Energy Deposition by Solar Energetic Particles in the Upper Atmospheres of Venus-like Extrasolar Planets

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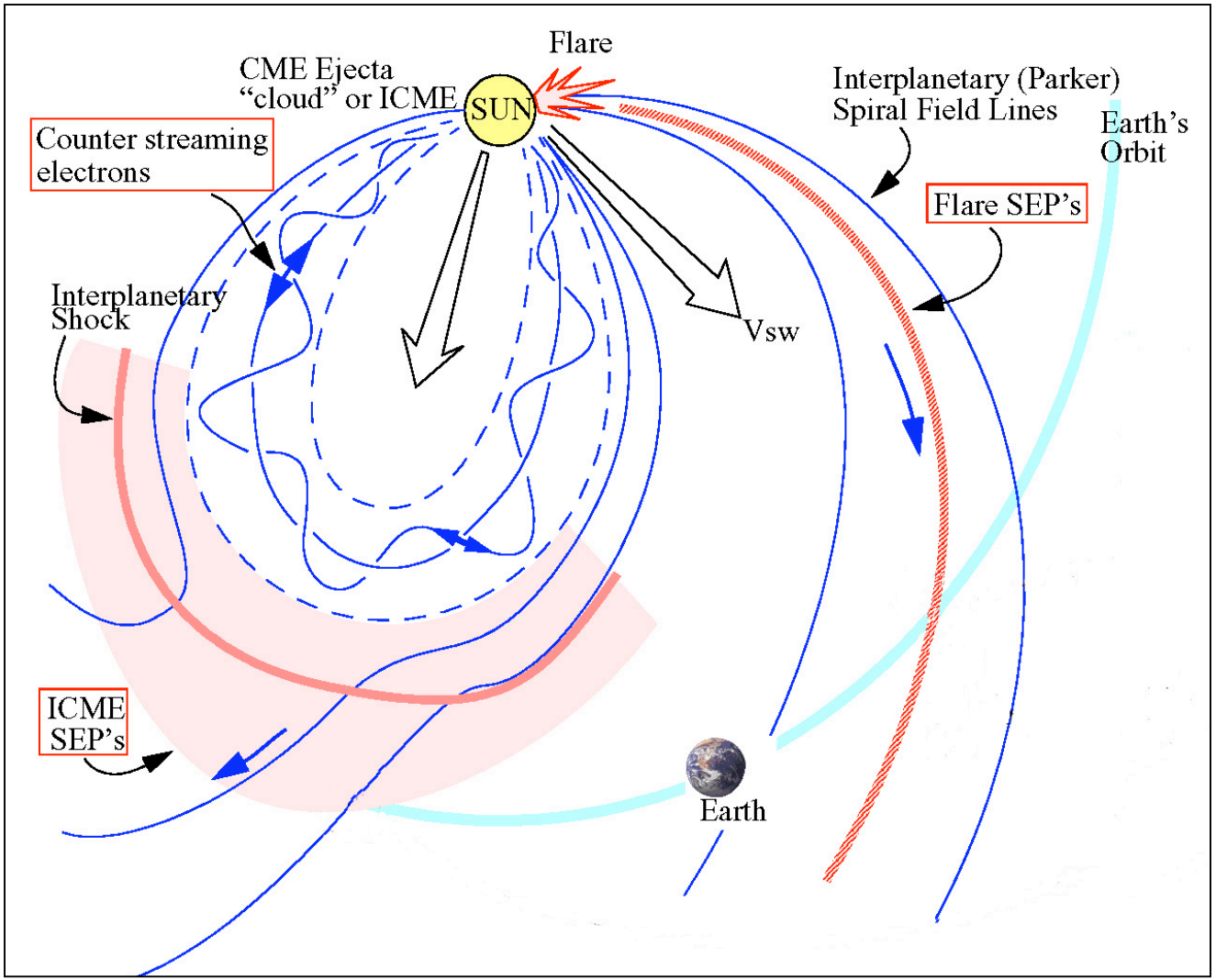
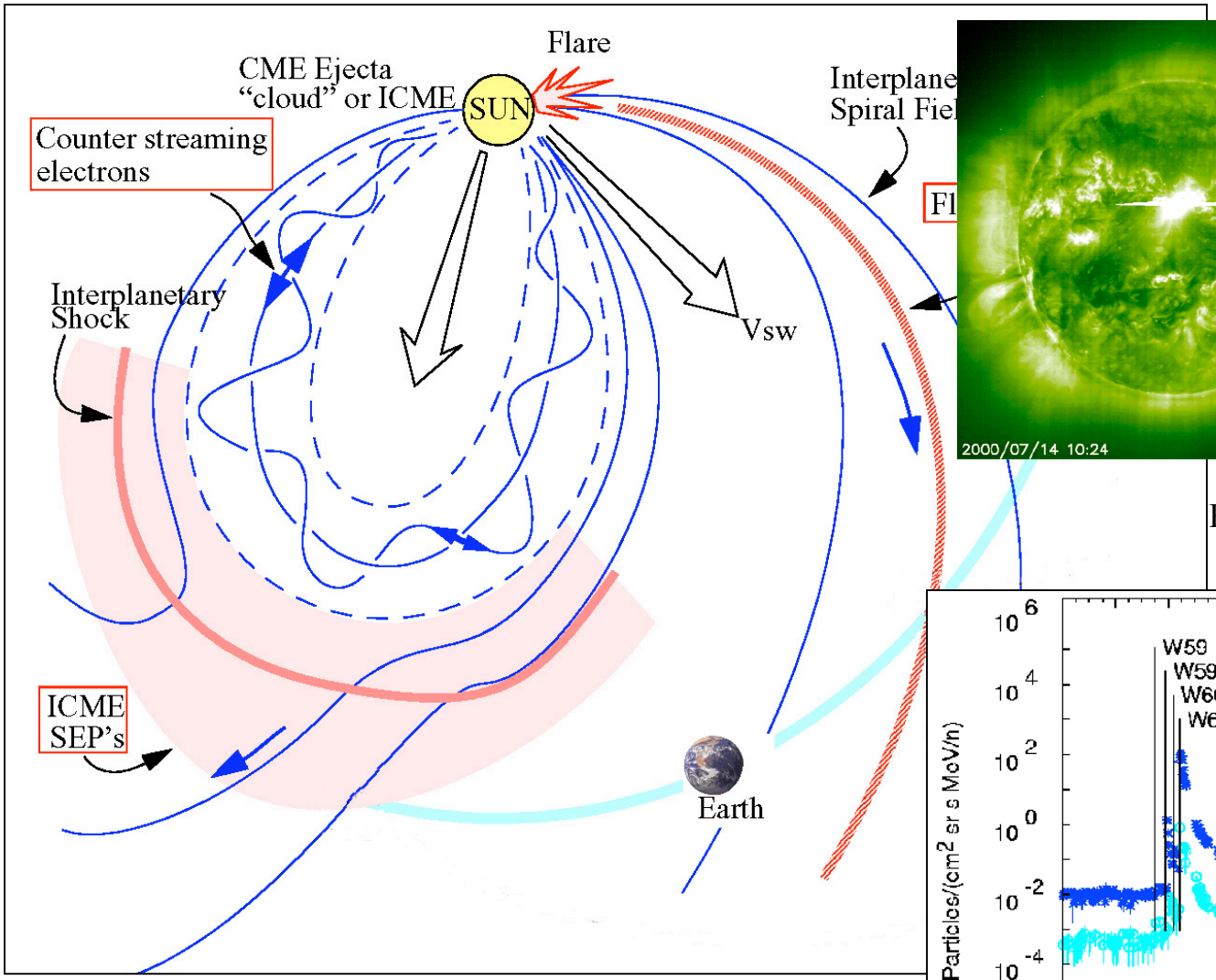
Solar Energetic Particle Events



Courtesy J. Luhmann & C. Lee

Solar Energetic Particle Events



Courtesy J. Luhmann & C. Lee

SOHO
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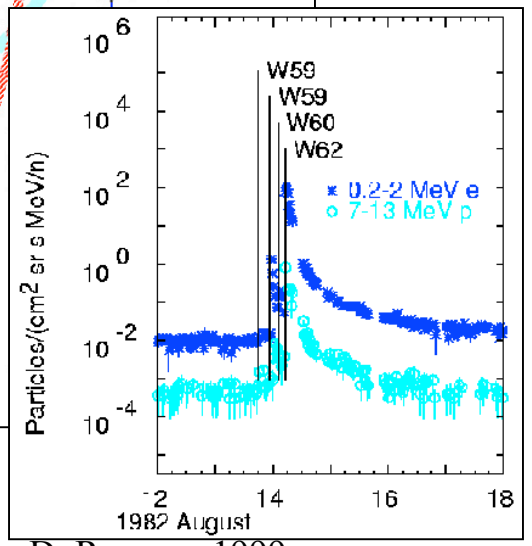
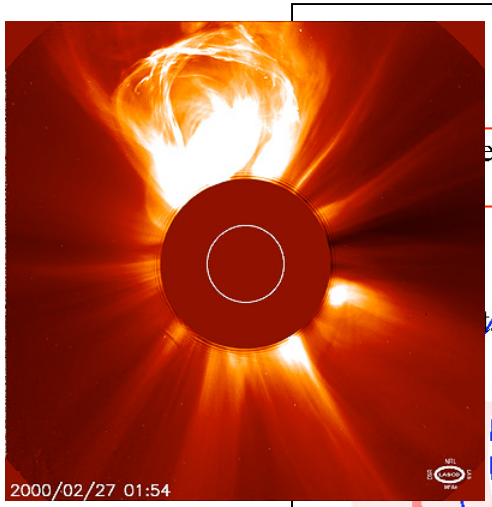


D. Reames, 1999

Solar Energetic Particle Events



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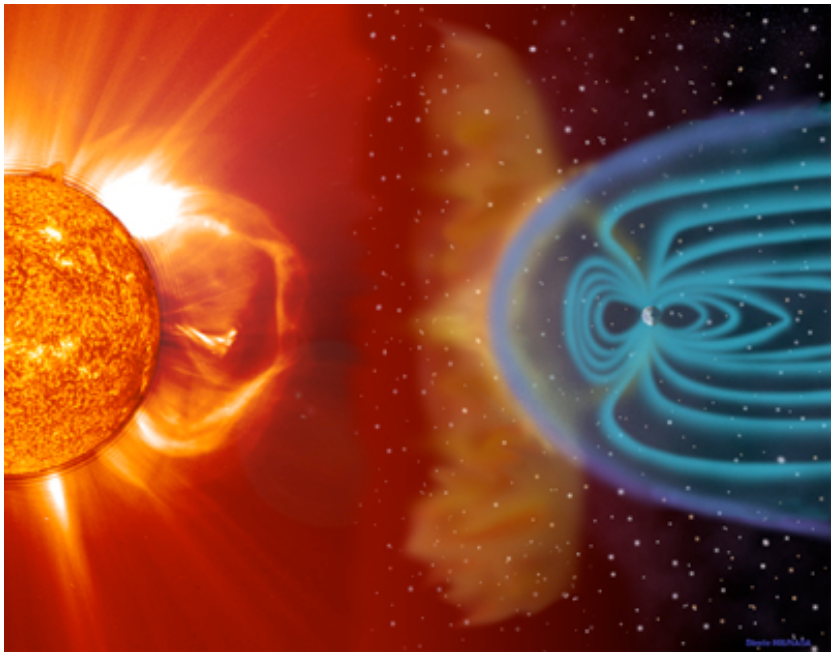
D. Reames, 1999

Courtesy J. Luhmann & C. Lee

D. Reames, 1999

SEP Effects at Planets

- Geomagnetic storms
- S/C anomalies and failures
- Disruption of surface systems
- Reduction in stratospheric ozone
- Large electric fields at the Moon
- Increased atmospheric ionization
- Thermospheric density reduction

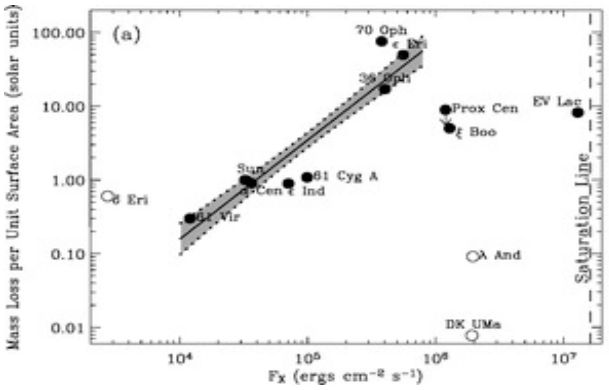


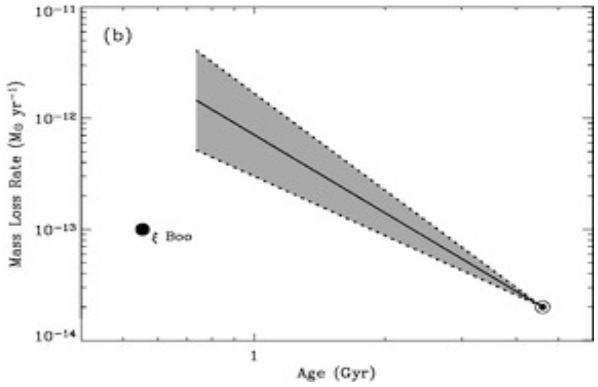
ESA

SEP Effects in Other Stellar Systems

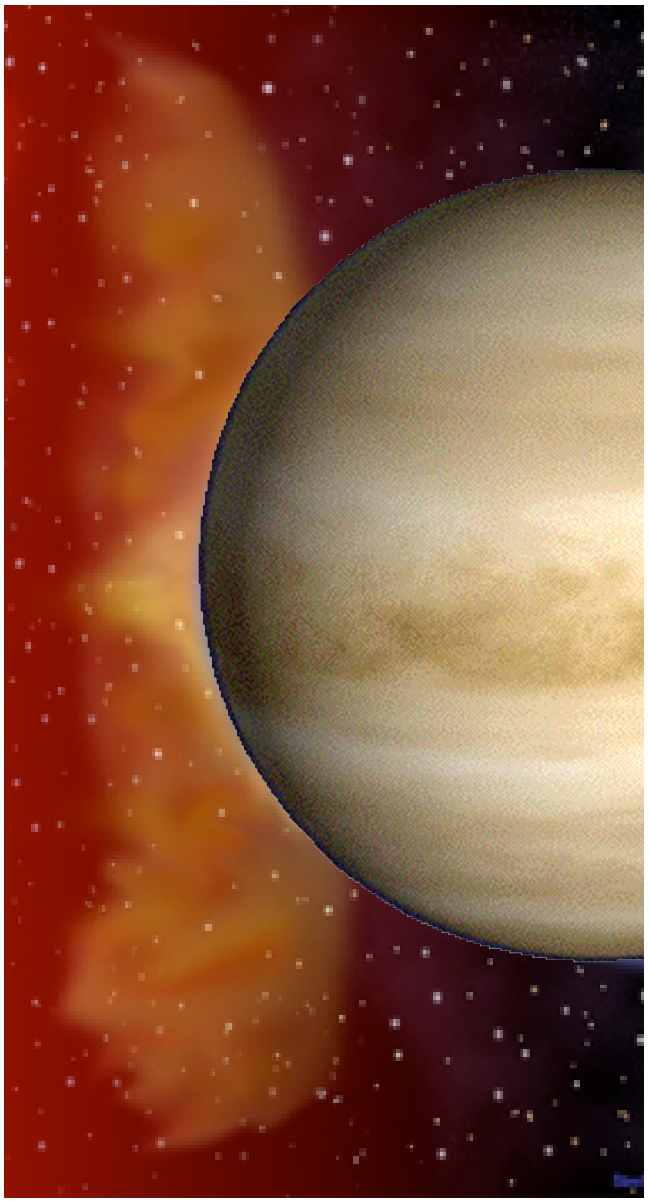
- Unmagnetized planets particularly vulnerable
- SEP fluxes likely higher at more active stars
- One rocky ESP is close to its parent star
  - $v_{esc} > 2\ v_{esc} \oplus$
    - ➔ could have thick atmosphere
  - unmagnetized or very compressed B
    - ➔ SEPs could heat atmosphere

How much?

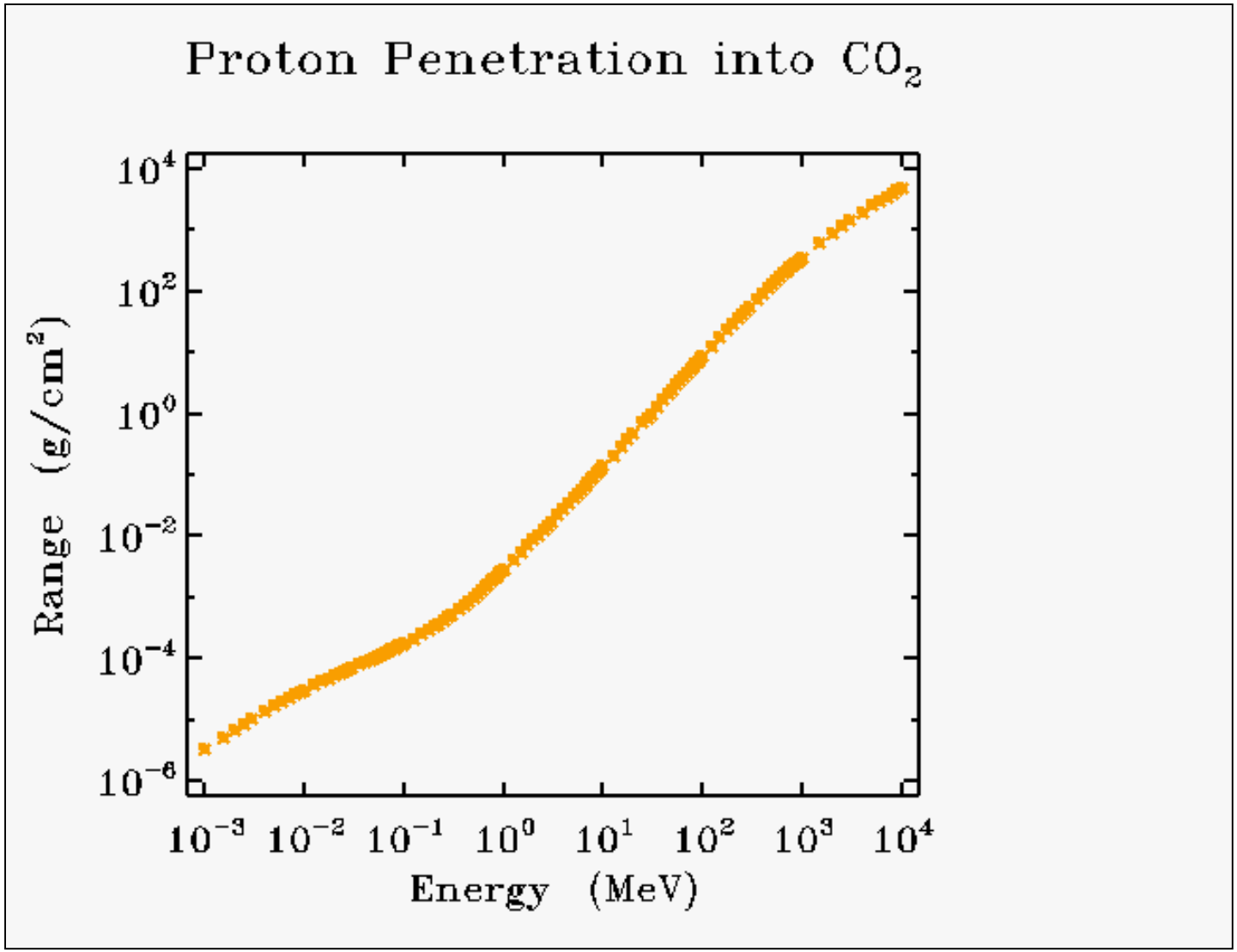




Wood et al., 2005

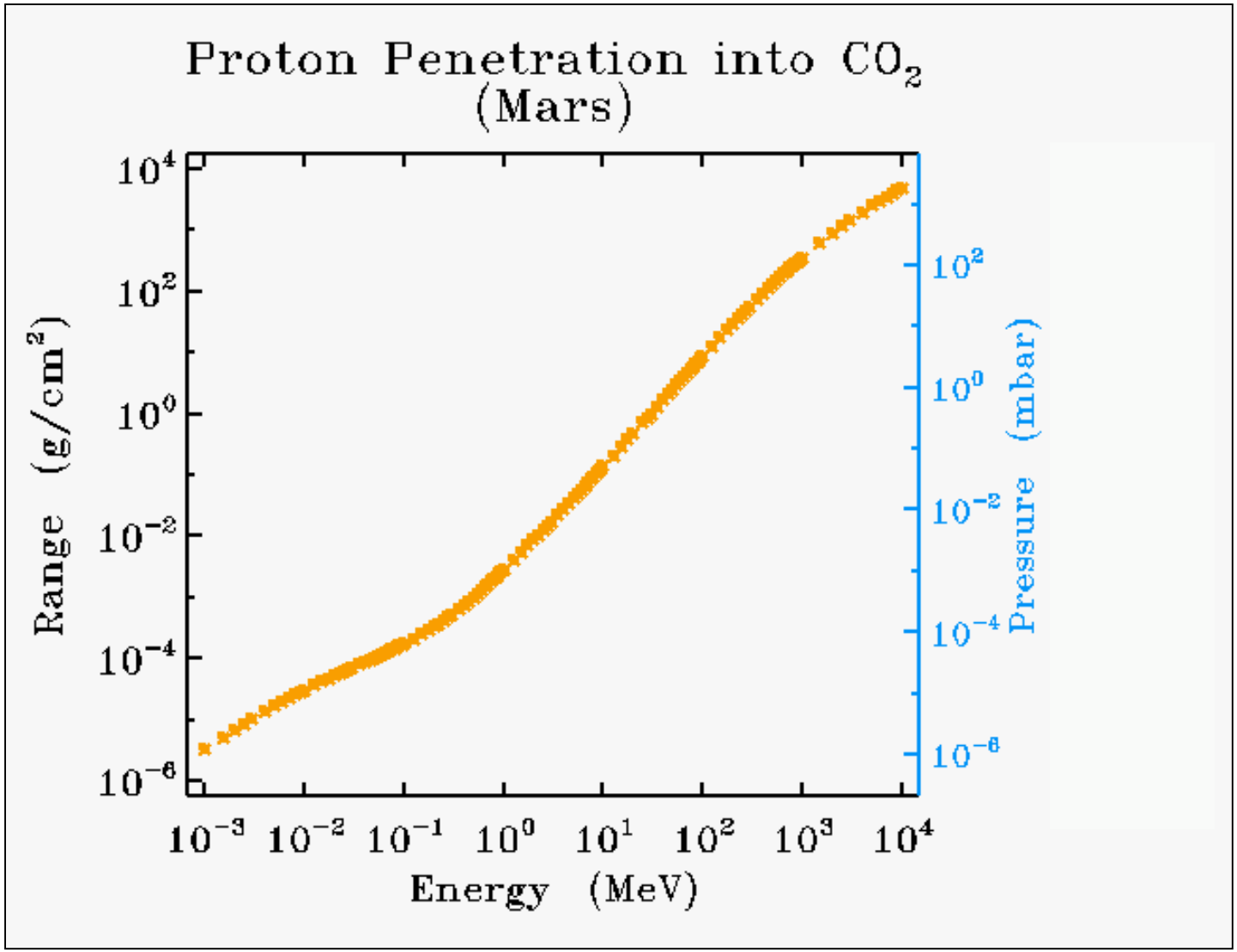


SEP Penetration Depth



http://physics.nist.gov/PhysRefData/Star/Text/contents.html

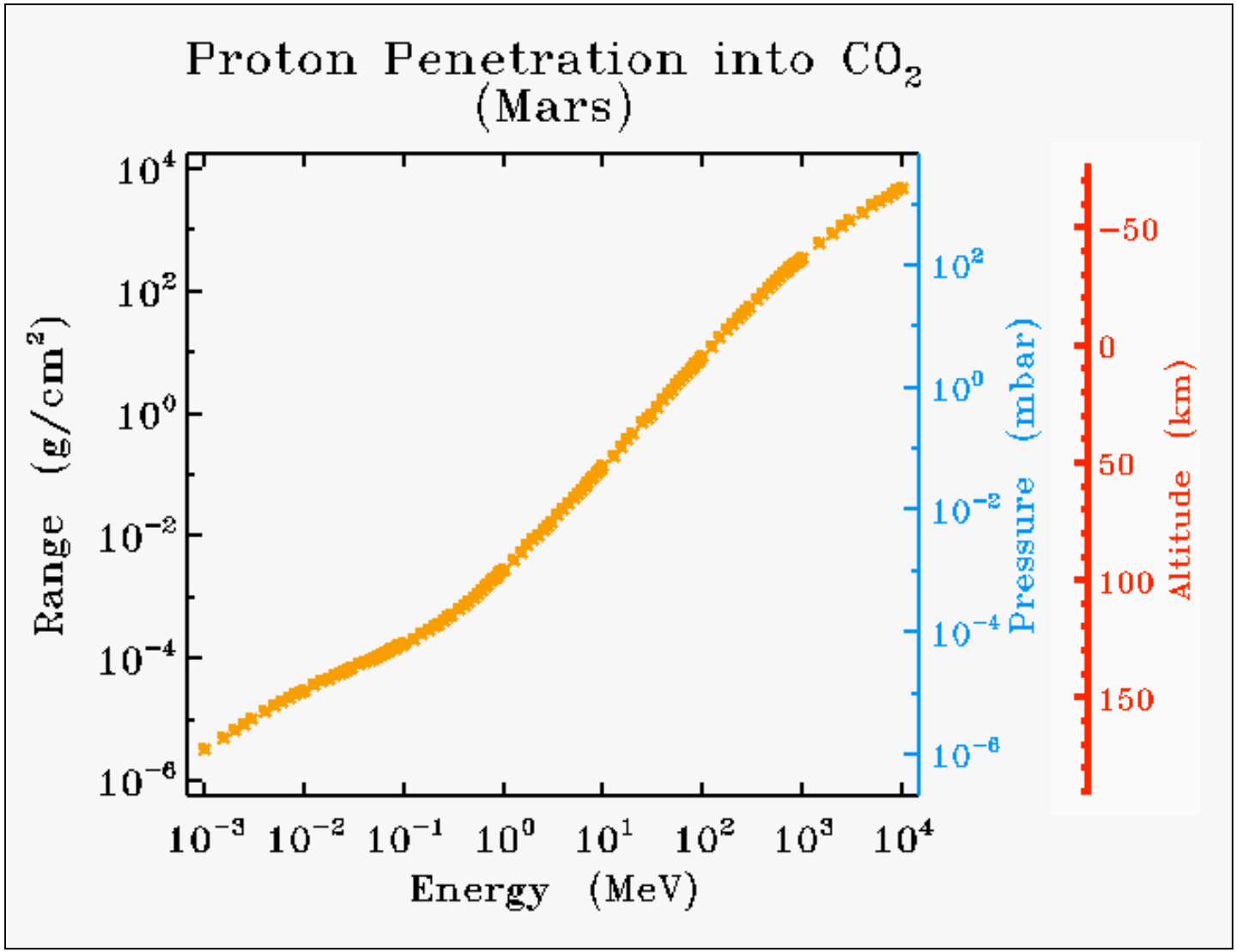
SEP Penetration Depth



g = 3.71 m/s²

http://physics.nist.gov/PhysRefData/Star/Text/contents.html

SEP Penetration Depth

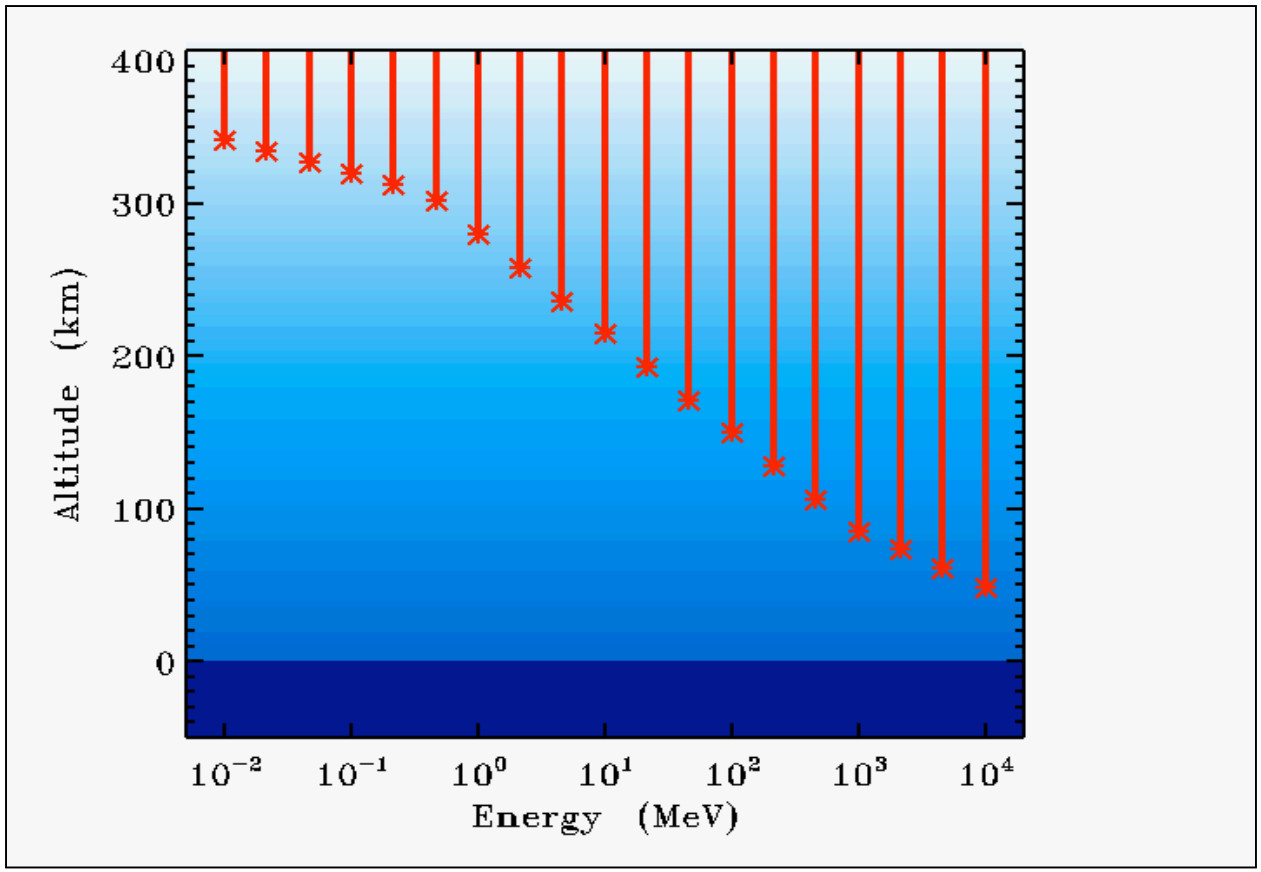


g = 3.71 m/s²
P(0) = 6.36 mbar
H = 11.1 km

http://physics.nist.gov/PhysRefData/Star/Text/contents.html

SEP Input: Venus

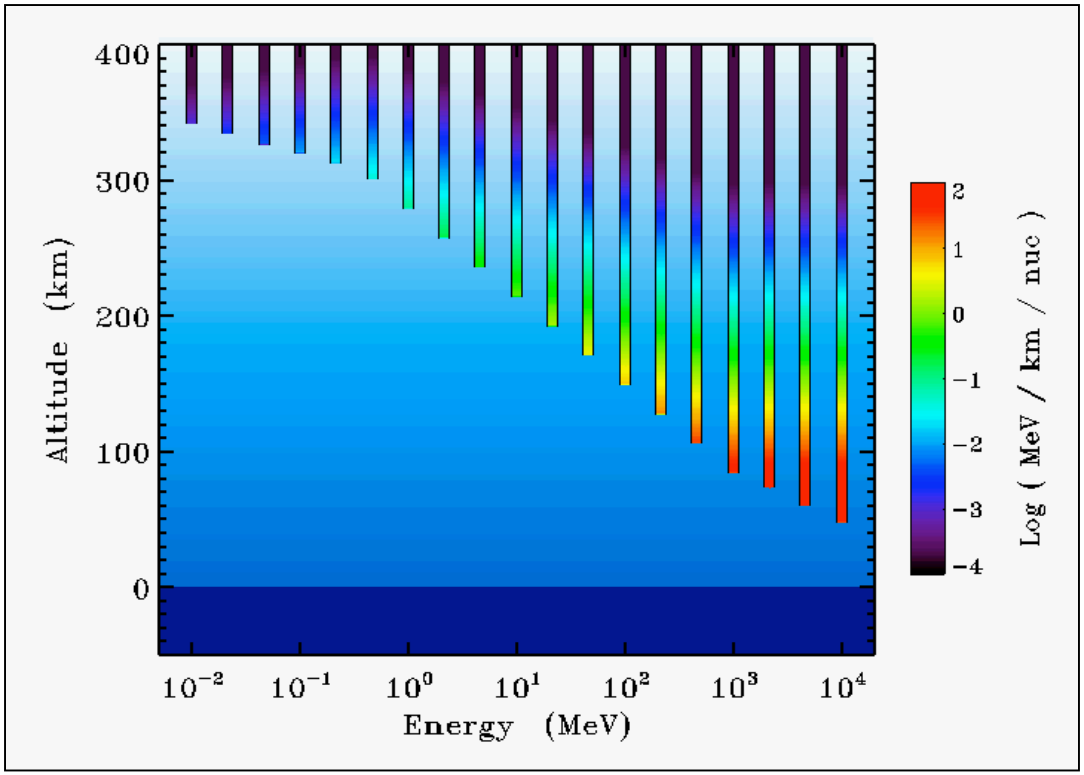
(isothermal)



$$z_0 = -H \ln\left(\frac{g \cos\chi}{P_0} R(E)\right)$$

SEP Input: Venus

(isothermal)

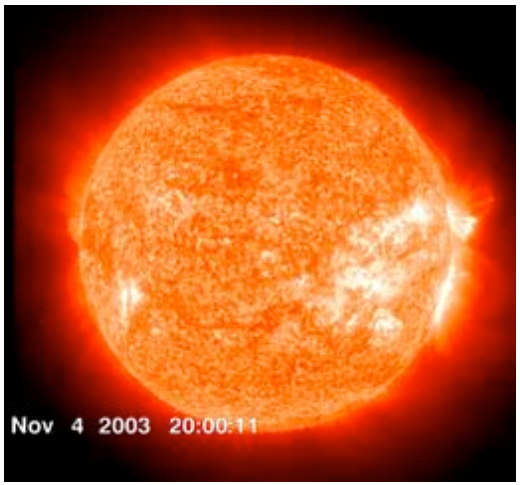


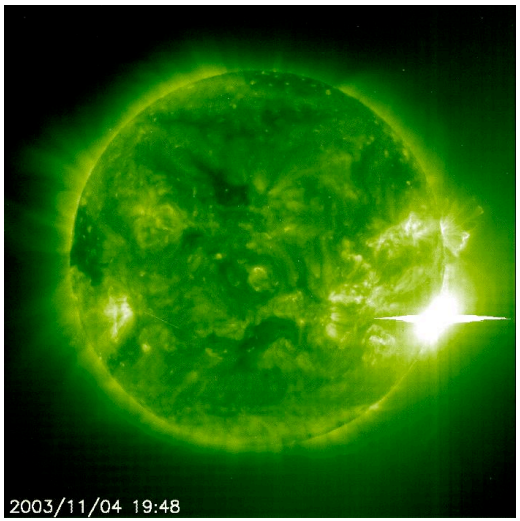
$$\Delta E = E_{in}\frac{\Delta}{R(E_{in})}$$

$$= \frac{E_{in}}{R(E)}\frac{P_0}{g\cos\theta}\left[e^{-\frac{z}{H}} - e^{-\frac{z+\Delta z}{H}}\right]$$

Large SEP Events

Sun





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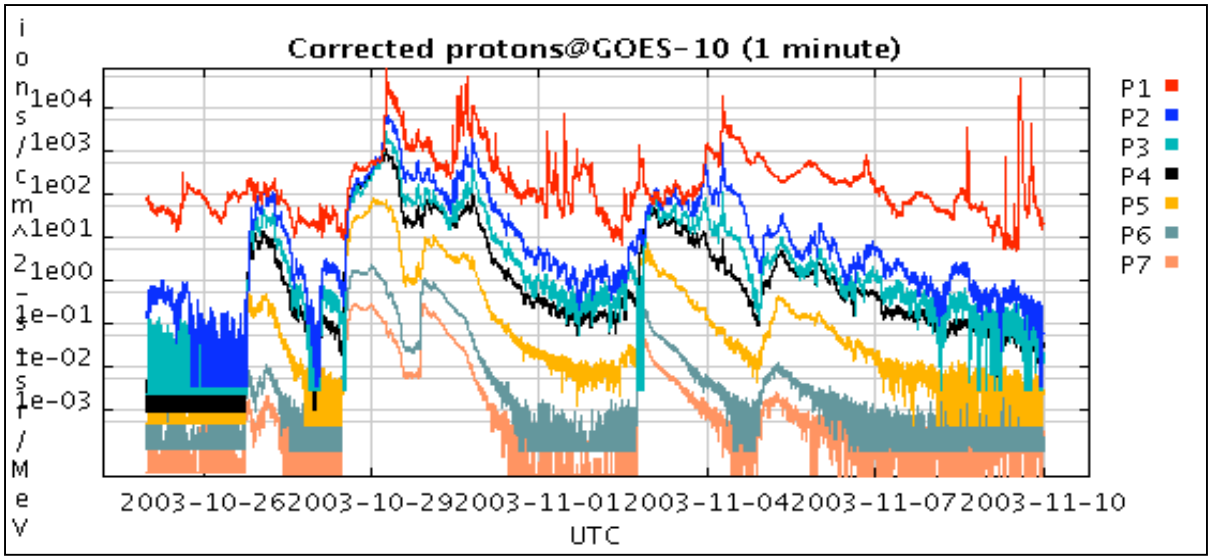
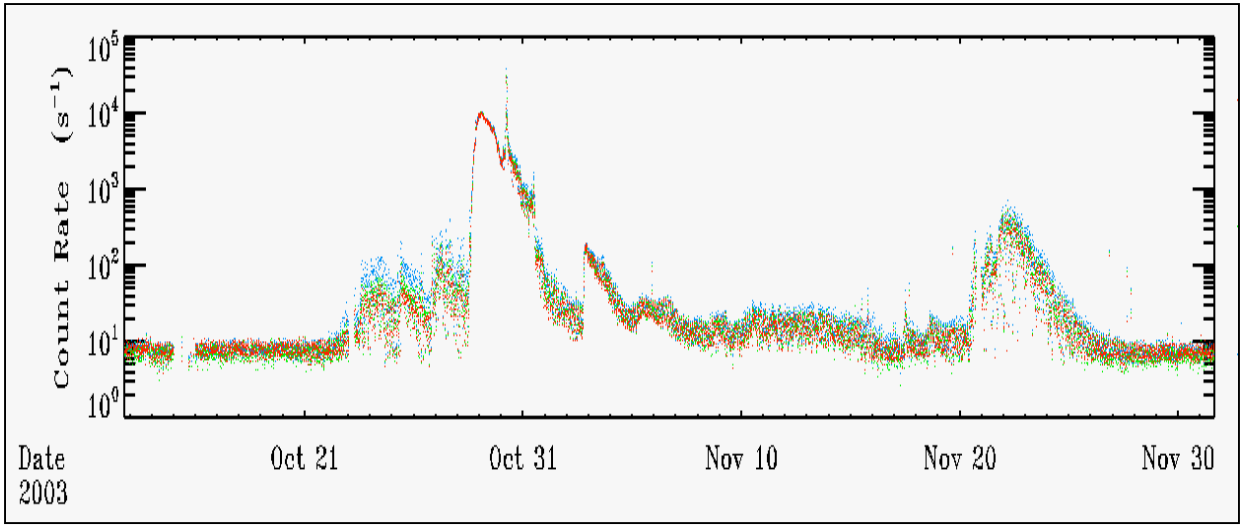
Earth

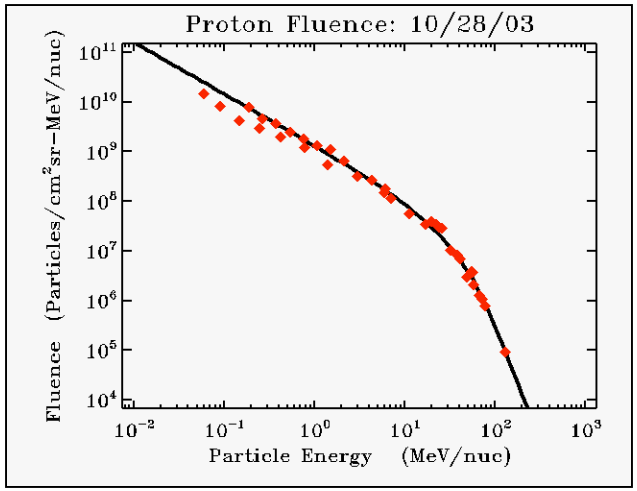
Courtesy R. Mewaldt



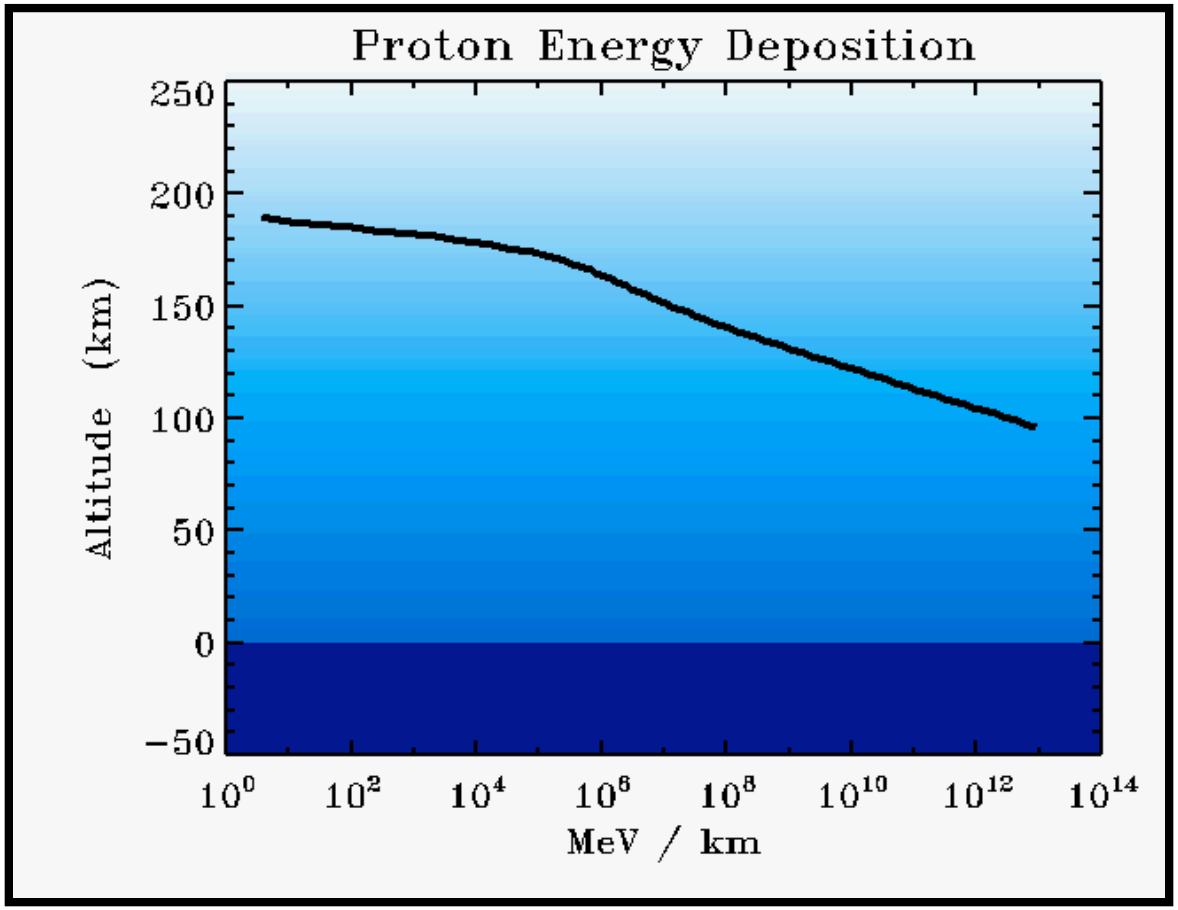
Mars



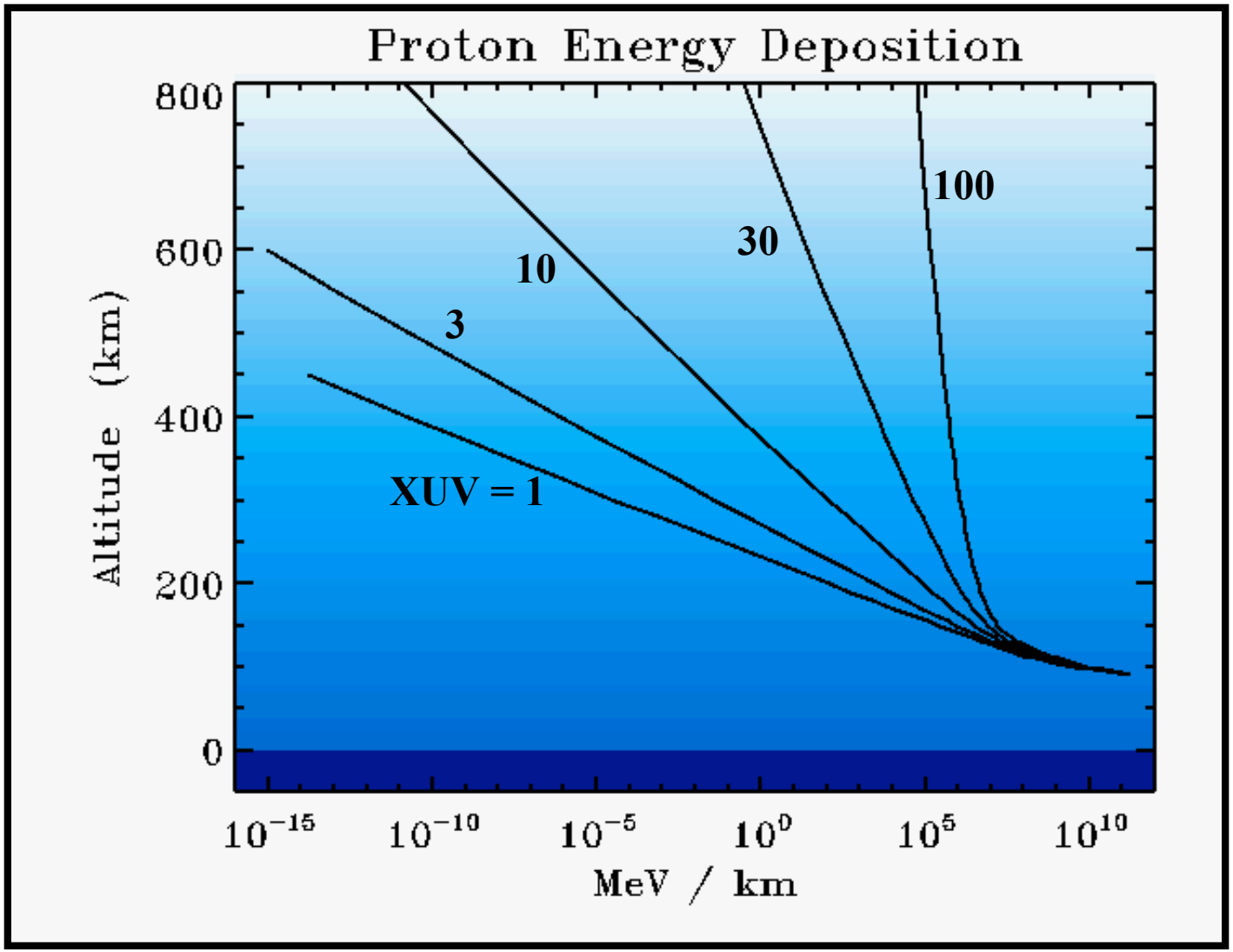
Energy Deposition: Venus Today



After Mewaldt et al., 2005



Energy Deposition: Early Venus



Future Directions

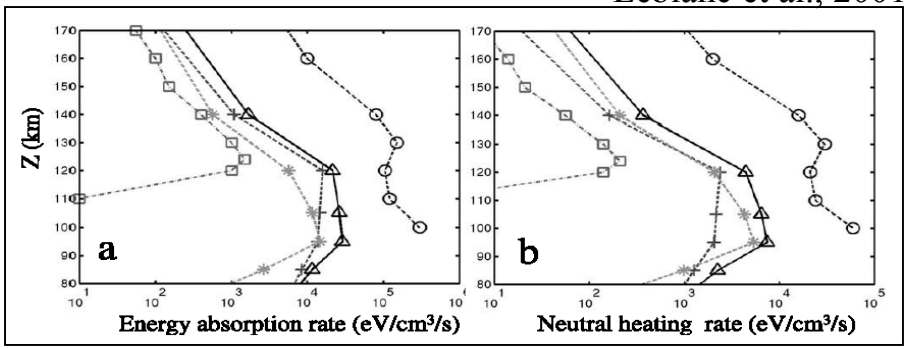
Methods

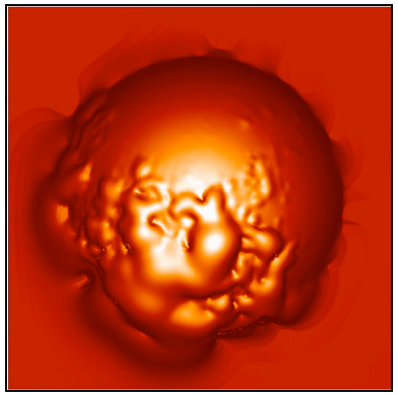
- Put in context with other energy sources
- Use more sophisticated code
- Calculate ionization vs. heating
- Consider planetary plasma interaction
- Non-uniform energy deposition

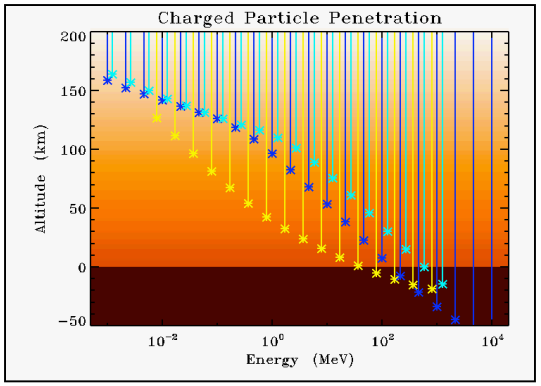
Inputs

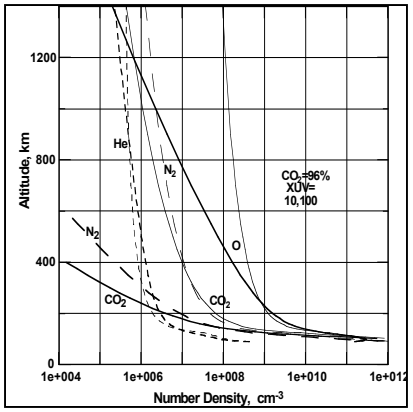
- Use multi-species atmosphere
- Examine other SEP events
- Consider alphas, heavy ions, e^-
- Investigate lower atmosphere

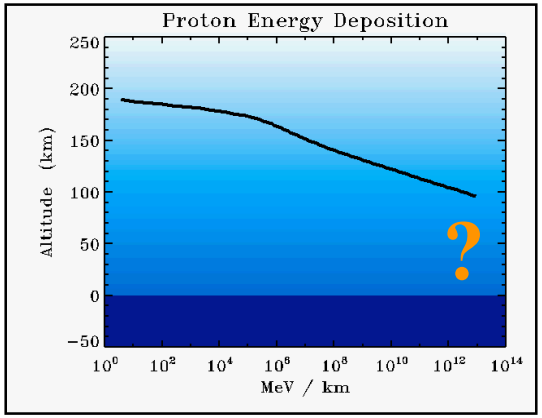
Leblanc et al., 2001











Courtesy H. Lammer

Summary

- Solar Energetic Particle events influence planetary environments via relatively large energy injections over short time periods

- SEPs may provide significant energy contributions to atmospheres of unmagnetized planets orbiting active stars

- Energy deposition, ionization and chemistry, and heating can be calculated for a range of realistic conditions at planets orbiting Sun-like stars