Simulations of the effects of extreme solar flares on technological systems at Mars

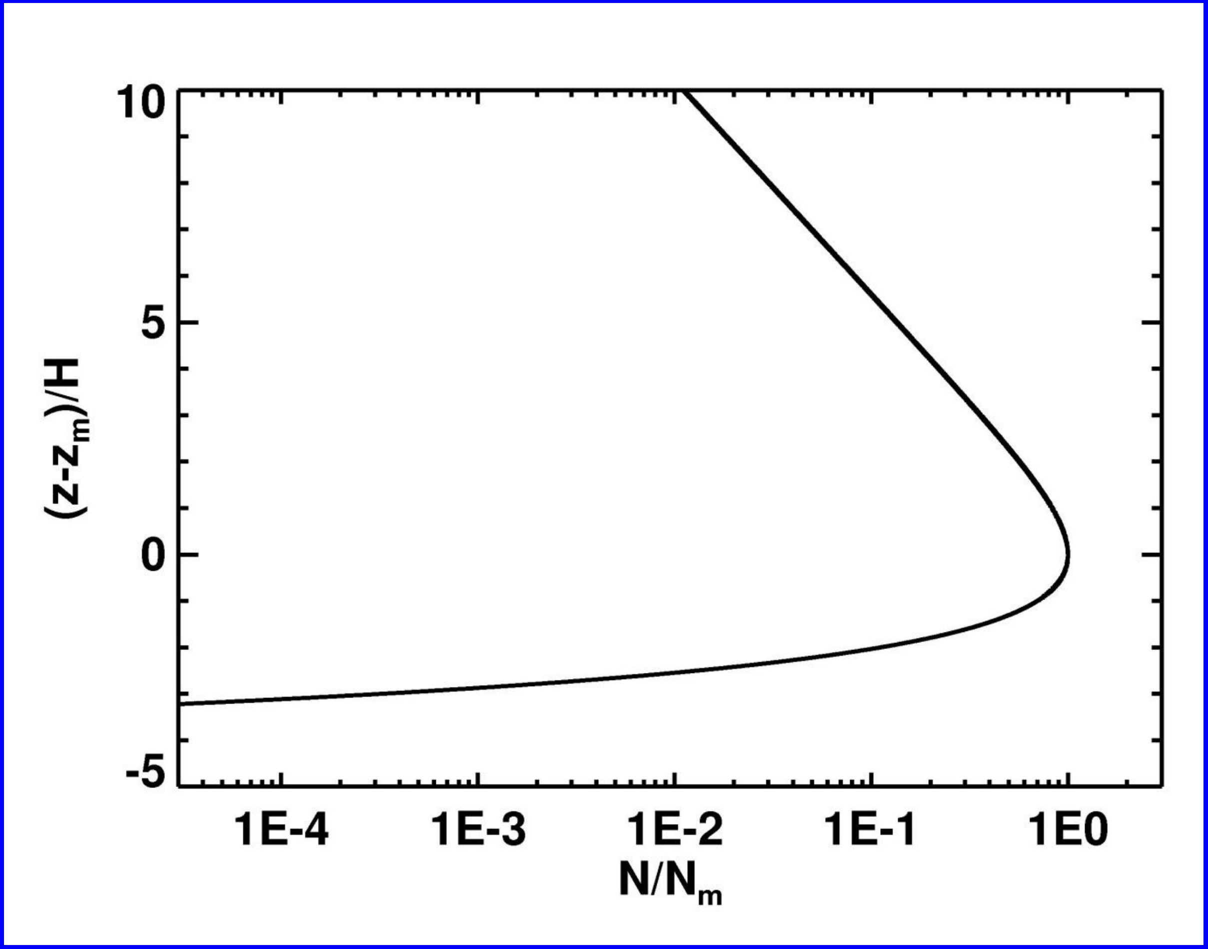
Paul Withers, Boston University
(withers@bu.edu)

Sunday 2009.12.20

Meeting of LWS TRT Focus Team on "Extreme Space Weather Events in the Solar System"

San Francisco, CA

Chapman ionosphere

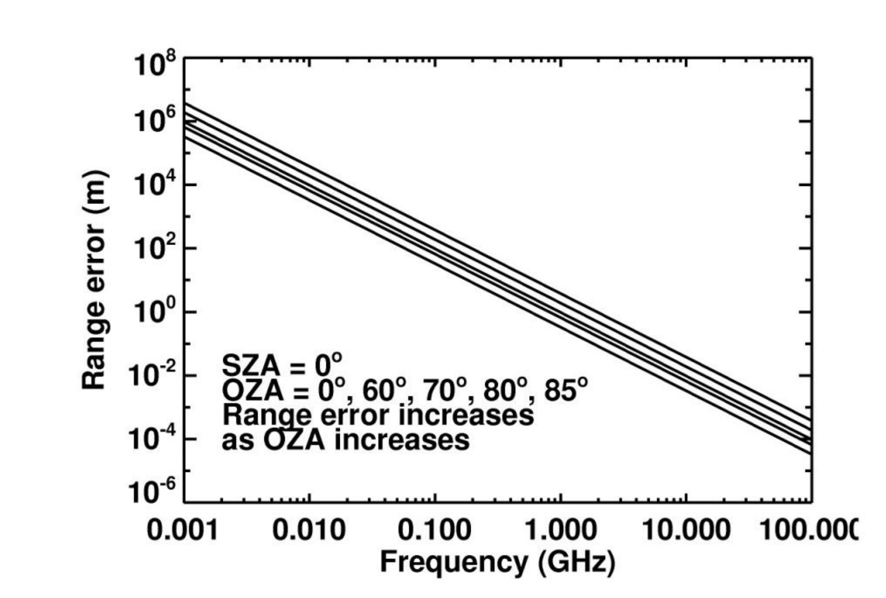


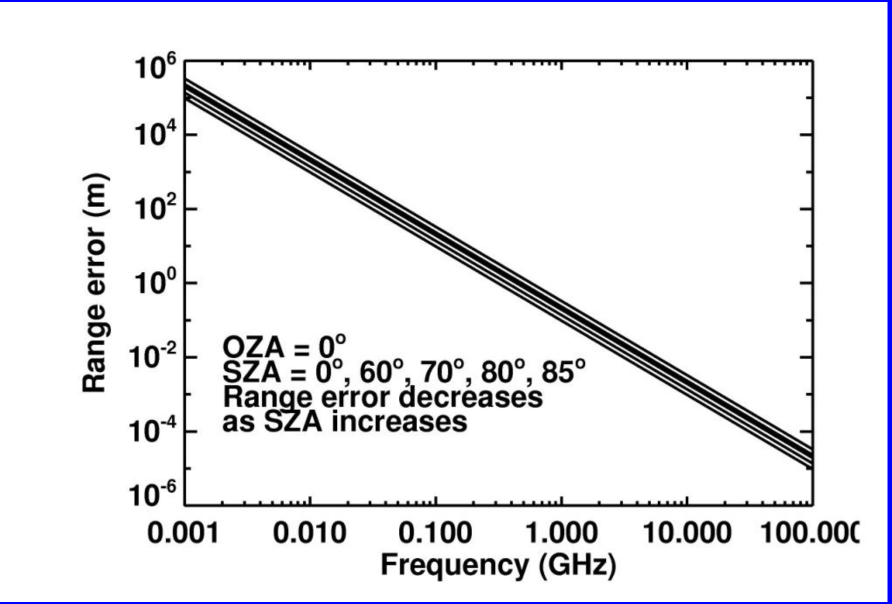
Nm = 2E5 cm^{-3} , zm = 120 km, H = 10 km

Nm decreases as SZA increases

zm increases as SZA increases

GPS range error





General case

$$\Delta D = \frac{0.403\ \mathrm{m}}{\cos(\mathrm{OZA})} \left(\frac{\mathrm{GHz}}{f}\right)^2 \frac{\int N_e\, dz}{1\mathrm{E}16\ \mathrm{m}^{-2}}$$

Chapman layer

$$\Delta D = 0.33\mathrm{m}\ \frac{\sqrt{\cos(\mathrm{SZA})}}{\cos(\mathrm{OZA})} \left(\frac{\mathrm{GHz}}{f}\right)^2 \frac{N_0}{2\mathrm{E}11\mathrm{m}^{-3}} \frac{H}{10\mathrm{km}}$$

Signal attenuation theory

$$K = \frac{dE}{E\,dl}$$

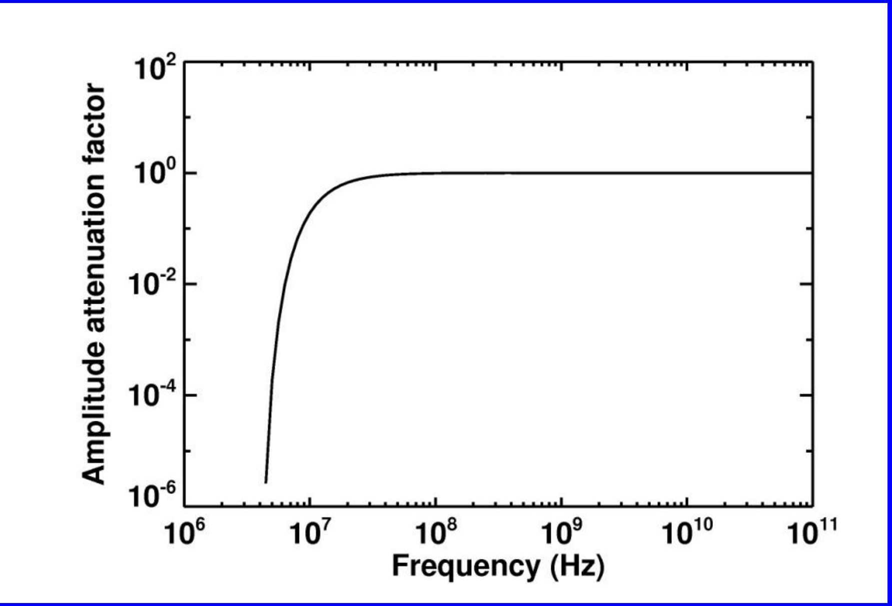
$$K = \frac{e^2}{2mc\epsilon_0}\,\frac{N_e}{\mu}\,\frac{\nu}{\nu^2+\omega^2}$$

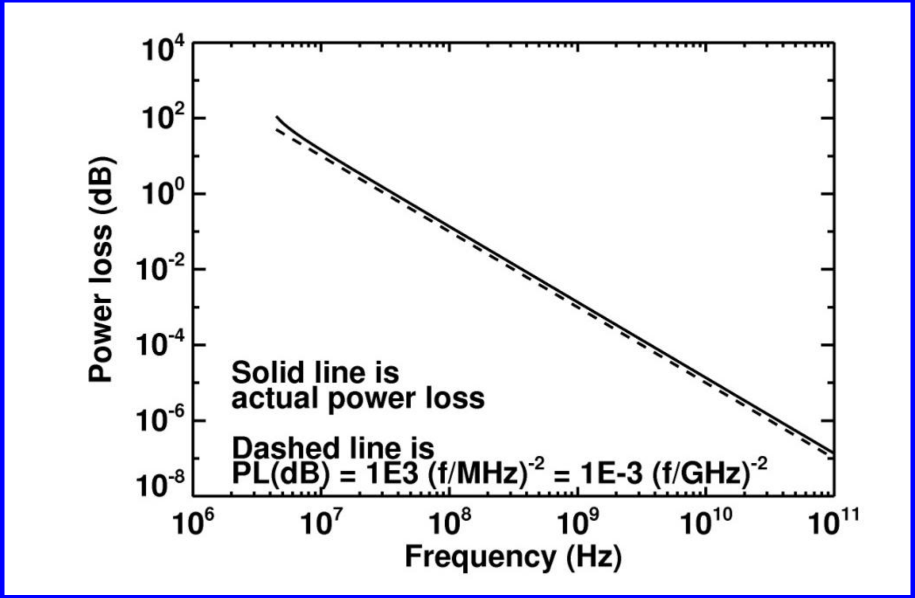
$$\nu = 10^{-13}\ \mathrm{m}^3\ \mathrm{s}^{-1} \times n_{CO2}$$

$$\mu^2 = 1 - \frac{N_e e^2}{m\epsilon_0\omega^2}$$

$$\frac{E_r}{E_t} = \exp\left(-\int K\,dl\right) = \exp\left(-\int K\,dz\right)^{\mathrm{sec(OZA)}}$$

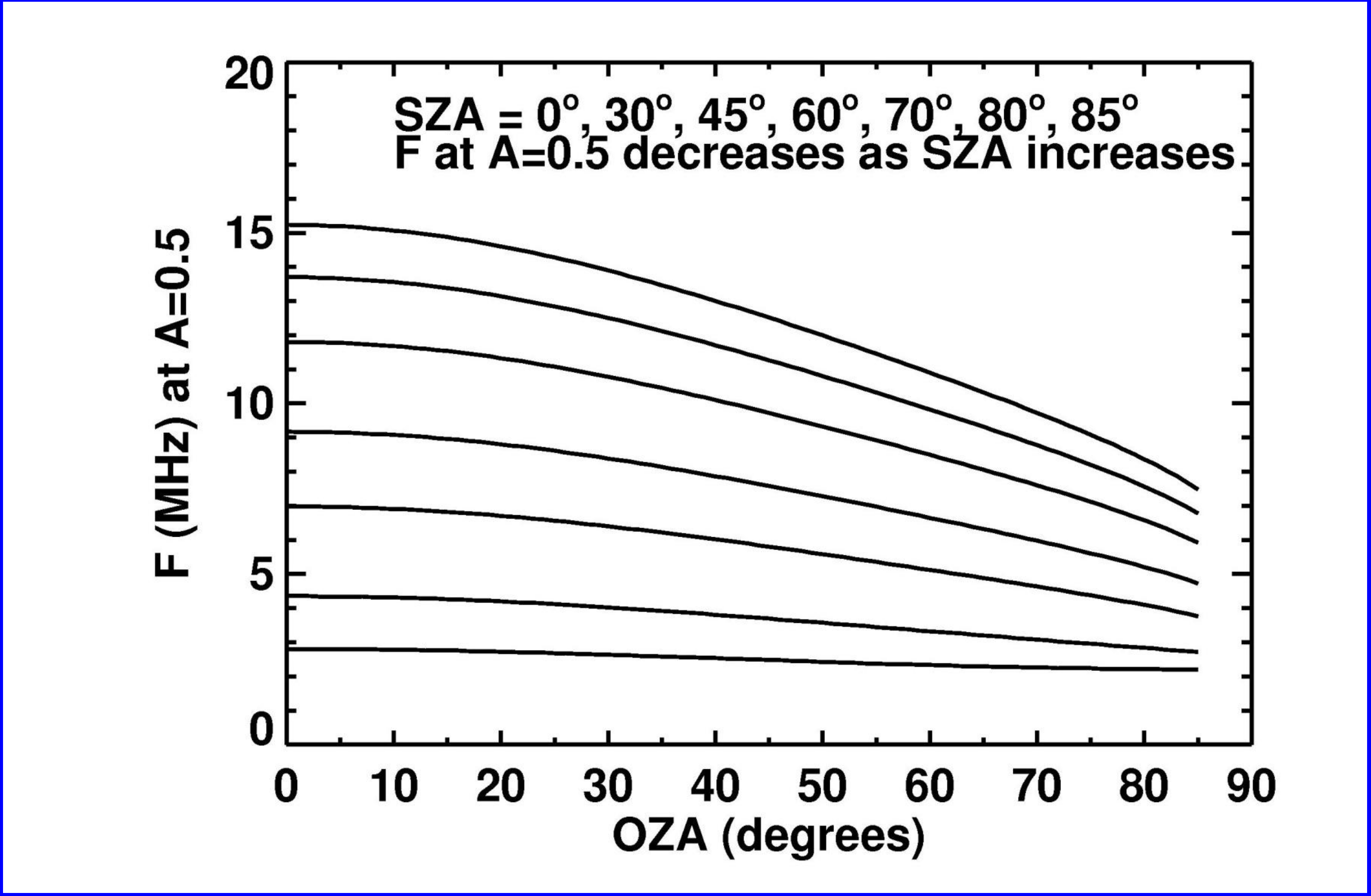
Signal attenuation results





SZA = 0 degrees, OZA = 0 degrees

“Half amplitude” frequency



Beyond Chapman ionosphere

- Observed electron density profiles
- Simulations from models

- Normal conditions
- Solar flares
- Energetic particle events
- Meteoric layers
- Galactic cosmic rays

Solar energetic particle event

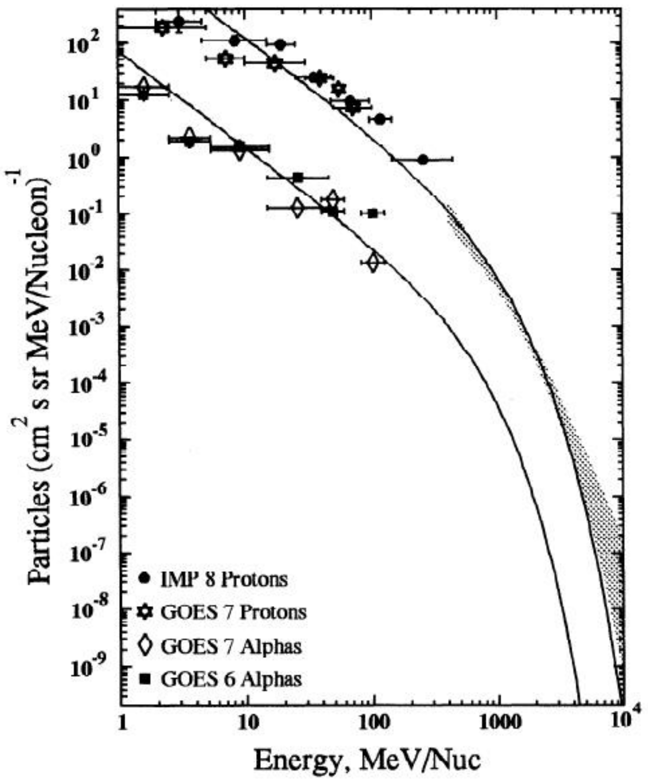
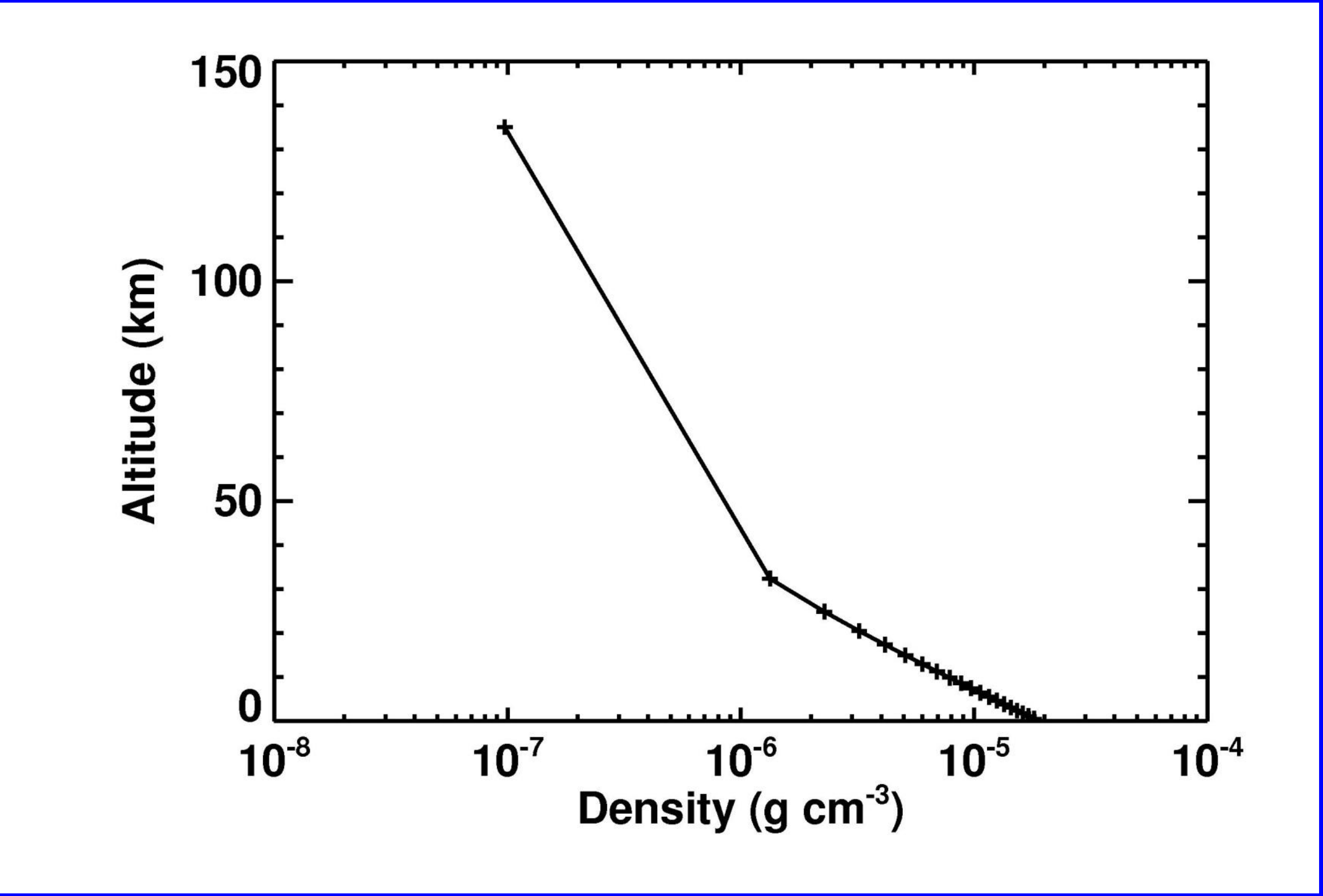


Figure 4. Hourly proton and alpha particle data from IMP 8, GOES 6, and GOES 7 (as indicated) and neutron monitor spectrum (shaded area). Fitted curves are of the *Ellison and Ramaty* [1985] shock acceleration spectral form.

Figure 4 of Lovell et al. (1998)

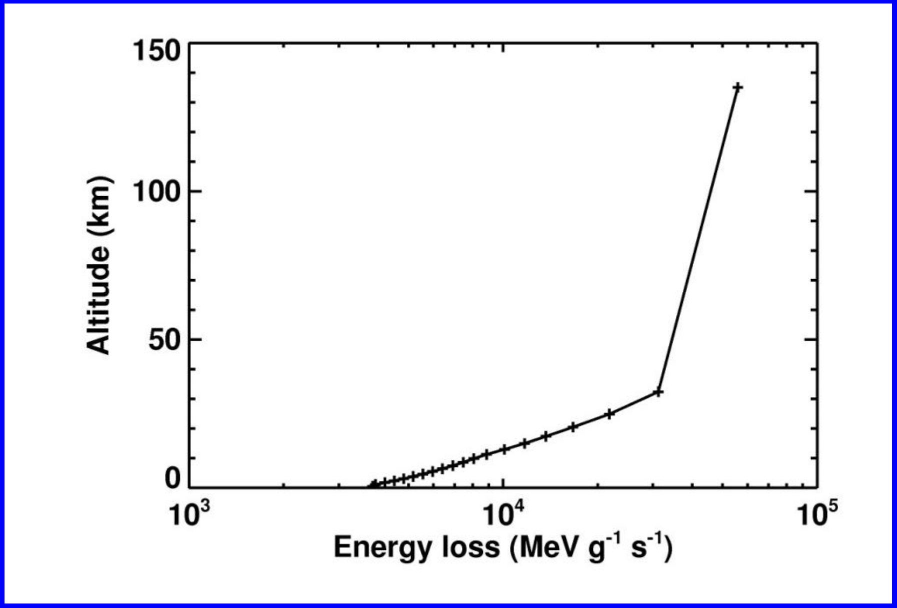
- 29 September 1989
- Energy deposition in atmosphere of Mars simulated by Shawn Kang and Insoo Jun at JPL
- Ionization rate inferred from energy deposition
- Plasma and electron densities inferred from ionization rate by analogy with real ionospheric models

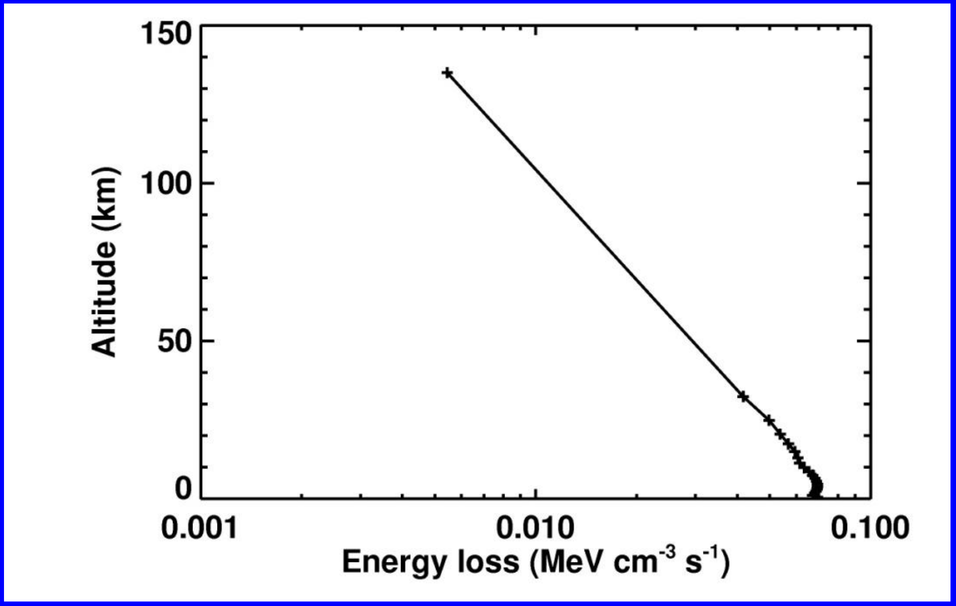
Atmospheric model



Layers of 1 g cm^{-2} used, total atmosphere is 20 g cm^{-2}

Energy deposition





Linking ionization rate and density of plasma and electrons

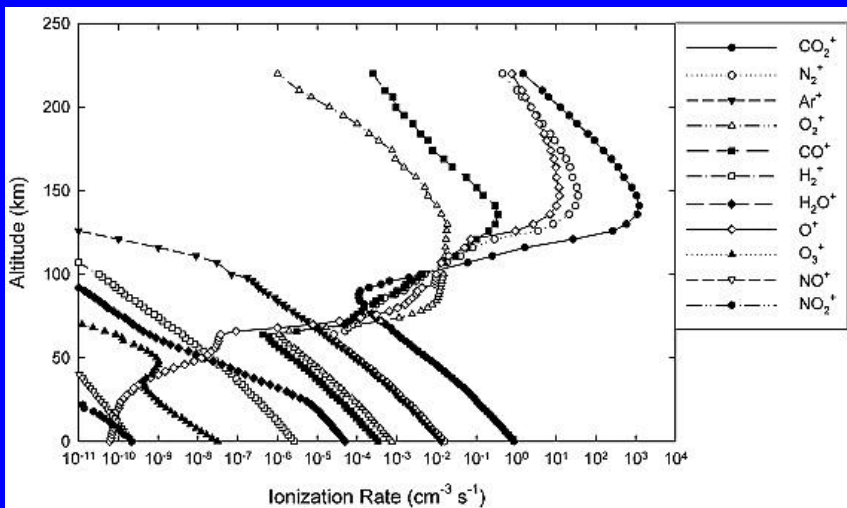


Figure 2 of Haider et al. (2009)

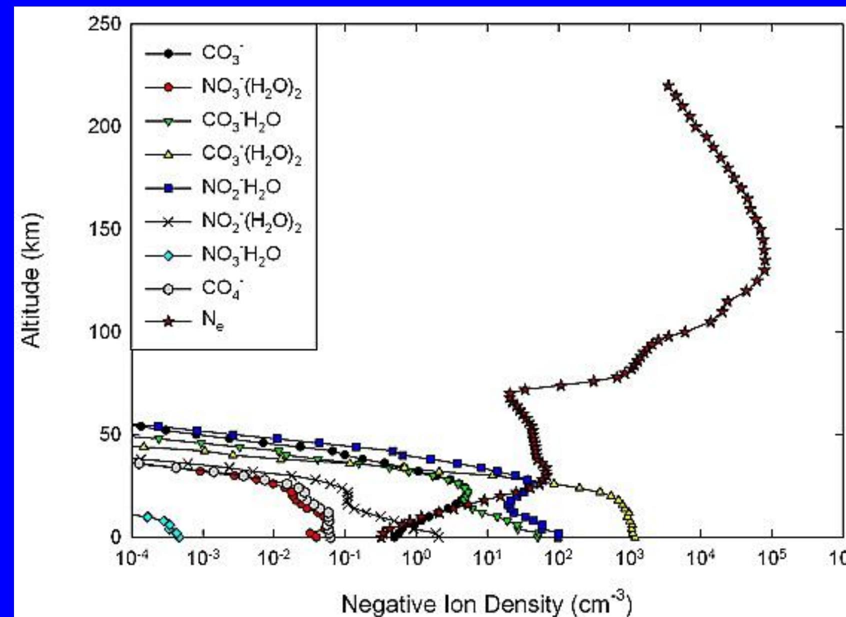


Figure 4 of Haider et al. (2009)

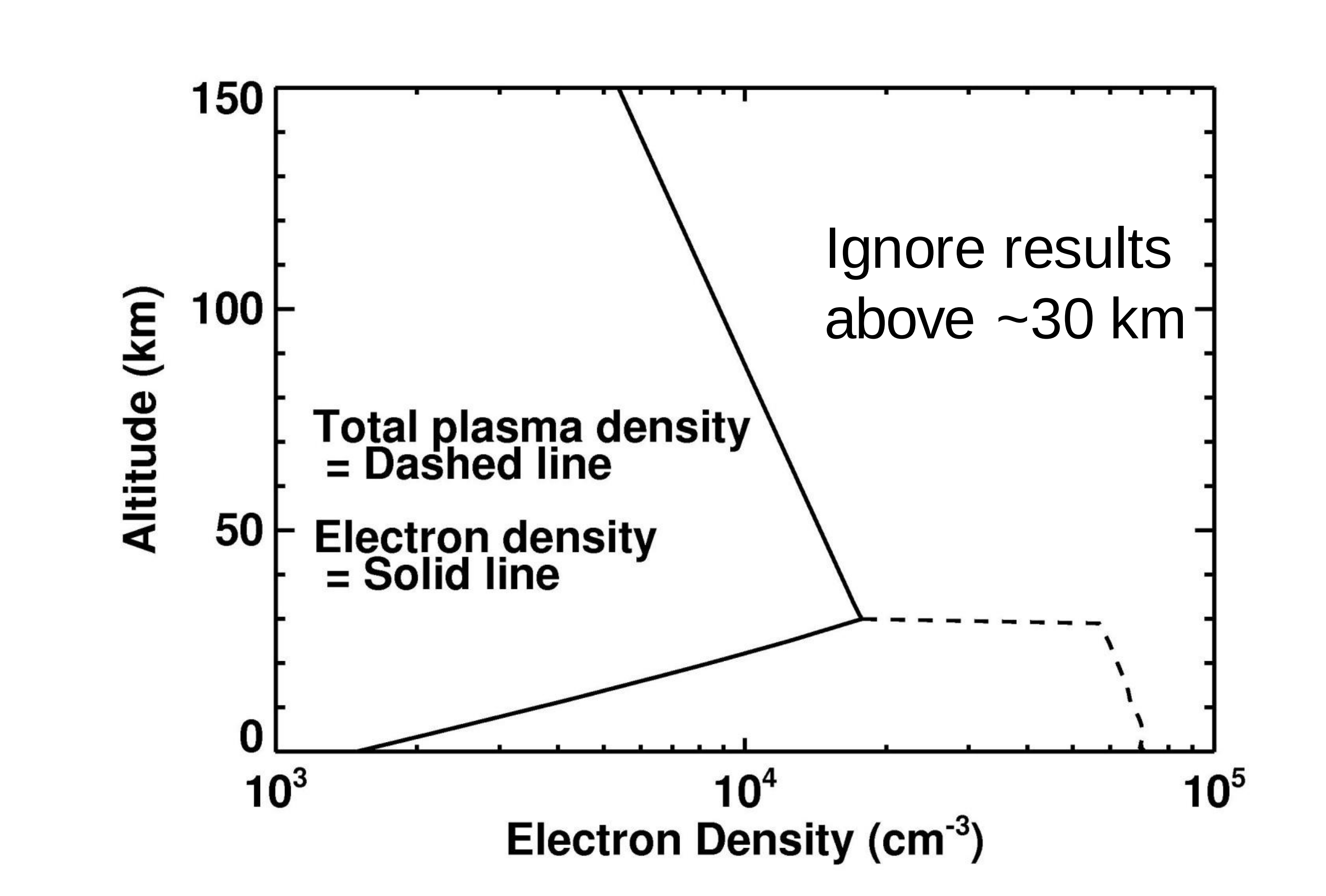
$P = k N_{tot}^2$

k = 4E-6 cm^3 above 30 km, 4E-7 cm^3 below 30 km

Ne = N_{tot} above 30 km

Ne (z) x neutral density (z) = Ne (30 km) x neutral density (30 km)

Inferred ionosphere



Future work

- Sensitivity of attenuation to assumed neutral atmospheric profile
- GPS range error and signal attenuation for "easy" data and models
- "Harder" models
  - Time-dependent solar flare
  - Additional SEP events and improved analysis