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

Or Why Not to Fly Commercial Electronic Components in Space

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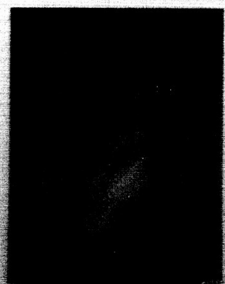
Outline

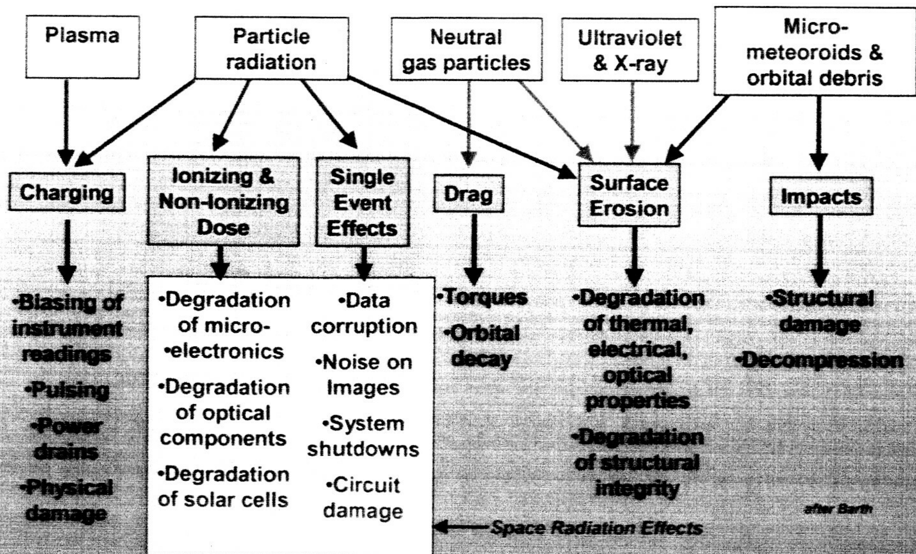
- The Space Radiation Environment Overview
- The Environment in Action
  - Solar Event from 2003
- Real Estate
  - Location and Timing
- Engineering Models
- Final Remark

The NATURAL Space Radiation Environment



STARFISH detonation –
Nuclear attacks are not considered in this presentation

Space Environments and Related Effects

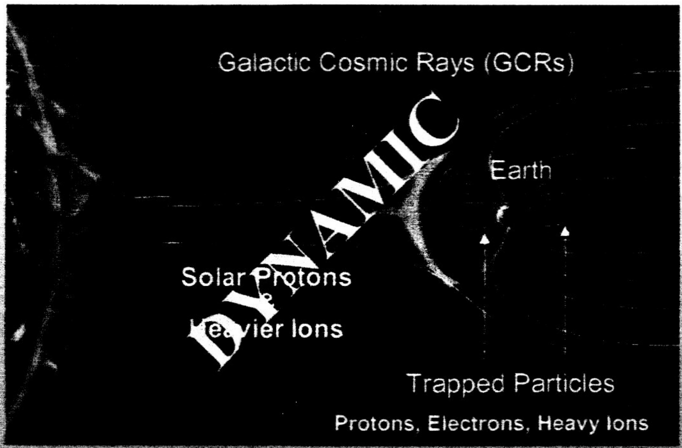


What is the Space Radiation Environment Hazard?

- **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

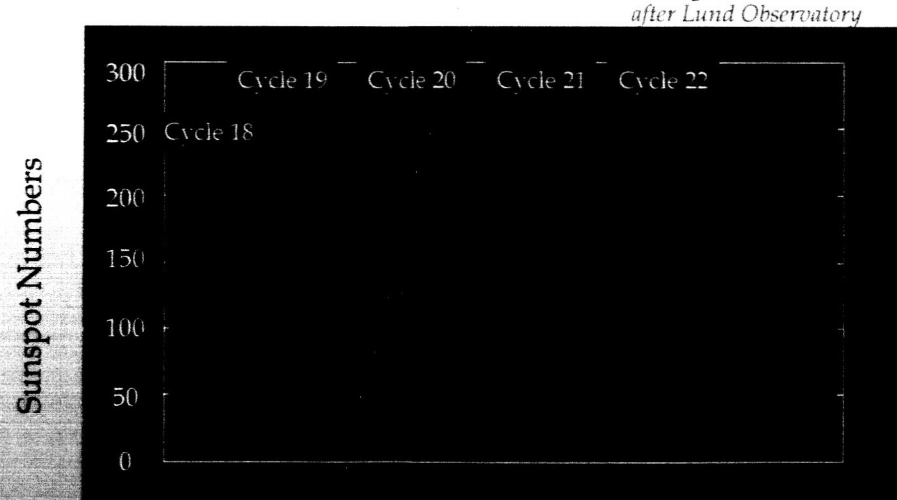
Solar Particle Events

Holloman AFB/SOON

- 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

Sunspot Cycle: An Indicator of the Solar Cycle

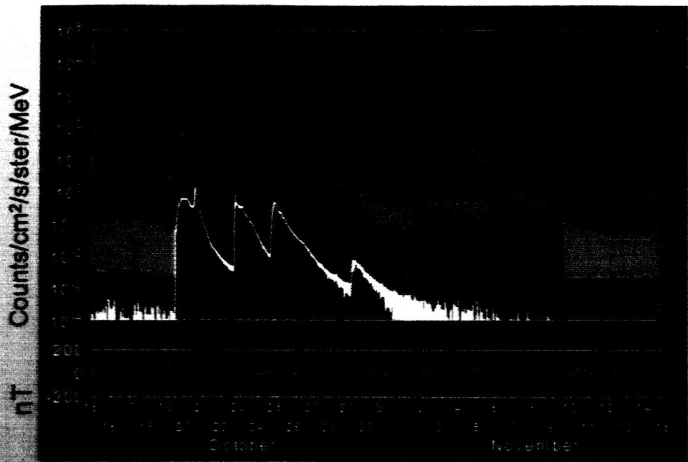
after Lund Observatory



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"

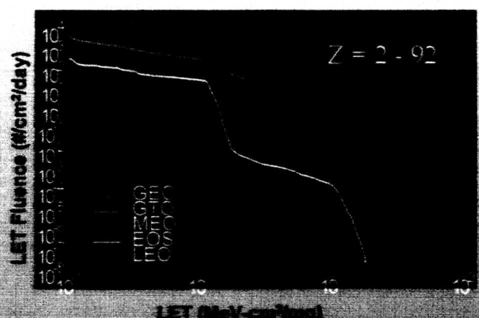


GOES Space Environment Monitor

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).

CREME 96, Solar Minimum, 100 mils (2.54 mm) Al

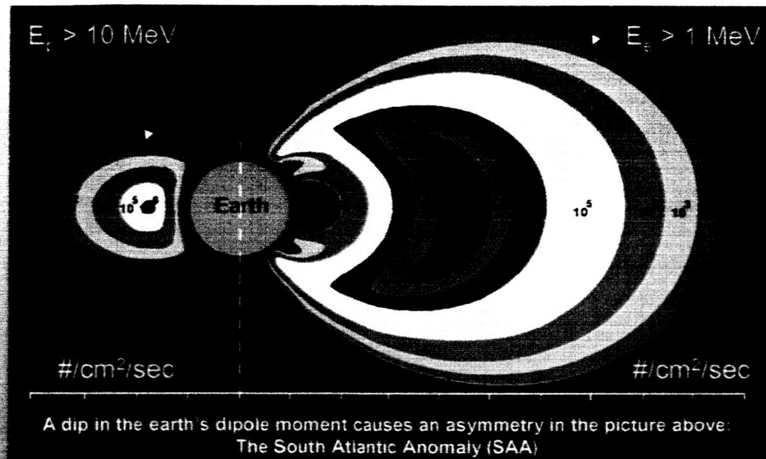


Time

Commercial Technology Sensitivity

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

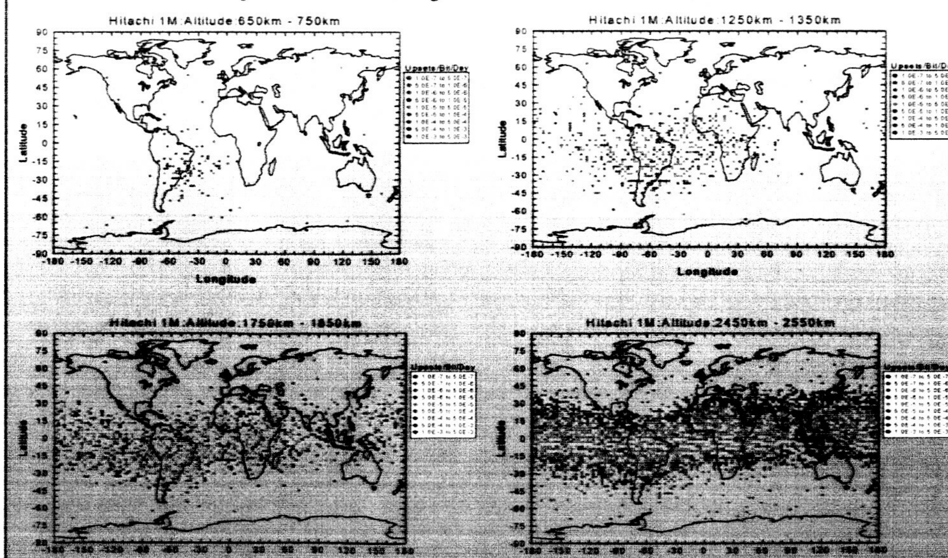
AP-8 Proton Model AE-8 Electron Model



L-Shell

Geomagnetic cutoff supplies 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

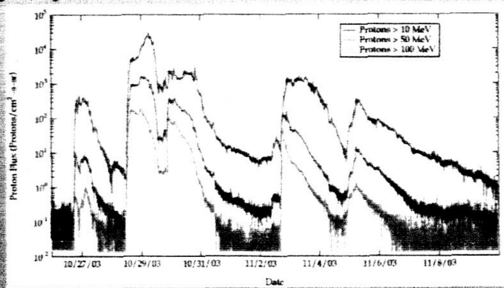
Light bulb shaped CME courtesy of SOHO/LASCO C3 Instrument

The Environment in Action

"There's a little black spot on the sun today"

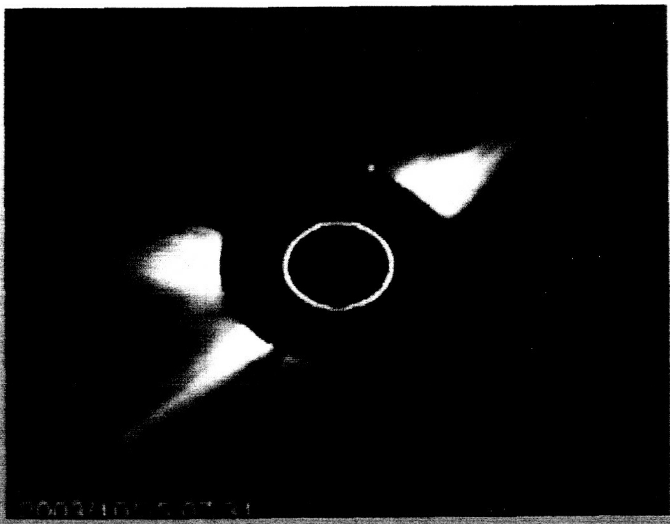
Recent Solar Events – A Few Notes and Implications

- 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...**

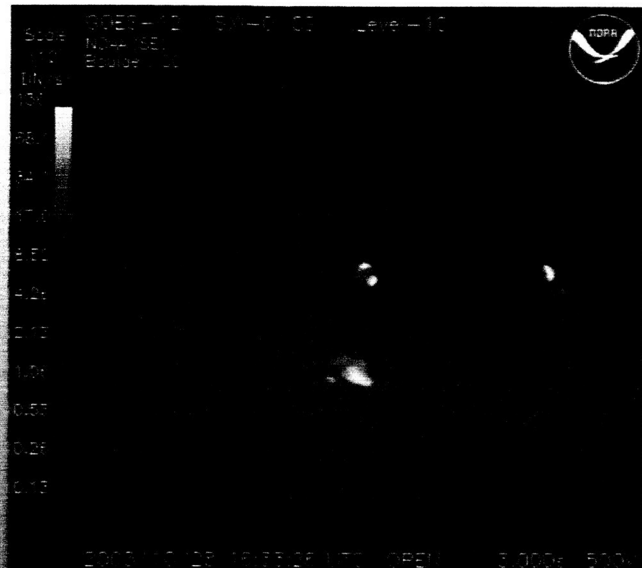


Proton fluxes during "Halloween Event"

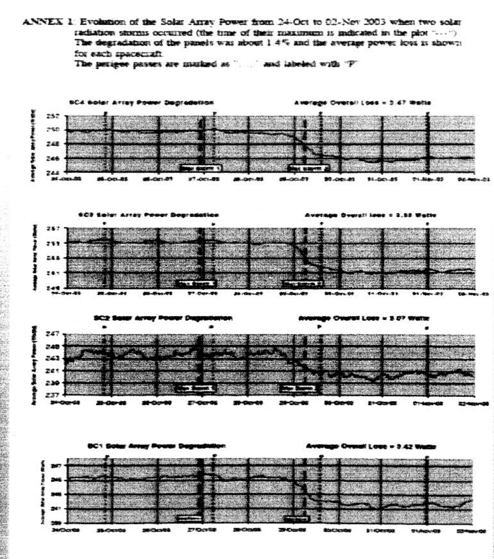
SOHO LASCO C2 of the Halloween Solar Event of 2003



GOES SXI View of the Halloween Event



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



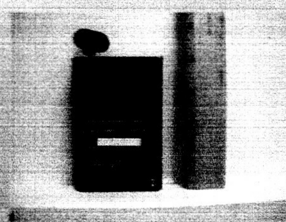
Many other spacecraft to noted similar degradation as well.

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.

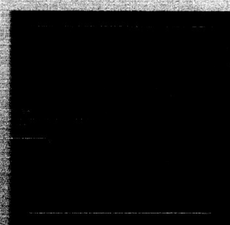


Real Estate: Location and Timing Drive Radiation Exposure

- 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