Core Technologies for Space Systems

Space Radiation Environments

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Greenbelt, Maryland
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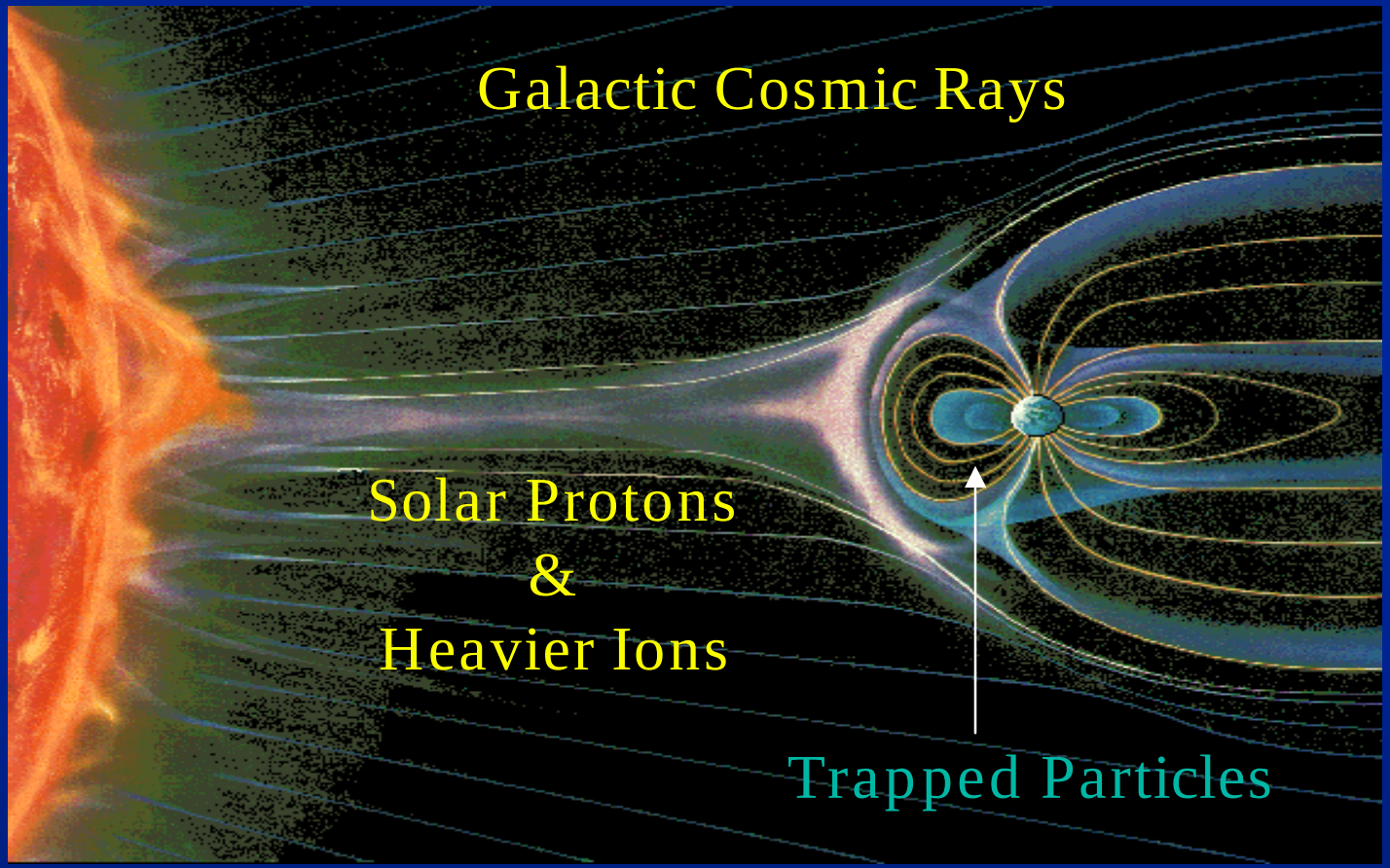
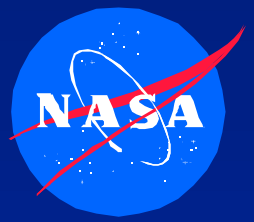
The Radiation Environment



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



Effects on Electronics

- Total Ionizing Dose
  - Trapped Protons & Electrons
  - Solar Protons
- Single Event Effects
  - Protons
    - Trapped
    - Solar
  - Heavier Ions
    - Galactic Cosmic Rays
    - Solar
  - Neutrons
- Displacement Damage
  - Protons
  - Electrons
  - Neutrons

Sun: Dominates the Environment

Source

Protons

Heavier Ions

Trapped Particles

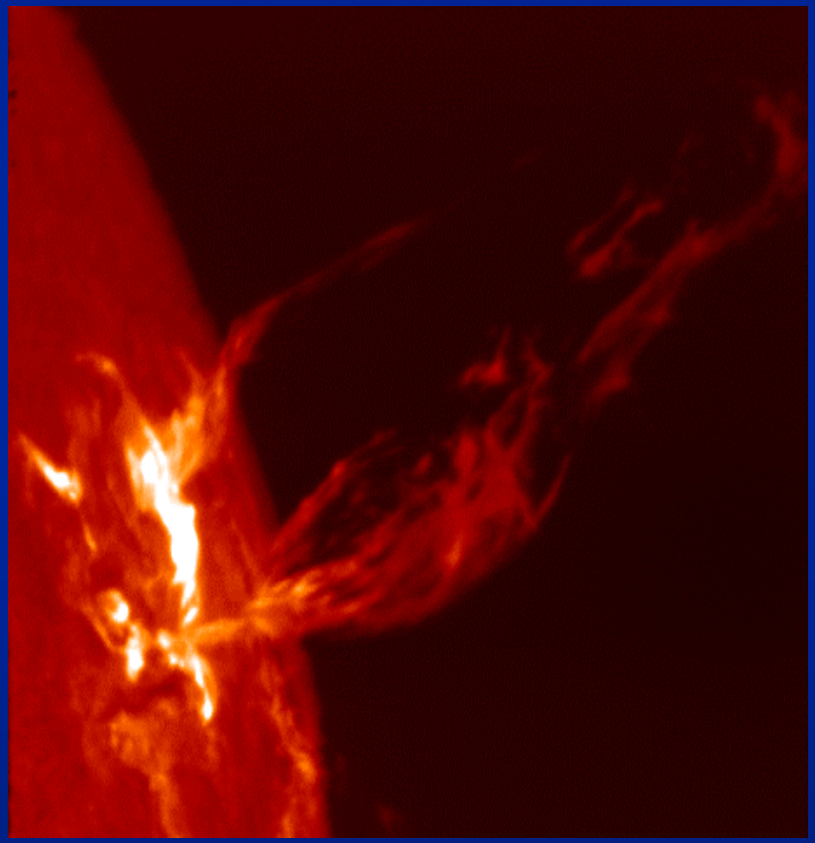
Modulator

Galactic Cosmic Rays

Atmospheric Neutrons

Trapped Particles

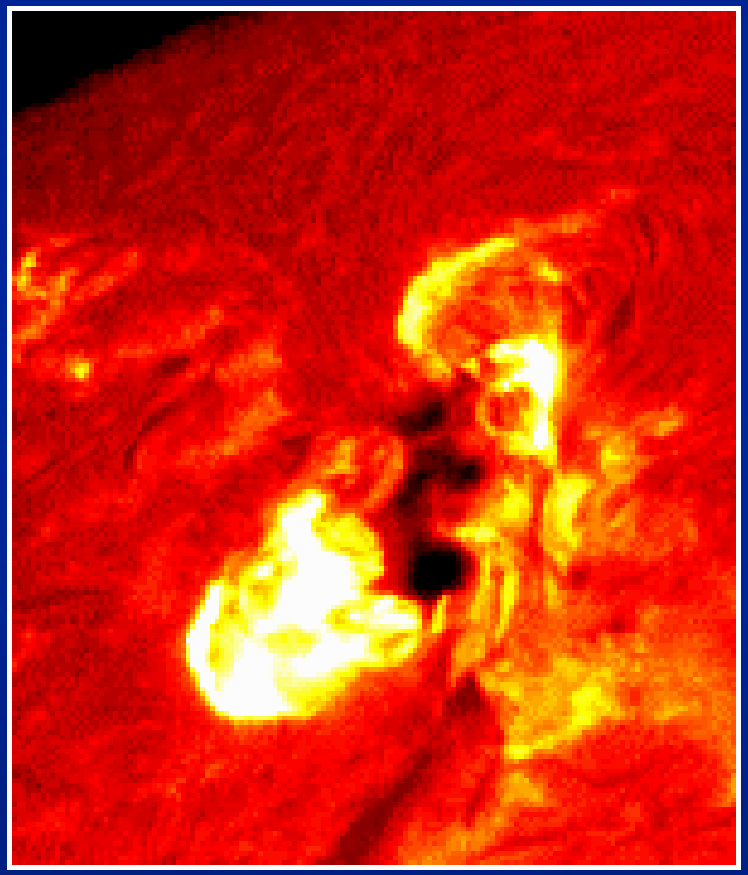
Gradual Events



Holloman AFB/SOON

- Coronal Mass Ejections
- Particles Accelerated by Shock Wave
- Largest Proton Events
- Decay of X-Ray Emission Occurs Over Several Hours
- Large Distribution in Solar Longitude

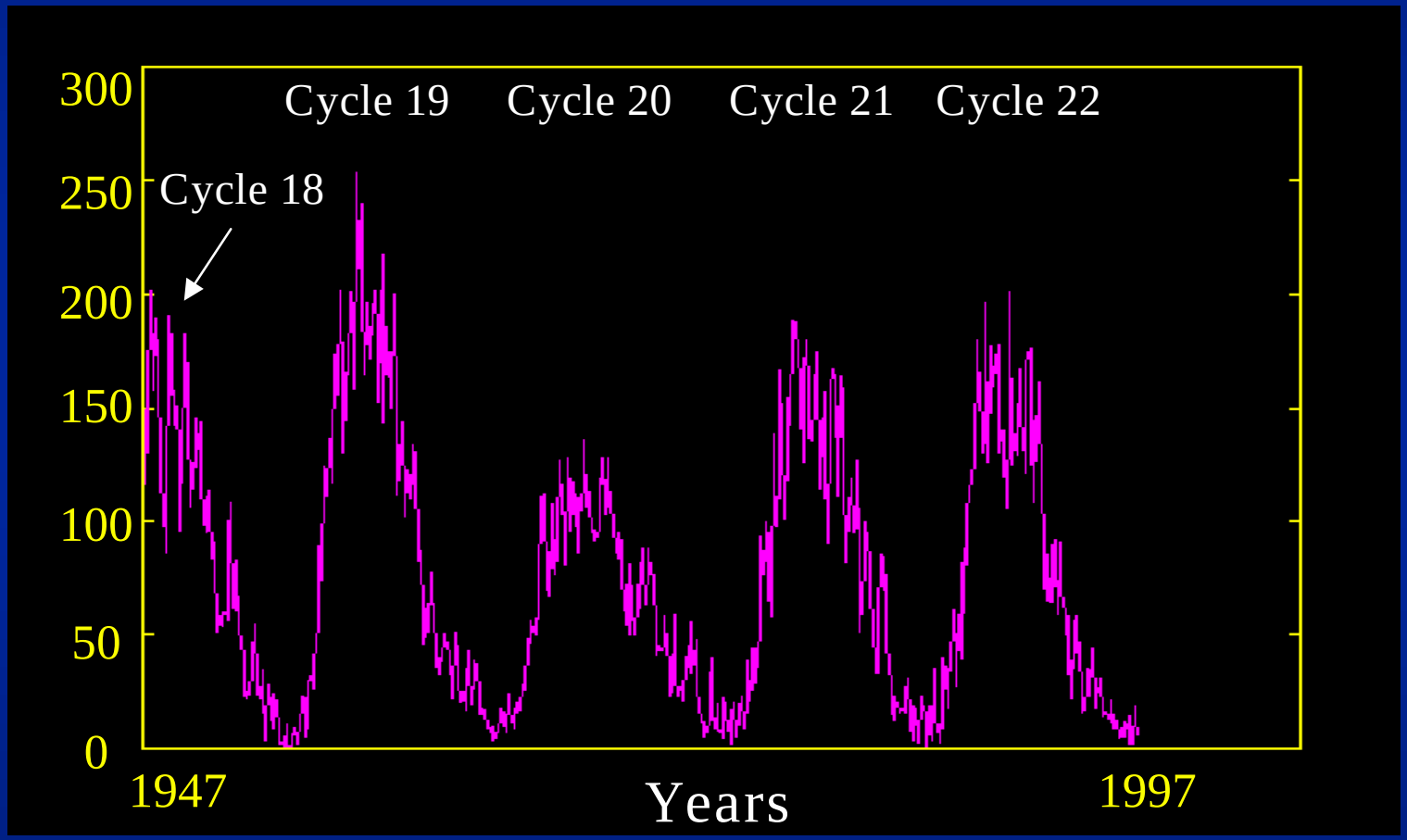
Impulsive Events



- Solar Flares
- Particles Accelerated Directly
- Heavy Ion Rich
- Sharp Peak in X-Ray Emission
- Concentrated Solar Longitude Distribution

Sunspot Cycle

after Lund Observatory



Length Varies from 9 - 13 Years

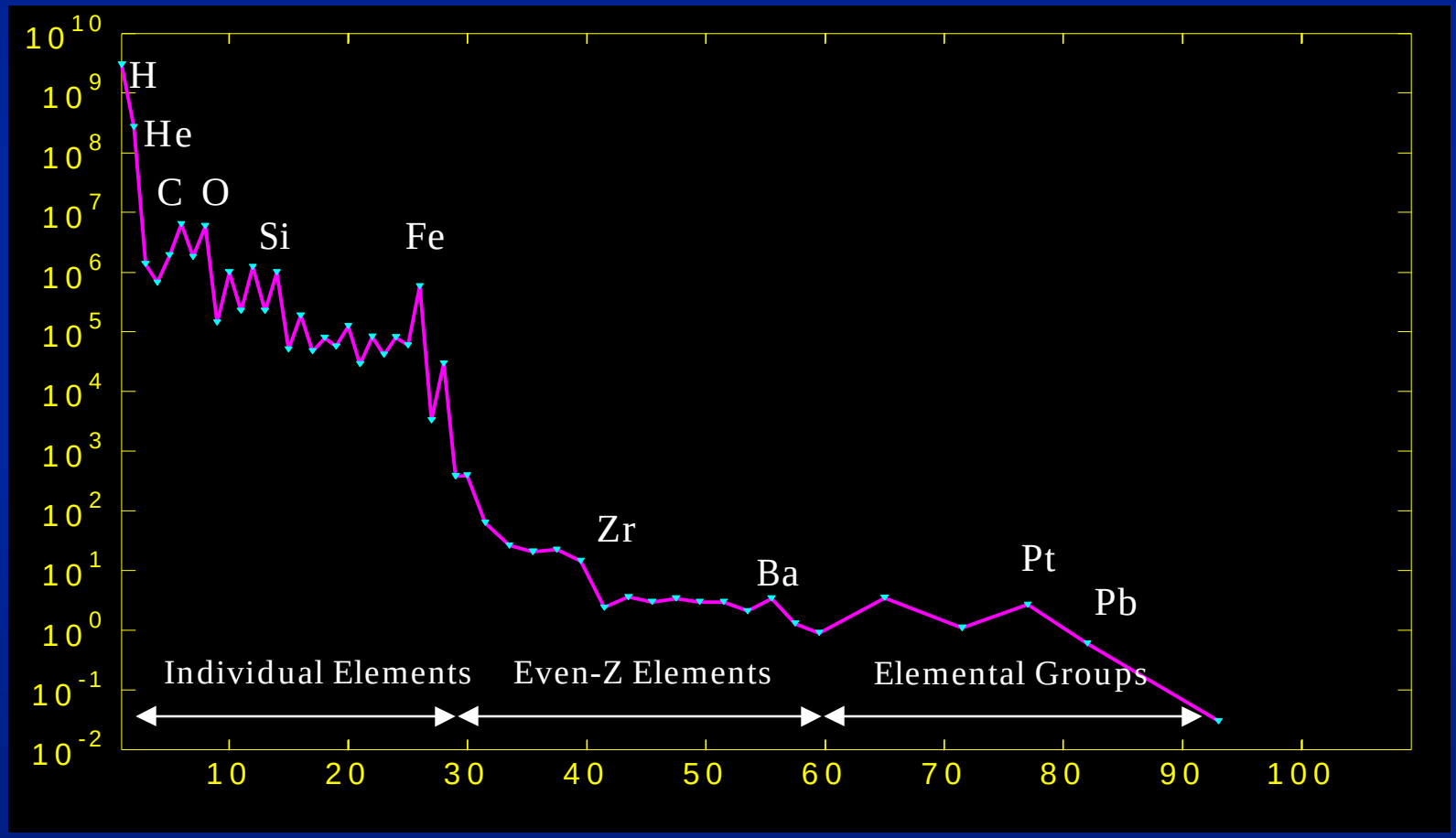
7 Years Solar Maximum, 4 Years Solar Minimum

Galactic Cosmic Ray Ions

- All Elements in Periodic Table
- Energies in GeV
- Found Everywhere in Interplanetary Space
- Omnidirectional
- Mostly Fully Ionized
- Cyclic Variation in Fluence Levels
  - Lowest Levels = Solar Maximum Peak
  - Highest Levels = Lowest Point in Solar Minimum
- Single Event Effects Hazard
- Model: CREME96

GCRs: Nuclear Composition

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



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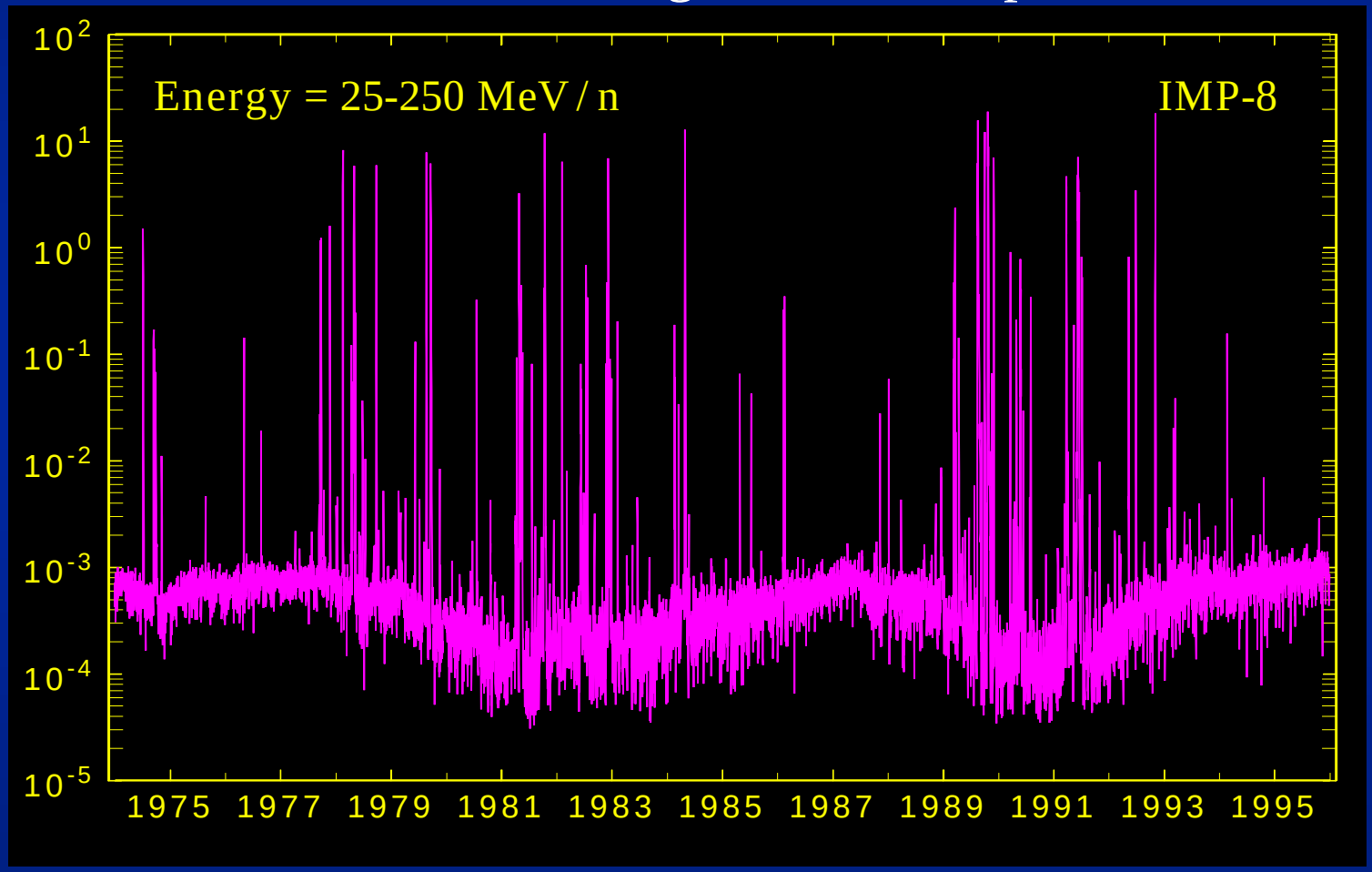
GCRs: Solar Modulation

CNO - 24 Hour Averaged Mean Exposure Flux



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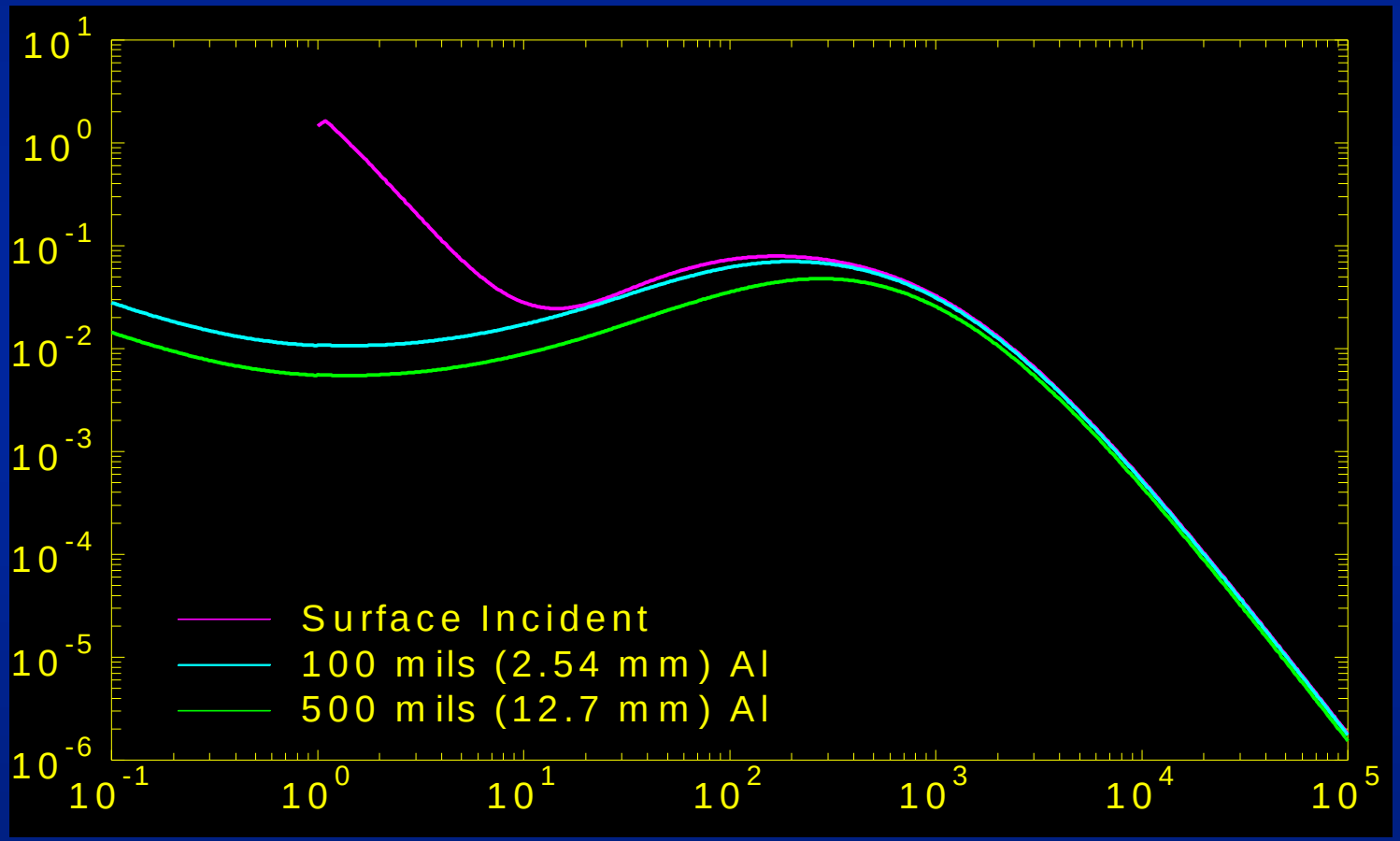
GCRs: Shielded Fluences - Fe

Interplanetary, CREME 96, Solar Minimum



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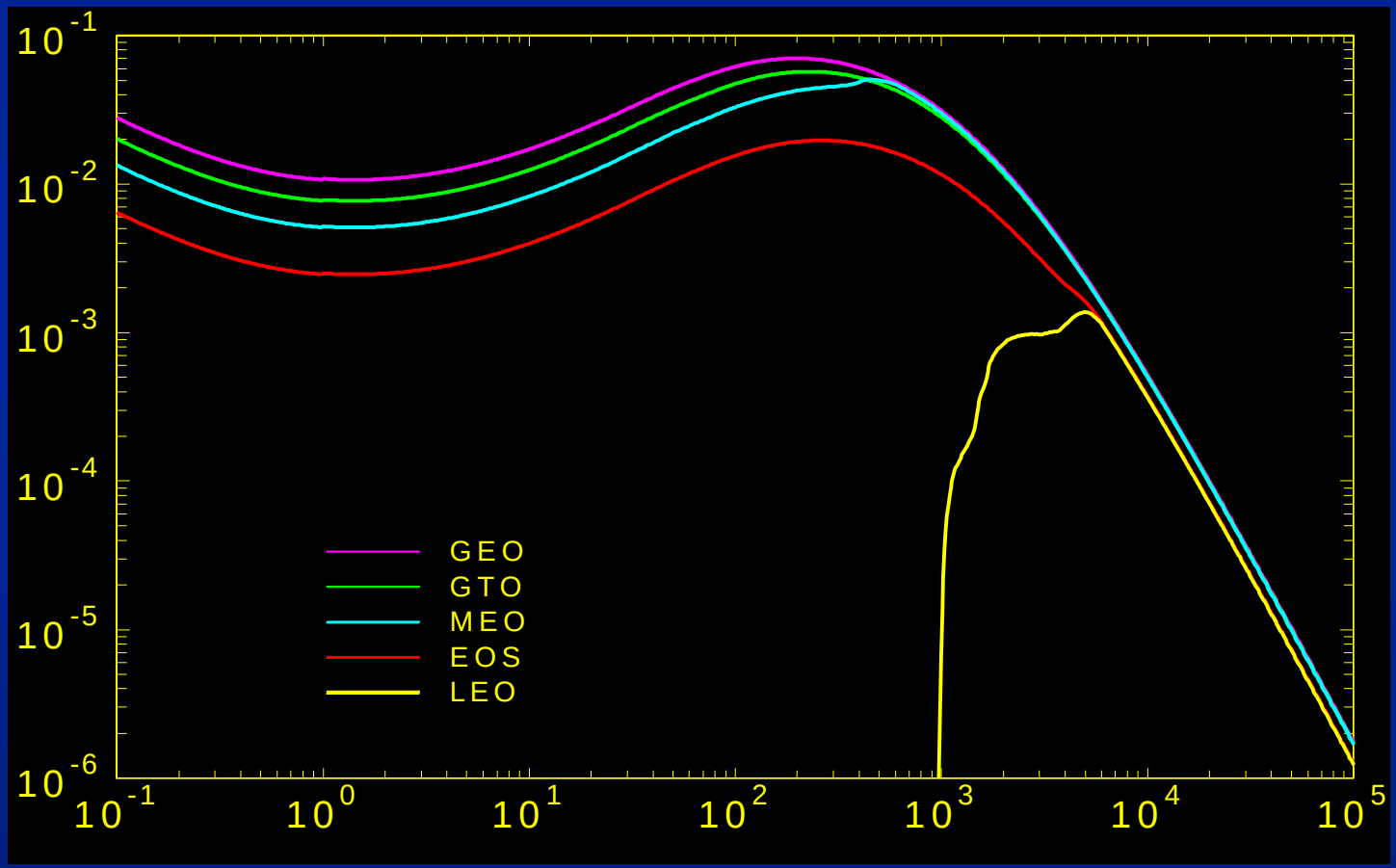
GCRs: Shielded Fluences - Fe

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



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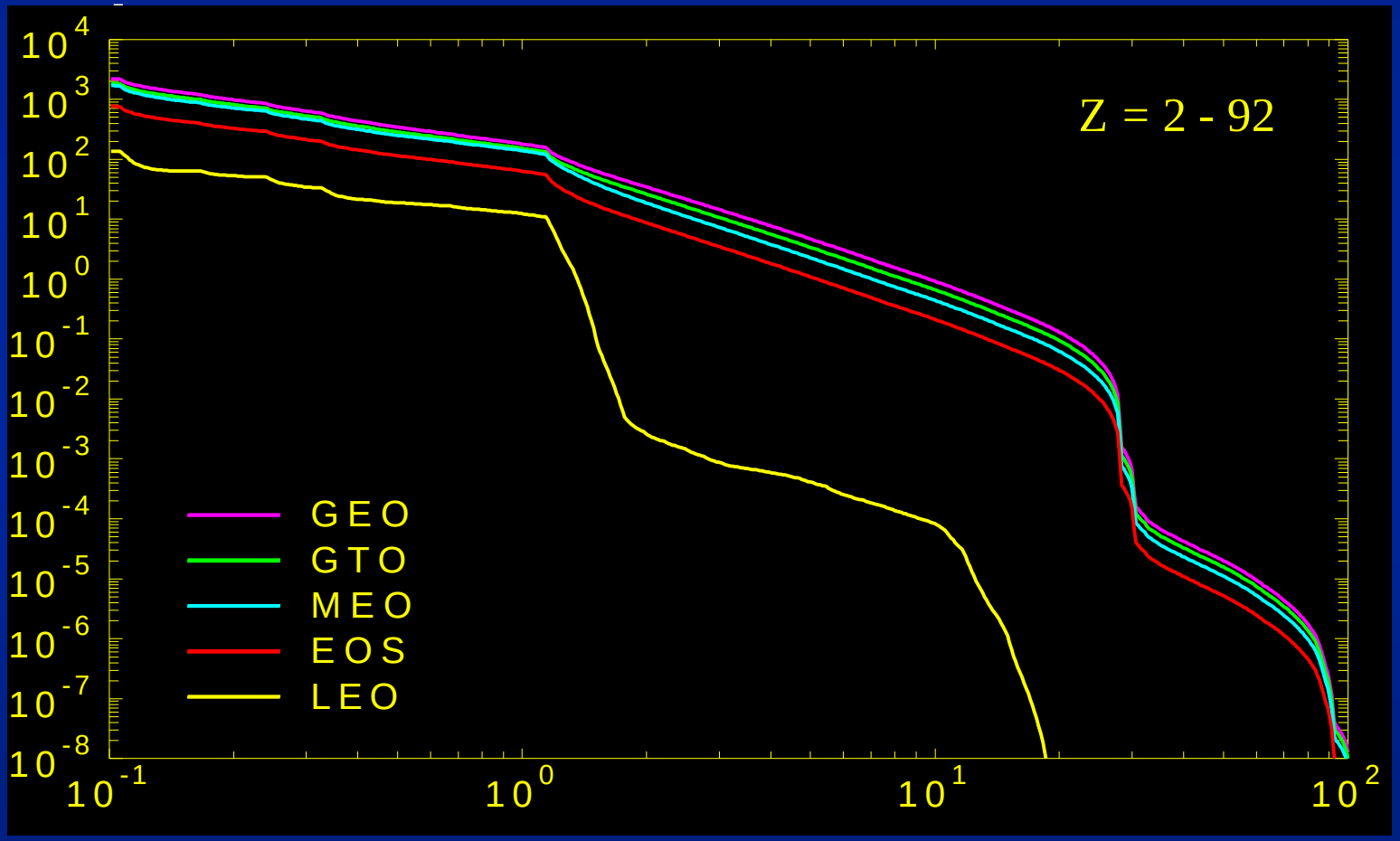
GCRs: Integral LET Spectra

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



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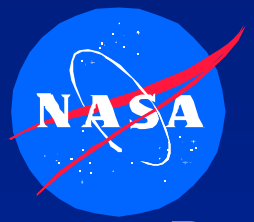
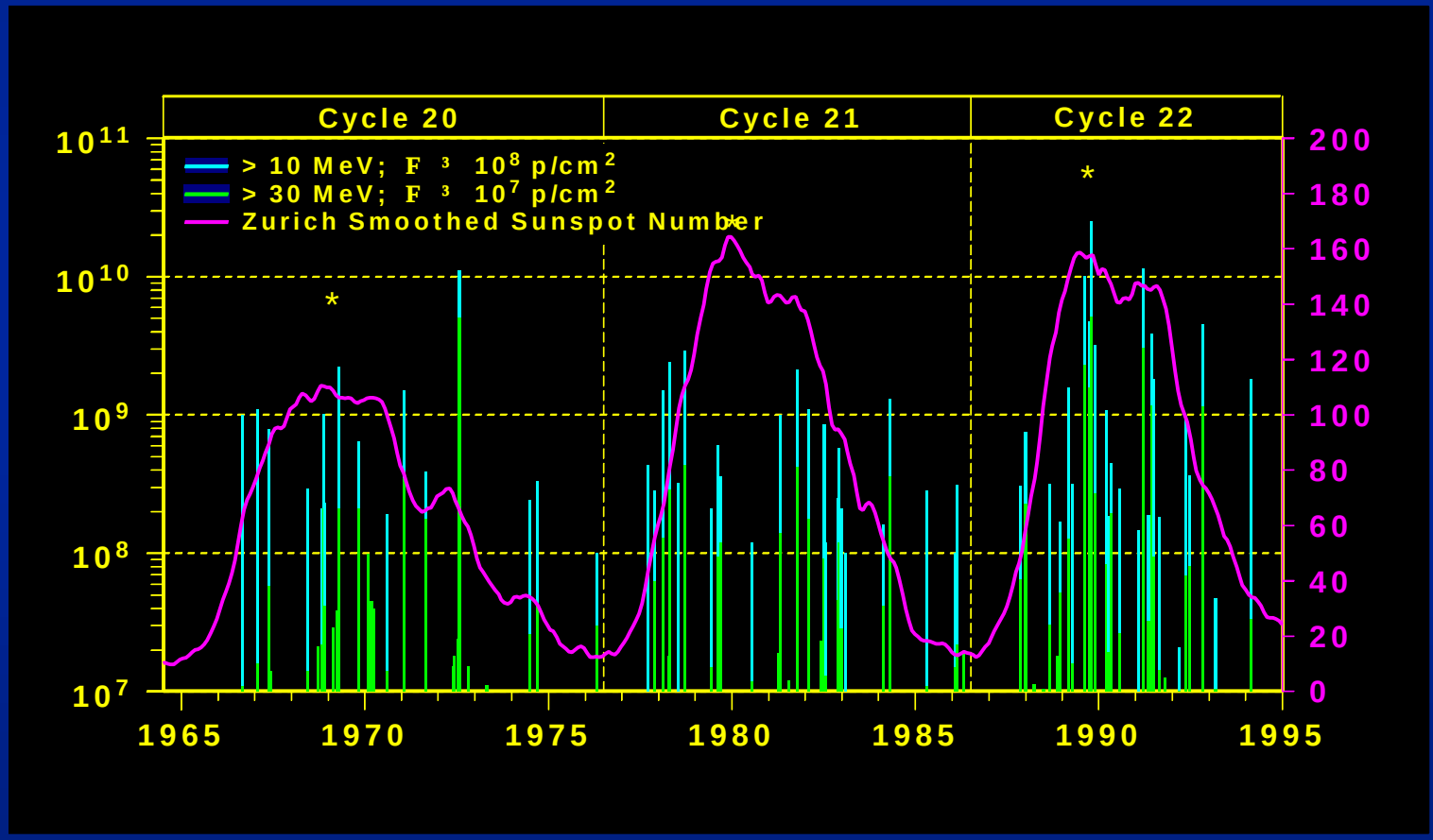


Solar Particle Events

- Results in Increased Levels of Protons & Heavier Ions
- Energies
  - Protons - 100s of MeV
  - Heavier Ions - 100s of GeV
- Abundances Dependent on Radial Distance from Sun
- Partially Ionized - Greater Ability to Penetrate Magnetosphere Than Galactic Cosmic Rays
- Number & Intensity of Events Increases Dramatically During Solar Maximum
- Models
  - Dose & Displacement Damage - SOLPRO, JPL, Xapsos / NRL
  - Single Event Effects - CREME96 (Protons & Heavier Ions)

Sunspot Cycle with Solar Proton Events

Proton Event Fluences



Protons (# / cm²)

Smoothed Sunspot Numbers

Year

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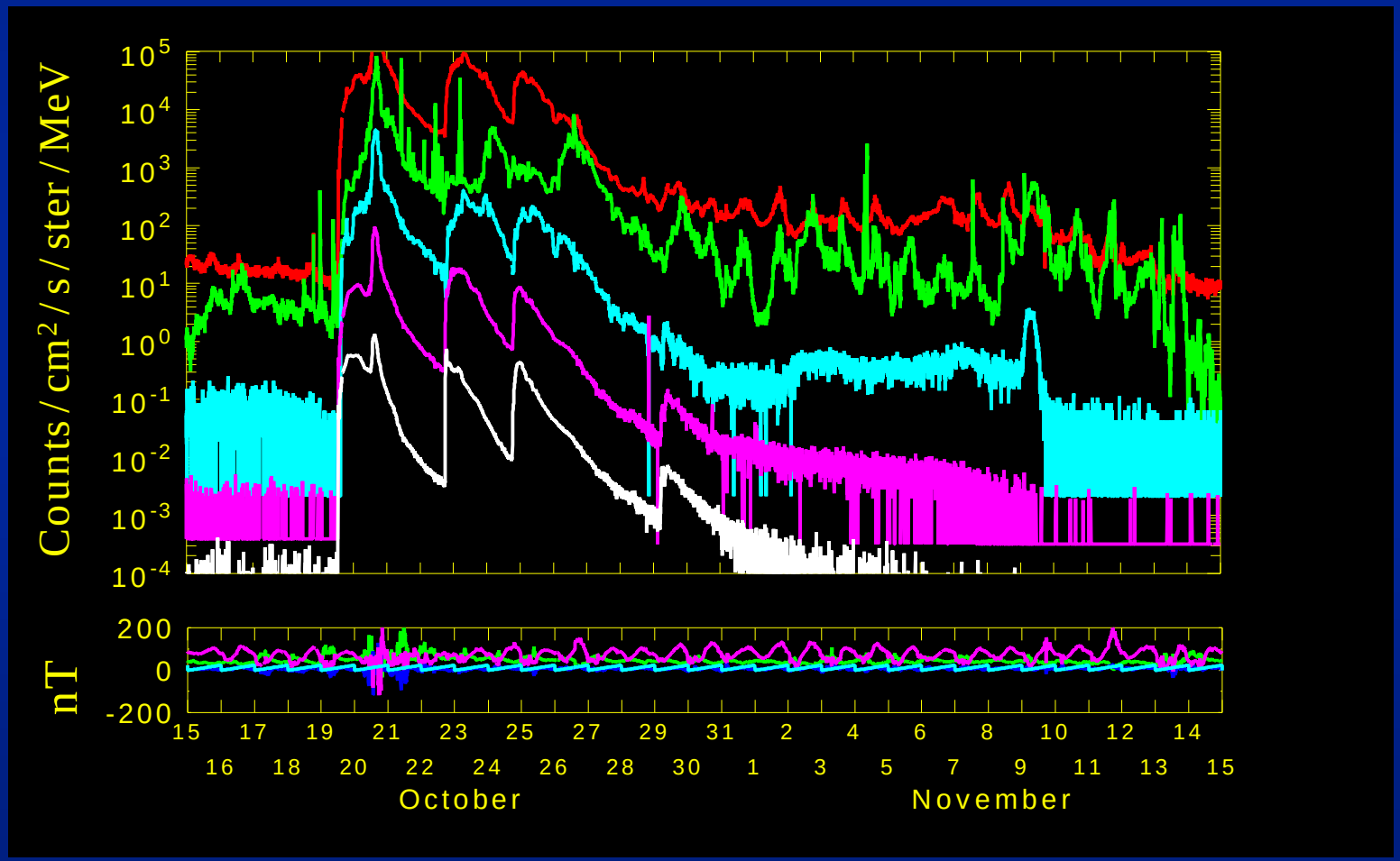
Solar Proton Event - October 1989

Protons & Electrons - Magnetic Field

99% Worst Case Event



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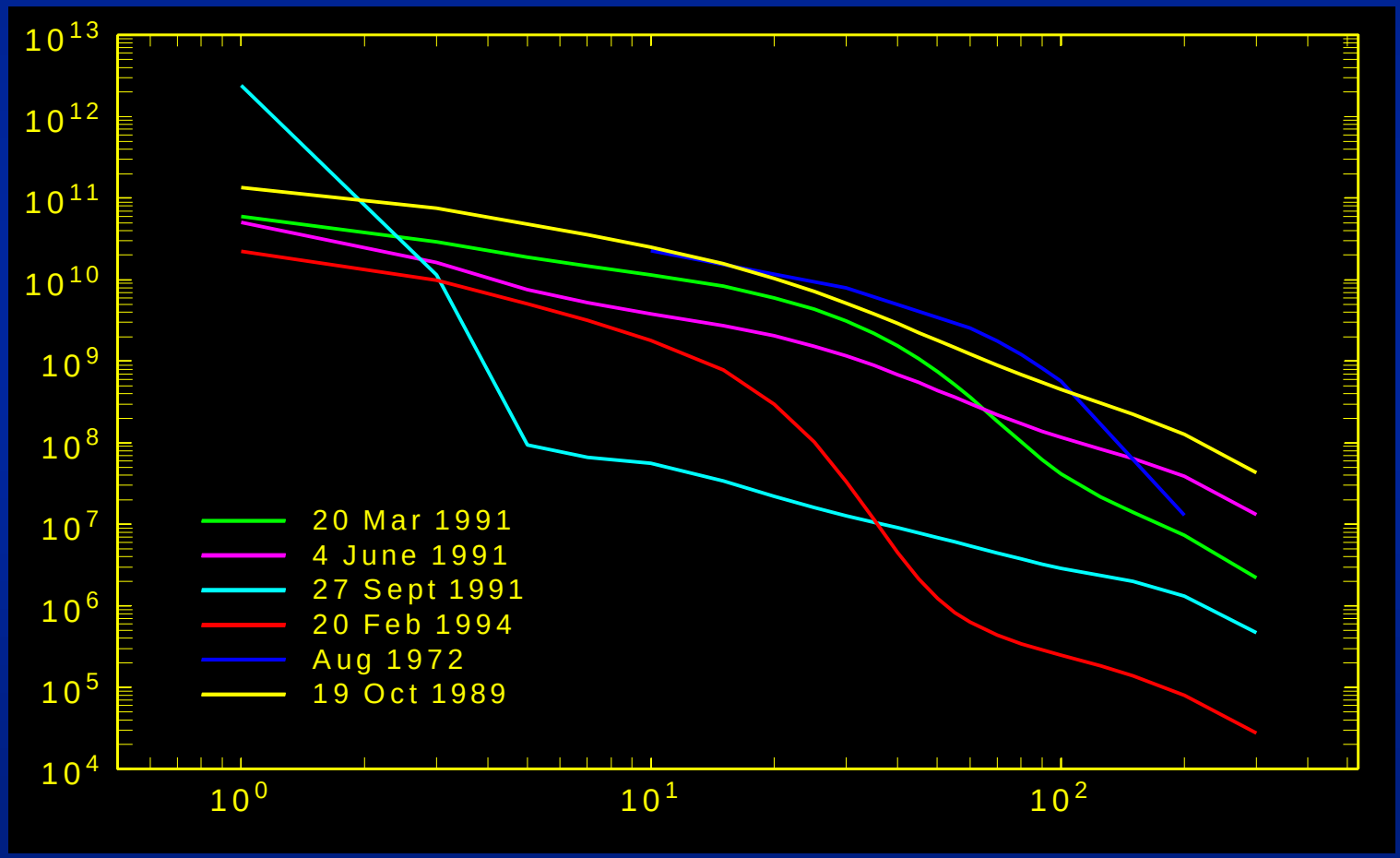
GOES Space Environment Monitor

Proton Event Spectra - Cycle 22

Total Integral Proton Fluence



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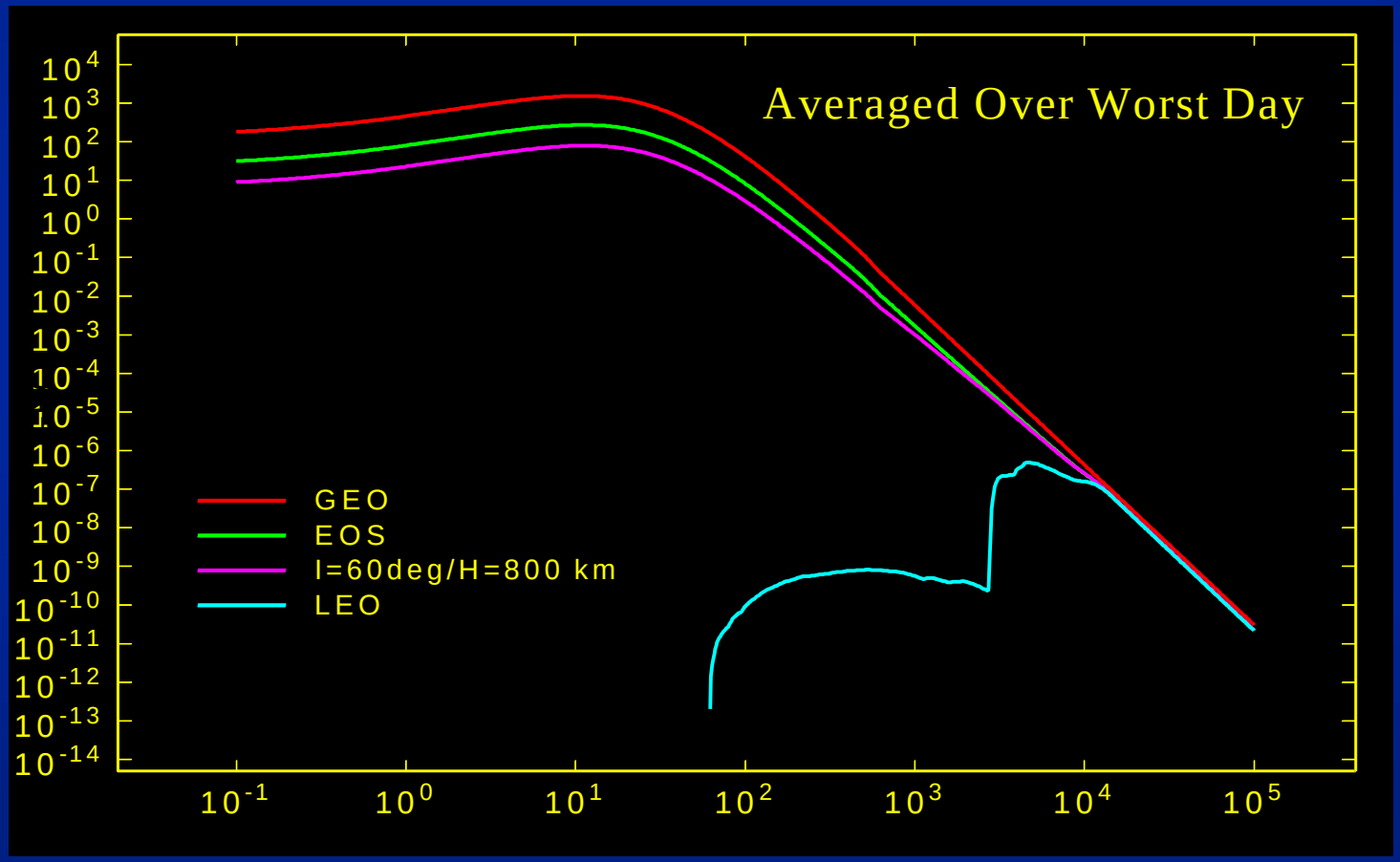
Solar Protons: Orbits

Proton Levels Predicted by CREME 96



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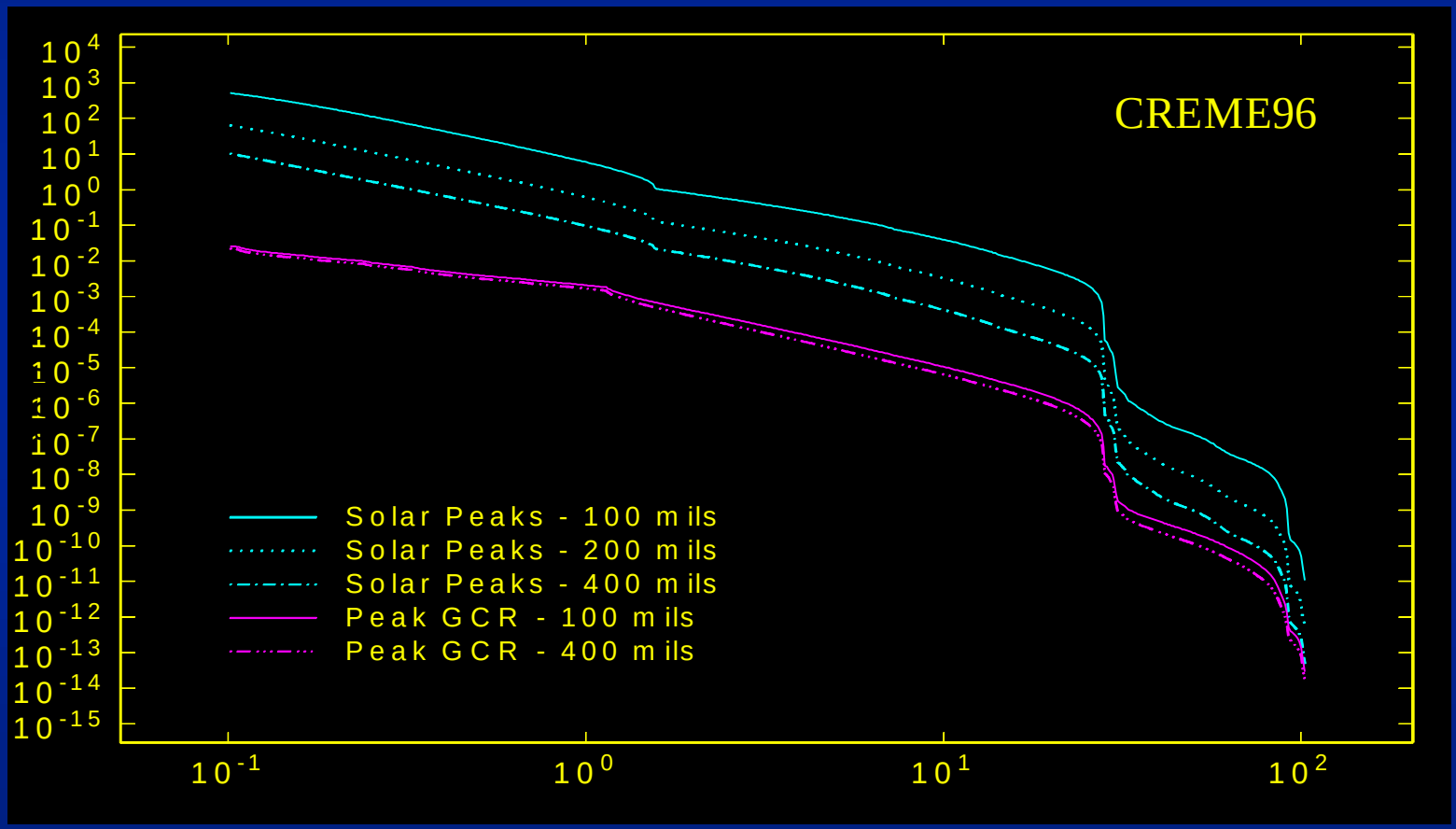
Effect of Shielding on Heavy Ions

Transient Particles Unattenuated by the Magnetosphere



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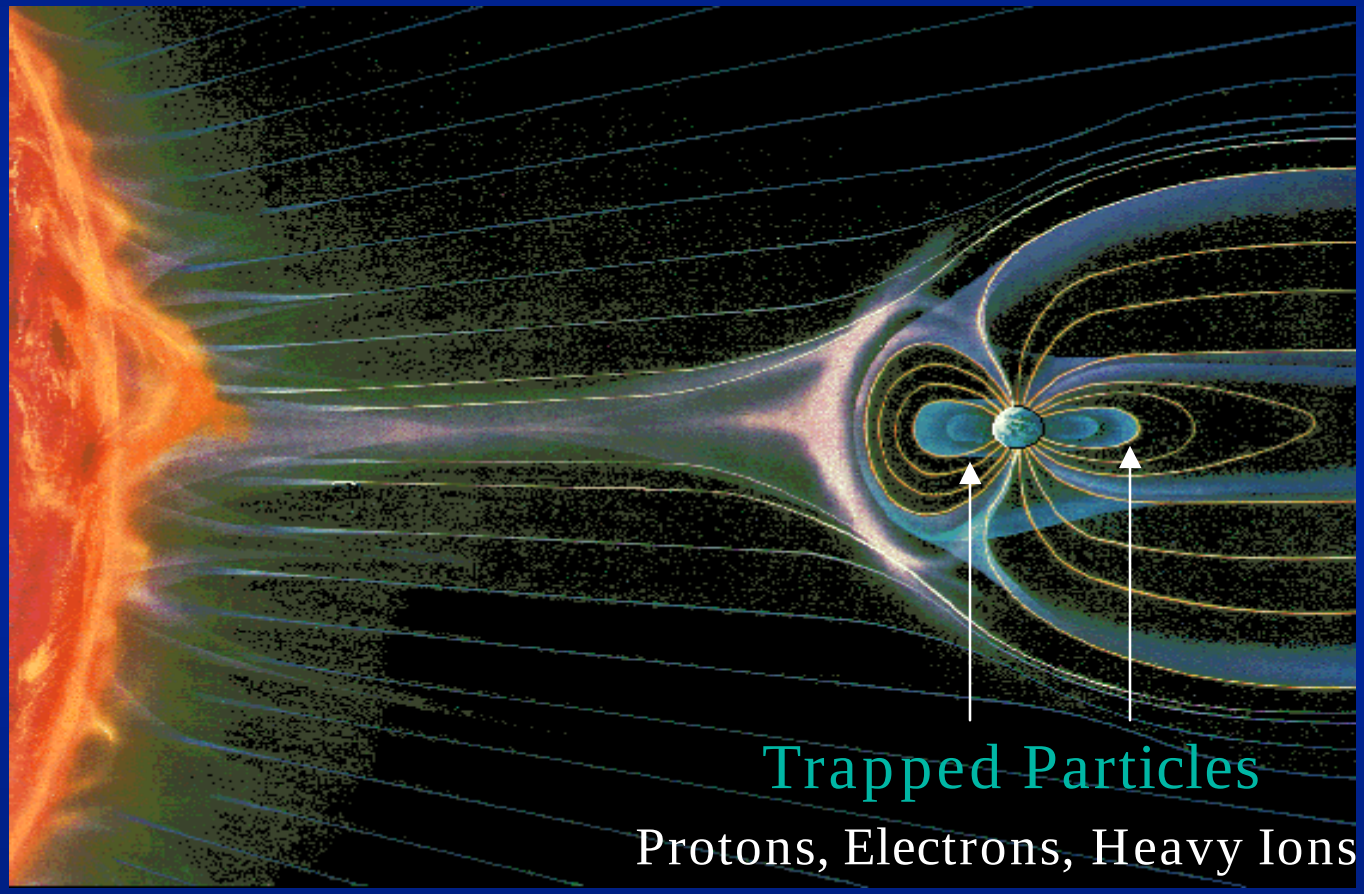
Trapped Radiation



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

Trapped - Van Allen Belts

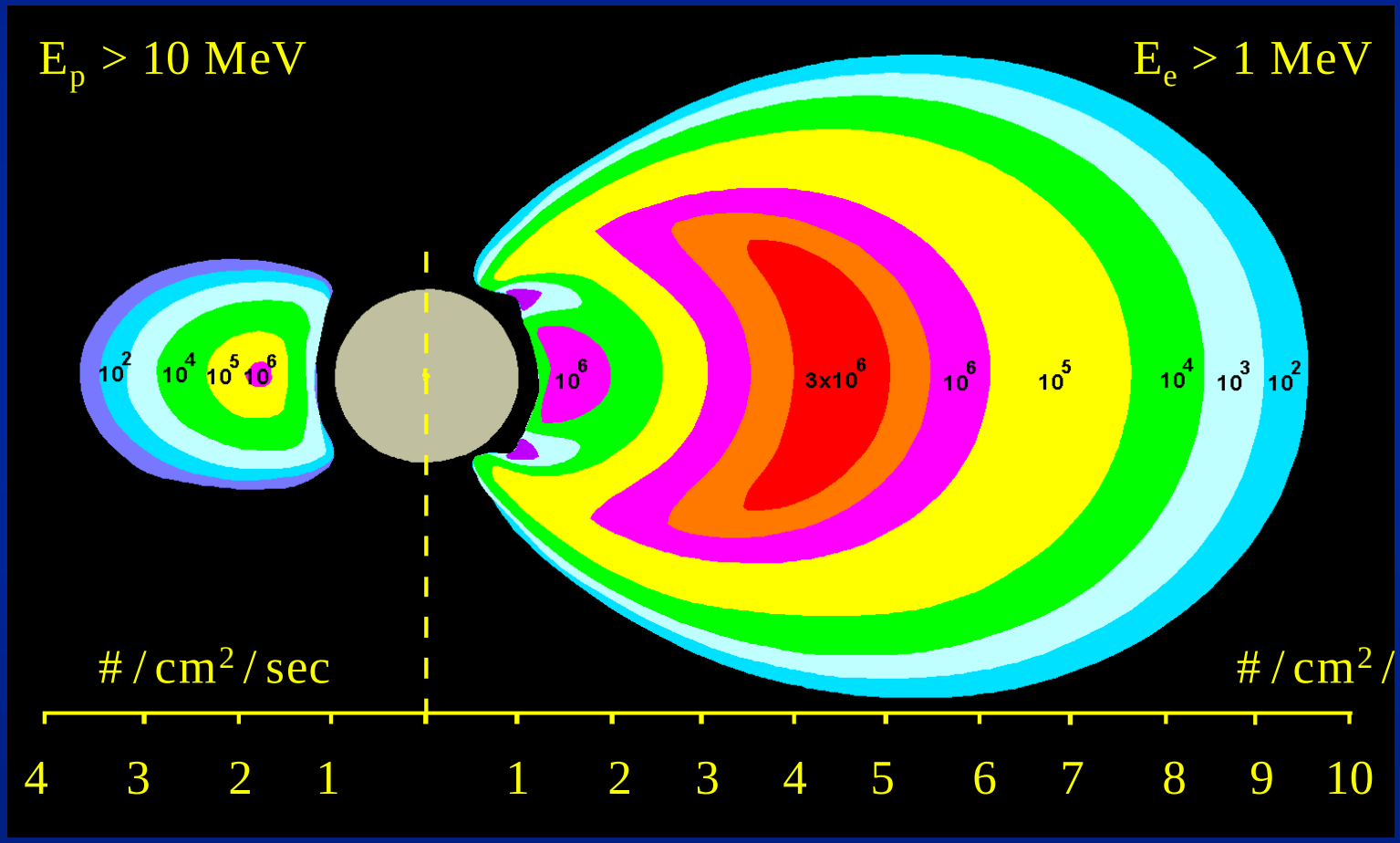
- Omnidirectional
- Components
  - Protons: E ~ .04 - 500 MeV
  - Electrons: E ~ .04 - 7(?) MeV
  - Heavier Ions: Low E - Non-problem for Electronics
- Location of Peak Levels Depends on Energy
- Average Counts Vary Slowly with the Solar Cycle
- Location of Populations Shifts with Time
- Counts Can Increase by Orders of Magnitude During Magnetic Storms
  - March 1991 Storm - Increases Were Long Term

Trapped Particle Models

- NASA AP-8 & AE-8
- Air Force CRRES & APEX Models
  - CRRESPRO, CRRESELE, CRRESRAD & APEXRAD
- New Models - NASA Space Environment and Effects Program
  - Low Altitude Model for Protons- < 1000 km
    - Boeing
    - Based on TIROS Data
  - Model Being Extended to Higher Altitudes
    - Will Combine CRRES and TIROS Data
  - Will Begin Electron Modeling if Funding is Available

Proton & Electron Intensities

AP-8 Model AE-8 Model



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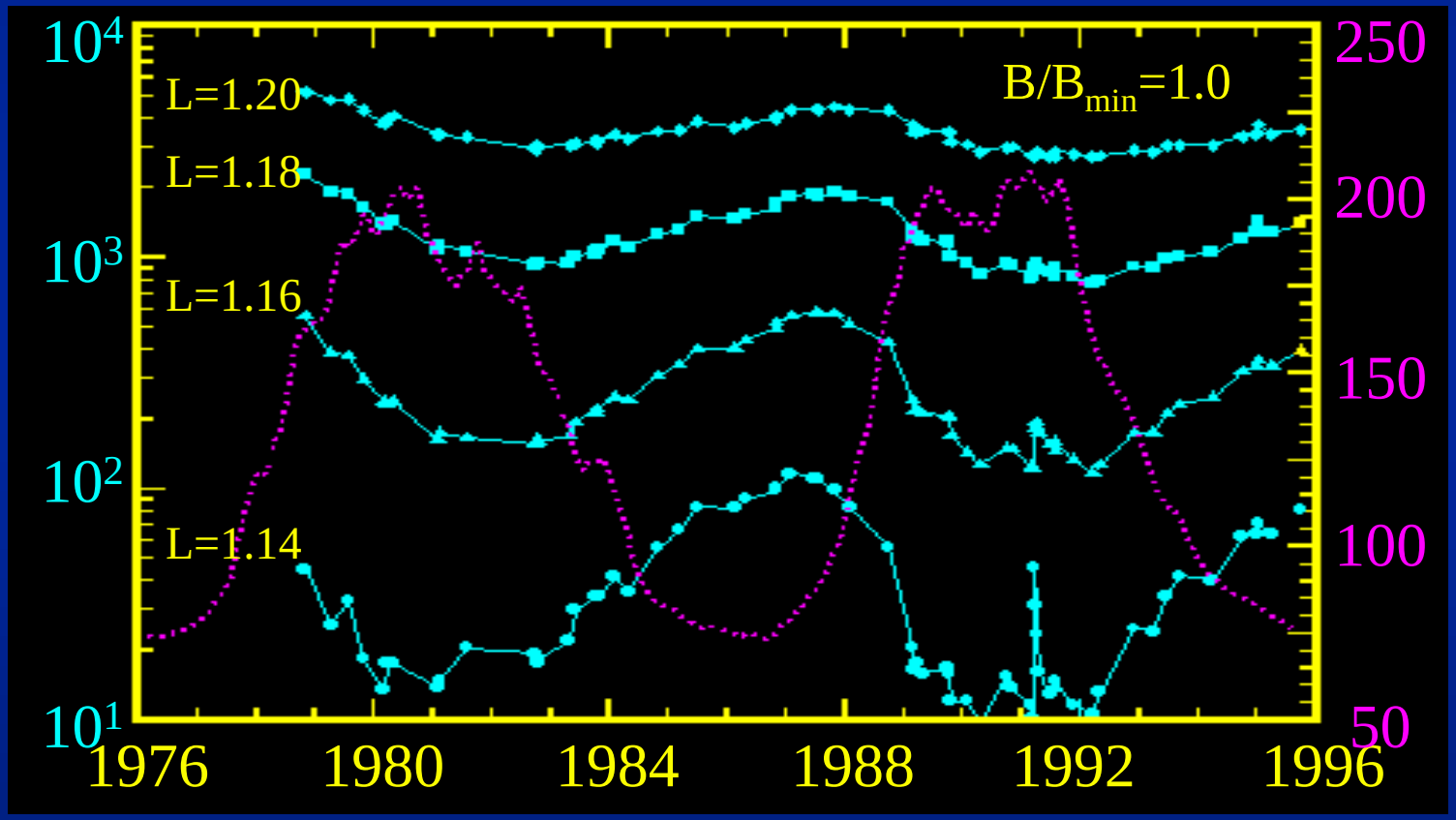
NASA / GSFC

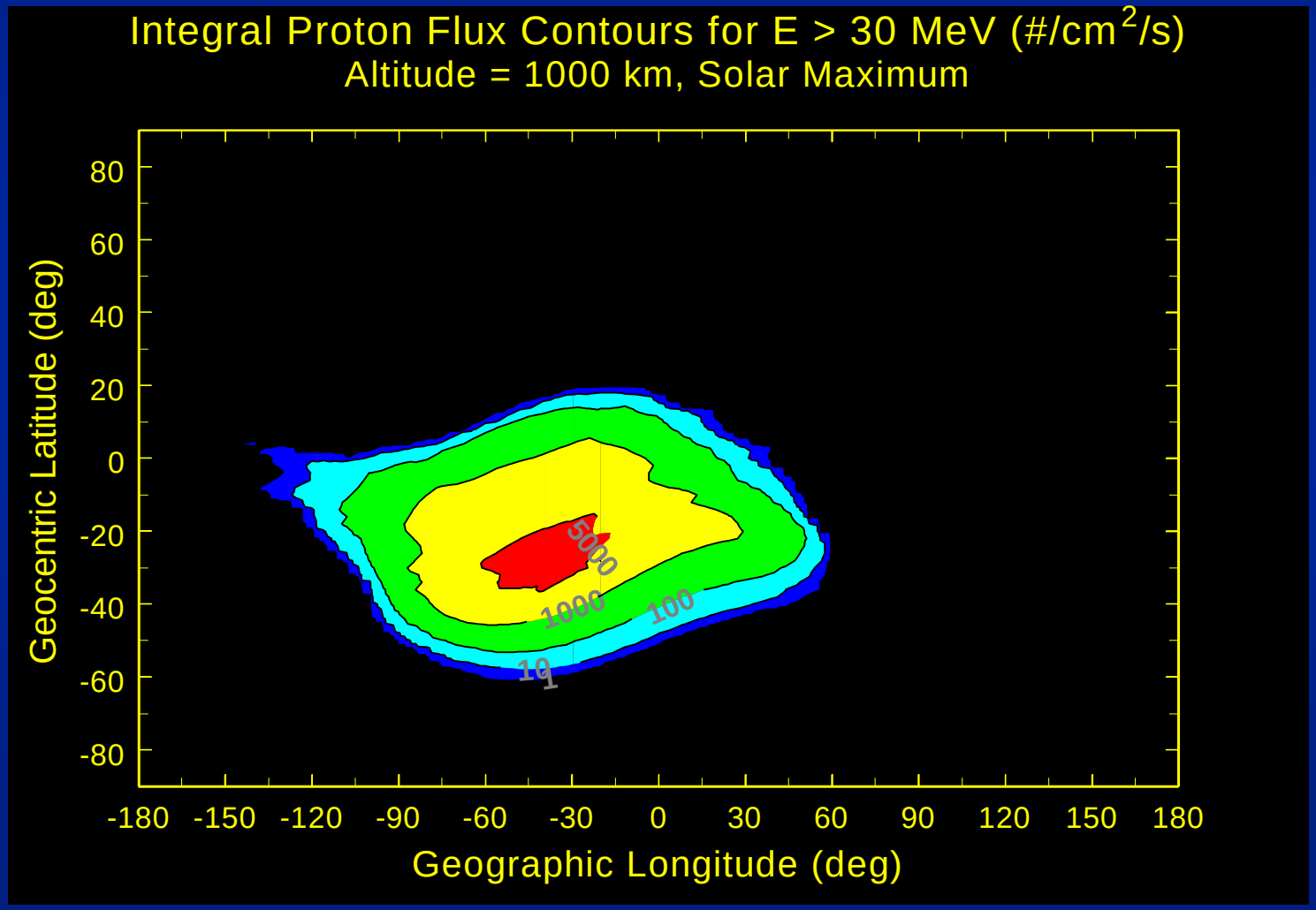
TIROS/NOAA Trapped Protons

Solar Cycle Variation: 80-215 MeV Protons



Huston et al.

Trapped Protons - 1000 km



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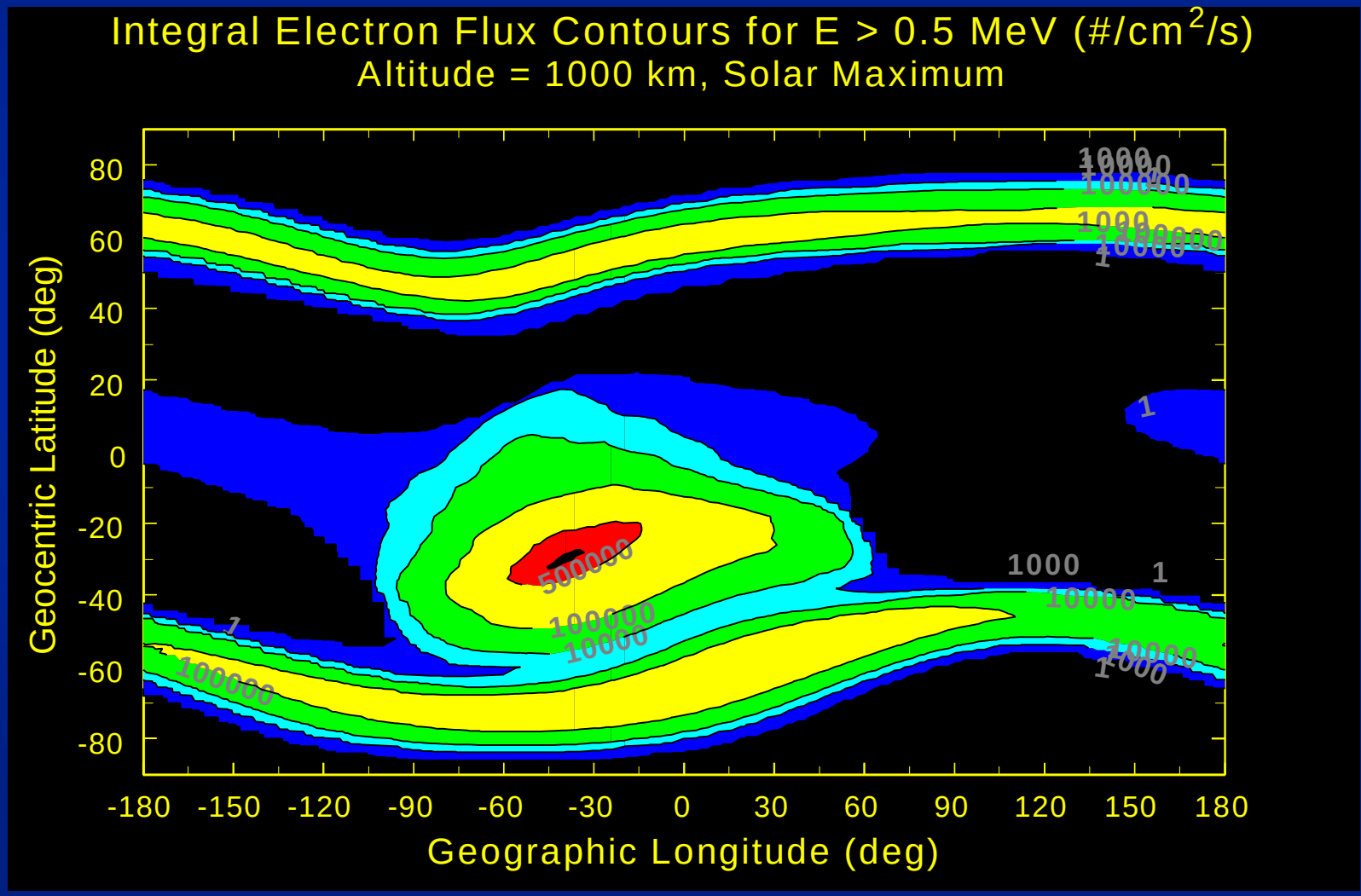
Trapped Electrons - 1000 km



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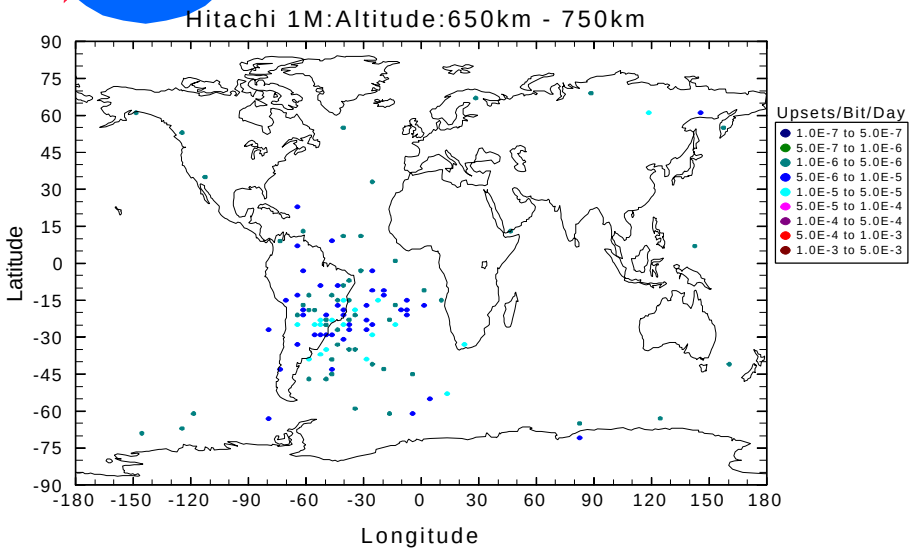
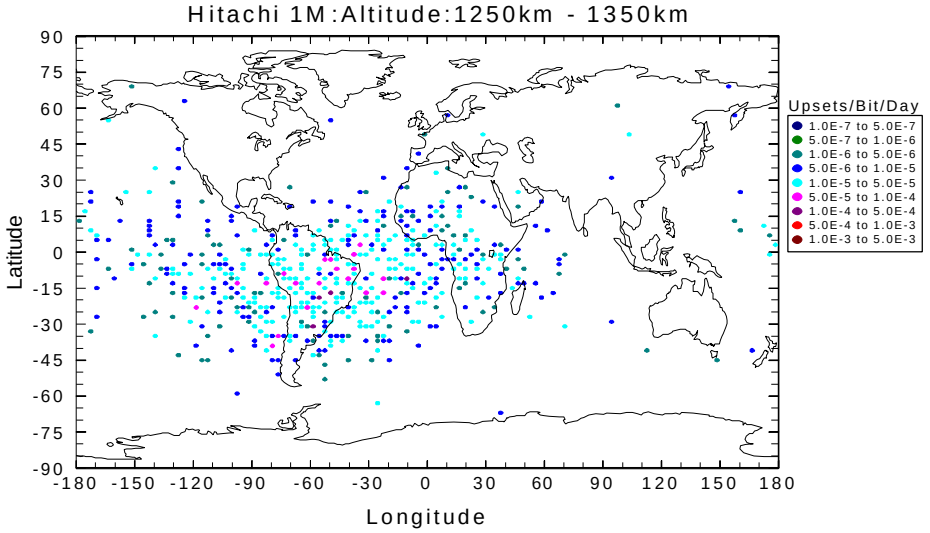
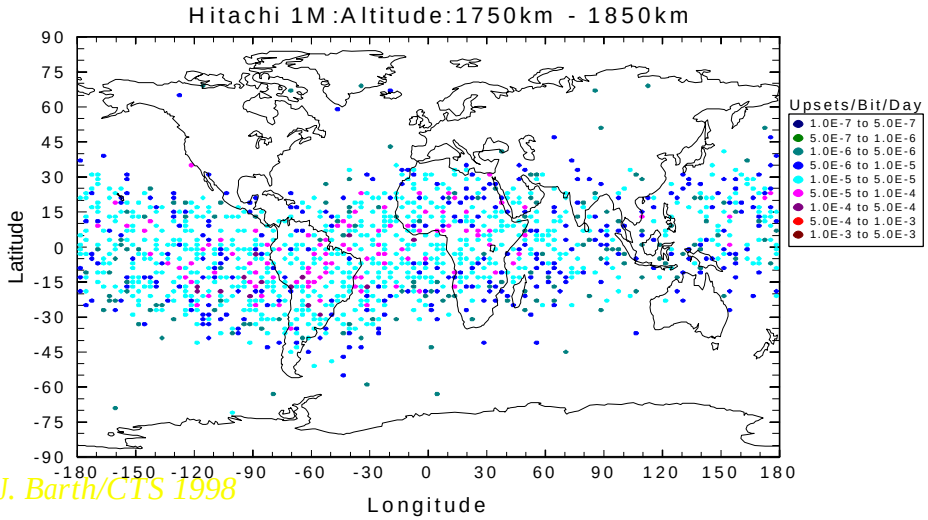
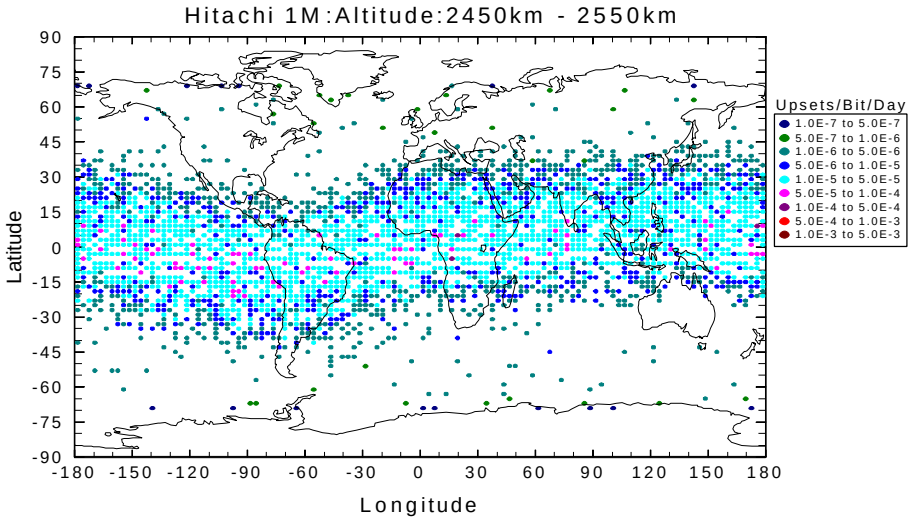
SRAM Upset Rates on CRUX/APEX









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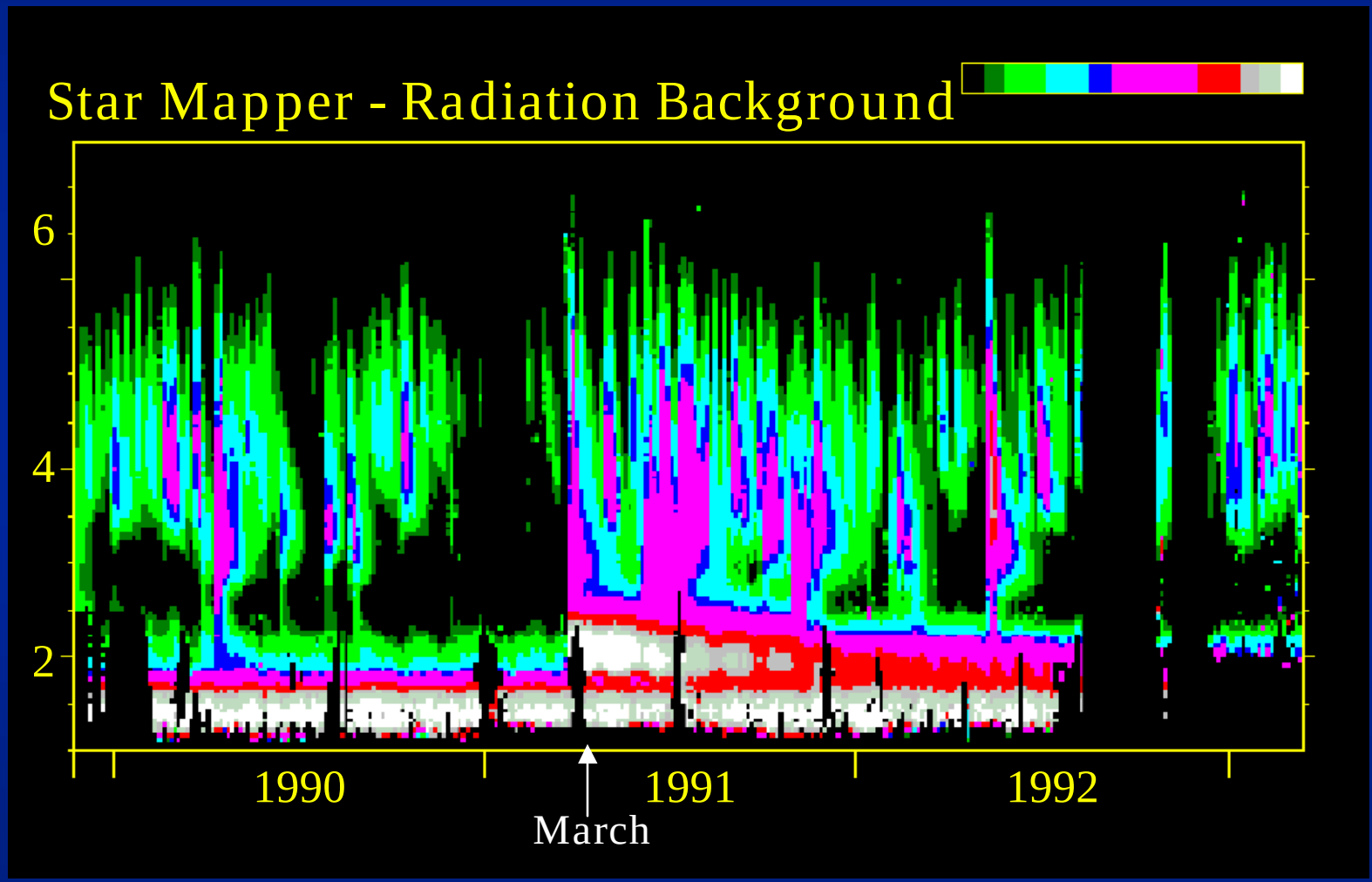
Magnetic Storms - Hipparcos



4-Day, 9-Orbit Averages

Daly, et al.

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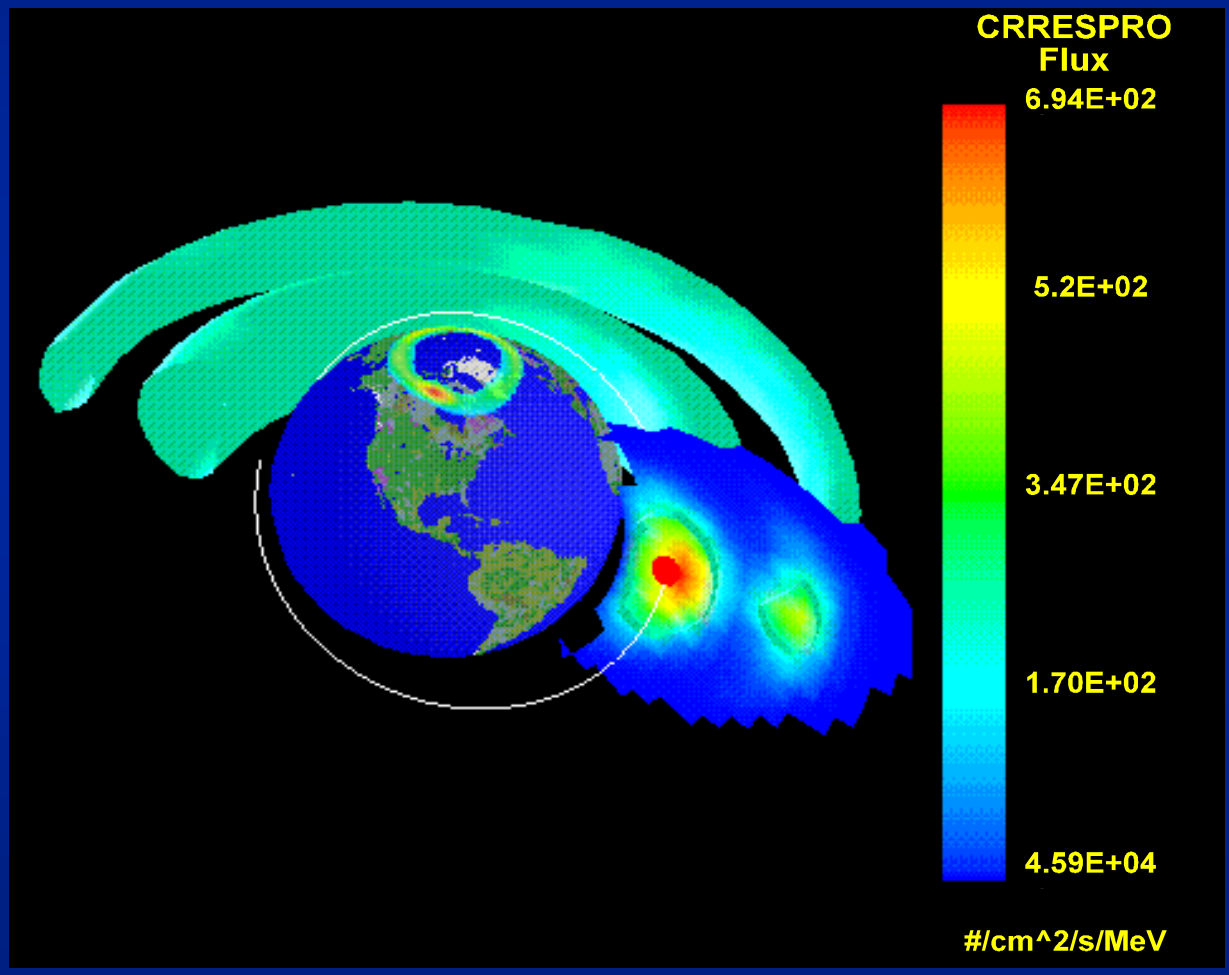
CRRES - Measured Proton Belt



AF Phillips Laboratory, SPD/GD

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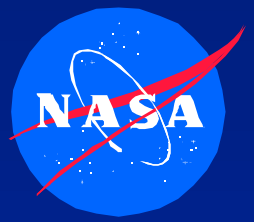

Solar Cycle Effects

- 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

Models of the Environment

- Trapped Particles
  - NASA AP-8 & AE-8 - Data from 1960s & 1970s
  - AFRL CRRESPRO & CRRESELE - Solar Max Only
  - MDAC* - Low Altitude Improvements for Protons Based on NOAA/TIROS Data
  - "AP-9"* in Development
  - Will Begin "AE-9" Development if Funding Levels Permit
- Galactic Cosmic Ray Heavy Ions
  - CREME96* - Update to Outdated CREME86
- Solar Protons - Dose & Degradation
  - New Solar Proton Model* - Total Fluence
- Solar Heavy Ions - Single Event Effects
  - CREME96* - Update to Inadequate CREME86

* Supported by NASA/Space Environment & Effects Program

Environment Definition

- Total Ionizing Dose
  - Dose-Depth Curves or Spacecraft Specific Dose Levels
    - Trapped Protons & Electrons
    - Solar Protons
    - Secondary Bremsstrahlung (High Electron Environments)
- Single Event Effects - Average & Peak Conditions
  - Galactic Cosmic Ray Heavy Ions (LET Spectra)
  - Solar Heavy Ions (LET Spectra)
  - Solar Protons (Energy Spectra)
  - Trapped Protons (Energy Spectra)