

Anomalous Ionospheric Profiles

Association of Anomalous Profiles and Magnetic Fields

The Effects of Solar Flares on Earth and Mars

Examples of the Response of the Mars Ionosphere to Solar Flares

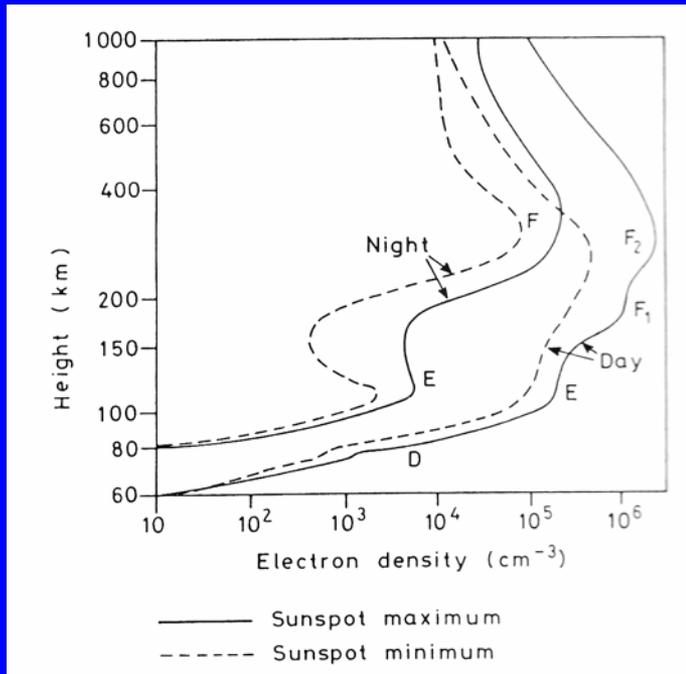
Implications for Radio Propagation

Ionospheric disturbances at Mars: Implications for radio propagation

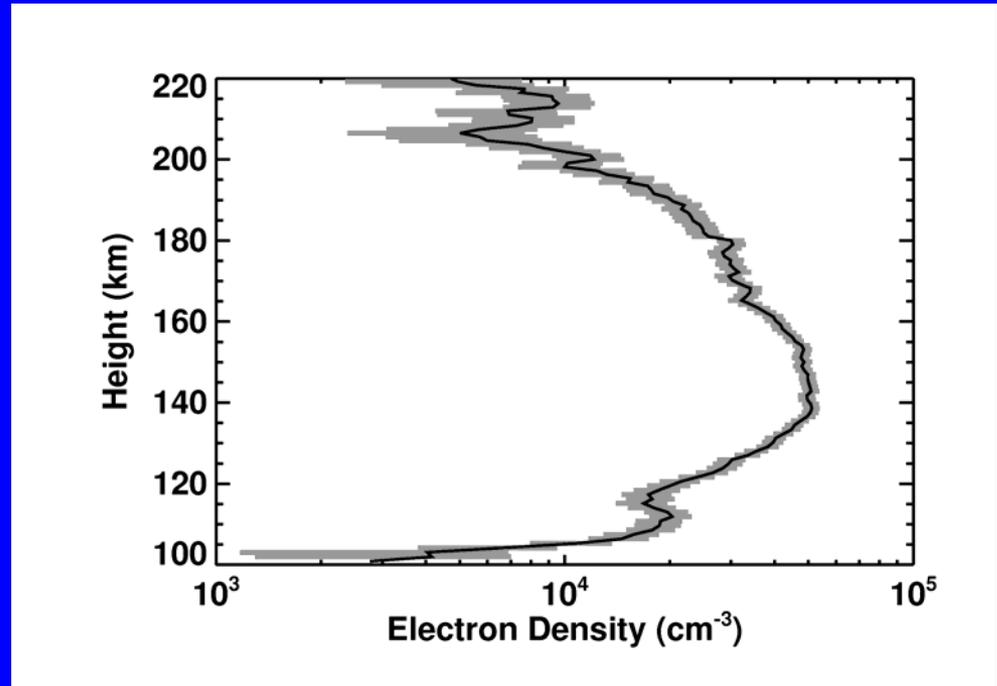
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EGU Meeting 2006, Vienna, Austria

Typical Ionospheric Profiles



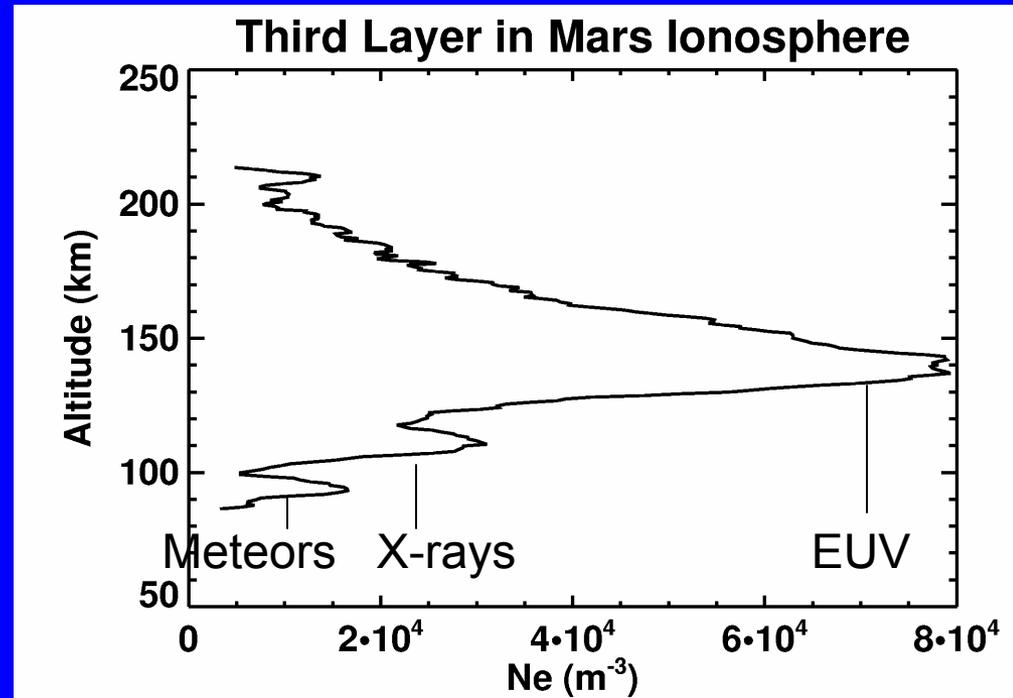
Earth (Hargreaves, 1992)
F layer due to EUV photons
E layer due to soft X-rays
D layer due to hard X-rays
Soft ~ 10 nm, hard ~ 1 nm



Mars (MGS RS data)
Main peak at 150 km due to EUV photons
Lower peak at 110 km due to X-rays. Lower peak is very variable and often absent

Ionospheric Disturbances at Mars

- Localized depletions and enhancements are seen above regions of strong crustal magnetic fields. These strong gradients could seed plasma instabilities that cause fluctuations in communication signals.
- Solar flares enhance electron density below ~110 km. Increases at 60 km due to hard X-rays will cause “D-layer absorption” of radio signals.

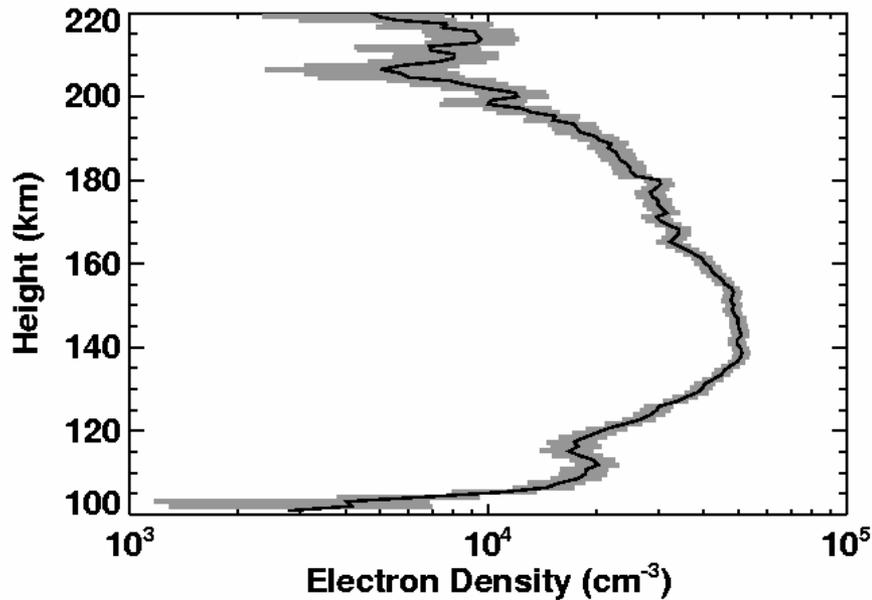


Meteors cause ionization around 80 km. These localized events could also seed plasma instabilities.

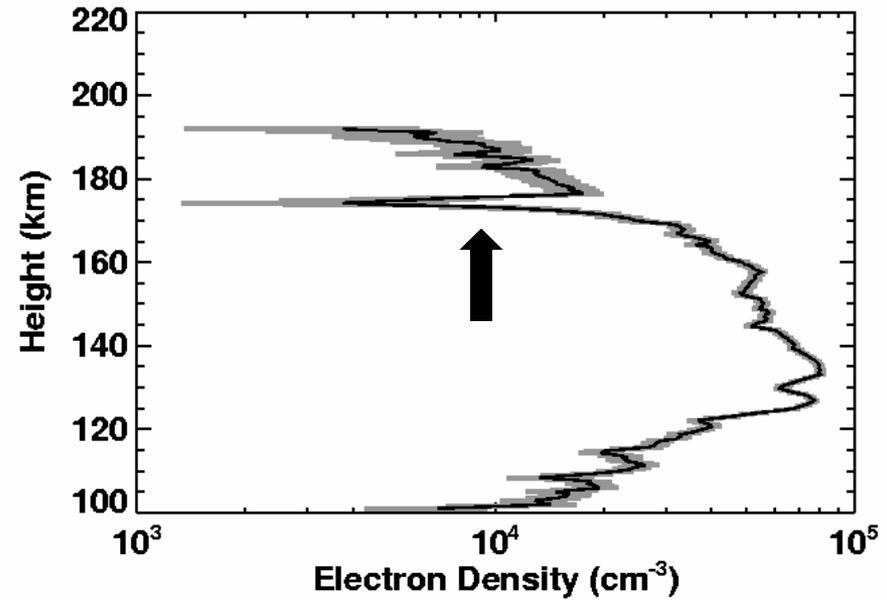
Planetary Properties at Ionospheric Peak

	Venus	Earth E-region	Mars
g (m s ⁻²)	8.9	9.8	3.7
Solar distance (AU)	0.7	1.0	1.4 – 1.7
z _{peak} (km)	140	110	120
Neutrals	CO ₂	N ₂ , O ₂	CO ₂
Ions	O ₂ ⁺	O ₂ ⁺ , NO ⁺	O ₂ ⁺
Production process	CO ₂ +hv → CO ₂ ⁺ + e CO ₂ ⁺ +O → CO + O ₂ ⁺	N ₂ +hv → N ₂ ⁺ + e N ₂ ⁺ + O → N + NO ⁺ O ₂ +hv → O ₂ ⁺ + e	CO ₂ +hv → CO ₂ ⁺ + e CO ₂ ⁺ +O → CO + O ₂ ⁺
Loss process	Dissociative Recombination	DR	DR
N _n (cm ⁻³)	1 E 11	1 E 13	1 E 11
N _e (cm ⁻³)	7 E 5	1 E 4	2 E 5
T _n (K)	200	300	200
T _e (K)	1000	300 – but ~1000 at 150 km	200

Normal Profile



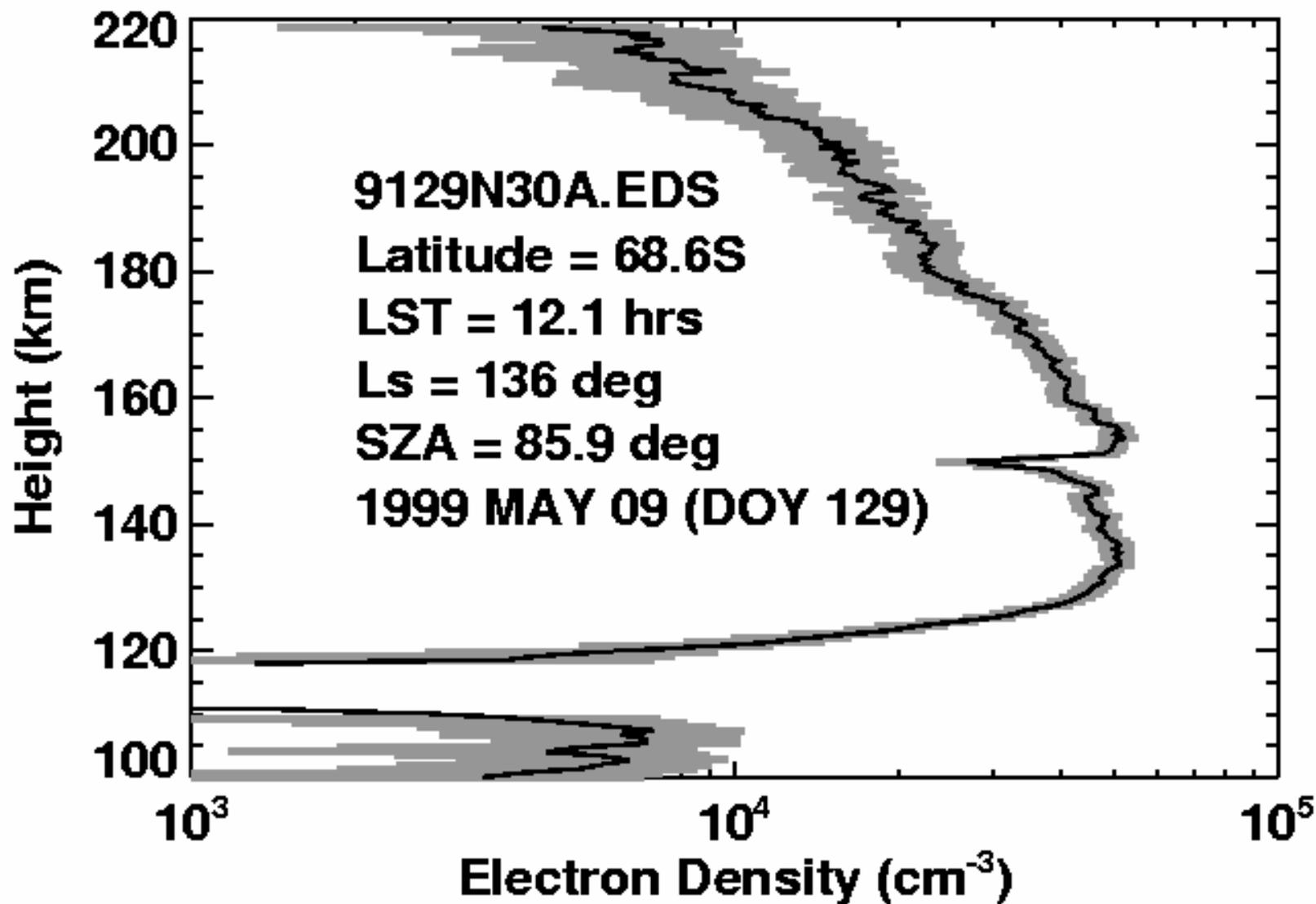
Anomalous Profile

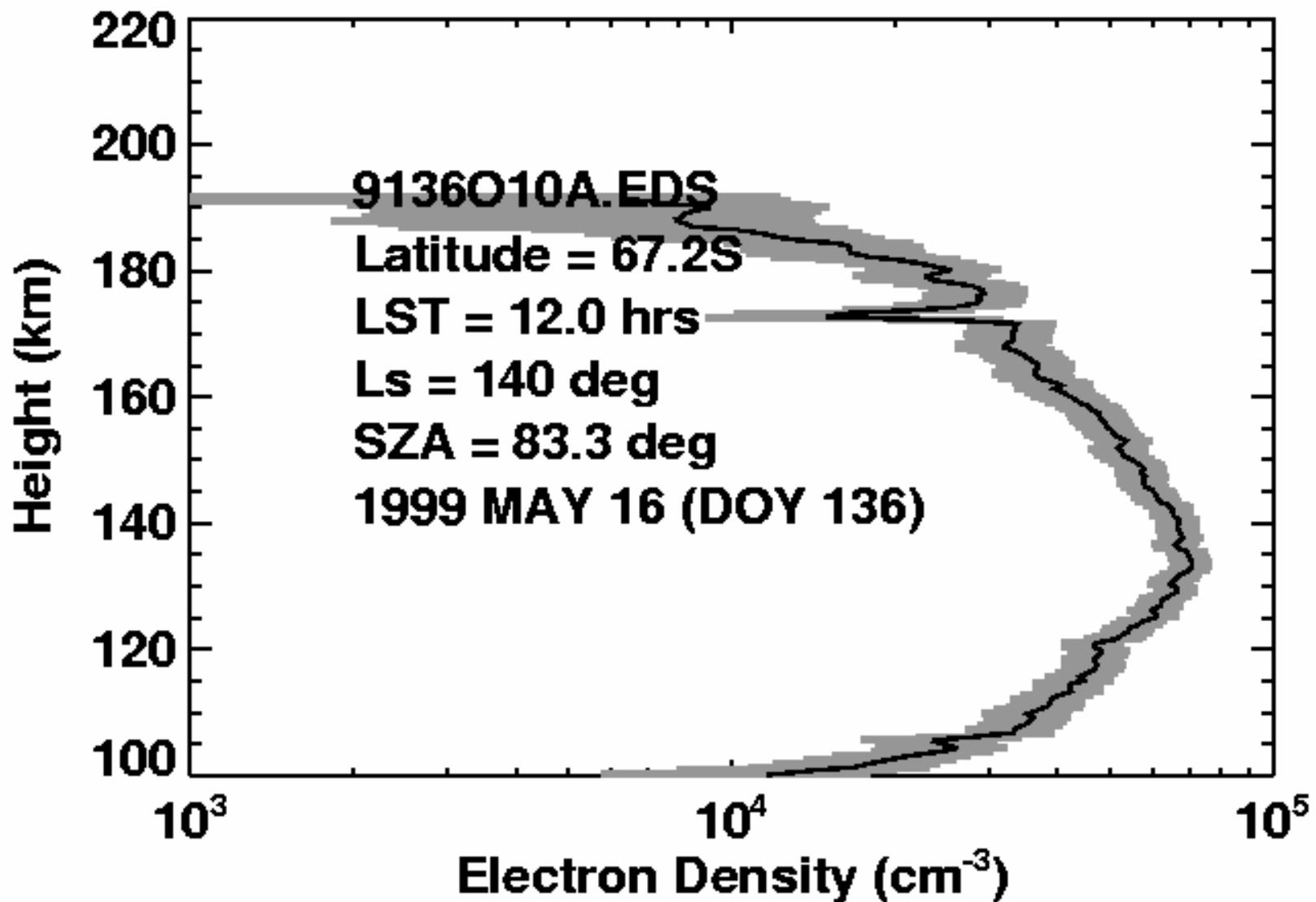


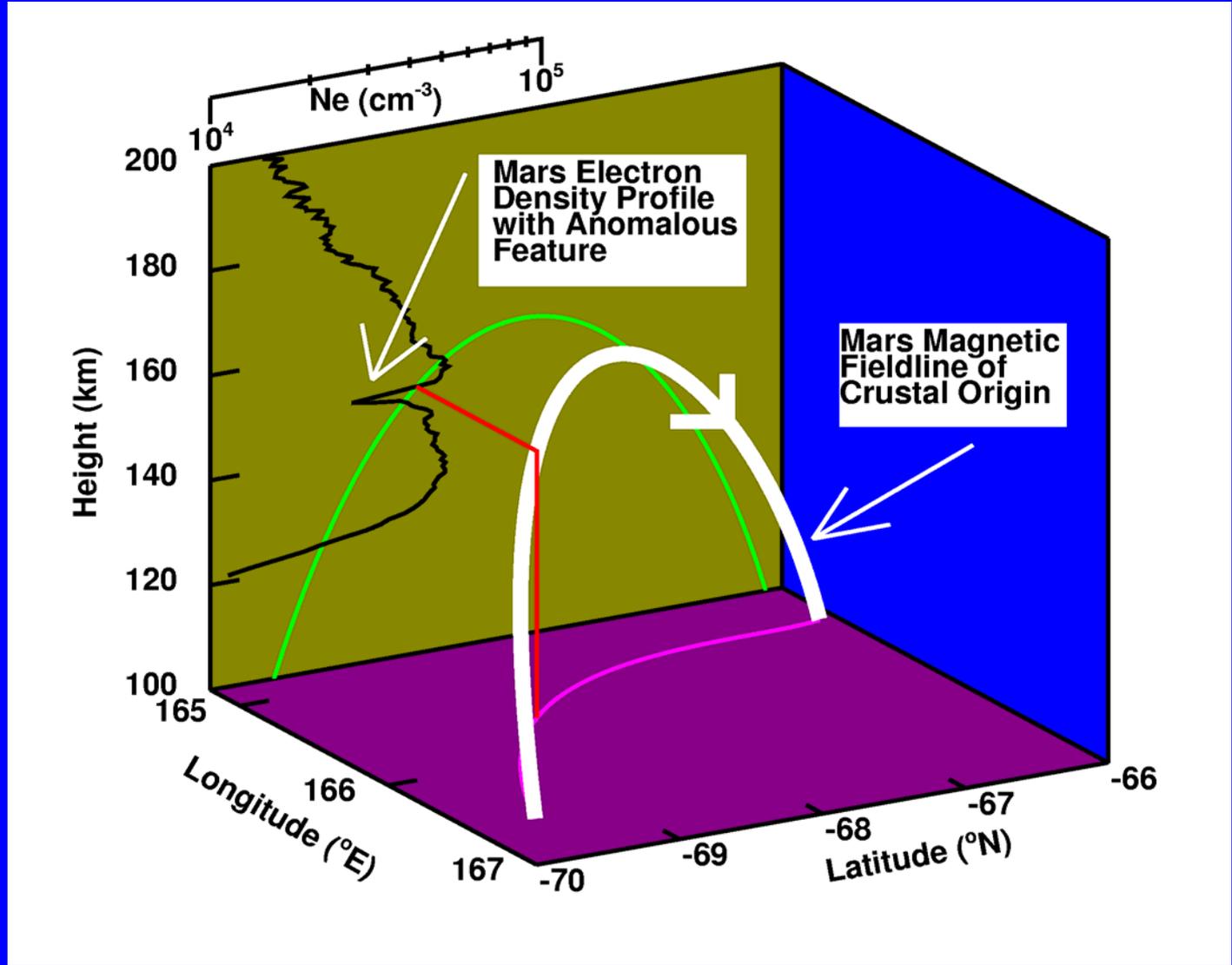
“Anomalous” defined as: $\max |dN_e/dz| / \max(N_e) > 1 / 6 \text{ km}$
Our aim is to identify profiles with large changes in N_e over a short distance. Other definitions are possible.

The horizontal measurement scale, $\sqrt{H R}$, is $\sim 200 \text{ km}$

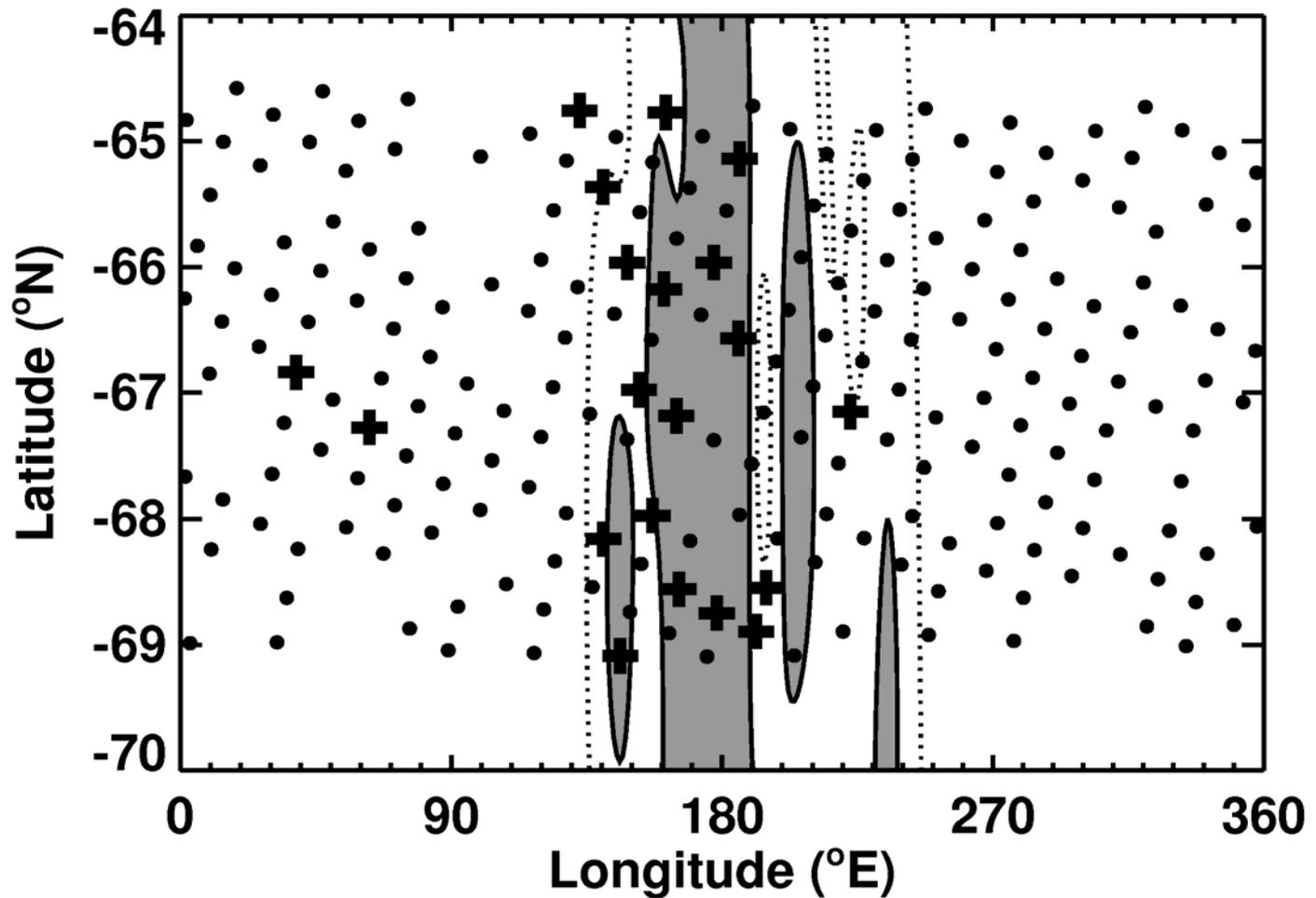
Two more examples of anomalous profiles are shown below.







Magnetic fieldline that passes through the height of the anomalous feature (150.5 km) in profile 9129N30A at the profile's latitude (68.6S) and longitude (165.6E). Magnetic fieldlines on Mars are very different from terrestrial dipolar fieldlines. In this example, the crest of the fieldline is only a scale height above the anomalous feature.



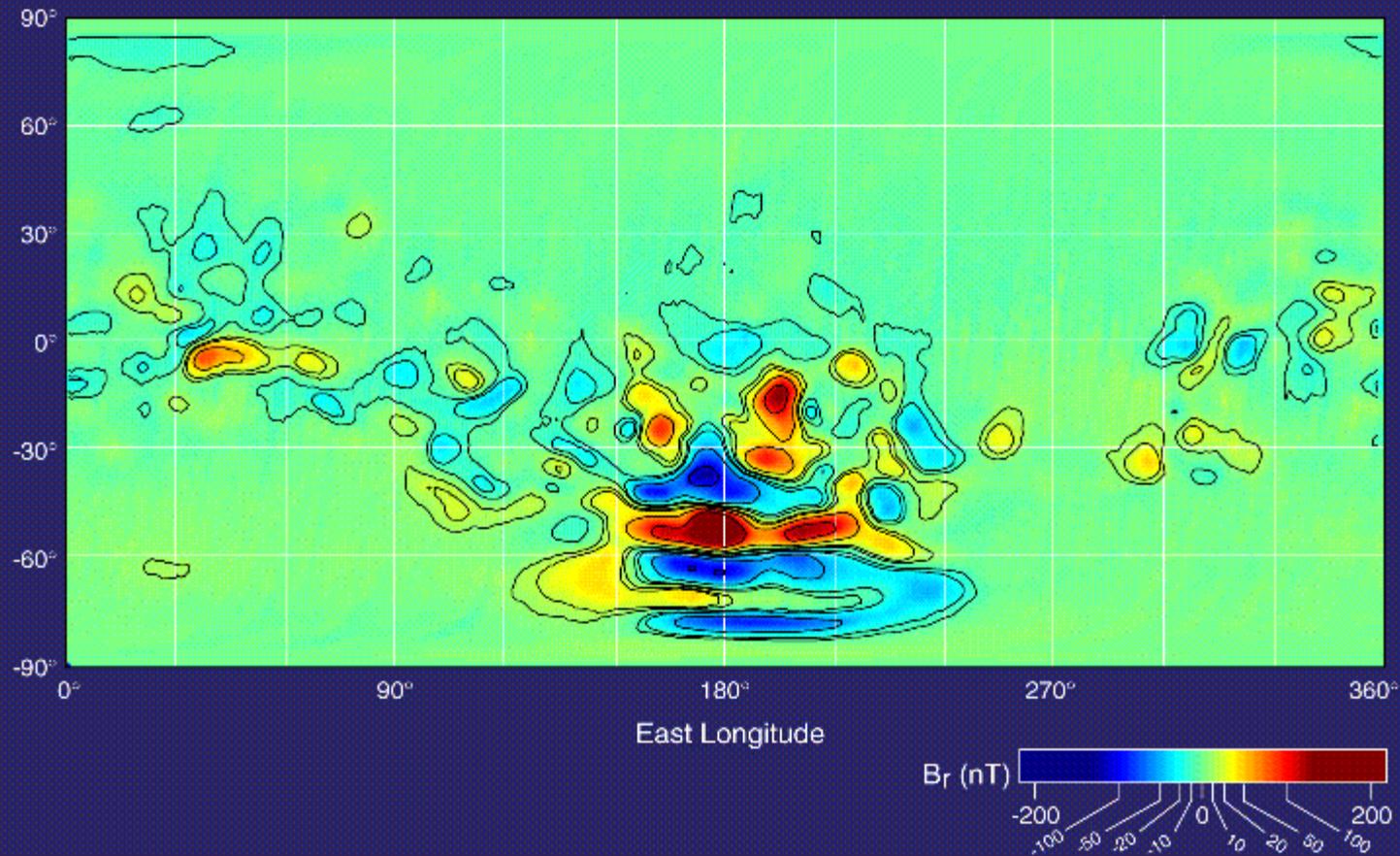
Anomalous MGS ionospheric profiles (crosses) and normal profiles (dots) from the Southern Hemisphere in 1999. The magnetic field at 150 km is shown by dotted contours at 100 nT and solid contours at 200 nT. Regions where the magnetic field is stronger than 200 nT are shaded.

Anomalous profiles are associated with strong magnetic fields.

Mars Crustal Magnetism

Mars Global Surveyor

MAG/ER

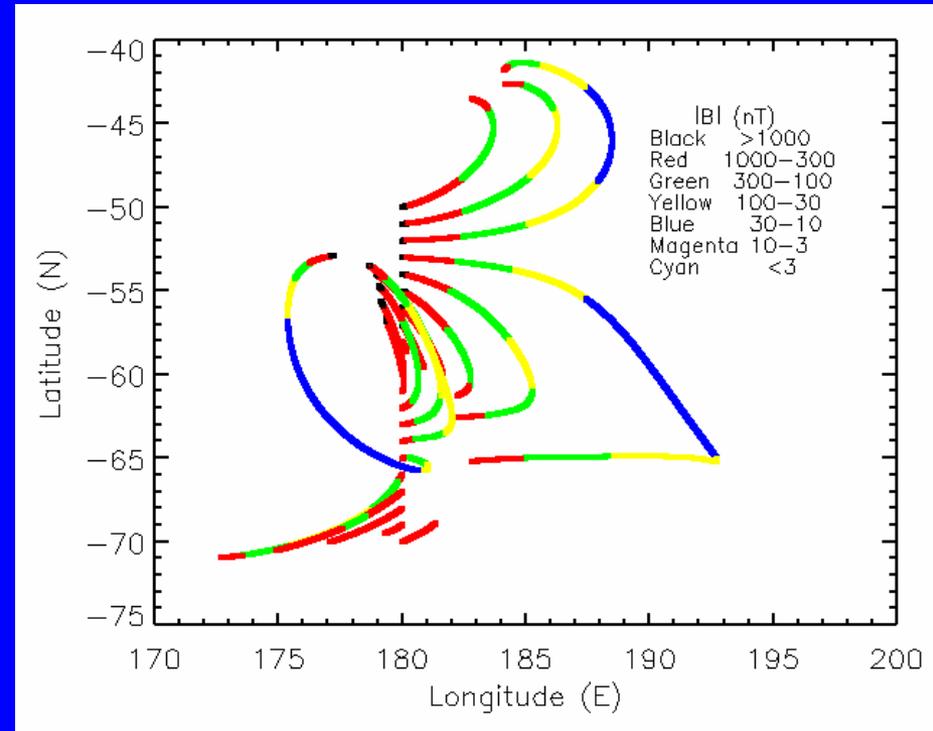
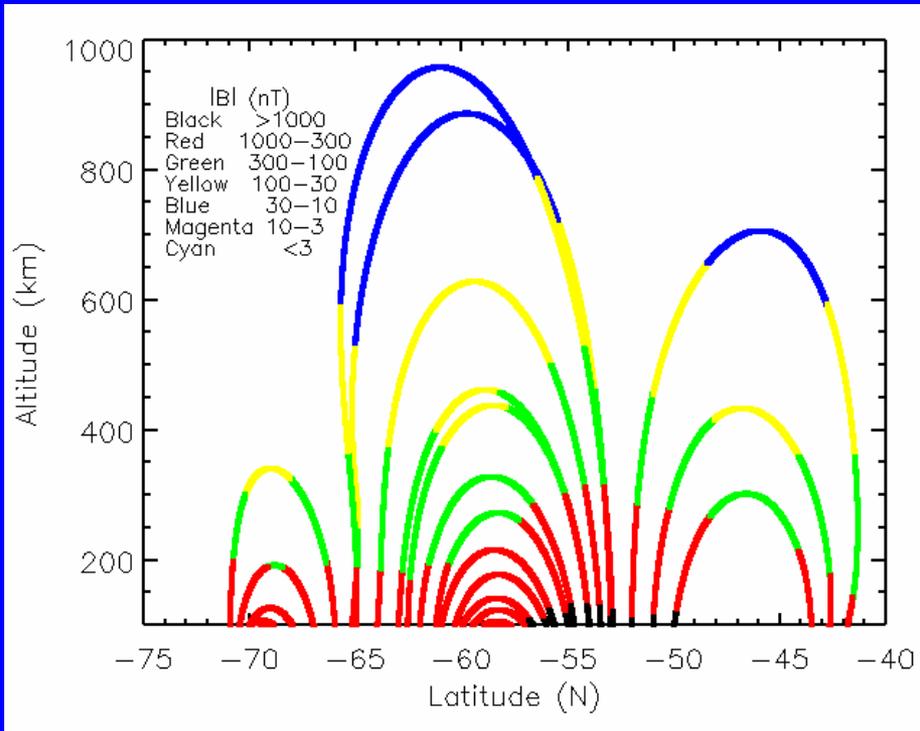


Connerney et al., *Geophys. Res. Lett.*, 28, 4015-4018, 2001.

ConJ2001187.001v

Map of the magnetic field of Mars at MGS mapping altitude of 400 (+/-30) km. The radial component of the magnetic field associated with crustal sources is illustrated using the color scale shown. Isomagnetic contours are drawn for $B_r = \pm 10, 20, 50, 100, 200$ nT. **The martian magnetic field is not dipolar.**

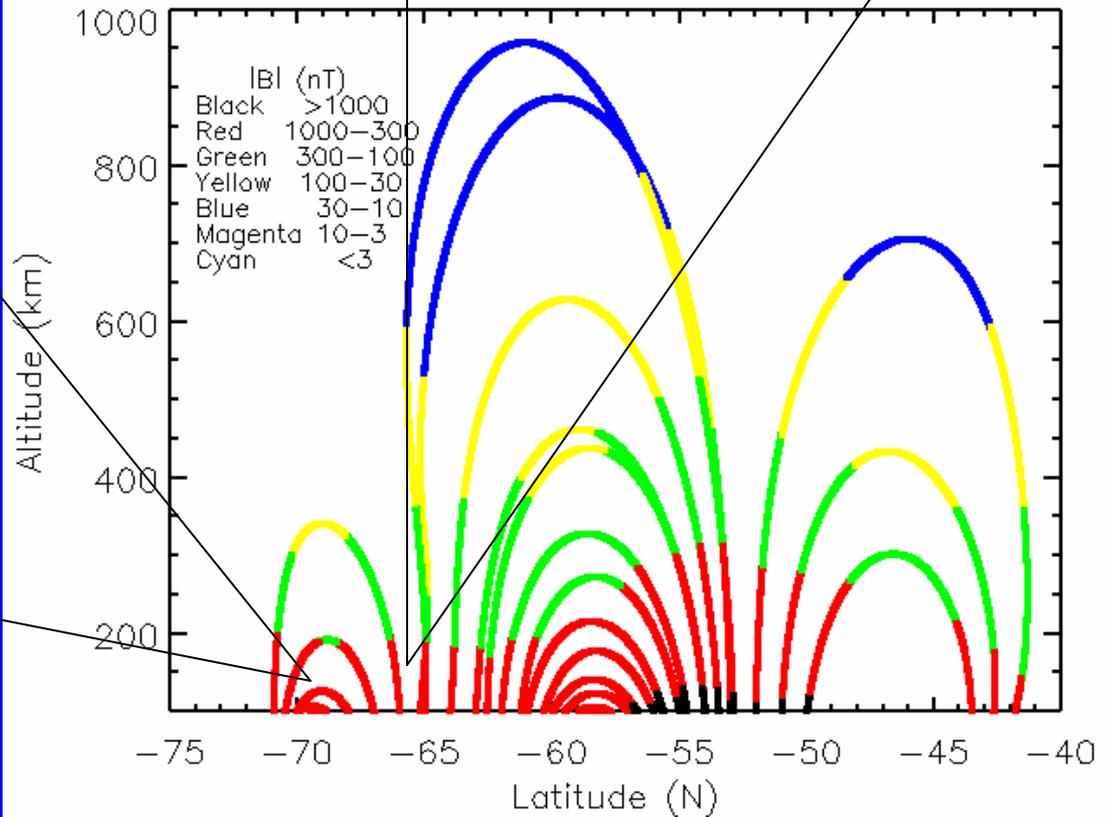
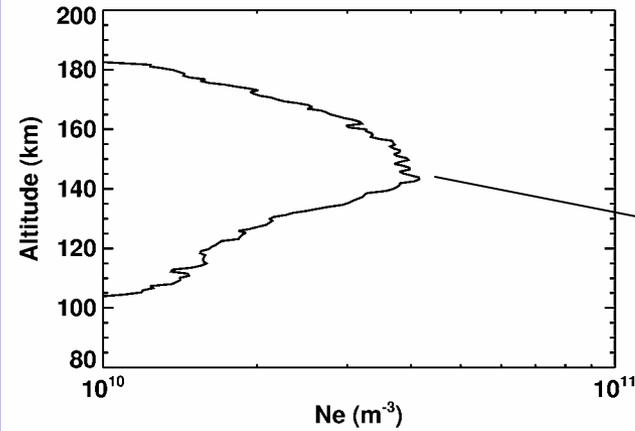
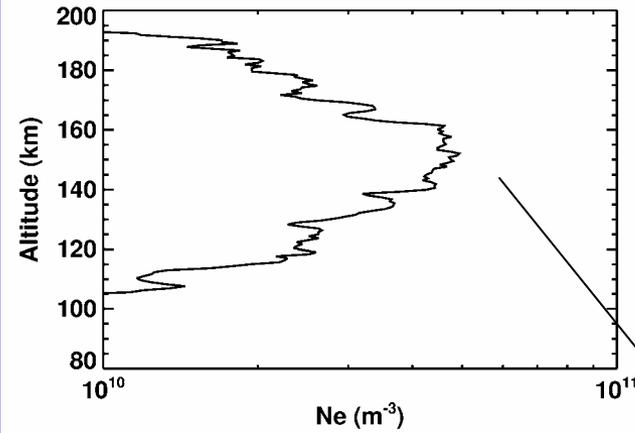
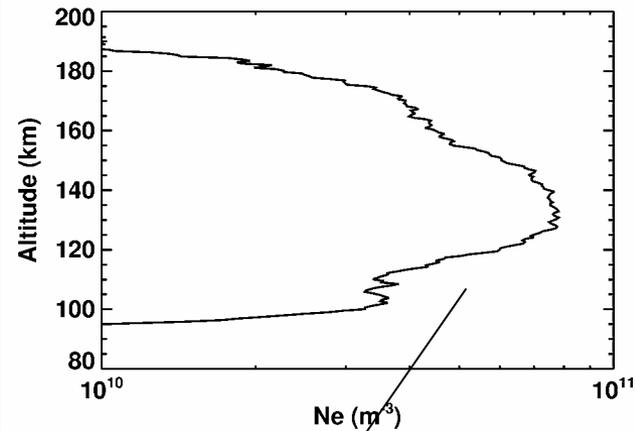
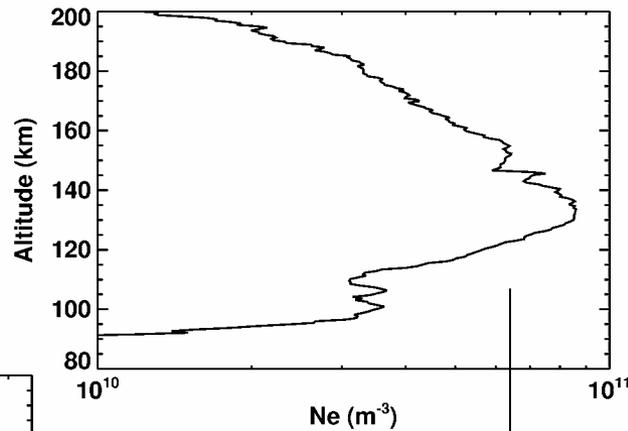
Magnetic Field Geometry



- Regions with vertical fieldlines (cusp-like) are close to regions with horizontal fieldlines (equator-like). The magnetic field geometry and strength change over very short distances.
- Note that the solar wind magnetic field is neglected in this model

Mars Ionosphere Variability

MGS Ne(h) profiles over crustal B-fields using Arkani-Hamed model



Solar Flares

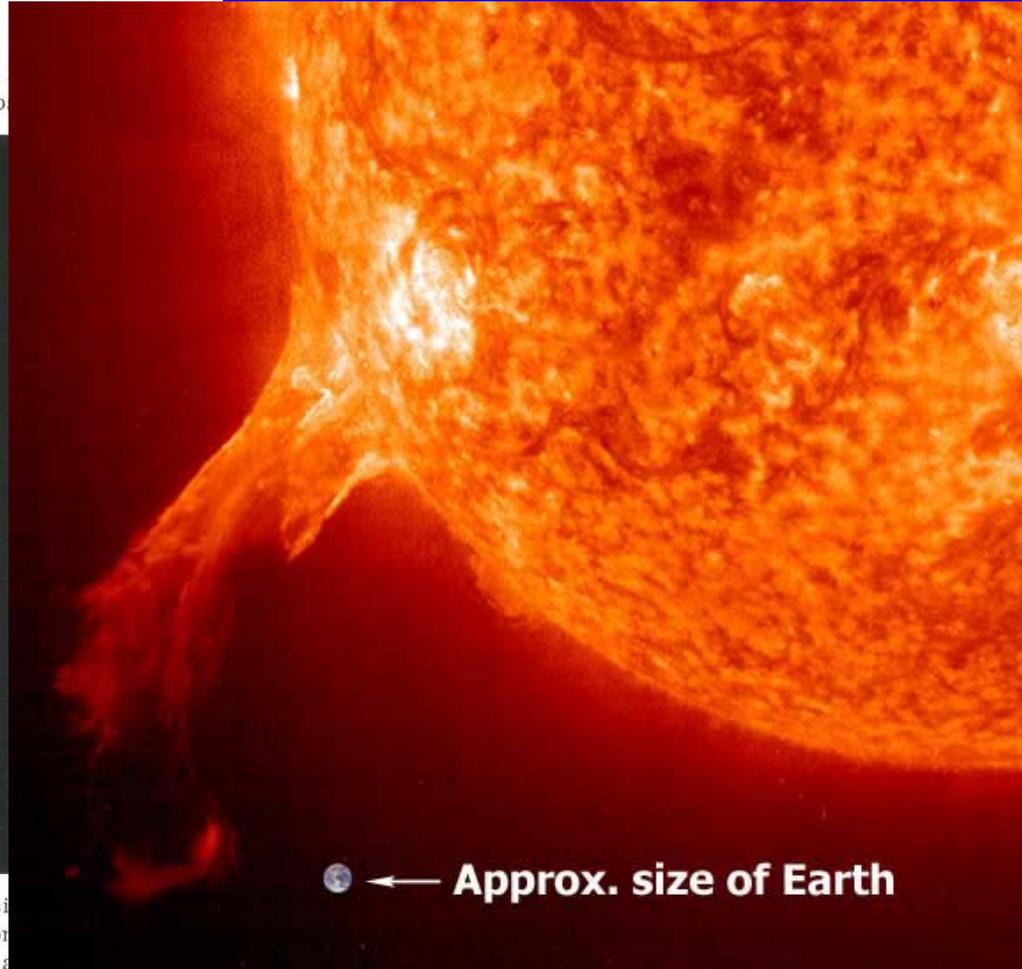
*SOLAR FLARE PHOTOGRAPHED AT BOYDEN OBSERVATORY
ON THE 11TH AUGUST 1972, AT 14h44m SAST*

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



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

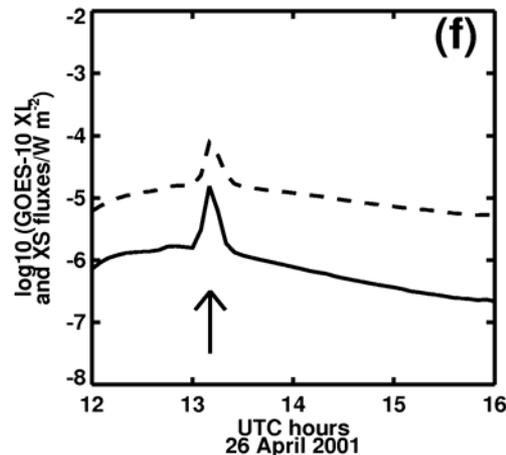
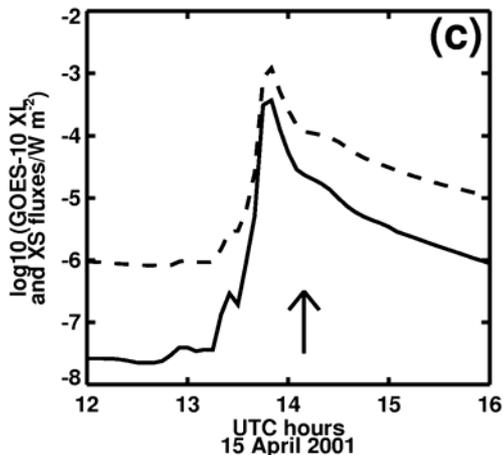
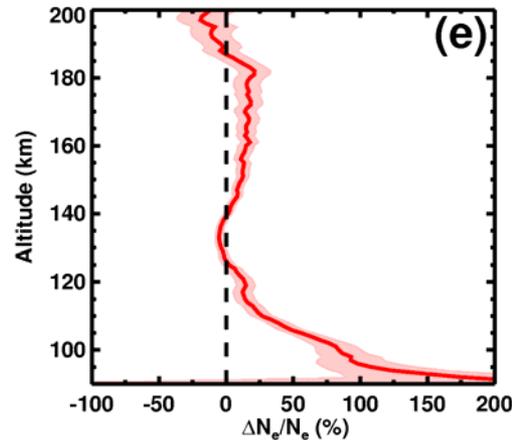
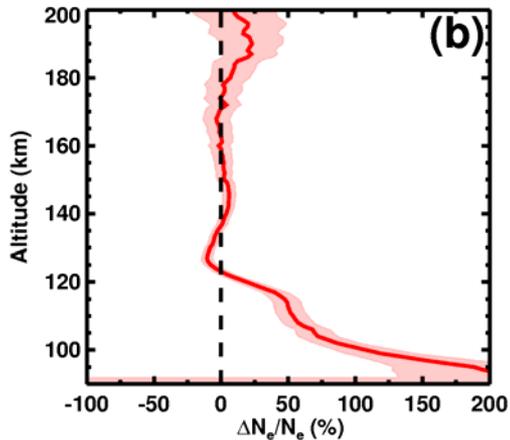
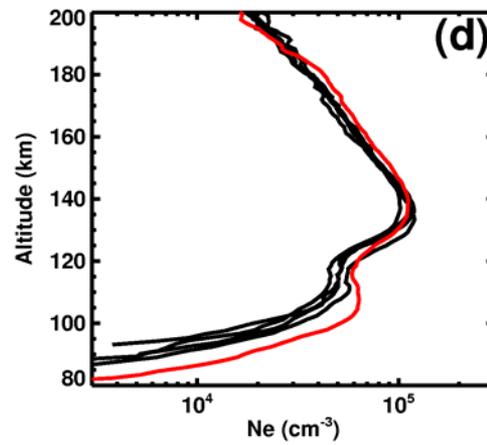
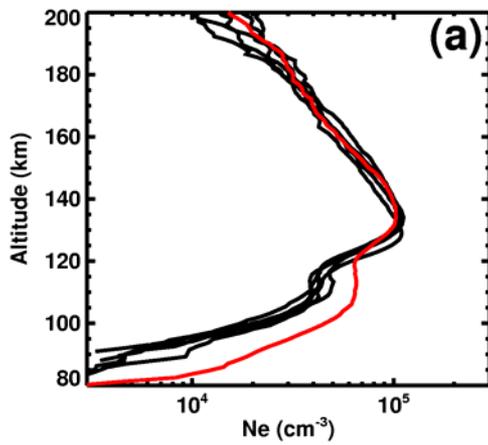
A Fabry-Perot interferometer was placed between the filters and the camera to investigate the temperature distribution in the flare from measurements of the fringe halfwidths - some of the halfwidths are shown in the photograph to the left of the flare. (The photograph has been processed to emphasize the flare itself rather than the fringes which cross it).



← **Approx. size of Earth**

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

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



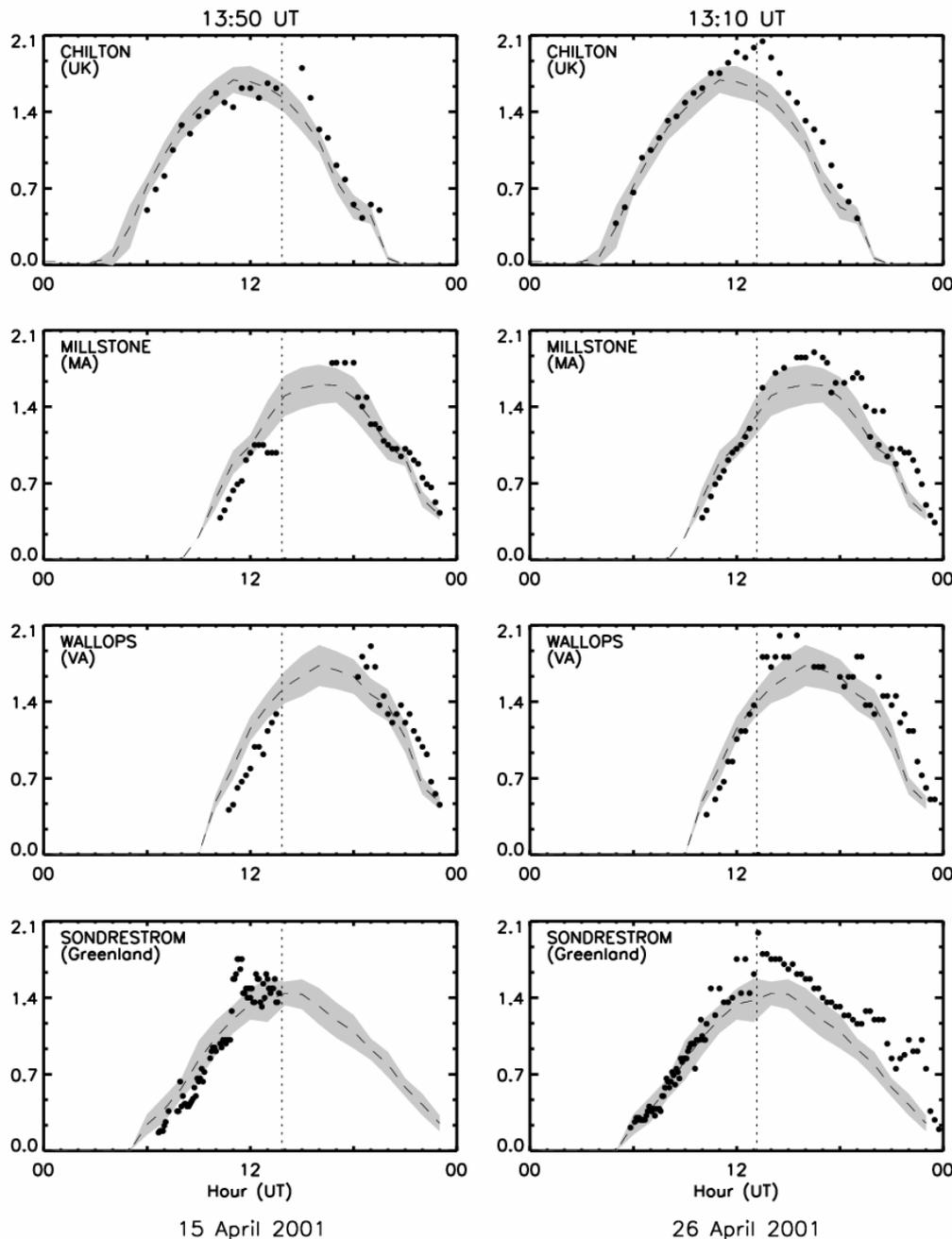
(a) MGS RS electron density profiles from 15 April 2001. Electron densities are enhanced at low altitudes for one profile, marked in red.

(b) Percentage difference between the red, enhanced profile and the mean of the black, non-enhanced profiles

(c) X-ray fluxes at Earth on this day between 0.5-3 Å (solid, XS) and 1-8 Å (dashed, XL). Arrow marks observation time of enhanced profile. Data from GOES satellites

(d), (e), (f)
As (a), (b), (c) but for 26 April 2001

E-Layer Peak Density, N_mE ($\times 10^4 \text{cm}^{-3}$)



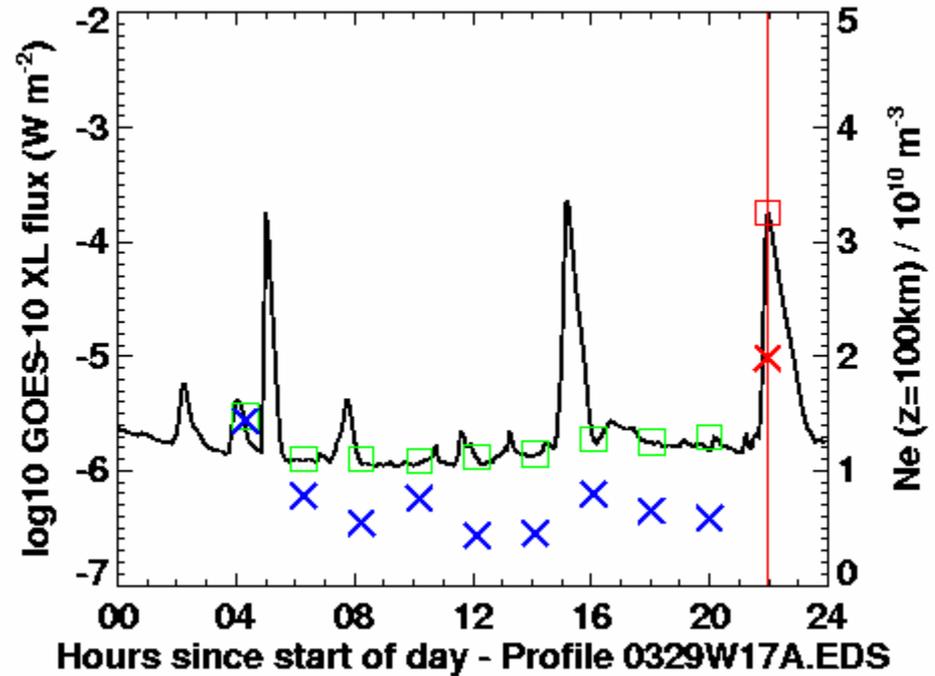
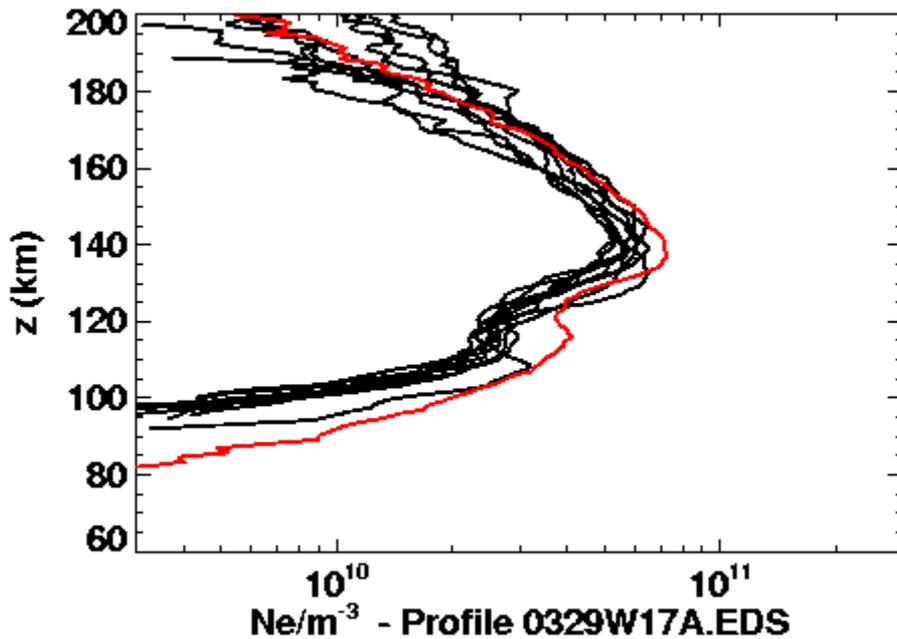
Measurements of the terrestrial ionosphere on 15 and 26 April 2001, left and right columns respectively. Dots are observations, dashed lines and shaded areas are average values for the month. Vertical lines show times of peak flare fluxes.

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.

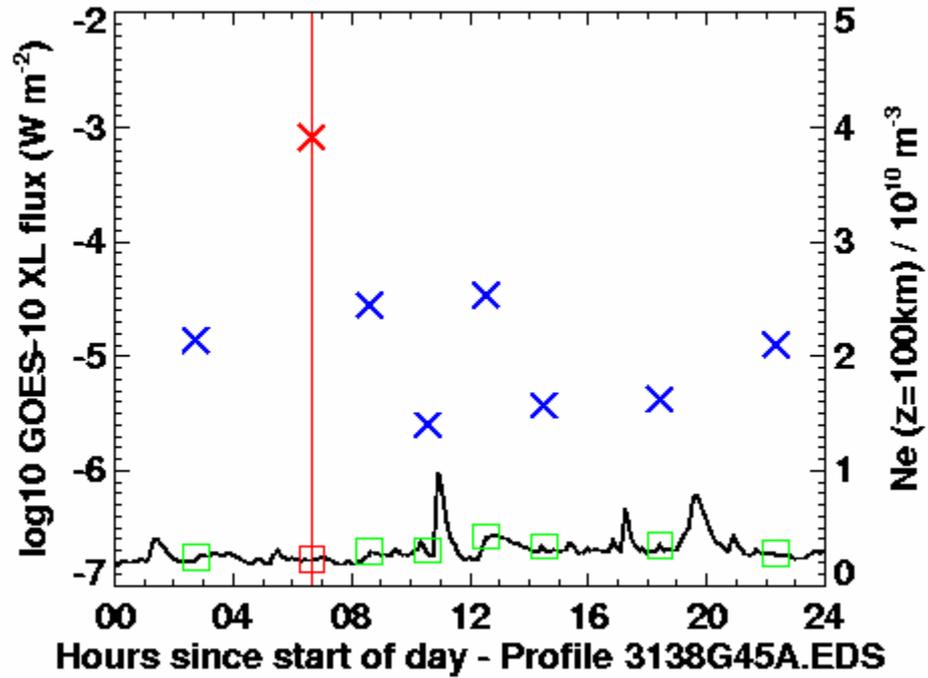
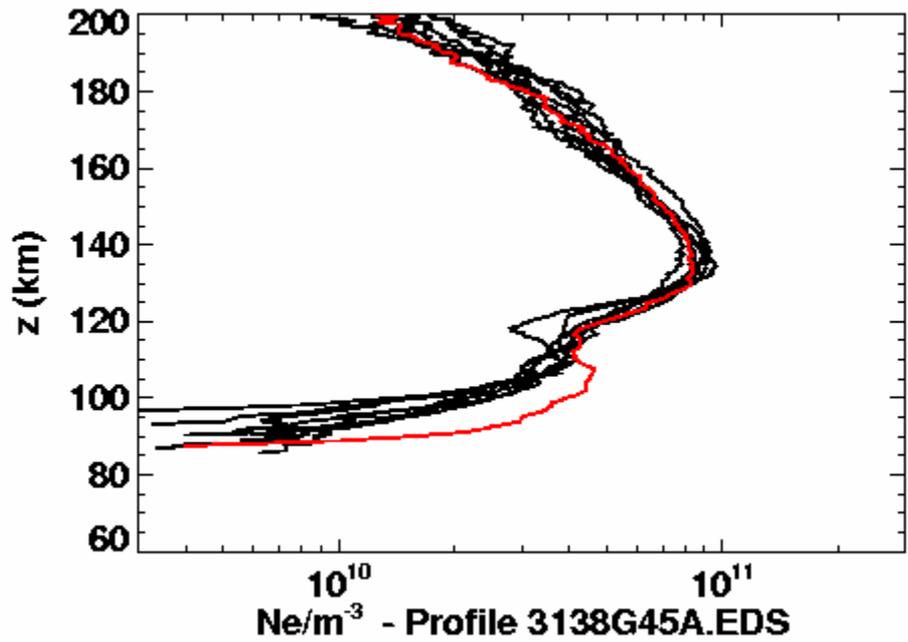


Left panel. Profile with enhanced electron density (red line) and other profiles from that day (black lines)

Right panel. GOES 1-8 A flux at Earth (black line), with values during occultations at Mars highlighted by green squares.

Blue crosses show electron density at 100 km. Red symbols indicate values from the red profile in the left panel.

Very clear enhancement in electron density below 120 km
Coincident with large increase in flux at Earth



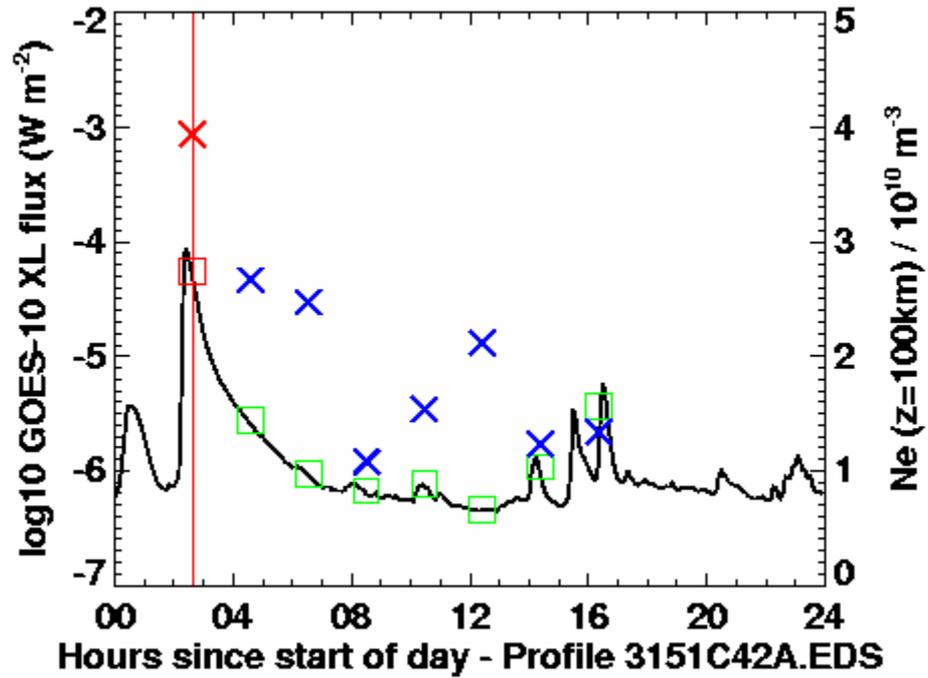
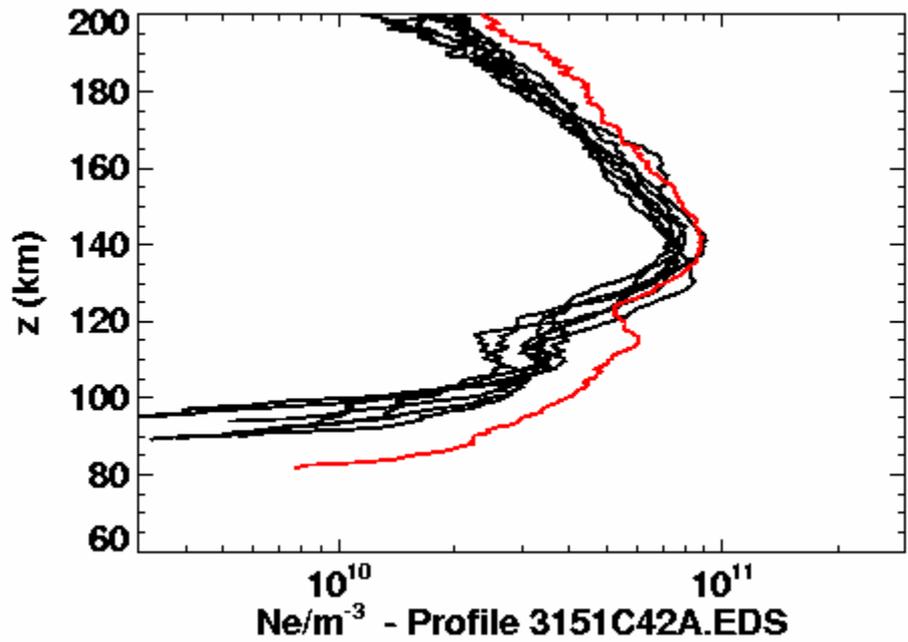
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Right panel. GOES 1-8 A flux at Earth (black line), with values during occultations at Mars highlighted by green squares.

Blue crosses show electron density at 100 km. Red symbols indicate values from the red profile in the left panel.

Clear enhancement in electron density below 110 km

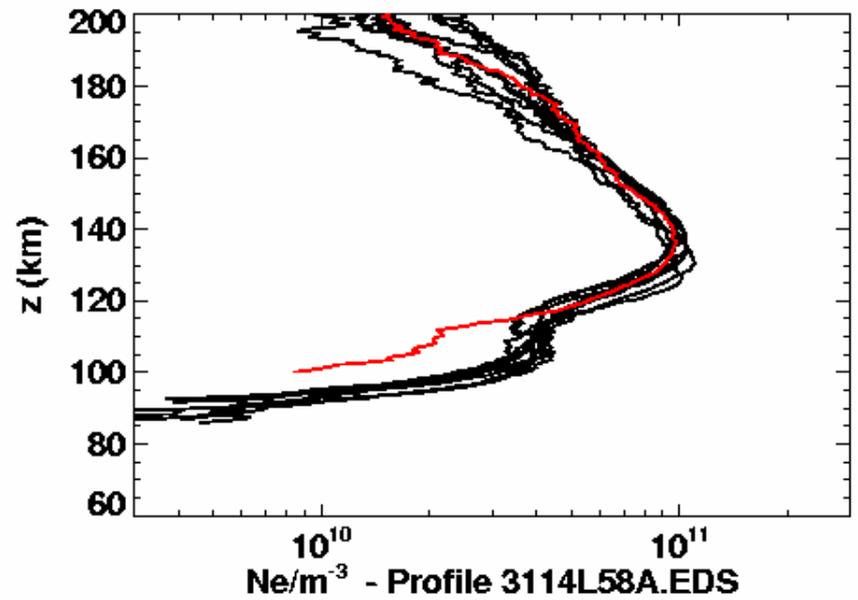
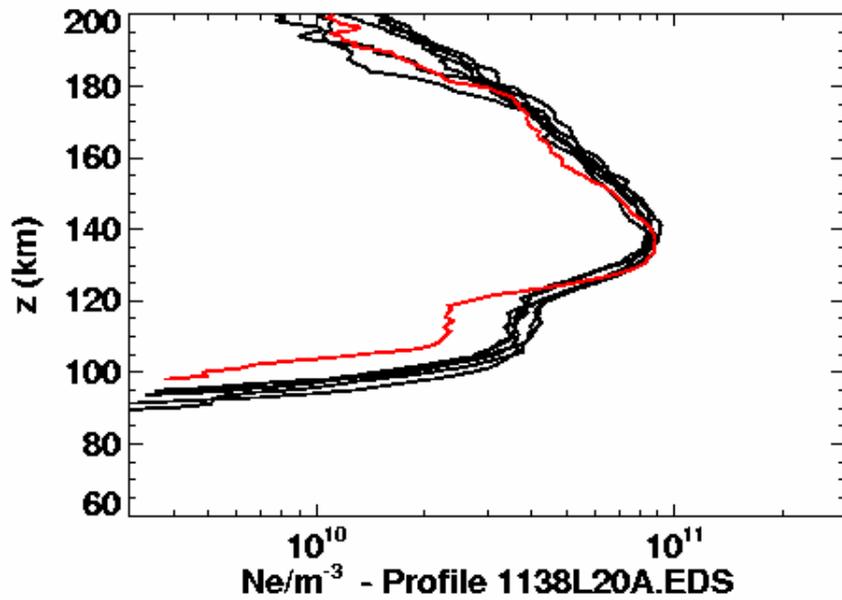
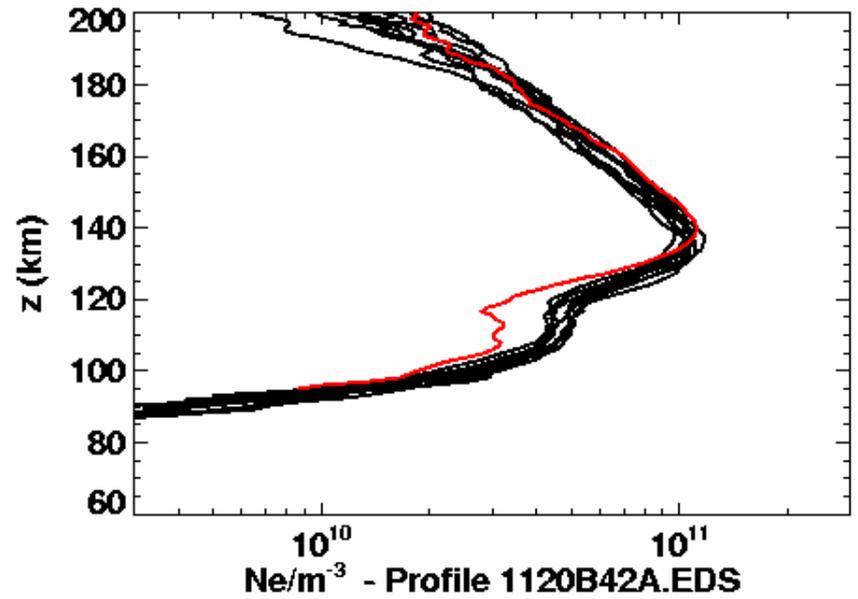
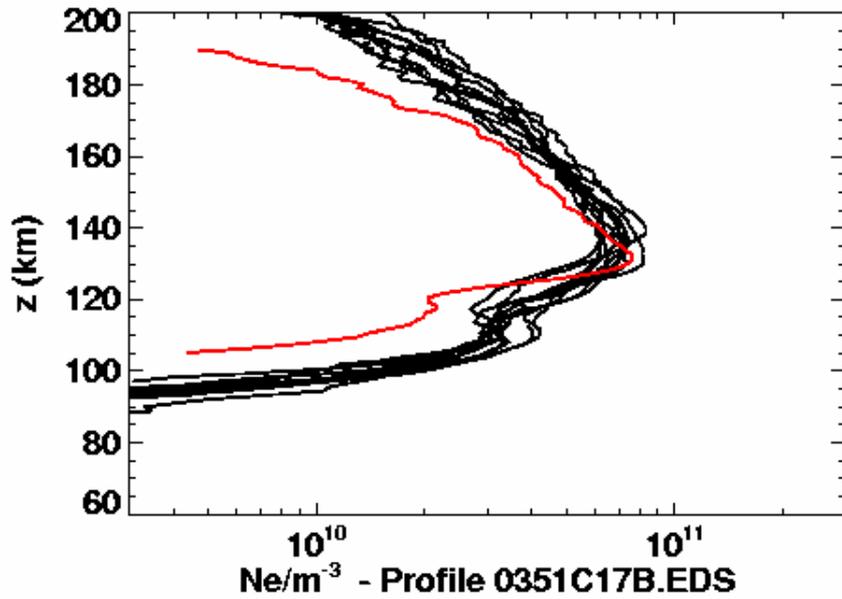
No increase in flux seen at Earth



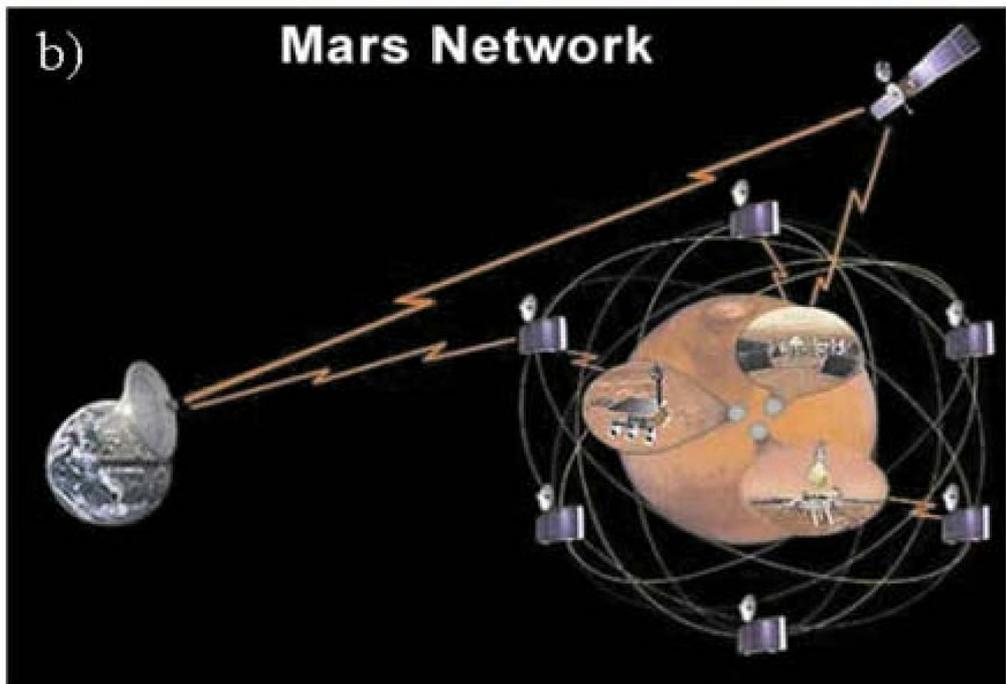
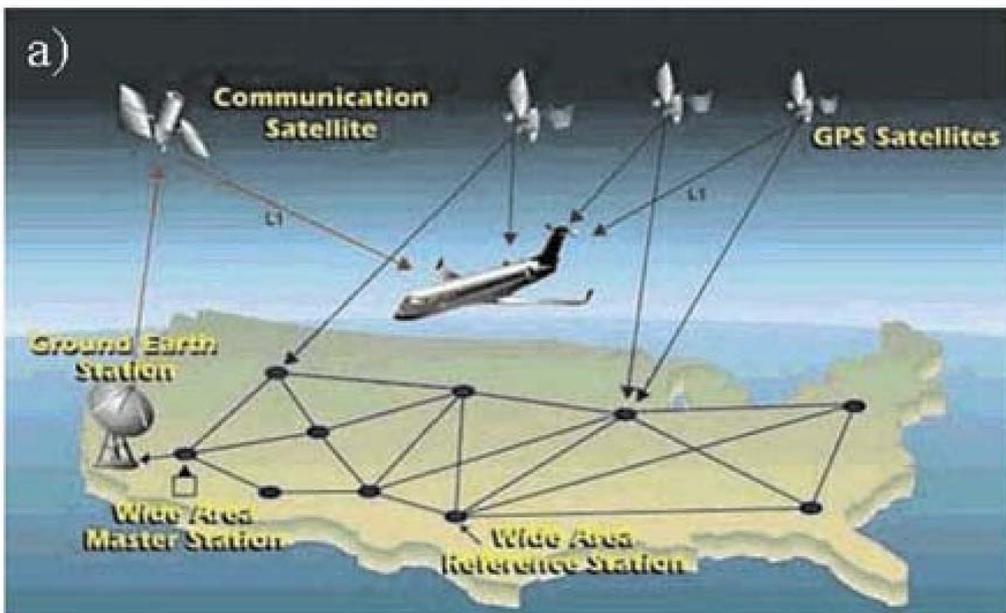
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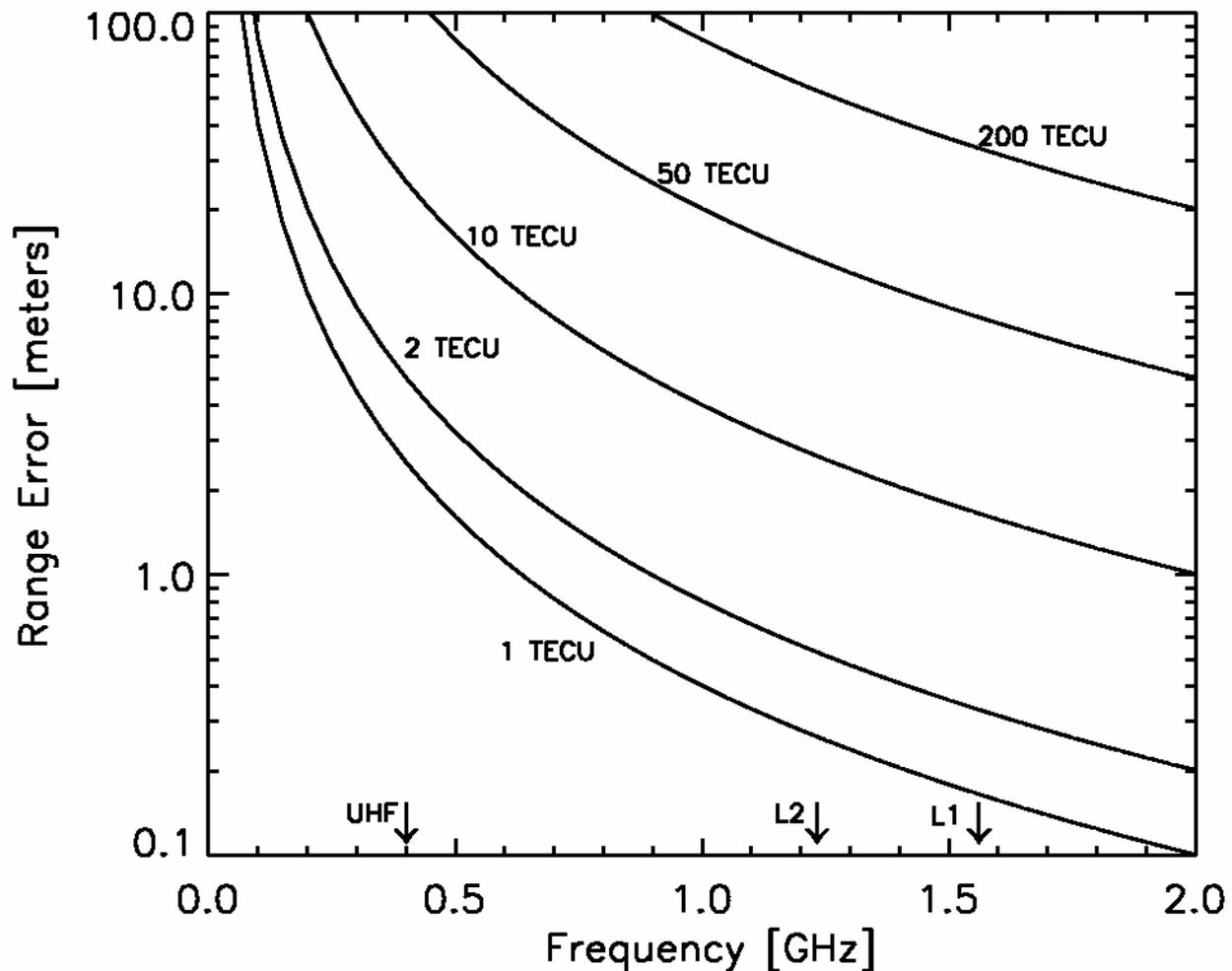
Very clear enhancement in electron density below 120 km
Coincident with large increase in flux at Earth



“Anti-flares” – Low electron densities around 110 km, cause unknown

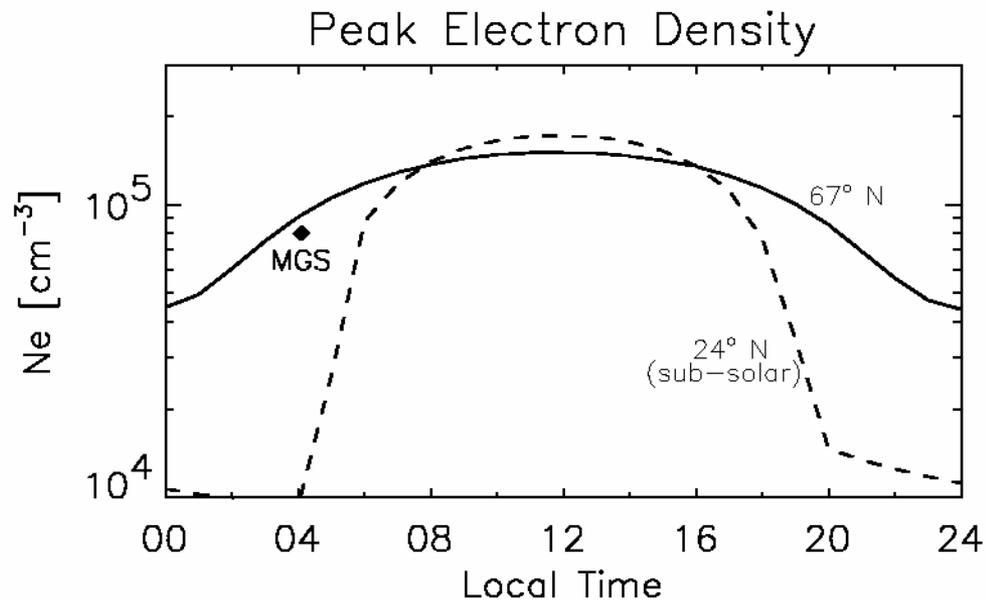


- a) Illustration of the use of GPS by aircraft for location and navigation. Radio transmissions through the ionosphere suffer retardation effects that can lead to range errors if not corrected for the total electron content (TEC) of the ionosphere along each ray path.
- b) A proposed Mars GPS network

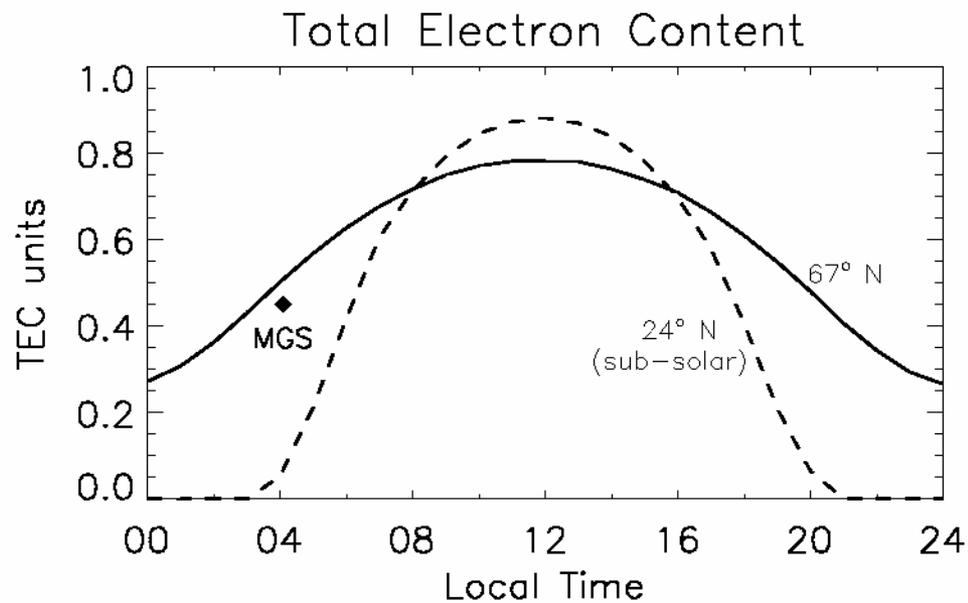


- $\Delta R = 0.4 \text{ TECU}/f^2$
- ΔR = Range error in metres
- TEC = Total electron content along ray path in TECU (10^{16} m^{-2})
- f = Frequency in GHz
- Actual TEC = Vertical TEC / cosine of elevation angle

Figure 4. Calculations of ionosphericly imposed range errors for vertical TEC versus the frequency used in a satellite navigation system. The arrows indicate a typical UHF (400 MHz) choice, as well as the L1 and L2 frequencies of the terrestrial GPS system.



- Photochemical model predictions of peak electron density and vertical TEC for 24N (dashed line) and 67N (solid line).
- Typical values from MGS observations are also marked.



- Maximum vertical TEC ~ 1 TECU. This corresponds to 5 TECU at an elevation angle of 80°.
- The resulting range error would be ~1m at 1GHz (GPS L1/L2) or ~10m at 400 MHz (UHF)

Conclusions

- Localized disturbances that could seed plasma instabilities are common above magnetized regions on Mars
- Solar flares enhance electron density below the ionospheric peak and will cause D-layer absorption that reduces signal strength
- During quiescent conditions, the range error introduced by the martian ionosphere will be ~ 1 - 10 m. These errors are too large for surface vehicles to safely navigate using uncorrected GPS networks.