Simulations of the Mars ionosphere during a solar flare

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Increased fluxes of X-rays during solar flares have been observed to enhance electron densities in the lower ionosphere of Mars. The photochemical timescale at these altitudes is on the order of minutes, so these electron density enhancements do not persist for substantially longer than the flare duration. We present the results of photochemical model simulations of the Mars ionosphere driven by temporally-varying solar fluxes, concentrating on 15 and 26 April, 2001. The Mars Global Surveyor (MGS) Radio Science (RS) instrument observed flare-enhanced electron densities on these dates. Solar fluxes are derived from the Flare Irradiance Spectral Model, which outputs the solar spectrum at 1 nm intervals from 0.5 to 195.5 nm every 1 minute. This empirical model is based on TIMED SEE, UARS SOLSTICE, GOES, and other observations. For a short period at the peak of a large solar flare, X-ray photoionization rates exceed EUV photoionization rates and the electron density peak altitude decreases by tens of kilometres. Simulations will be compared to MGS RS measurements of electron density profiles.

A Typical Mars Ionospheric Profile

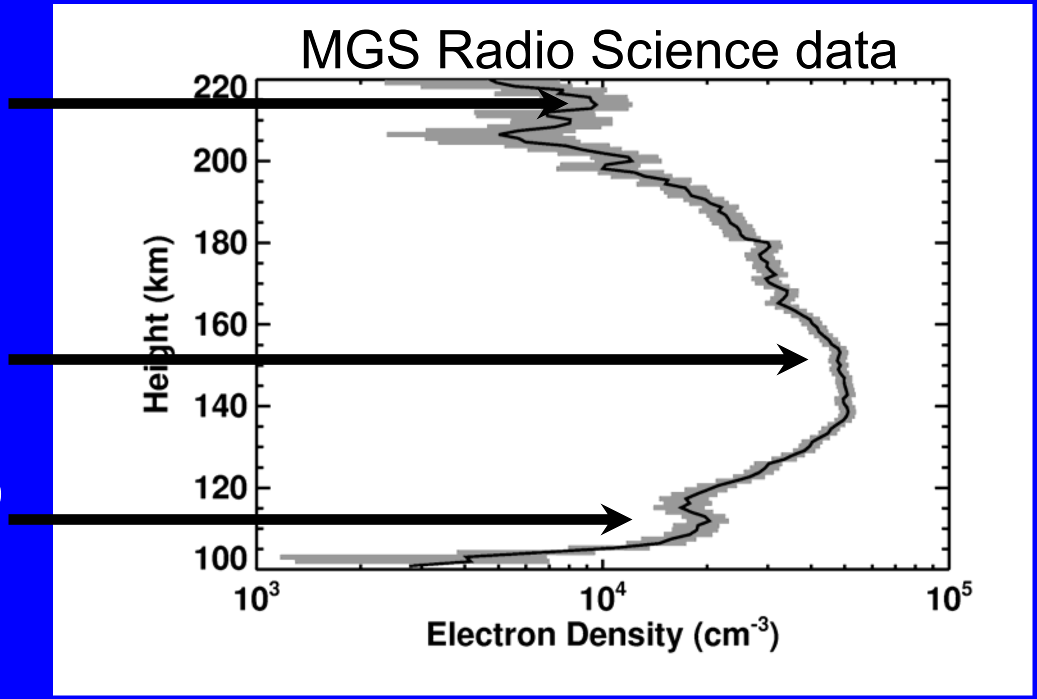
Transport important above ~180 km

Main peak at 140 km due to EUV photons

Lower peak at 110 km due to X-rays. Each X-ray that is absorbed produces multiple ion-electron pairs

"secondary ionization"

- $CO_2 + hv \rightarrow CO_2^+ + e$
  - (production)
- $CO_2^+ + O \rightarrow O_2^+ + CO$
  - (chemistry)
- $O_2^+ + e \rightarrow O + O$
  - (loss)



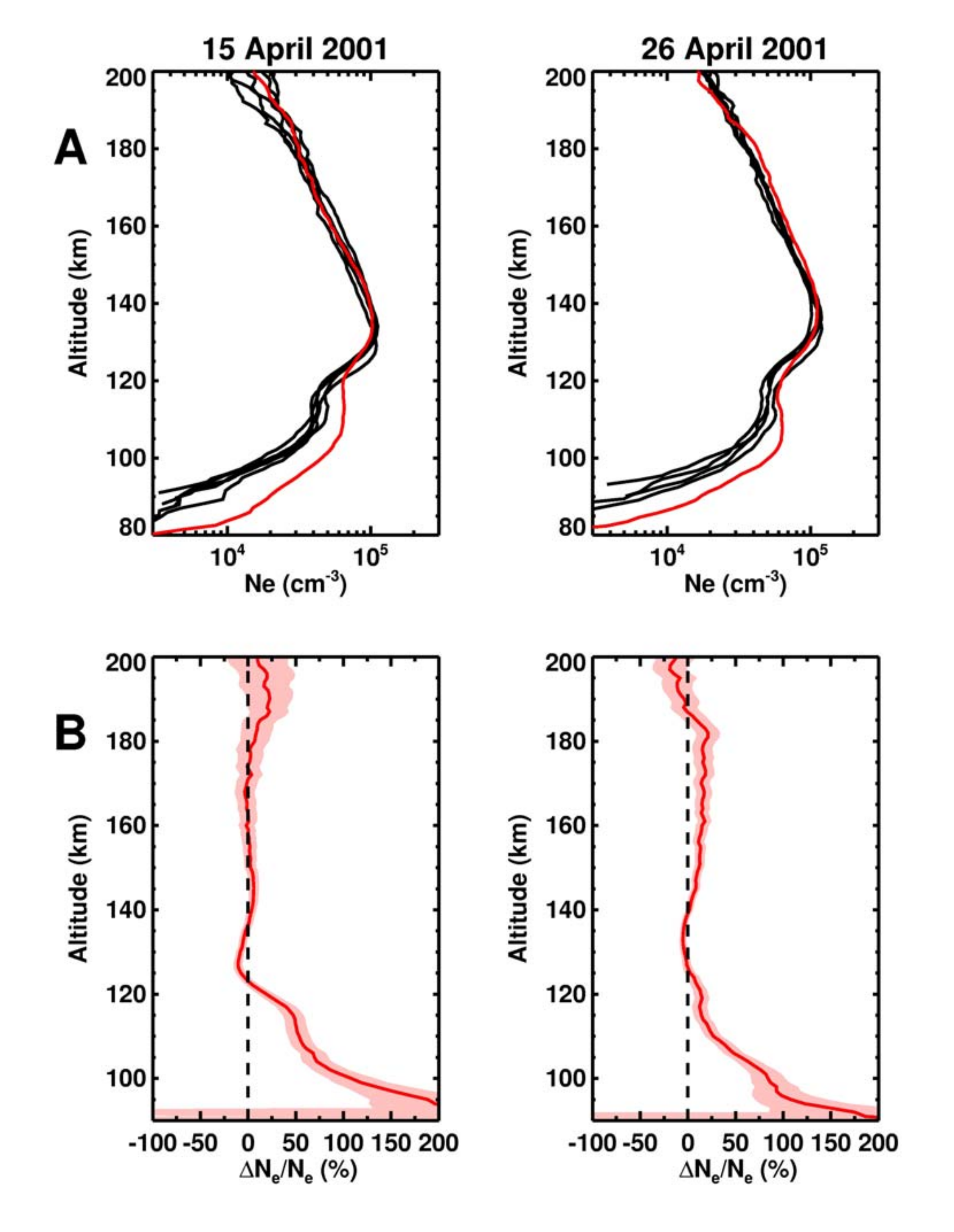
Outline of poster:

Observations of Mars ionosphere during a solar flare

Model description

Models of Mars ionosphere during a solar flare

Conclusions



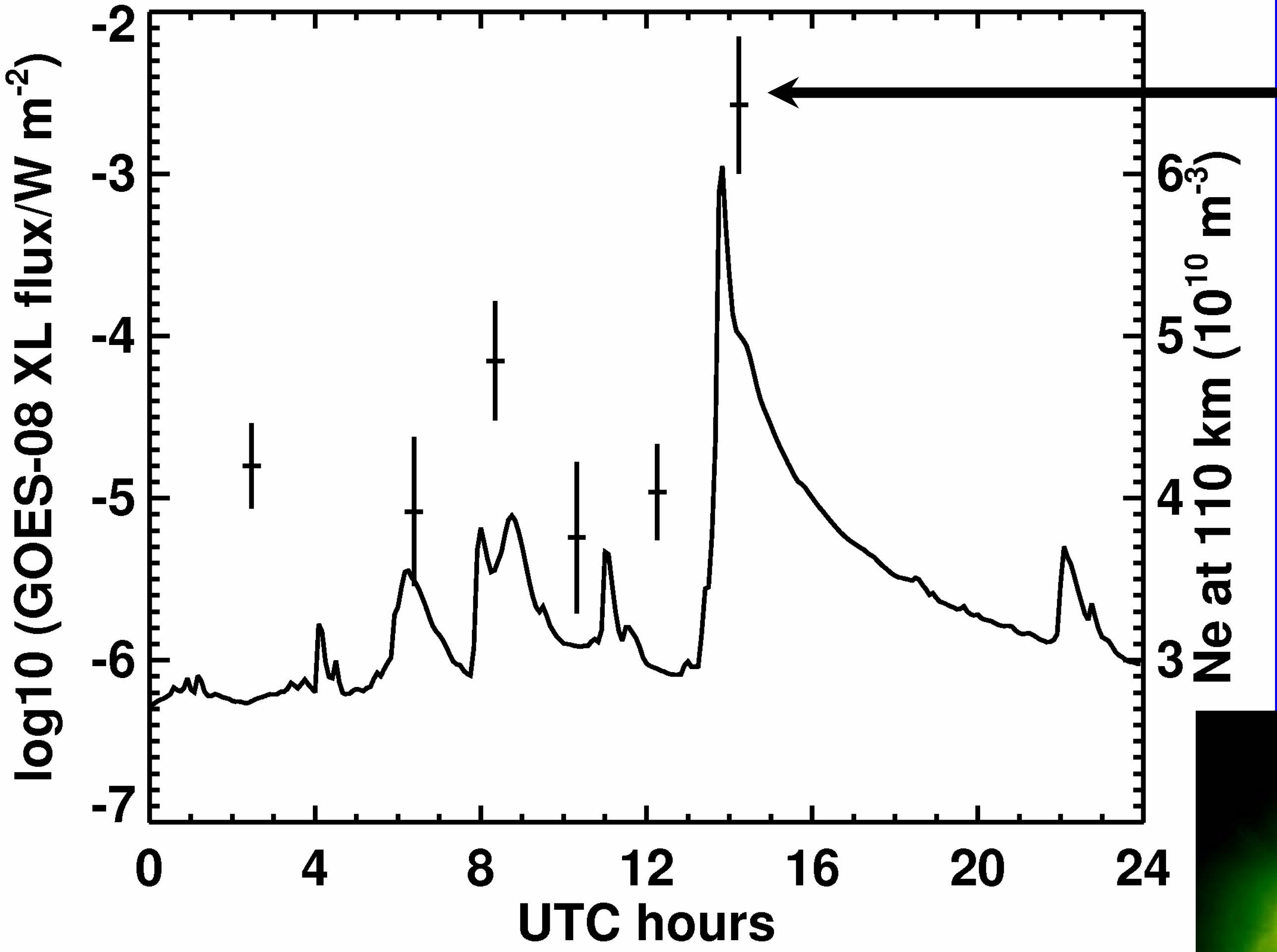
Enhanced electron densities seen below 120 km in one of six profiles on each day

Relative increase in electron density increases as altitude decreases

Suggests that relative increase in flux is greatest at shorter, more penetrating wavelengths

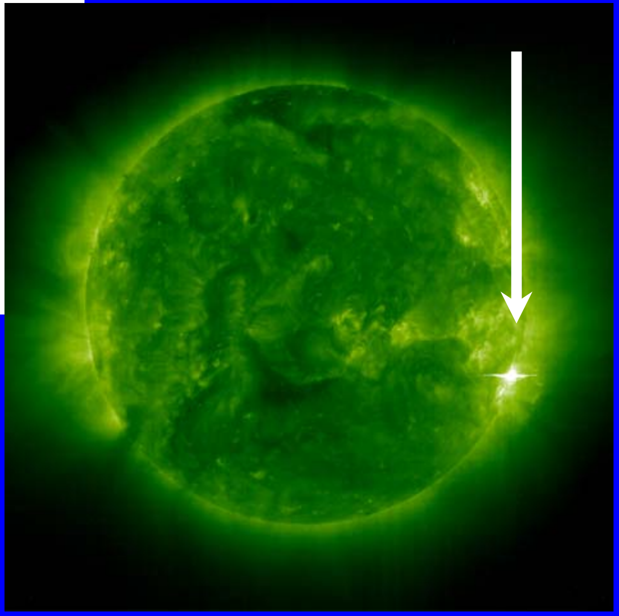
Factor of two increase in electron density at 100 km suggests factor of four increase in relevant ionizing flux. Optical depth ~ 1 at 100 km for 5 nm photons.

Tens of similar examples in the 5600 MGS profiles

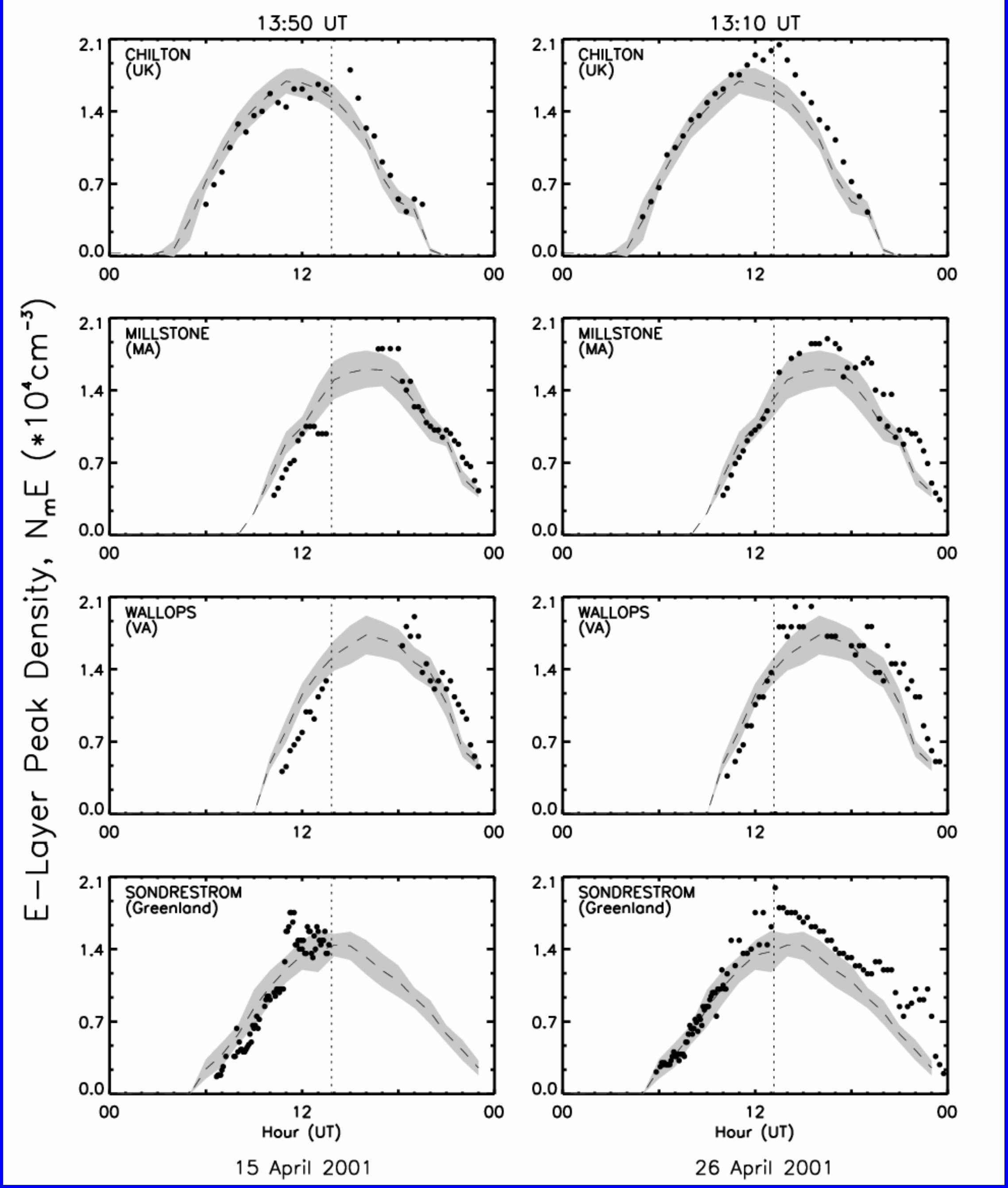


Electron density at 110 km for enhanced profile

SOHO/EIT image at 19.5 nm at flare onset



X-ray flux (0.1 to 0.8 nm) measured in Earth orbit.
Flux increases by 2-3 orders of magnitude



Measurements of the terrestrial ionosphere on 15 and 26 April 2001, left and right columns respectively. Dots are observations, dashed lines and shaded areas are average values for the month. Vertical lines show times of peak flare fluxes.

The 15 April flare, X14.4 magnitude, was so strong that the ionosonde's radio signal was absorbed by increased electron densities in the D region and the E region was not observable

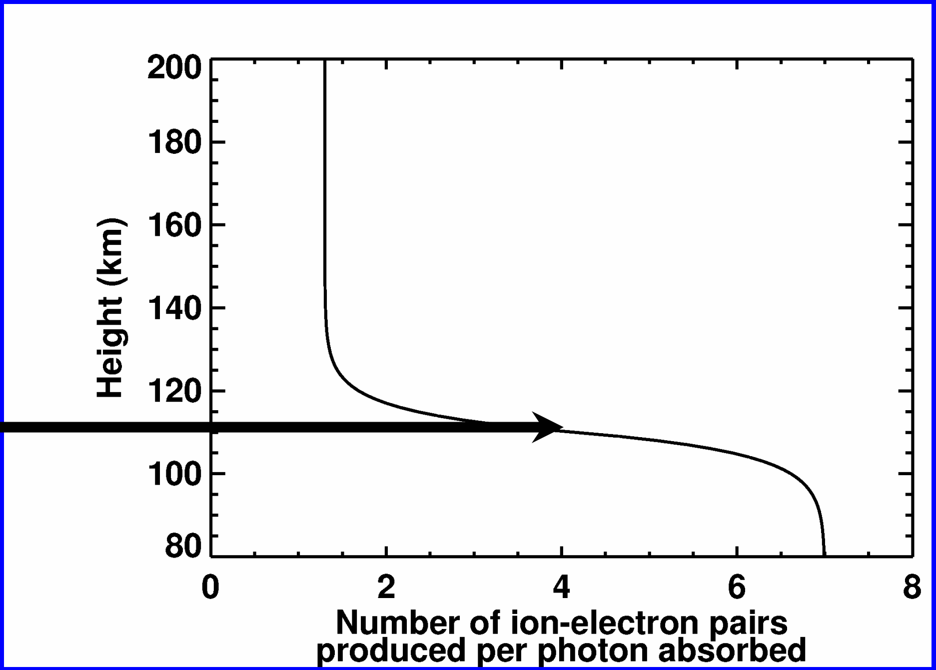
The 26 April flare, M7.8 magnitude, did lead to increased E region densities

Additional observations of similar ionospheric enhancements

- We have found 30 additional examples of ionospheric enhancements at Mars in the 3749 profiles archived by MGS using an automatic detection algorithm.
- We have compared the changes in electron density in the 32 enhanced profiles at Mars, the solar X-ray flux at Earth, and the Earth-Sun-Mars angle.
- We find that:
  - Large X-ray fluxes at Earth are more likely to be coincident with enhanced electron densities at Mars if the Earth-Sun-Mars angle is small than if it is large.
  - The increase in electron density is large when the increase in solar flux is large, but small when the increase in solar flux is small.
  - The relative increase in electron density increases as altitude decreases
- Short wavelength X-ray fluxes observed at Earth are not always large when enhanced electron density is observed at Mars
- We conclude that enhanced bottomside electron densities on Mars are caused by increases in solar flux. Models suggest that photons of 1-5 nm are responsible.

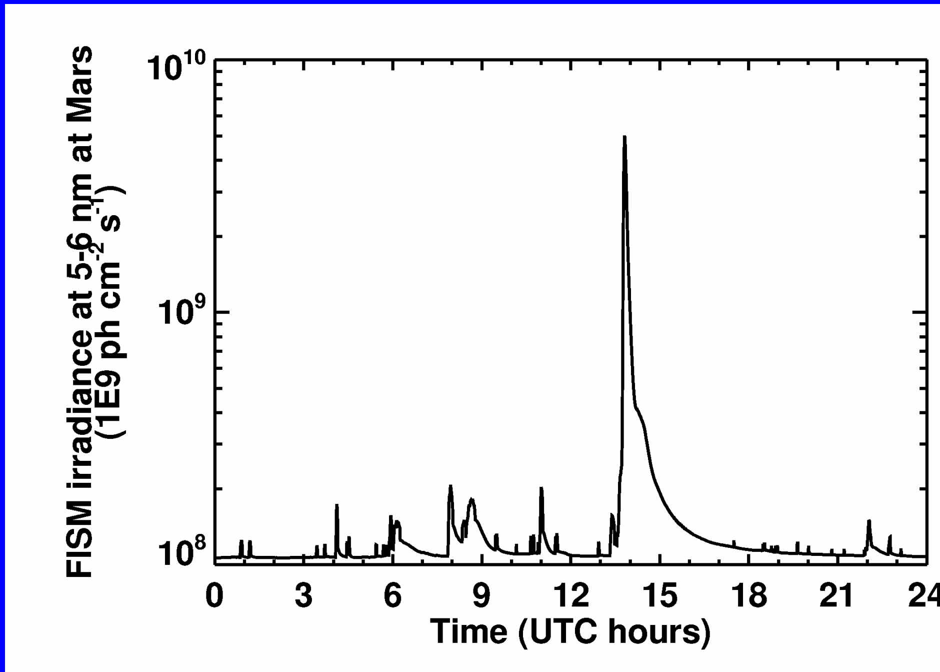
BU Photochemical Mars Ionosphere Model

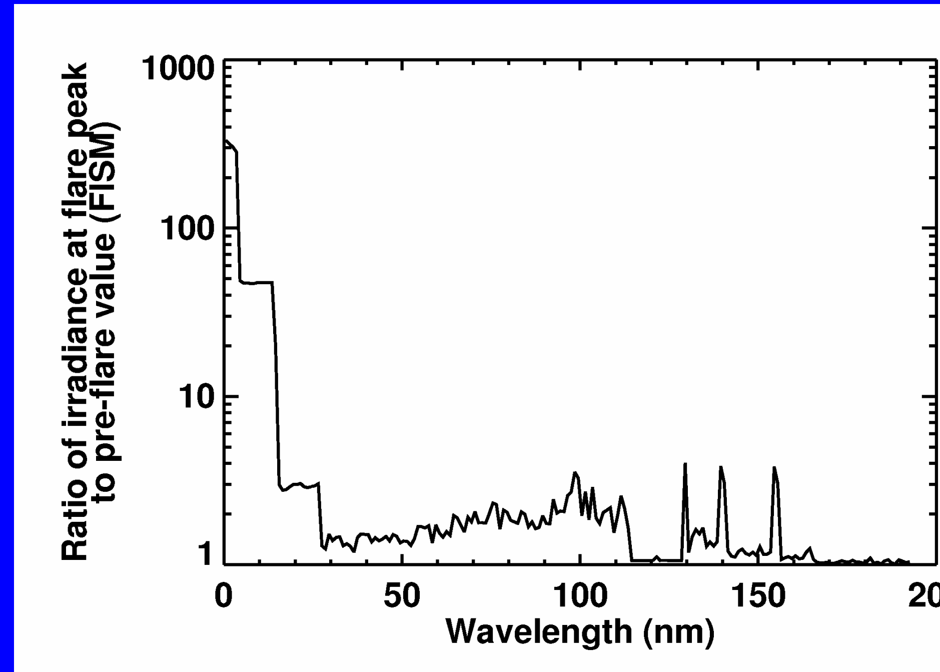
- Neutral atmosphere derived from Bougher MTGCM model
- Absorption and ionization cross-sections from Schunk and Nagy Ionospheres book (λ > 5 nm) and theoretical models of Verner (λ < 5 nm)
- Reaction rates from Schunk and Nagy Ionospheres book
- Secondary ionization parameterized as function of altitude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

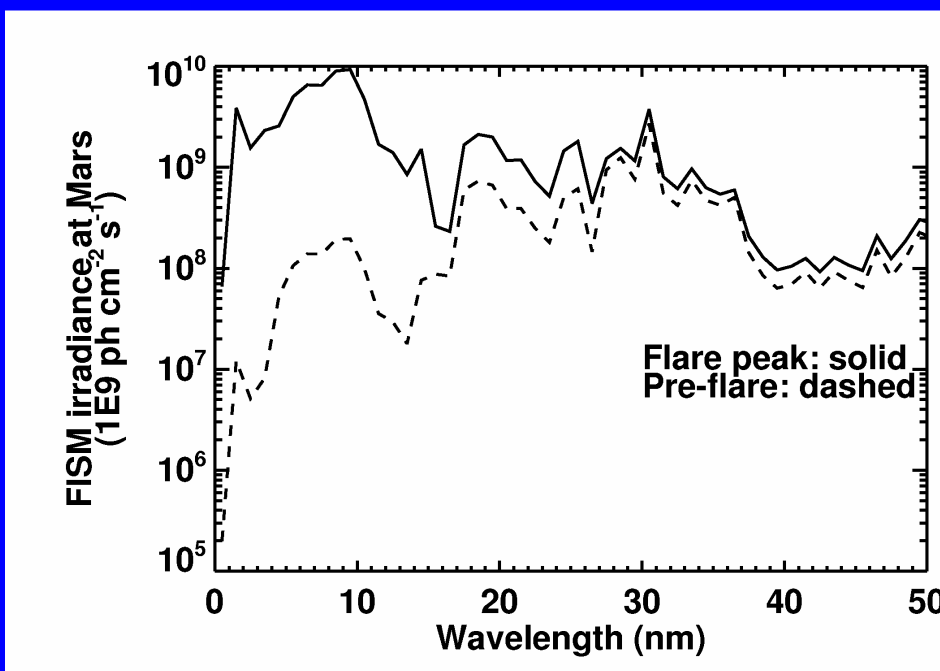


Solar Irradiances at Earth

- 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 (?)

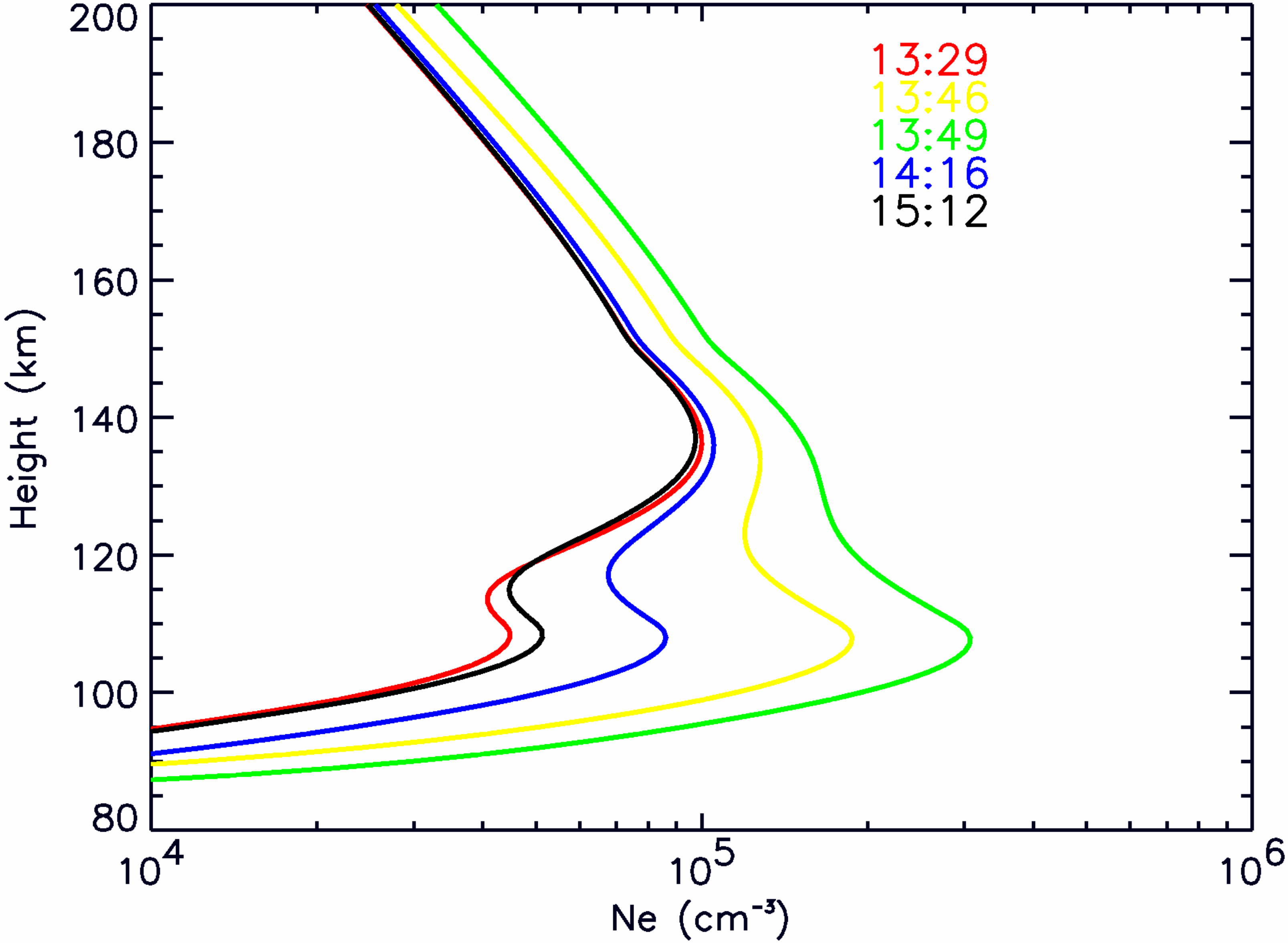




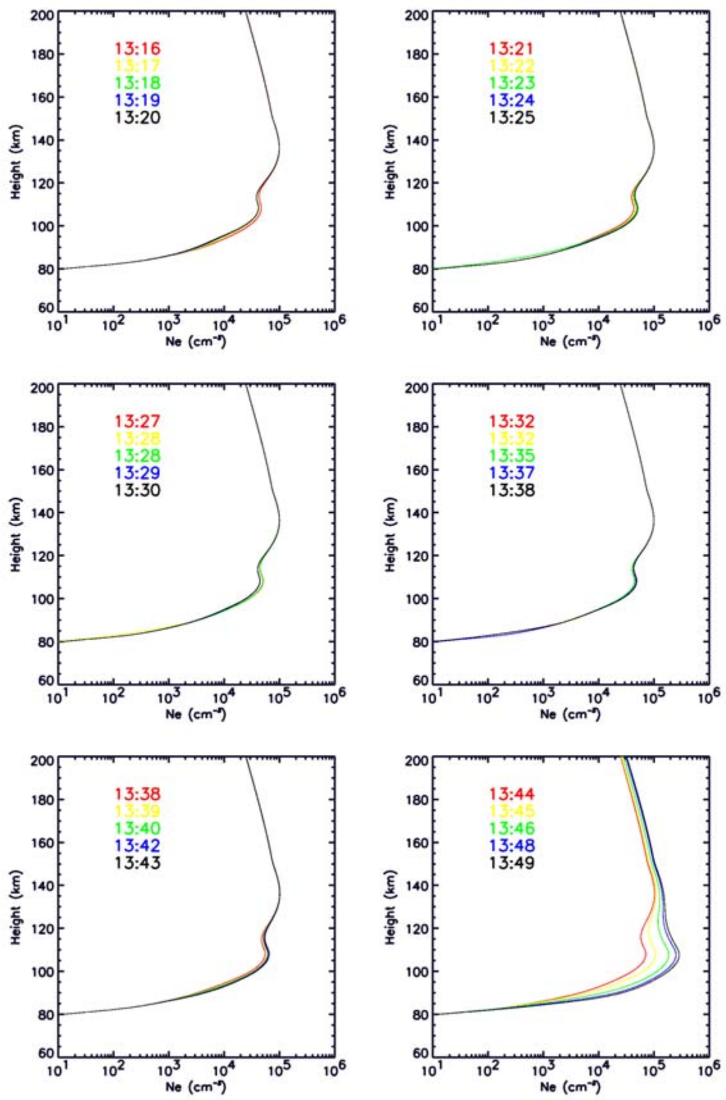


Time of flare-enhanced profile = 14:14 UTC, 8.7 hrs LST, 72 ^{o} SZA (84 ^{o}N)

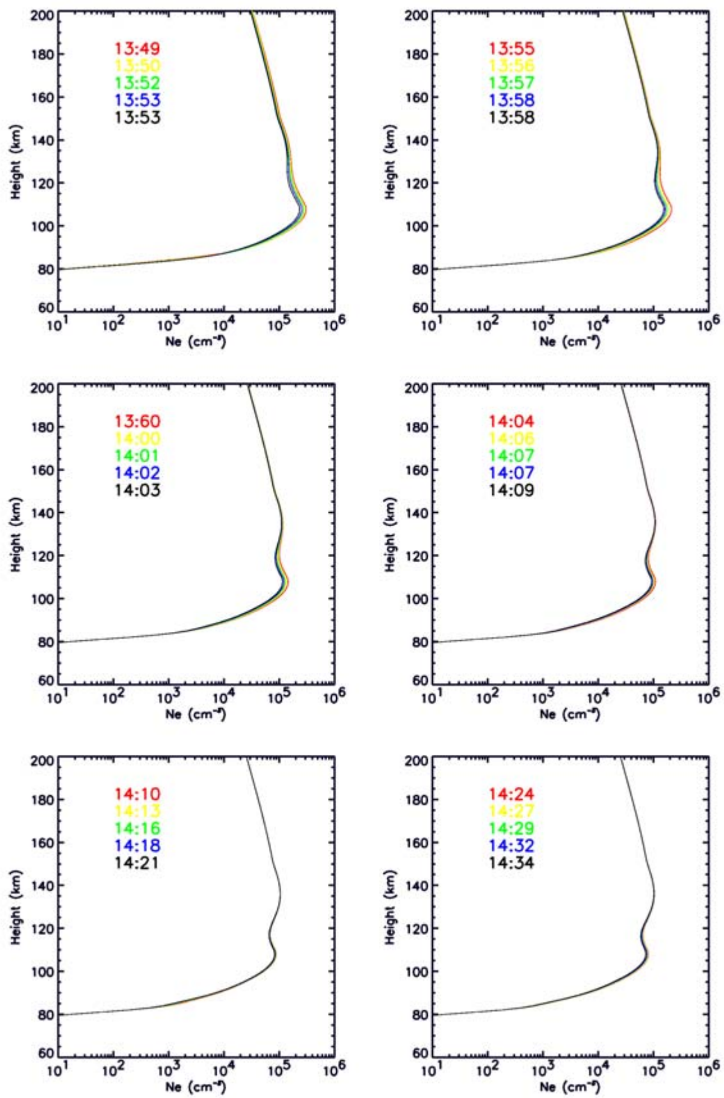
SZA = 71^{o} 1 hr earlier and 73^{o} 1 hr later – very small changes in Ne(z) due to this


13:29
13:46
13:49
14:16
15:12
Height (km)
200
180
160
140
120
100
80
10^4
10^5
10^6
Ne (cm^{-3})

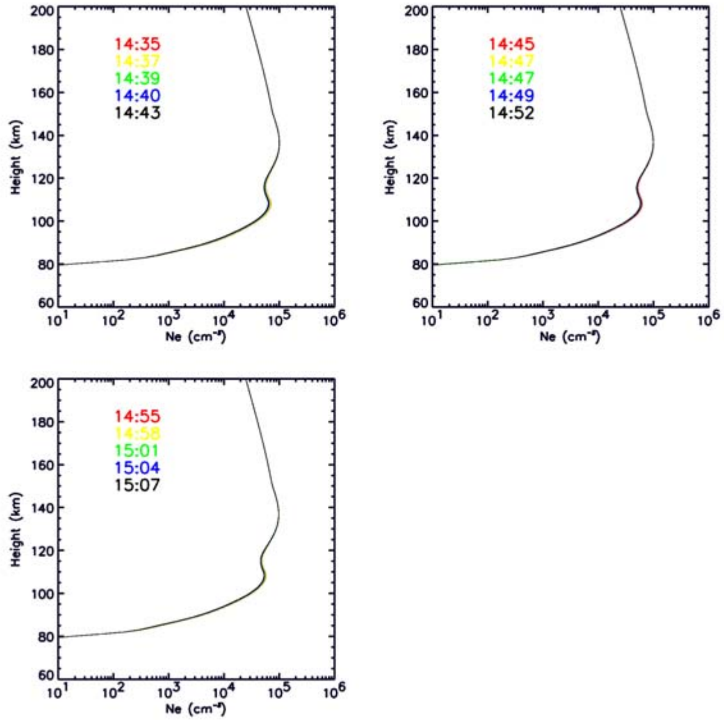
april15 S2k + FISM every ^ 1 min

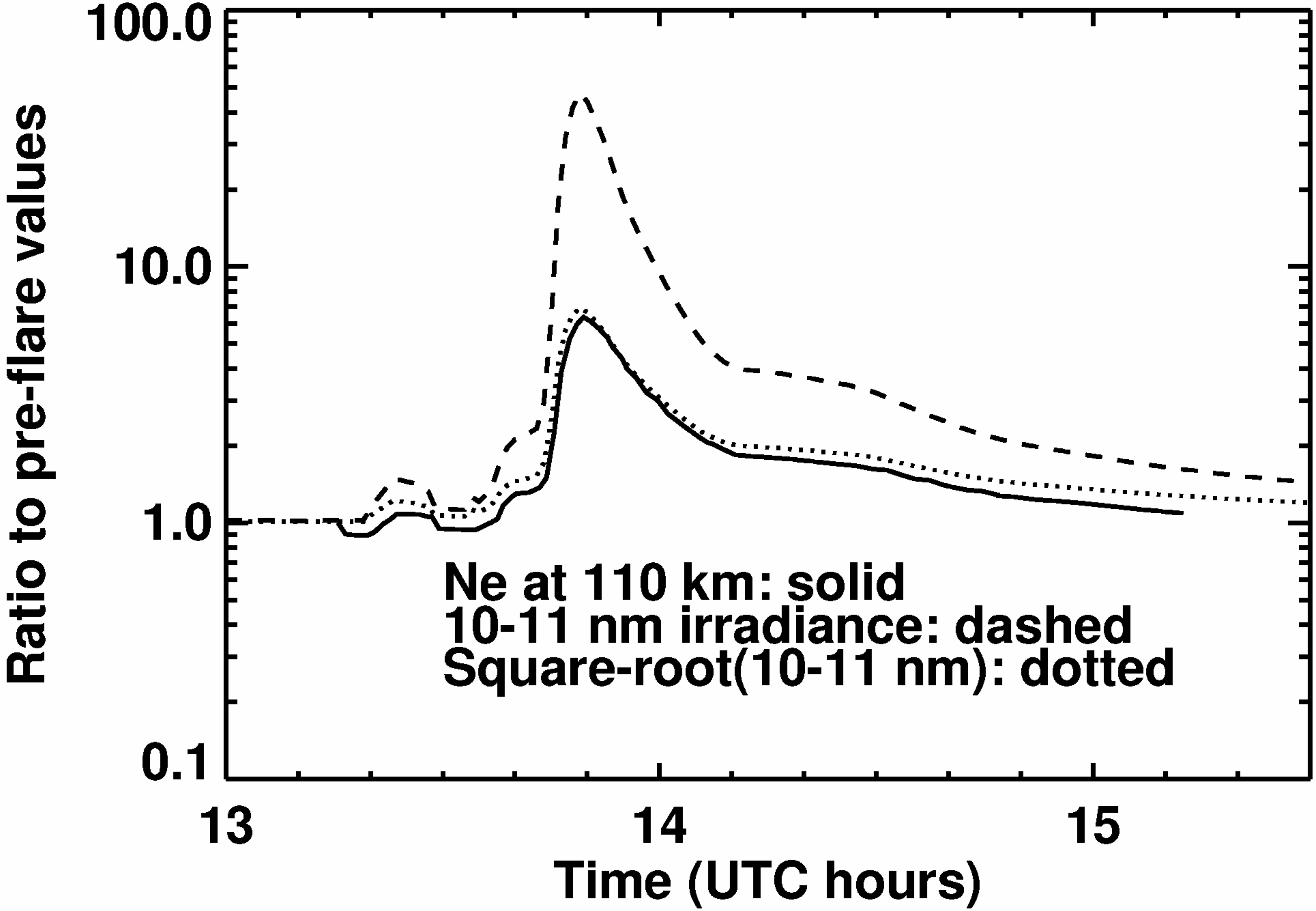


april15 S2k + FISM every ^ 1 min



april15 S2k + FISM every ^ 1 min




100.0
10.0
1.0
0.1
Ratio to pre-flare values
13
14
15
Time (UTC hours)
Ne at 110 km: solid
10-11 nm irradiance: dashed
Square-root(10-11 nm): dotted

Conclusions

- Observations show ionosphere responding to solar flares
- Photochemical model with time-varying solar flux can reproduce the basic characteristics of flare-affected profiles
- Secondary ionization parameterization is important
- Detailed comparisons between data and models are planned