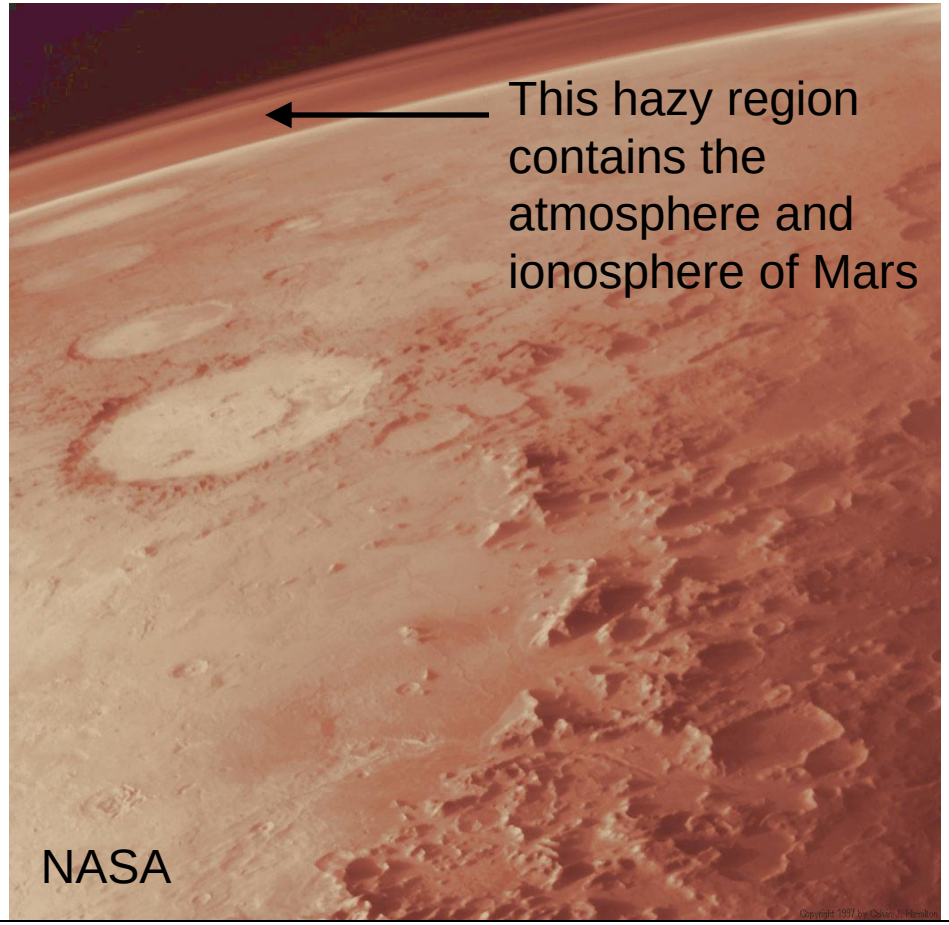
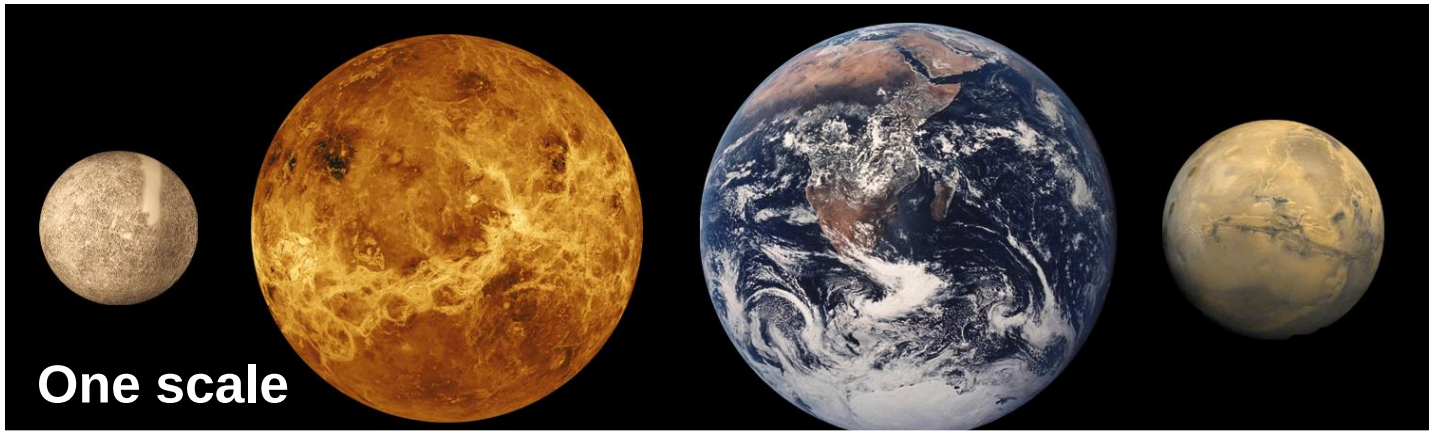
# Space physics of the ionosphere of Mars

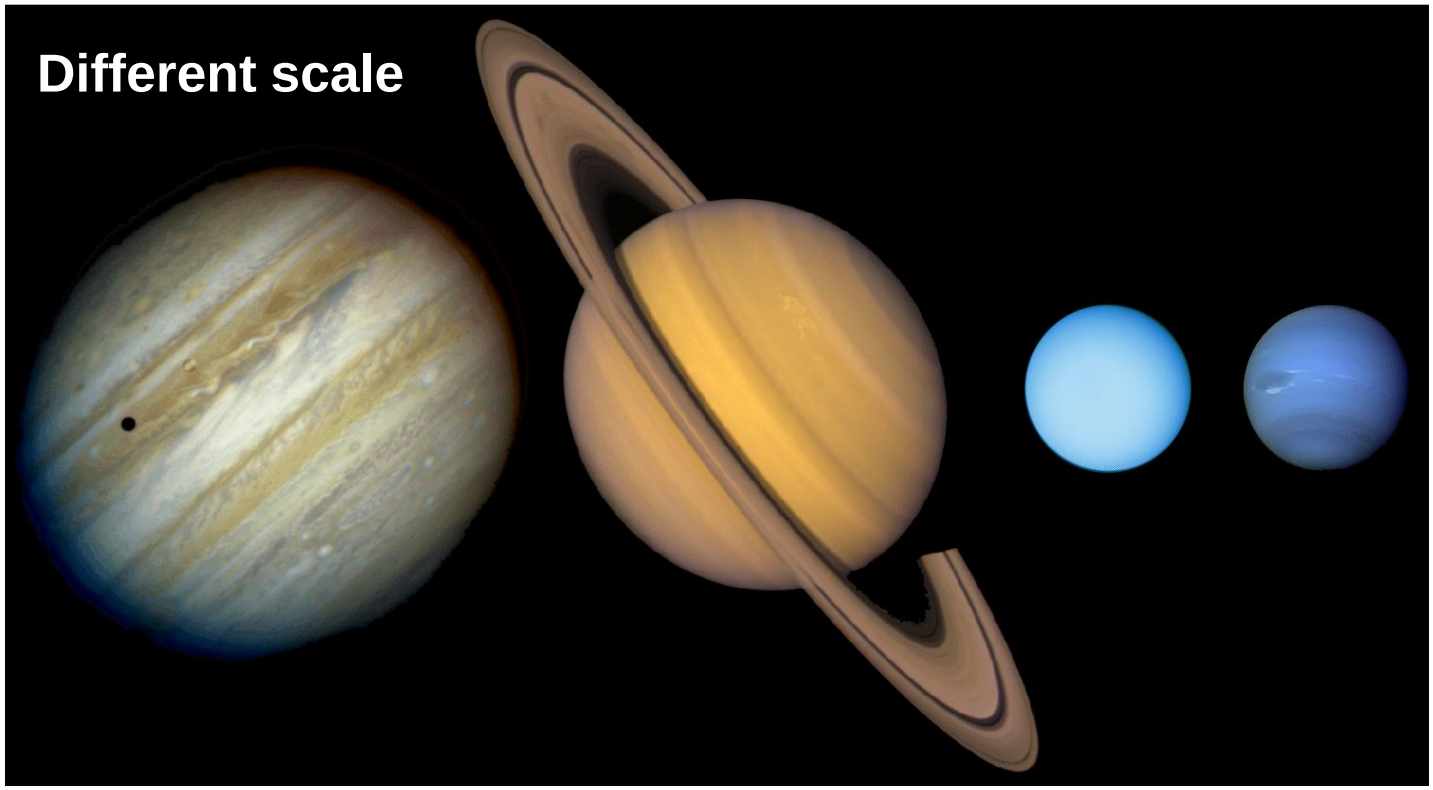



Paul Withers
Boston University
(withers@bu.edu)

Kerri Cahoy's space physics course, MIT
Room 54-1623

Tuesday 2013.05.14
11:00 – 12:30




www.solarviews.com

This is ⟵ Mars

0.5 x R-Earth

1.5 AU from Sun

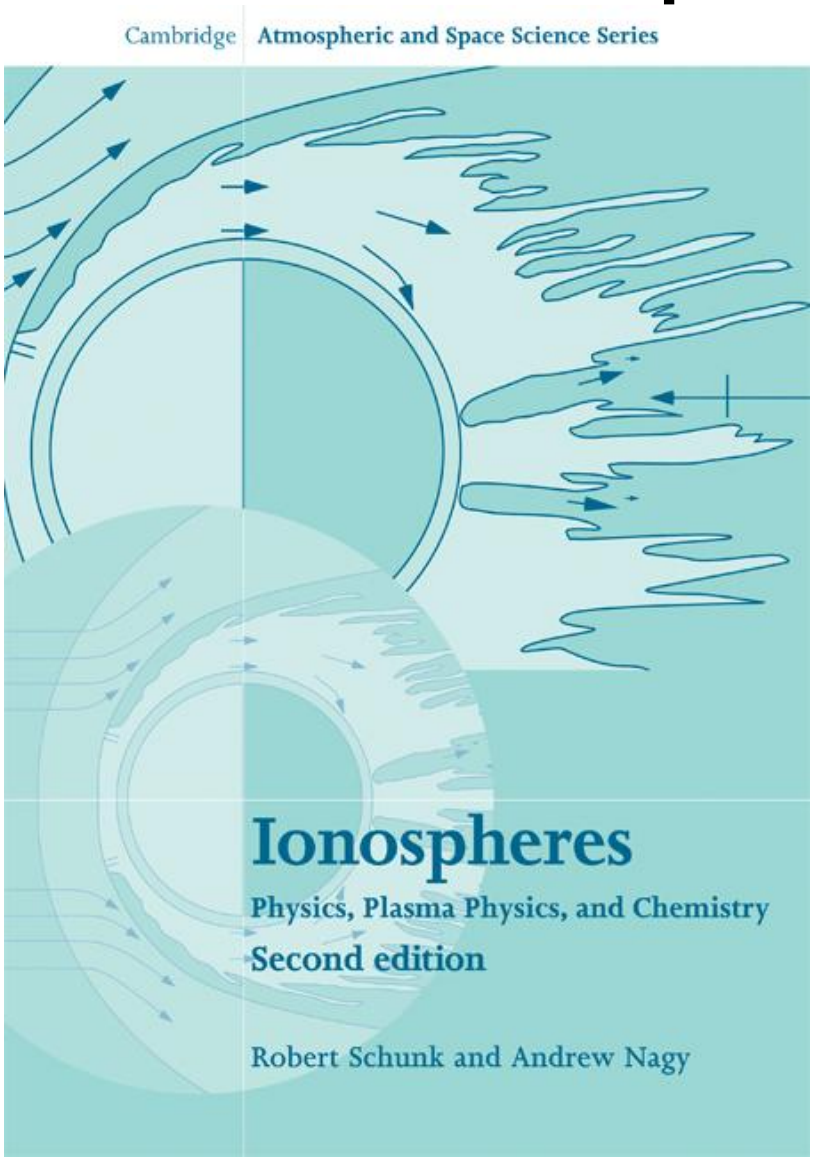
Same rotation rate as Earth

Carbon dioxide atmosphere

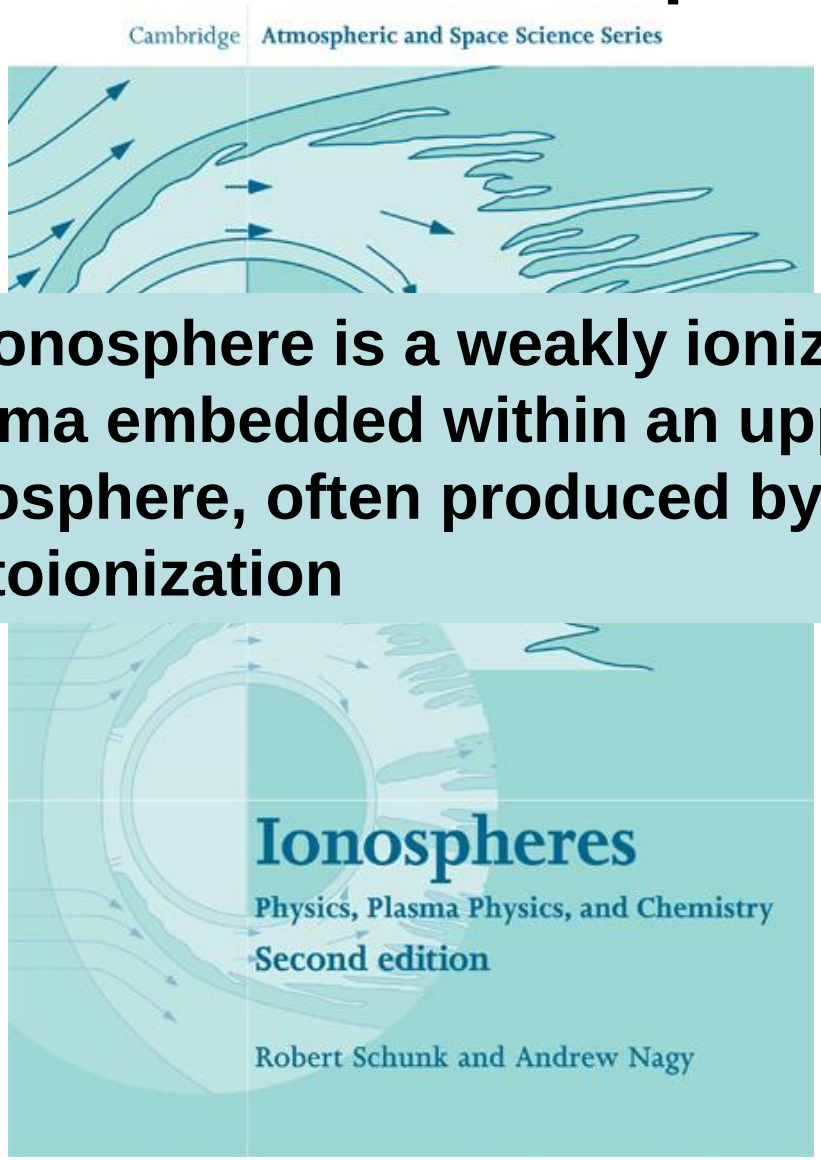
100x smaller surface pressure

Target of many spacecraft in last 15 years

# What is an ionosphere?



# What is an ionosphere?

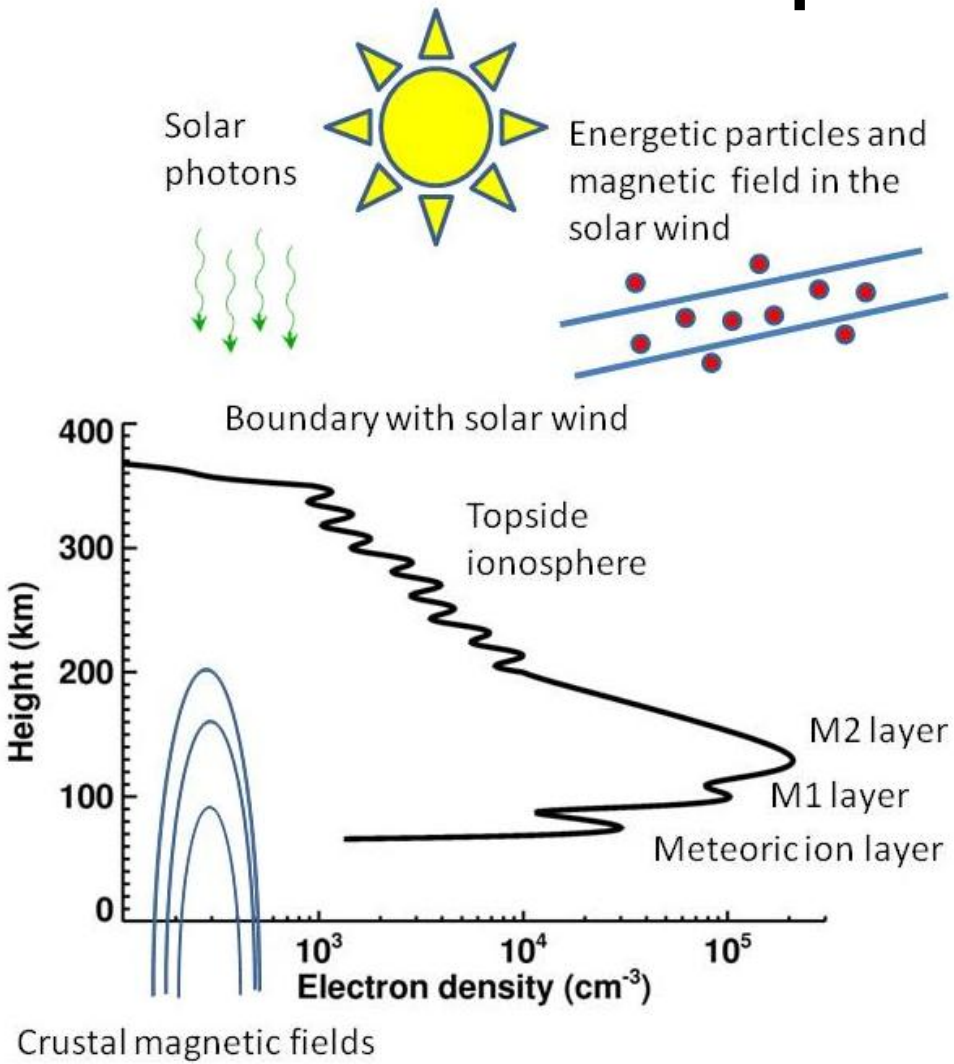



**An ionosphere is a weakly ionized plasma embedded within an upper atmosphere, often produced by photoionization**

# What does that actually mean?

| | Atmosphere | Ionosphere | Space physics |
|---|---|---|---|
| Chemistry | ✗ | ✓ | ✗ |
| Gravity | ✓ | ✓ | ✗ |
| Sunlight | ✓ | ✓ | ✗ |
| Magnetic fields | ✗ | ? | ✓ |
| Composition | Neutrals | Ions, electrons, and neutrals | Protons and electrons |

# 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

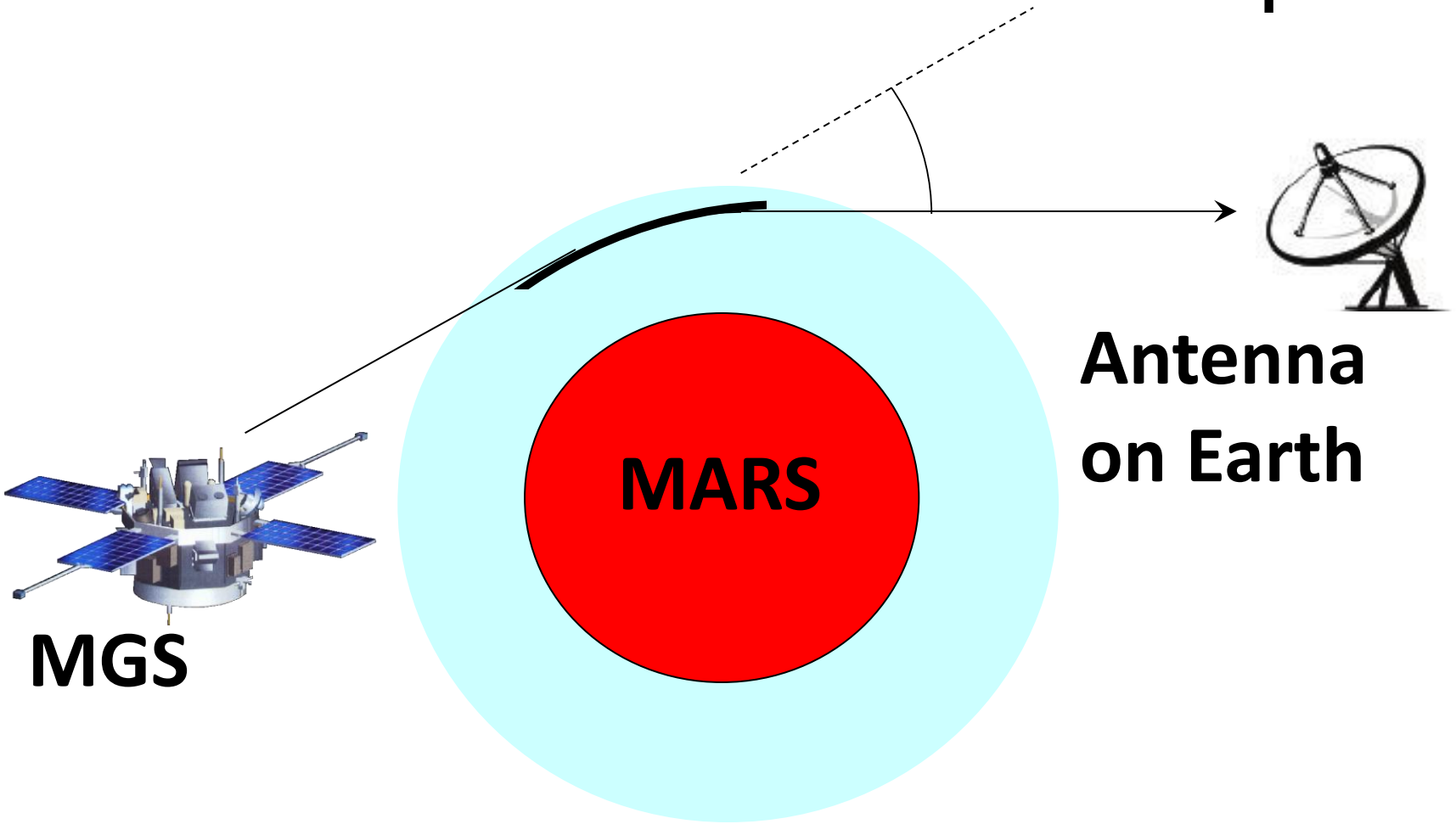
Transport only important in topside ionosphere

Withers et al. (2009) Decadal Survey white paper

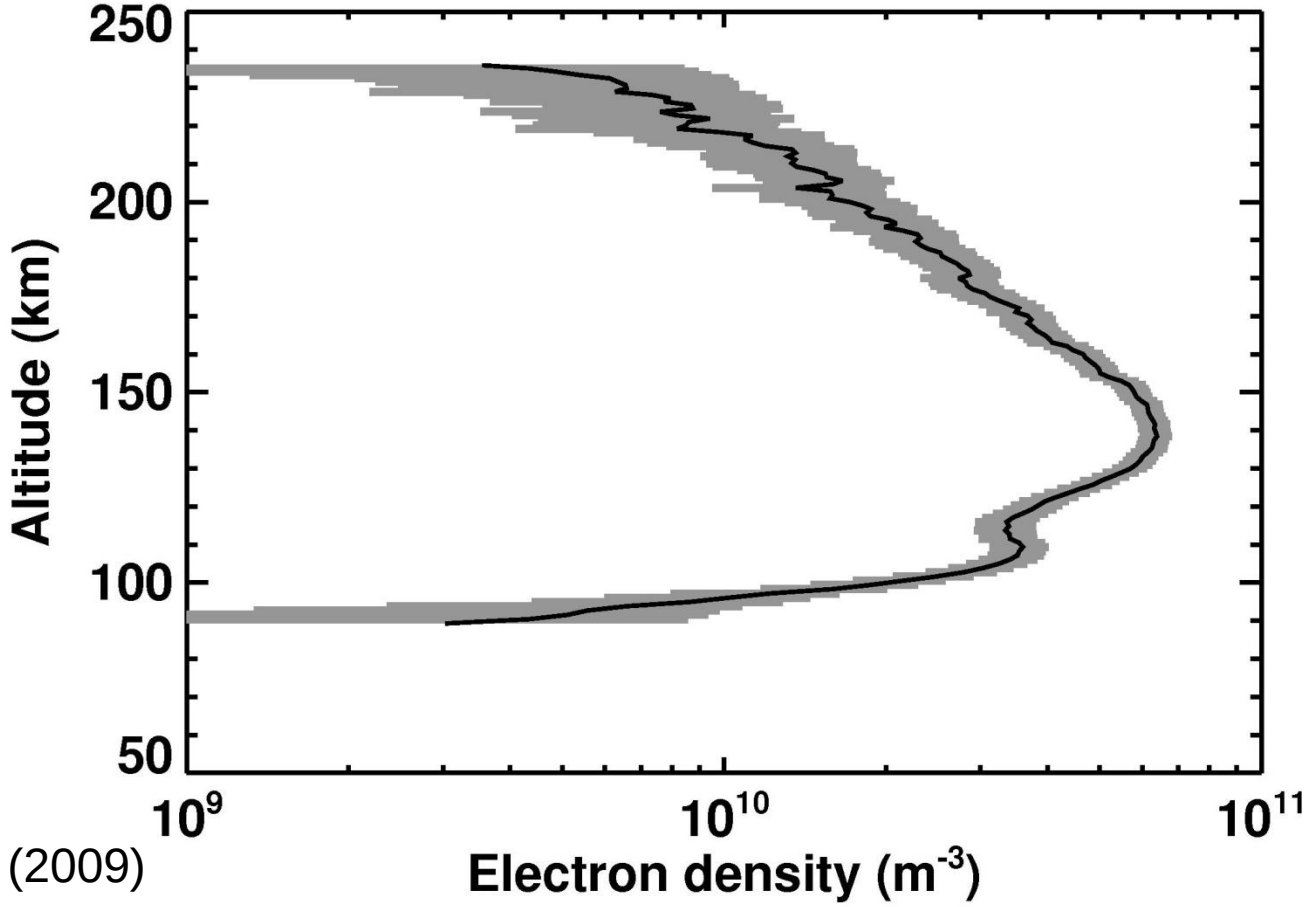
# Outline for this talk

- Measurement techniques at Mars
- Introduce some “Sun-planet connections” at Mars
- Consequences of bizarre magnetic field
- Opportunities for discussion

# Radio occultation technique

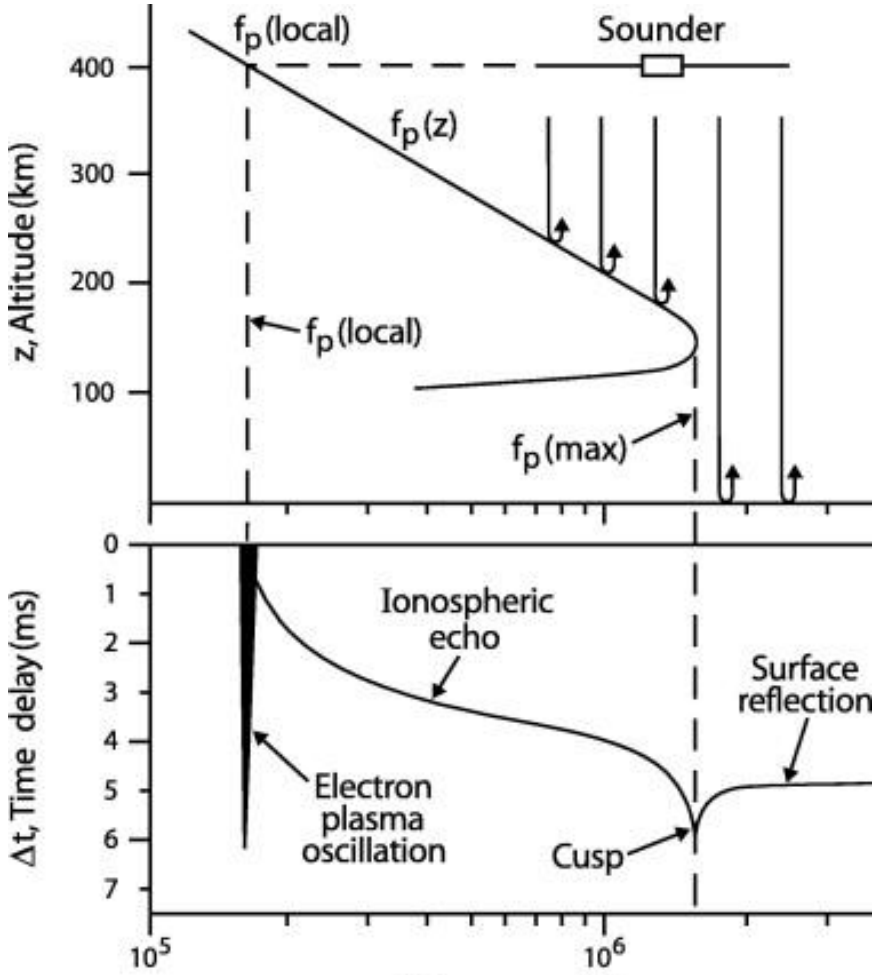


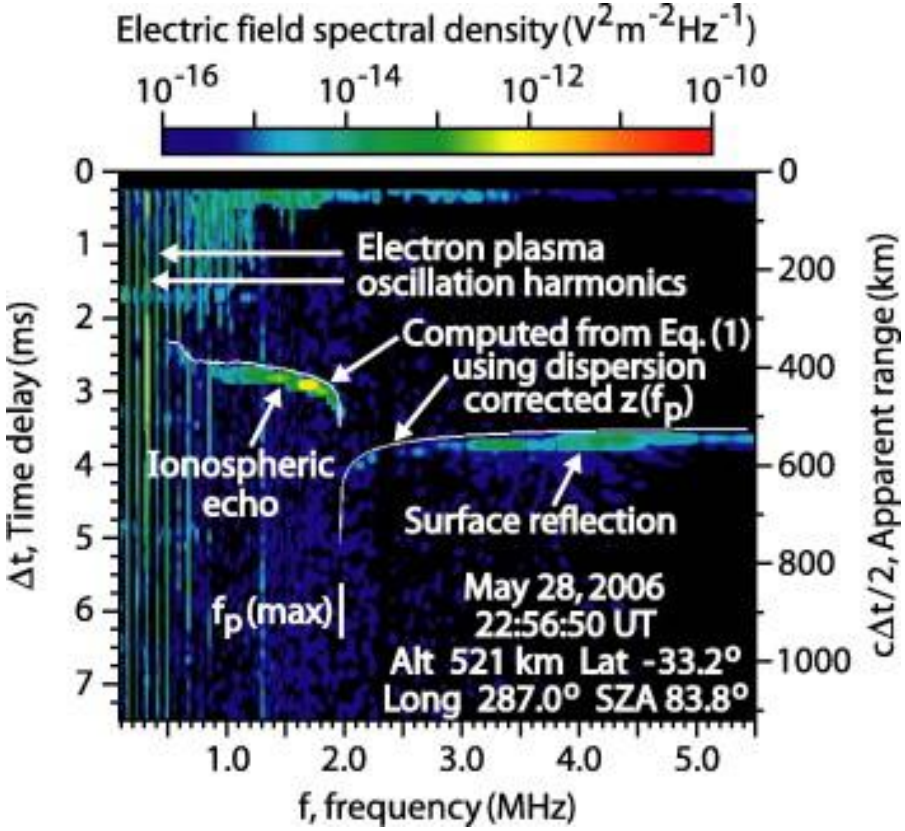
# Radio occultation results




Withers et al. (2009)

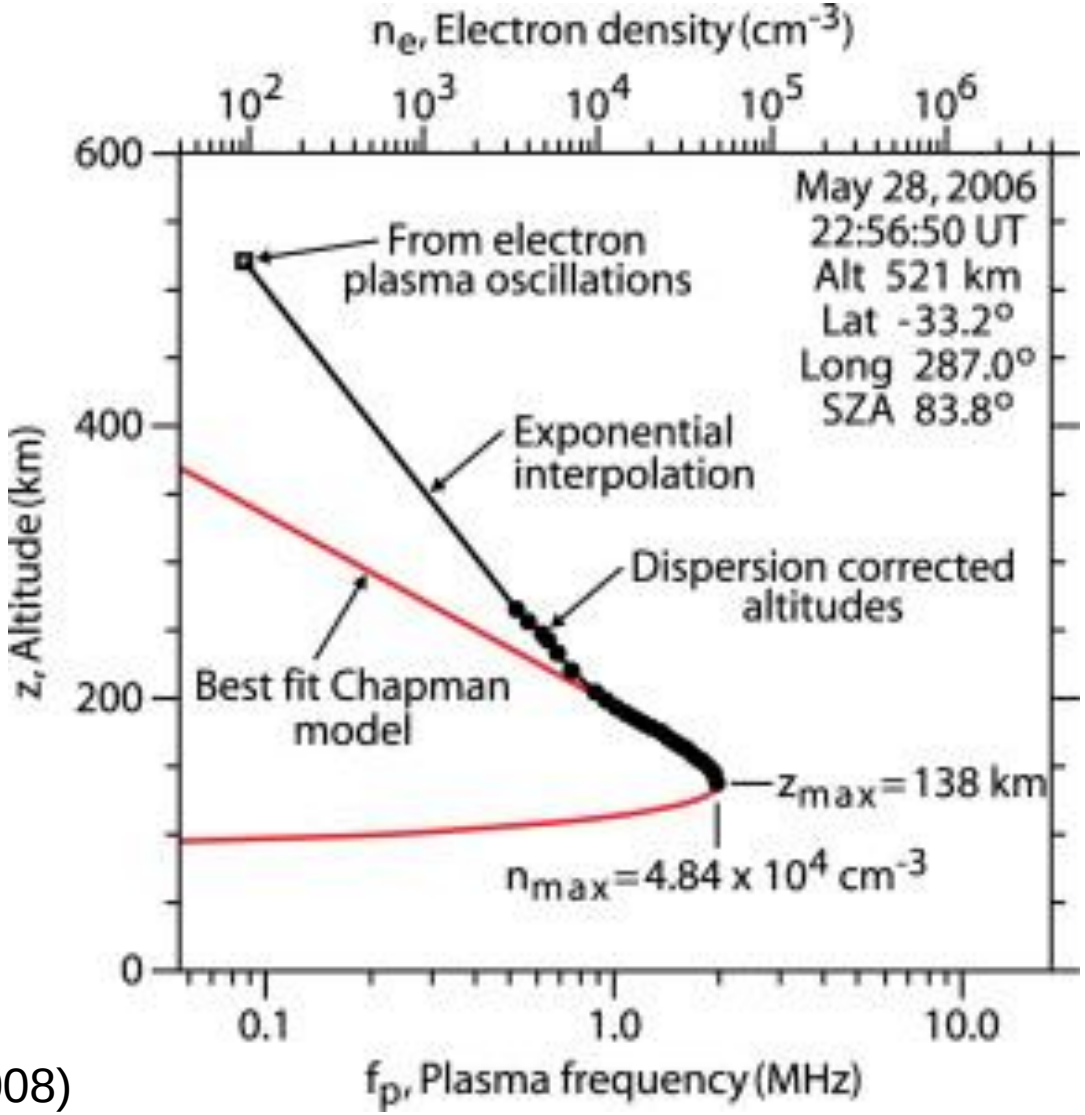
# MARSIS radar sounding




Gurnett et al. (2008)

# MARSIS results




Gurnett et al. (2008)

# Complementary techniques

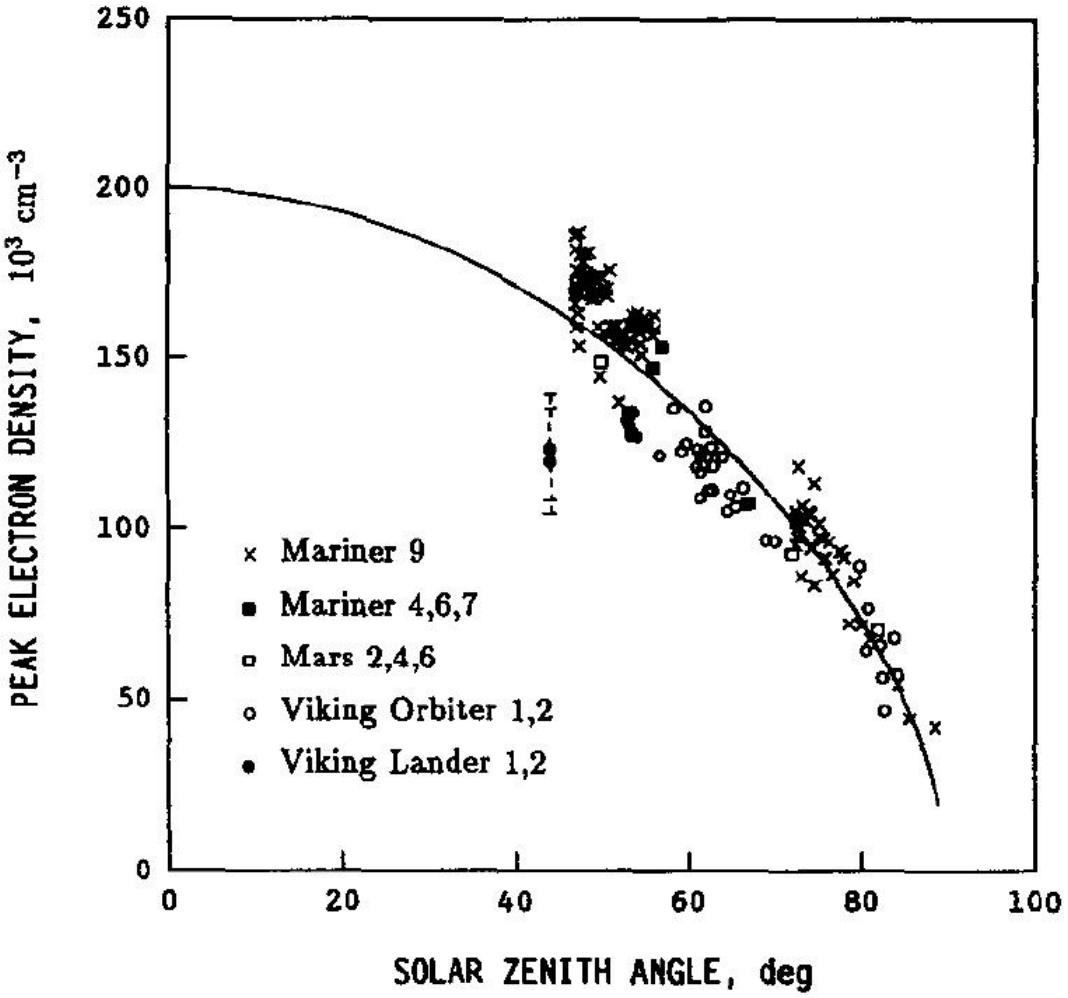
Radio occultation

- Precise vertical scale
- 1 km vertical resolution
- Full vertical coverage
- ~200 km horizontal averaging
- Alias horizontal structure to vertical
- Limited opportunities

Radar sounding

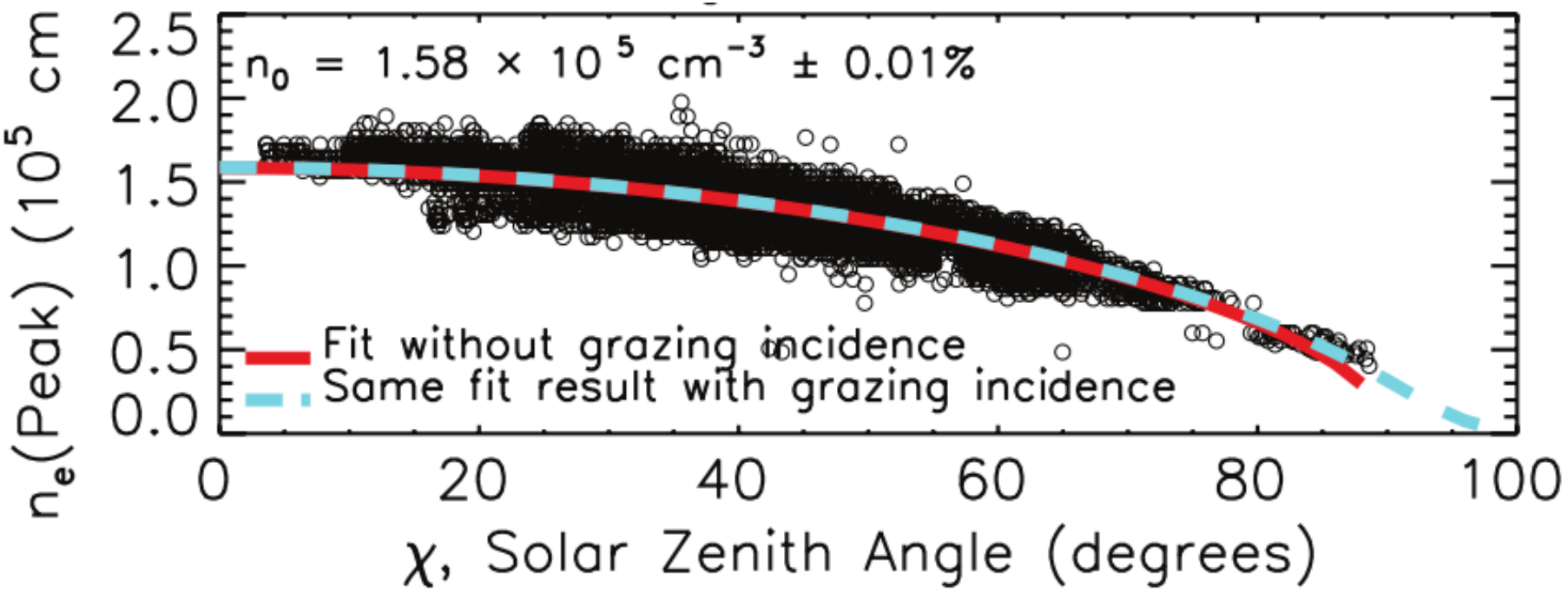
- Derived vertical profiles affected by noisy ionograms and coarse time resolution
- Topside only, monotonic increase
- No horizontal averaging
- Many opportunities, no geometric limitations

# Solar zenith angle and Nmax



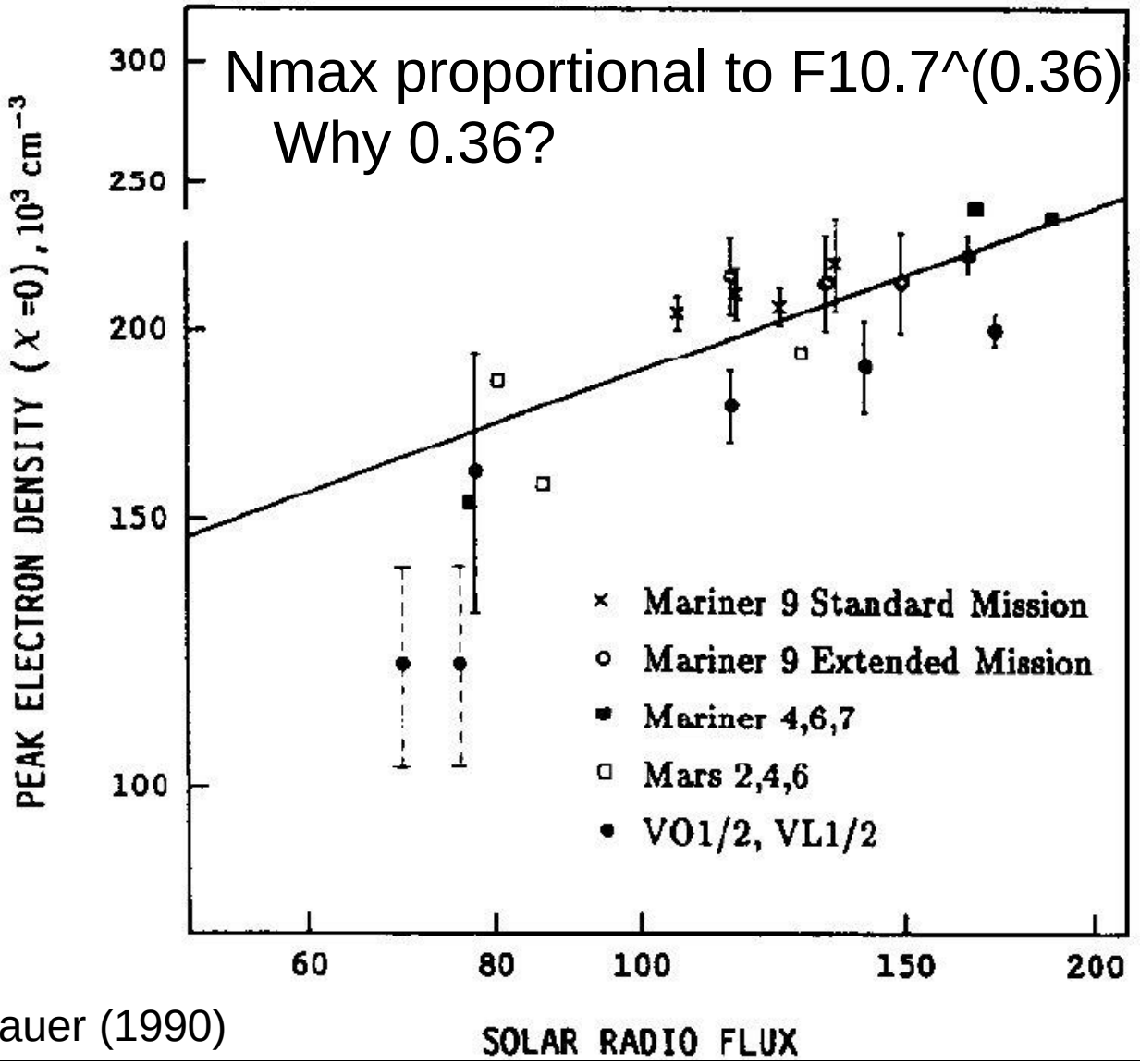

Hantsch and Bauer (1990) – Radio occultation observations

# Solar zenith angle and Nmax



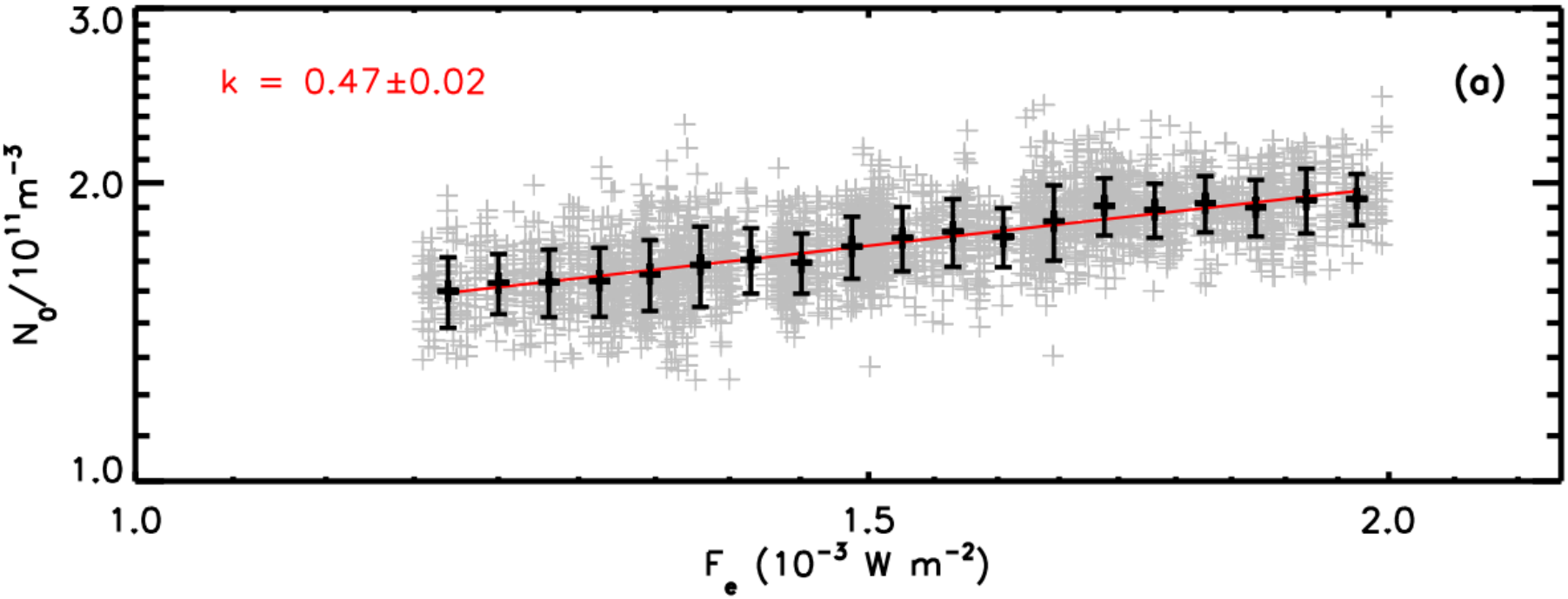

Morgan et al. (2008) – Radar sounder observations

# The solar cycle matters




Hantsch and Bauer (1990)

# F10.7 is not solar flux



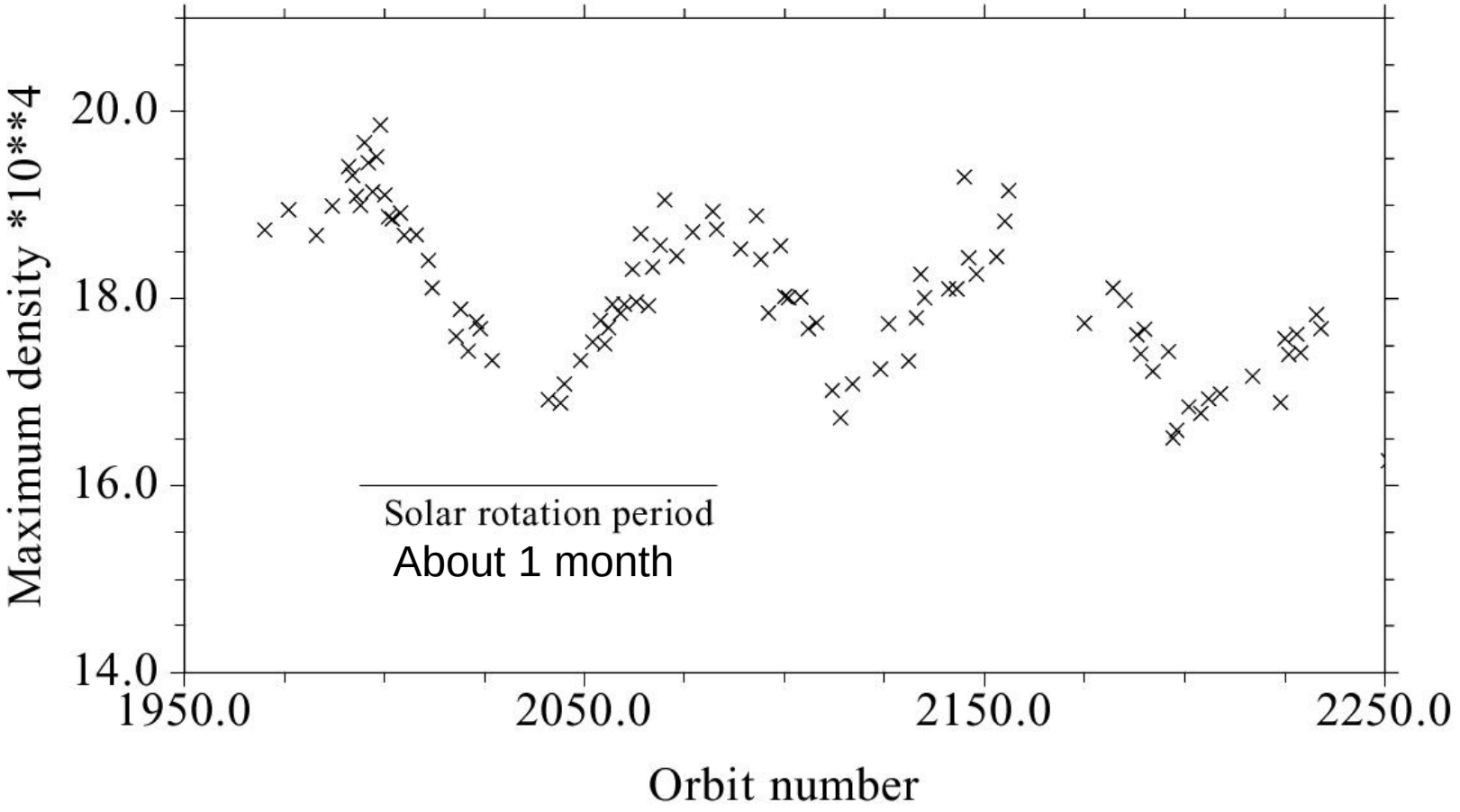

Fe = Energy $m^{-2}$ $s^{-1}$ from 0 to 90 nm from TIMED SEE

k =0.47 +/- 0.02, much larger than past values

(also rather close to k=0.5)

Girazian and Withers (2013)

# Solar rotation also matters

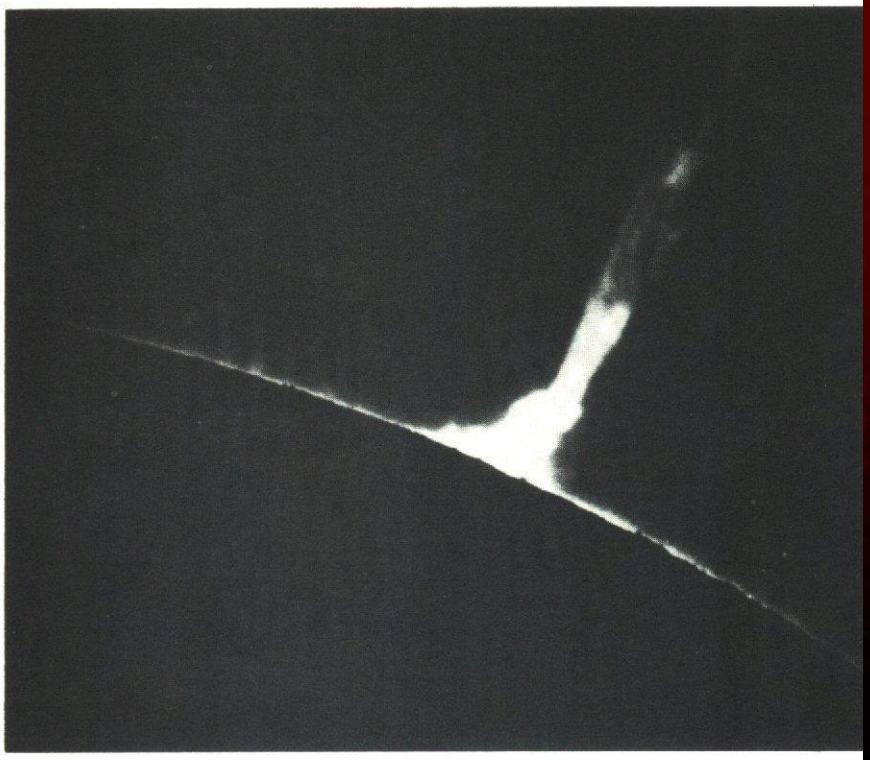



Nielsen et al. (2008)

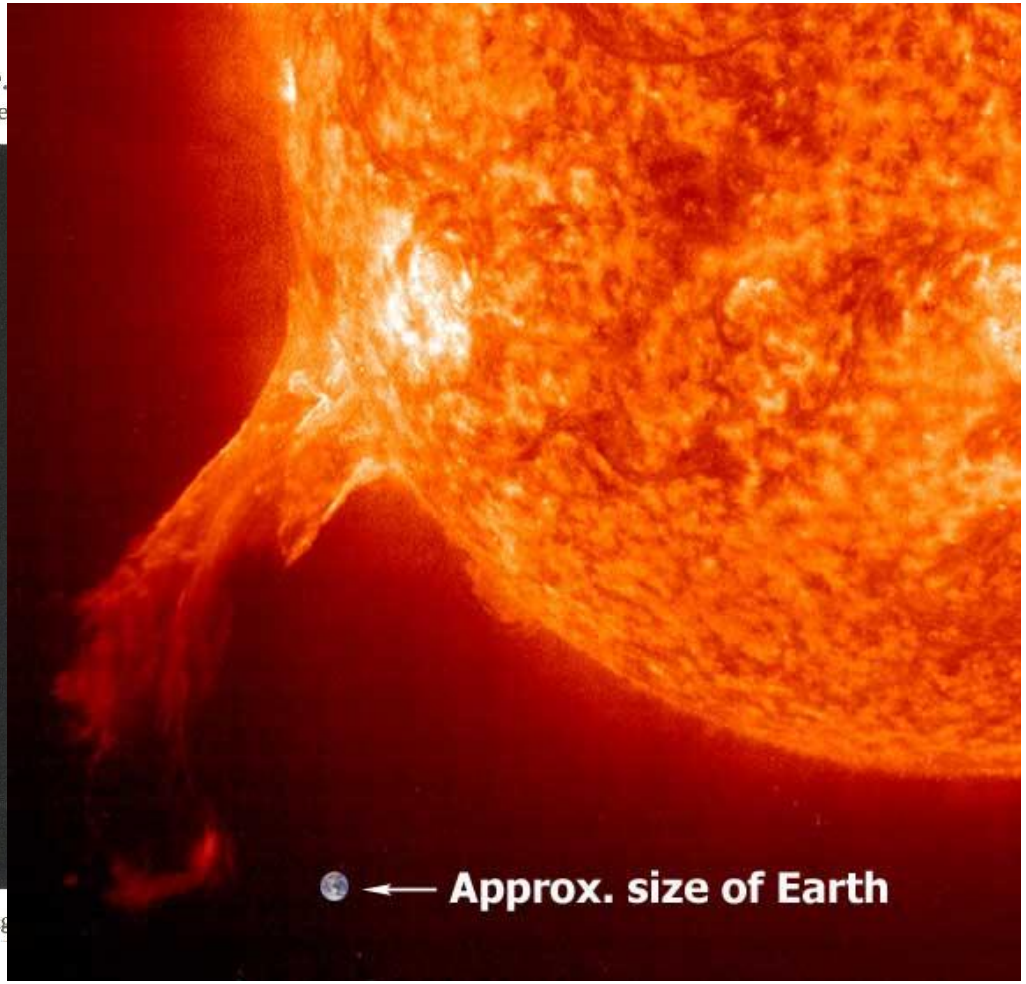
# Solar flares

*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



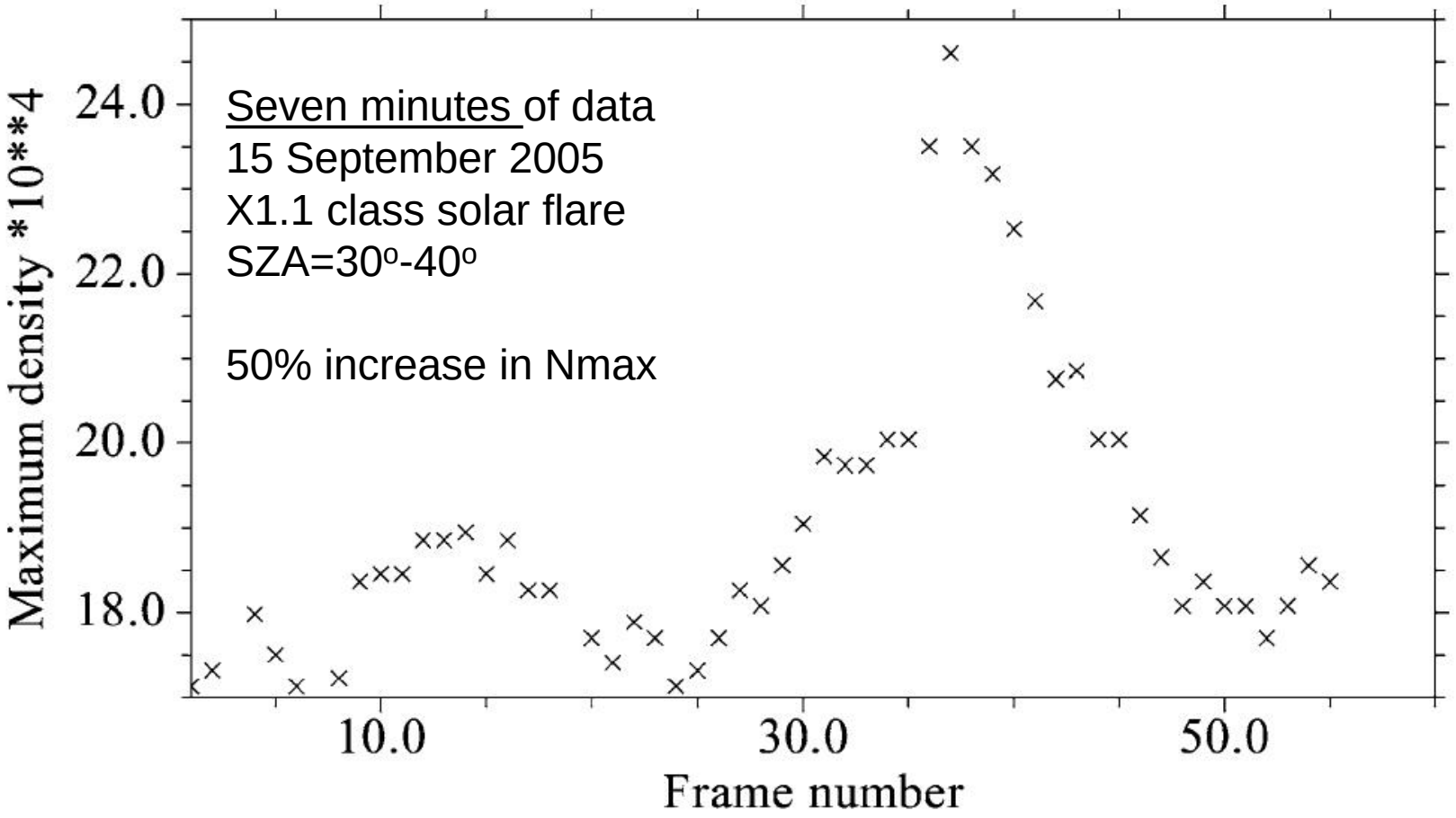
The photograph was taken with a 15 cm aperture solar telescope using



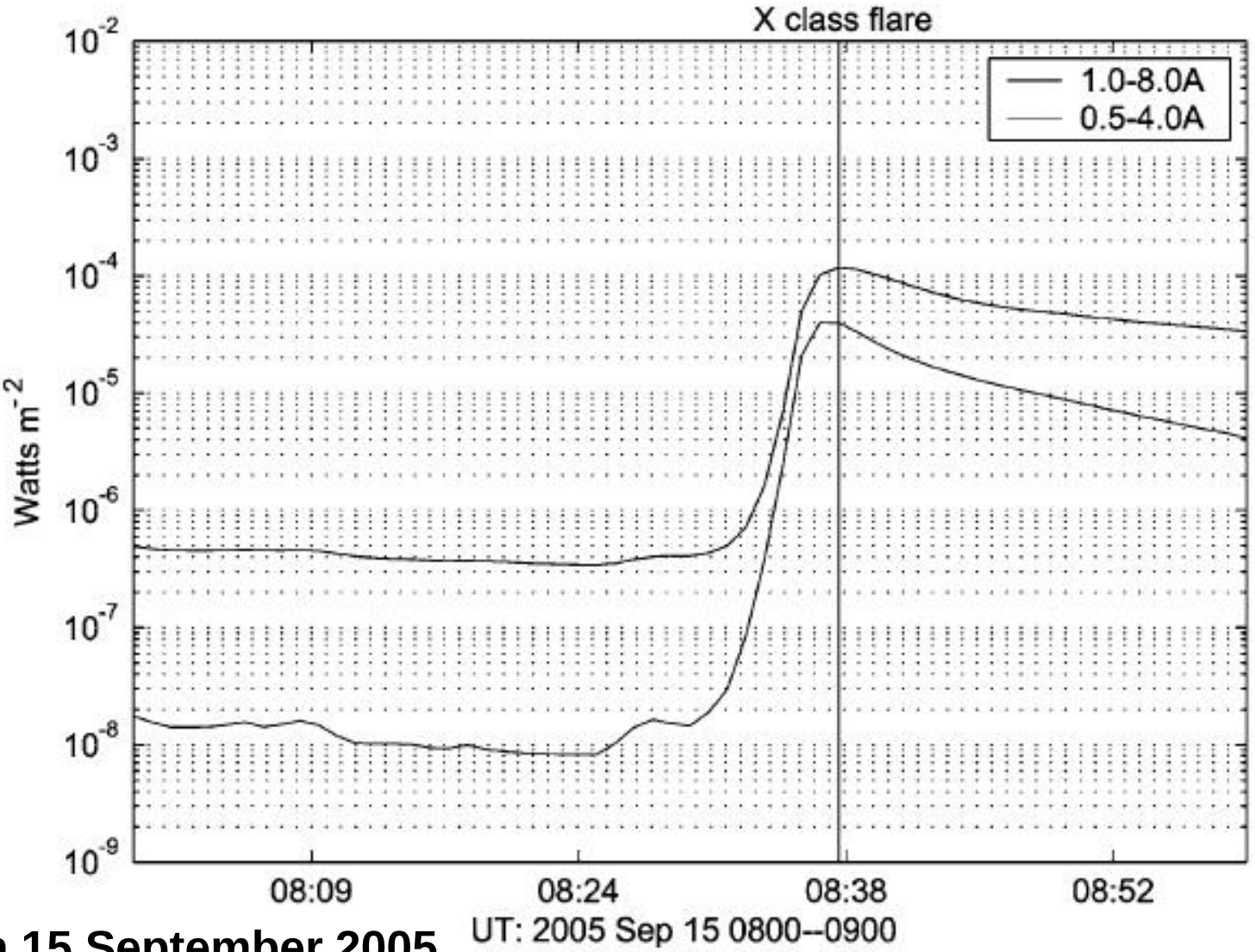

http://www.assabfn.co.za/pictures/solar_boydenflare_historical_articles.jpg

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

# Solar flares have impacts…



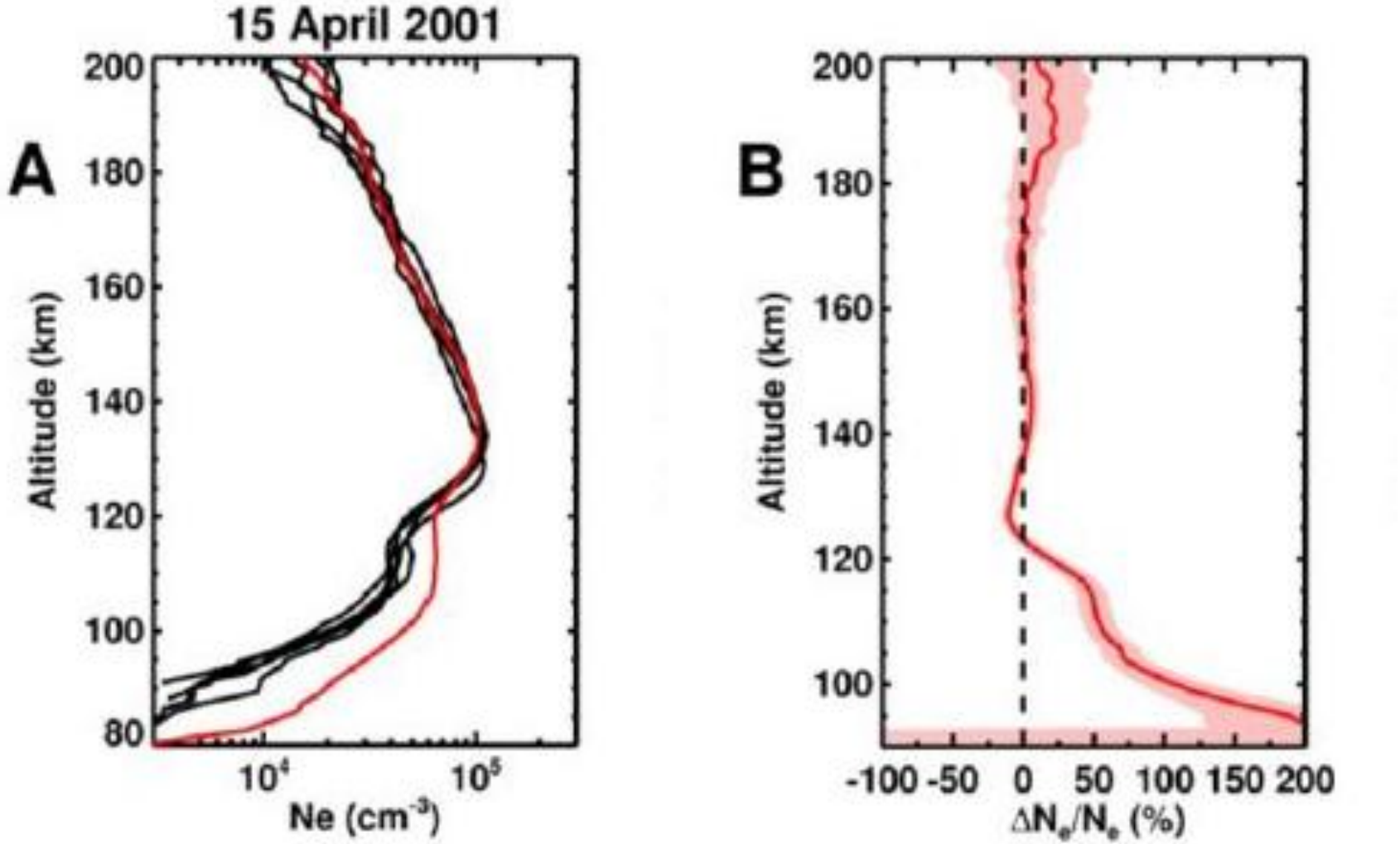

Nielsen et al. (2008)




**X1.1 flare on 15 September 2005**
**GOES X-ray fluxes surge at time of MARSIS observations**

Nielsen et al. (2008)

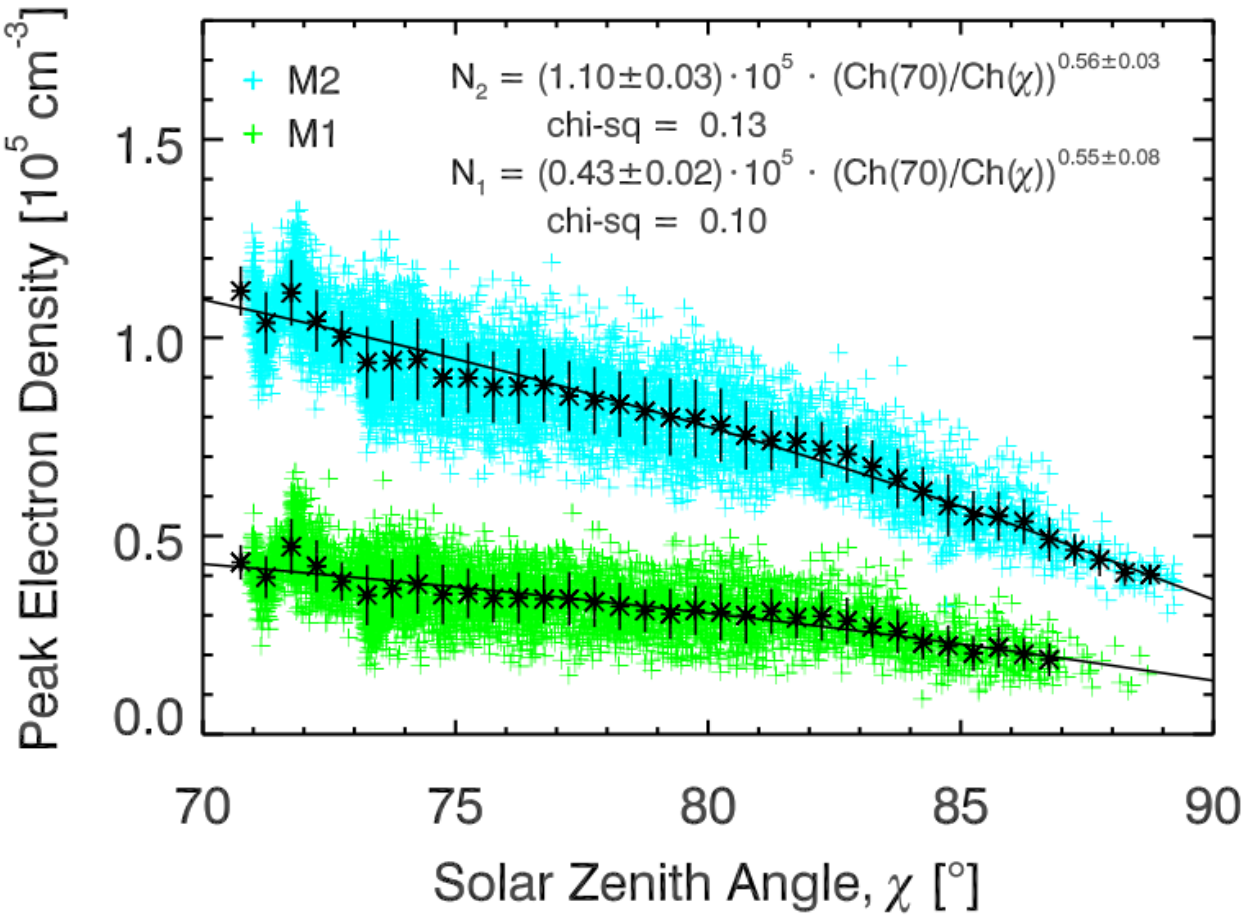
# ...over a range of altitudes




Mendillo et al. (2006)

Soon after an X14 solar flare

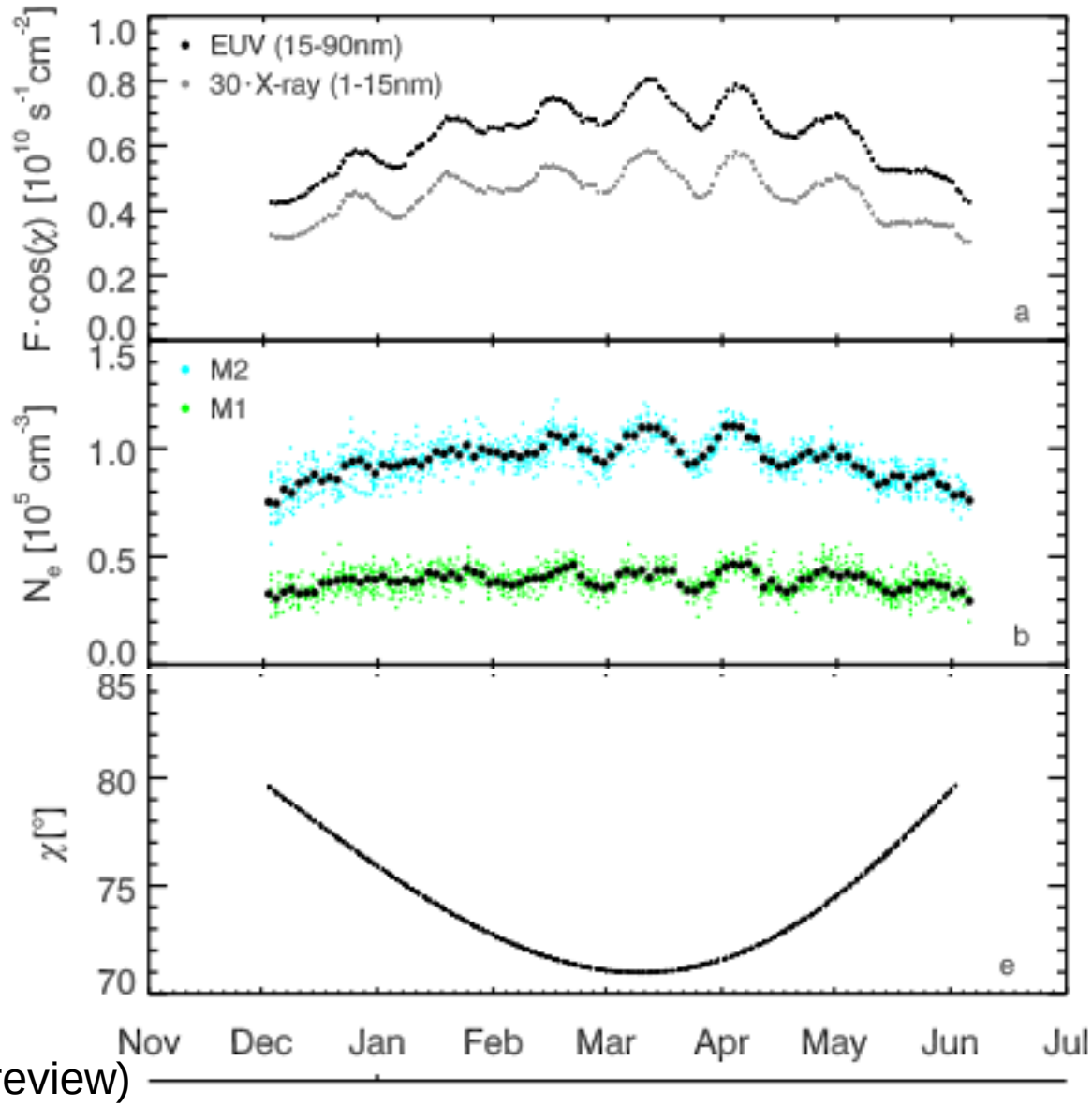
# Let's look at that lower peak




Fallows et al. (2013, under review)

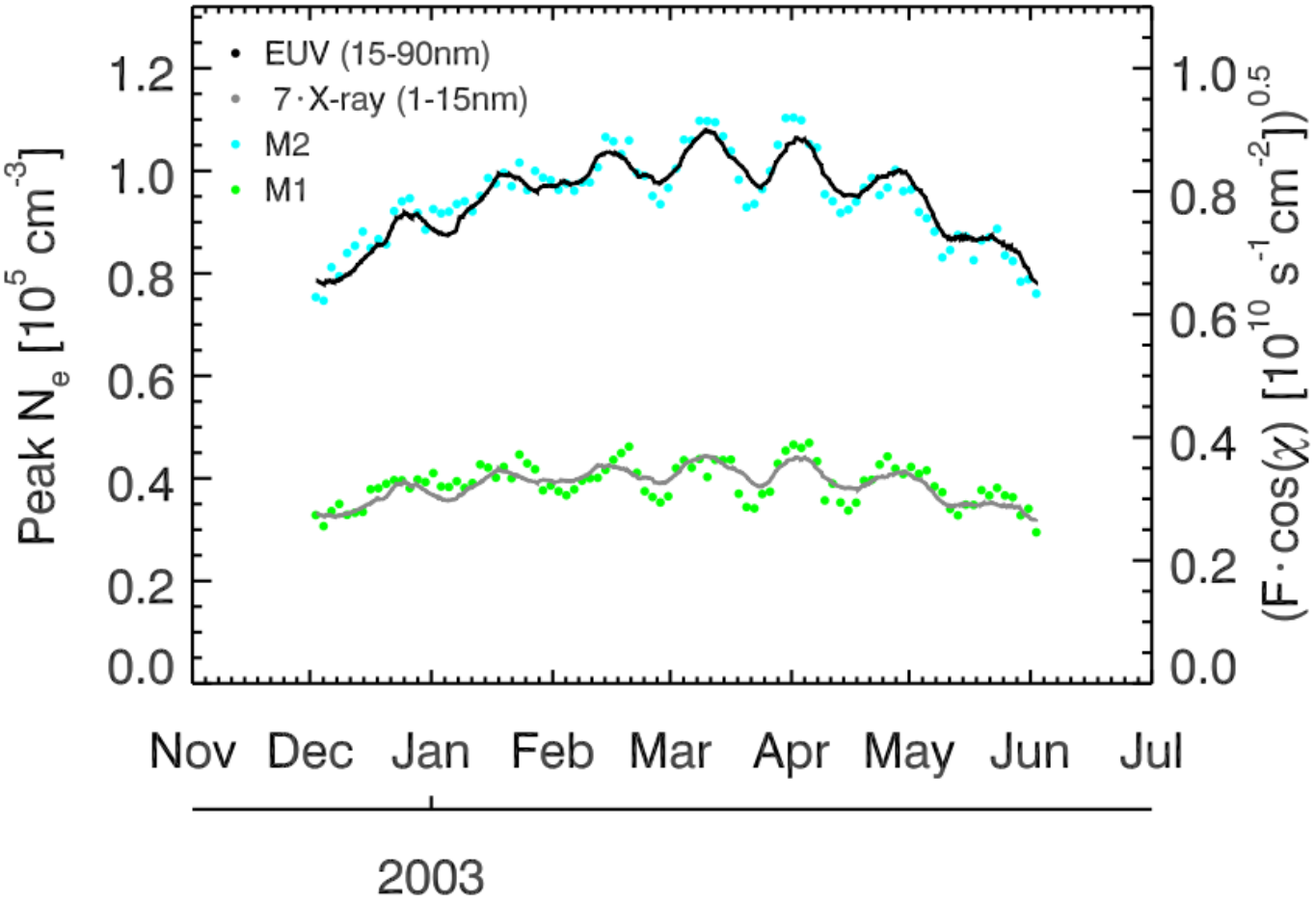
Seems a lot like the main peak

# More solar rotation effects



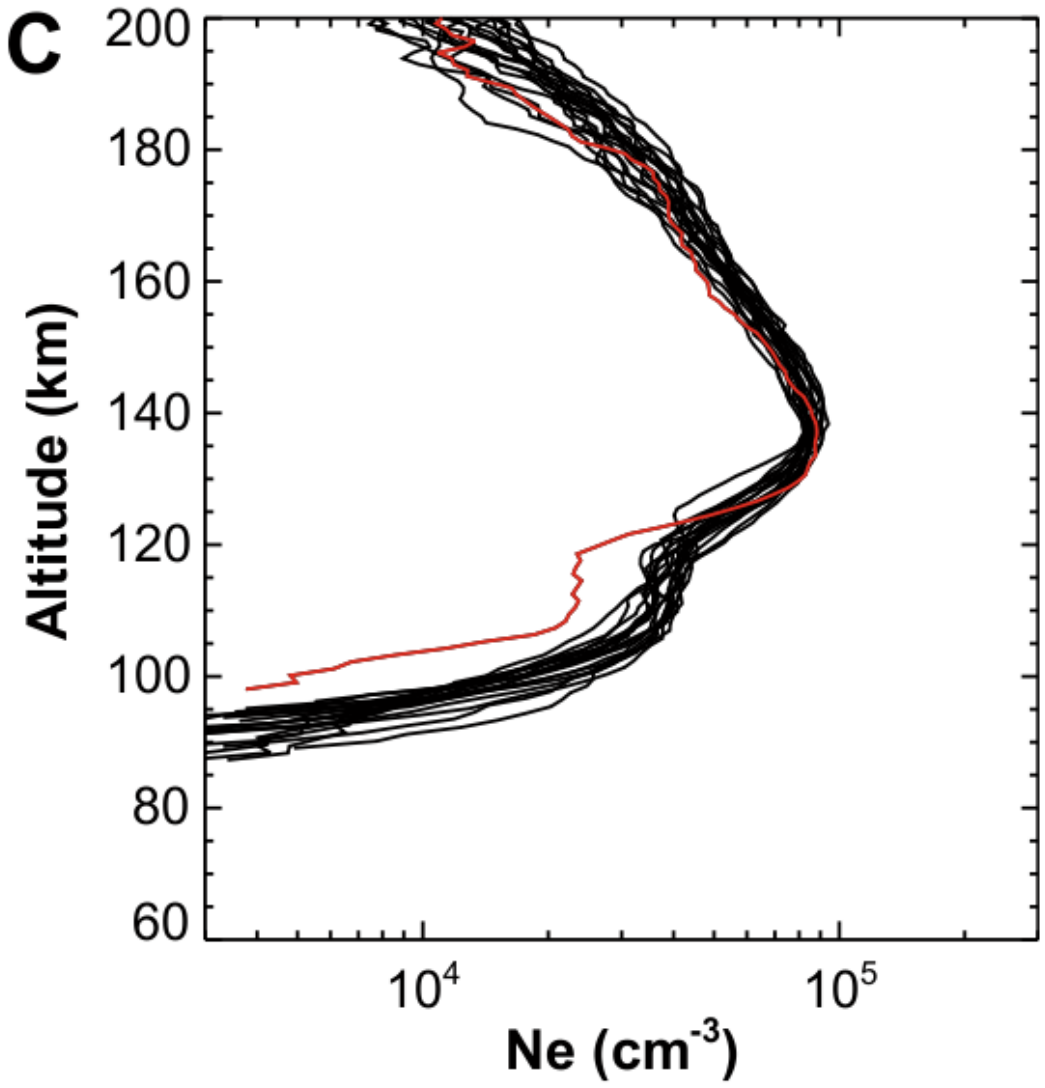

Fallows et al.
(2013, under review)

# Nice agreement – and a bonus



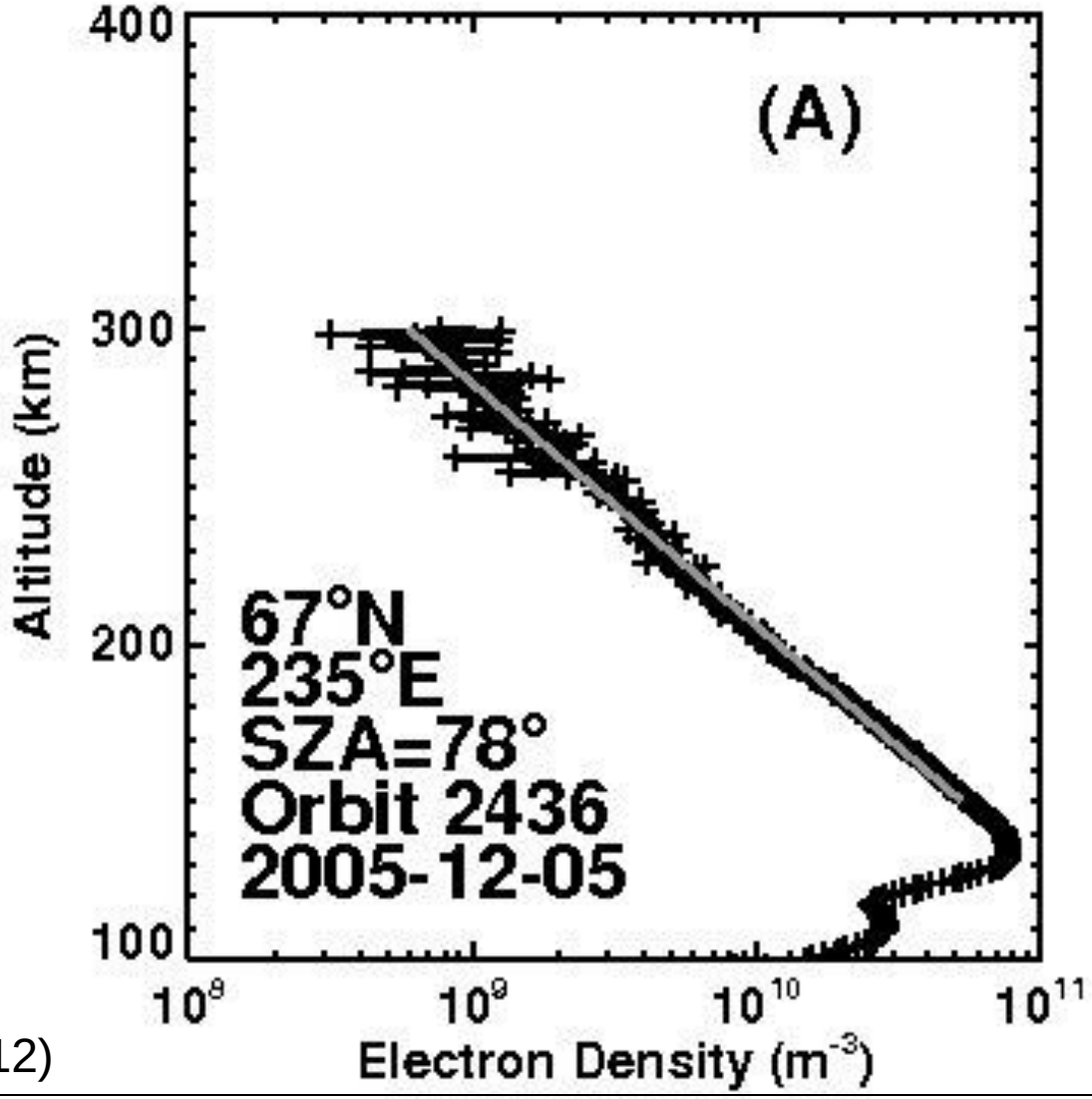

Fallows et al. (2013, under review) How many ions/electrons per photon?

# Anti-flares?




Withers (2009)

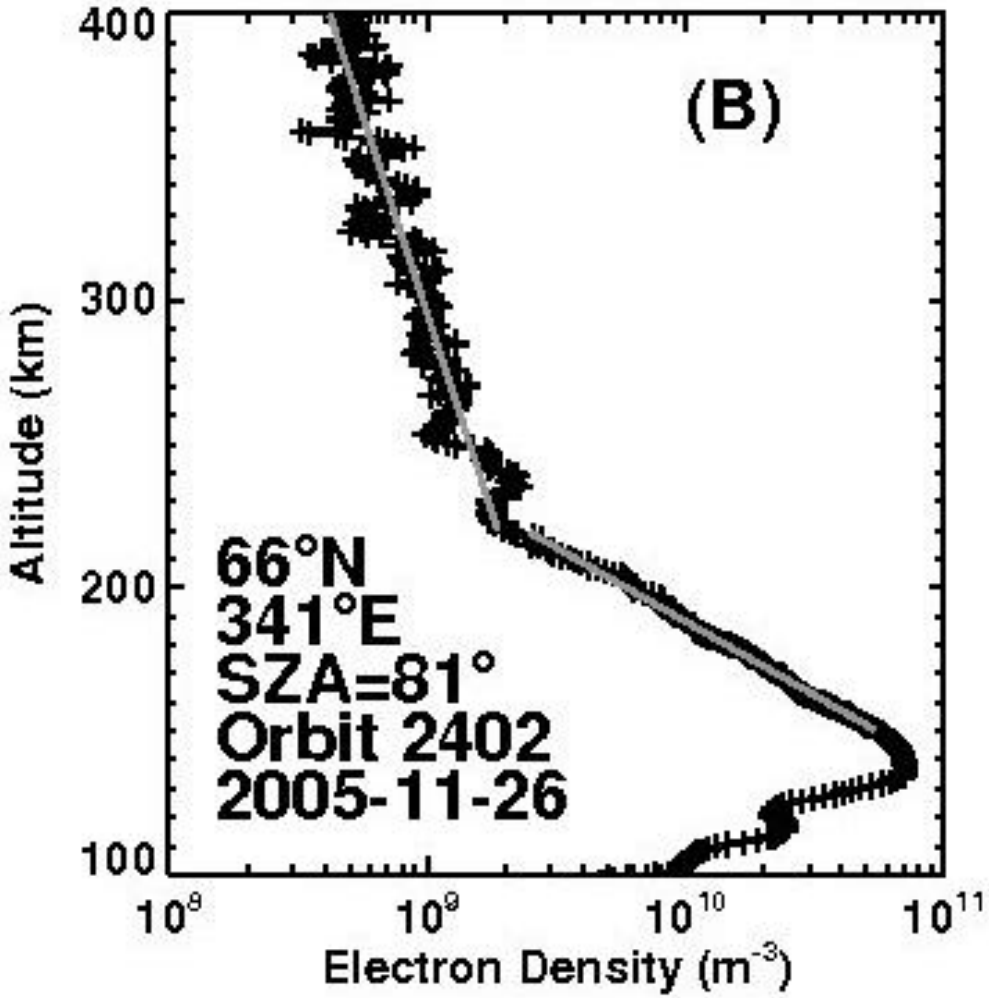
# Upwards to the topside




Consistent with
no transport

Withers et al. (2012)

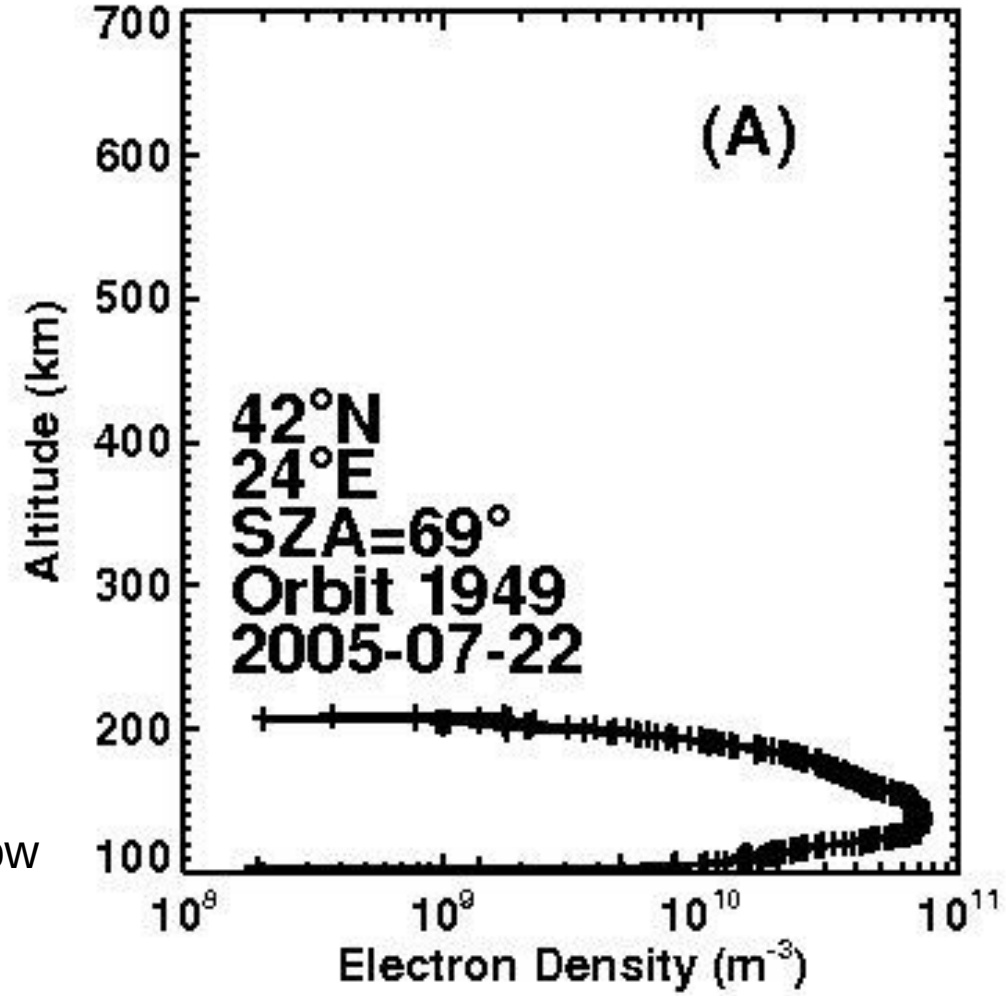
# What controls change in topside morphology?




Consistent with diffusive equilibrium

Withers et al. (2012)

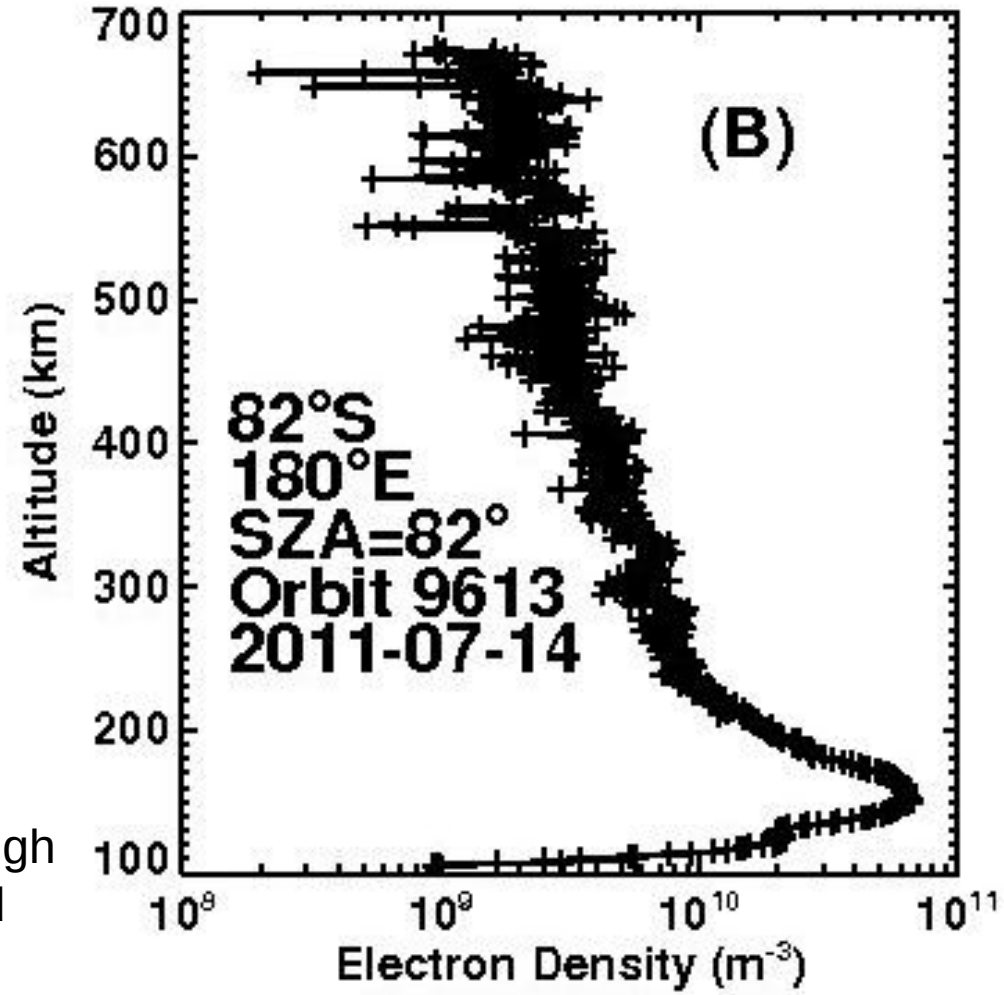
# Where's the ionopause?




Sometimes very low CME?

Withers et al. (2012)

# Where's the ionopause?

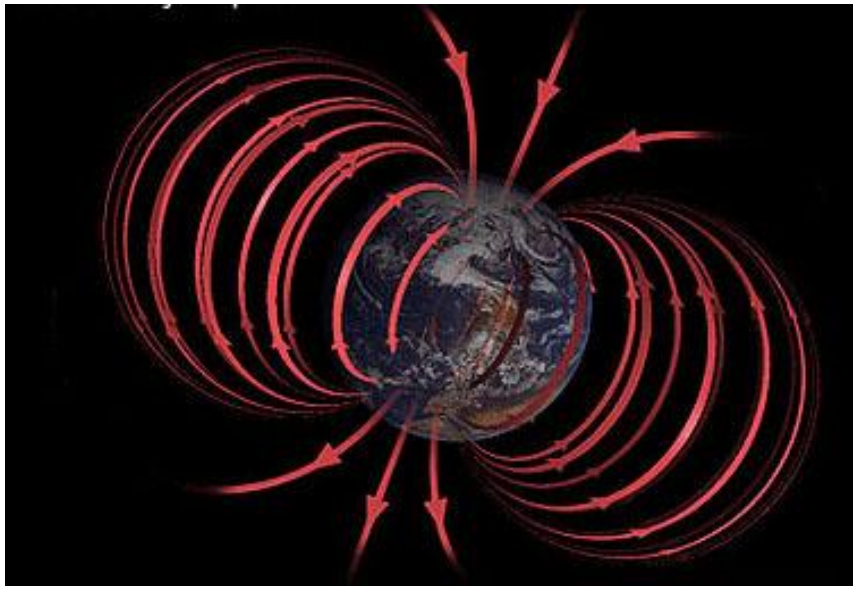



Sometimes very high
Strong crustal field

Withers et al. (2012)

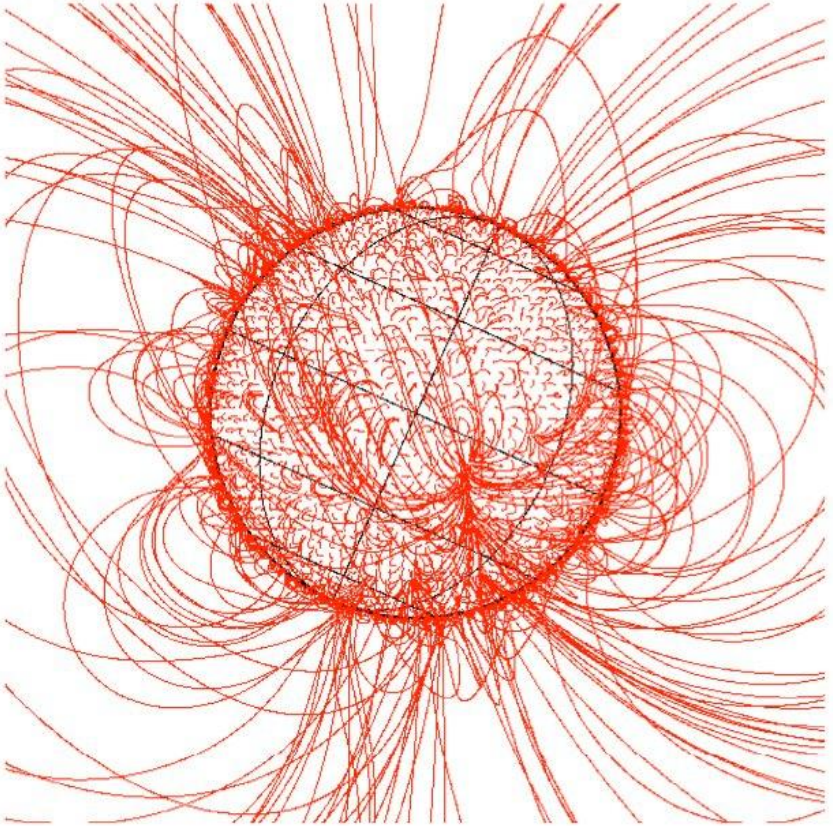
# Mars is magnetically crazy

Earth magnetic field



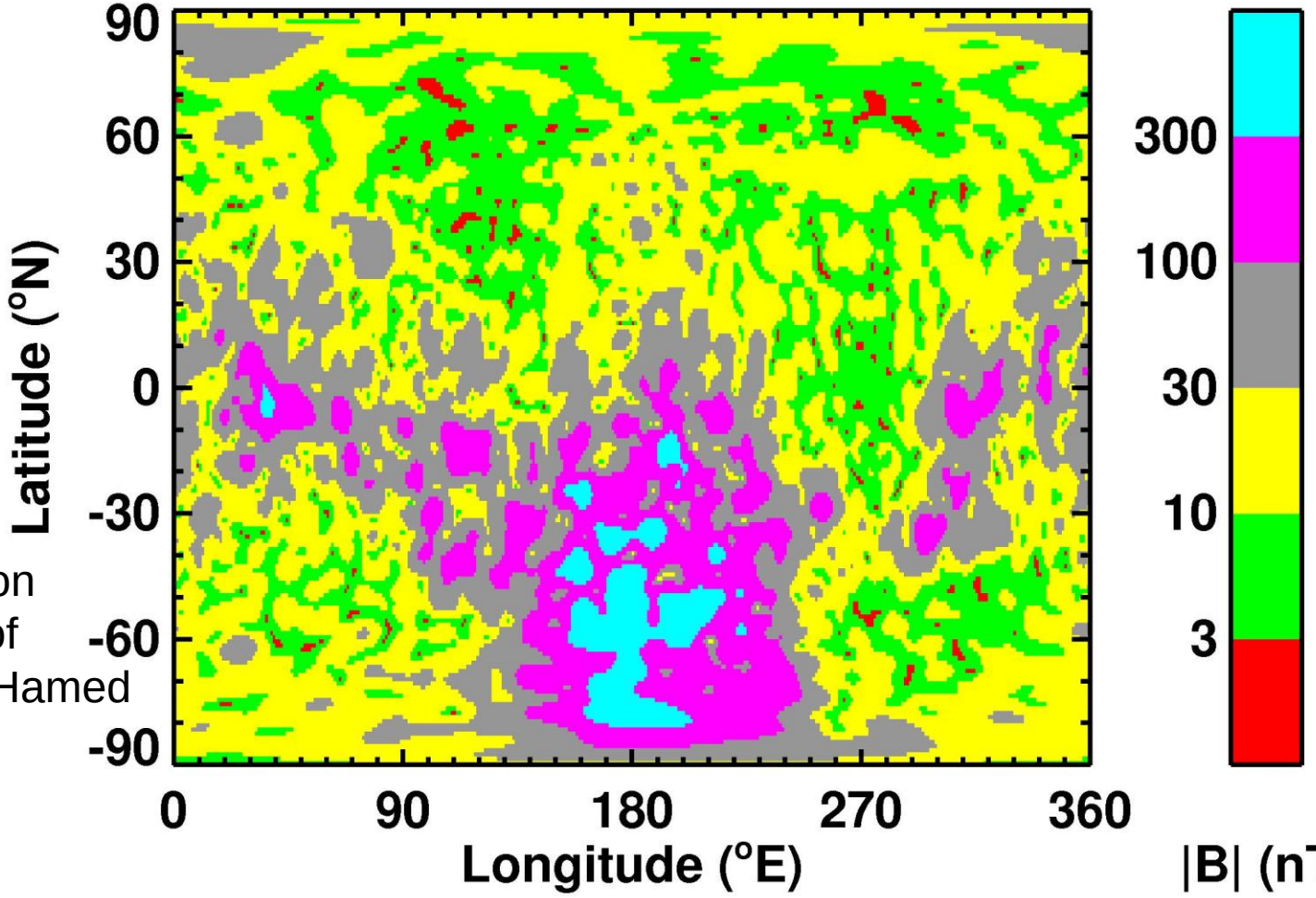
www.windows2universe.org

Mars magnetic field



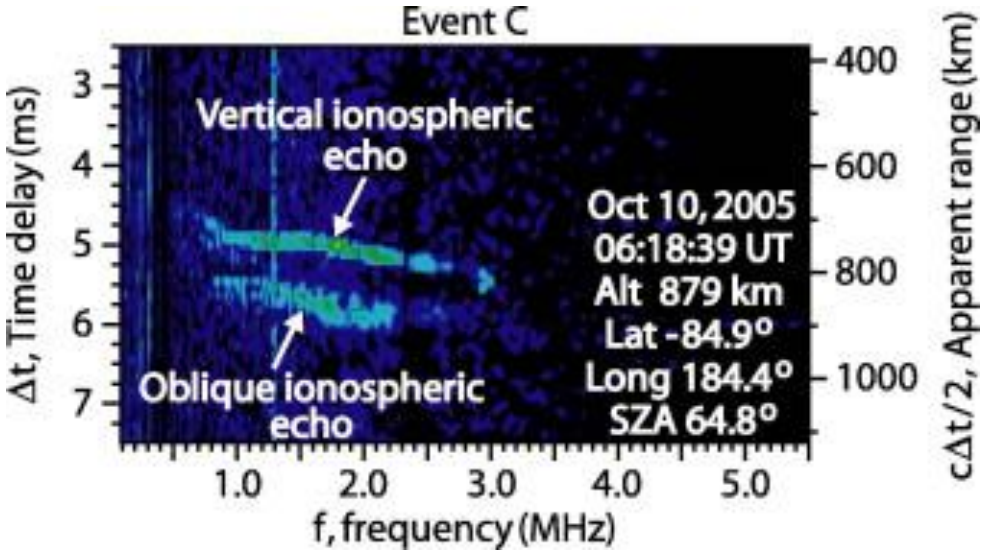
Brain (2002)

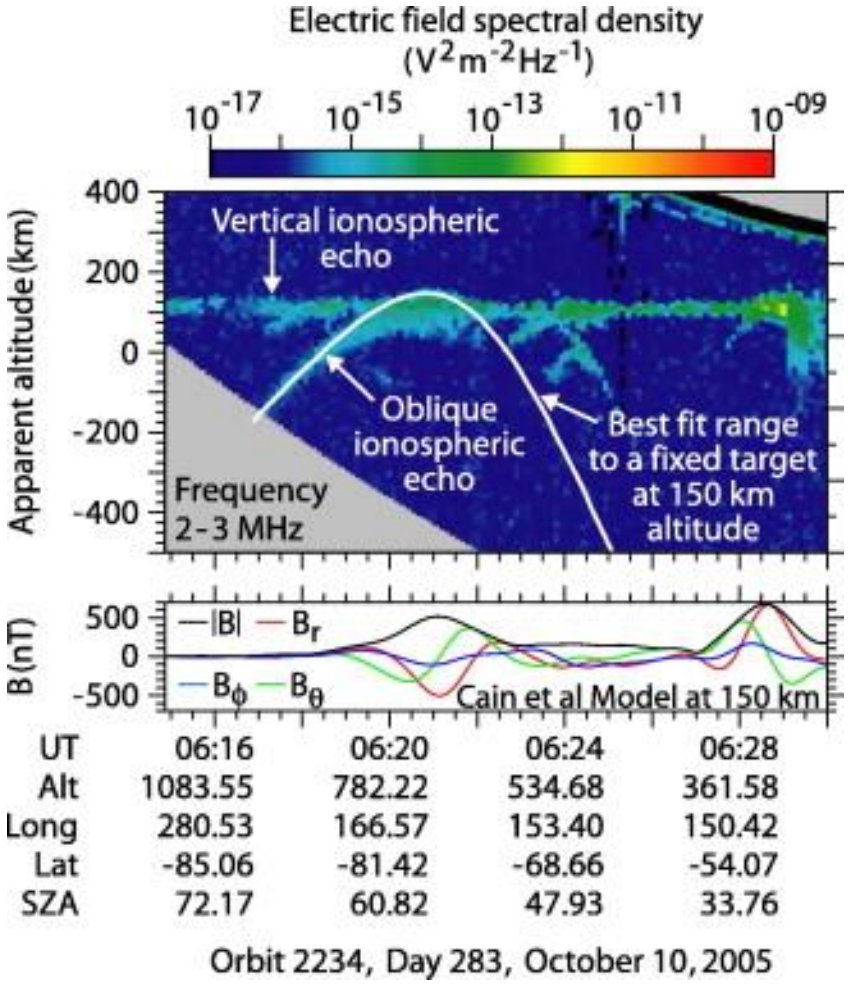
# Magnetic field at Mars




Based on model of Arkani-Hamed (2004)

# What is the ionosphere like in strongly-magnetized regions?

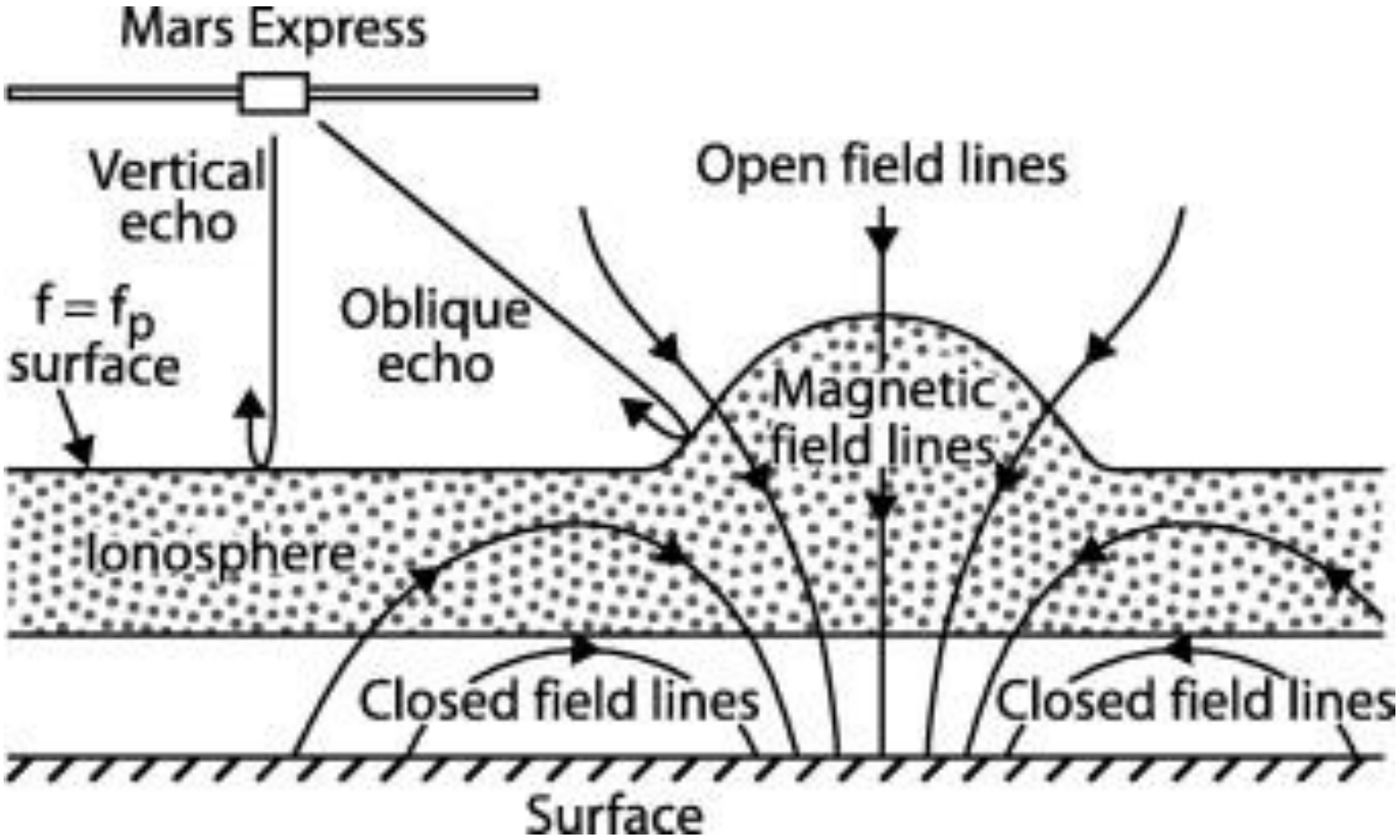



**Oblique echoes seen over strong and vertical crustal magnetic fields**

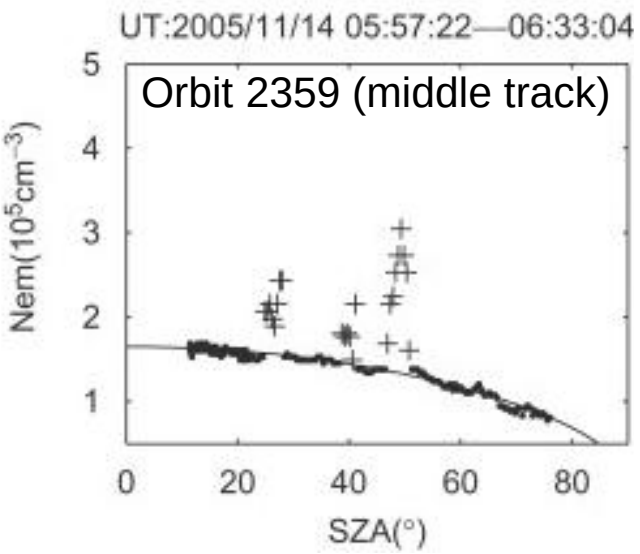
Gurnett et al. (2008)
(both figs)

# Ionosphere is “inflated”




Gurnett et al. (2008)

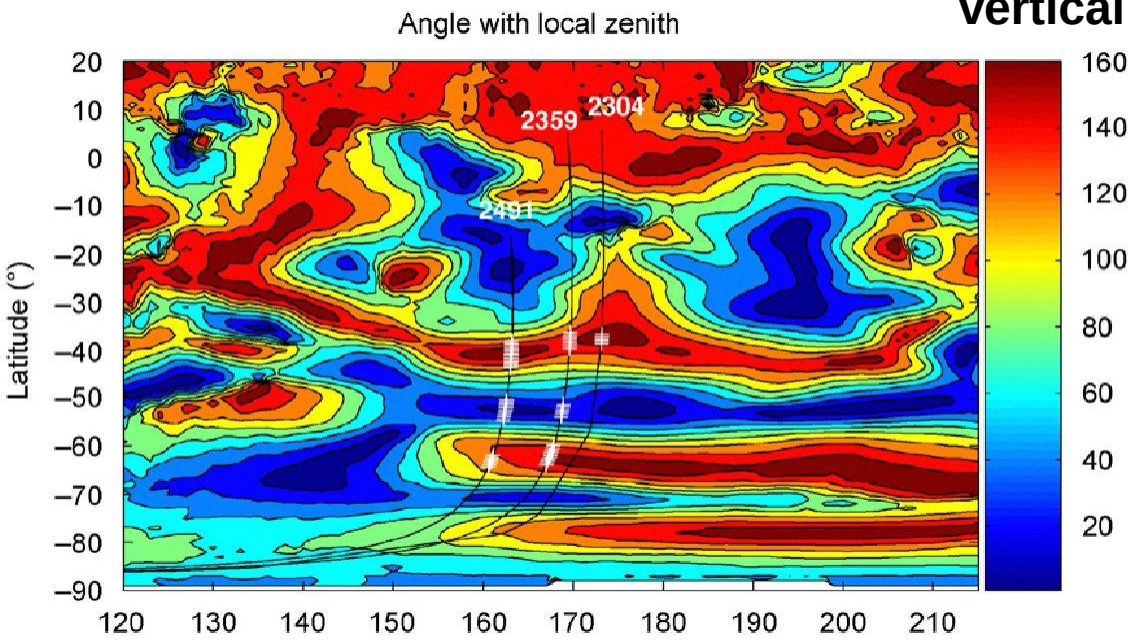
# Enhancements are localized




Nielsen et al. (2007)

**Peak electron densities**

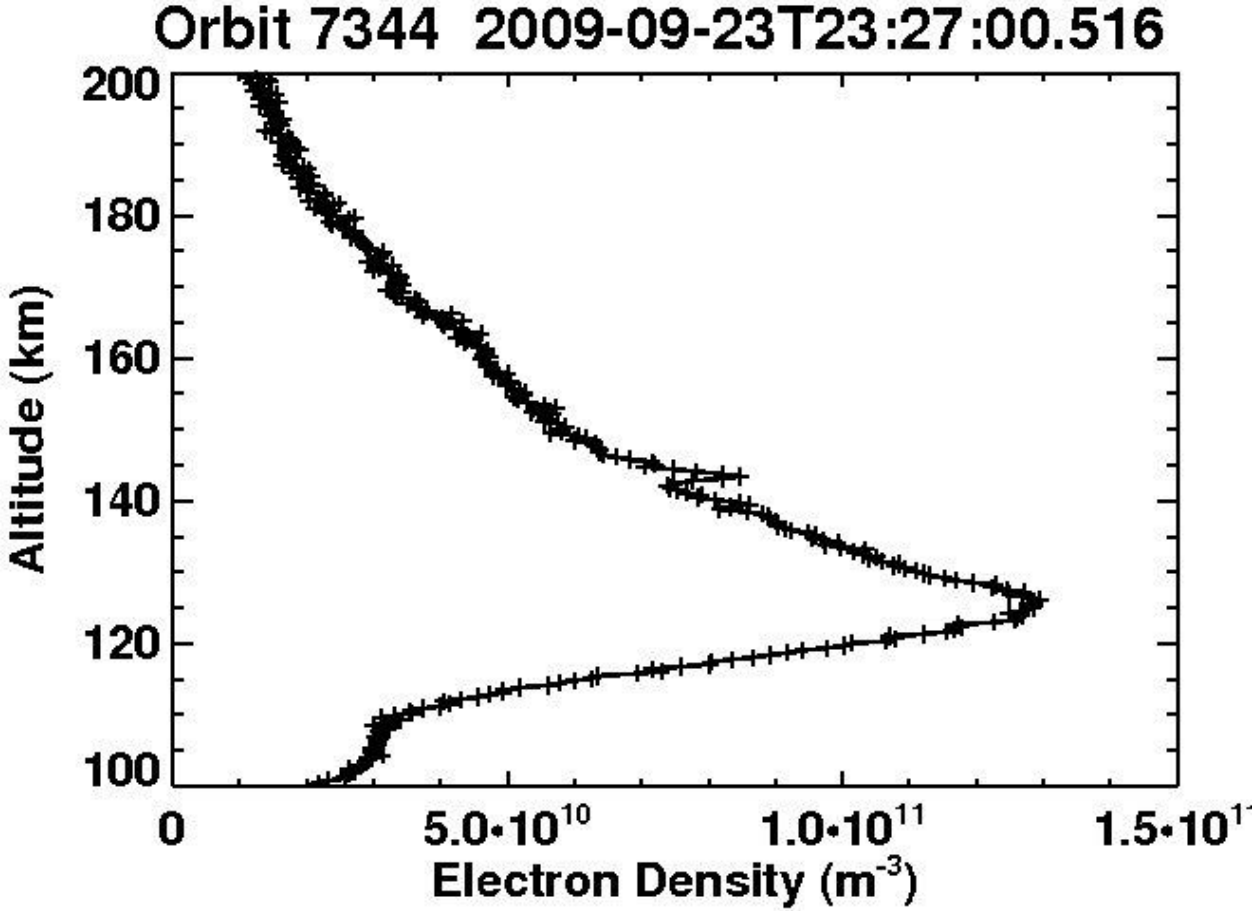
**Angle between field and vertical**




Nielsen et al. (2007)

**Enhancements seen over strong and vertical crustal magnetic fields**

# Radio occultation view differs




MEX RS electron density profile from orbit 7344 on 23 September 2009 at solar zenith angle of 52 degrees, latitude 34ºS, longitude 137ºE.
Withers et al. (2012)

# Exploring the ionosphere of Mars

- MARSIS and radio occultations are highly complementary for exploring ionospheric spatial and temporal structure
- Key questions are the effects of the Sun and magnetic fields

- MAVEN mission (2013) will reveal chemistry, dynamics, and energetics

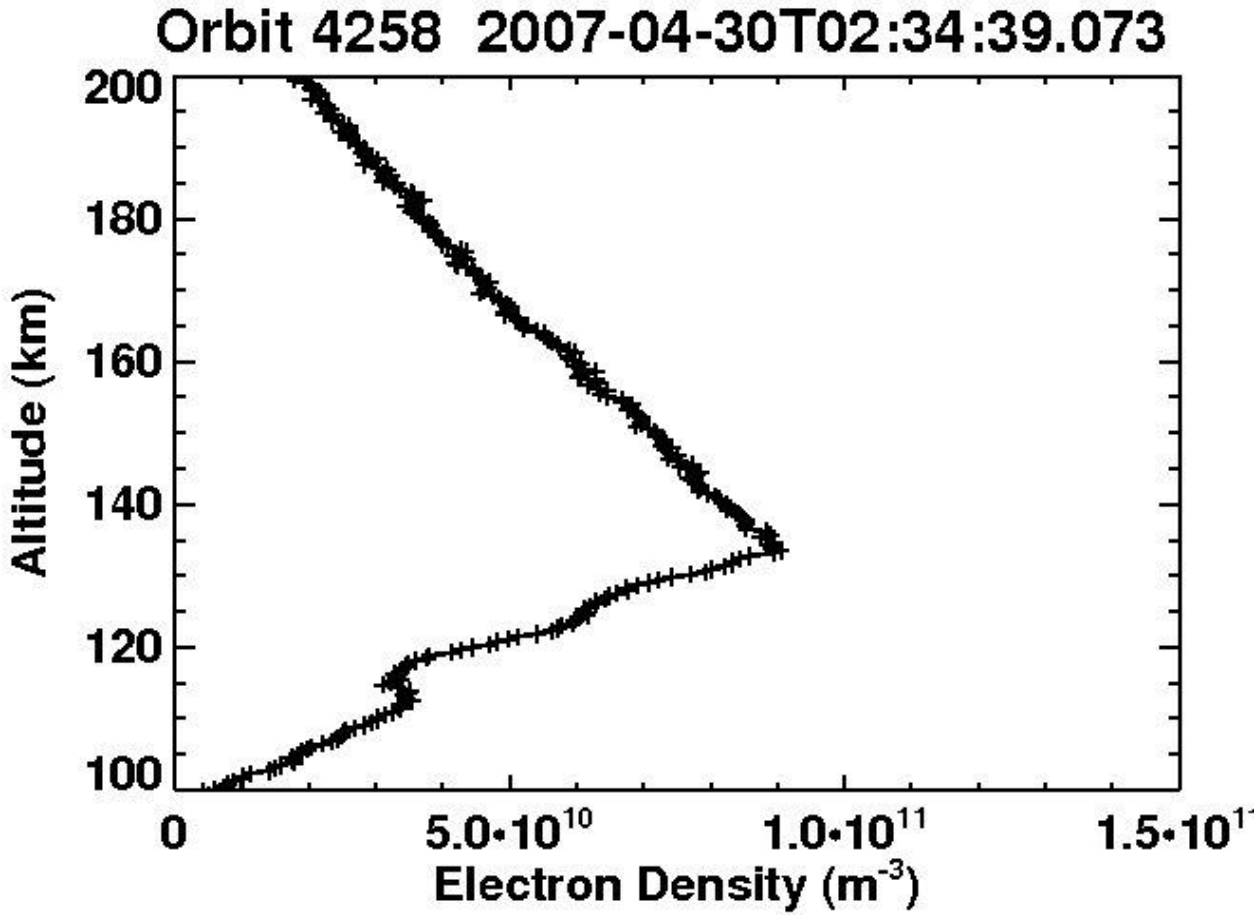



Figure 2A: Electron density profile from orbit 4258 on 30 April 2007 at solar zenith angle of 68 degrees, latitude 46$^{o}$N, longitude 278$^{o}$E.

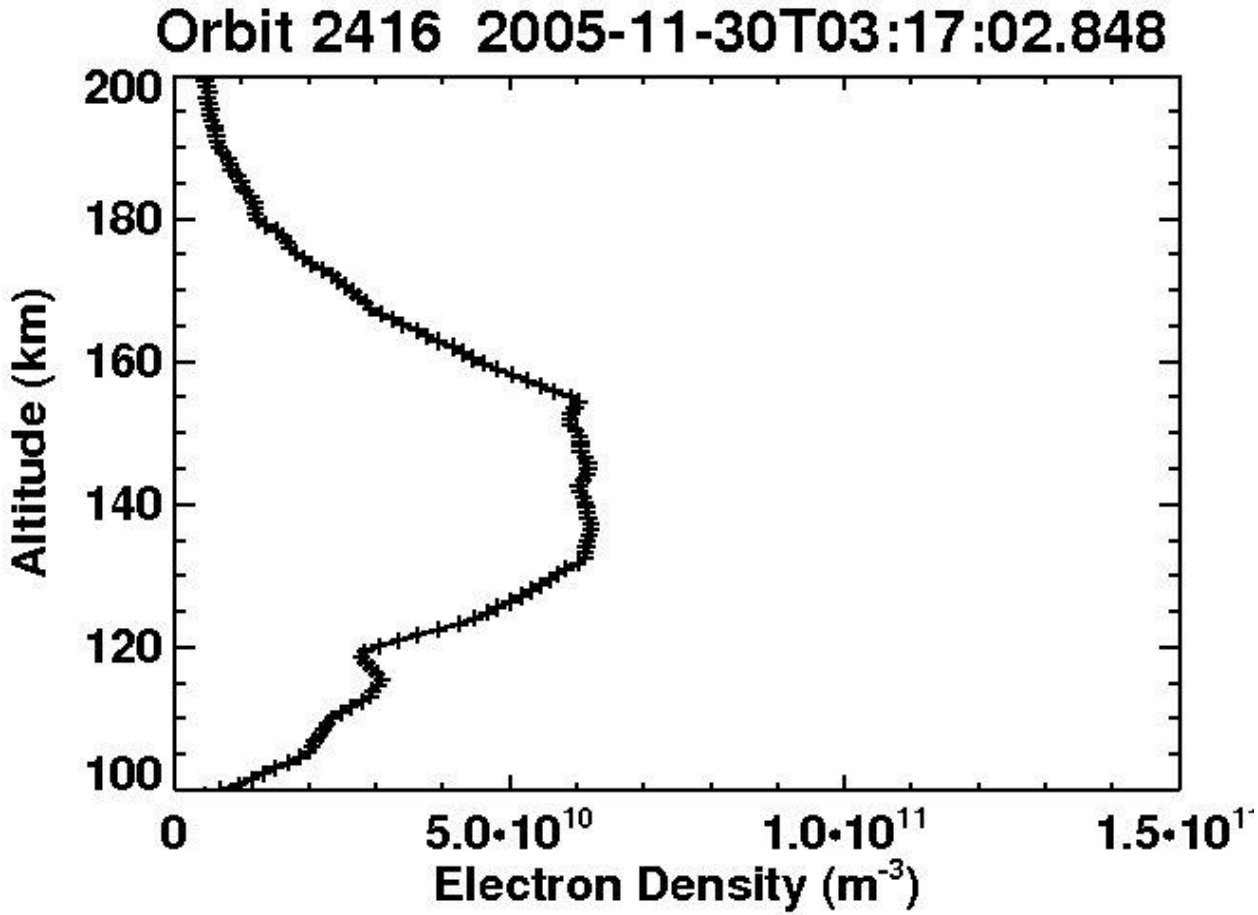



Figure 2B: Electron density profile from orbit 2416 on 30 November 2005 at solar zenith angle of 79 degrees, latitude 67$^{o}$N, longitude 42$^{o}$E.

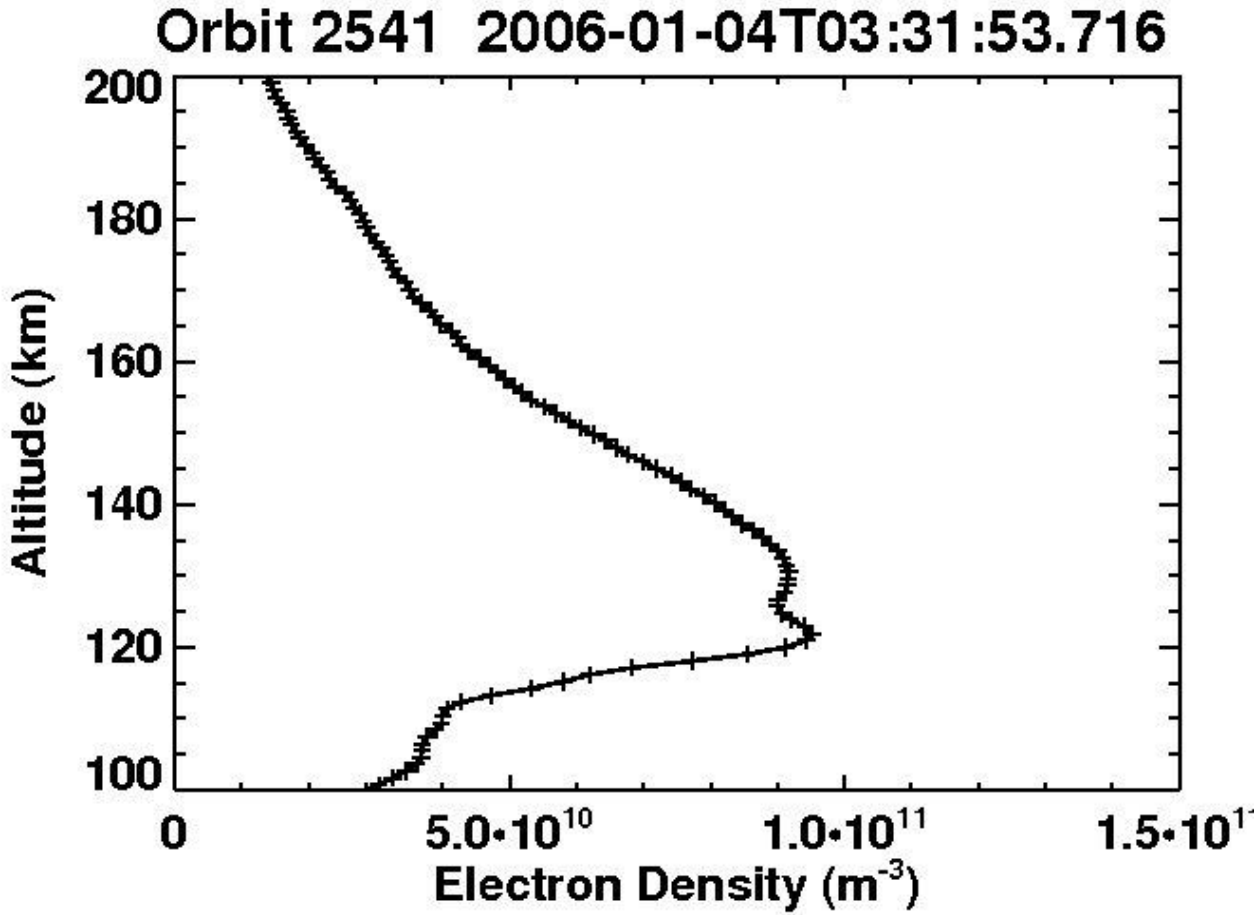



Figure 2C: Electron density profile from orbit 2541 on 4 January 2006 at solar zenith angle of 66 degrees, latitude 60$^{o}$N, longitude 17$^{o}$E.

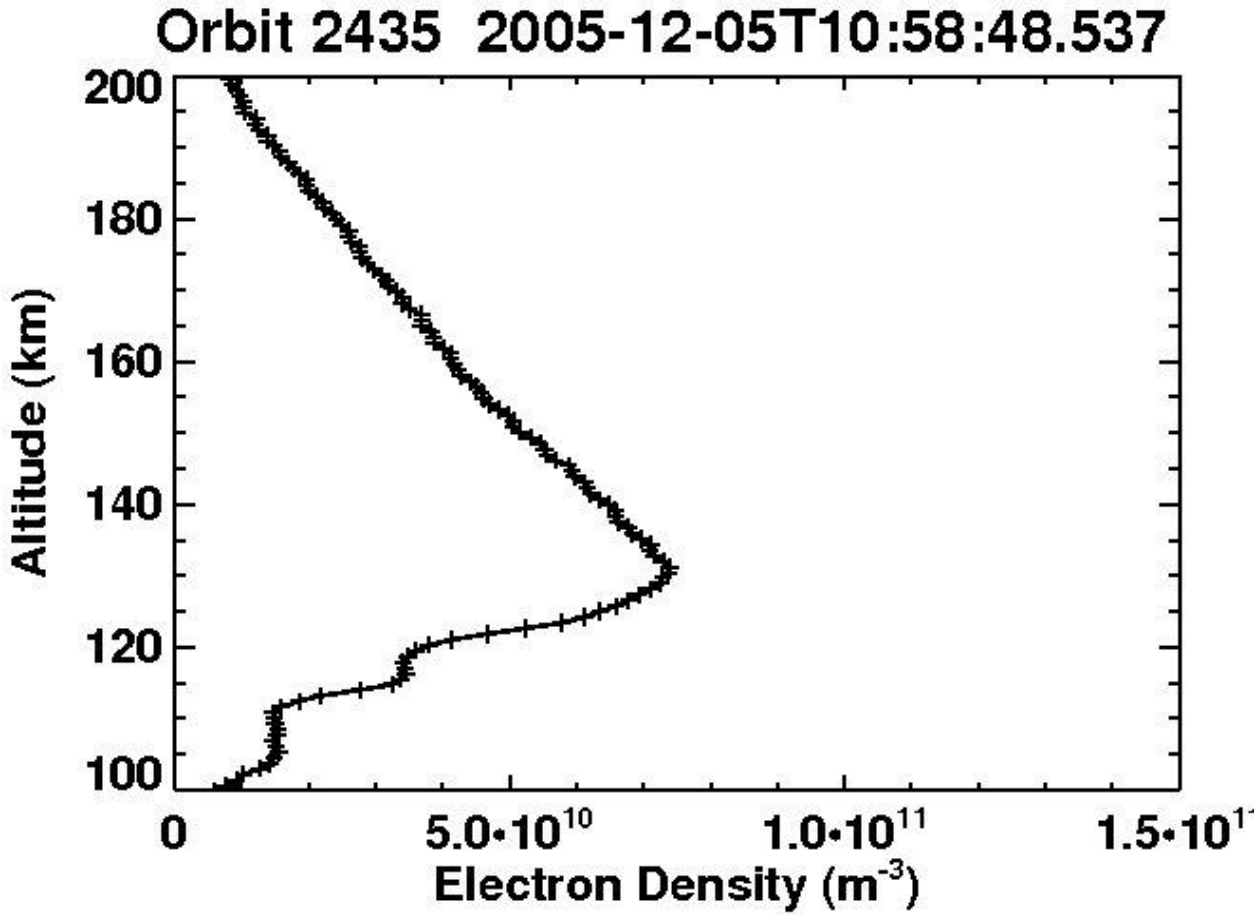



Figure 2D: Electron density profile from orbit 2435 on 5 December 2005 at solar zenith angle of 78 degrees, latitude 67°N, longitude 333°E.

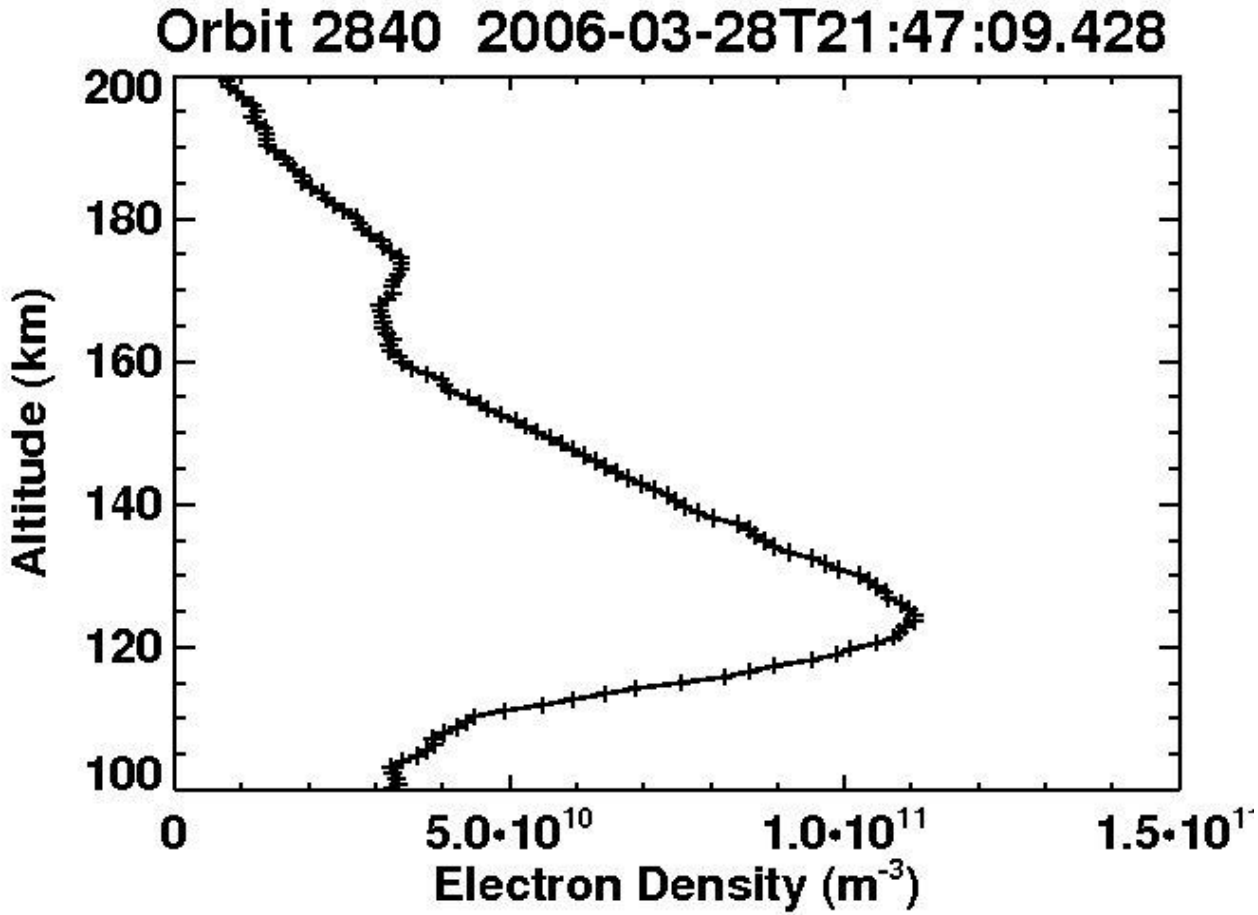



Figure 2E: Electron density profile from orbit 2840 on 28 March 2006 at solar zenith angle of 55 degrees, latitude 15$^{o}$N, longitude 217$^{o}$E.

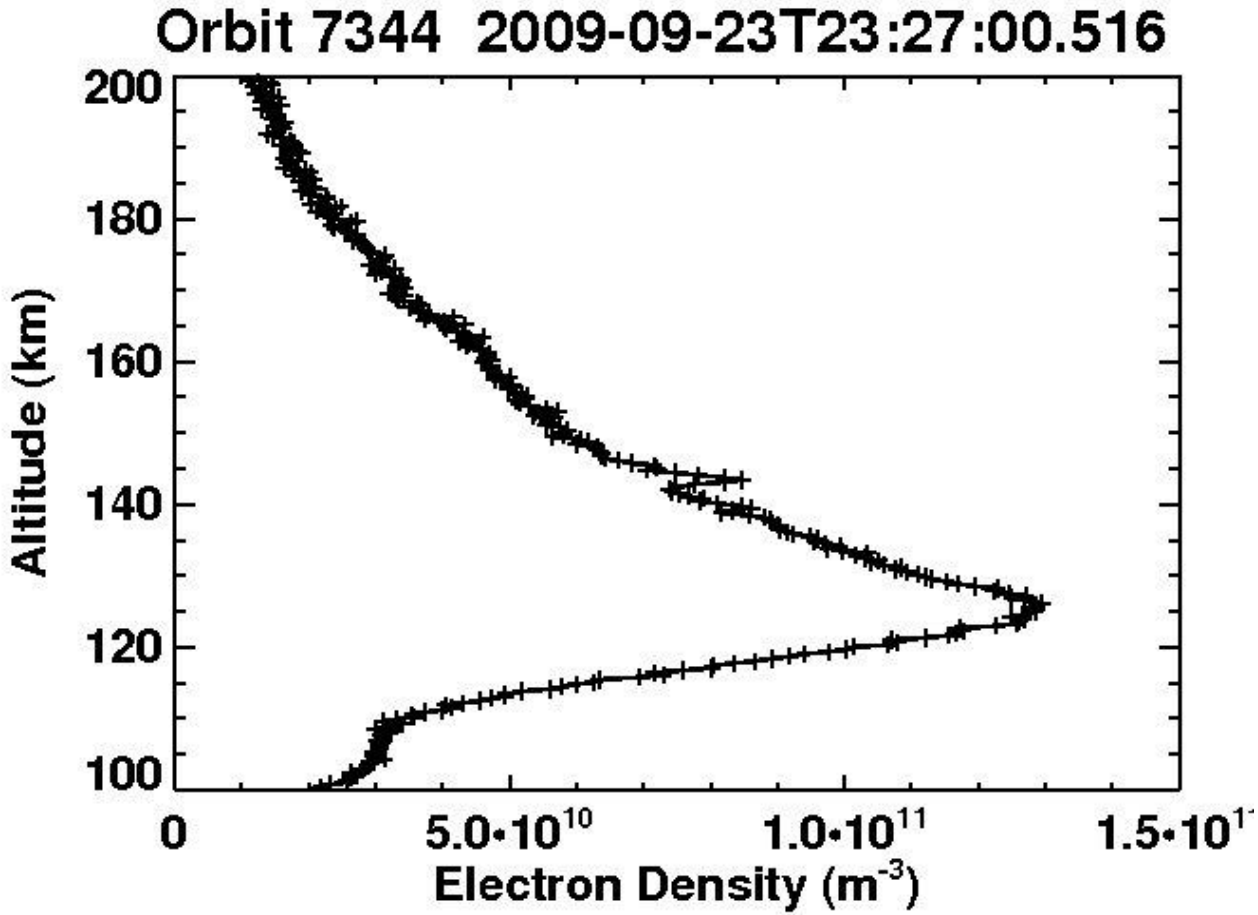



Figure 2F: Electron density profile from orbit 7344 on 23 September 2009 at solar zenith angle of 52 degrees, latitude 34$^{o}$S, longitude 137$^{o}$E.