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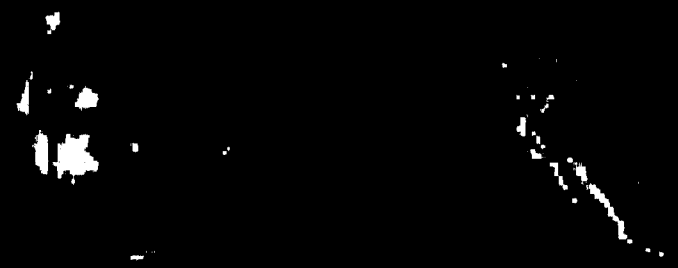
Radiation Environments and Environmental Models



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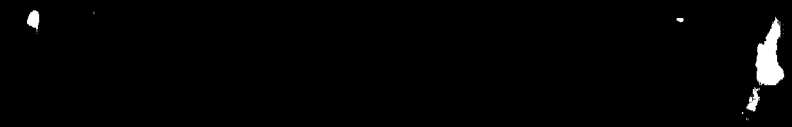
Outline

- Background - Solar Activity
- Solar Particle Events
- Galactic Cosmic Rays
- Trapped Radiation
- Summary

Background: Solar Activity

The Sun

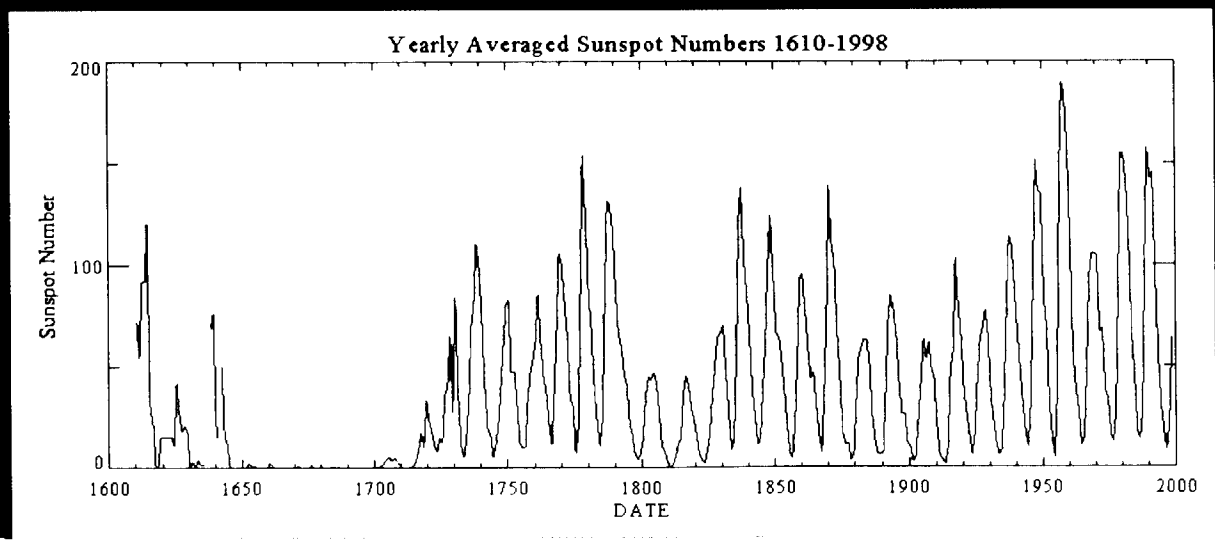
- Controls space environments
  - » Source
  - » Modulator
- Structure
  - » Photosphere
  - » Chromosphere
  - » Corona



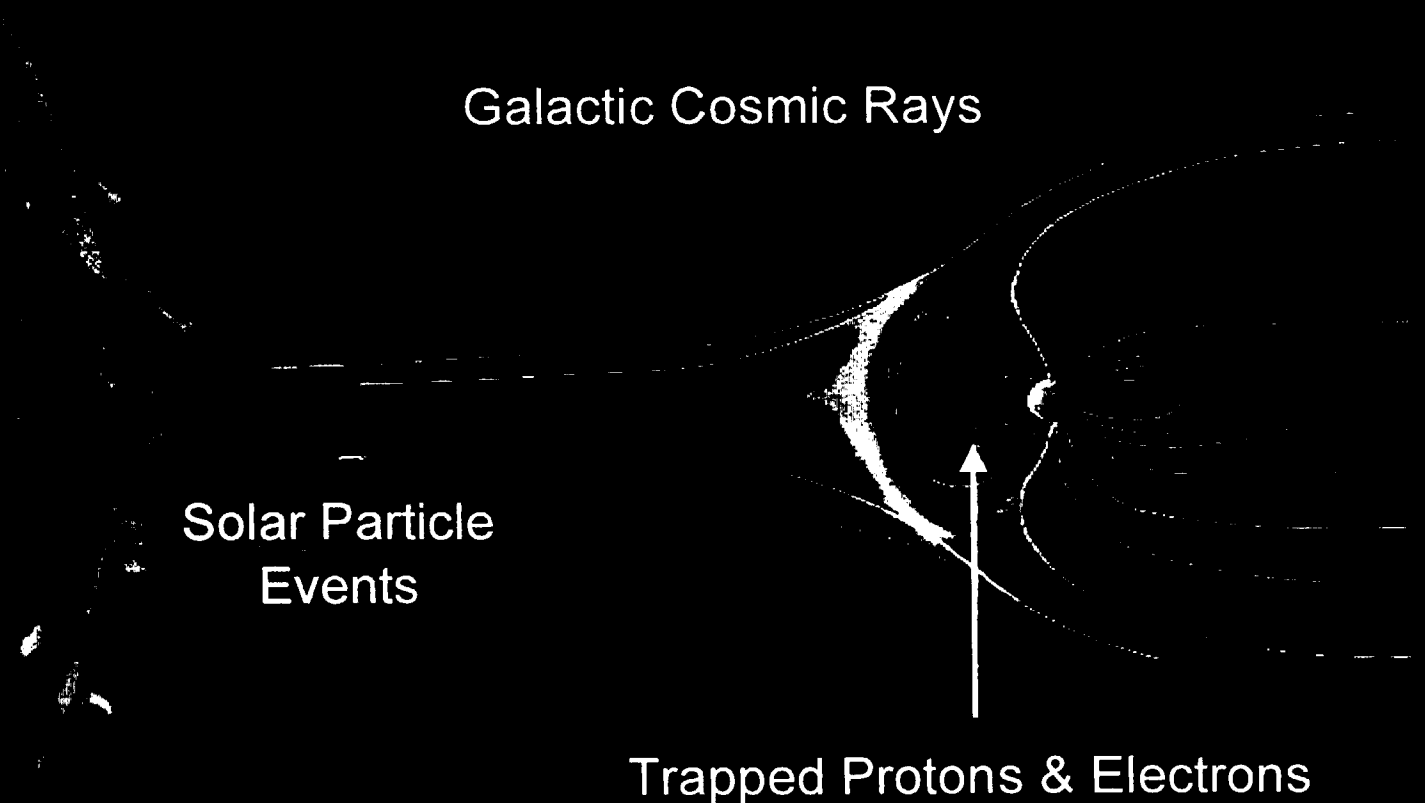
The Solar Activity Cycle

- Solar cycle is typically 11 years:
  - Solar Maximum (7 years)
  - Solar Minimum (4 years)

- Common indicators of solar activity:
  - sunspot numbers
  - 10.7 cm radio flux



High Energy Radiation Particles



Solar Particle Events

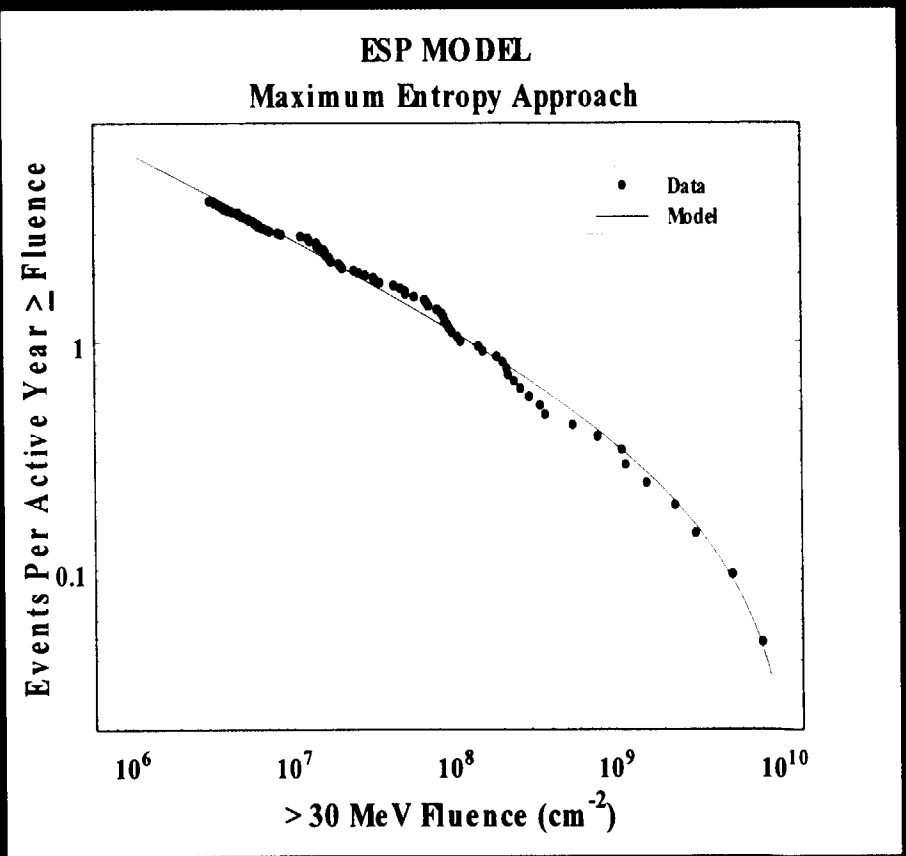
Solar Particle Event Characteristics

- Occur randomly in time, more frequently during solar maximum
- Event sizes span orders of magnitude
- Radiation consists of protons, heavy ions, electrons, x-rays,…
- Energies: up to ~GeV/nucleon
- Duration: hours to days
- Ionizing dose: up to ~krad(Si)

SOLPRO = solar protons
JPL91 = Jet Propulsion Lab 1991
ESP = Emission of Solar Protons

Solar Proton Event Models

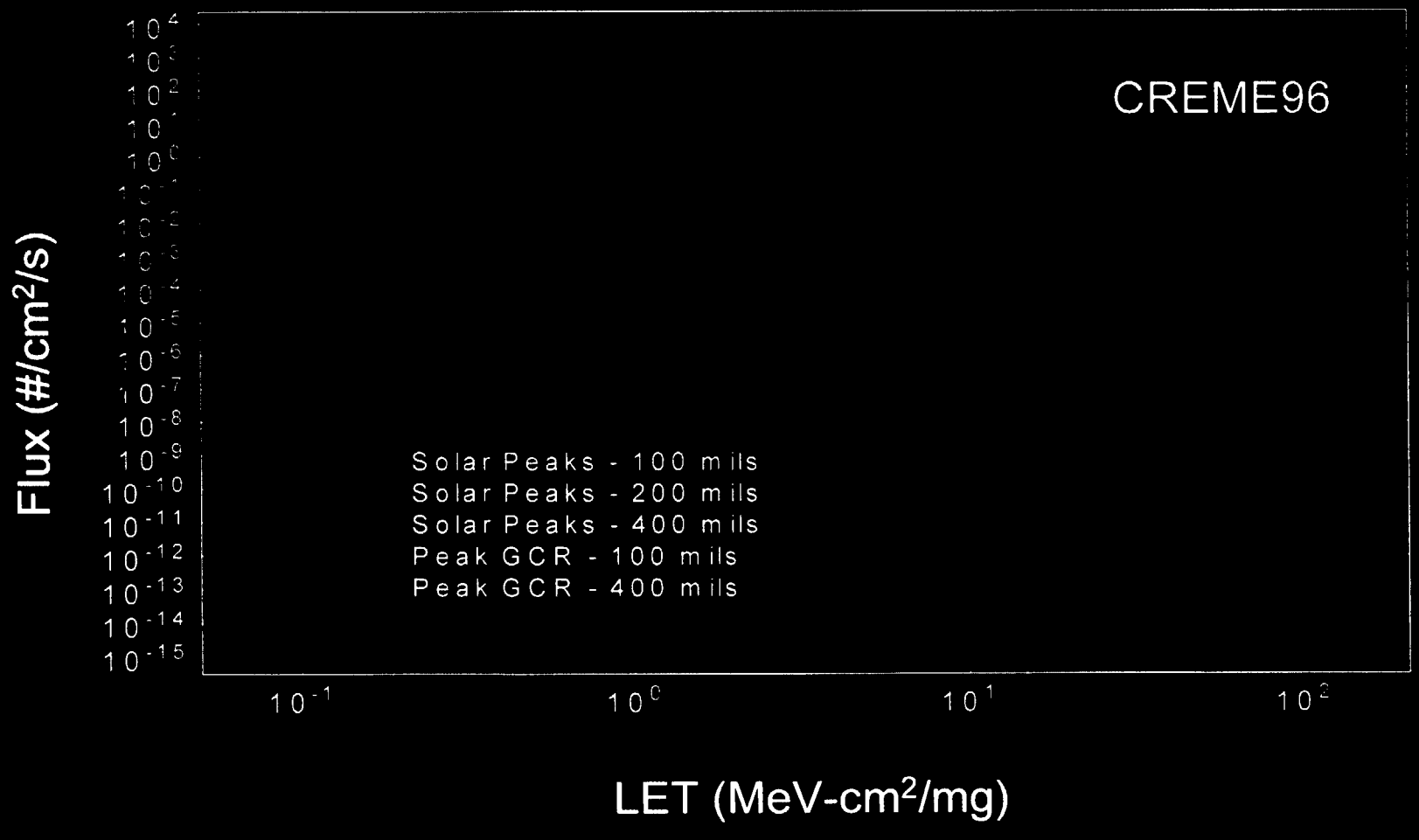
- Predict proton fluences for given confidence level and mission duration
  - » SOLPRO
  - » JPL91
  - » ESP
- ESP is most advanced
  - » Based on cycles 20-22
  - » Describes complete range of measured event sizes
  - » Cumulative fluences and worst case events
  - » Upper limit in event size agrees well with historical evidence



GCR = galactic cosmic ray
LET = linear energy transfer
CREME96 = cosmic ray effects on microelectronics 1996

Solar Heavy Ions

Unattenuated by Magnetosphere



Galactic Cosmic Rays

Galactic Cosmic Ray Ion Characteristics

- Originate beyond our solar system
  - » Isotropic distribution
- Composed of all naturally occurring nuclei ranging from protons to uranium
  - » 87% protons
  - » 12% alpha particles
  - » 1% heavier ions
- Highly or completely ionized
- Energies up to at least 10^{11} GeV!
  - » Energy spectrum peaks ~1 GeV / nucleon

Galactic Cosmic Ray Solar Cycle Modulation

- **Cyclic variation of ion fluences**
  - » **Lowest fluences during solar maximum**
  - » **Highest fluences during solar minimum**
  - » **Cyclical nature most pronounced at low energies; differences not seen at ~10 MeV/nucleon and beyond**

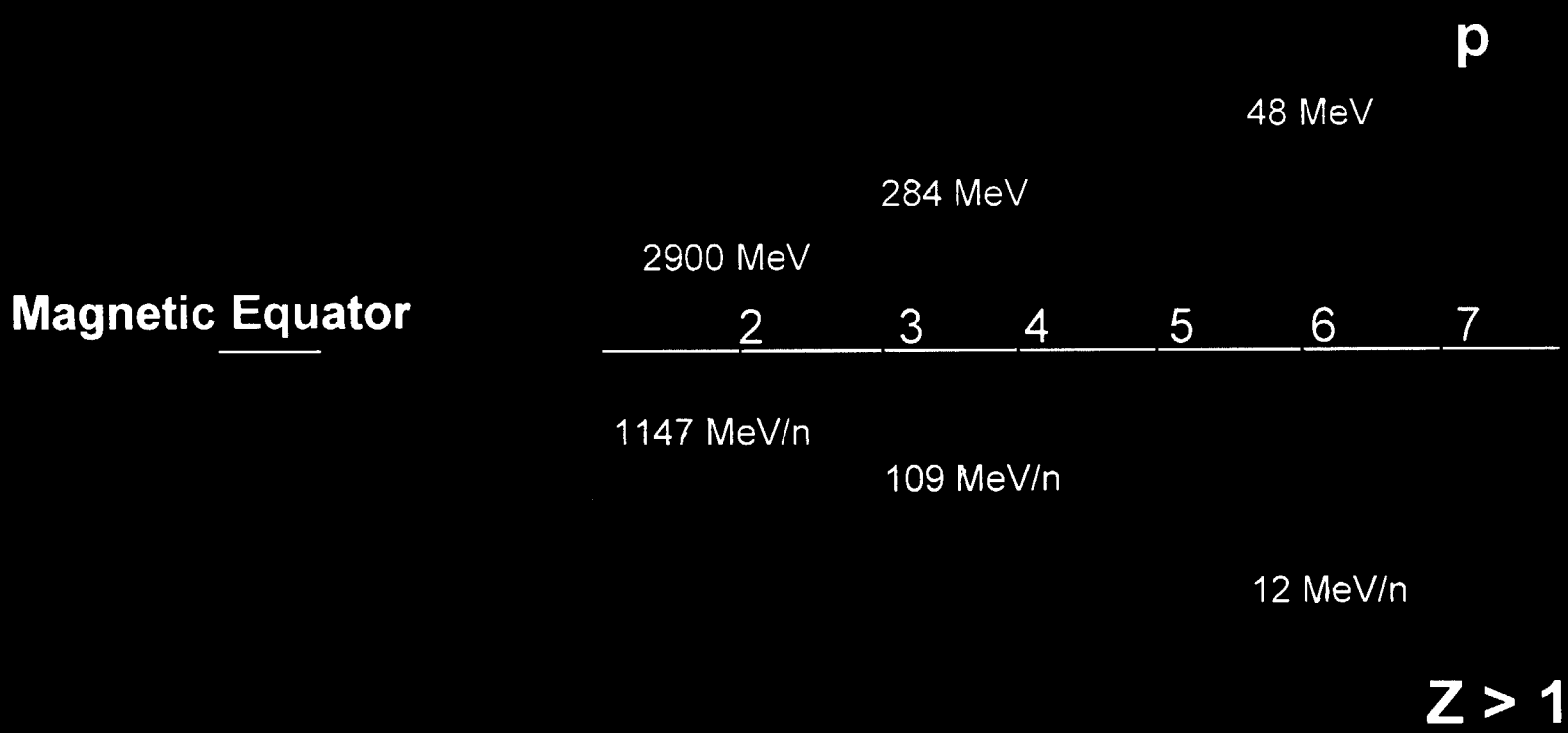
- **Current models – diffusion/convection theory**
  - » **Describe cyclical variation with semi-empirical deceleration potential; interaction with solar wind**
    - **Badhwar and O'Neill**
    - **Nymmik**
    - **Lee and Adams**
    - **Chenette**

CNO = carbon, nitrogen, oxygen
IMP = interplanetary monitoring platform

Heavy Ion Population

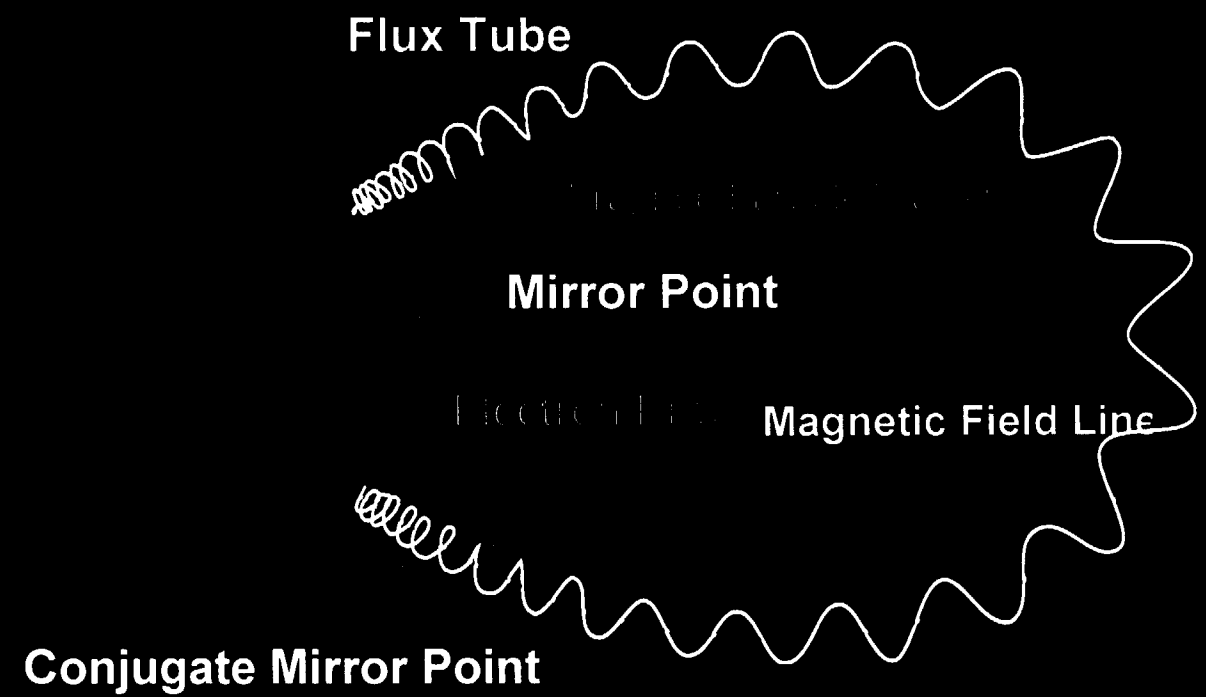
CNO - 24 Hour Averaged Mean Exposure Flux

Energy Required to Penetrate Magnetosphere



Trapped Particles

Trapped Particle Motions



Trapped Proton Characteristics

- Single trapped proton region
- Proton energies up to ~ 500 MeV
- Low Altitudes (< 1000 km)
  - » Exposure mainly due to South Atlantic Anomaly
  - » Average exposure gradually decreases during solar maximum by factor of ~ 2.
- Fluxes in medium earth orbits generally quite severe.

L = dipole shell parameter

Trapped Electron Characteristics

- **Inner Belt:**
  - 1.0 < L < 2.8
  - Energies < 4.5 MeV
- **Outer Belt:**
  - 2.8 < L < 12
  - Energies < 7 (?) MeV
- **Average fluxes gradually increase during solar maximum by factor of ~ 2**
- **Fluxes Dynamic**
  - Greater variability with increasing altitude
  - Correlation with solar rotation period

AP = Aerospace Proton
AE = Aerospace Electron

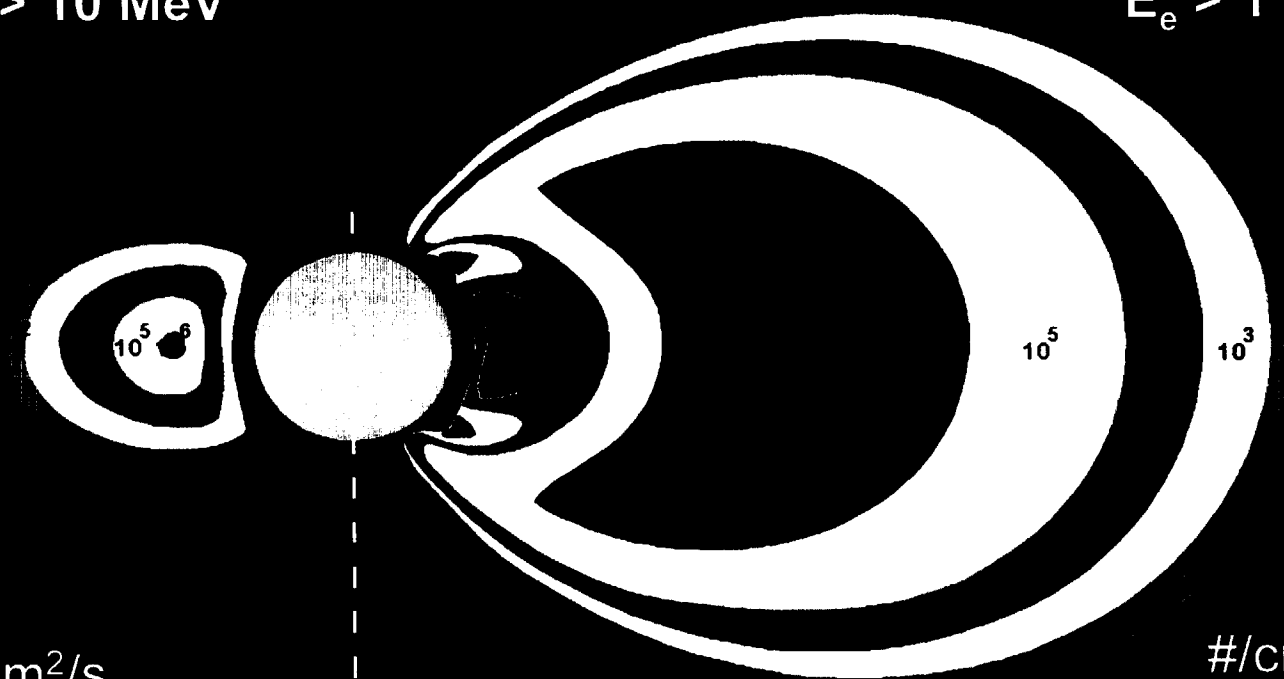
Proton & Electron Intensities

AP-8 Model

$E_p > 10$ MeV

AE-8 Model

$E_e > 1$ MeV



CRRESPRO = combined release radiation effects satellite - protons
CRRESELE = combined release to radiation effects satellite - electrons

AFRL = air force research lab

Some Recent Trapped Particle Models

- **Low Altitude Trapped Proton Model (Huston and Pfitzer)**
  - » **Accounts for variation with solar cycle activity**
- **CRRESPRO (AFRL)**
  - » **Quiet and active proton environment for $1.15 < L < 5$**
- **CRRESELE (AFRL)**
  - » **Trapped electrons for different levels of magnetic activity for $2.5 < L < 6.5$**

Trapped Particles - Jupiter

- Jupiter has largest magnetosphere in solar system.
- Very severe trapped radiation environment measured by Galileo spacecraft
  - » Protons
  - » Oxygen
  - » Sulphur
- Modeling effort by JPL ongoing.

MSFC = Marshall Space Flight Center
SEE = Space Environments & Effects

SPENVIS = space environments information system

Summary

- **Space radiations covered:**
  - » Solar particle events
  - » Galactic cosmic rays
  - » Trapped particles
- **Recommended sources:**
  - » MSFC SEE Program –
  - » SPENVIS –
  - » CREME96 –
  - » Langley technical publications –