

Space Weather: Origins and Impacts

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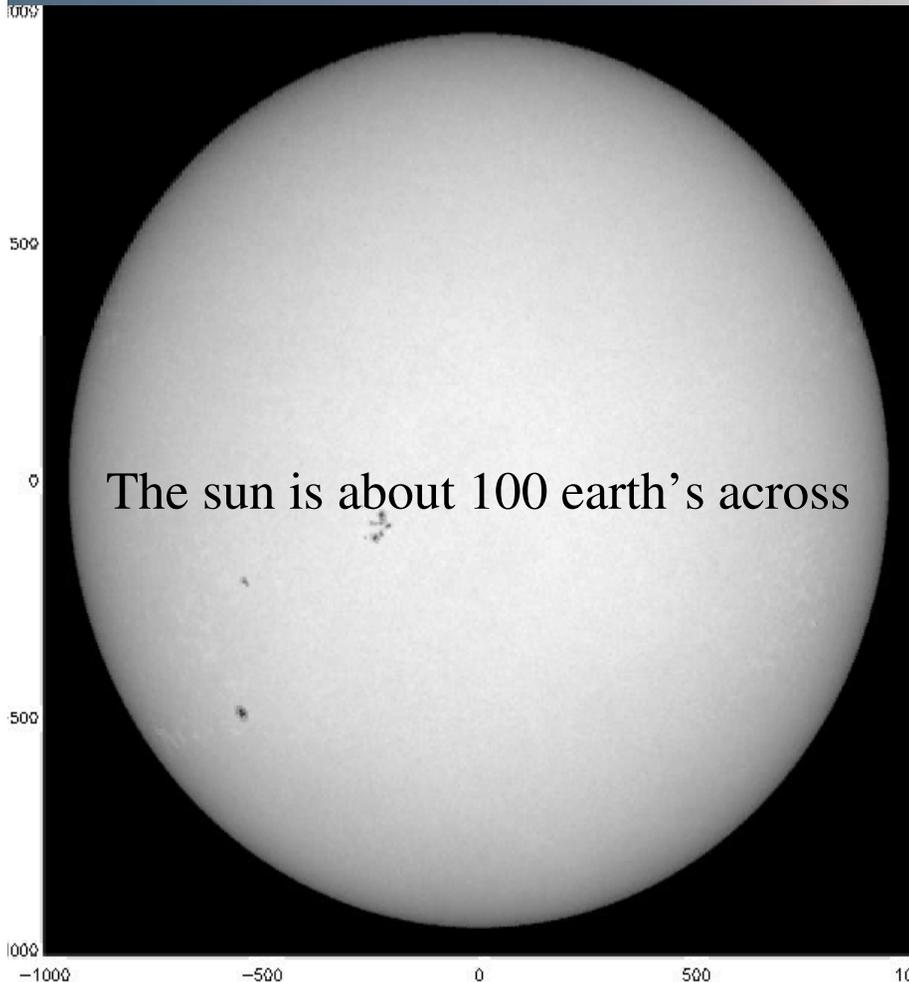
U.S. Department of State

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Acknowledgements: Dr. Tom Bogdan

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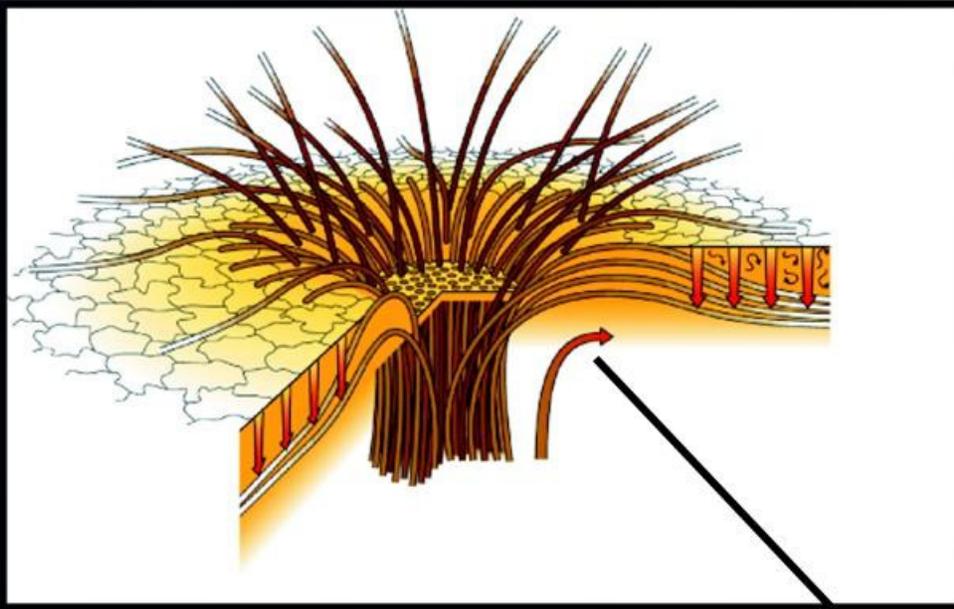
Space Weather comes
from the sun



There are temporal changes in
the sun's radio and EUV flux
(100 – 1000x)

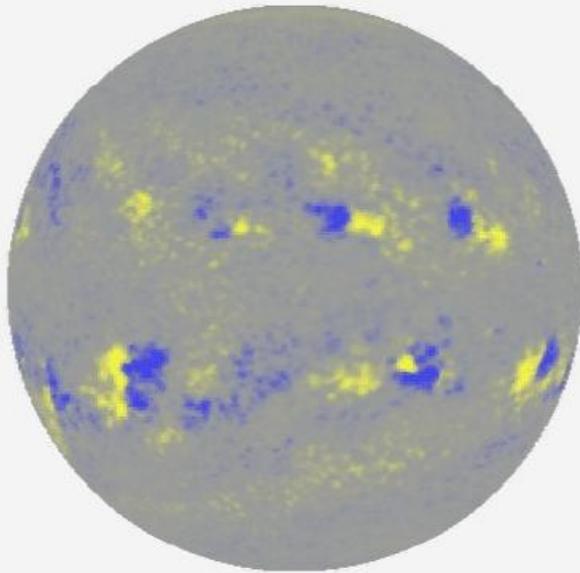
The sun sheds portions of its
atmosphere

These are due to interactions
between the sun's magnetic
field and its outer convecting
layer of plasma.

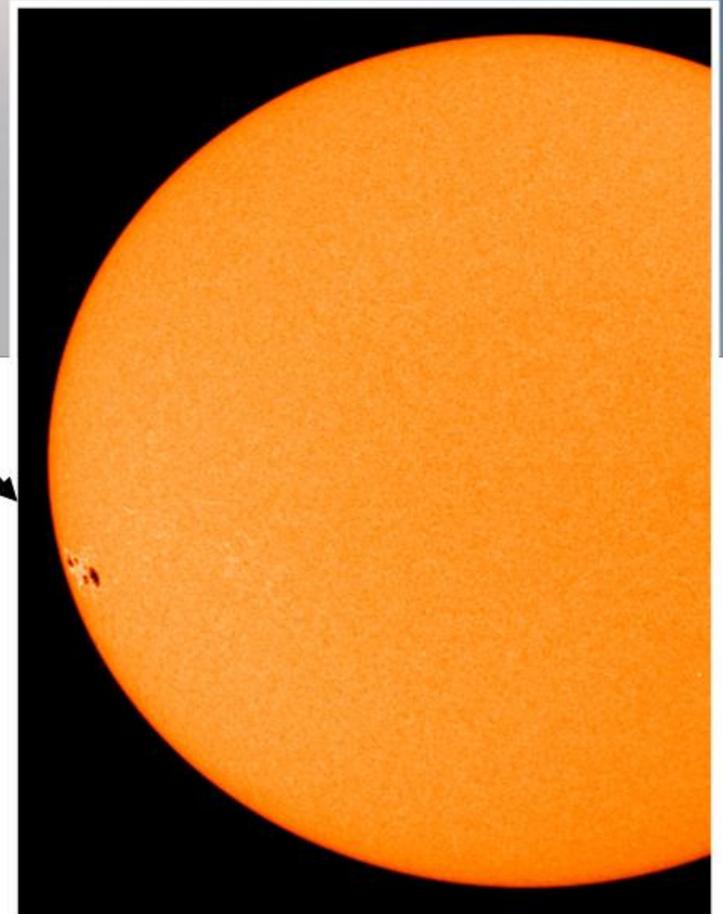


Plasmas and Frozen-in
Field Lines

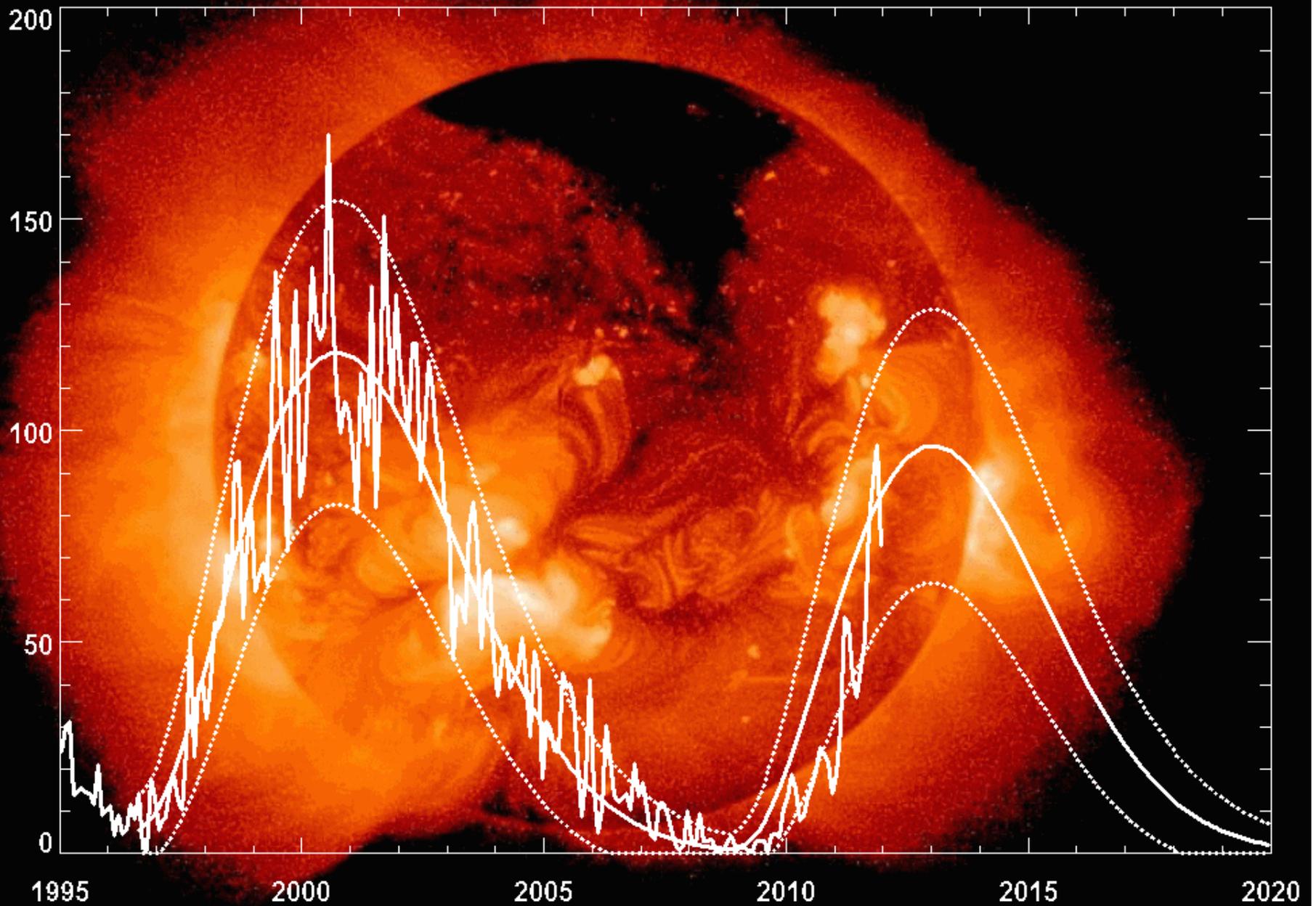
Convection can
concentrate magnetic field



N-S Pole Pairs



Cycle 24 Sunspot Number Prediction (January 2012)



Hathaway/NASA/MSFC

THREE VARIETIES OF SPACE WEATHER

“SPACE TORNADOS”

FLARES: photons, energetic ions

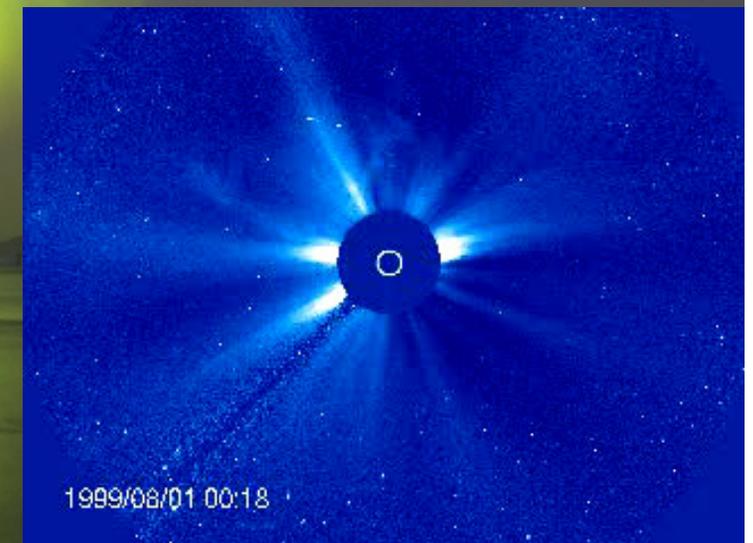
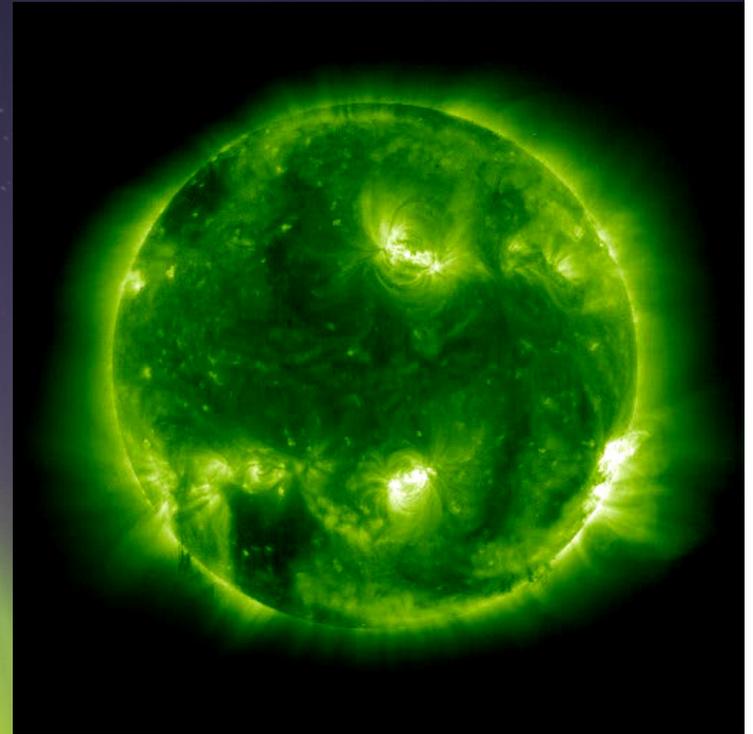
“SPACE HURRICANES” or “SOLAR TSUNAMIS”

***CORONAL MASS EJECTIONS:
plasma, magnetic field, energetic ions,
energetic electrons***

“SPACE WEATHER”

SOLAR WIND: thermal plasma, energetic electrons

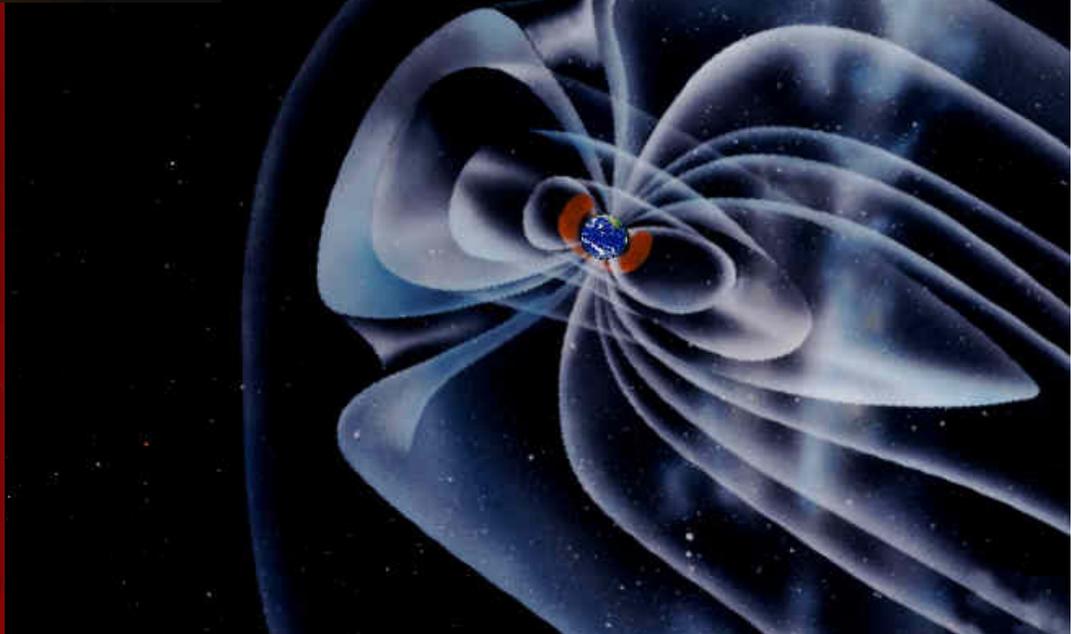
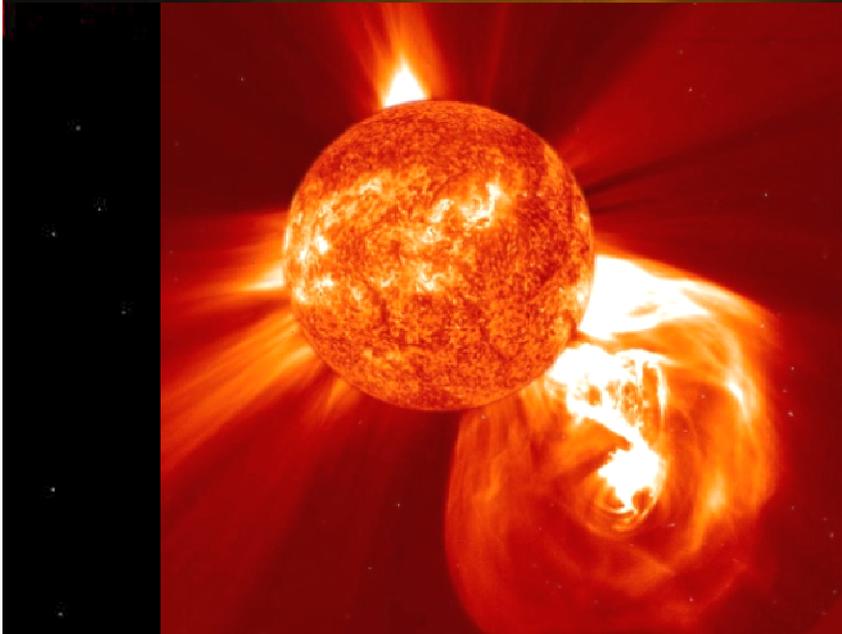
***We have limited forecasting ability that is dependent
on the nature of the particular event***





When the sun sheds atmosphere, the magnetic field goes with it

This can modify earth's magnetic field

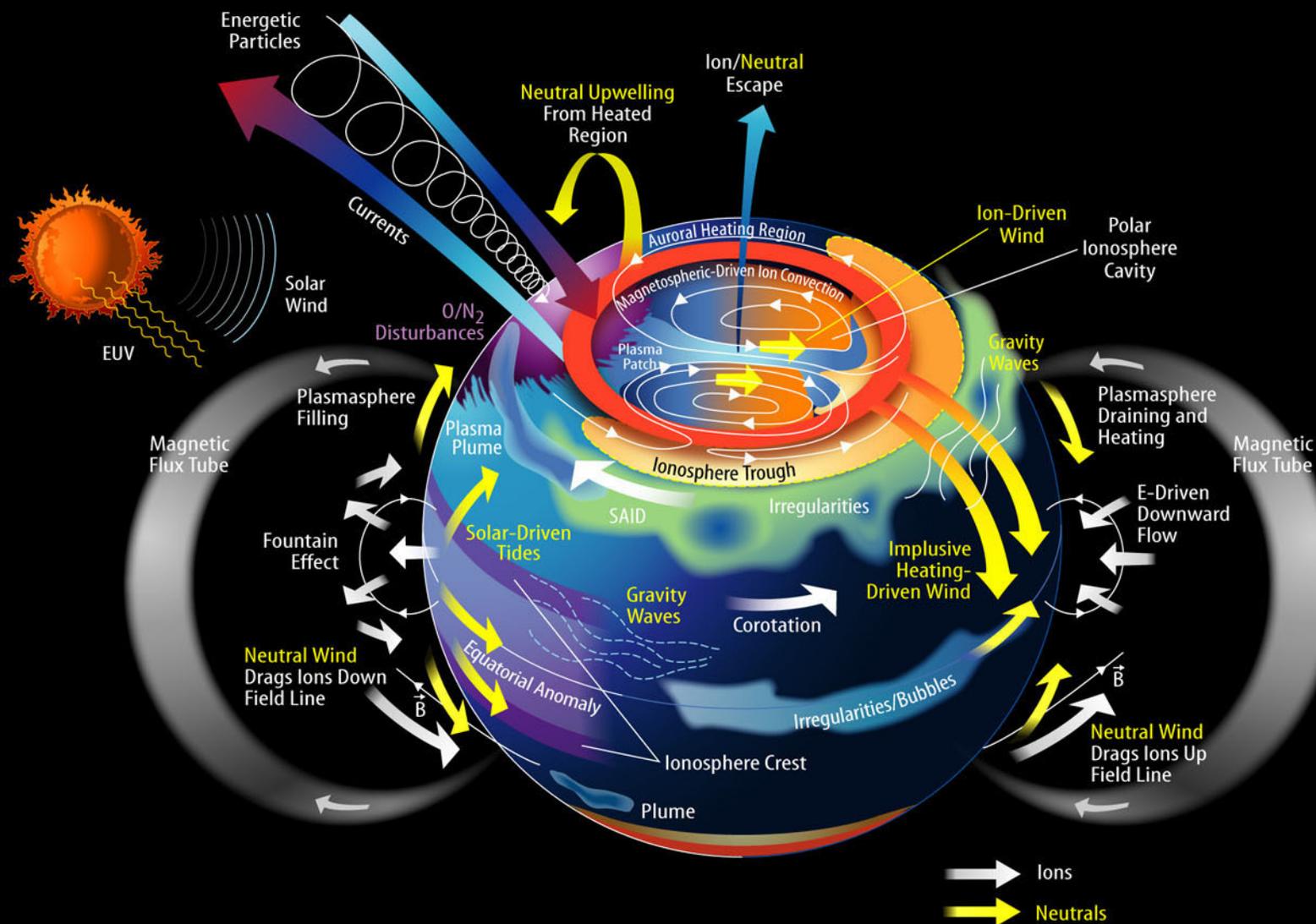


Space Weather Effects Summary

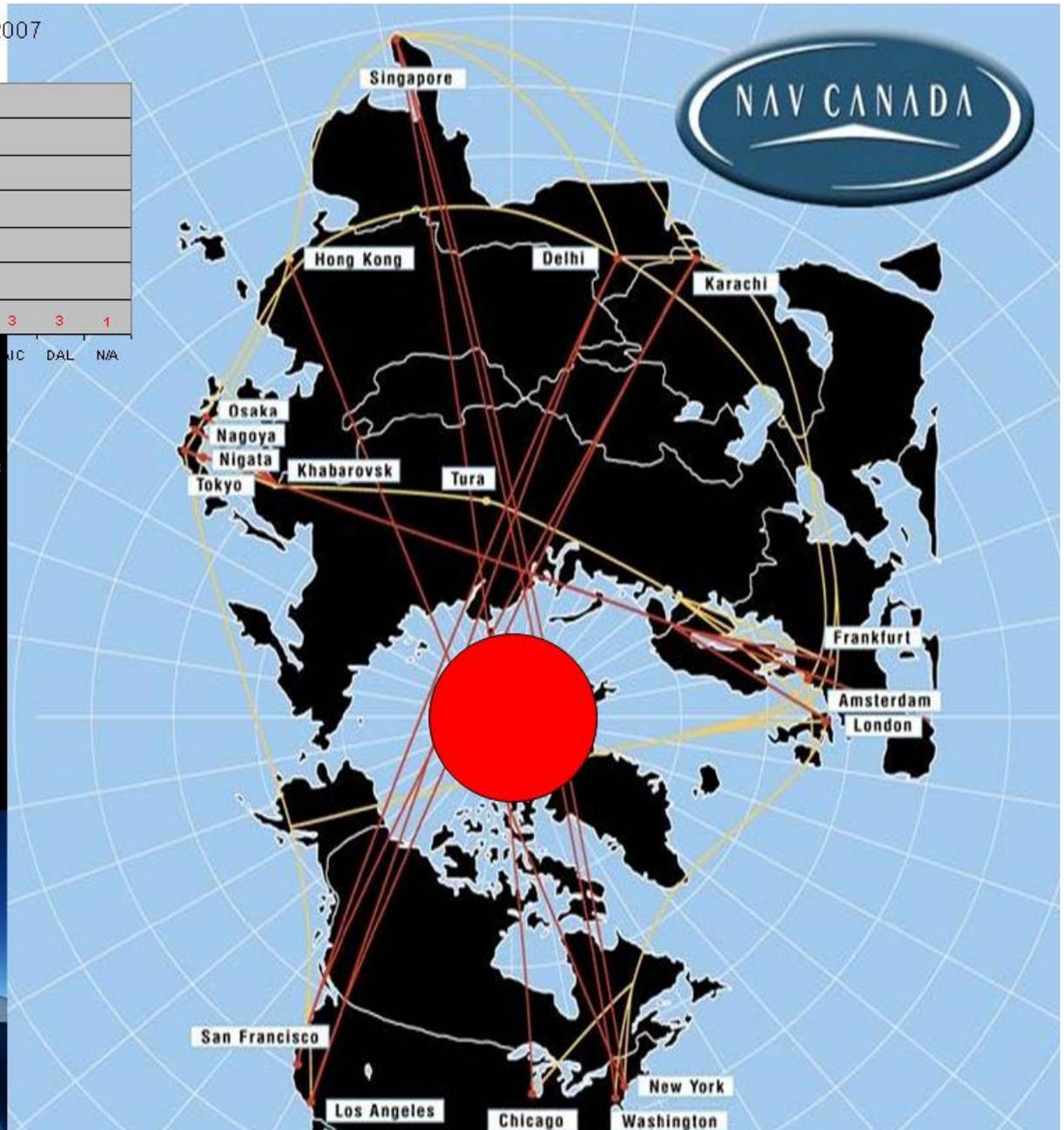
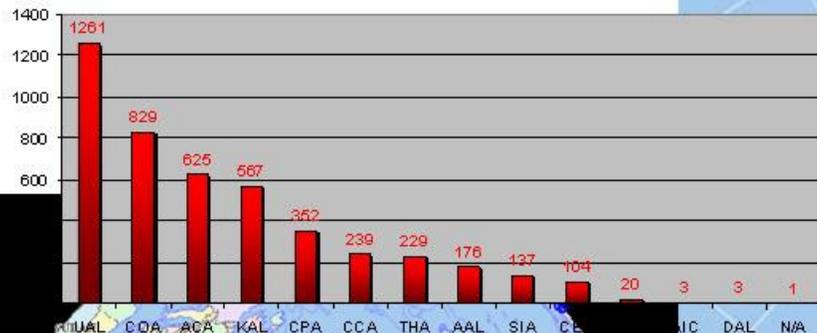
- **Flares** (warning time is zero; 10 min to 2 days)
 - EUV swells the atmosphere – increased drag, space situational awareness
 - Ionospheric effects can hamper or deny communications and navigation signals
 - Radio noise can jam GPS
 - Radiation can damage or destroy satellite electronics and solar cells
- **CMEs** (warning time is 1.5 to 4 days)
 - Induced currents can cause blackouts, enhance pipeline corrosion
 - Radiation can damage or destroy satellite electronics, solar cells
- **Solar Wind** (warning time is an hour to a month)
 - Radiation can damage or destroy satellite electronics, solar cells

**Solar events have not increased in strength or ferocity;
We've increased our reliance upon vulnerable systems**

Ionosphere is Impacted from Space and from the Atmosphere



Annual Traffic Per Carrier in Jan - Aug 2007



Loss of HF communications at high latitude, excessive radiation at high latitude, high altitude

Impacts on Communication on the Dayside Hemisphere and Polar Regions

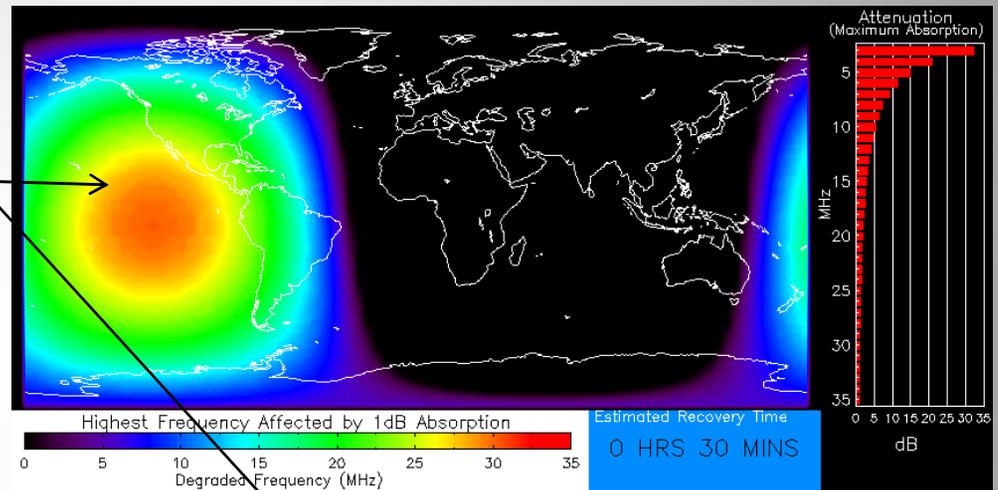
2011 March 7 20 UTC

X-Ray Flares create HF radio communication outages over the daylight region

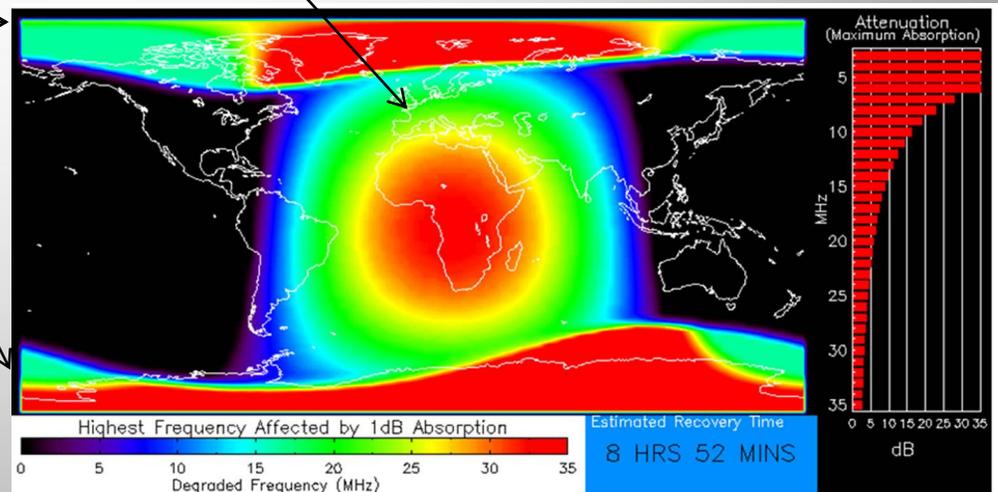
Energetic Particles create HF Radio communication outages and increased radiation at high latitudes

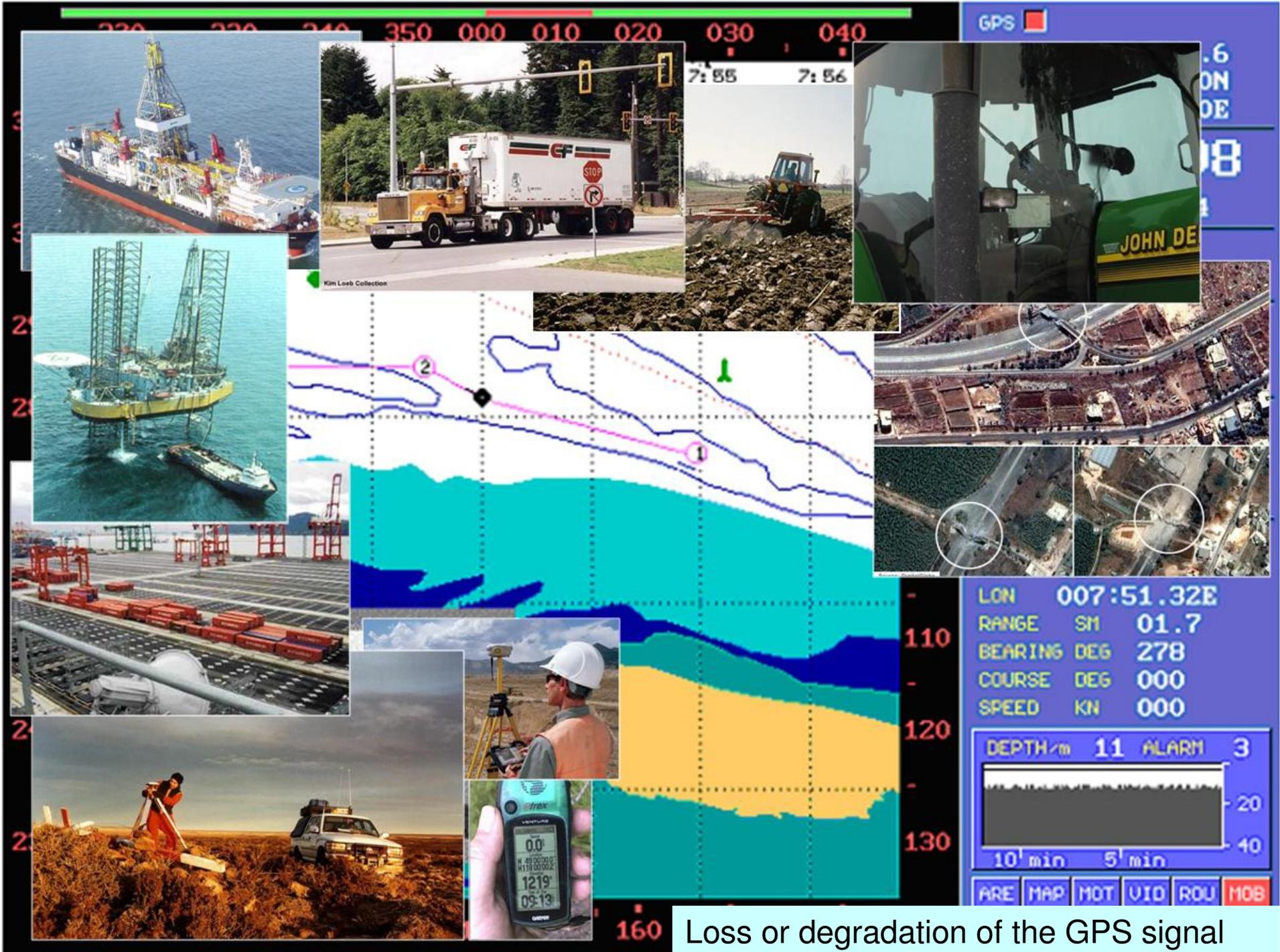
HF Communication is critical for:

- Commercial Airlines
- Humanitarian Operations
- Numerous other applications



2011 March 8 10:48 UTC





Loss or degradation of the GPS signal

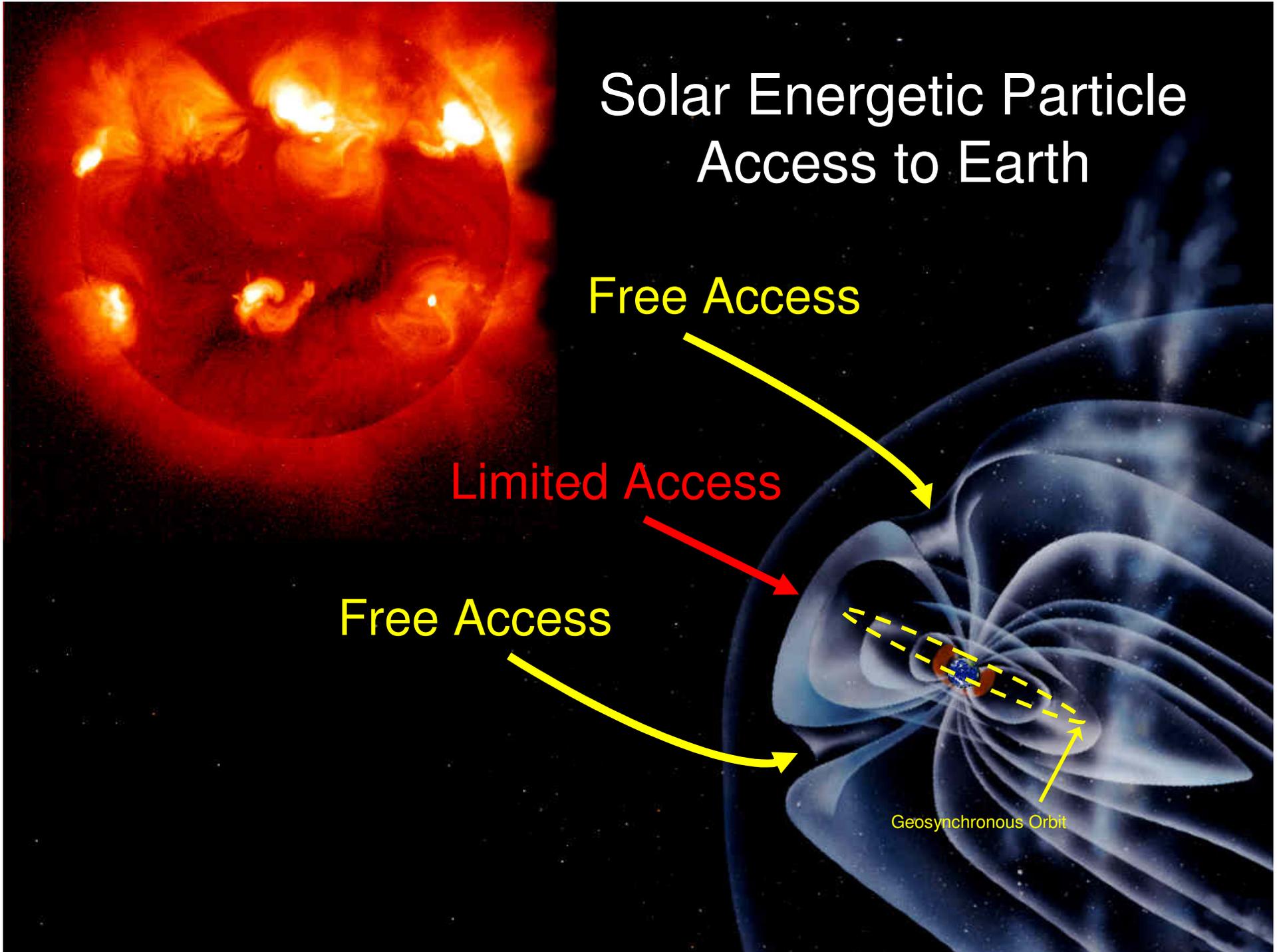
Solar Energetic Particle Access to Earth

Free Access

Limited Access

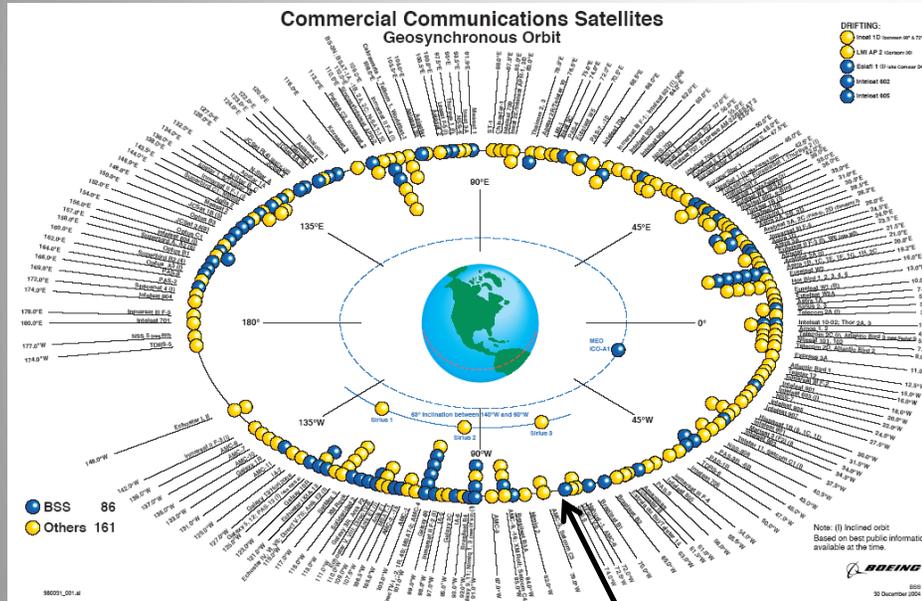
Free Access

Geosynchronous Orbit

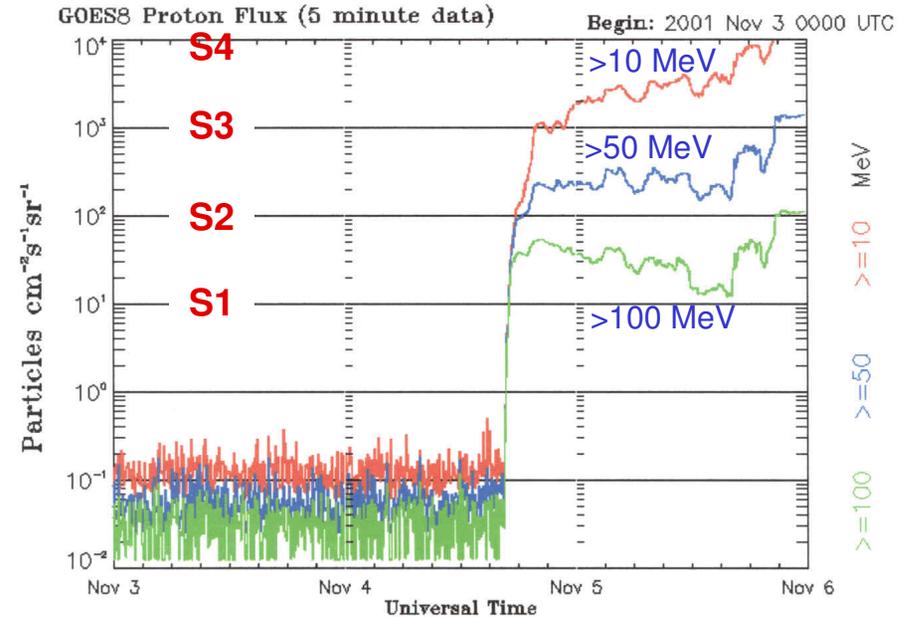


Solar Energetic Particles Impact On-Orbit Satellites

Satellites in Geostationary Orbit

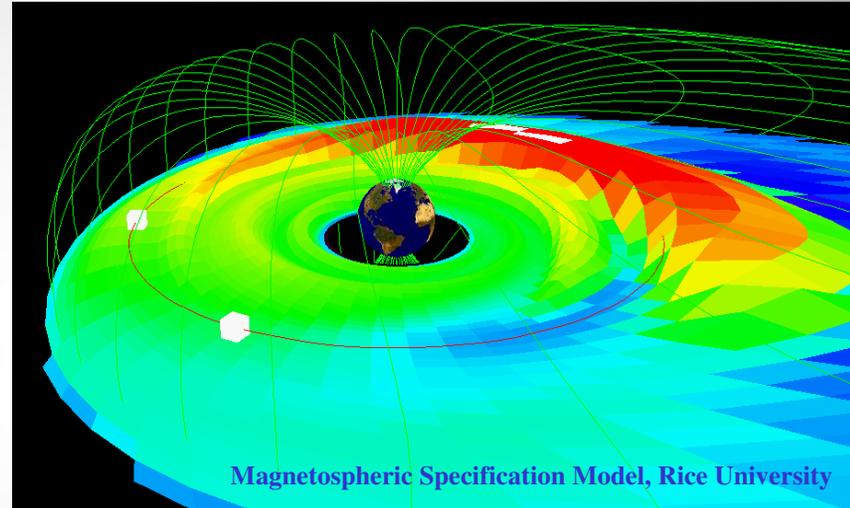
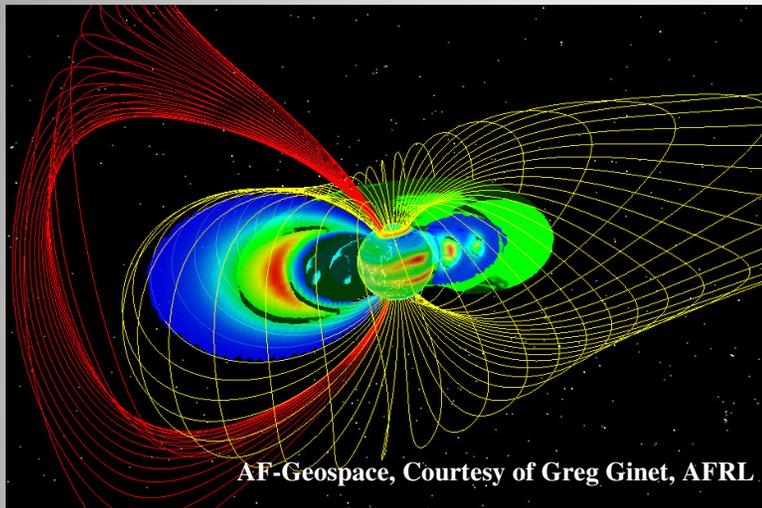


Solar Radiation Storm



NOAA GOES Satellite Measurements

Electron Environment and Spacecraft Charging



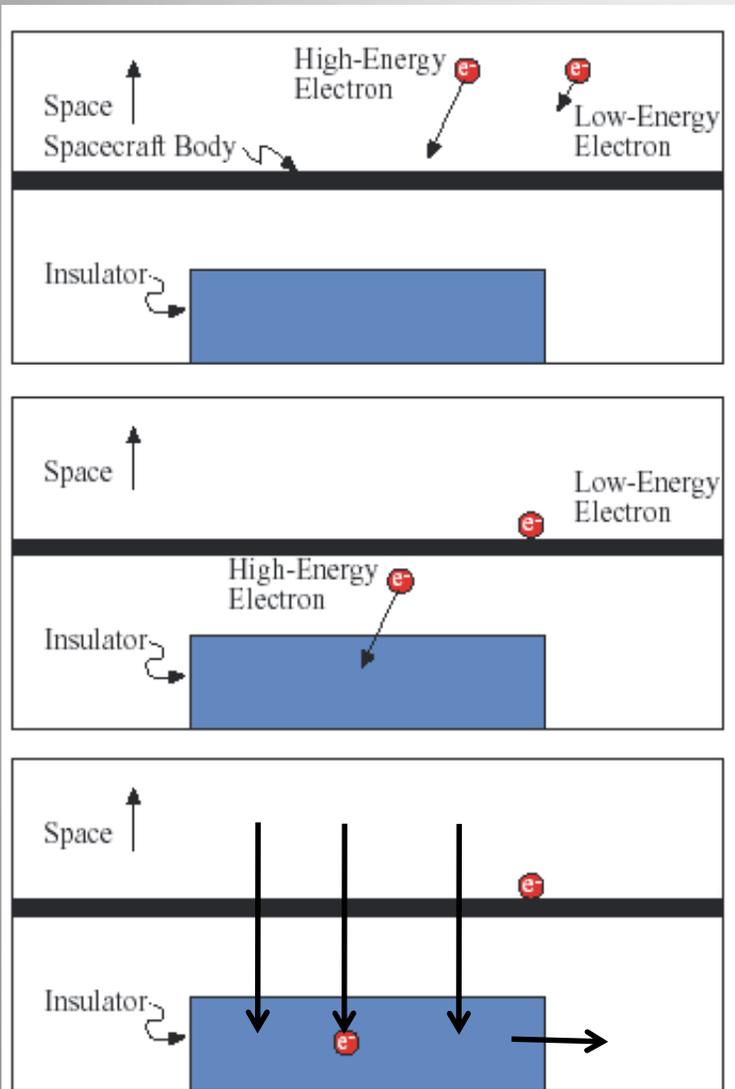
Radiation belt electrons: > 500 keV Deep dielectric charging

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.

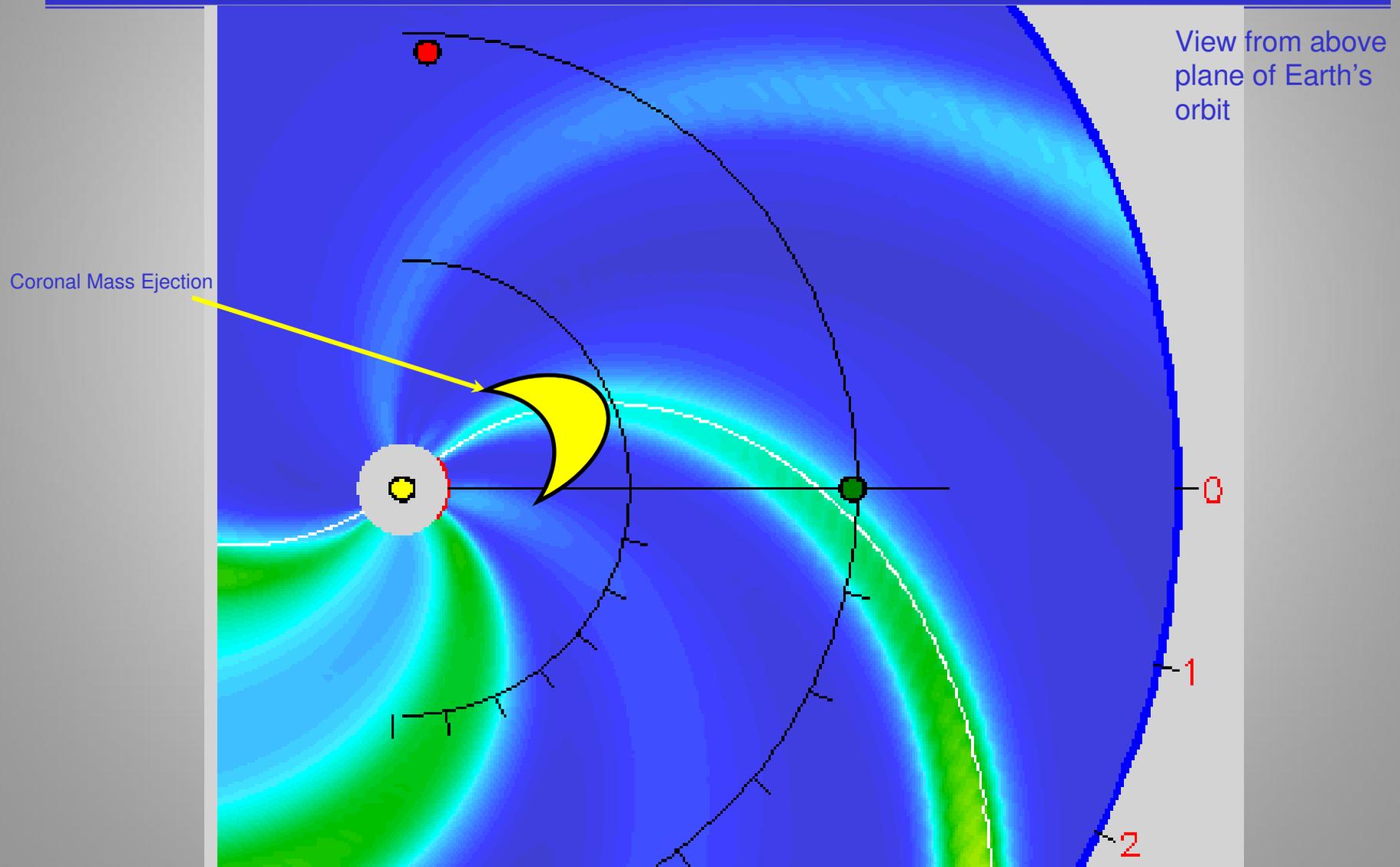
Satellite Impacts During Storm Period: October 19 – November 7, 2003

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

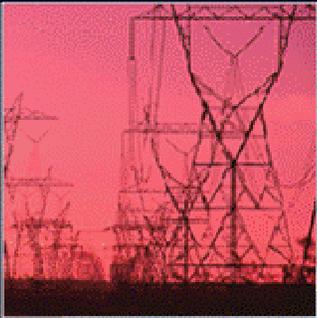
Fast Coronal Mass Ejections: Carry magnetic field to the earth, produce radiation



Moving magnetic field induces electrical currents
(Faraday's Law)

Induced currents can burn out transformers

Extremely high voltage transformers are particularly vulnerable and difficult to replace



Prediction and mitigation requires both space-based and global terrestrial instrumentation



**This job is too big for any one nation:
International Cooperation is Required**