The effects of solar flares on planetary ionospheres

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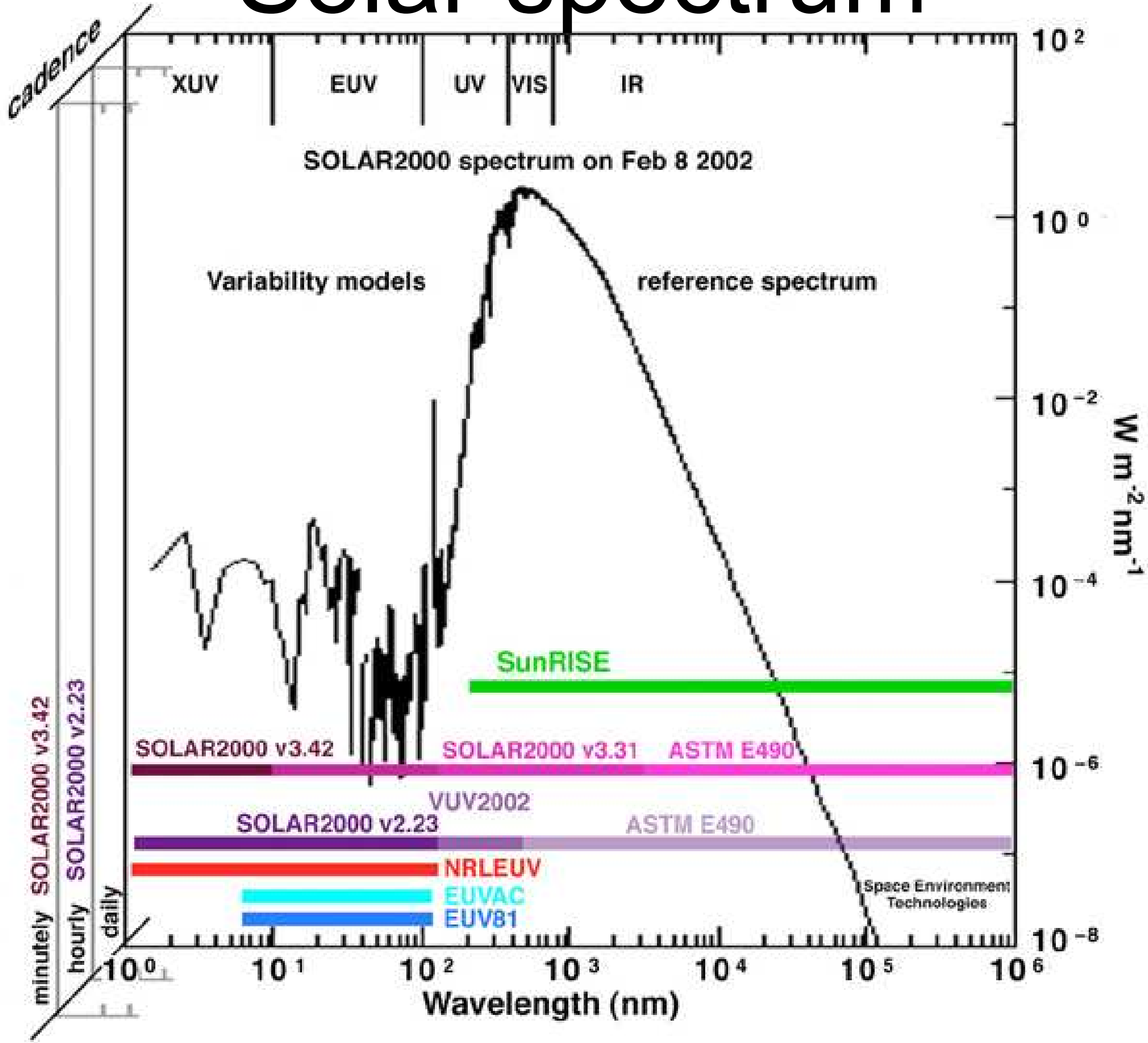
PS14-A004
Saturday 2009.08.15 11:00-12:30
AOGS Meeting, Singapore

Outline

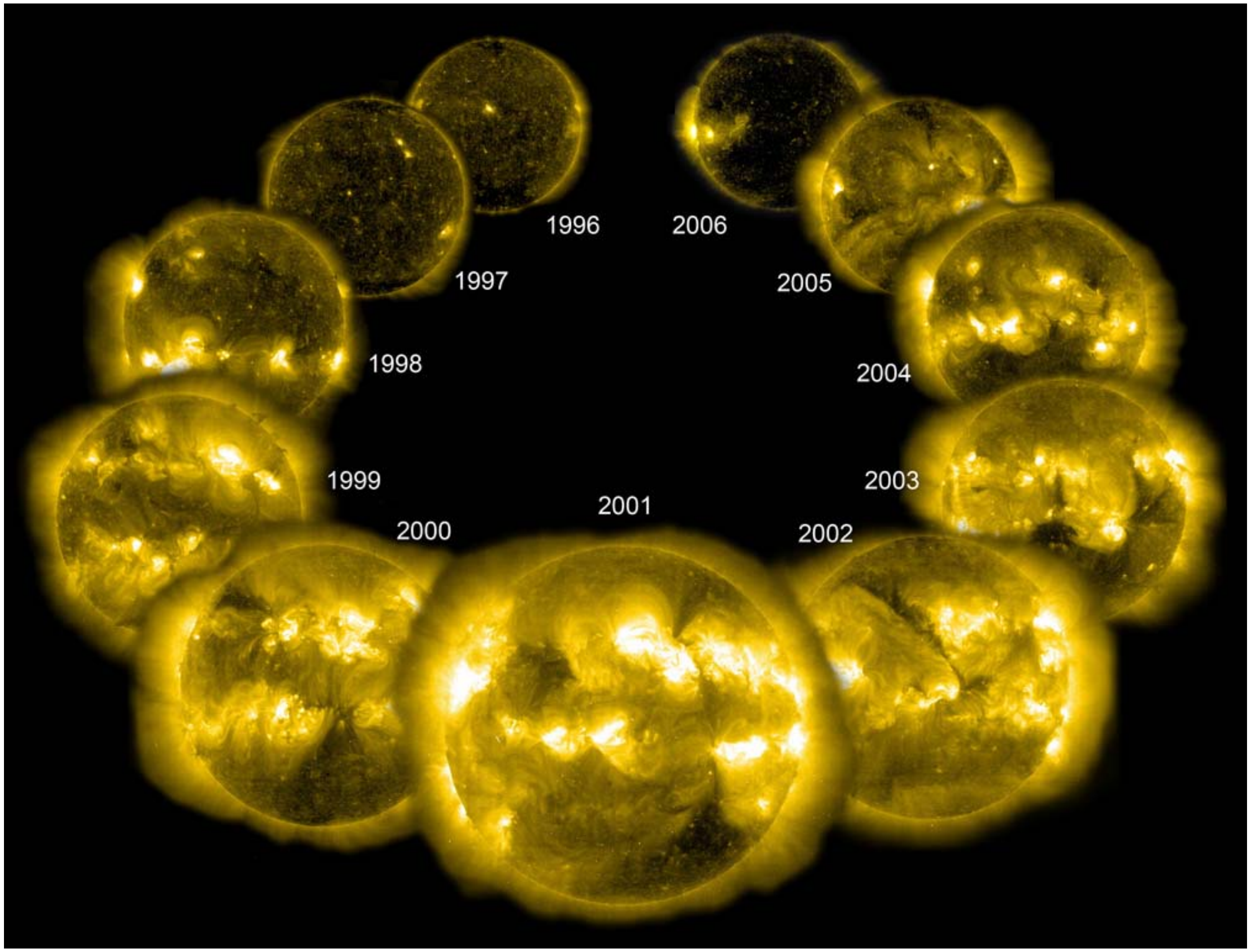
- The Sun, solar cycle, solar flares
- Observed effects on ionosphere of Mars
- Simulated effects on ionosphere of Mars
- Comparative discussion of other planets

Solar spectrum



http://www.spacewx.com/images/Solar_spectrum_144px.jpg

Solar cycle



SOHO images at EUV wavelengths (28.4 nm)

http://apod.nasa.gov/apod/image/0712/solarcycle_soho_big.jpg

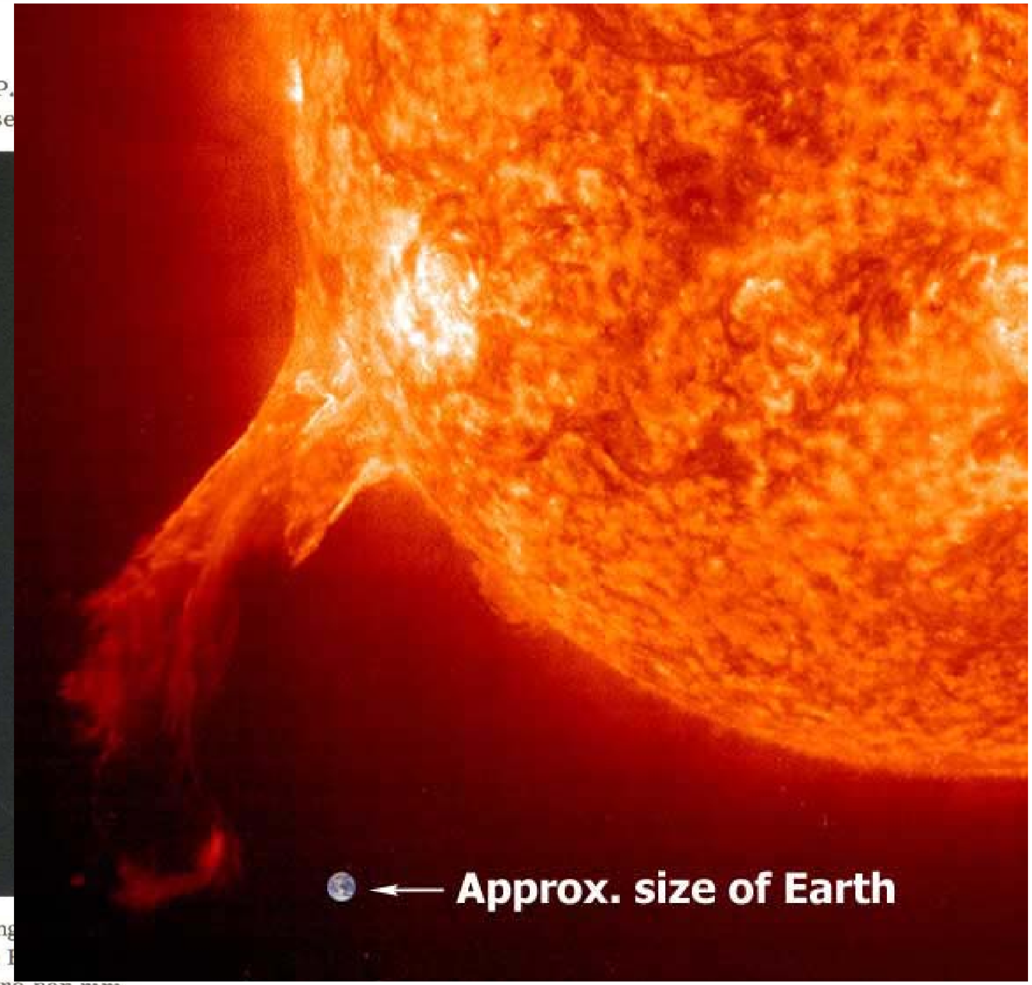
Solar flares

SOLAR FLARE PHOTOGRAPHED AT BOYDEN OBSERVATORY
ON THE 11TH AUGUST 1972, AT 14h44m SAST

The accompanying photograph, taken by Mr. H. Bacik and Mr. J. P. has been sent to us by Prof. A.H. Jarrett, Director of the Boyden Obse

The photograph was taken with a 15 cm aperture solar telescope using ference filters in series giving an effective halfwidth of 15Å centred on 6563Å. The scale on the original 35 mm negative was 6.4 seconds of arc per mm, the photograph being enlarged ten times. The film was Kodak infrared high speed 2481, and exposure time four seconds.

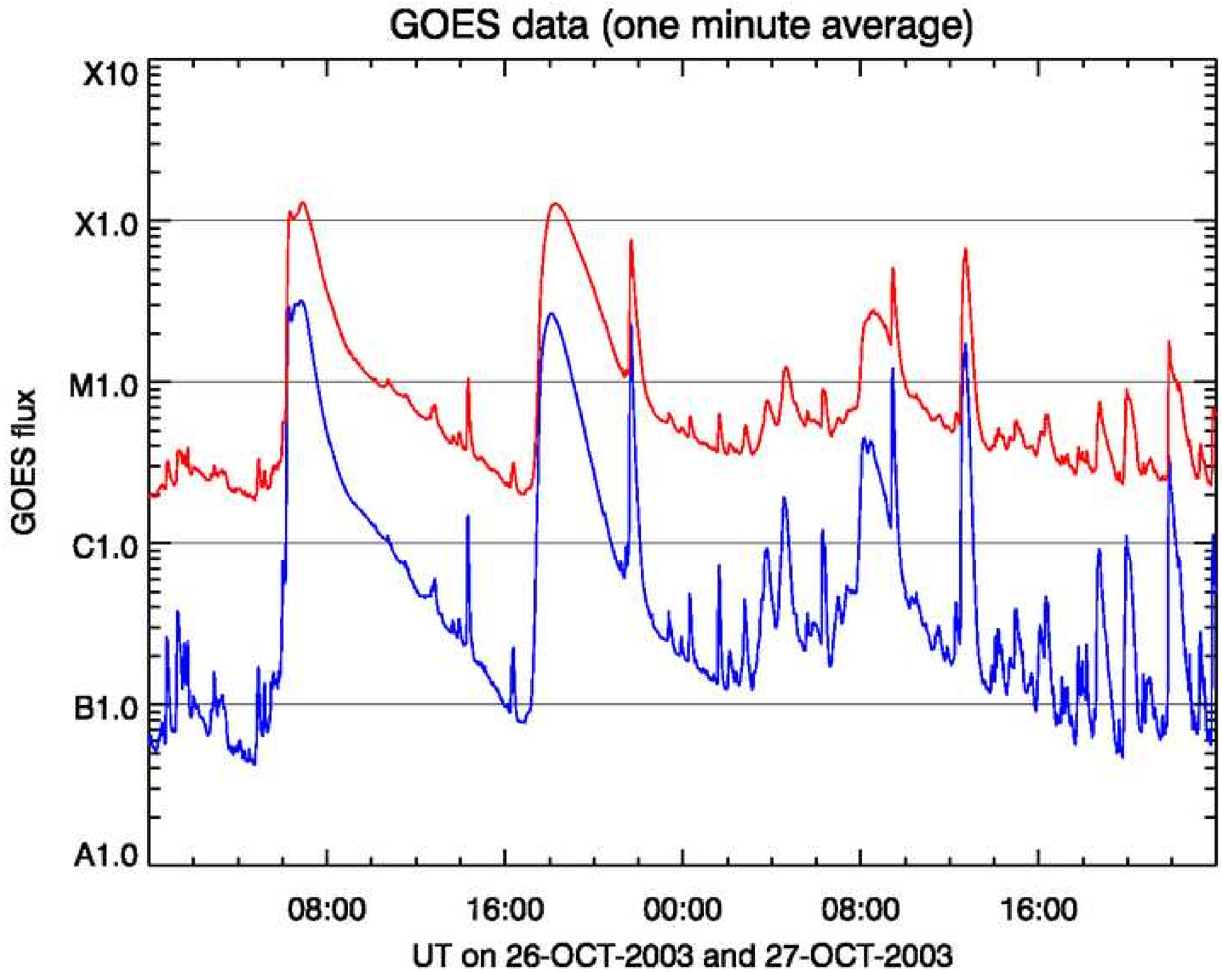
A Fabry-Perot interferometer was placed between the filters and the camera to investigate the tem fringe halfwidths - some of the H alpha fringes can be seen on the photograph to the left of the flare. (The photograph has been processed to emphasize the flare itself rather than the fringes which cross it).



http://www.assabfn.co.za/pictures/solar_boydenflare_historical_articles.jpg

http://rednova.com/news/stories/1/2003/10/24/story002.html

Dramatic changes during a flare



Red
0.1-0.8 nm
(GOES XL)

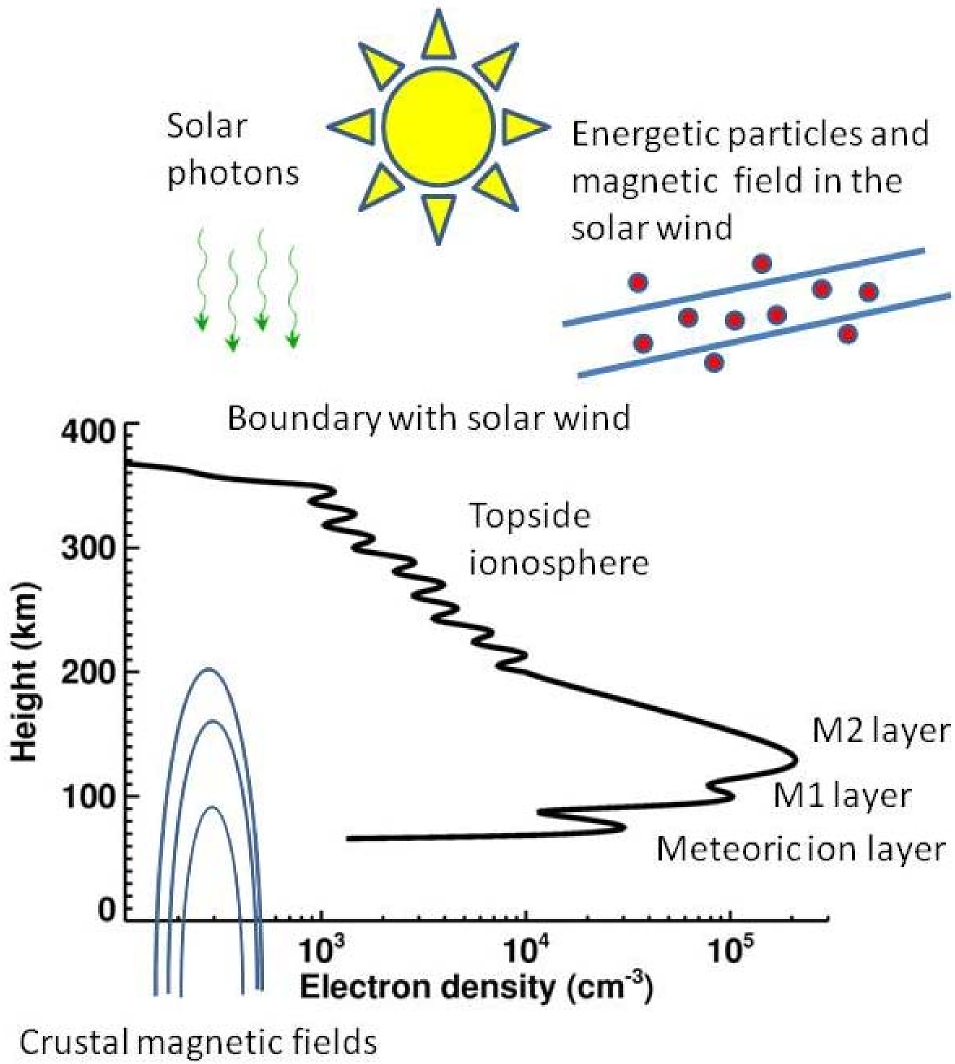
Blue
0.05-0.4 nm
(GOES XS)

http://en.wikipedia.org/wiki/Solar_flare

Planetary ionospheres

- Most photoionization events occur due to absorption of solar EUV photons at 10 nm to 100-150 nm
- Smaller number occurs due to absorption of solar soft X-rays at 1 nm to 10 nm
  - Often dominates ionization at low altitudes
  - Enhanced by multiplier effect of secondary ionization
  - Flux varies by several orders of magnitude during solar flares

The ionosphere of Mars

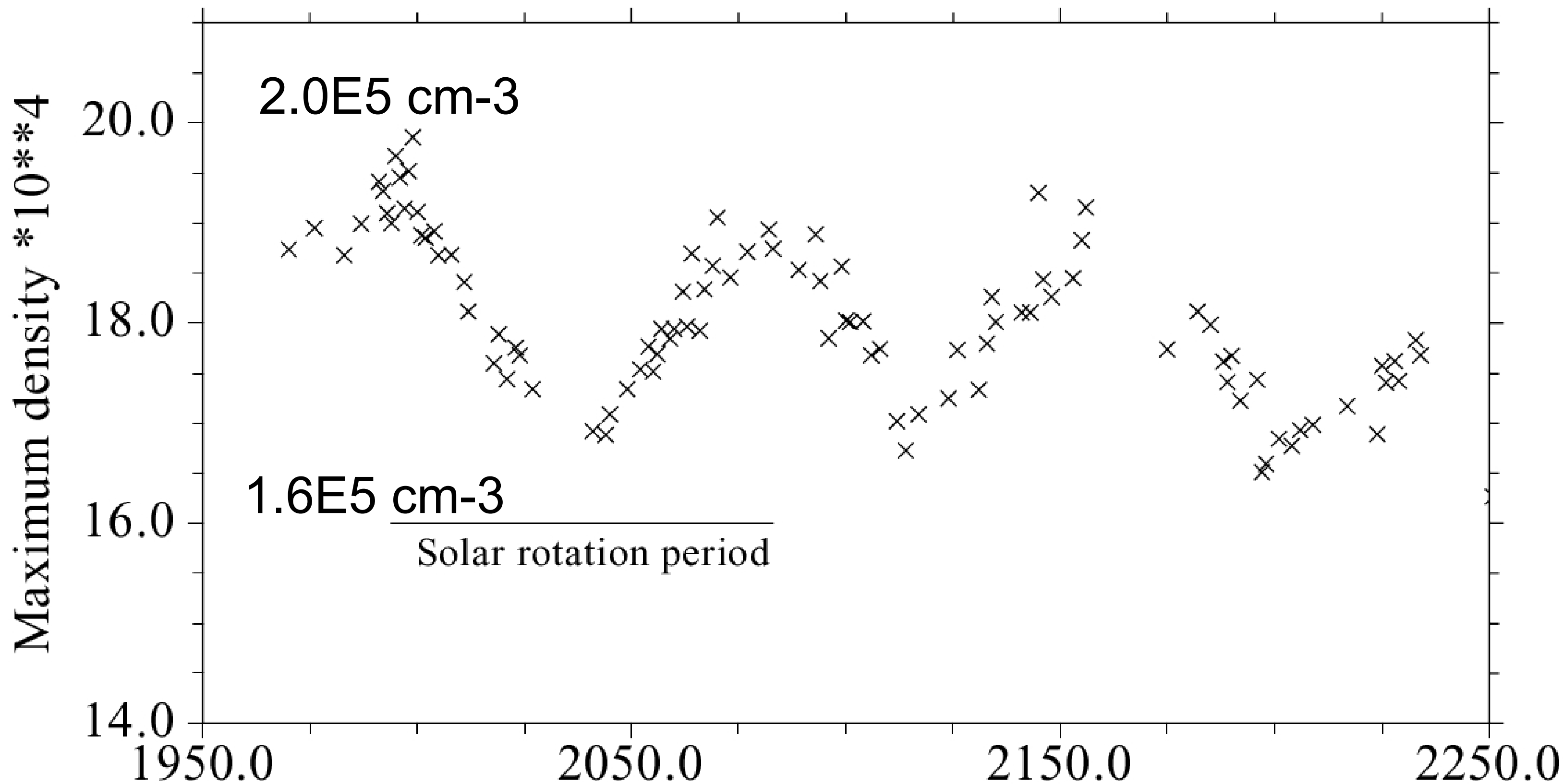


Neutral atmosphere is mainly CO_2, O becomes significant at high altitudes

O_2^+ is main ion at all altitudes (?)

EUV photons responsible for main M2 layer
Soft X-ray photons and secondary ionization responsible for lower M1 layer

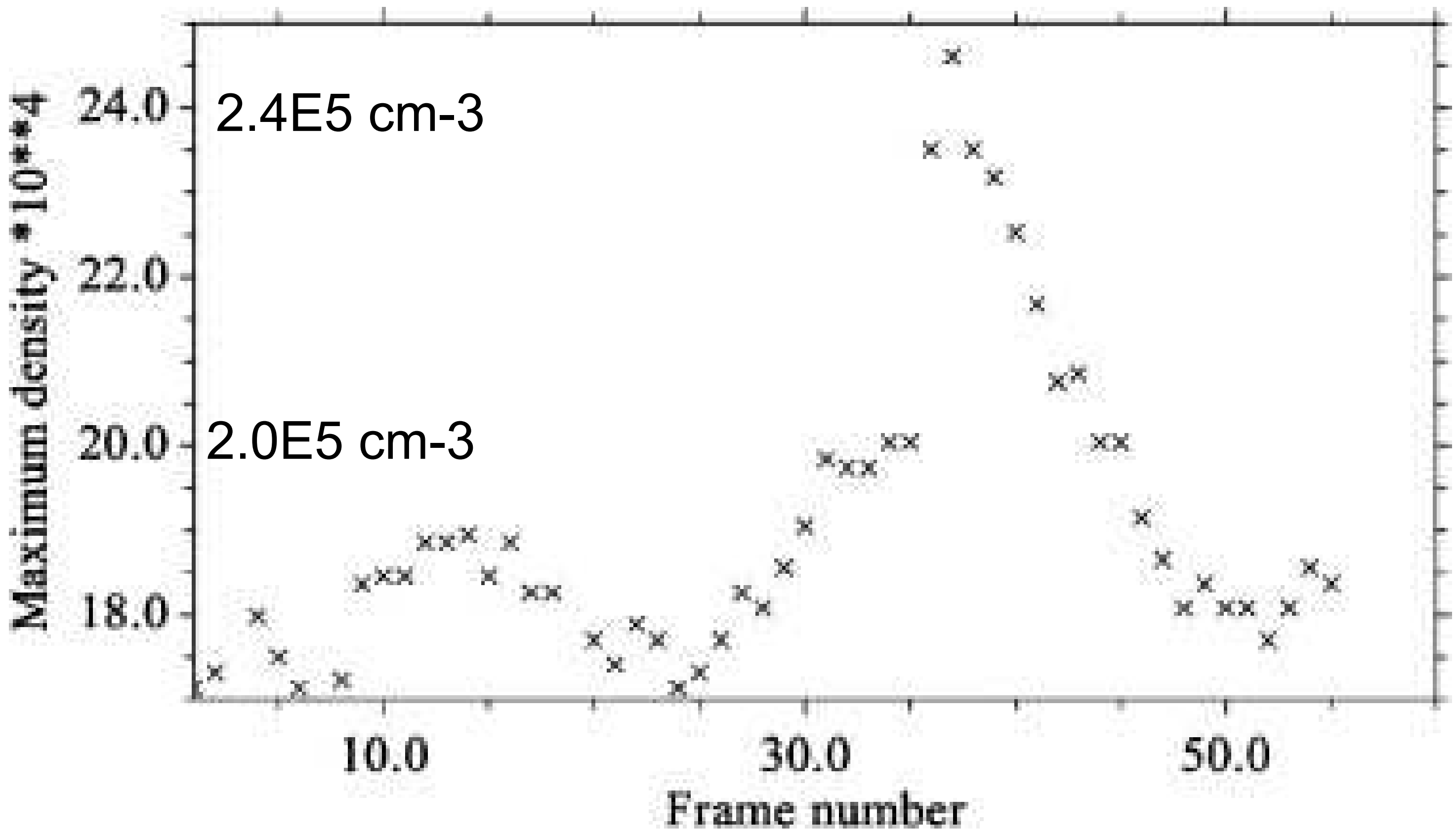
Peak density depends on solar irradiance



22 July 2005 14 October 2005

Figure 3 of Nielsen et al. (2006)

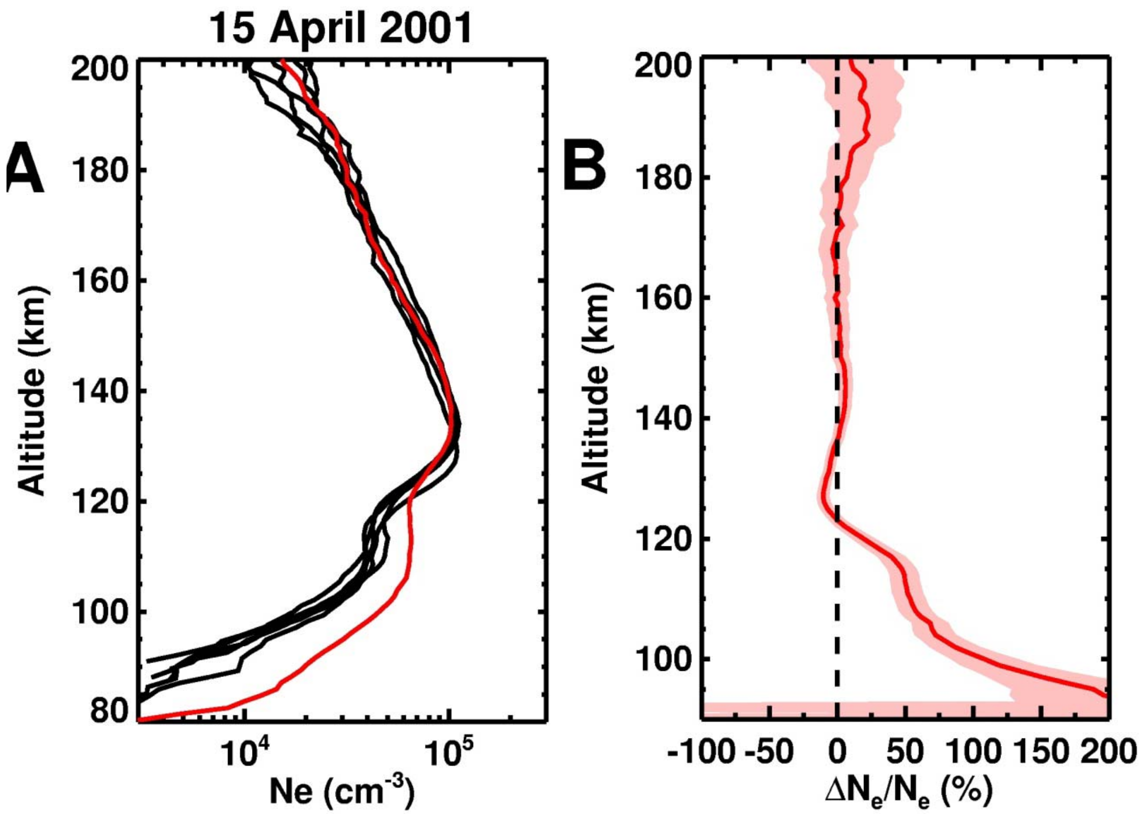
Peak density increases during a solar flare



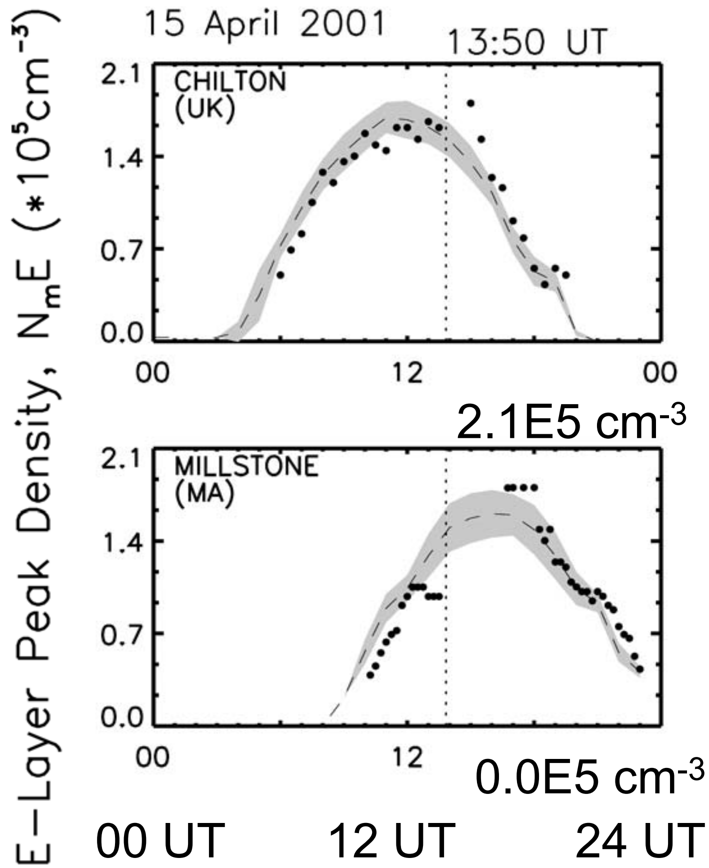
Seven minutes of data, time increases linearly
X1.1 solar flare on 15 September 2005

Figure 4 of Nielsen et al. (2006)

Lower ionosphere affected by an X14 solar flare



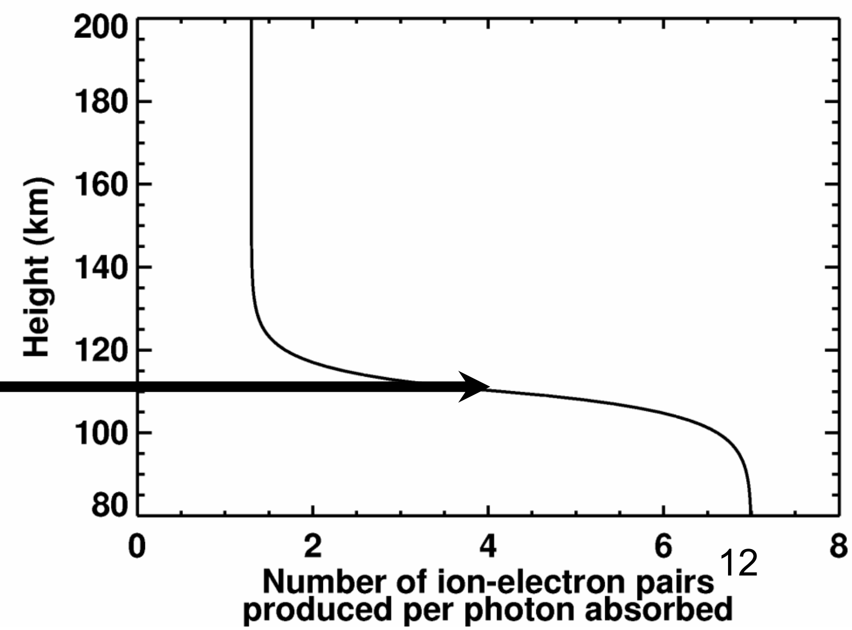
Figs 1 and 3 of Mendillo et al. (2006)



Enhanced electron densities seen throughout lower ionosphere of Mars
Doubling at 100 km, greatest increases at lowest altitudes
Terrestrial E-region also affected

BU Photochemical Mars Ionosphere Model

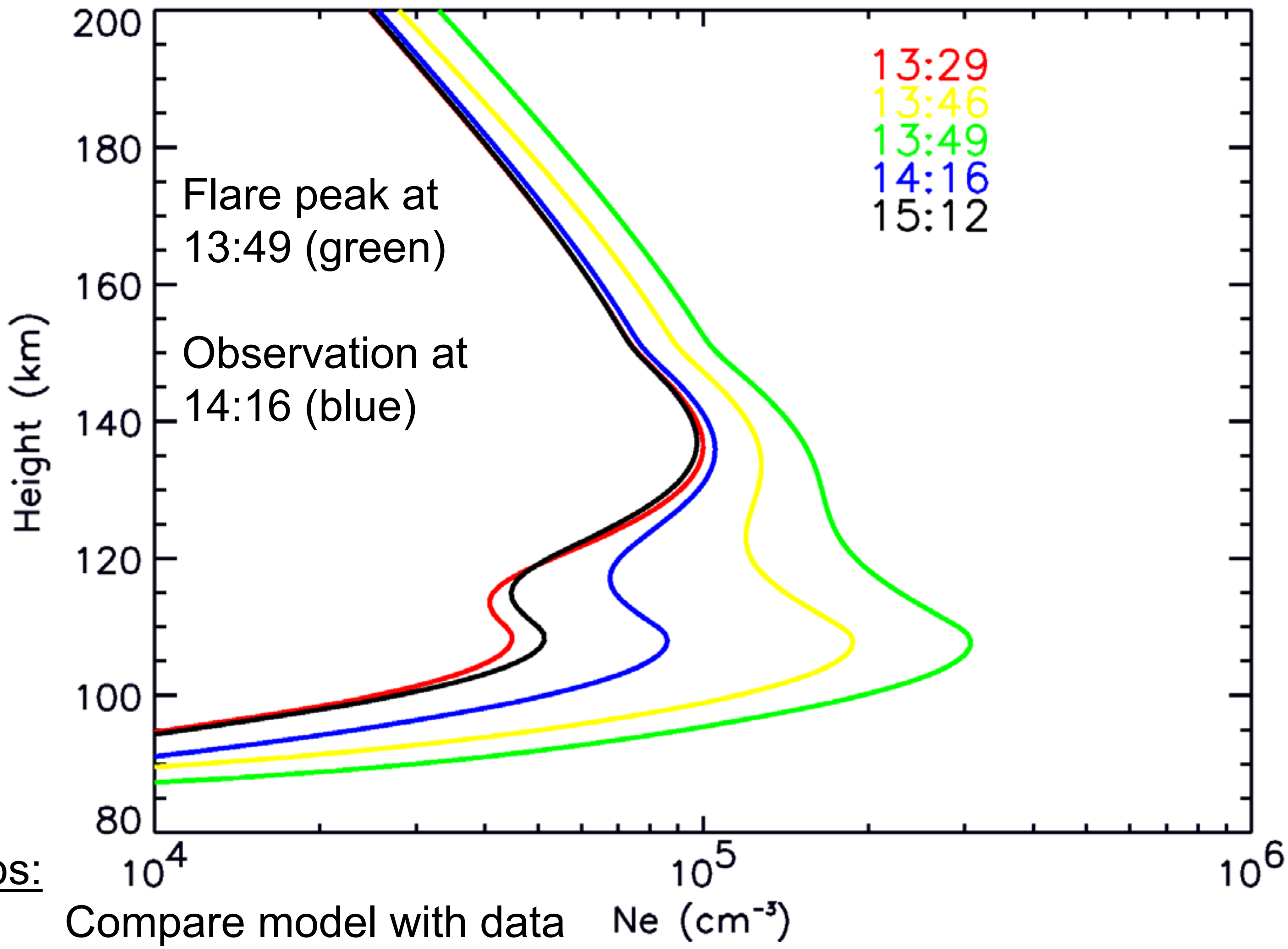
- Neutral atmosphere derived from Bougher MTGCM model
- Absorption and ionization cross-sections from Schunk and Nagy Ionospheres book (λ > 5 nm) and theoretical models of Verner (λ < 5 nm)
- Reaction rates from Schunk and Nagy Ionospheres book
- Secondary ionization parameterized as function of altitude based on results of Fox



Solar irradiance models at Earth

- Solar2000 (Tobiska)
  - 39 or 867 bins from 1.8 – 105.0 nm
  - One spectrum every day
  - Empirical model
- Flare Irradiance Spectral Model (Chamberlin)
  - 195 bins of 1 nm width from 0.5 – 195.5 nm
  - One spectrum every minute
  - Empirical model based on TIMED SEE, UARS SOLSTICE, GOES
- Irradiances resampled so that we have 20 bins shortward of 5 nm, 37 bins longward of 5 nm
- Spin up with Solar2000, then transition to FISM
- No previous Mars ionosphere model has used time-varying solar irradiance (?)

Simulated ionosphere



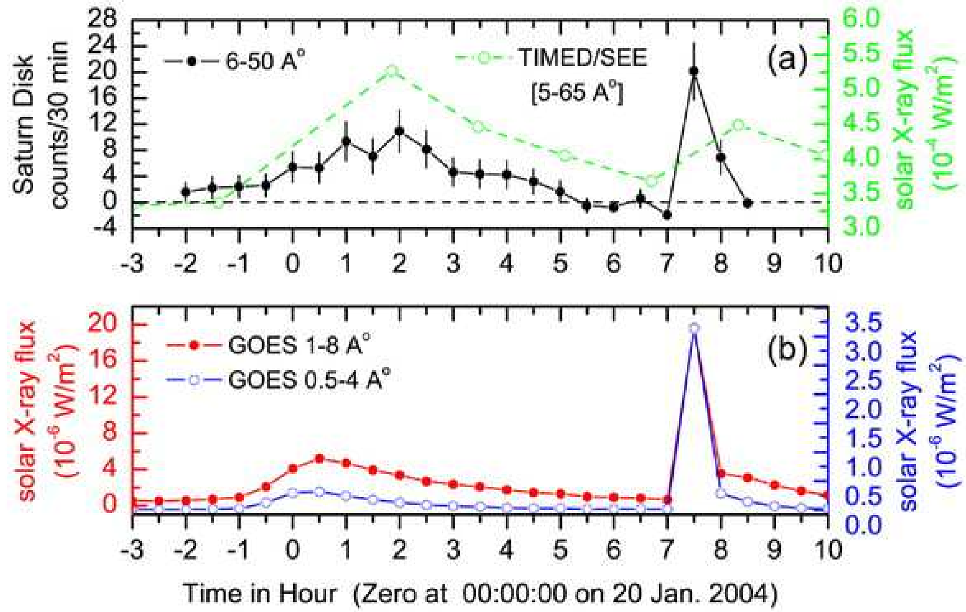
<u>Next steps:</u>

Compare model with data

Optimize model inputs

Are optimized inputs like the atmosphere, electron temperatures, secondary ionization realistic?

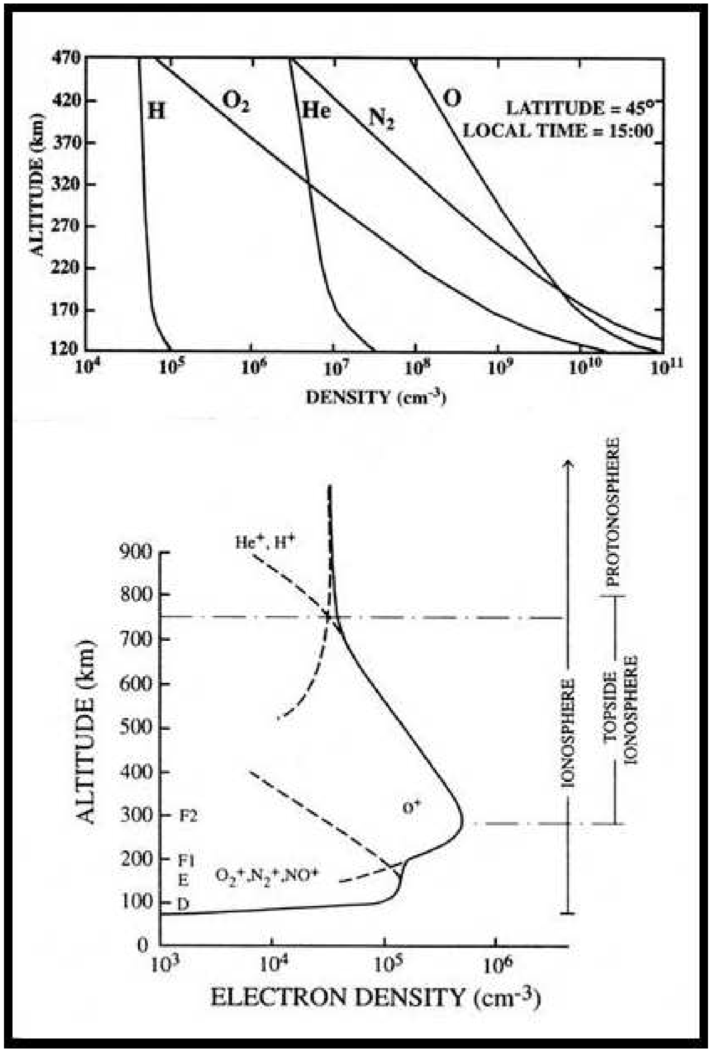
Other Planets



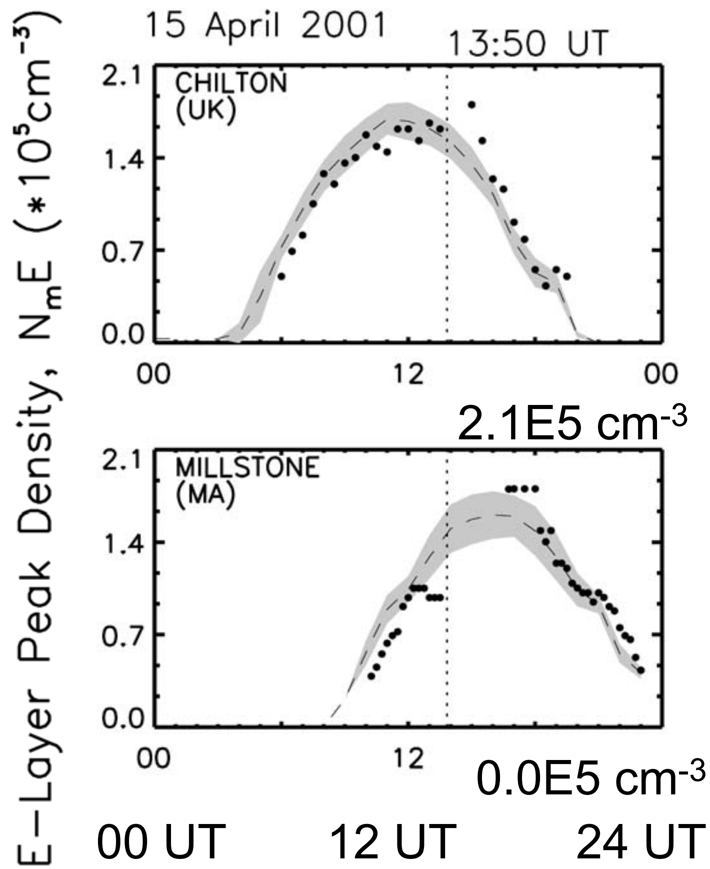
Saturn, Figure 2 of Bhardwaj et al. (2005)

- Earth and Venus
  - Next pages
- Giant planets
  - H_2 atmospheres
  - H_3^+ and H^+ are major ions
  - Minimal data available
  - Increased X-ray emissions from giant planets observed during solar flares, scattering process

Earth



(right)
Fig 3 of
Mendillo et
al. (2006)



N_2-O_2 atmosphere, O_2^+, NO^+, O^+ ions abundant, transport key in F-region
Extensive database of ionospheric properties exists – but I am still searching for good example of time series of electron density profiles during a solar flare

Venus ionosphere

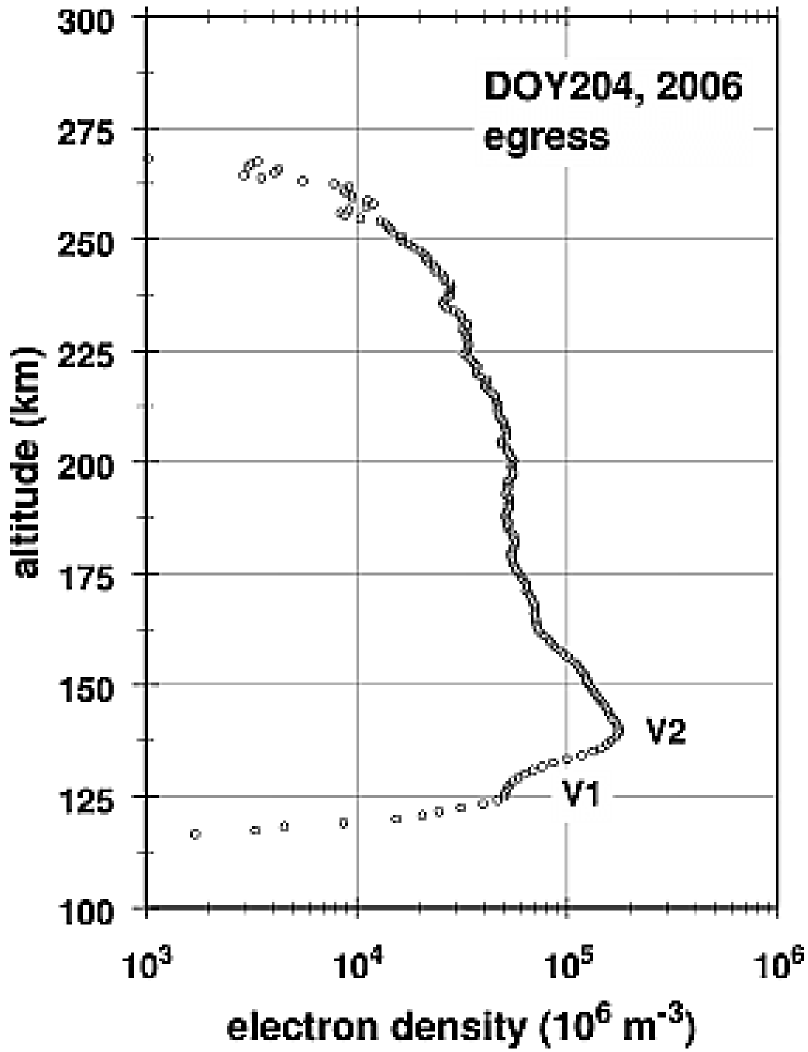


Figure 1 of Paetzold et al. (2009)

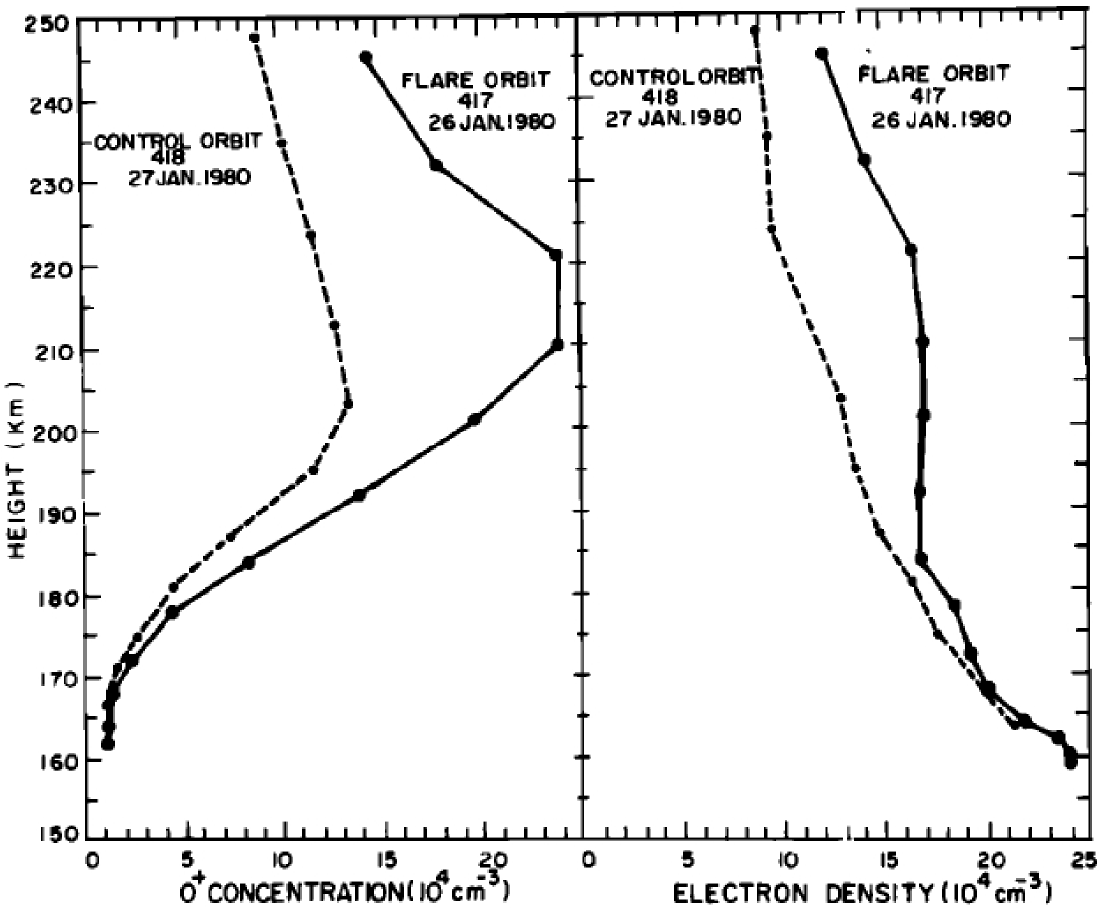
Very similar to Mars

Neutral atmosphere is mainly CO_2
O becomes significant at high altitudes

O_2^+ is main ion at main peak and below,
O^+ is main ion at high altitudes

EUV photons responsible for
main V2 layer
Soft X-ray photons responsible for
lower V1 layer

Venus during a solar flare



Enhanced O^+ and electron densities seen at high altitudes on orbit 417 of Pioneer Venus Orbiter (26 January 1980)

No enhancement in O^+, O_2^+ or electron densities below 170 km

Are solar photons or solar energetic particles the cause of this effect?

Figure 4 of Kar et al. (1986)

Conclusions

- The ionospheres of Earth and Mars respond strongly to solar flares
- Response at Venus is less clear
- Accurately reproducing the martian ionosphere during a solar flare is a challenging test for models
- Further studies are in progress