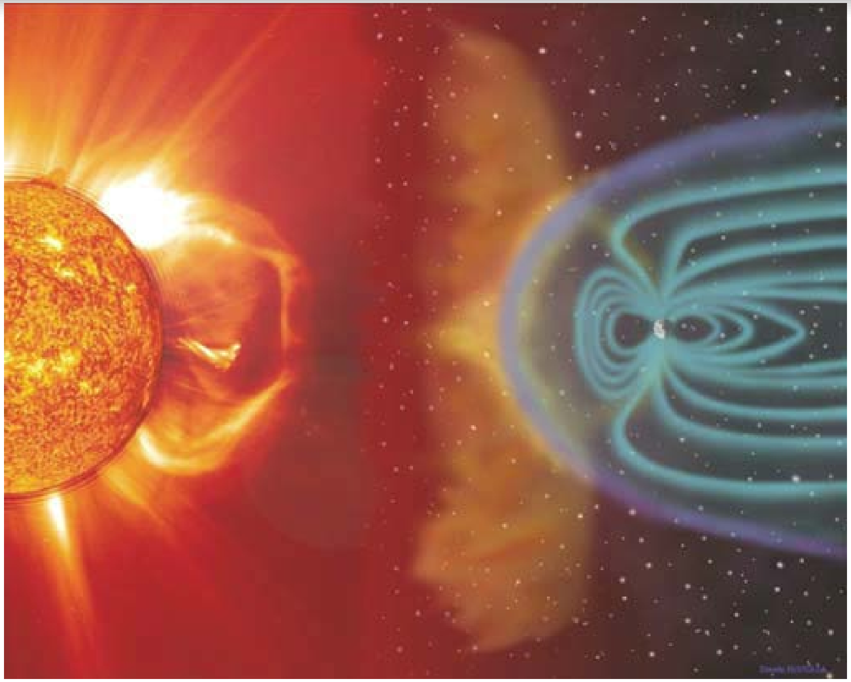
The Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS), a system of GPS signal corrections for aircraft navigation, was impacted by the current geomagnetic storm.

During the geomagnetic storm, the WAAS signals were unreliable.

Space Weather in the World Meteorological Organization (WMO)

- Benefits of WMO involvement:
  - Increased global awareness
  - International frameworks to coordinate data and services
  - Advocacy for data and services
  - Shared service responsibilities
  - Engagement with partners

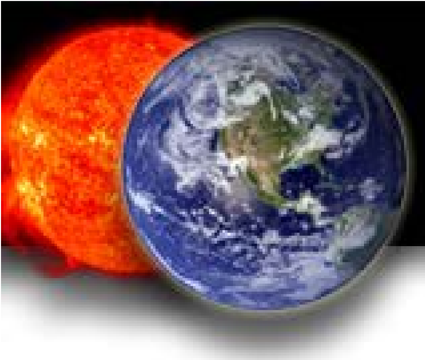
WMO can be used to advocate for the data and services needed for space sustainability



THE POTENTIAL ROLE OF WMO IN SPACE WEATHER

A REPORT ON THE POTENTIAL SCOPE, COST AND BENEFIT OF A WMO ACTIVITY IN SUPPORT OF INTERNATIONAL COORDINATION OF SPACE WEATHER SERVICES, PREPARED FOR THE SIXTIETH EXECUTIVE COUNCIL

April 2008



Inter-Programme Coordination Team for Space Weather

- Australia – Phil Wilkinson
- Belgium – Ronald Van der Linden
- Brazil – Hisao Takahashi
- Canada – Larisa Trichtchenko
- China (Co-chair) – Xiaoxin Zhang
- Colombia – Jaime Villalobos Velasco
- Ethiopia – Yitaktu Tesfatsion

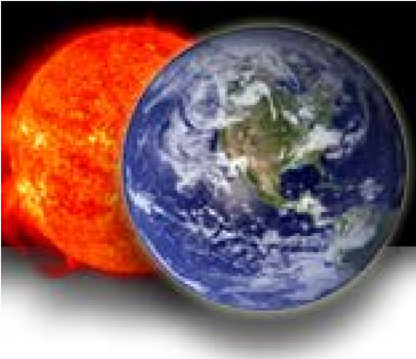
- Finland – Kirsti Kauristie
- Japan – Ken Murata
- South Korea Seok-Hee Bae, Daeyun Shin
- Russian Federation – Vyacheslav Burov
- United Kingdom – David Jackson
- United States (Co-chair) – Terry Onsager, Jim Head, Joe Davila, Kelly Hand

- European Space Agency – Alain Hilgers
- International Civil Aviation Organization – R. Romero
- International Space Environment Service – David Boteler
- International Telecommunication Union – Sergio Buonomo
- UN Office of Outer Space Affairs – Hans Haubold
- WMO – Jerome Lafeuille

ICAO – WMO Coordination

Example: ICAO – WMO Coordination

- International Civil Aviation Organization
  - Develop operational requirements for space weather information
  - Develop space weather training materials
  - Coordinate operational service and data requirements with WMO team
- WMO Space Weather Team
  - Obtain service requirements from ICAO team
  - Identify observations required to provide services
  - Standardize data exchange
  - Harmonize end products and services



Additional United Nations Space Weather Activities

- International Committee on GNSS
  - GNSS Interference Detection and Mitigation
  - Cooperate to predict and to detect natural interference
  - Utilize space weather service infrastructure for disseminating information on GNSS interference

- Committee on Peaceful Uses of Outer Space – Long-Term Sustainability of Space Activities – Space Weather Working Group
  - Collection, sharing, and dissemination of information
  - Coordinate ground-based and space-based observations

- International Space Weather Initiative
  - Encourage deployment of research instruments

Summary

- Space weather affects a wide variety of space sustainability issues
- Space weather services include historical data, real-time information on current conditions, and event forecasts
- International coordination efforts are expanding
- WMO and other UN activities can provide advocacy for data and services needed to support sustainable space activities