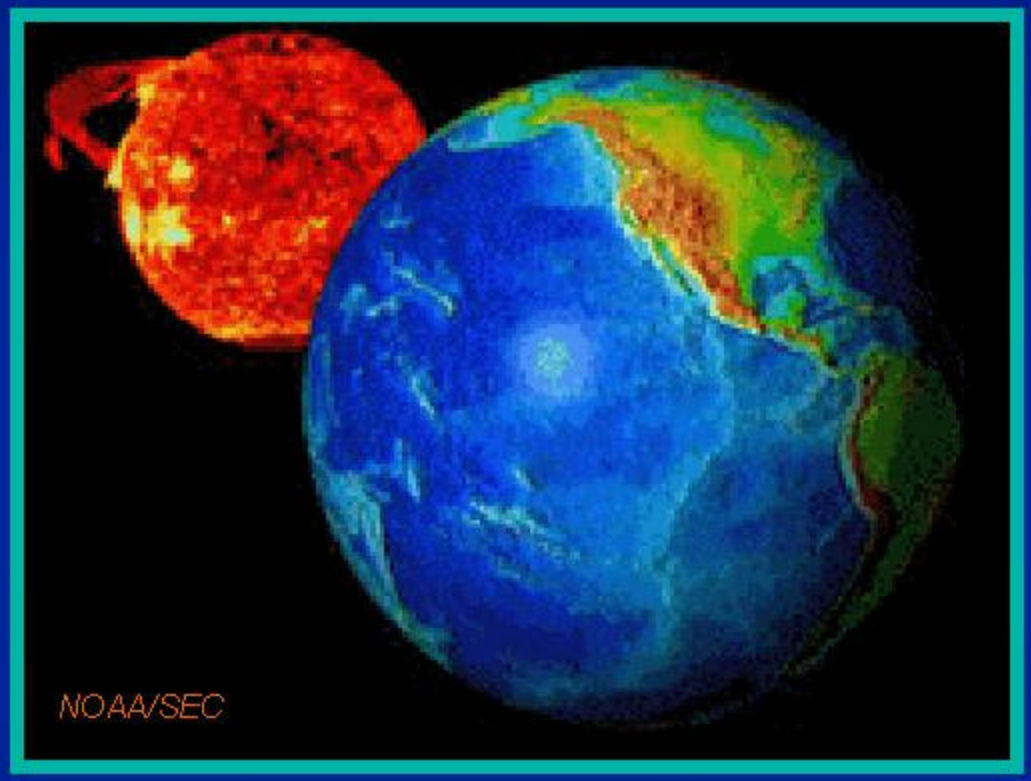
Radiation Environments and Environmental Models



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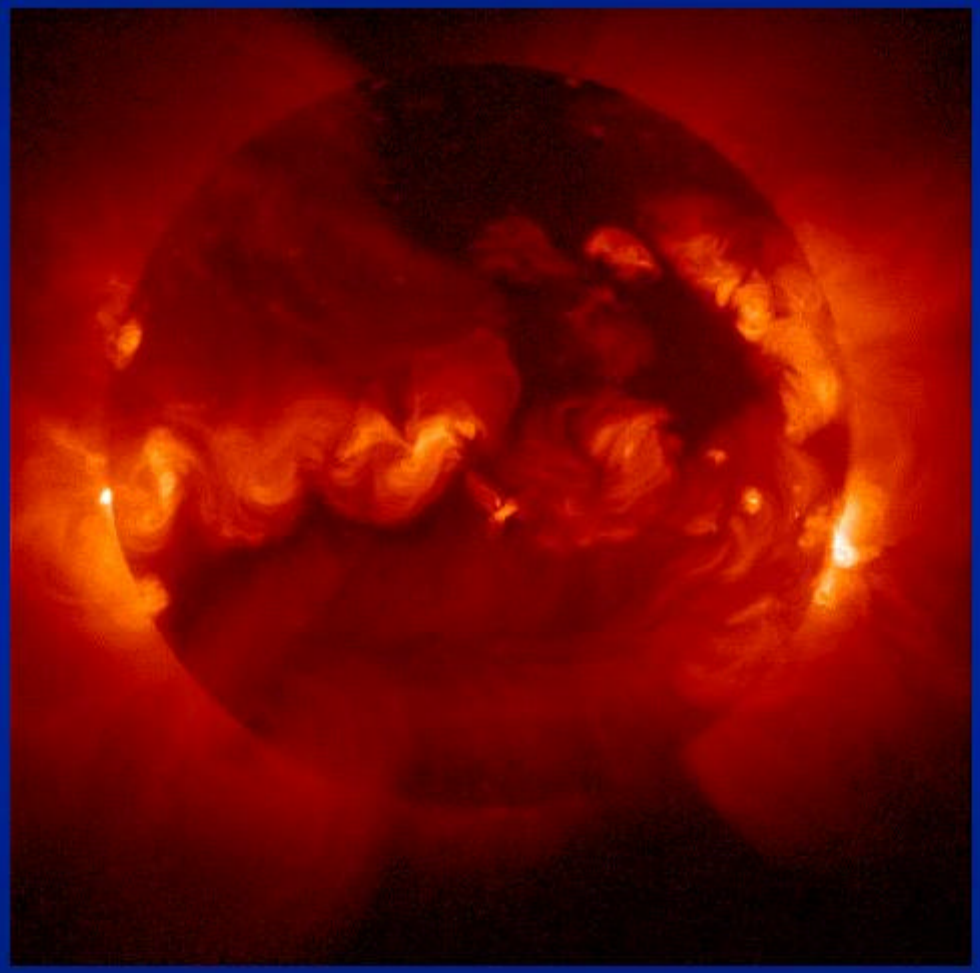
Outline

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

Background: Solar Activity

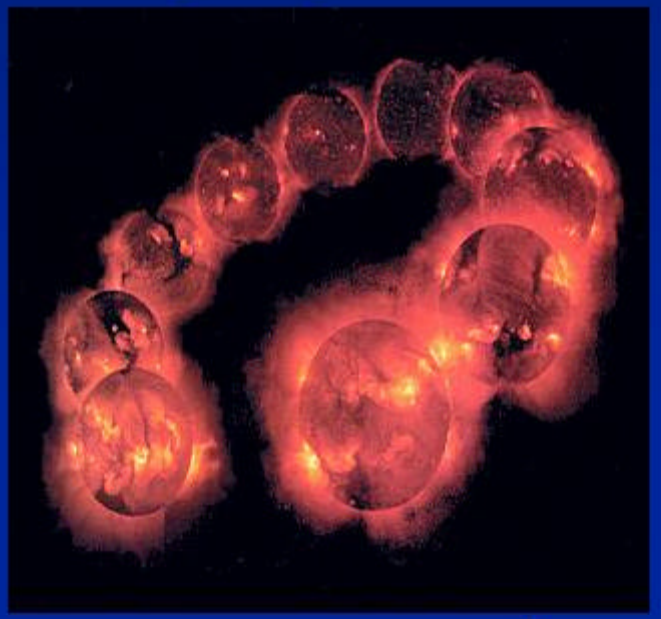
The Sun

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

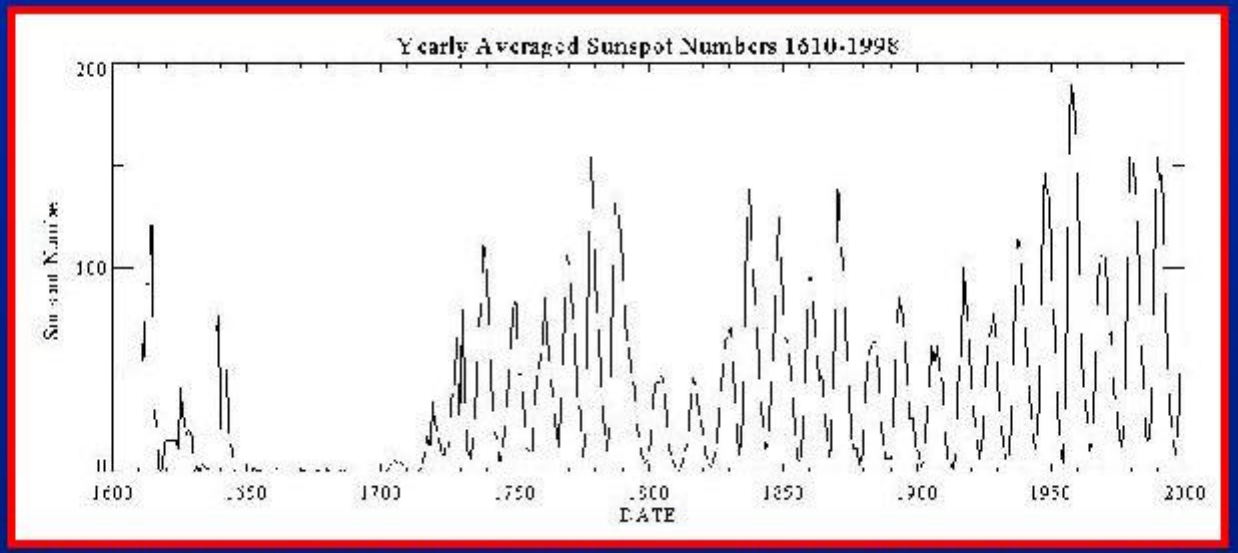


Yohkoh/SXT

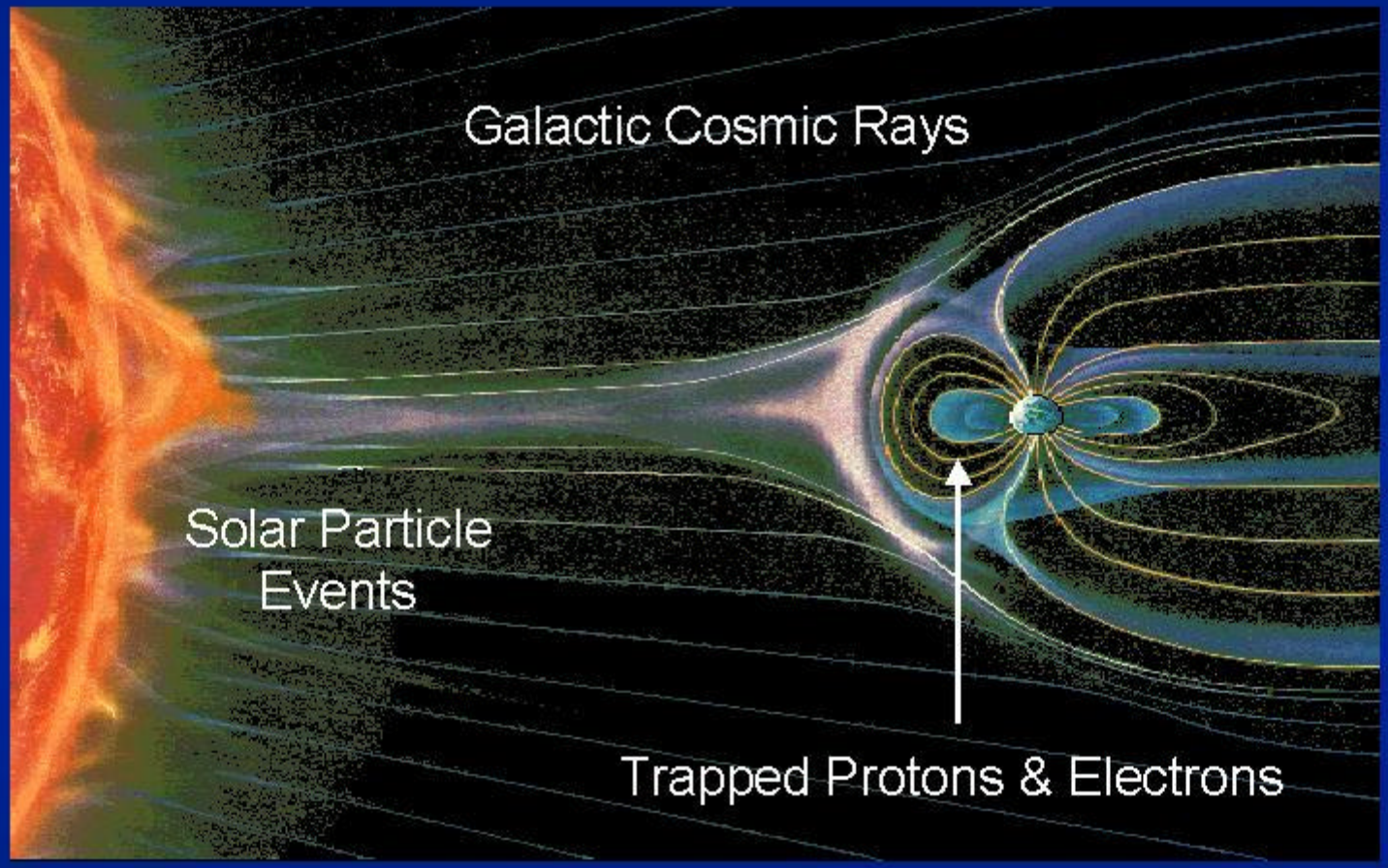
The Solar Activity Cycle



- 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



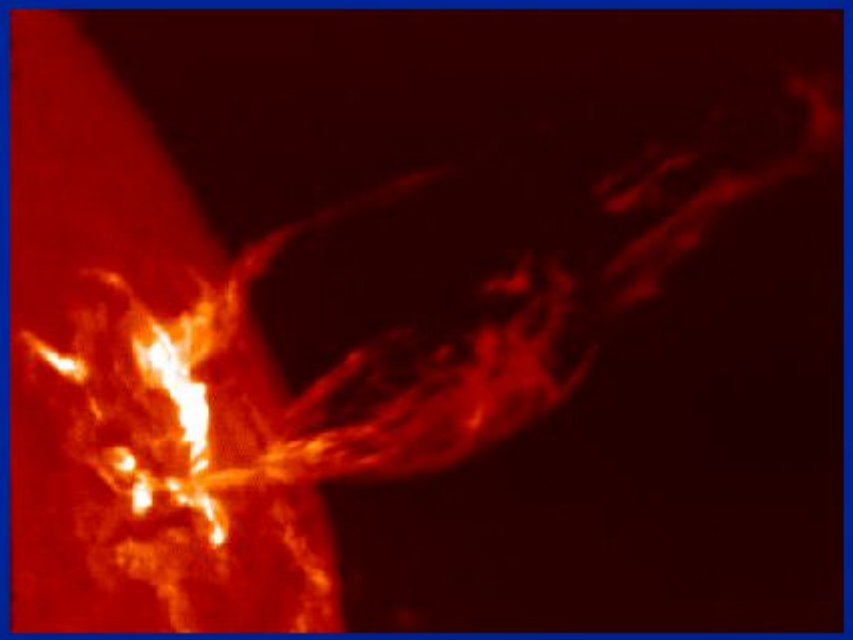
High Energy Radiation Particles



Solar Particle Events

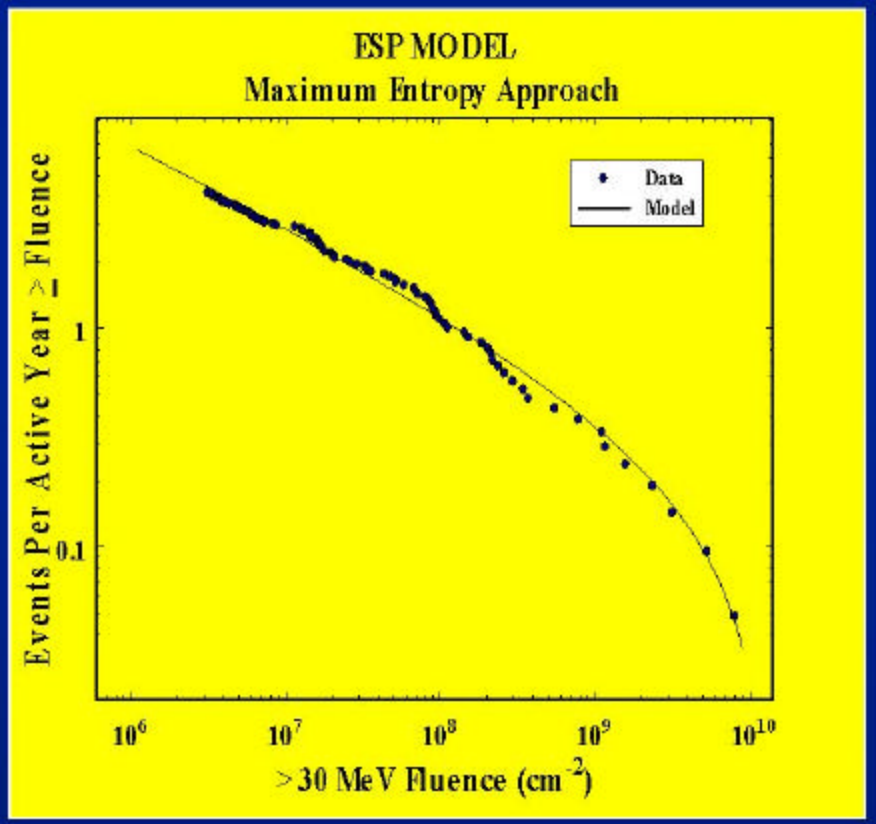
Solar Particle Event Characteristics

- 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)



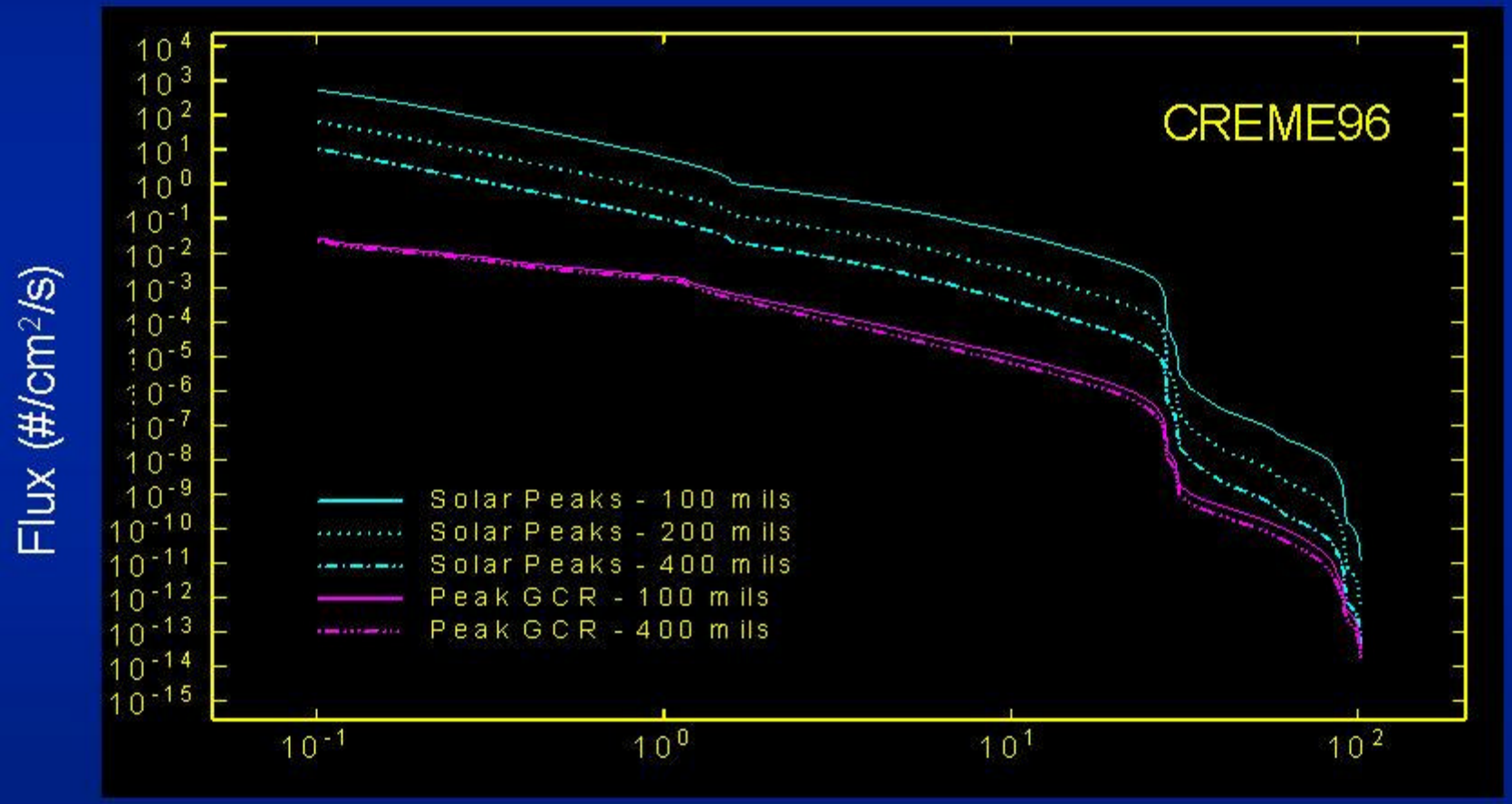
Solar Proton Event Models

- 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



Solar Heavy Ions

Unattenuated by Magnetosphere



Galactic Cosmic Rays

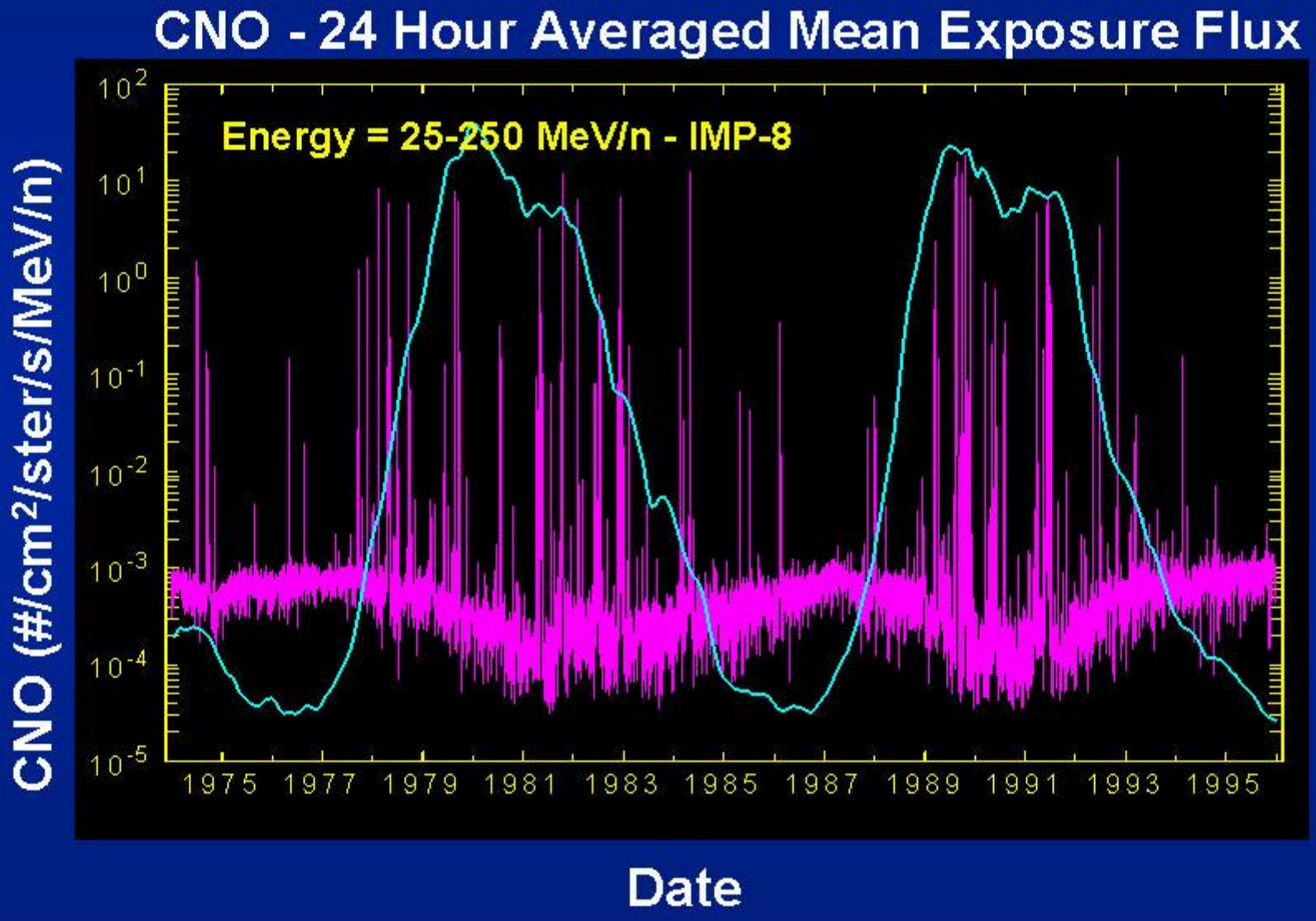
Galactic Cosmic Ray Ion Characteristics

- **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**

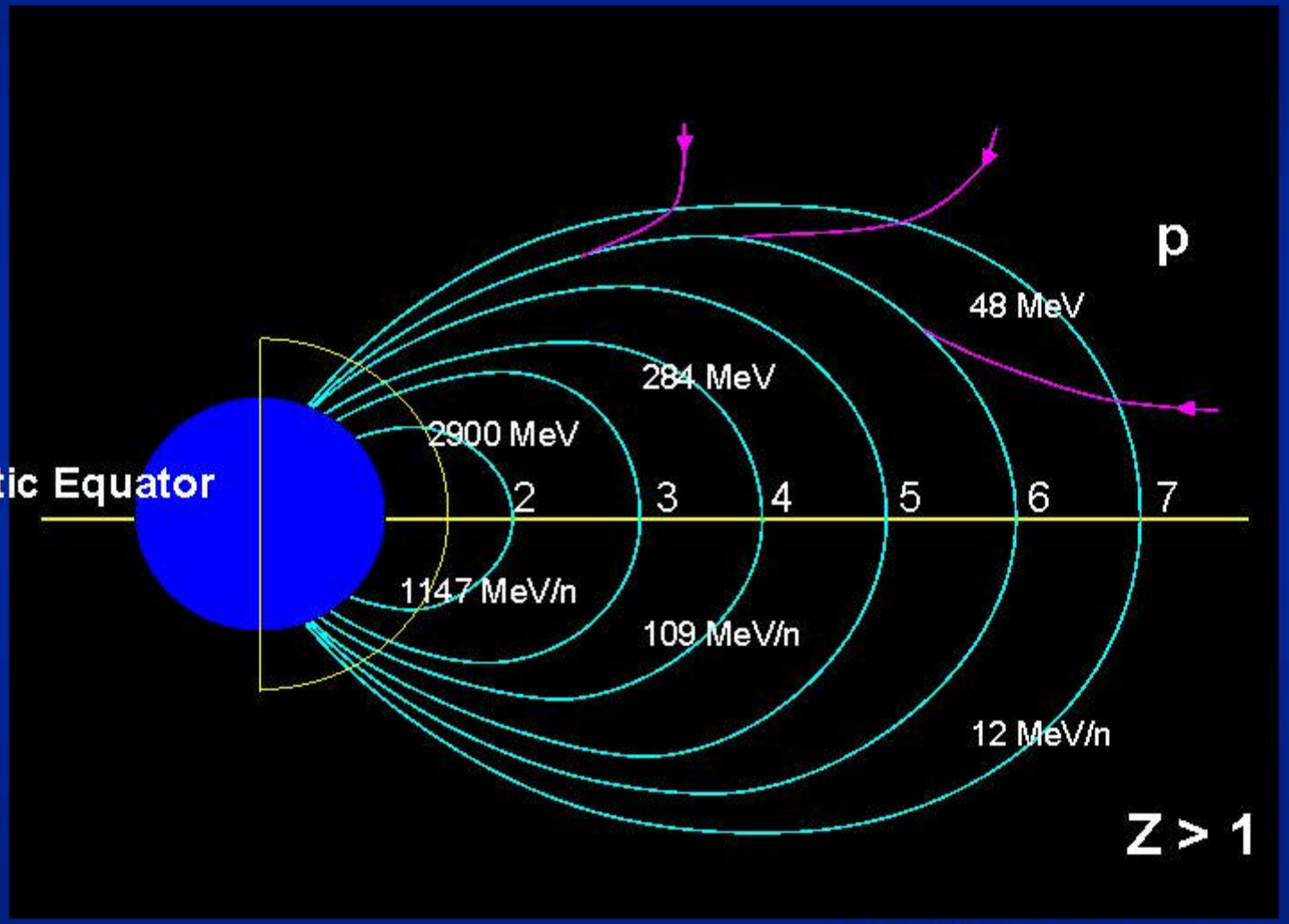
Galactic Cosmic Ray Solar Cycle Modulation

- 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

Heavy Ion Population



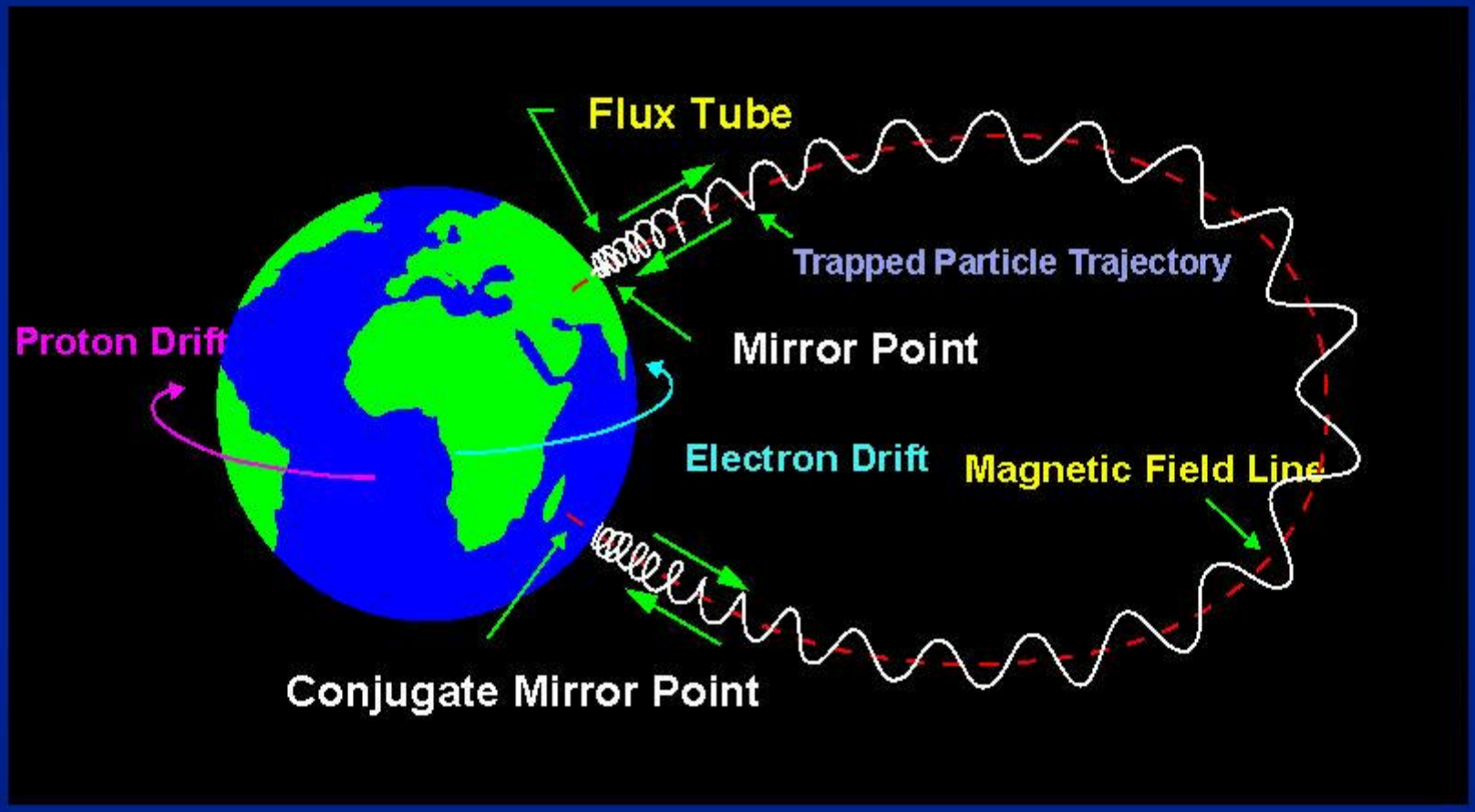
Energy Required to Penetrate Magnetosphere



after Stassinopoulos

Trapped Particles

Trapped Particle Motions



after Hess

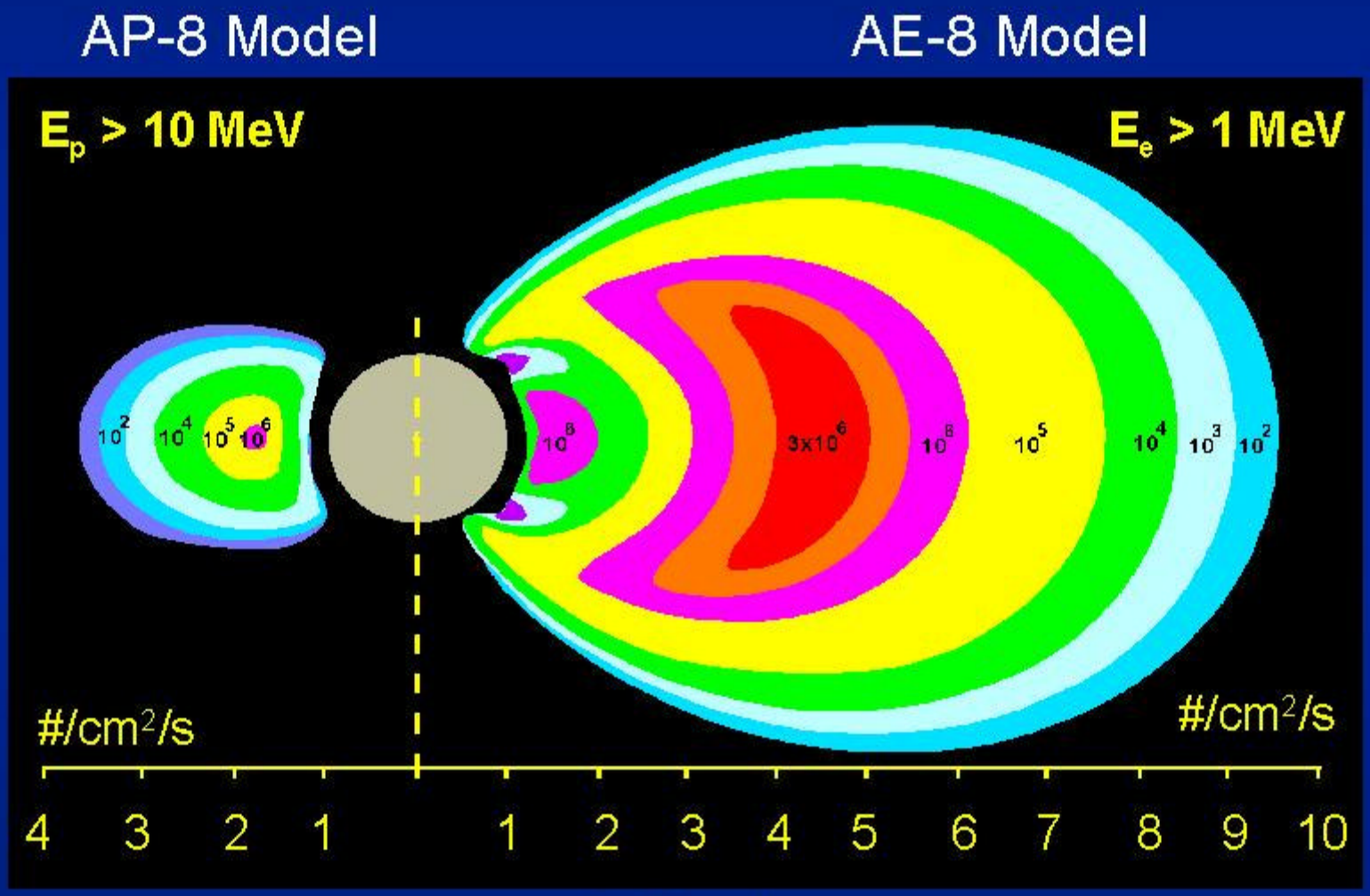
Trapped Proton Characteristics

- 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.

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**

Proton & Electron Intensities



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.**

Summary

- **Space radiations covered:**
  - **Solar particle events**
  - **Galactic cosmic rays**
  - **Trapped particles**

- **Recommended sources:**
  - **MSFC SEE Program – http://see.msfc.nasa.gov**
  - **SPENVIS – www.spenvis.oma.be/spenvis/**
  - **CREME96 – http://crsp3.nrl.navy.mil/creme96/**
  - **Langley technical publications – http://techreports.larc.nasa.gov/ltrs/**