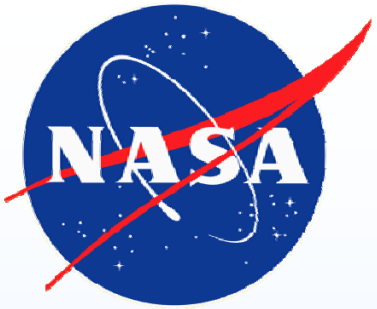

The Space Radiation Environment as It Relates to Electronic System Performance:

Or Why Not to Fly Consumer Electronics Components in Space

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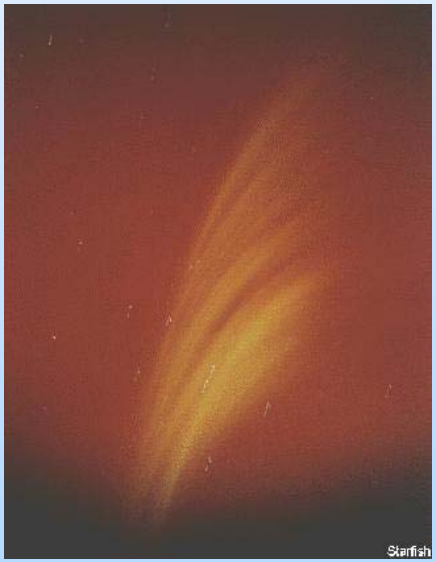
This presentation is supported by the NASA Electronic Parts and Packaging (NEPP) Program

Outline

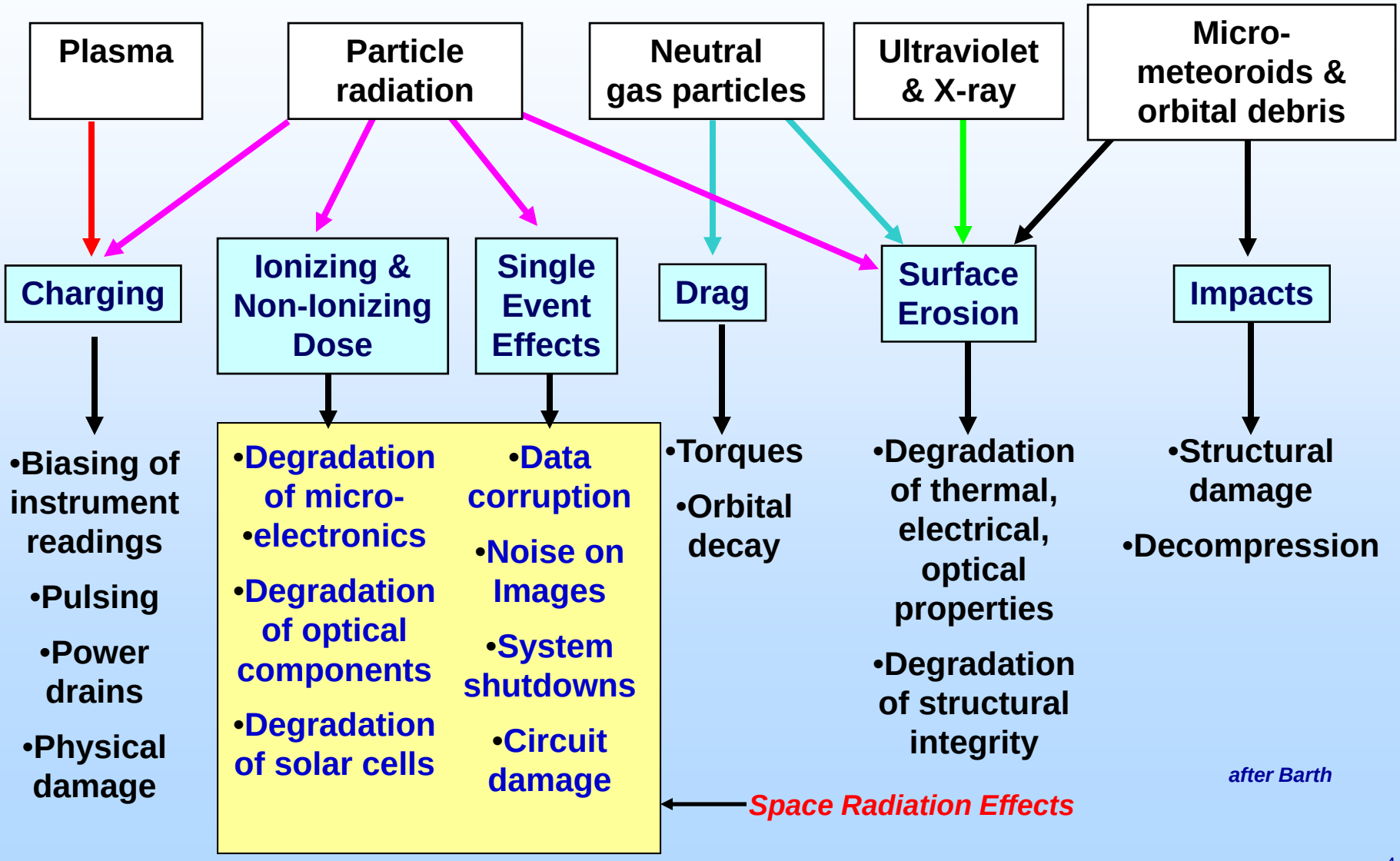
- The Space Radiation Environment Overview
- The Environment in Action
  - Solar Event from 2003
- Real Estate
  - Location and Timing
- Engineering Models
- Final Remark

The NATURAL Space Radiation Environment



STARFISH detonation –
Nuclear attacks are not considered in this presentation

Space Environments and Related Effects

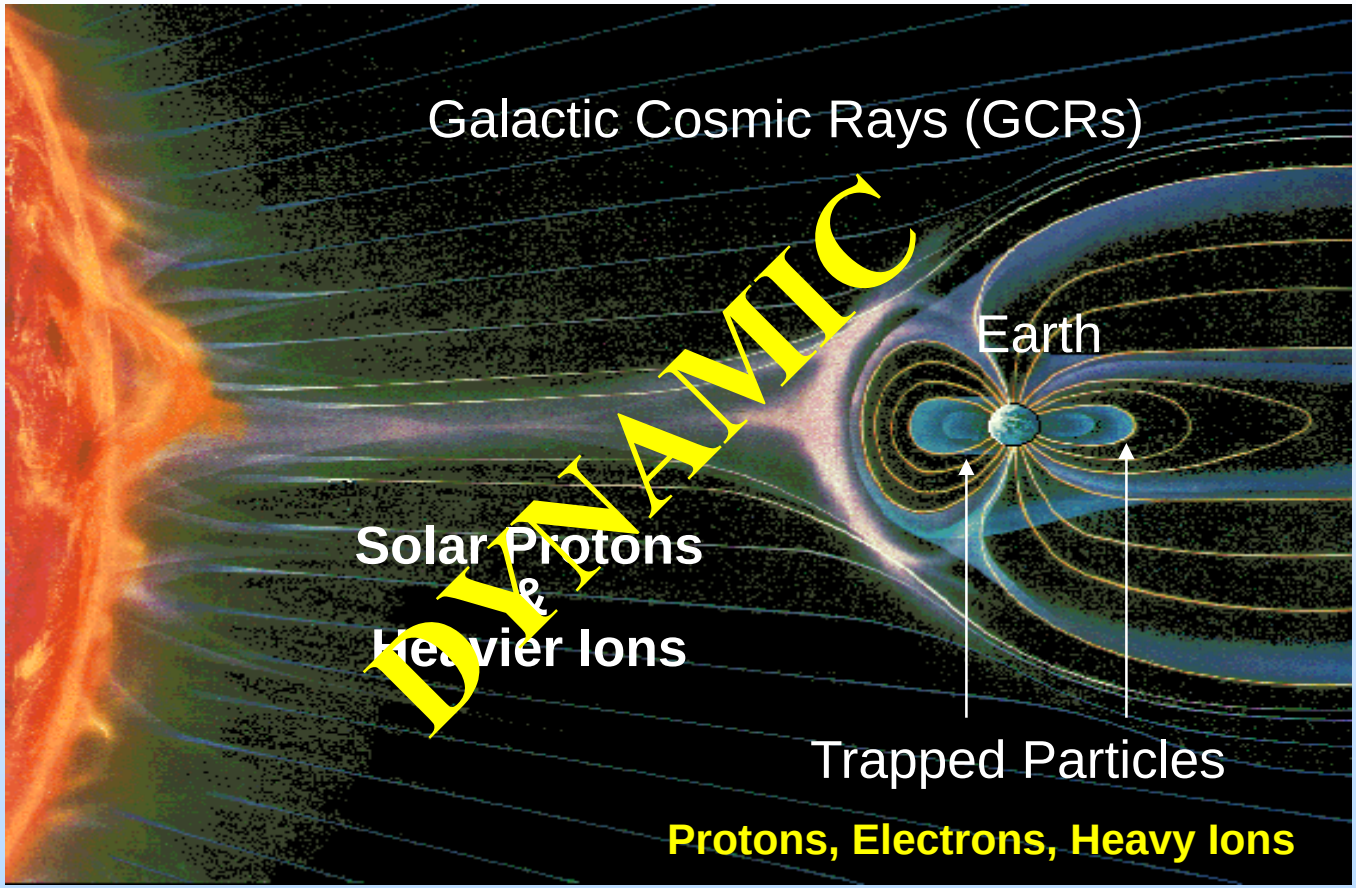


What is the Space Radiation Environment Hazard?

- Energetic particles
  - Protons. Electrons, Heavy ions (ex., charged Fe ion)
- Particles can come from the Sun
  - Ex., Solar events
- Particles can be “trapped”
  - Located within a magnetic field
    - Ex., Van Allen Belts
- Particles can come from somewhere else in the galaxy
  - Ex., Galactic Cosmic Rays (GCRs) – Heavy Ions of “unknown” origin
- Sun (solar cycle) acts as modulator for environment

Near-Earth Space Radiation Environment

after
Nikkei Science, Inc.
of Japan, by K. Endo

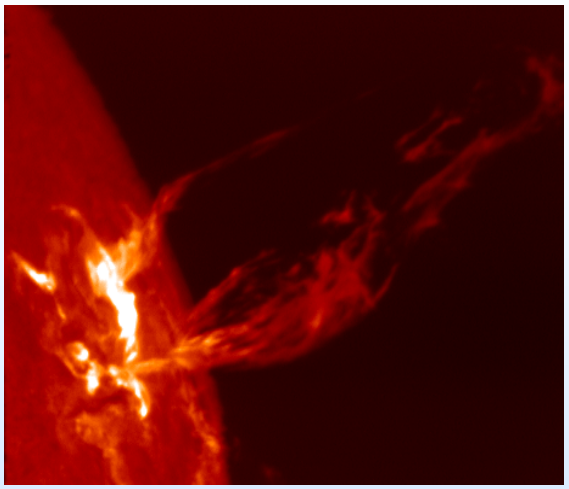


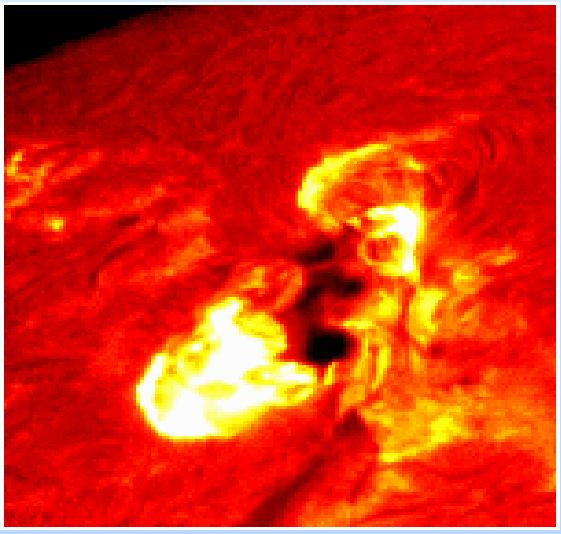
Deep-space missions may also see: neutrons from planetary background, nuclear source or other trapped particle belts
Atmosphere and terrestrial may see GCR and secondary particles

Solar Particle Events

- Cyclical (Solar Max, Solar Min)
  - 11-year AVERAGE (9 to 13)
  - Solar Max is more active time period
- Two types of events
  - Gradual (Coronal Mass Ejections – CMEs)
    - Proton rich
  - Impulsive (Solar Flares)
    - Heavy ion rich
- Abundances Dependent on Radial Distance from Sun
- Particles are Partially Ionized
  - Greater Ability to Penetrate Magnetosphere than GCRs
    - Also generates neutrons in the atmosphere

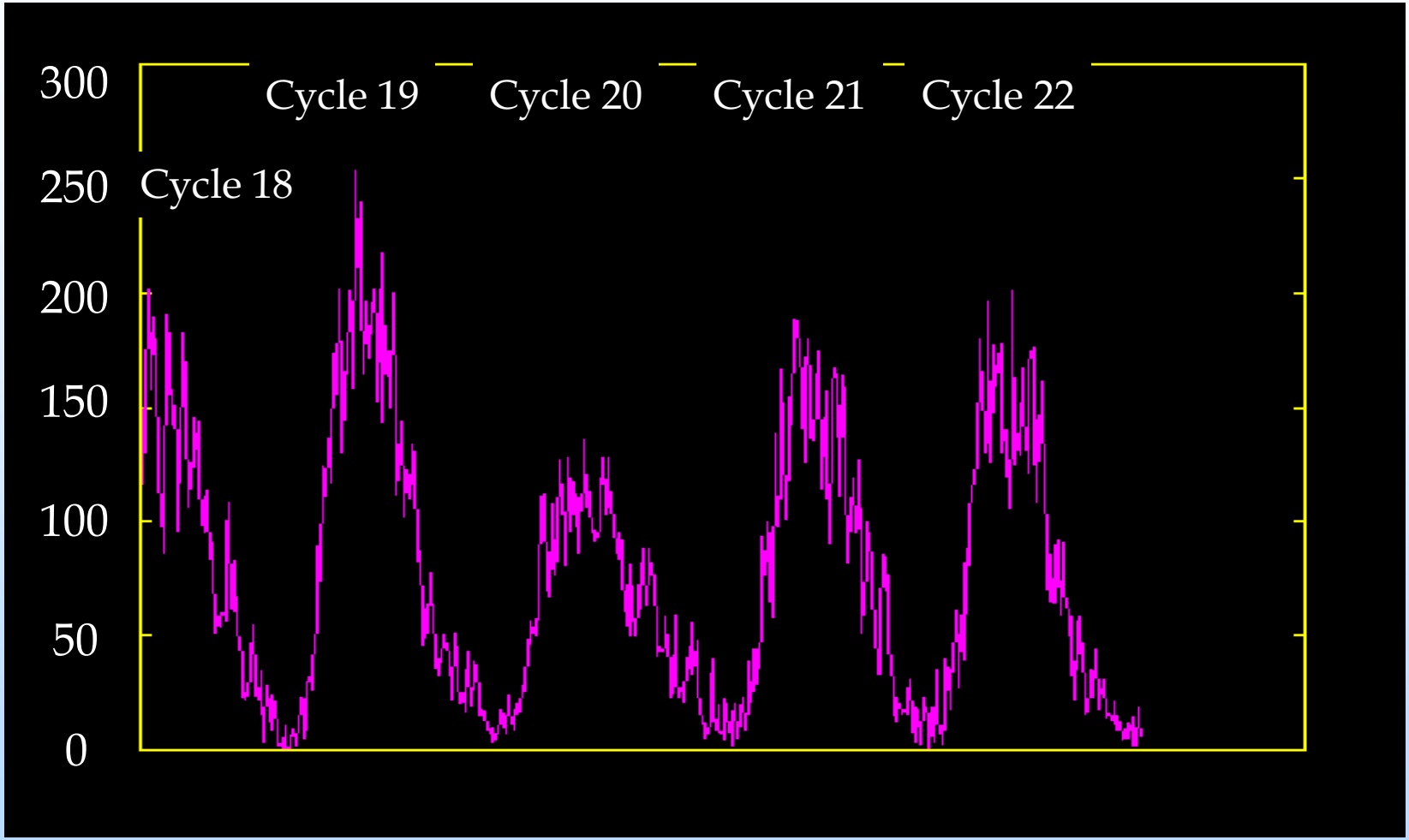
Holloman AFB/SOON





Sunspot Cycle: An Indicator of the Solar Cycle

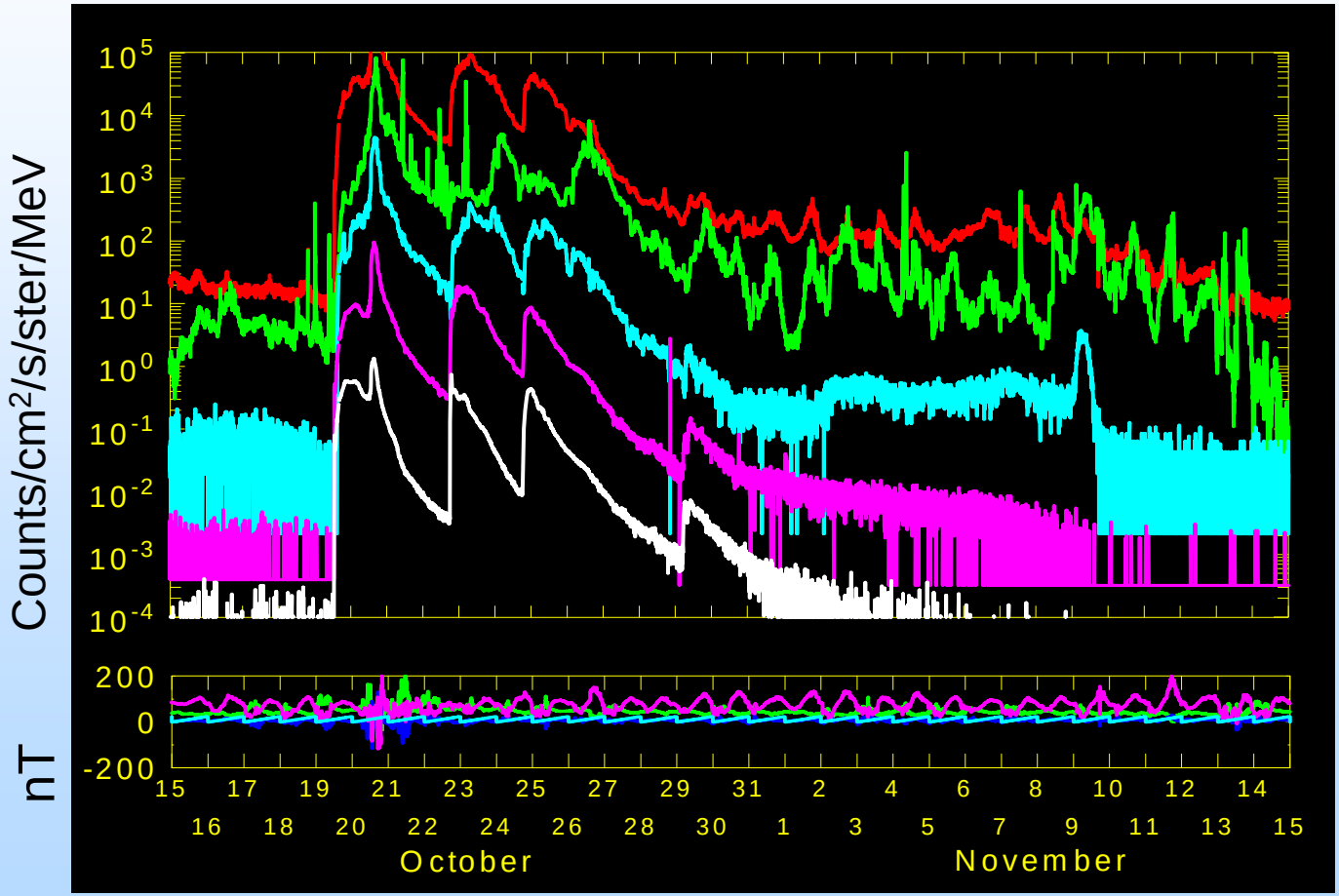
after Lund Observatory



Length Varies from 9 - 13 Years
7 Years Solar Maximum, 4 Years Solar Minimum

Solar Proton Event - October 1989

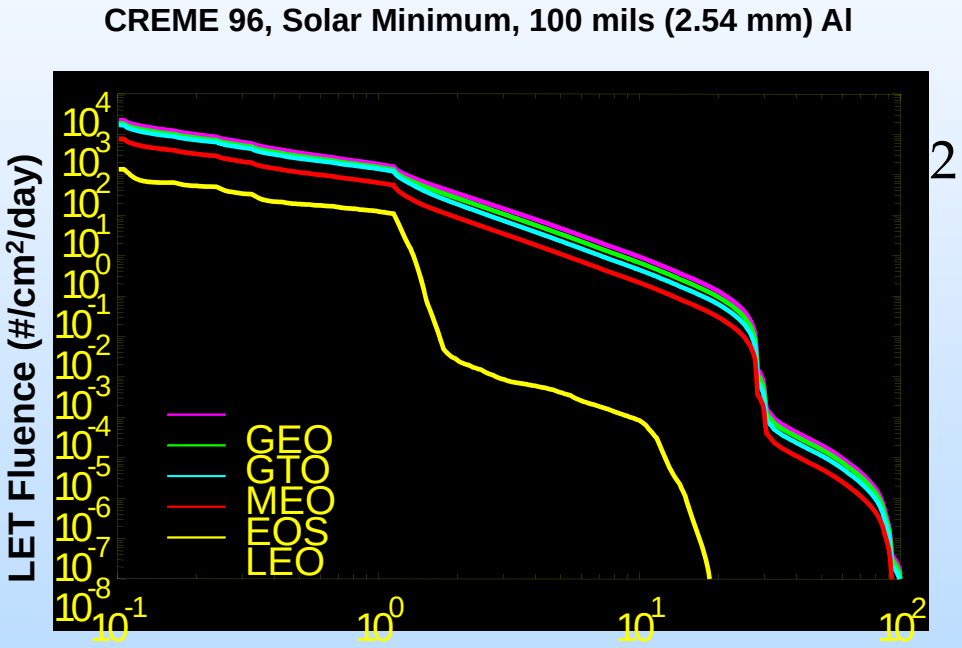
Proton Fluxes – "99% Worst Case Event"



GOES Space Environment Monitor

Free-Space Particles: Galactic Cosmic Rays (GCRs) or Heavy Ions

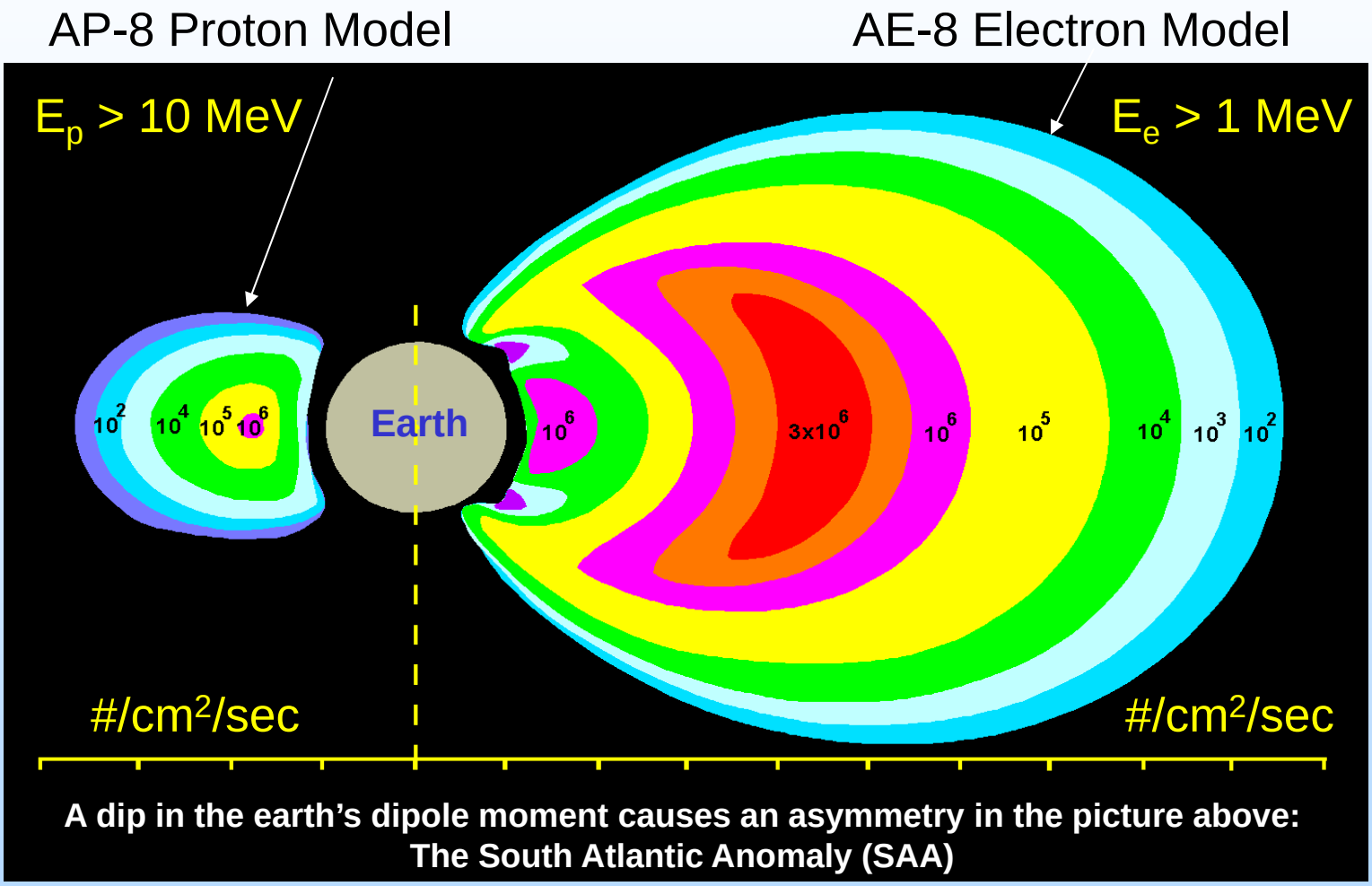
- **Definition**
  - **A GCR ion is a charged particle (H, He, Fe, etc)**
  - **Typically found in free space (galactic cosmic rays or GCRs)**
    - **Energies range from MeV to GeVs for particles of concern for SEE**
    - **Origin is unknown**
  - **Important attribute for impact on electronics is how much energy is deposited by this particle as it passes through a semiconductor material. This is known as Linear Energy Transfer or LET (dE/dX).**



Time

Commercial Technology Sensitivity

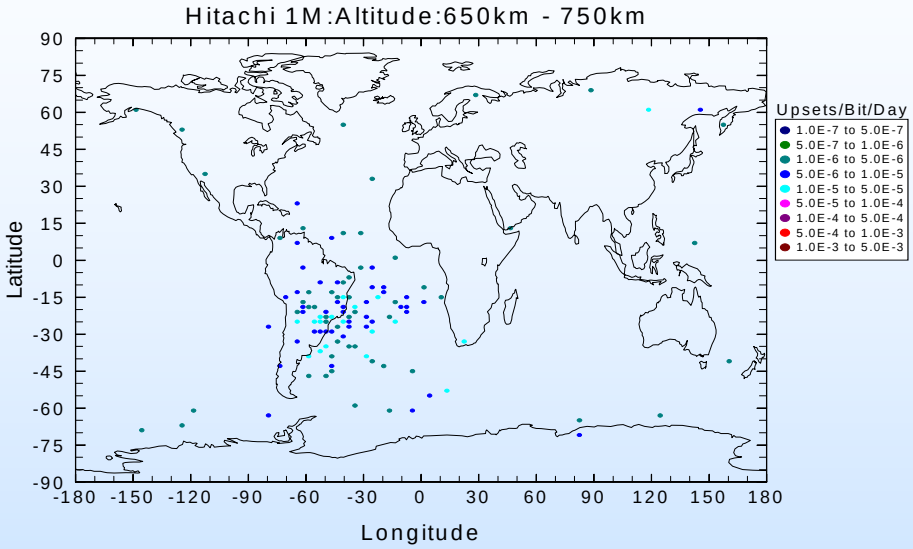
Trapped Particles in the Earth's Magnetic Field: Proton & Electron Populations

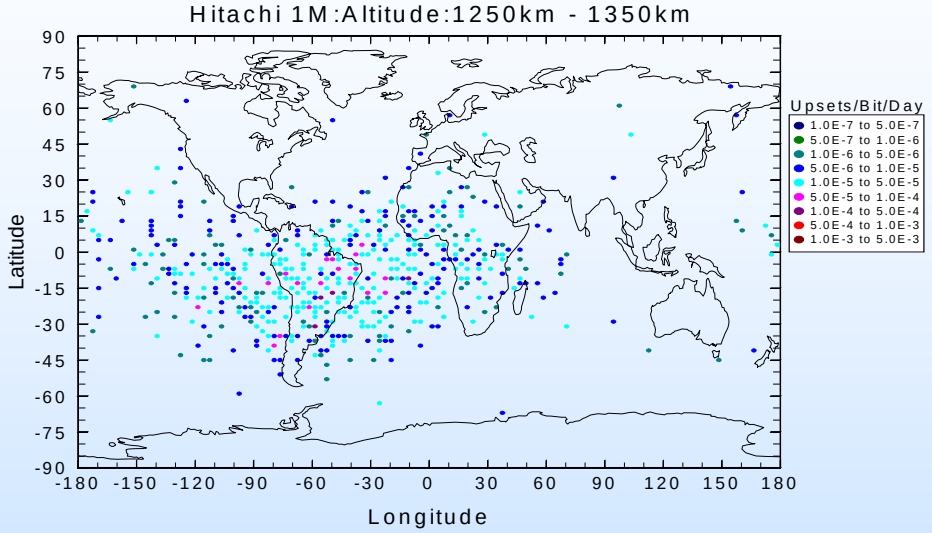


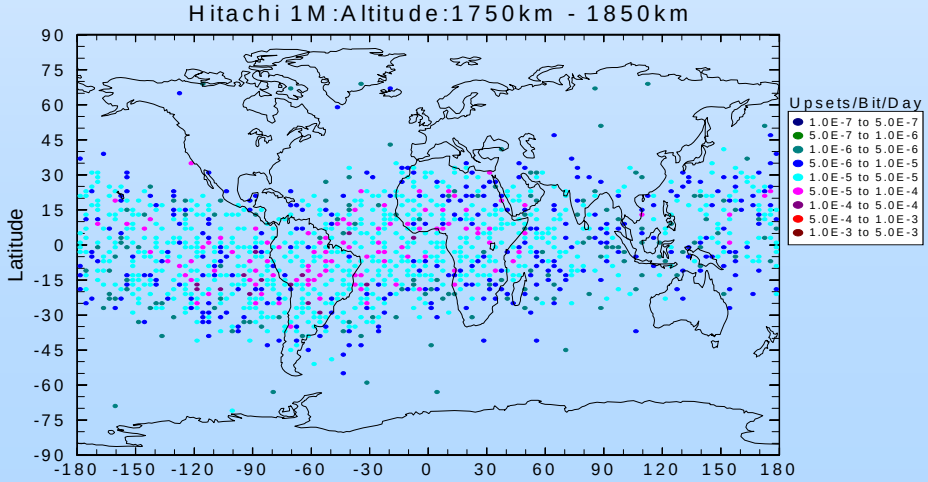
L-Shell

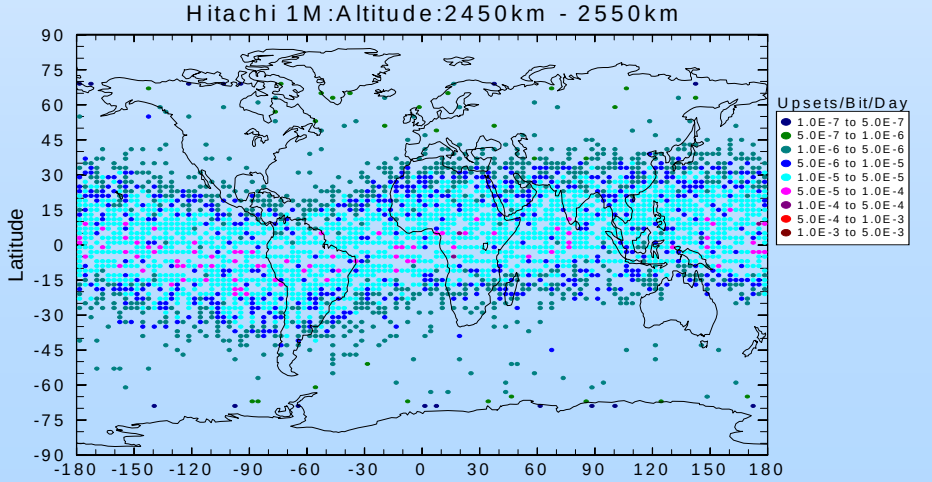
Geomagnetic cutoff implies some shielding protection from GCR and solar particles

SAA and Trapped Protons:
SRAM Upset Rates by Altitude Slices on CRUX/APEX



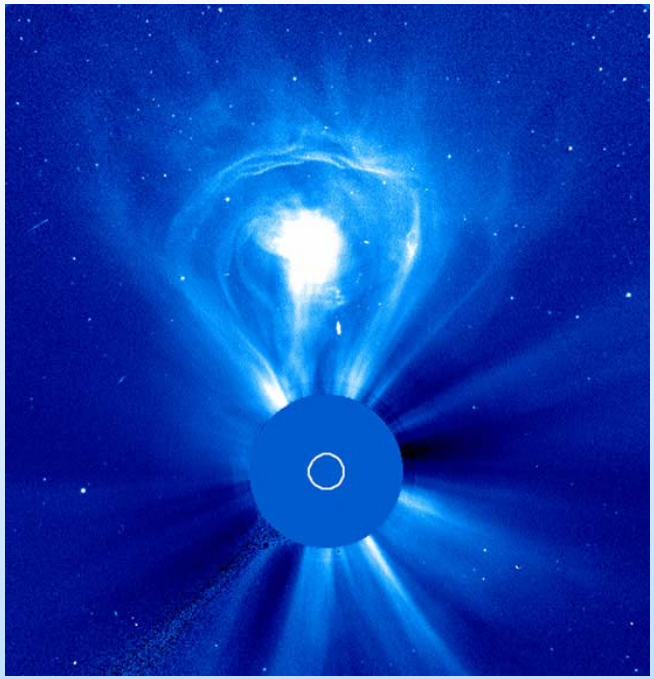






Solar Cycle Effects: Modulator and Source

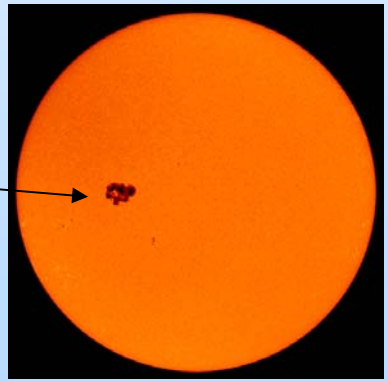
- **Solar Maximum**
  - Trapped Proton Levels Lower, Electrons Higher
  - GCR Levels *Lower*
  - Neutron Levels in the Atmosphere Are Lower
  - Solar Events More Frequent & Greater Intensity
  - Magnetic Storms More Frequent --> Can Increase Particle Levels in Belts
- **Solar Minimum**
  - Trapped Protons Higher, Electrons Lower
  - GCR Levels *Higher*
  - Neutron Levels in the Atmosphere Are Higher
  - Solar Events Are Rare



Light bulb shaped CME
courtesy of SOHO/LASCO C3 Instrument

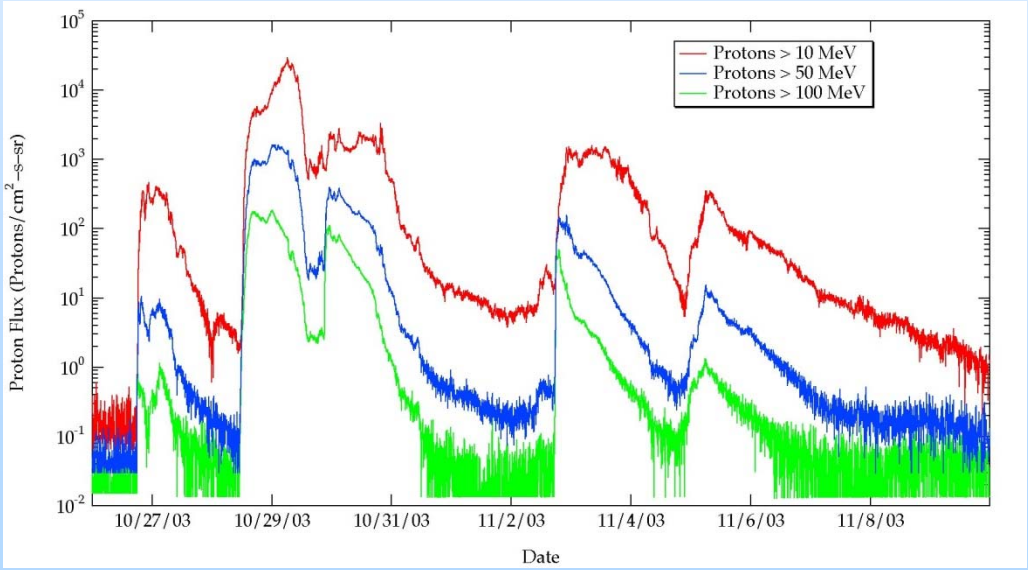
The Environment in Action

“There’s a little black spot on the sun today”



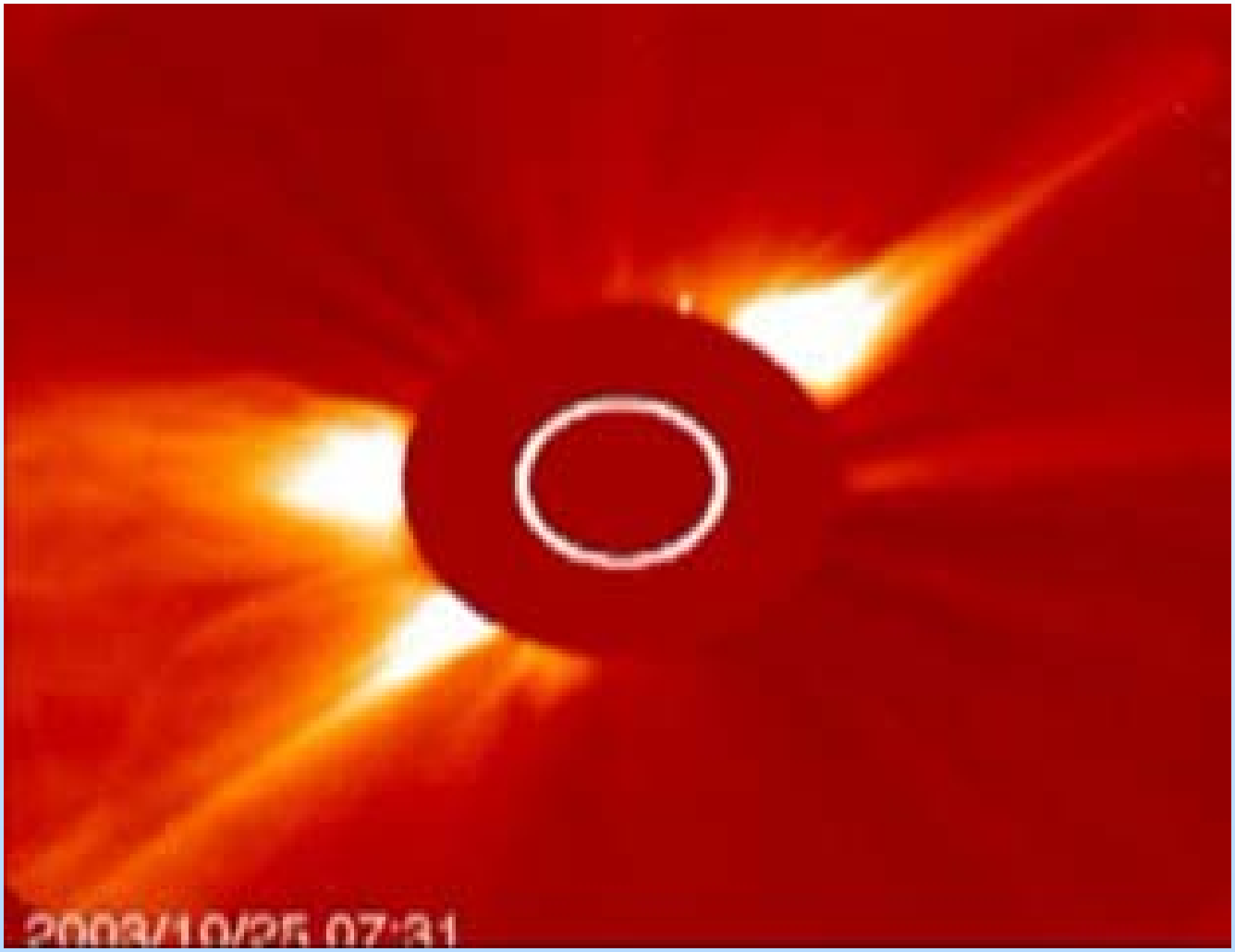
Recent Solar Events – A Few Notes and Implications

- **In Oct-Nov of 2003, a series of X-class (X-45!) solar events took place**
  - **High particle fluxes were noted**
  - **Many spacecraft performed safing maneuvers**
  - **Many systems experienced higher than normal (but correctable) data error rates**
  - **Several spacecraft had anomalies causing spacecraft safing**
  - **Increased noise seen in many instruments**
  - **Drag and heating issues noted**
  - **Instrument FAILURES occurred**
  - **Two known spacecraft FAILURES occurred**
- **Power grid systems affected, communication systems affected…**



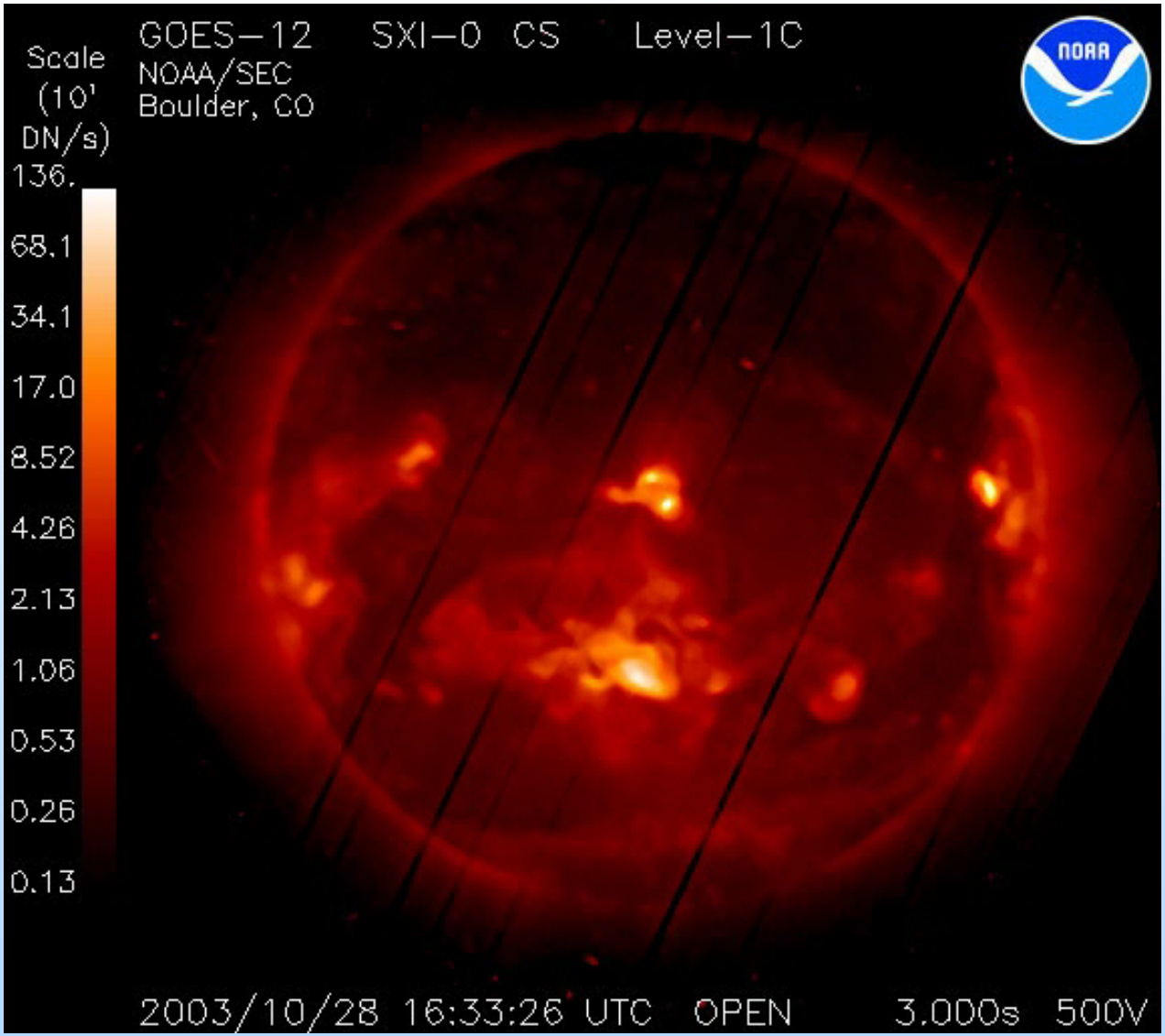
Proton fluxes during "Halloween Event"

SOHO LASCO C2 of the Halloween Solar Event of 2003



To run this video see http://radhome.gsfc.nasa.gov/radhome/papers/c2_SOHO.mpg

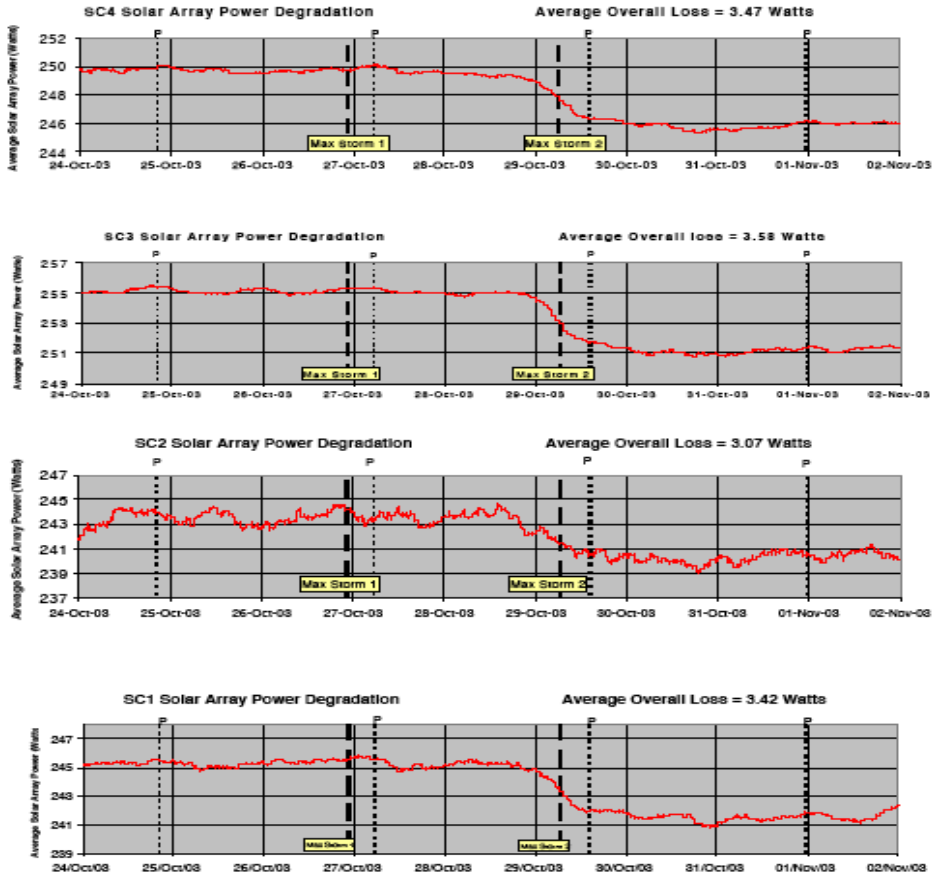
GOES SXI View of the Halloween Event



To run this video see http://radhome.gsfc.nasa.gov/radhome/papers/GOES_SXI_SPEC.mpeg

Solar Event Effect - Solar Array Power Output Degradation on CLUSTER Spacecraft

ANNEX 1: Evolution of the Solar Array Power from 24-Oct to 02-Nov 2003 when two solar radiation storms occurred (the time of their maximum is indicated in the plot "---"). The degradation of the panels was about 1.4% and the average power loss is shown for each spacecraft.
The perigee passes are marked as "....." and labeled with "P"



Many other spacecraft to noted similar degradation as well.

Selected Other Consequences

- Orbits affected on several spacecraft
- Power system failure
  - Malmo, Sweden
- High Current in power transmission lines
  - Wisconsin and New York
- Communication noise increase
- FAA issued a radiation dose alert for planes flying over 25,000 ft

Important note:
Effects propagated to terrestrial levels

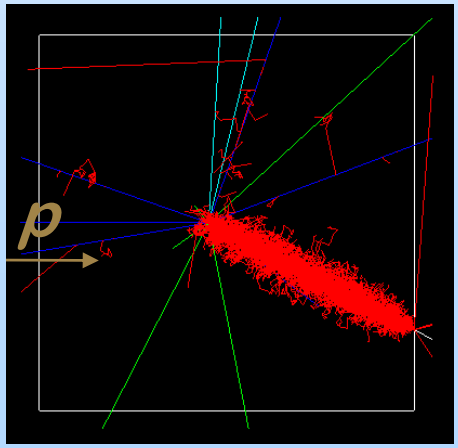
A NASA-built radiation monitor that can aid anomaly resolution, lifetime degradation, protection alerts, etc.

Real Estate: Location and Timing Drive Radiation Exposure

- **Location**
  - **Where you fly and the route you take to get there impacts the levels of radiation exposure**
    - **GEO, LEO, Lunar, Mars, Jovian all have vastly different exposure levels**
  - **Where your system is within a spacecraft affects the hazard**
    - **Shielding plays a role in reducing some radiation exposure (but not a panacea!)**
- **Timing**
  - **Two issues impact exposure levels**
    - **When you fly**
      - **Activity level of environment**
    - **How long you fly**
      - **Cumulative exposure levels and activity level**
- **Two examples to follow**
  - **LEO (Hubble), Lunar**

LEO Radiation Environment
Low Inclination

- **Pros**
  - **Fly below the earth's magnetic belts**
  - **Limited direct exposure to GCR and solar particles**
  - **Relatively low levels of particles for longer-term damage**
    - **Assumes location inside the spacecraft**



- **Cons**
  - **Exposure to trapped particles in SAA**
    - **Protons can induce noise or upsets in commercial and non-radiation hardened devices**
    - **Optics systems must also be concerned with trapped electrons**
  - **Some GCR and solar particles may penetrate**
    - **Secondaries**

Sample particle interaction of a 100 MeV proton in a 5um Si block using the GEANT4 toolkit. after Weller, 2004

Lunar Environment

- **Pros**
  - **No trapped particles**
    - **Low "quiet" day particle levels**
  - **Low level, low energy neutrons**
    - **Created from GCR interaction with the lunar atmosphere/surface**
- **Cons**
  - **Full exposure to GCR**
    - **Can be destructive to commercial electronics**
  - **Full exposure to solar particles**
    - **Long-term and transient effects issues**

Lunarscape
Courtesy of
JPL Photojournal Archive

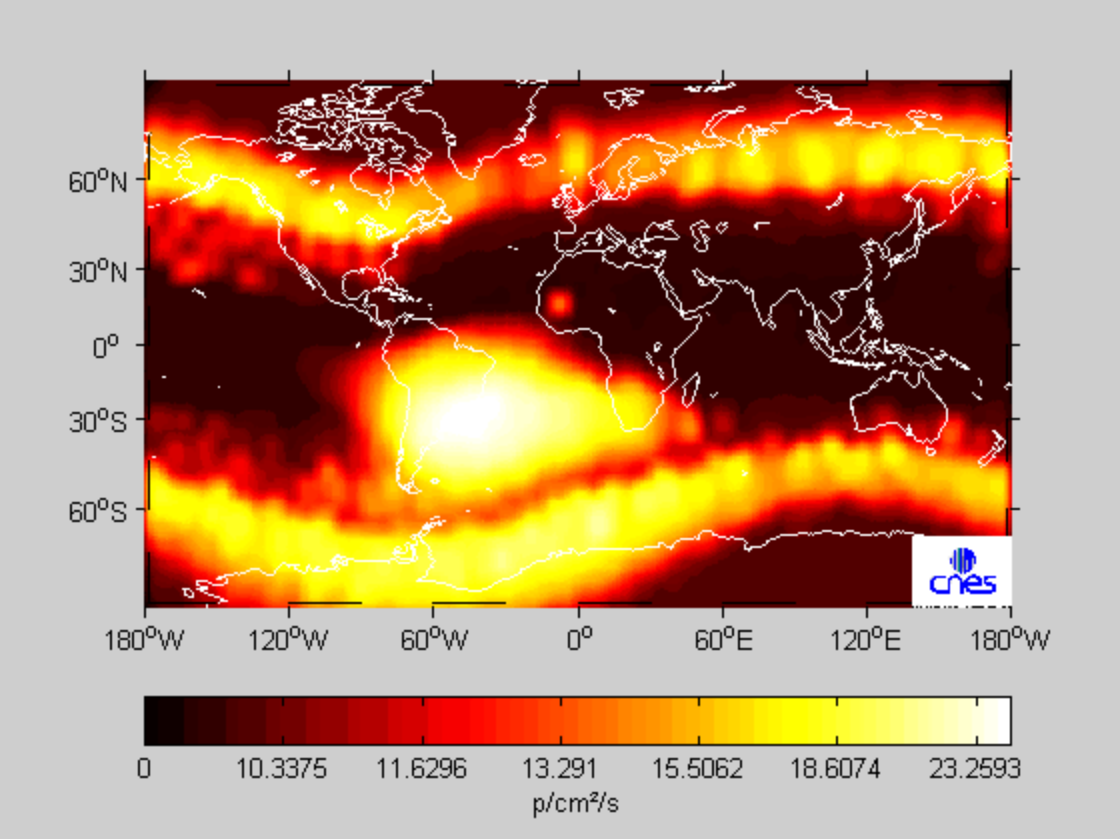
Lunar footprint
Courtesy of
NASA archives

Radiation Environment Models

- **Trapped particles (Earth)**
  - **NASA standard is AP-8 (proton) and AE-8 (electron)**
    - **One model for Solar Max, one for Solar Min**
    - **These are static averages of old data**
  - **Updates being worked based on newer data, statistics, etc**
    - **Boeing TPM (Trapped Proton Model)-1 based on NOAA/TIROS and CRRES data**
    - **ONERA-LANL POLE model for GEO electrons**
- **Trapped Particles (Jovian)**
  - **Original model from the 1980's: Divine model (proton and electrons)**
    - **Update based on Galileo data: Galileo Interim Radiation Electron (GIRE) Model**
- **Solar Particles**
  - **NASA PSYCHIC model for solar protons and heavy ions**
- **GCR**
  - **NRL CREME96 model**
  - **NASA Badhwar and O'Neill model**

Final Remark

- **Beyond the "standard" concerns of space radiation environment for electronics/optics, solar magnetic storms impact needs to be considered**
  - ***Presentation available NLT 2-14-05 at http:/radhome.gsfc.nasa.gov***



To run this video see http://radhome.gsfc.nasa.gov/radhome/papers/storm.avi