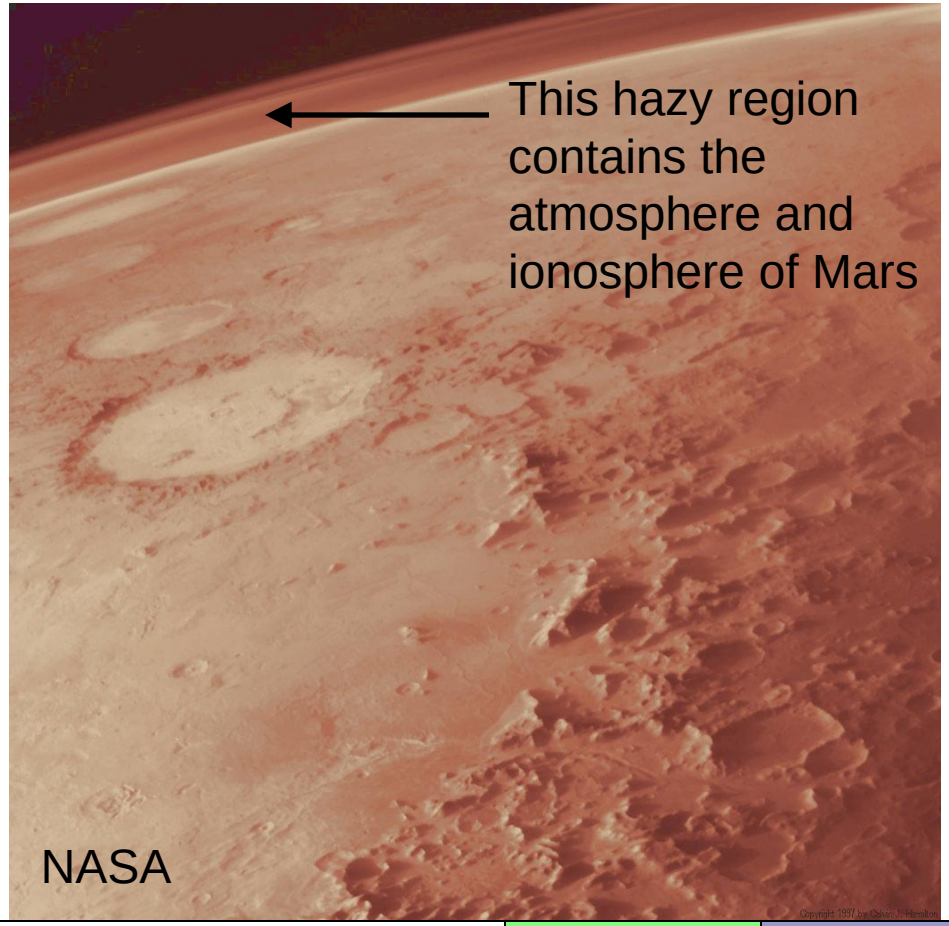
Exploring the ionosphere of Mars



Paul Withers
Boston University
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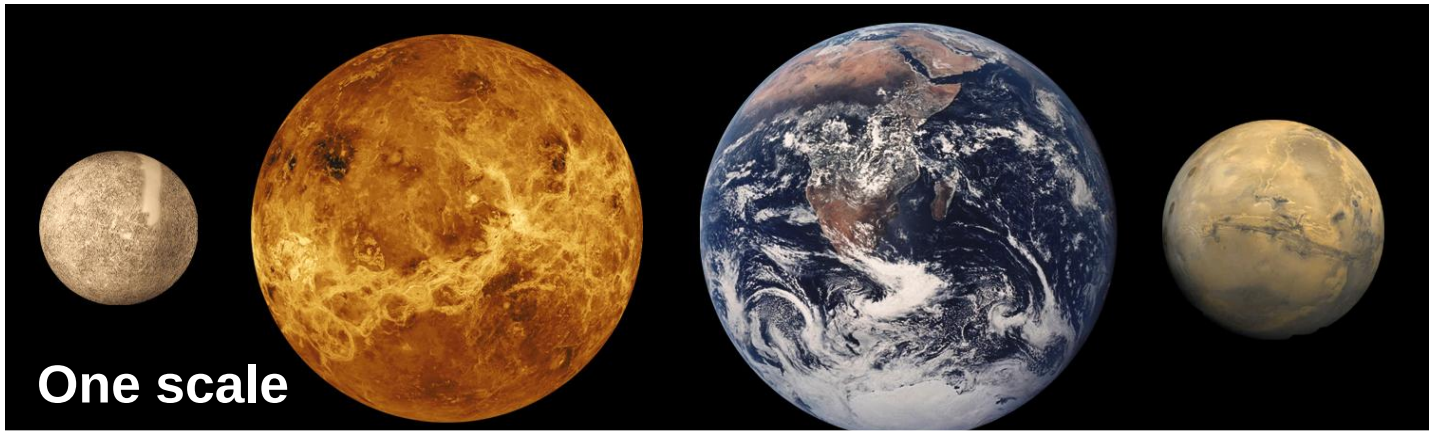
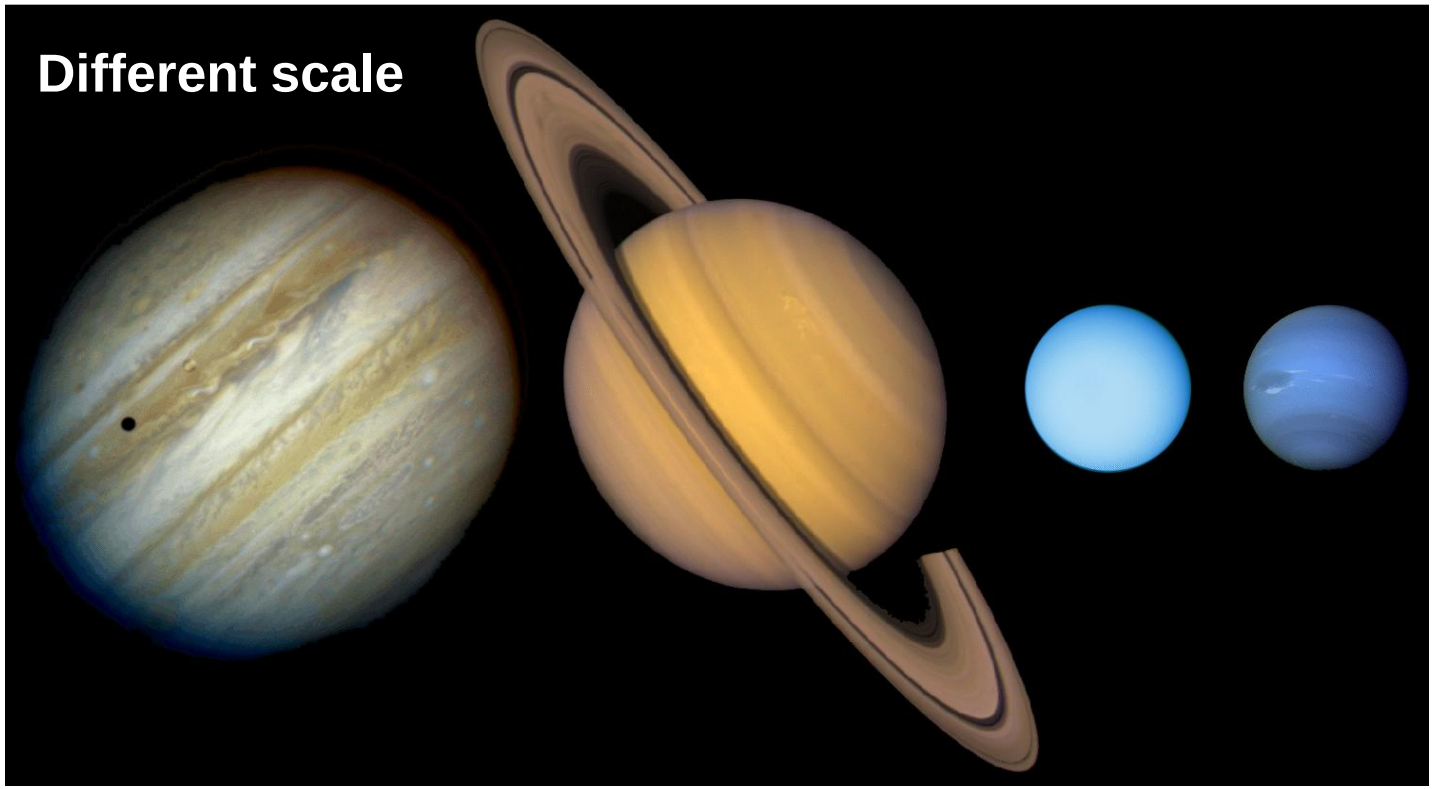
Department of Physics and Astronomy, University of Iowa, IA

Tuesday 2012.03.20
13:30





www.solarviews.com

This is ⟵ Mars

0.5 x R-Earth

1.5 AU from Sun

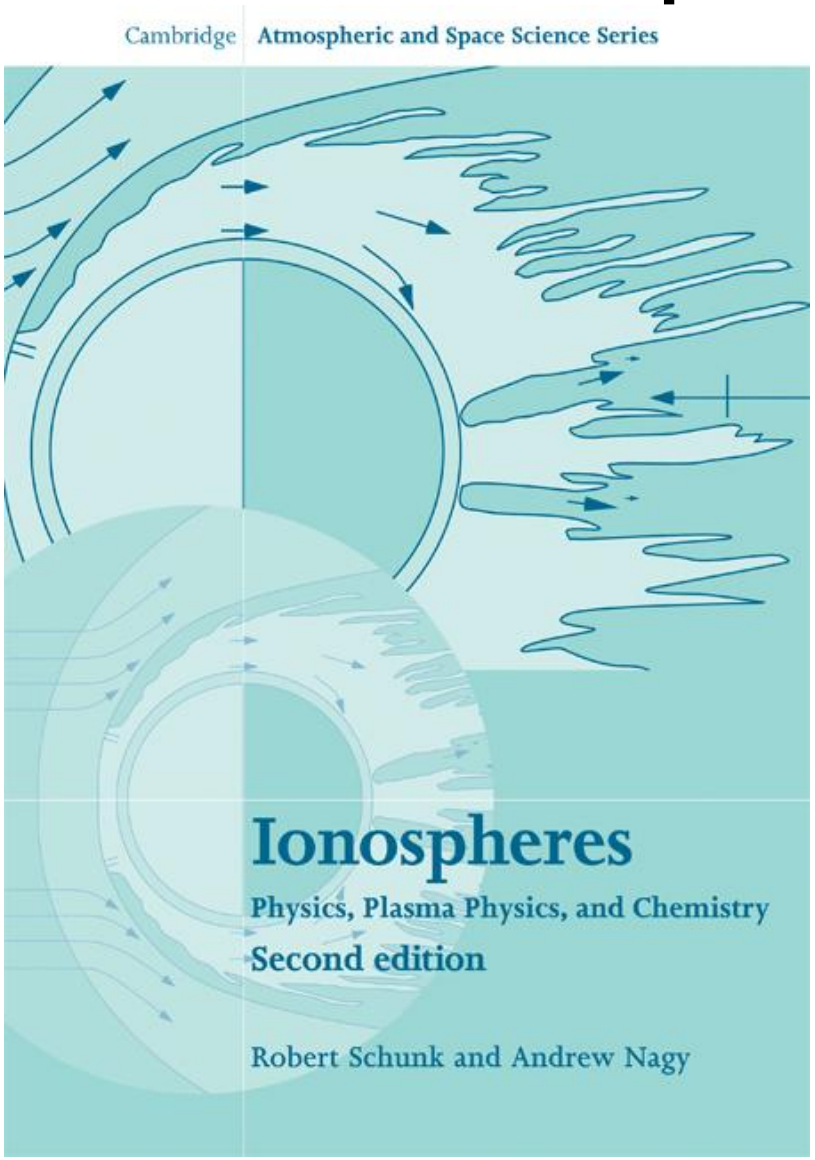
Same rotation rate as Earth

Carbon dioxide atmosphere

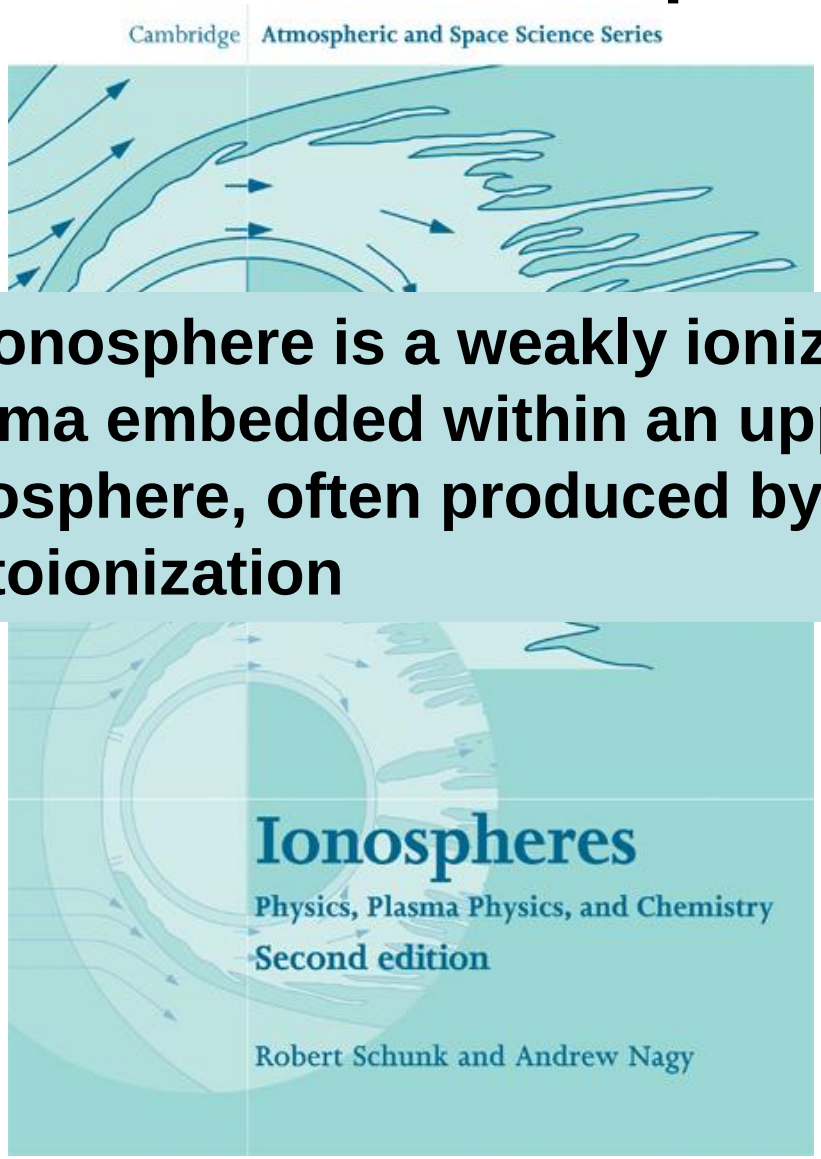
100x smaller surface pressure

Target of many spacecraft in last 15 years

What is an ionosphere?



What is an ionosphere?

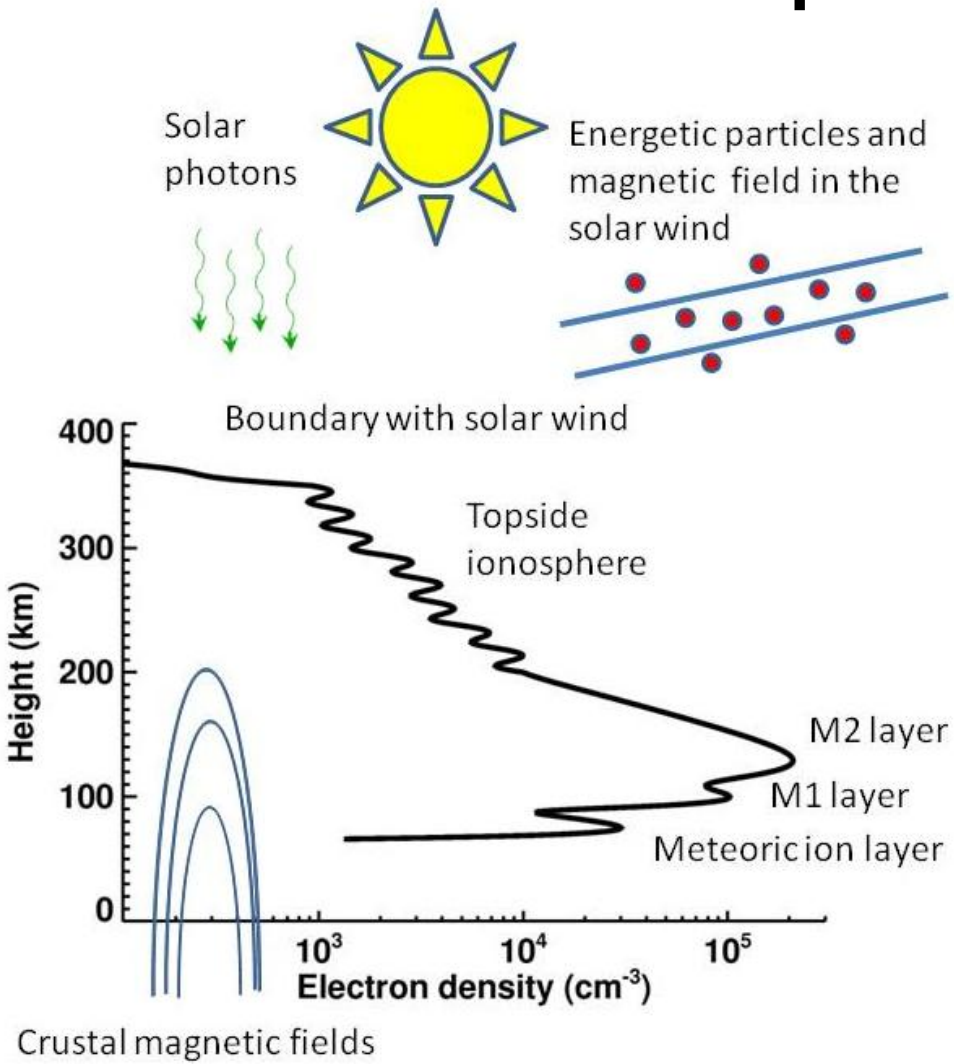


An ionosphere is a weakly ionized plasma embedded within an upper atmosphere, often produced by photoionization

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

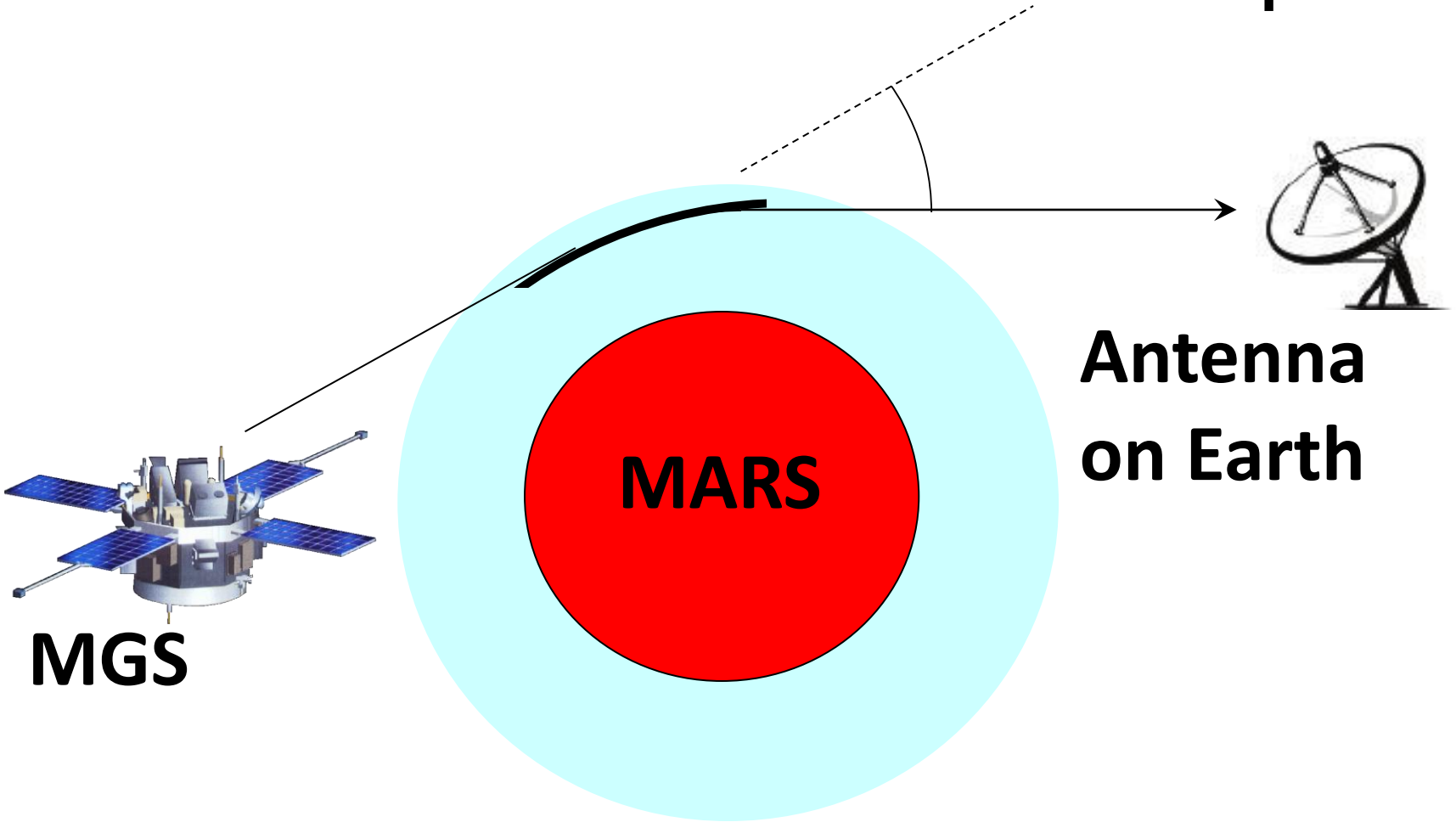
Transport only important in topside ionosphere

Withers et al. (2009) Decadal Survey white paper

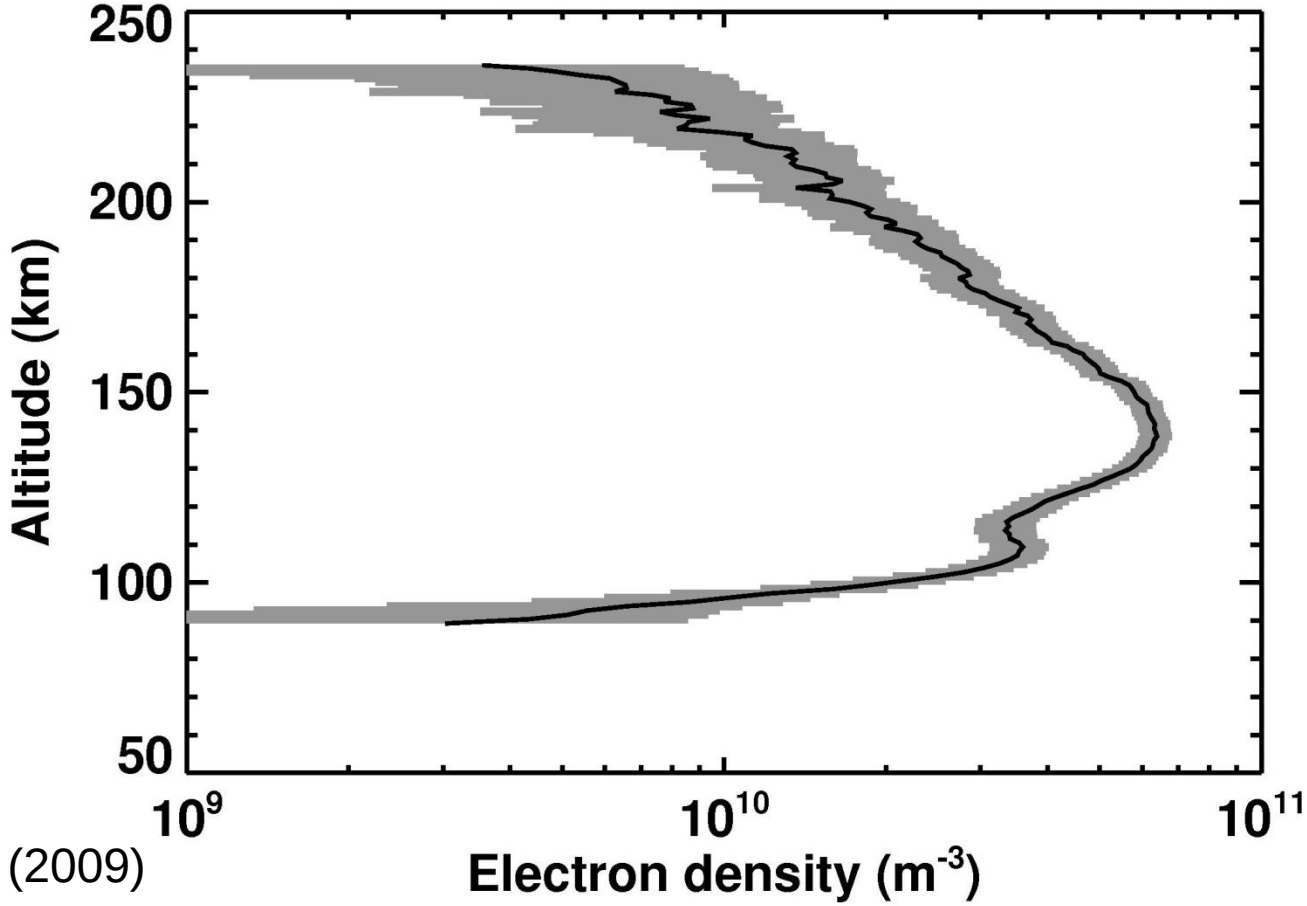
Goal for this talk

- Two measurement techniques are highly complementary to each other
- Show several examples of situations where using both datasets is helpful
- Science themes are spatial structure of Mars ionosphere, influences of the Sun and magnetic fields

Radio occultation technique

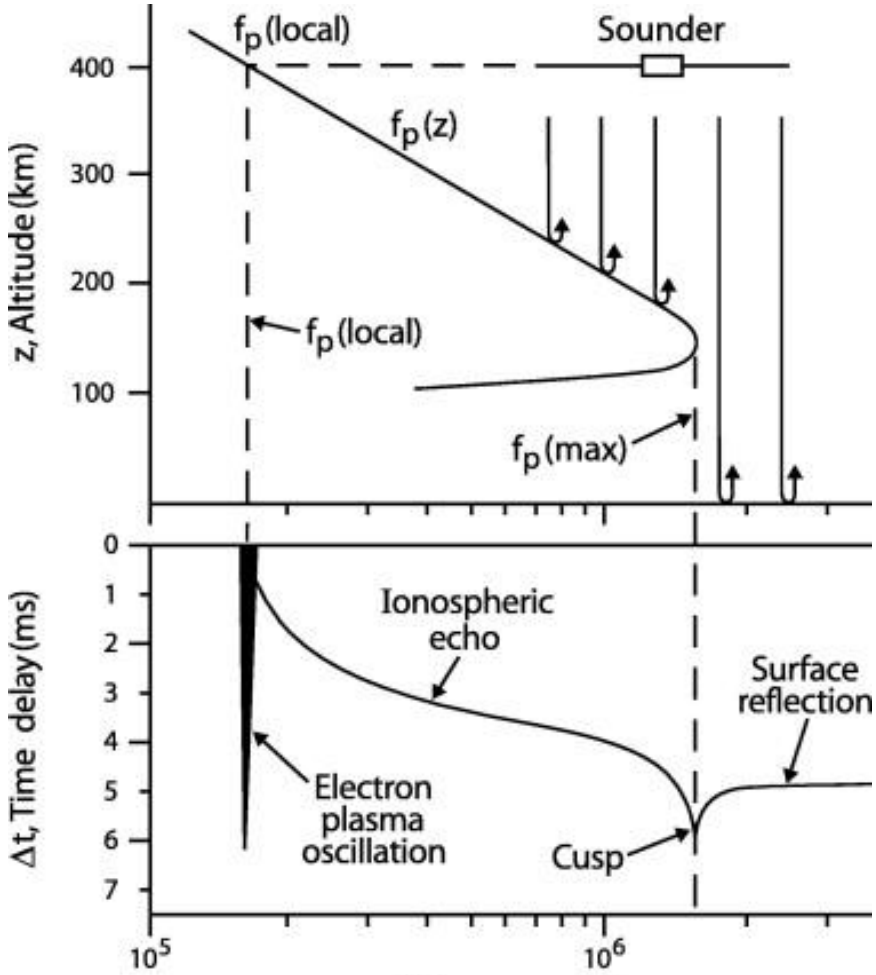


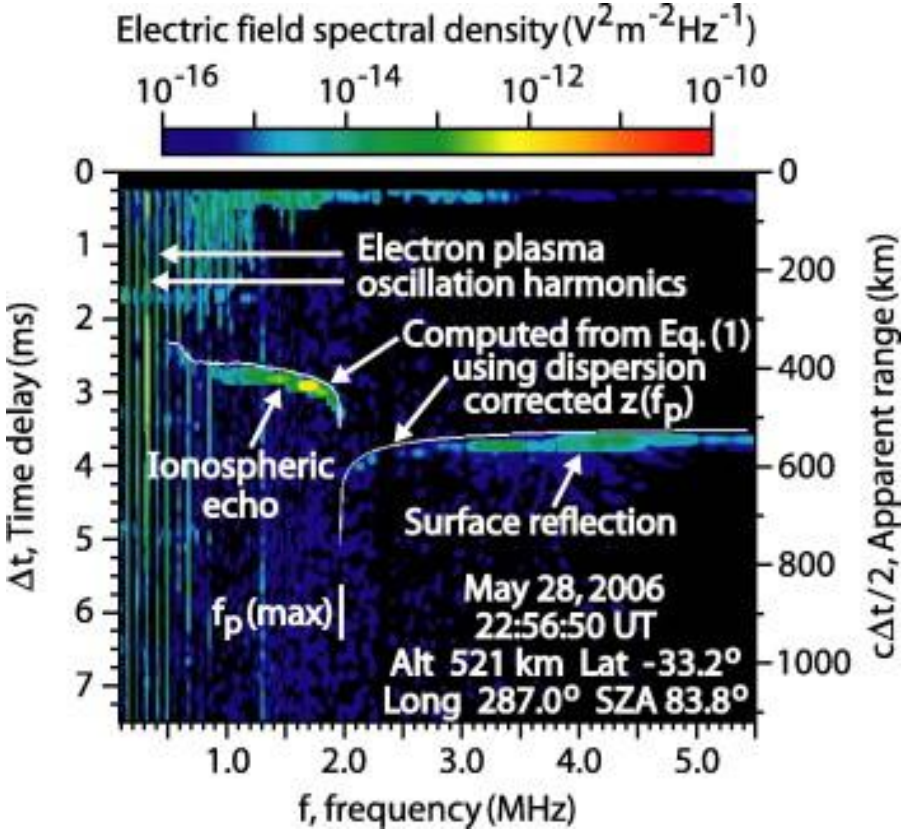
Radio occultation results



Withers et al. (2009)

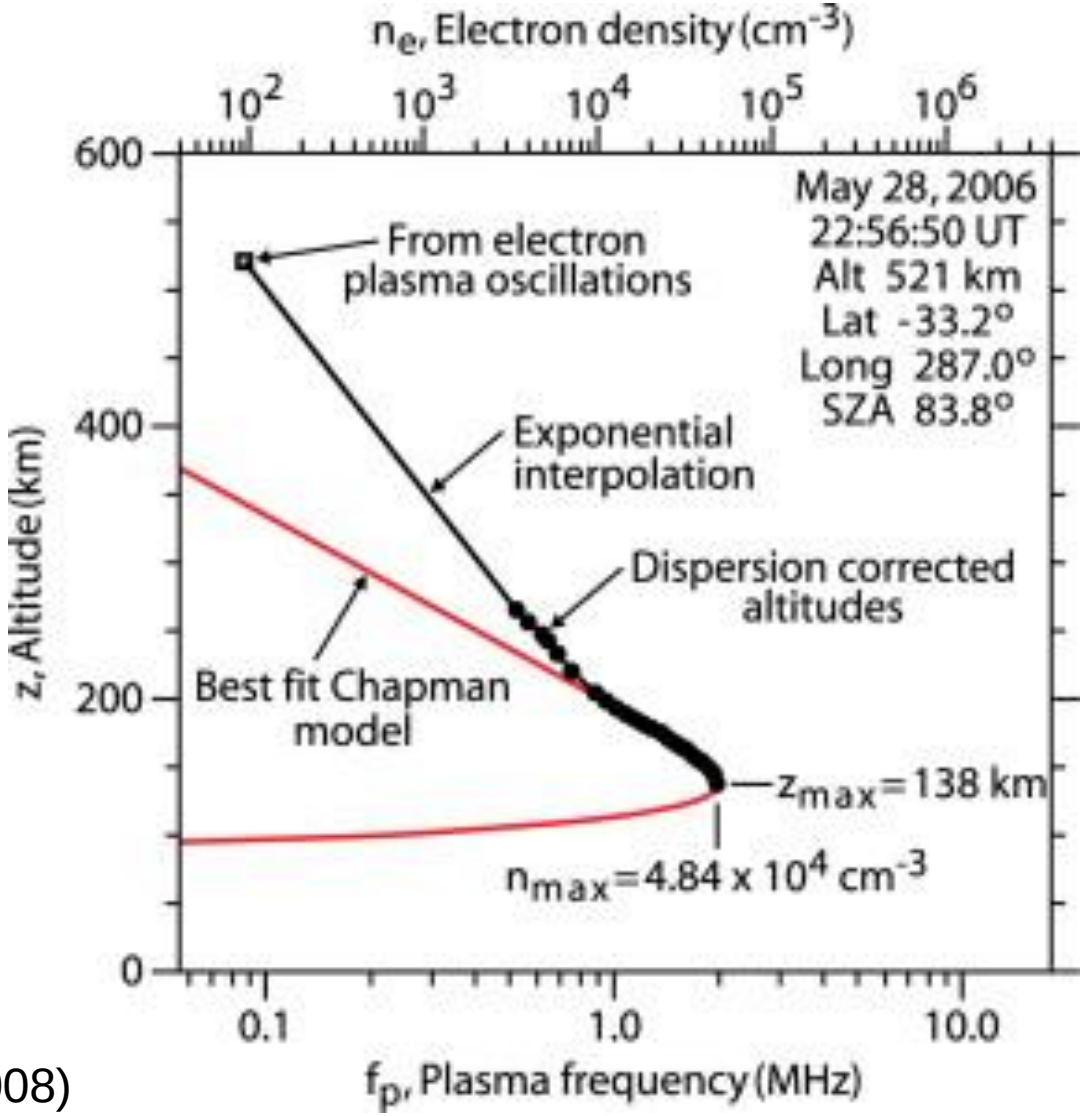
MARSIS radar sounding





Gurnett et al. (2008)

MARSIS results



Gurnett et al. (2008)

Complementary techniques

Radio occultation

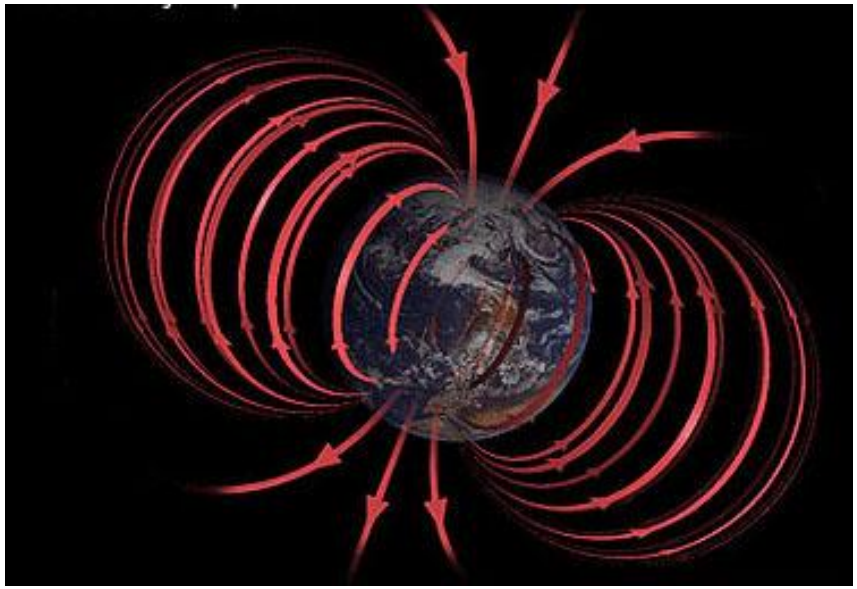
- Precise vertical scale
- 1 km vertical resolution
- Full vertical coverage
- ~200 km horizontal averaging
- Alias horizontal structure to vertical
- Limited opportunities

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

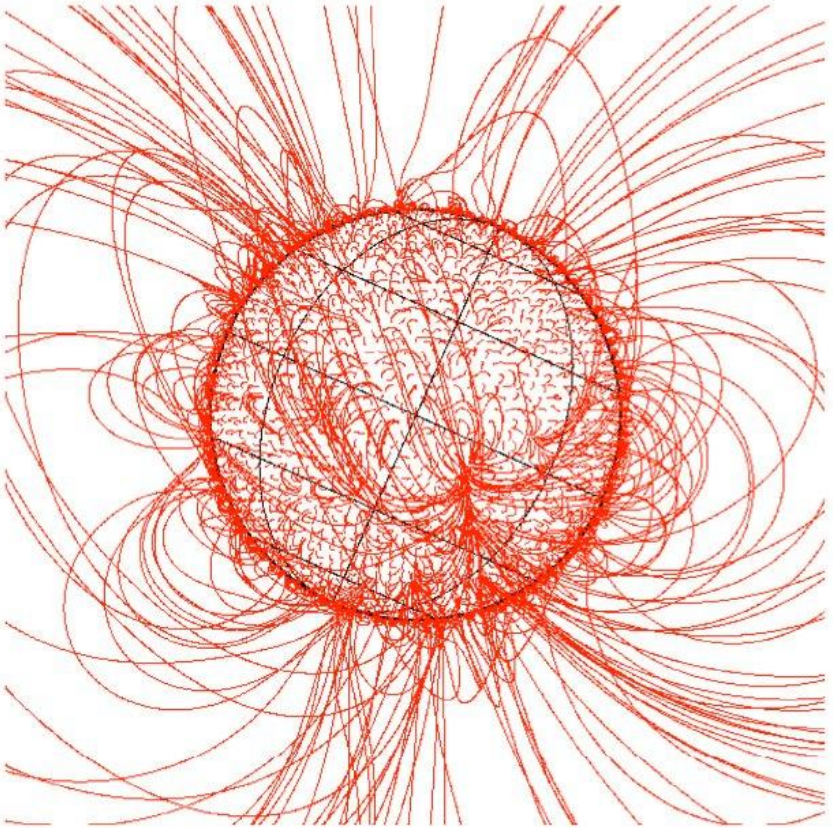
Mars is magnetically crazy

Earth magnetic field



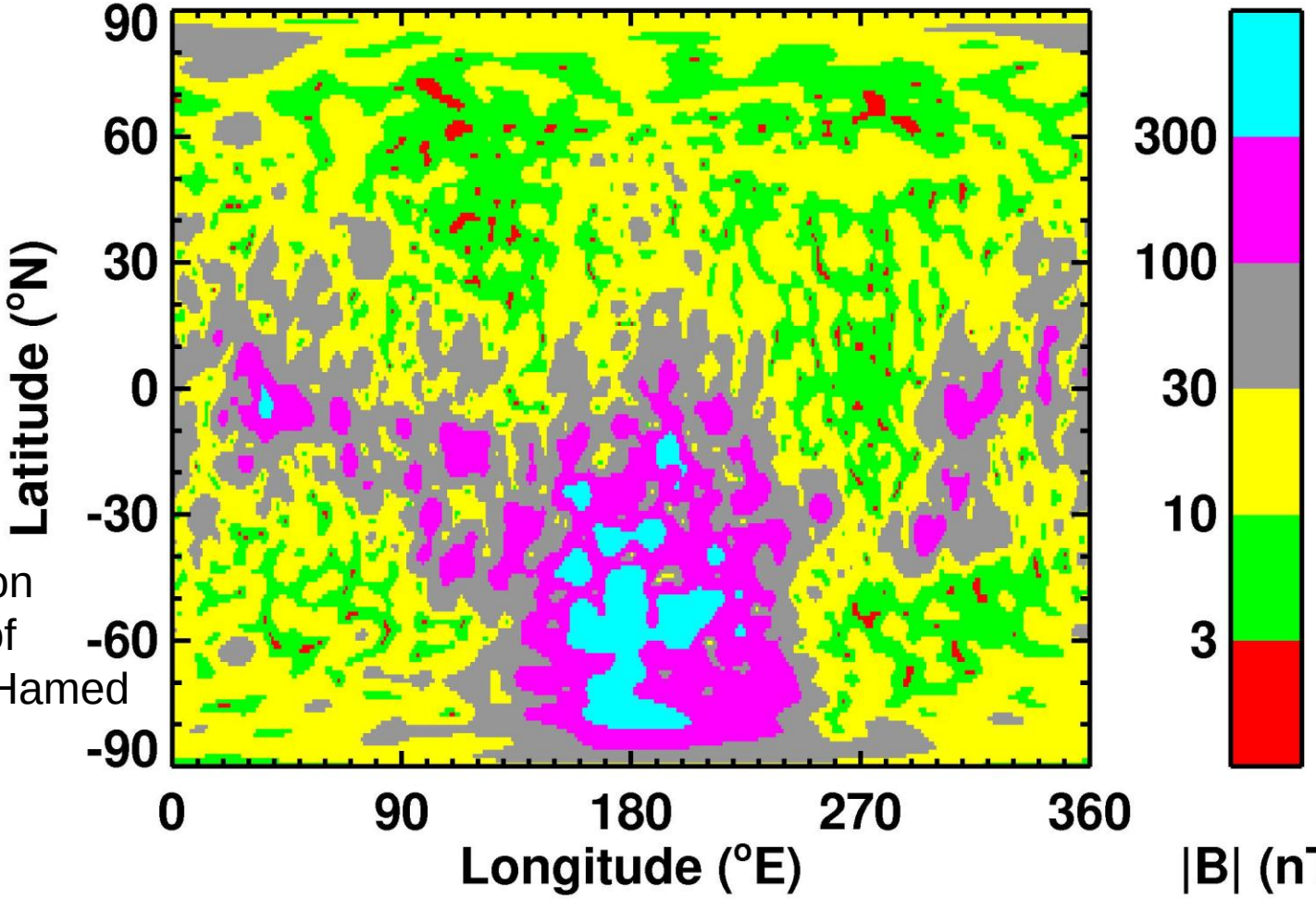
www.windows2universe.org

Mars magnetic field



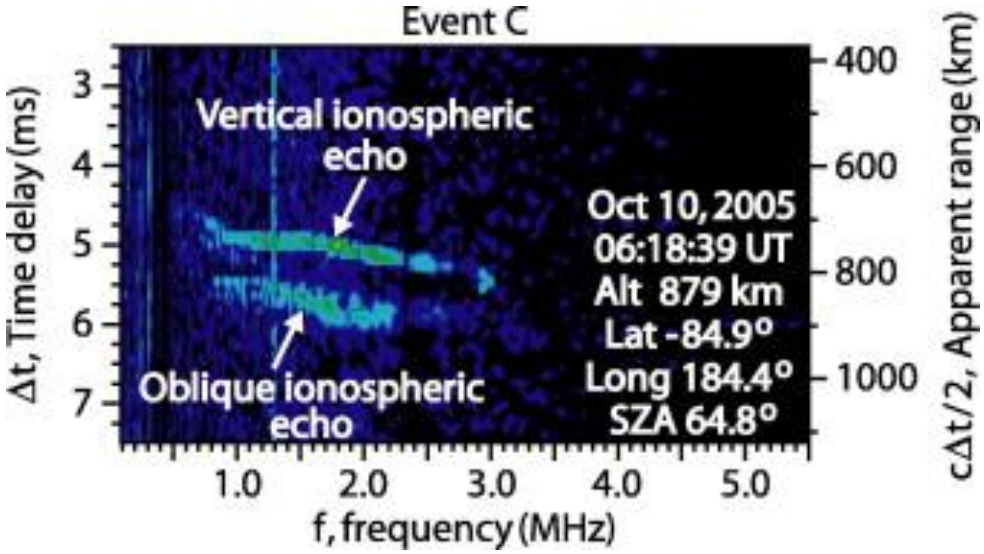
Brain (2002)

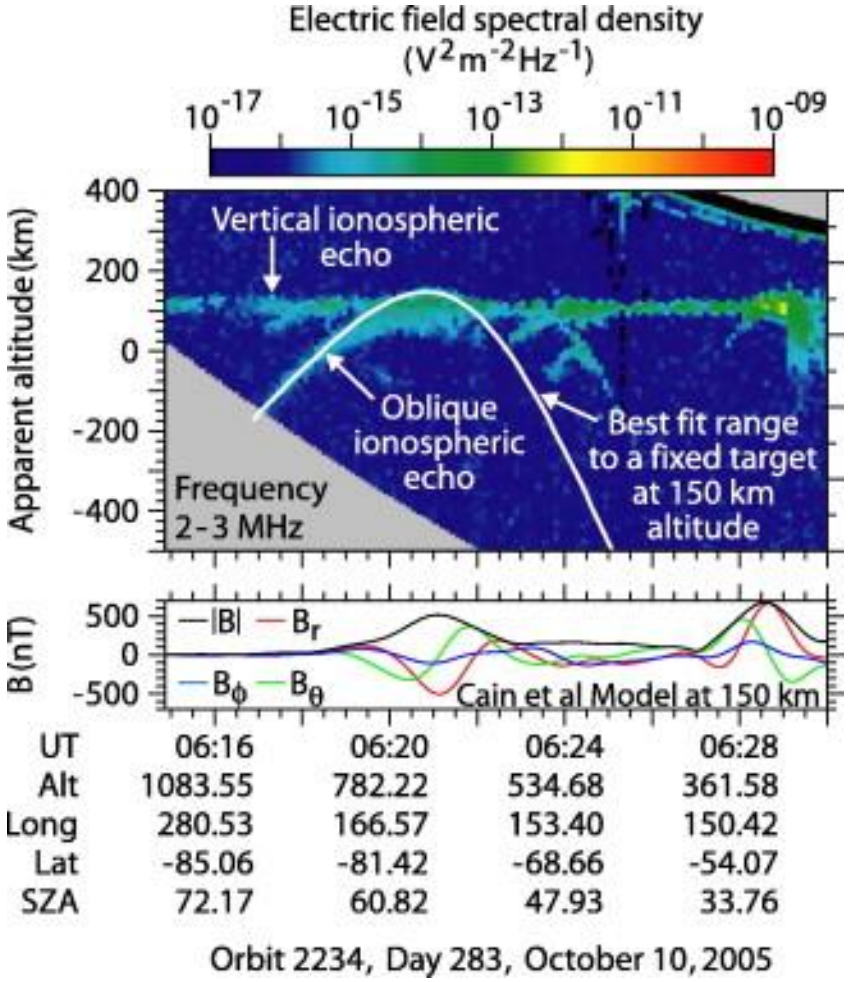
Magnetic field at Mars



Based on model of Arkani-Hamed (2004)

What is the ionosphere like in strongly-magnetized regions?

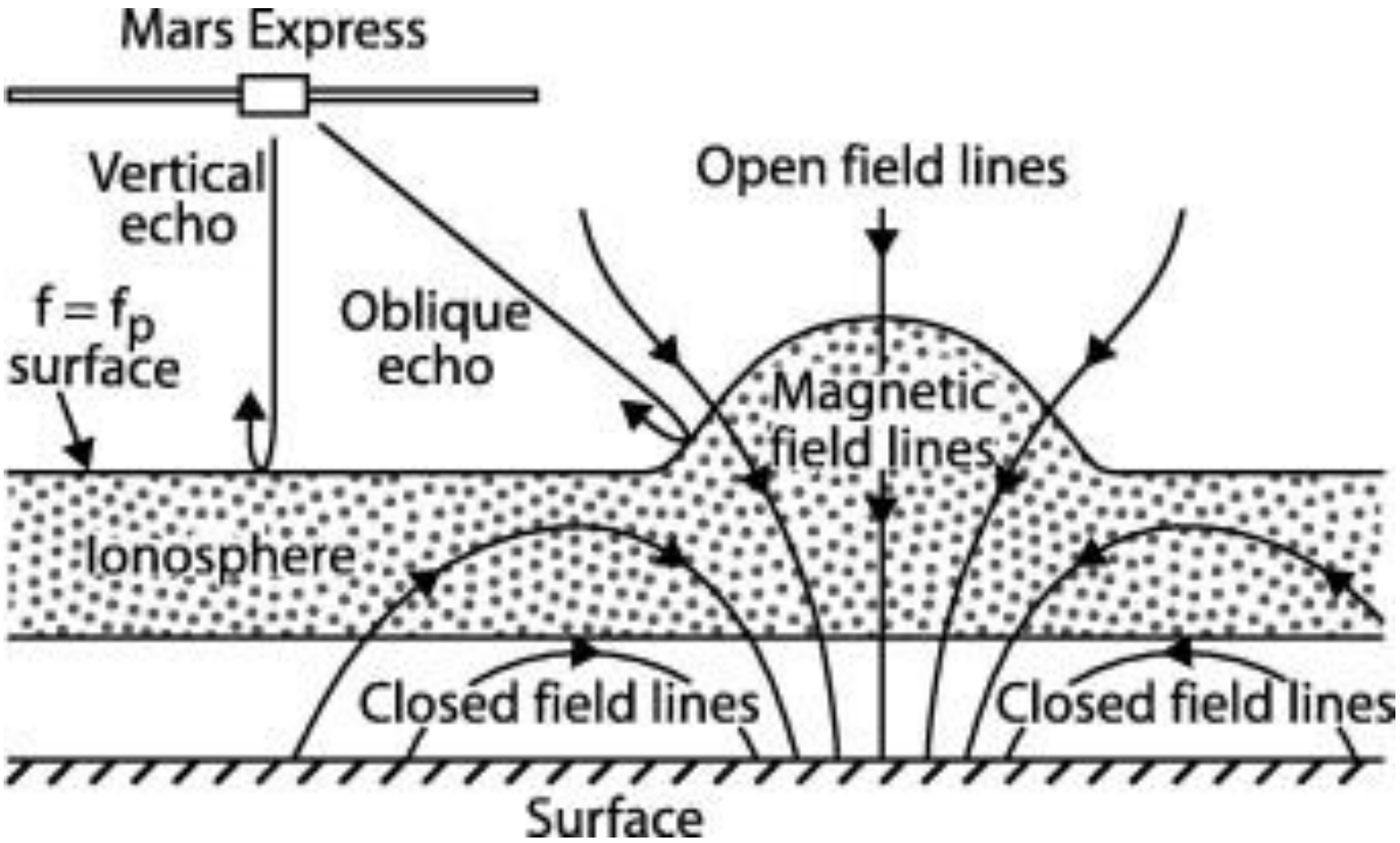




Oblique echoes seen over strong and vertical crustal magnetic fields

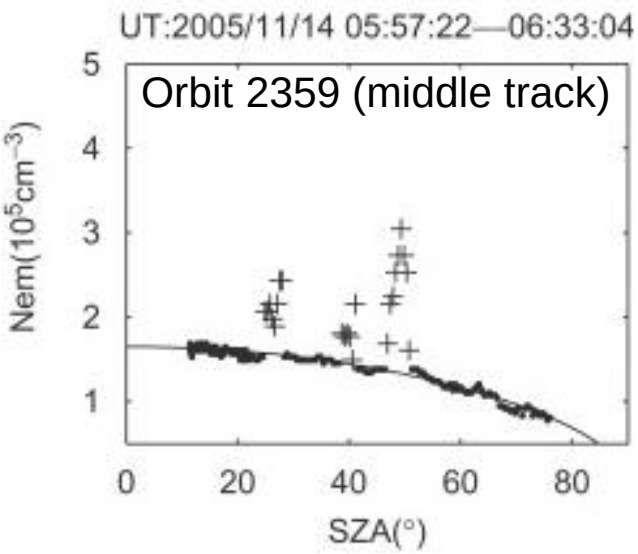
Gurnett et al. (2008)
(both figs)

Ionosphere is “inflated”



Gurnett et al. (2008)

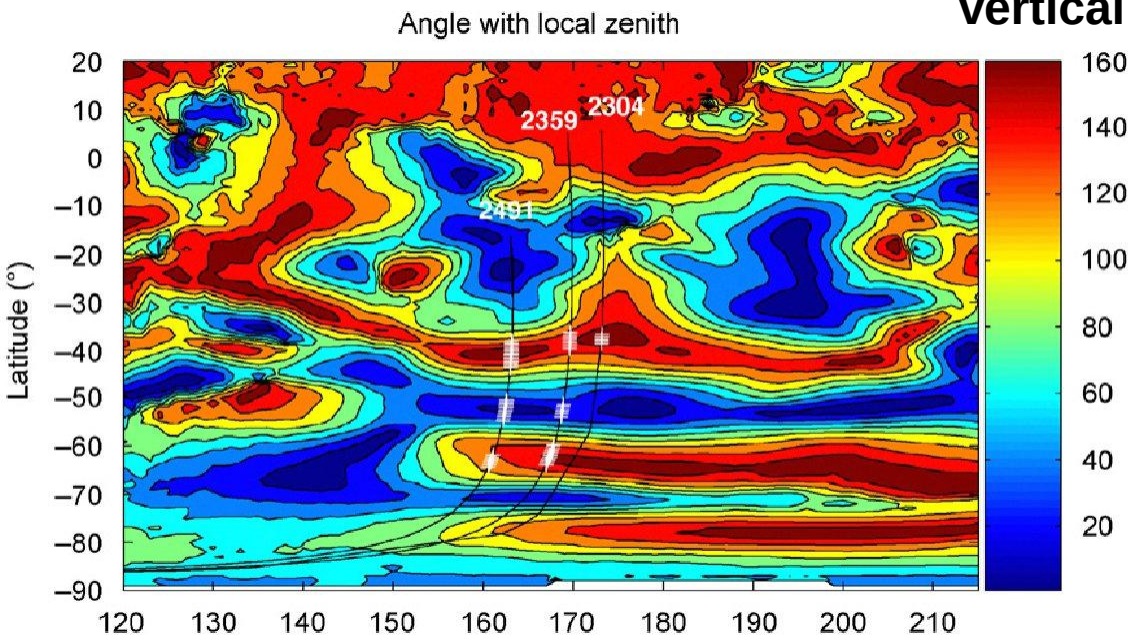
Enhancements are localized



Nielsen et al. (2007)

Peak electron densities

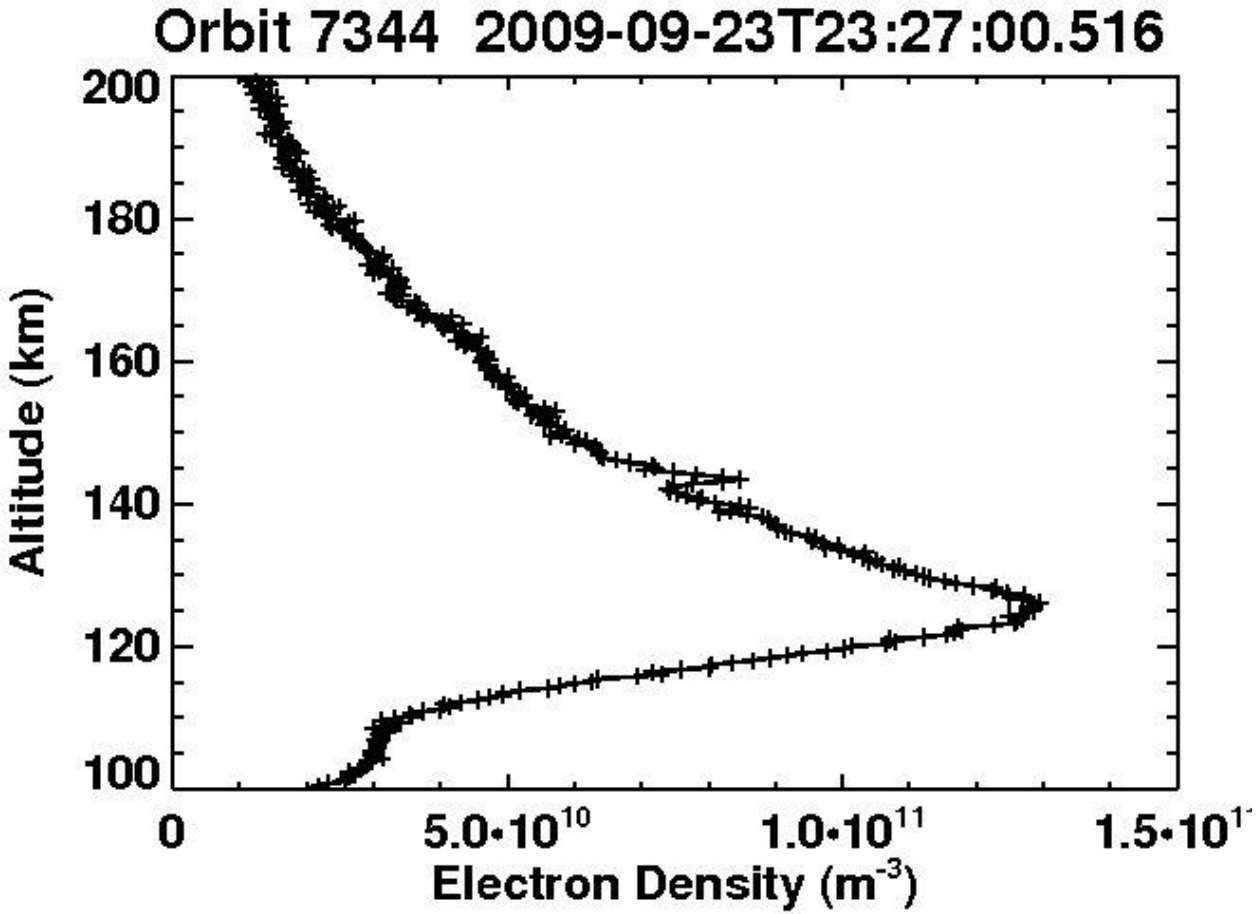
Angle between field and vertical



Nielsen et al. (2007)

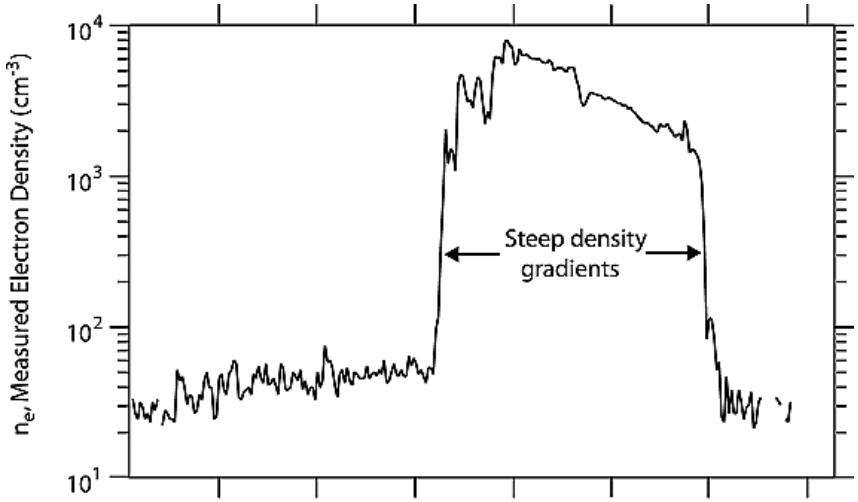
Enhancements seen over strong and vertical crustal magnetic fields

Radio occultation view differs



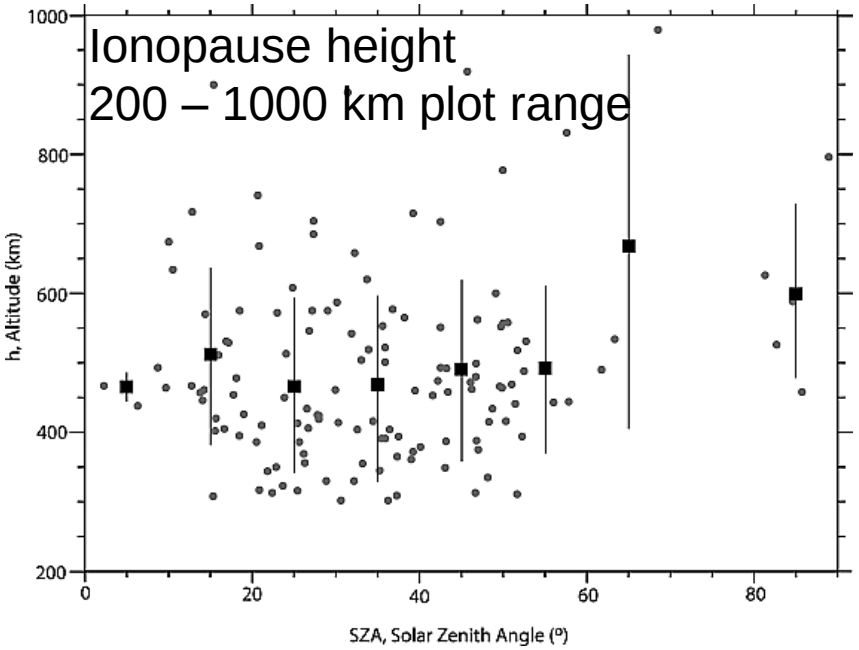
MEX RS electron density profile from orbit 7344 on 23 September 2009 at solar zenith angle of 52 degrees, latitude 34°S, longitude 137°E.

Where is the top of the ionopause?



UT (hr:min)	16:00	16:05	16:10	16:15	16:20	16:25	16:30
Alt (km)	888.65	560.04	344.69	277.36	370.67	607.05	949.82
Long (deg)	59.53	50.45	48.40	47.86	47.82	47.97	48.13
Lat (deg)	-78.53	-62.85	-44.58	-24.82	-5.17	12.83	28.39
LT (hr)	12.25	12.94	13.16	13.28	13.36	13.43	13.50
SZA (deg)	56.08	41.48	26.30	17.67	26.23	41.10	55.32

Orbit 2189, September 27, 2005

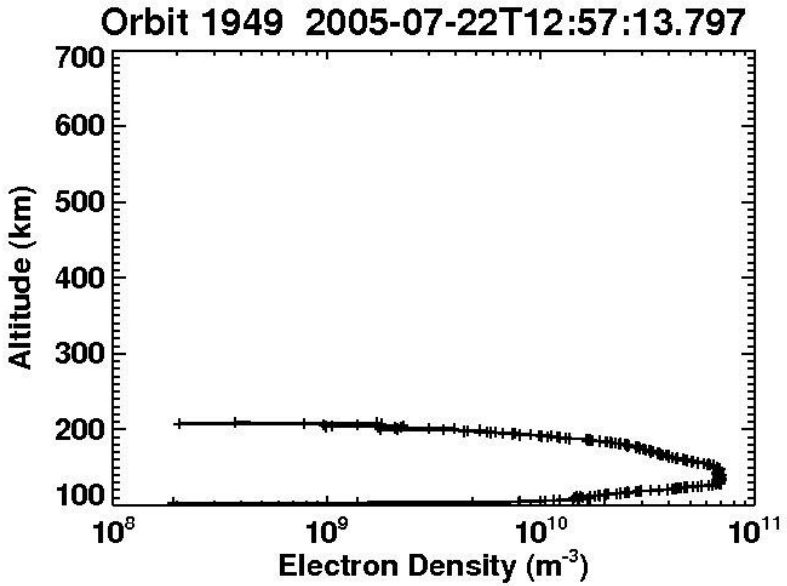


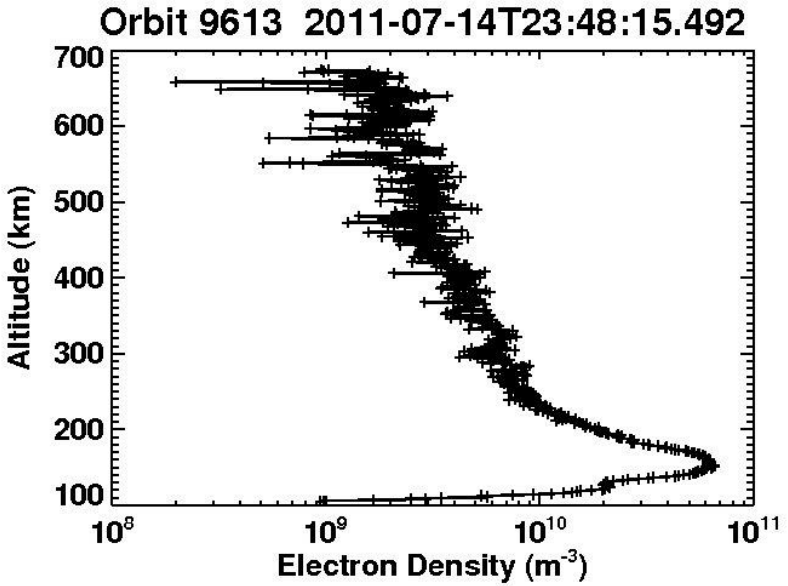
SZA 0 – 90 degrees plot range

Ionopause is not always present
When present, typically around 400 km

Duru et al. (2009) (both figs)

Occultations can't see the ionopause

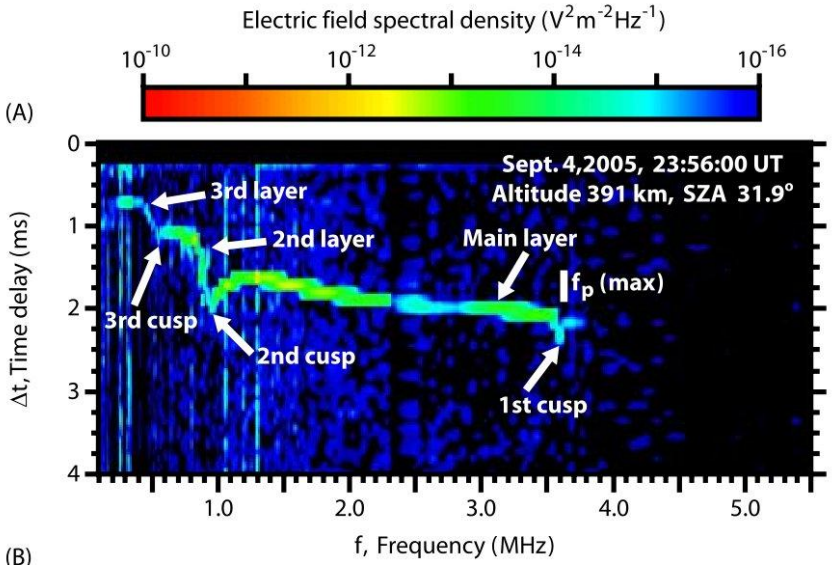




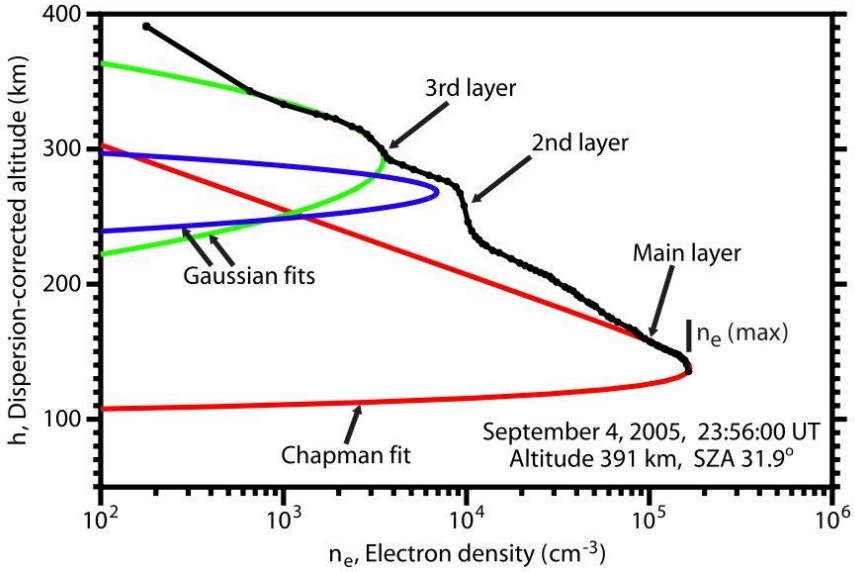
MEX RS electron density profile from orbit 1949 on 22 July 2005 at solar zenith angle of 69 degrees, latitude 42^{o}N, longitude 24^{o}E.

MEX RS electron density profile from orbit 9613 on 14 July 2011 at solar zenith angle of 82 degrees, latitude 82^{o}S, 180^{o}E.

Structure of topside ionosphere



Kopf et al. (2008)

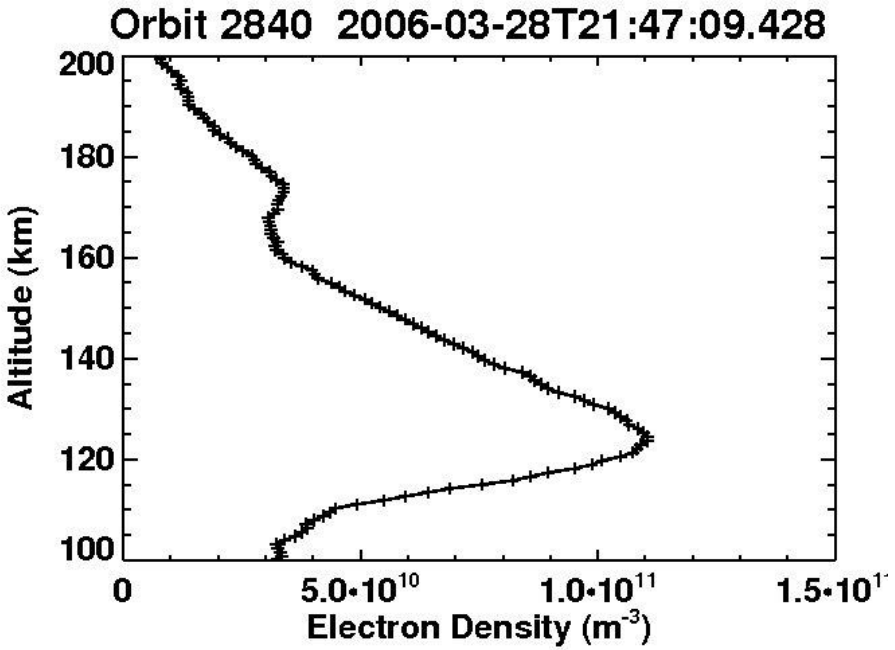


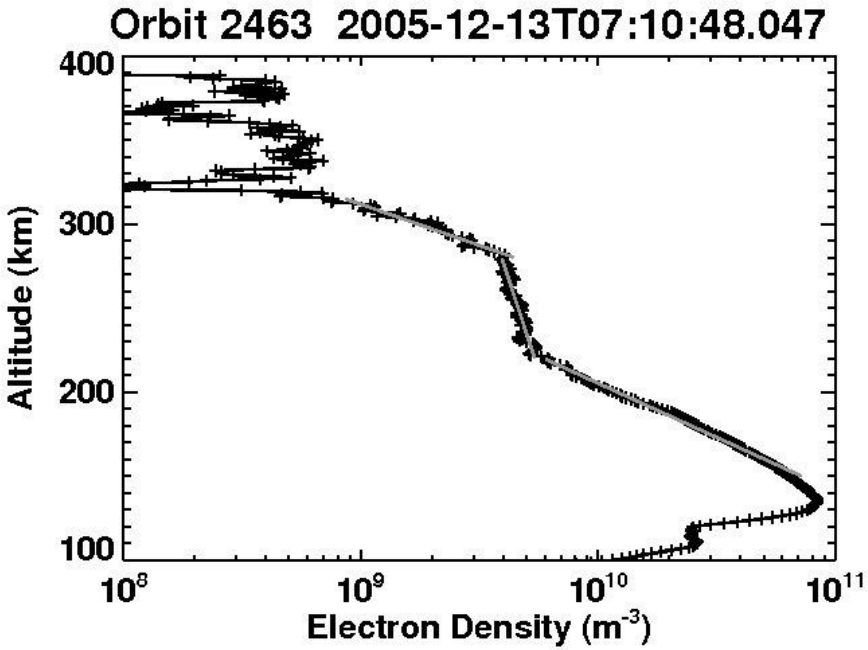
Kopf et al. (2008)

Each observed cusp (dip) means a local maximum in plasma density

This derived profile has some inherent flaws, is forced to assume a smooth shape

Lots of topside features seen by occultations

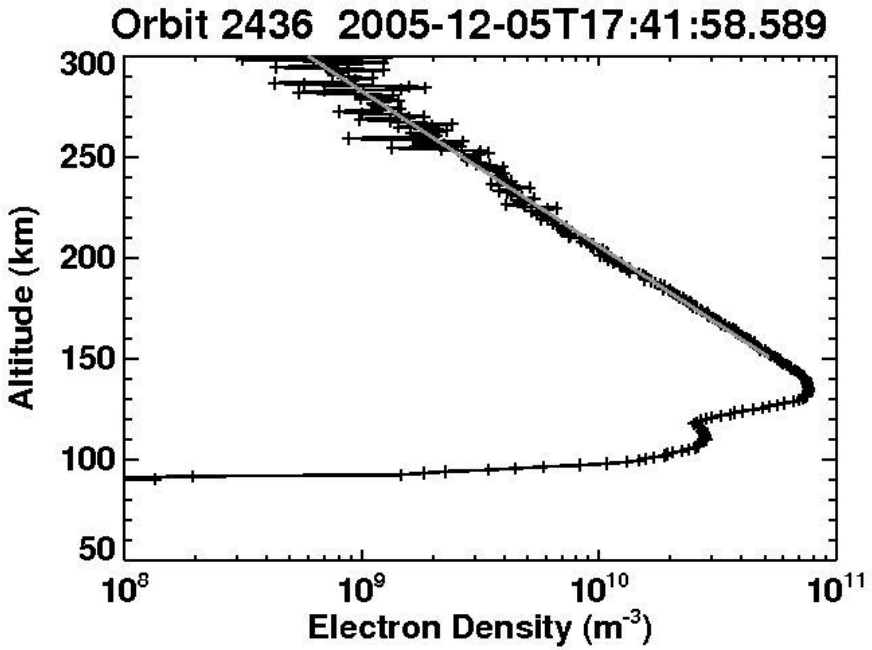




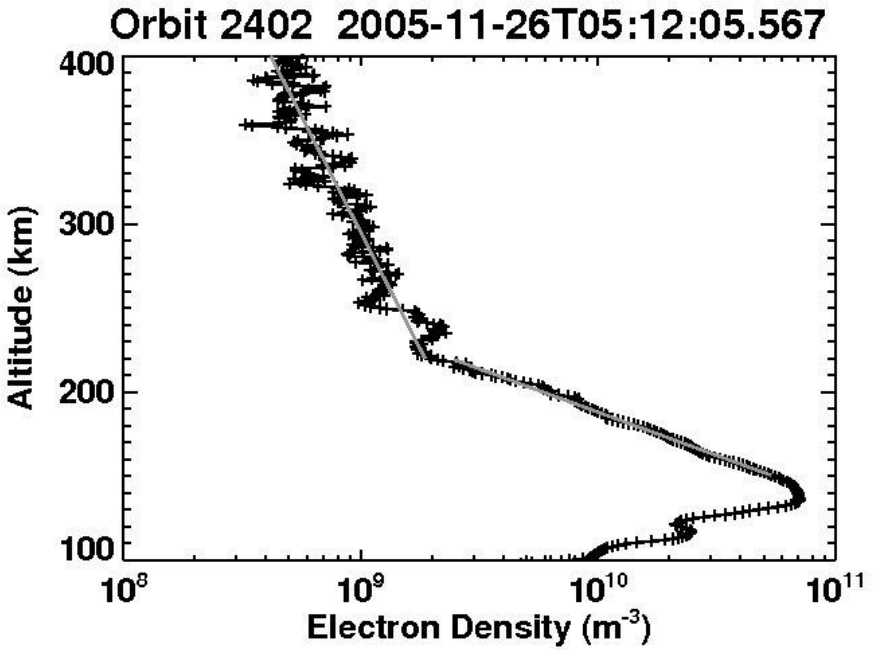
MEX RS electron density profile from orbit 2840 on 28 March 2006 at solar zenith angle of 55 degrees, latitude 15°N, longitude 217°E.

MEX RS electron density profile from orbit 2463 on 13 December 2005 at solar zenith angle of 75 degrees, latitude 66°N, longitude 103°E.

Lots of different structures



MEX RS electron density profile from orbit 2436 on 5 December 2005 at solar zenith angle of 78 degrees, latitude 67°N, longitude 235°E.

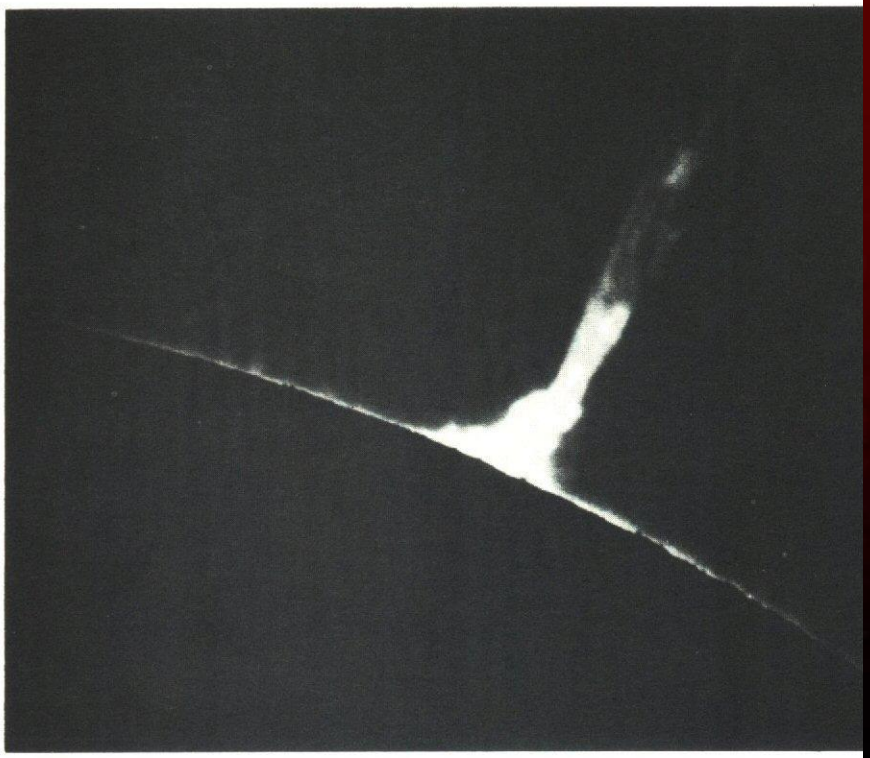


MEX RS electron density profile from orbit 2402 on 26 November 2005 at solar zenith angle of 81 degrees, latitude 66°N, longitude 341°E.

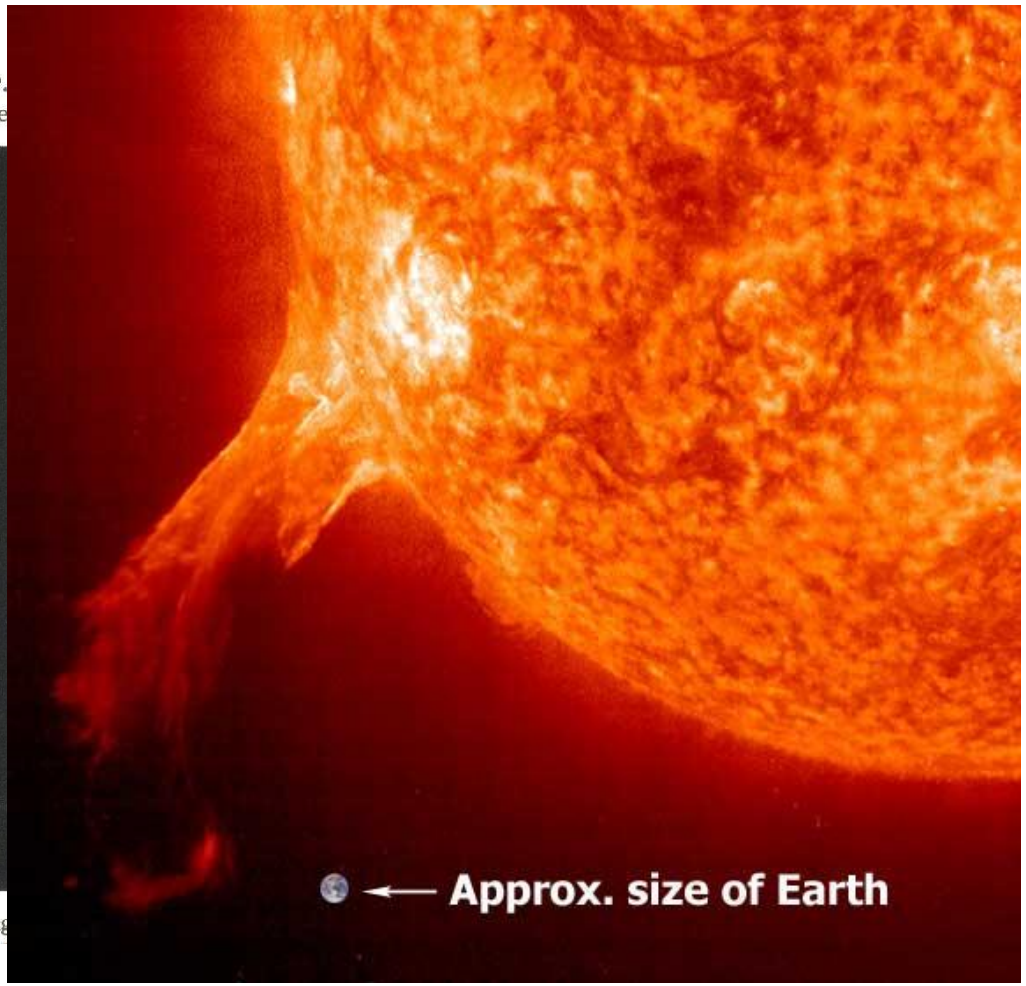
Solar Flares

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



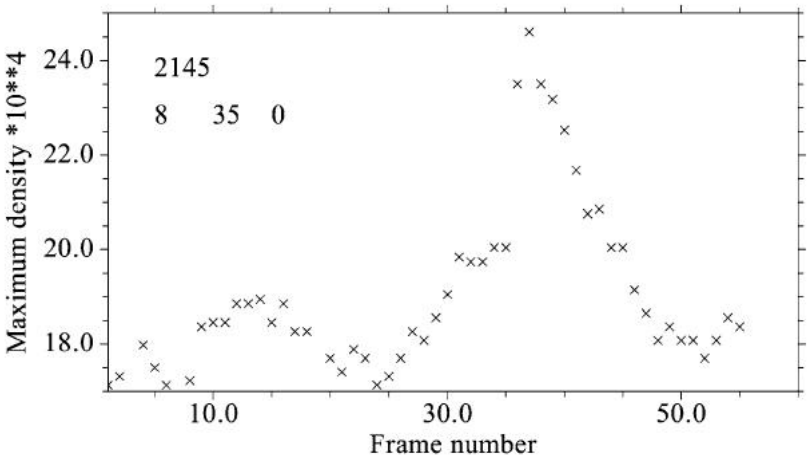
The photograph was taken with a 15 cm aperture solar telescope using



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

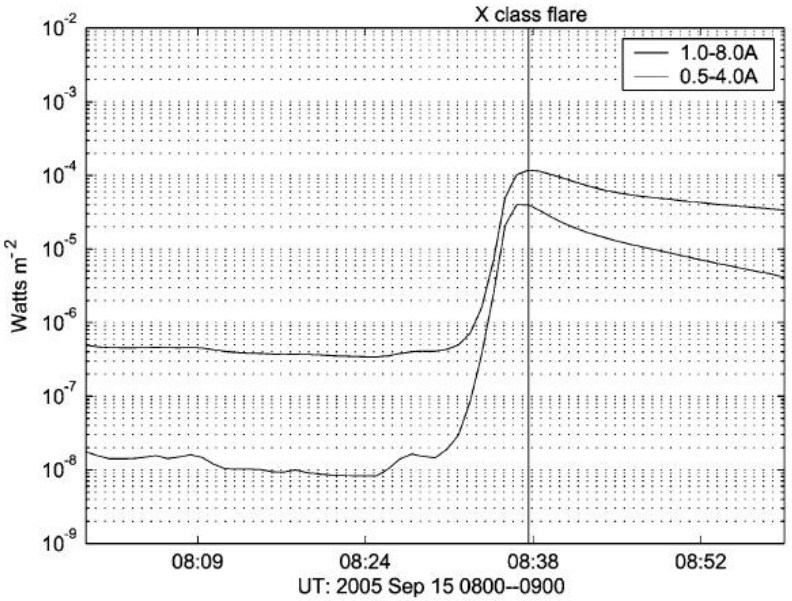
http://rednova.com/news/stories/1/2003/10/24/story002.html

High frequency of MARSIS measurements is invaluable



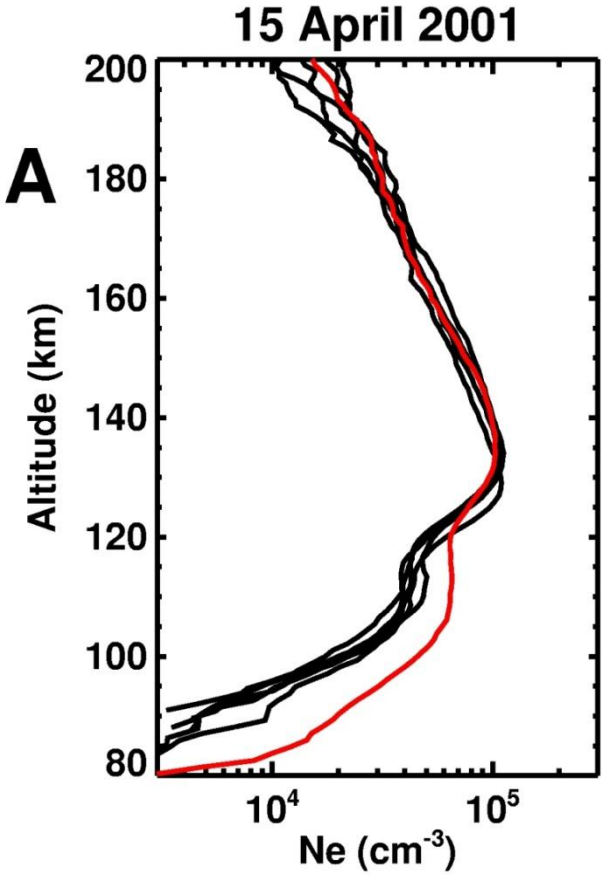
Seven minutes of MARSIS peak electron densities
Increase by 30% for a few minutes

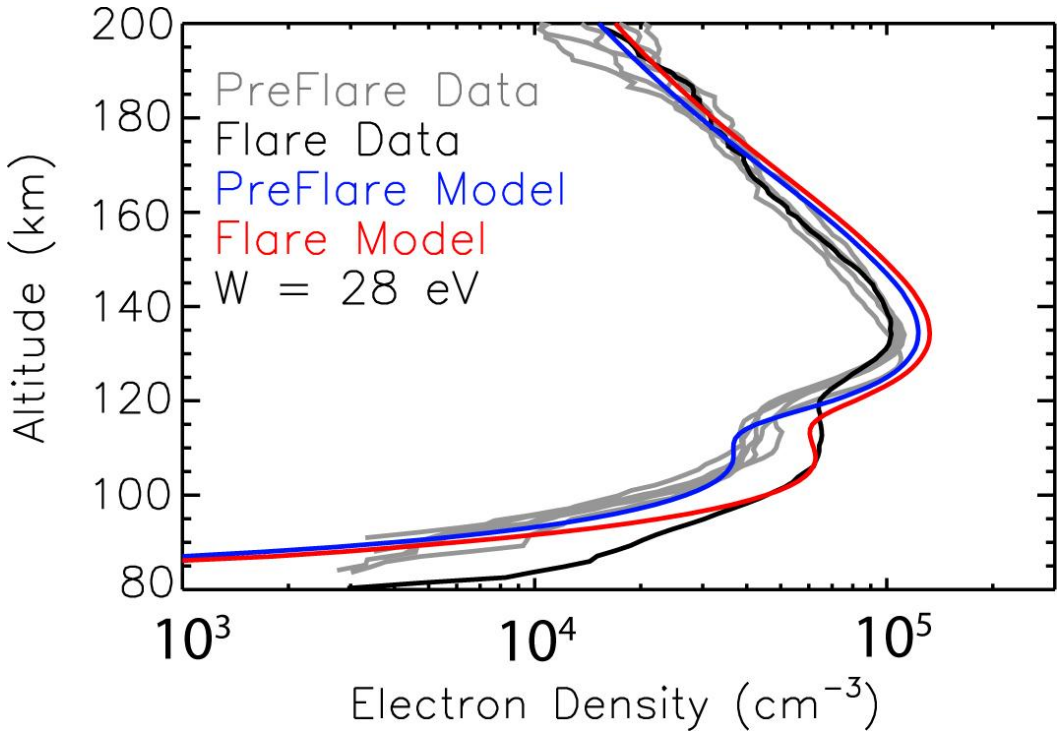
Nielsen et al. (2006)



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

Flares also seen by radio occultations





Observations and predictions for X14 flare on 15 April 2001

Mendillo et al. (2006)

Lollo 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

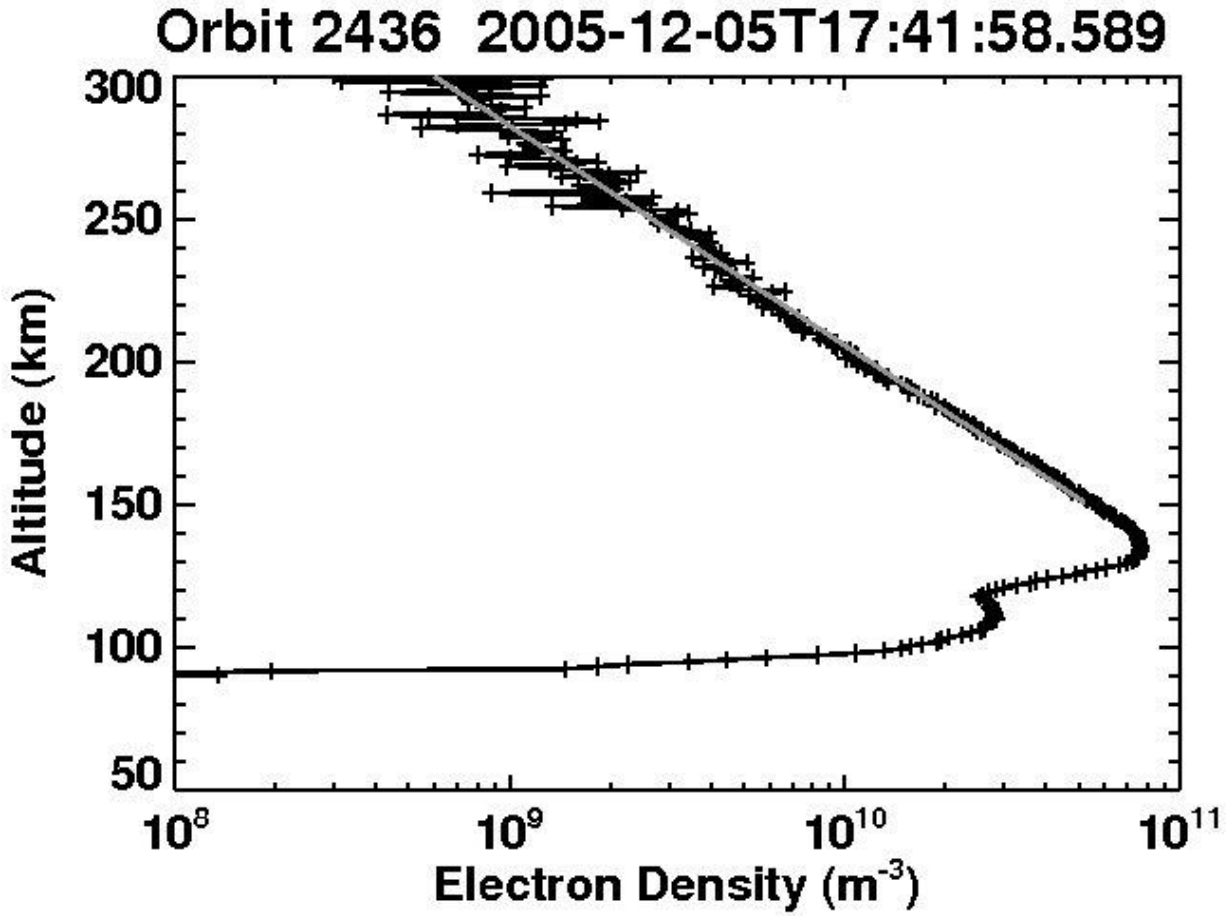


Figure 1A: Electron density profile from orbit 2436 on 5 December 2005 at solar zenith angle of 78 degrees, latitude 67°N, longitude 235°E. The grey solid line is an exponential fit to densities between 150 km and 300 km that has a scale height of 33 km.

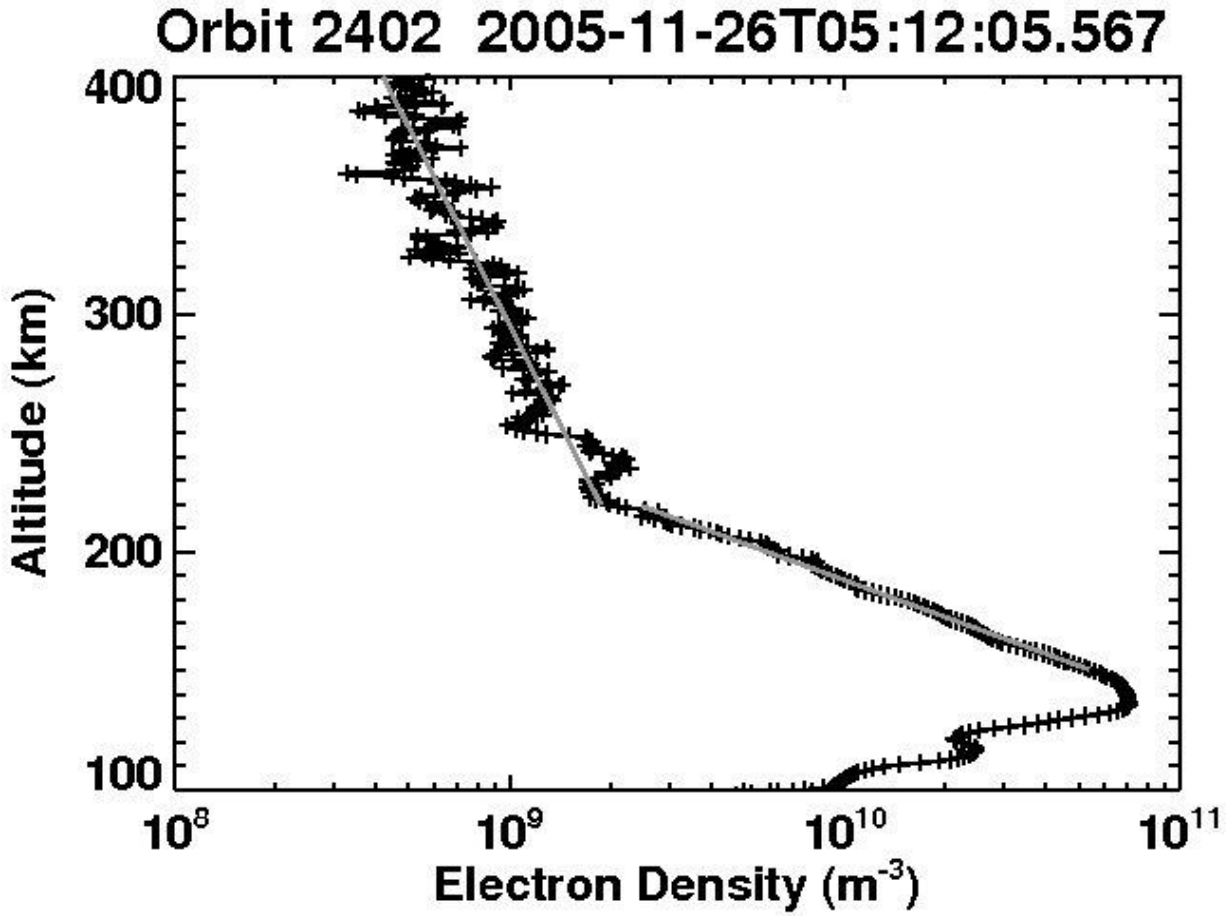


Figure 1B: Electron density profile from orbit 2402 on 26 November 2005 at solar zenith angle of 81 degrees, latitude 66ºN, longitude 341ºE. The lower and upper grey solid lines are exponential fits to densities at 150-220 km and 220-400 km, respectively, that have scale heights of 22 km and 120 km.

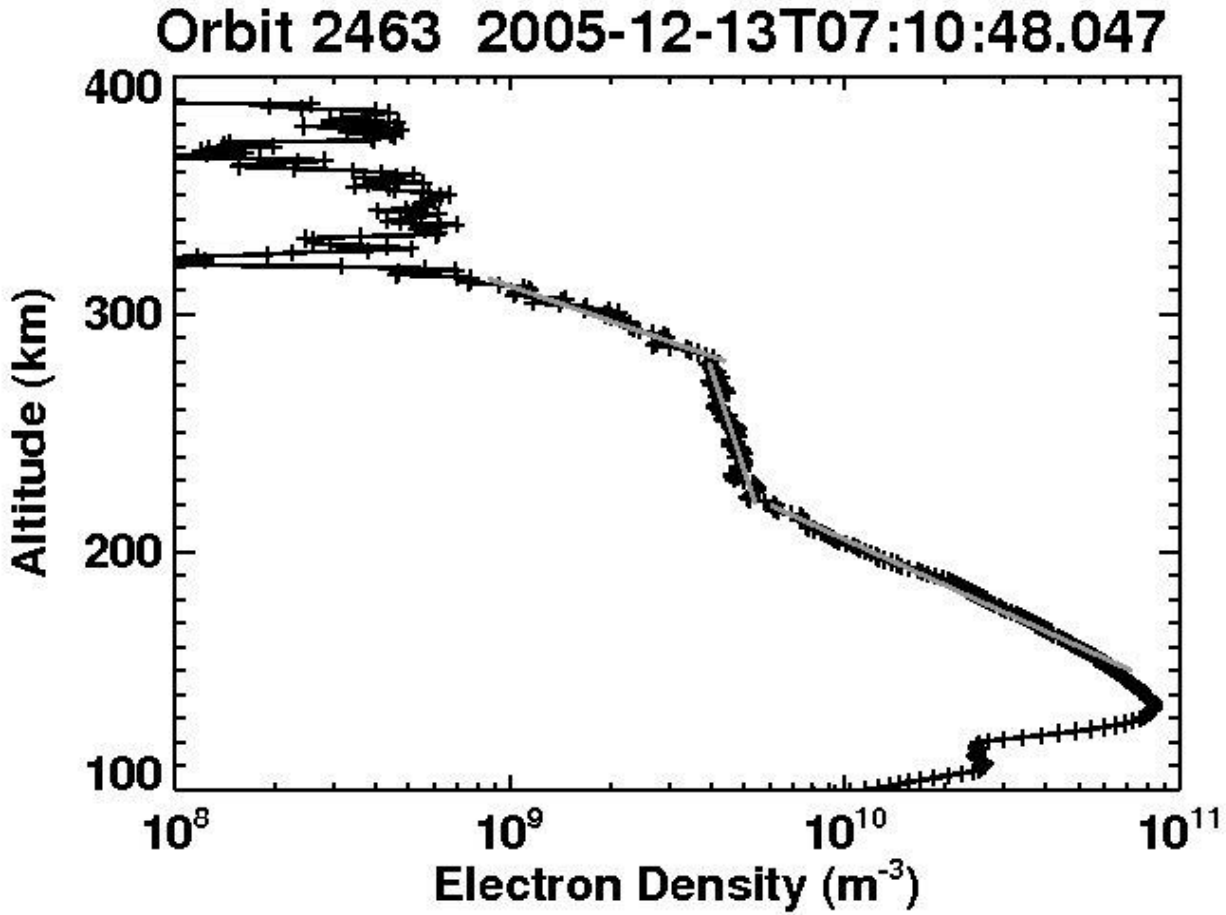


Figure 1C: Electron density profile from orbit 2463 on 13 December 2005 at solar zenith angle of 75 degrees, latitude 66ºN, longitude 103ºE. The lower, middle, and upper grey solid lines are exponential fits to densities at 150-220 km, 220-280 km, and 280-315 km, respectively, that have scale heights of 28 km, 190 km, and 21 km.

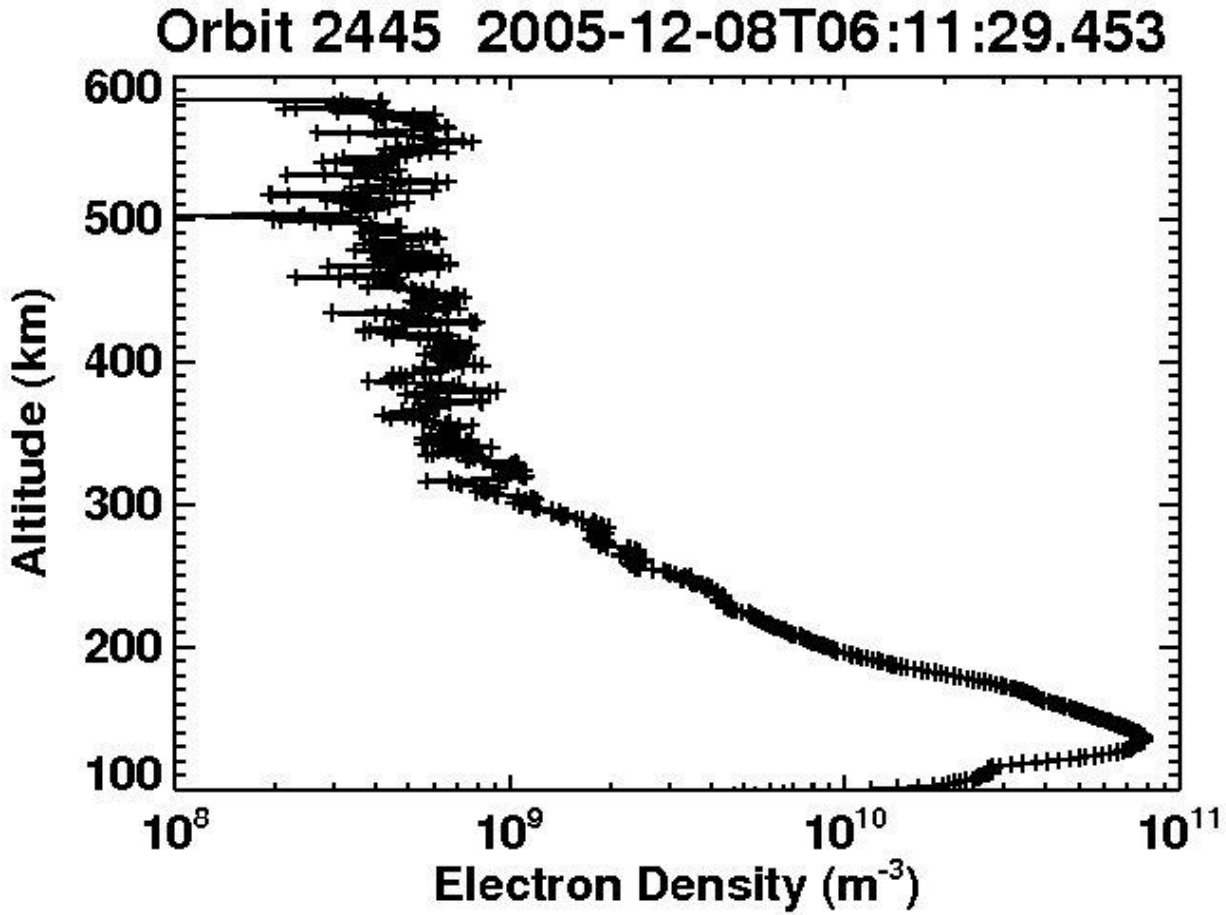


Figure 1D: Electron density profile from orbit 2445 on 8 December 2005 at solar zenith angle of 77 degrees, latitude 67ºN, longitude 70ºE. Electron densities are nearly uniform between 300 km and 580 km.

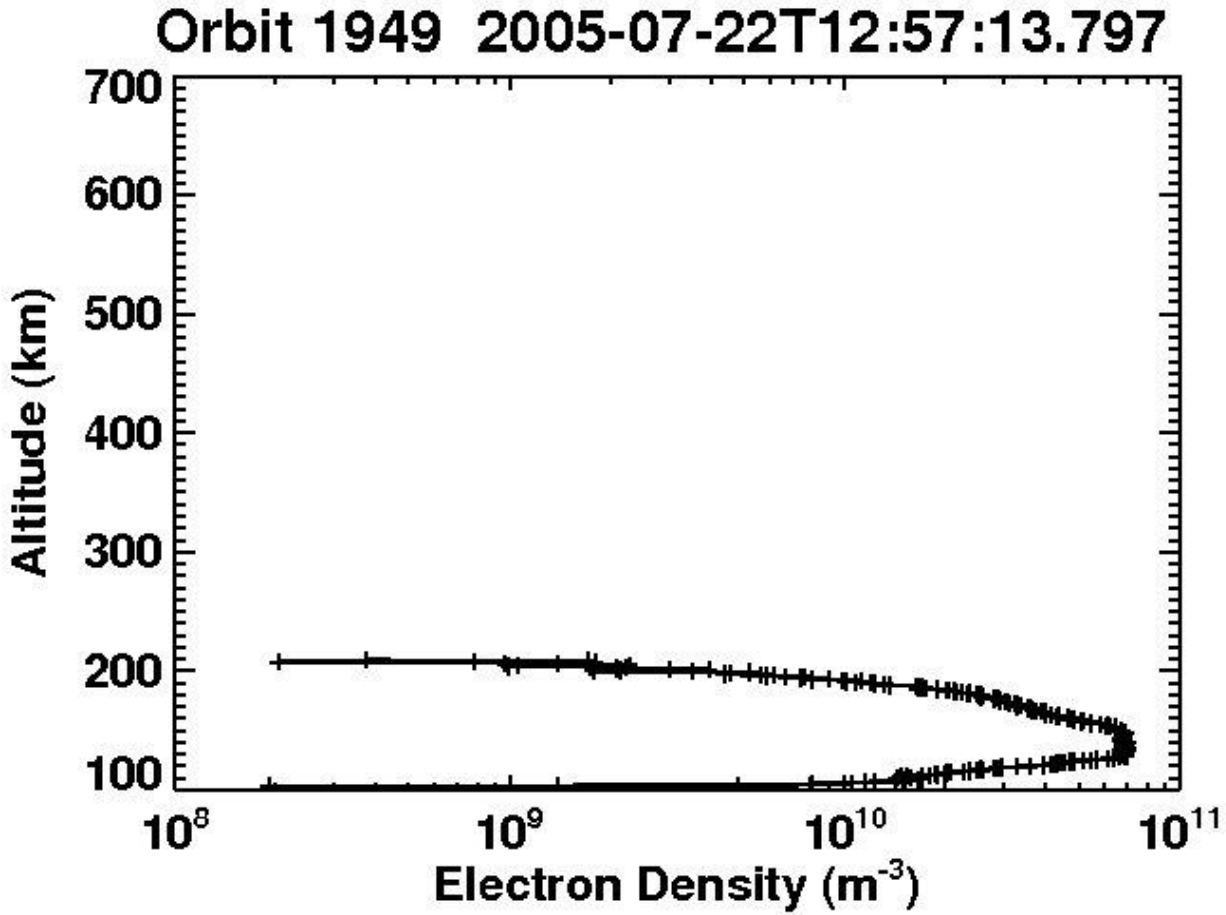


Figure 1E: Electron density profile from orbit 1949 on 22 July 2005 at solar zenith angle of 69 degrees, latitude 42ºN, longitude 24ºE. Electron densities drop below 10^9 m^{-3} by 200 km altitude.

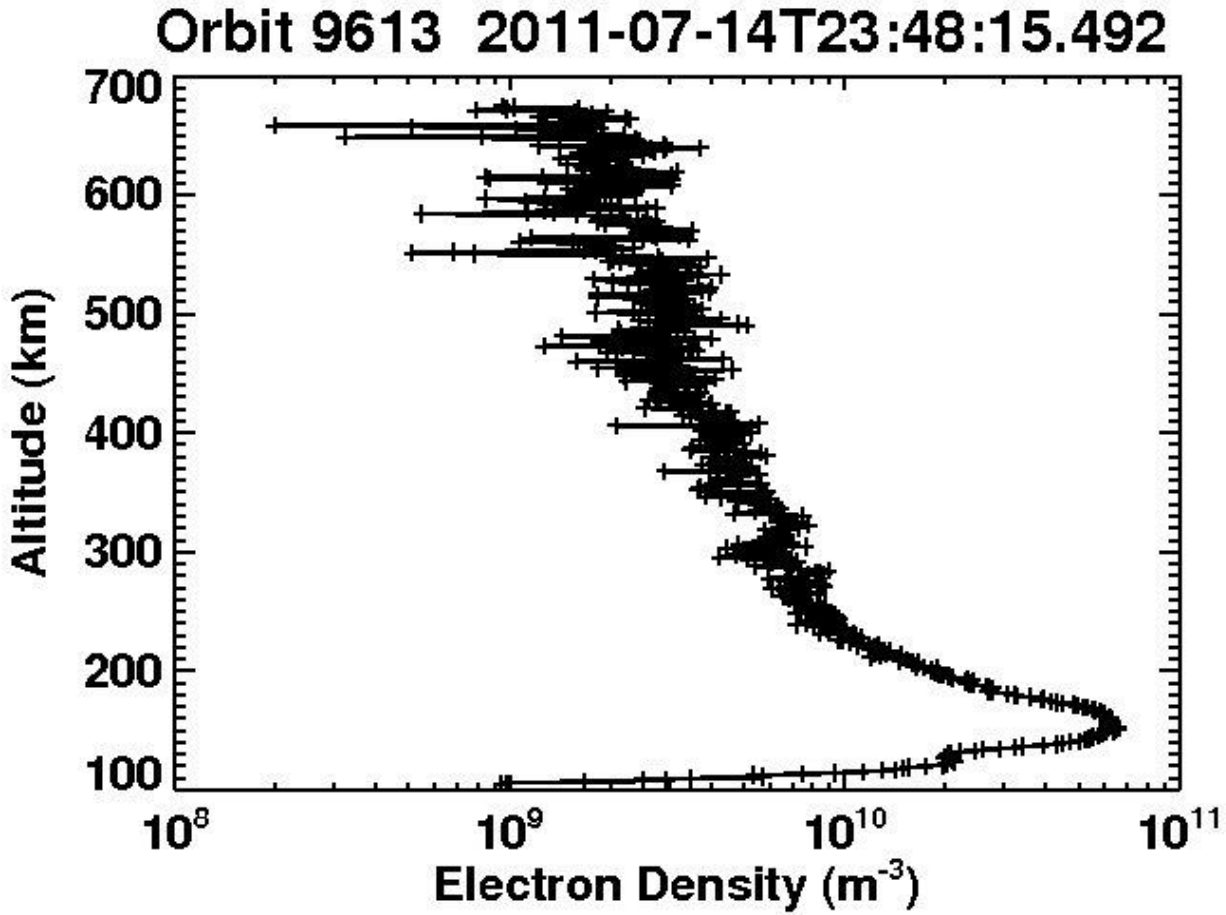


Figure 1F: Electron density profile from orbit 9613 on 14 July 2011 at solar zenith angle of 82 degrees, latitude 82°S, 180°E. Electron densities remain above 10^9 m^{-3} to 700 km altitude.

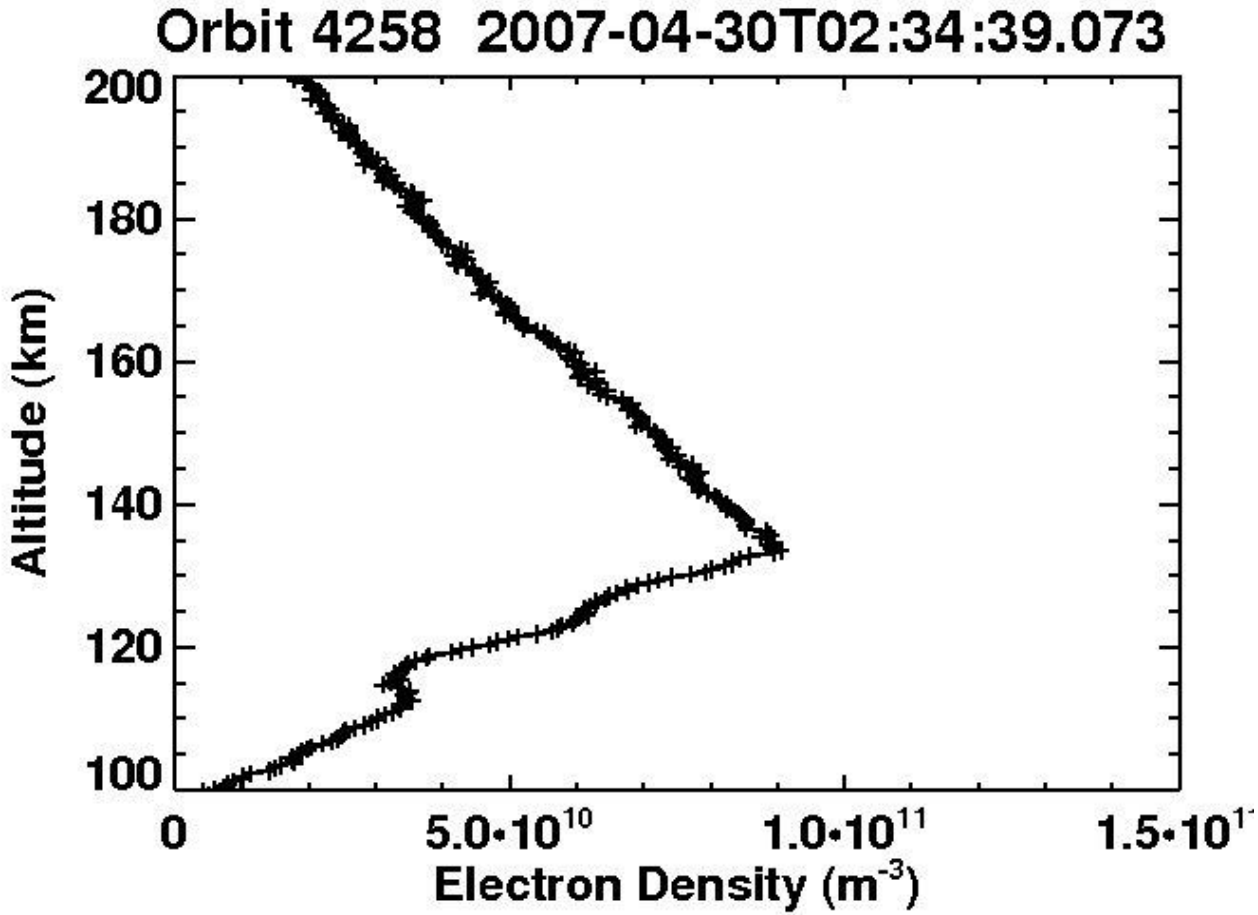


Figure 2A: Electron density profile from orbit 4258 on 30 April 2007 at solar zenith angle of 68 degrees, latitude 46^{o}N, longitude 278^{o}E.

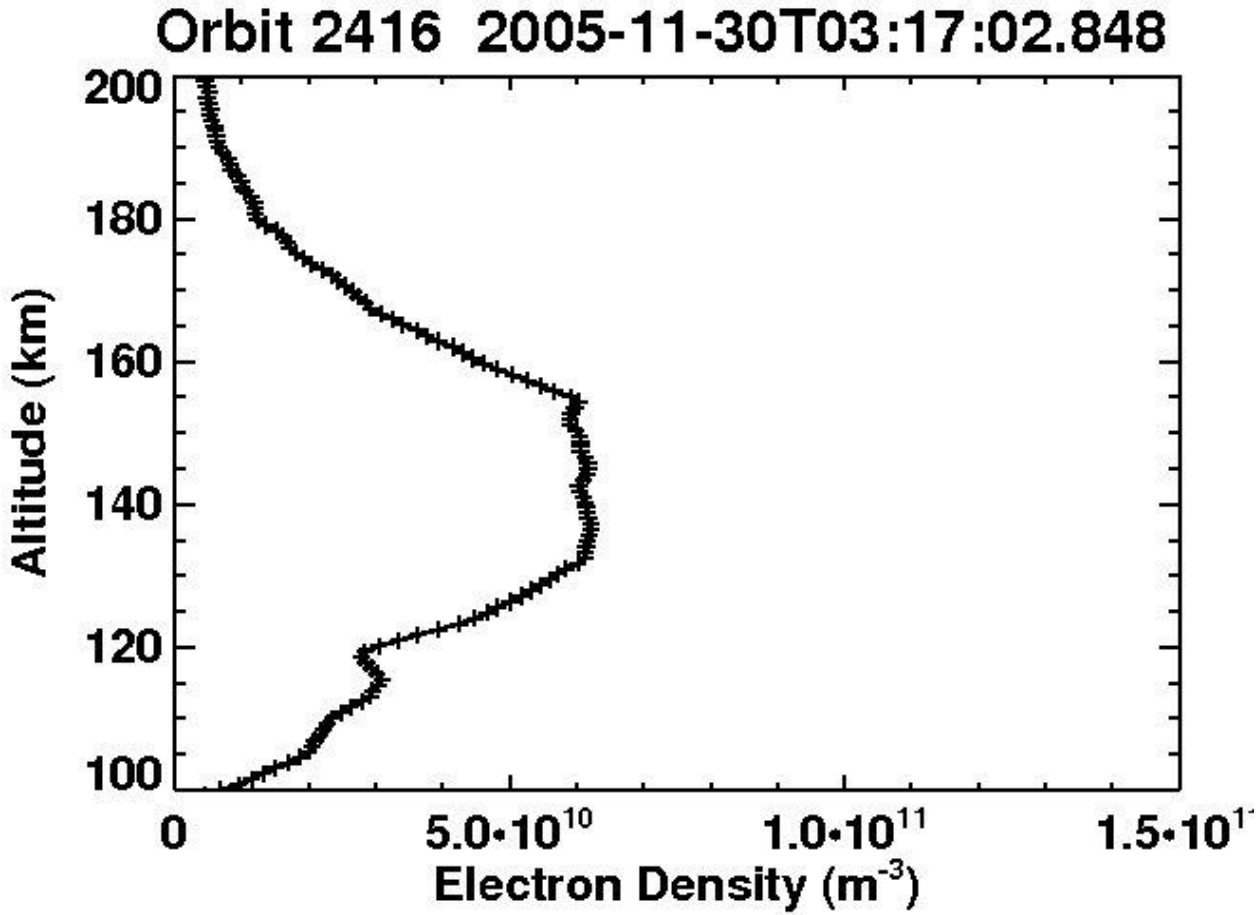


Figure 2B: Electron density profile from orbit 2416 on 30 November 2005 at solar zenith angle of 79 degrees, latitude 67°N, longitude 42°E.

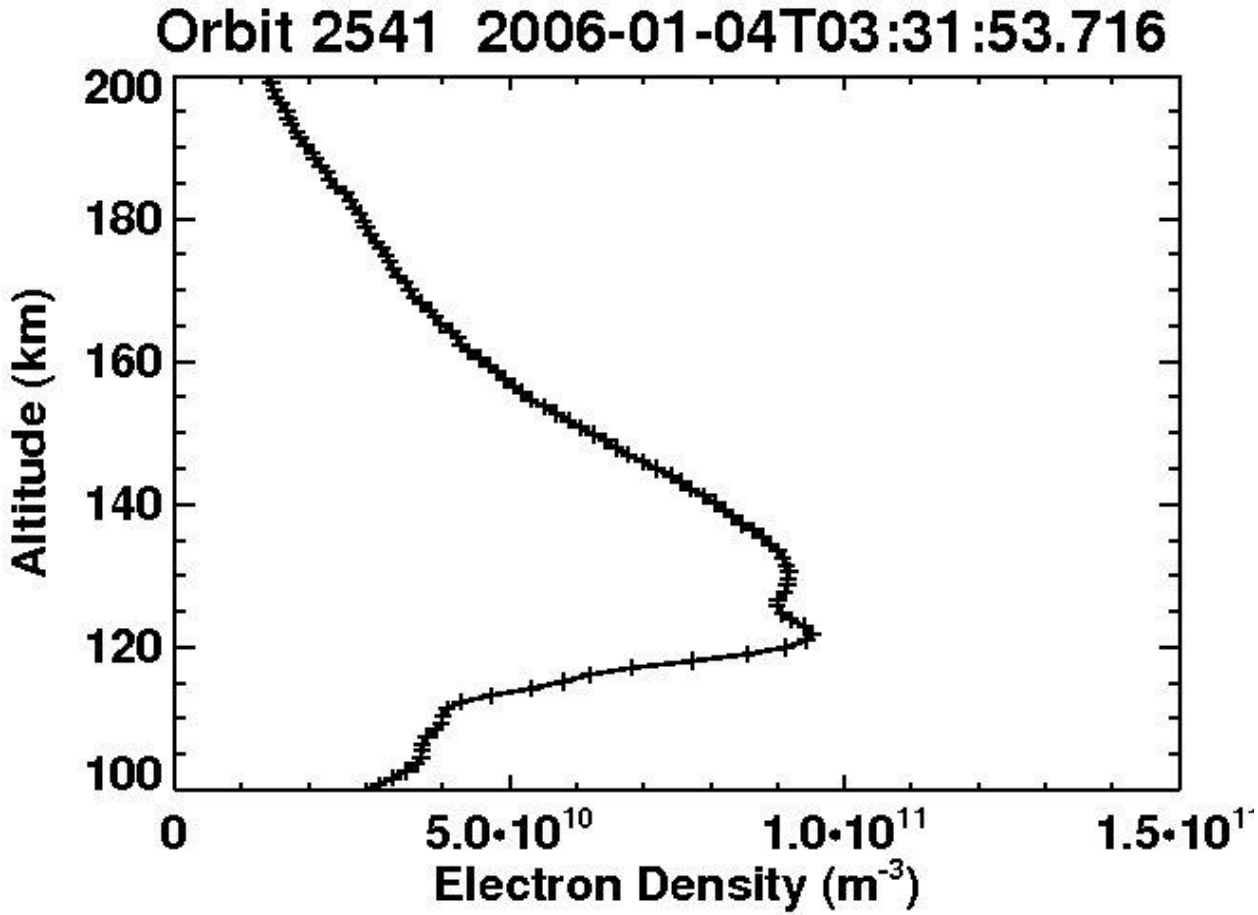


Figure 2C: Electron density profile from orbit 2541 on 4 January 2006 at solar zenith angle of 66 degrees, latitude 60^{o}N, longitude 17^{o}E.

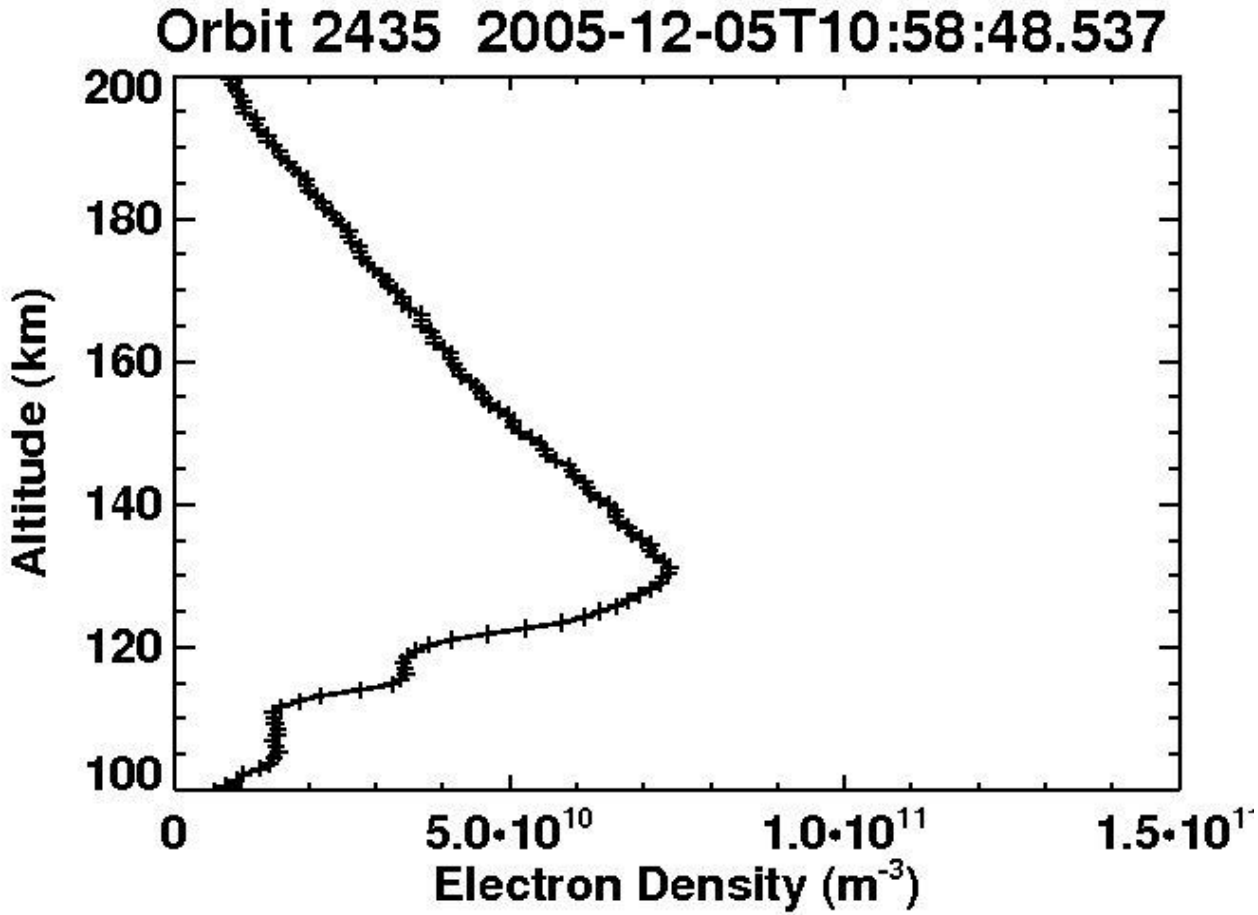


Figure 2D: Electron density profile from orbit 2435 on 5 December 2005 at solar zenith angle of 78 degrees, latitude 67°N, longitude 333°E.

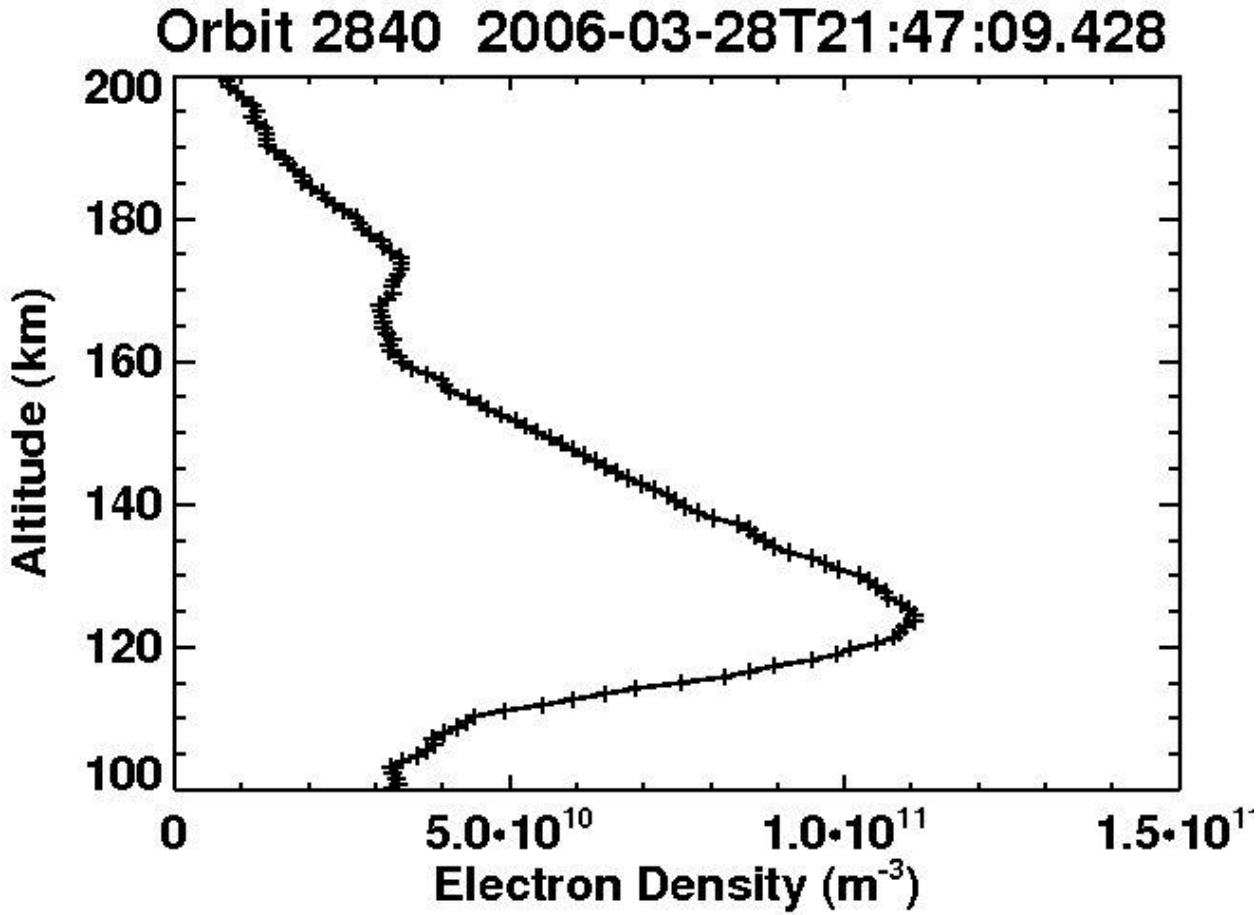


Figure 2E: Electron density profile from orbit 2840 on 28 March 2006 at solar zenith angle of 55 degrees, latitude 15^{o}N, longitude 217^{o}E.

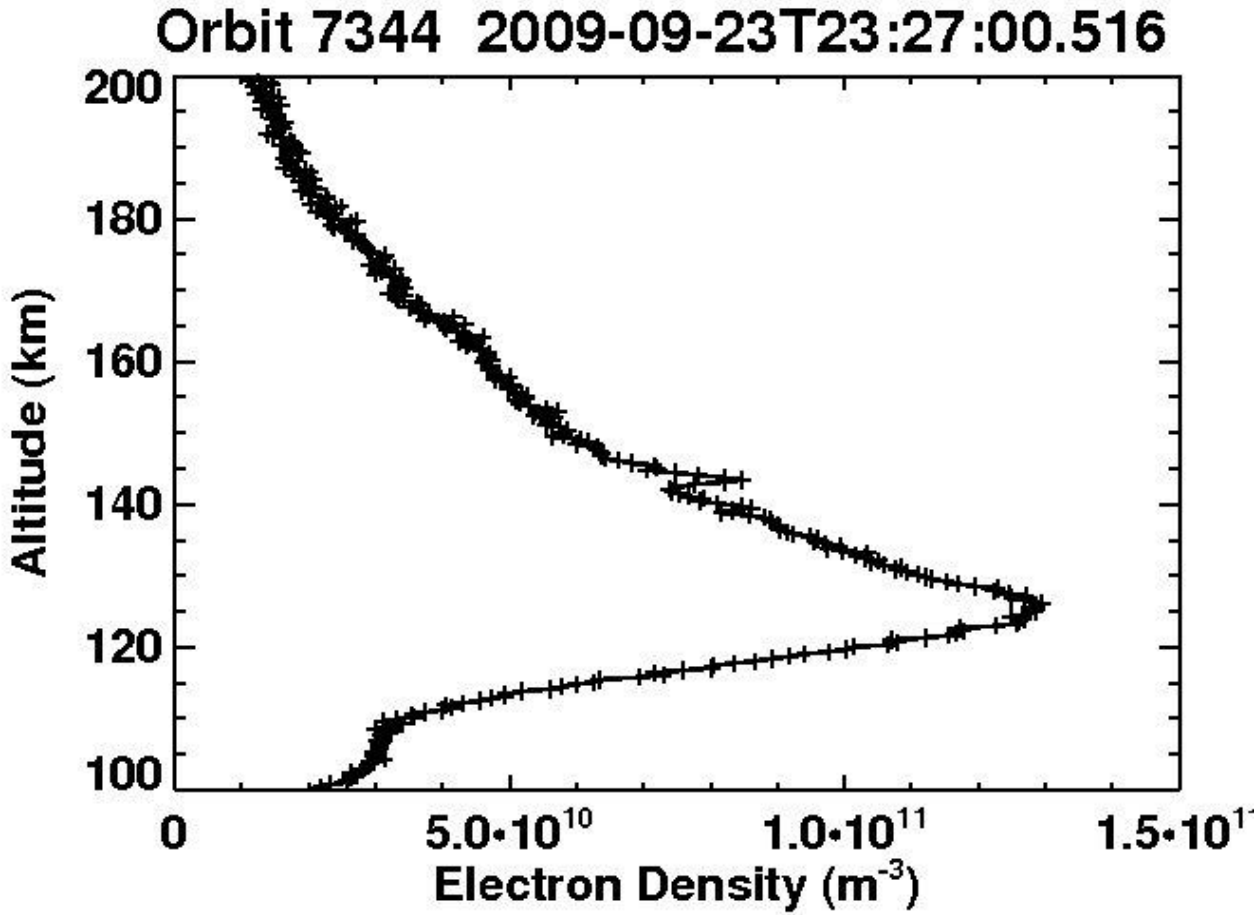


Figure 2F: Electron density profile from orbit 7344 on 23 September 2009 at solar zenith angle of 52 degrees, latitude 34°S, longitude 137°E.