Single Event Effects: Space and Atmospheric Environments

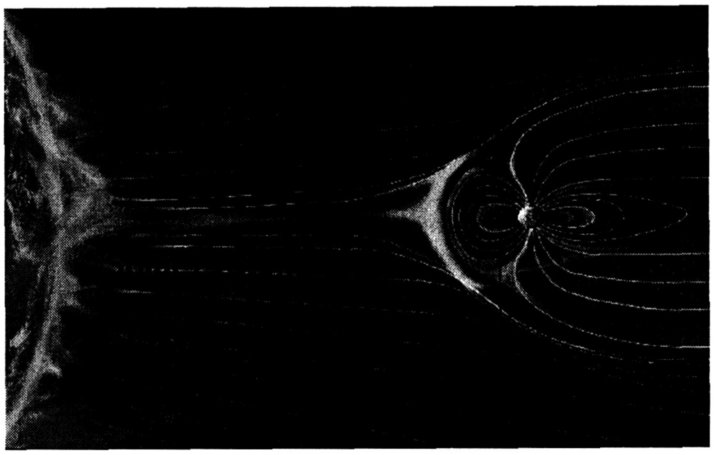
Janet L. Barth
NASA/GSFC
Flight Data Systems & Radiation Effects

Single Event Upsets in Future Computing Systems
Jet Propulsion Laboratory
May 20, 2003

Outline

- Sun-Earth Connections
- Heavy Ions
  - » Galactic Cosmic Rays
  - » Solar Particle Events
- Protons
  - » Solar Particle Events
  - » Trapped
- Atmospheric Neutrons
- Summary

The Radiation Environment



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

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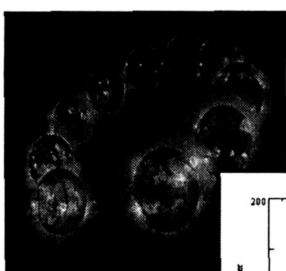
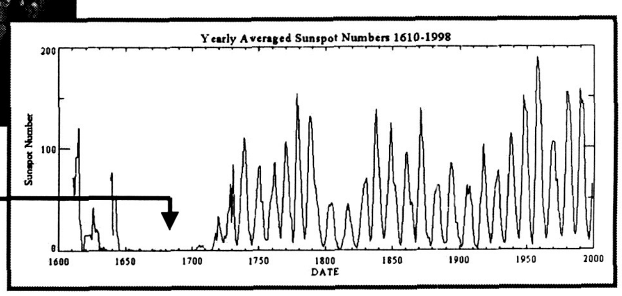
The 11-Year Solar Activity Cycle



Sunspot cycle discovered by Schwab in 1844



Little Ice Age in 1645 to 1715

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

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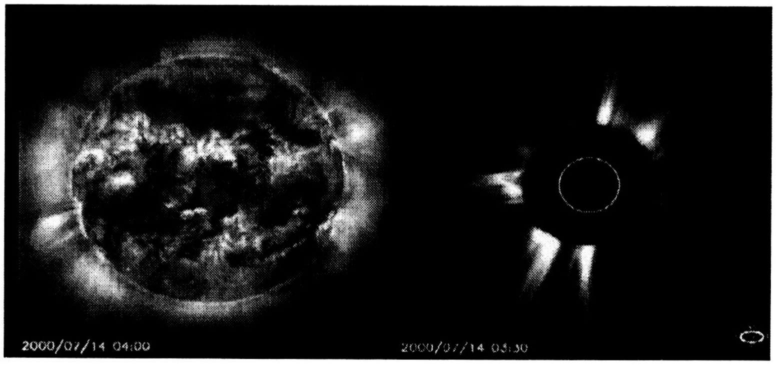
Solar Flare & Particles

SOHO Instruments/EIT & LASCO



Solar flares are observed as sudden brightening near sunspots.

The solar system's largest explosive events.

Particles are accelerated directly by event.

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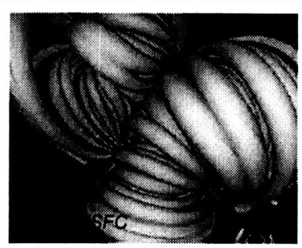
Coronal Mass Ejections

- **Bubble of gas & magnetic field**
- **Ejects billions of tons of matter.**
- **Shock wave accelerates particles to millions of km/hr throughout the Solar System.**



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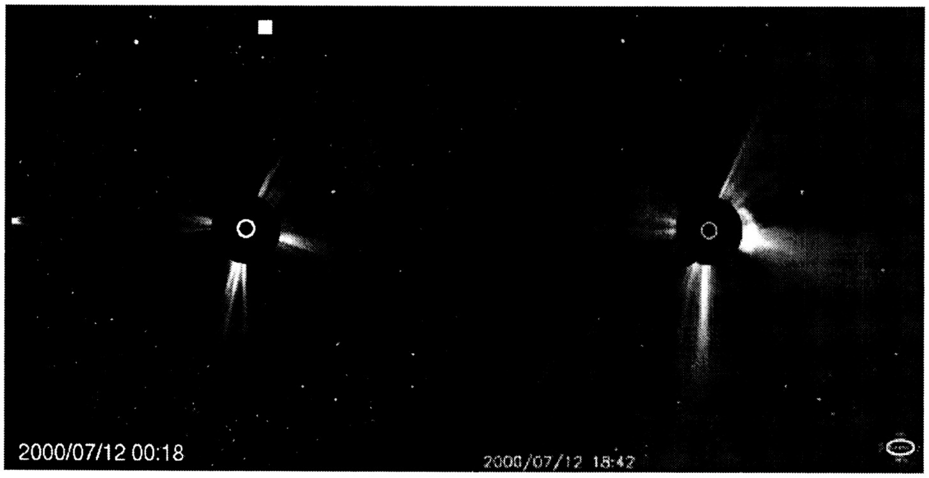
CME Movies – SOHO/LASCO



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Heavy Ions – Galactic Cosmic Ray & Solar

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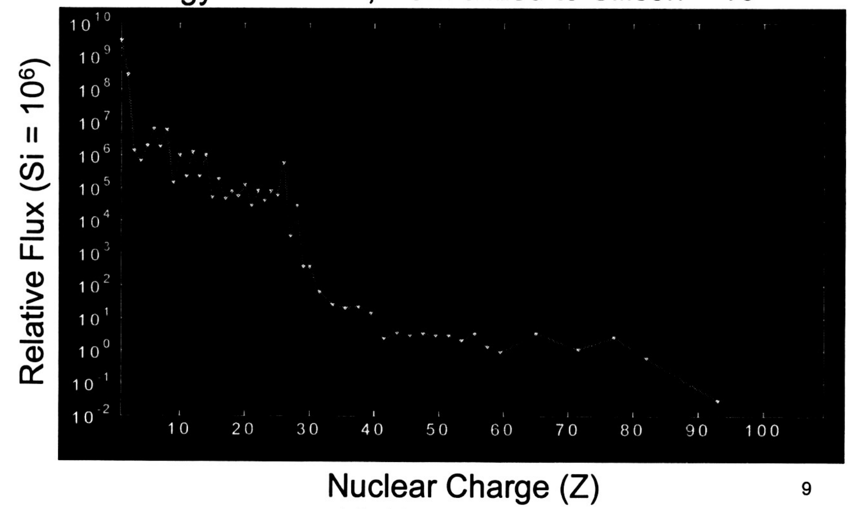
Galactic Cosmic Ray Ions – Relative Abundance

Energy = 2 GeV/n, Normalized to Silicon = 10^6



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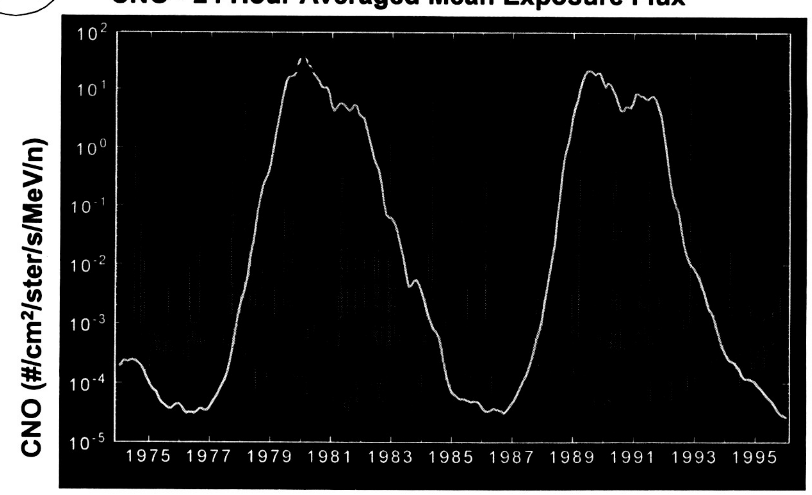
Heavy Ion Measurements

CNO - 24 Hour Averaged Mean Exposure Flux



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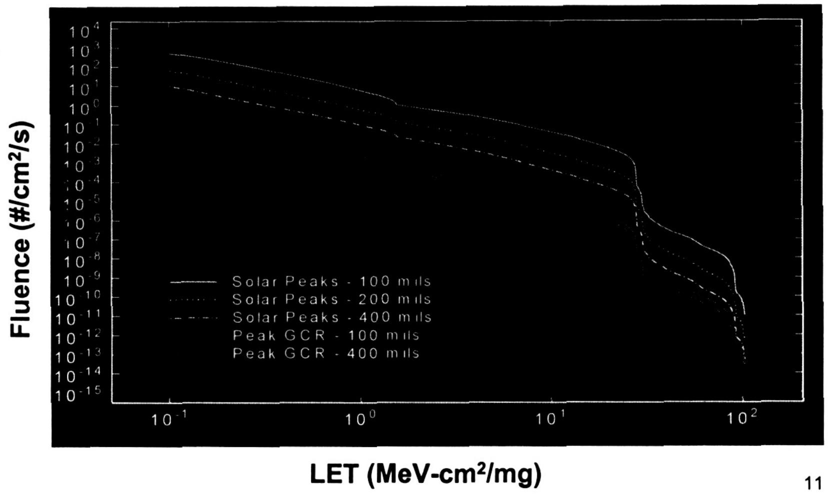
Heavy Ion LET Spectra

Transient Particles Unattenuated by the Magnetosphere



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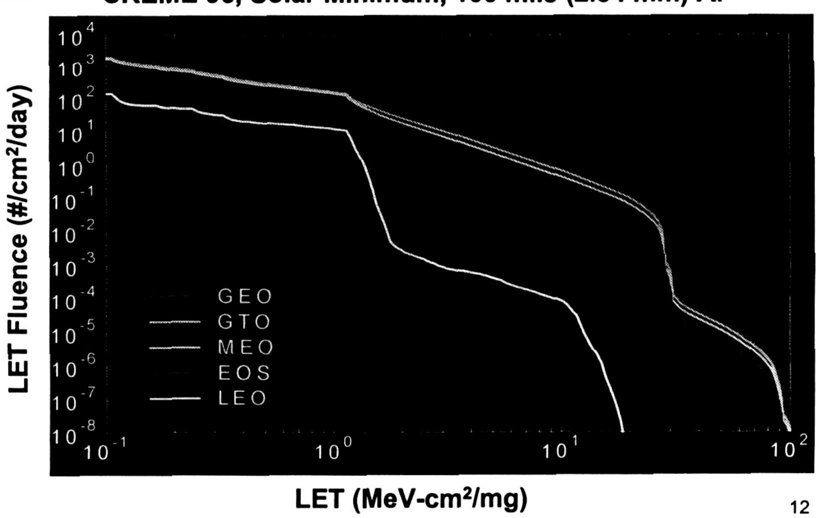
GCR Heavy Ions as a Function of Orbit

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



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Protons – Solar & Trapped

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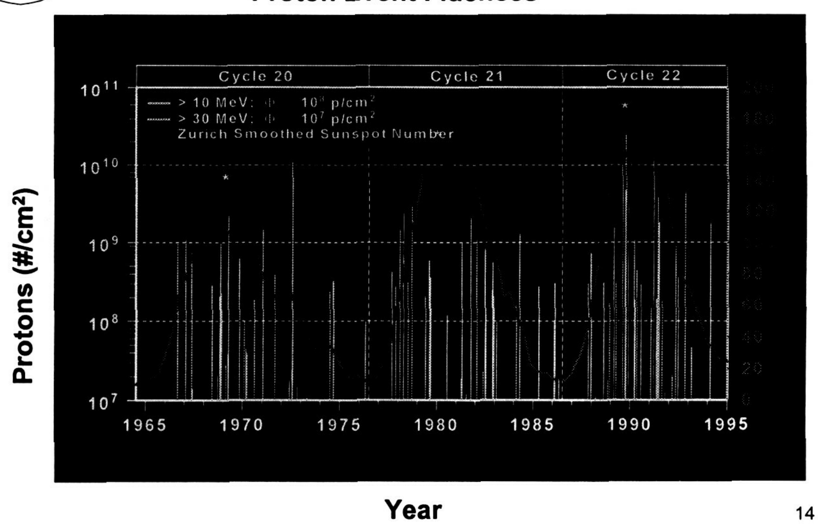
Solar Proton Events

Proton Event Fluences



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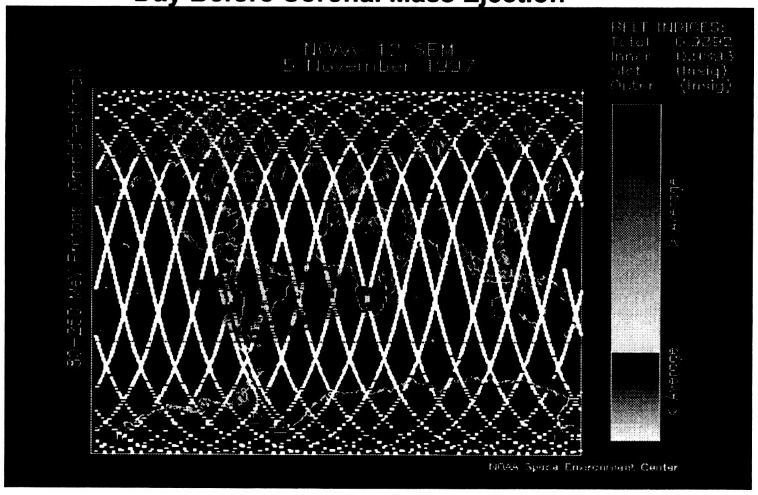
TIROS – Proton Detector

Day Before Coronal Mass Ejection



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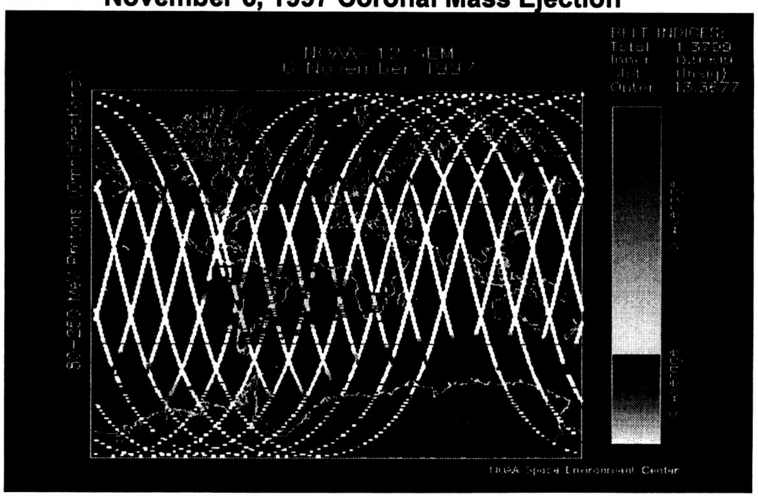
TIROS – Proton Detector

November 6, 1997 Coronal Mass Ejection



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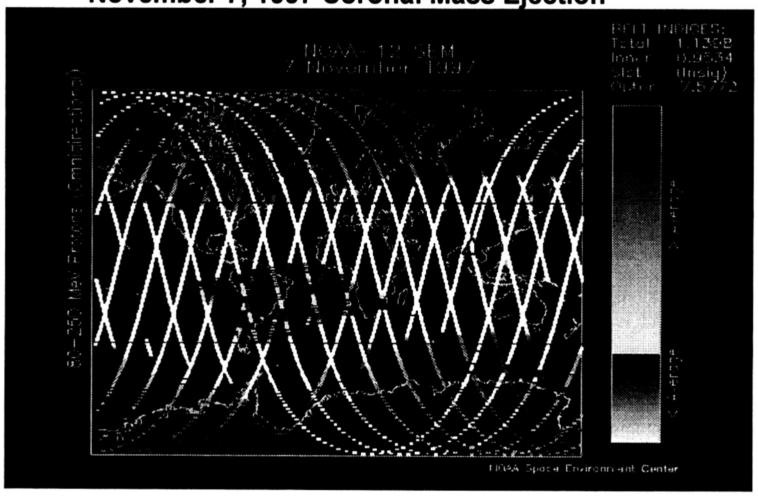
TIROS – Proton Detector

November 7, 1997 Coronal Mass Ejection



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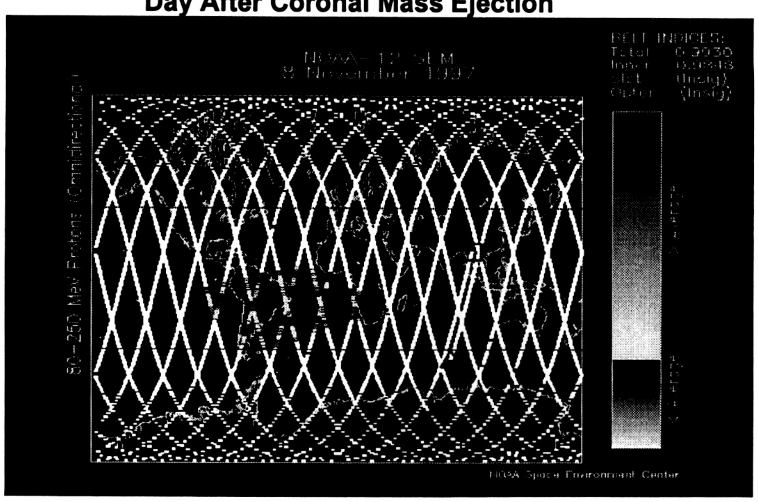
TIROS – Proton Detector

Day After Coronal Mass Ejection



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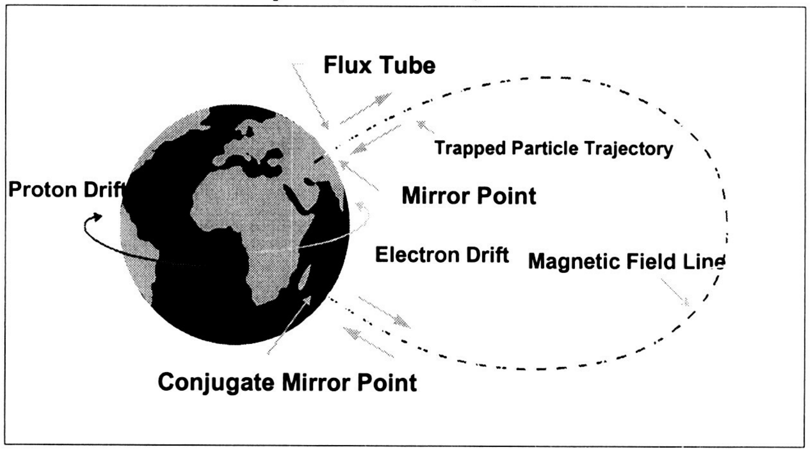
Trapped Particle Motions

Spiral, Bounce, Drift



after Hess 19

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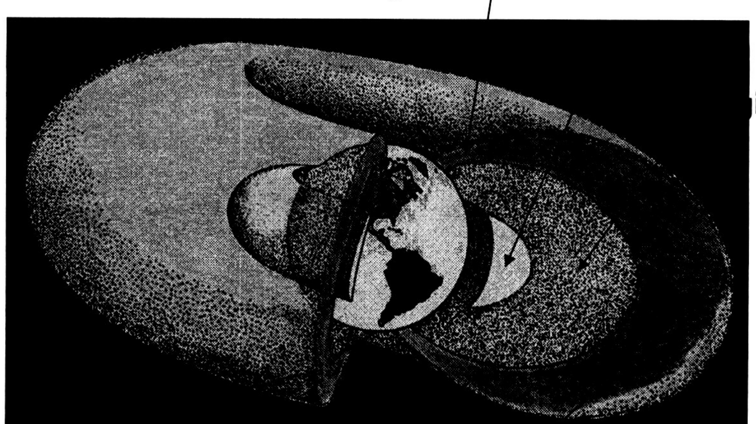
Van Allen Belts

High Latitude Horns

ion



Outer Belt *BIRA/IASB* 20

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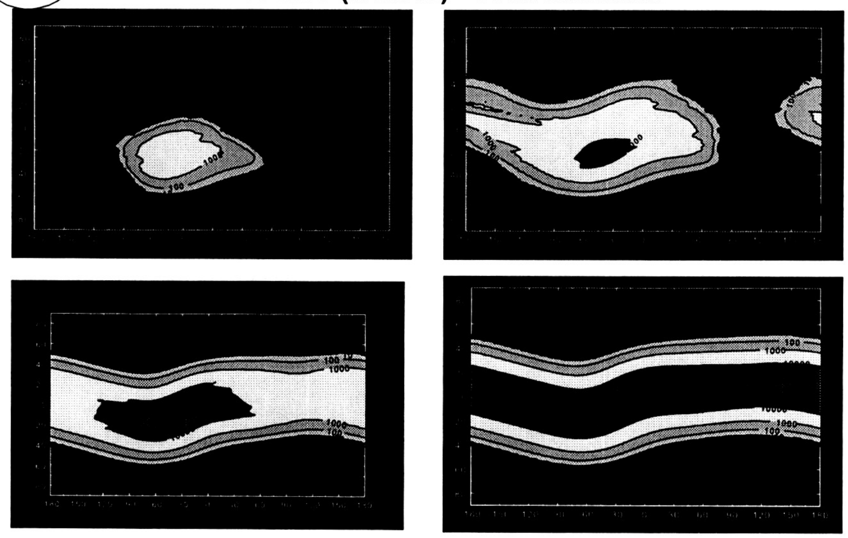
Trapped Protons – AP-8

E > 30 MeV (#/cm²/s) - Solar Minimum



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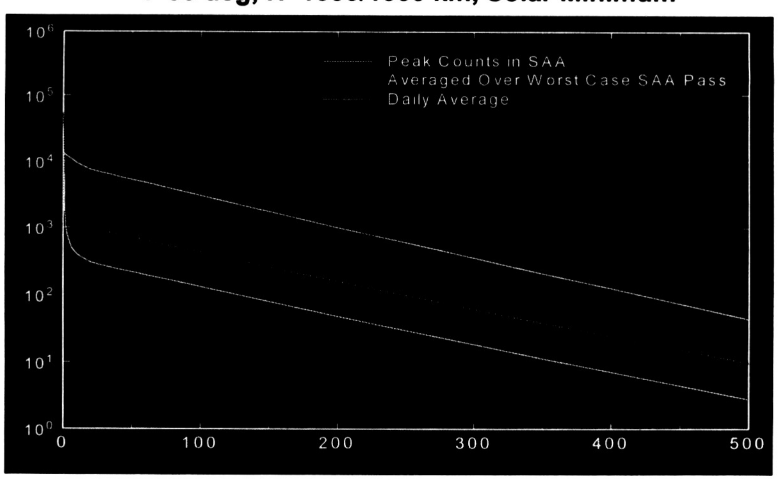
Trapped Proton Predictions

I=90 deg, H=1000/1000 km, Solar Minimum



Energy (> MeV)

Protons (#/cm²/s)

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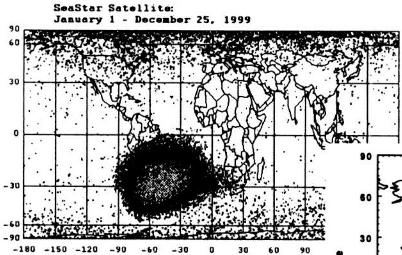
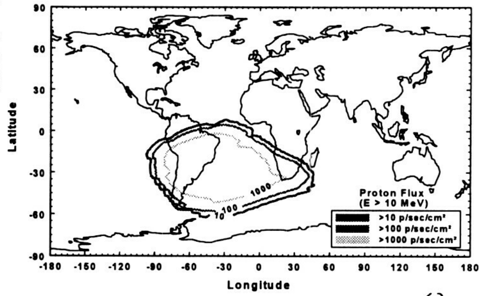
Seastar - Single Event Upsets

Single Event Upsets on Flight Data Recorder
January 1 - December 25, 1999 – 705 km



COTS DRAM Technology



No science data lost

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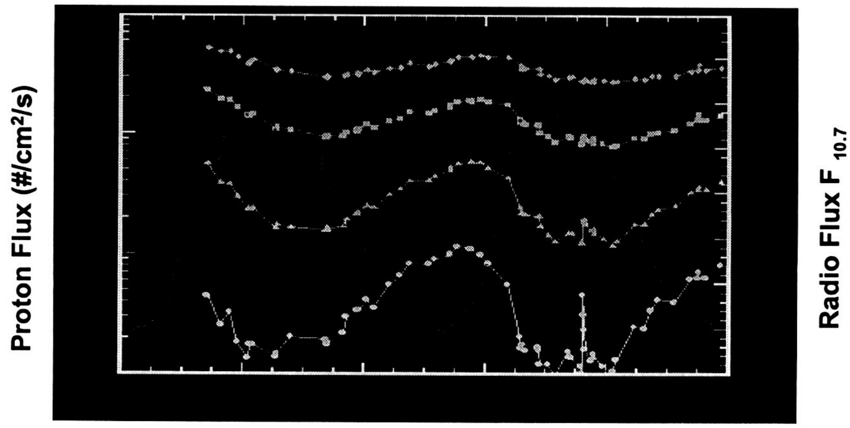
Trapped Protons – Solar Cycle

Solar Cycle Variation: 80-215 MeV Protons



Huston et al. 24

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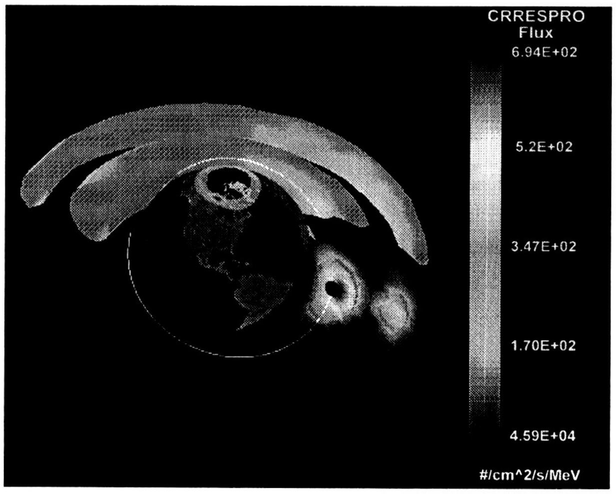
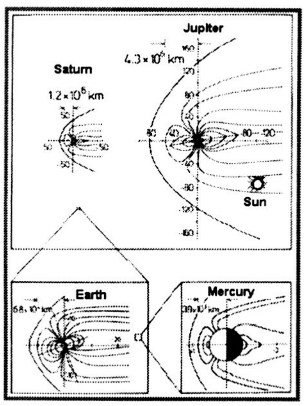
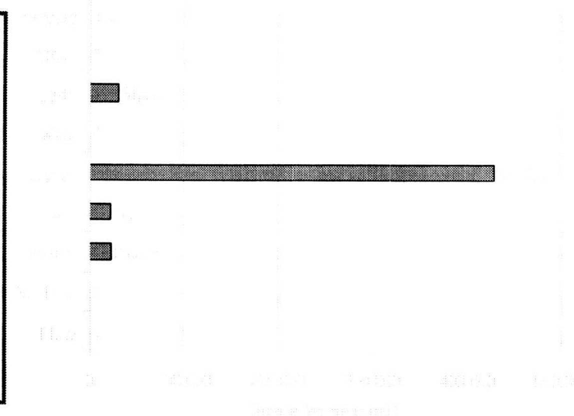
CRRES - Proton Storm Belt



AF Phillips Laboratory, SPD/GD

Planetary Magnetospheres/Trapping





Atmospheric Neutrons

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Neutrons

- Source - Secondary products of particle cascades
  - » Spacecraft materials
  - » Galactic comic ray collisions with atmospheric O & N
- Single event upset (latch-up?) hazard
  - » Ground level
  - » Avionics
  - » Low Earth Orbits - Shuttle
- First recognized as problem in 1980s

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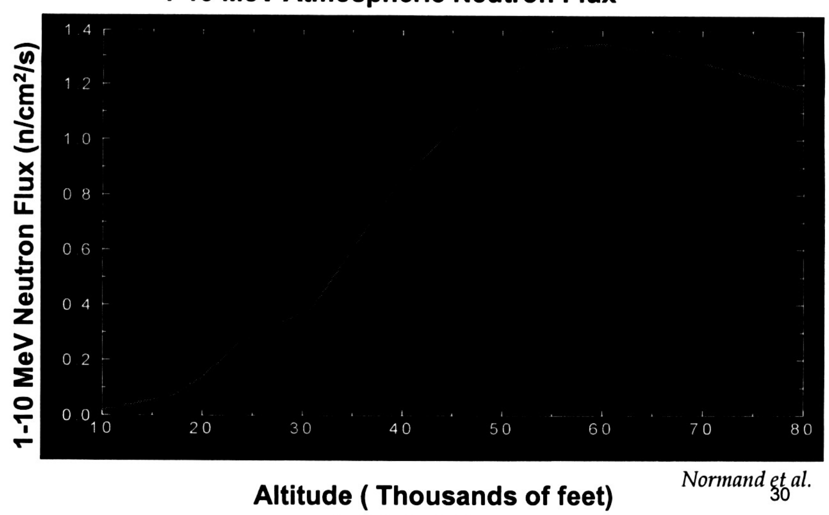
3 Models

- **Boeing**
  - » Function of Latitude, Altitude, and Energy
  - » Based on Studies by Mendall, Korff, and Armstrong
  - » Easy to Use
  - » Accurate
- **Wilson-Nealy**
  - » Function of Magnetic Rigidity & Atmospheric Depth
  - » More Accurate
  - » Includes Solar Cycle Modulation
- **Wilson**
  - » AIR model
  - » New model funded by NASA's Living With a Star Program

Neutron Models: Flux vs. Altitude

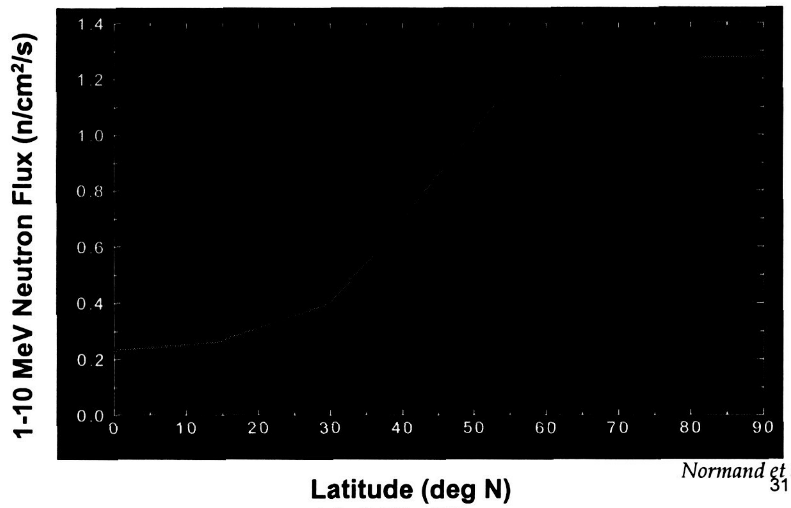
1-10 MeV Atmospheric Neutron Flux



Normand et al.

Neutron Model: Flux vs. Latitude

1-10 MeV Atmospheric Neutron Flux



Normand et al.

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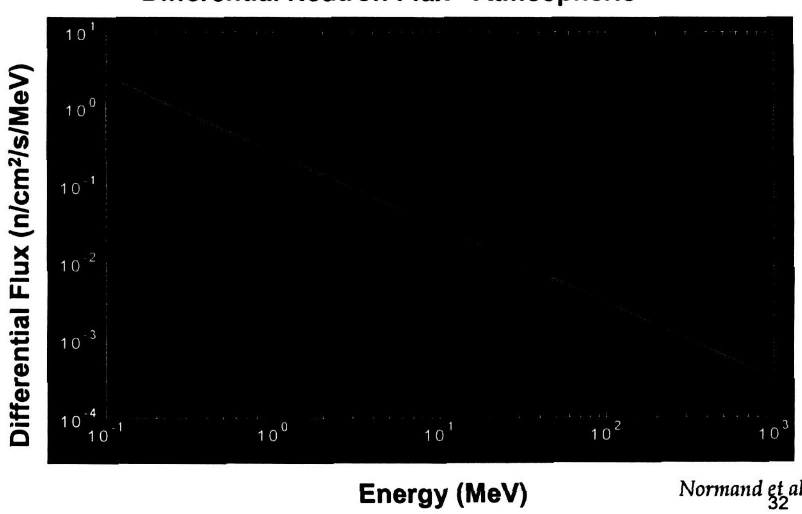
Neutron Model: Flux vs. Energy

Differential Neutron Flux - Atmospheric



Normand et al.

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Variations in Neutron Levels

- Magnetic rigidity determines distribution
- Solar cycle modulation
  - » Function of Galactic Cosmic Ray levels
    - Solar minimum - Higher
    - Solar maximum - Lower
  - » Measured difference ~ 25%
  - » Levels increase with solar events - *Dyer et al.*
- Dependent on atmospheric conditions
- Very penetrating - Aircraft shielding reduces levels by ~ 10%

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Summary

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Solar Cycle Effects

- **Solar Maximum**
  - » Trapped proton levels lower
  - » Background GCR levels lower
  - » Solar events more frequent & greater intensity
  - » Background neutrons levels lower but can increase suddenly from solar events
- **Solar Minimum**
  - » Trapped protons higher
  - » GCR levels higher
  - » Solar proton events are rare
  - » Background neutrons levels are higher

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Space Environment Models

Mission Concept Mission Planning Design	**Space Climate** Minimize Risk
Launch Operations	**Space Weather** Manage Residual Risk
Anomaly Resolution →	**Both**

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