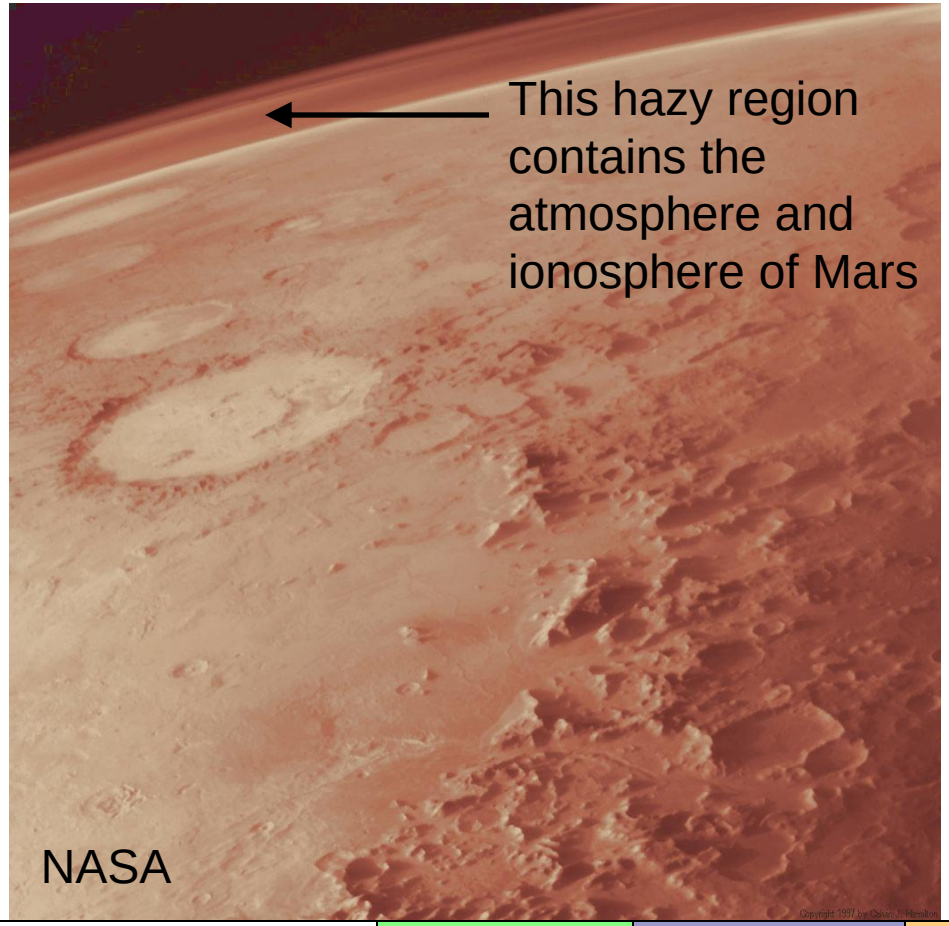
Exploring the ionosphere of Mars



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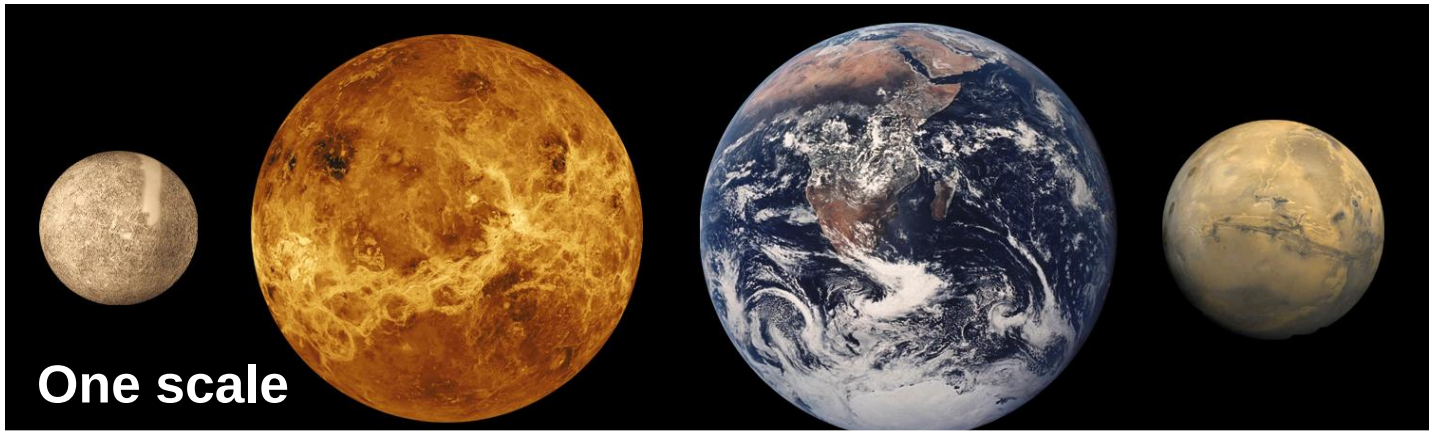
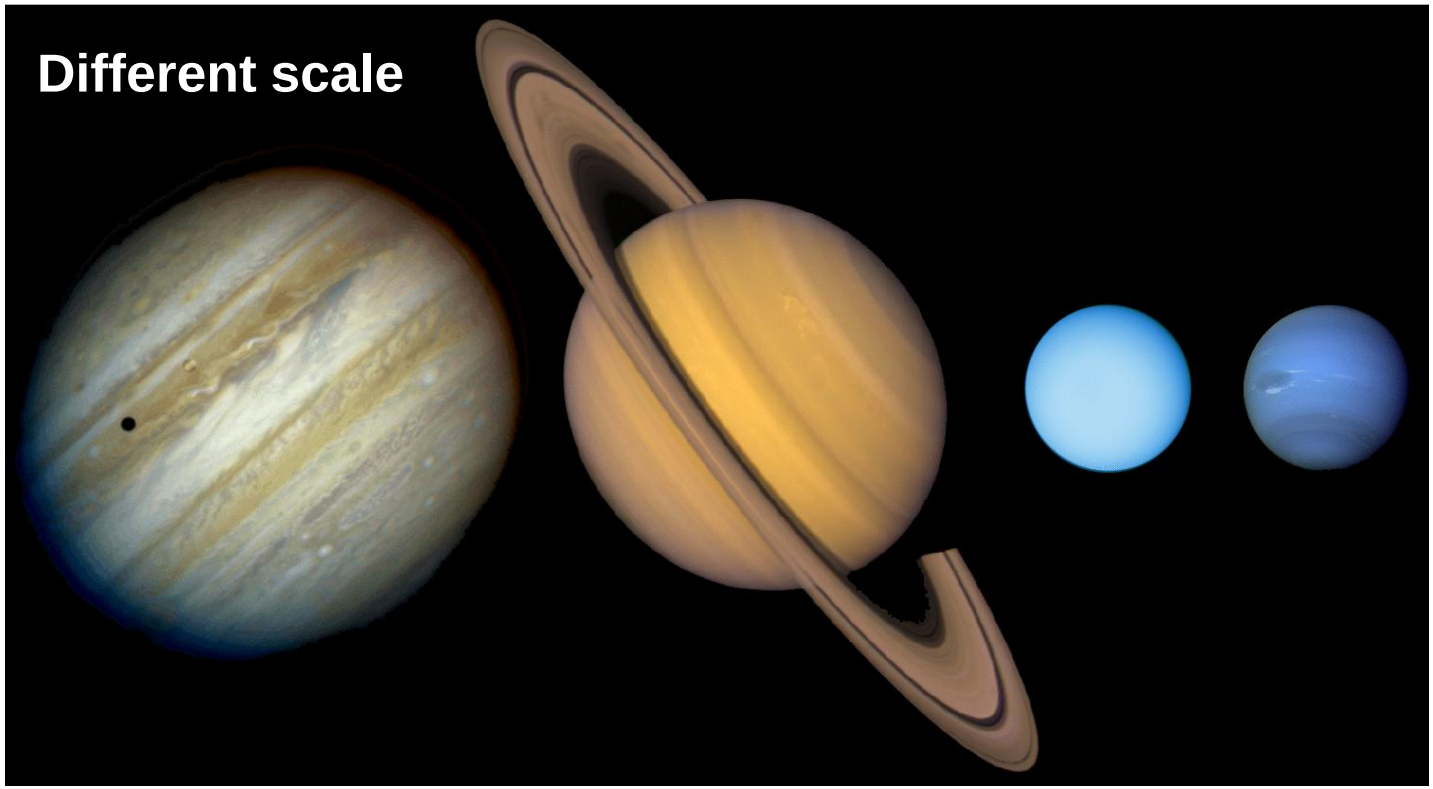
11-12 April 2012





www.solarviews.com

This is
← Mars

0.5 x R-Earth

1.5 AU from Sun

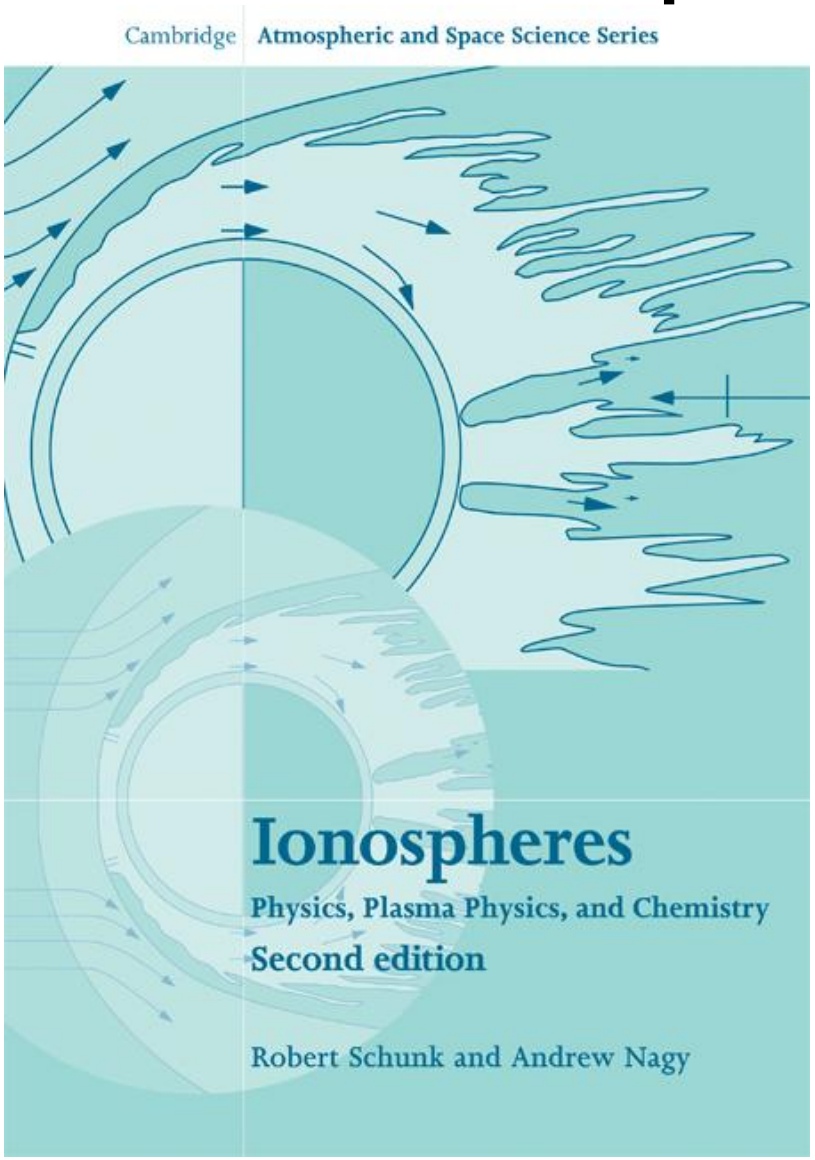
Same rotation rate as Earth

Carbon dioxide atmosphere

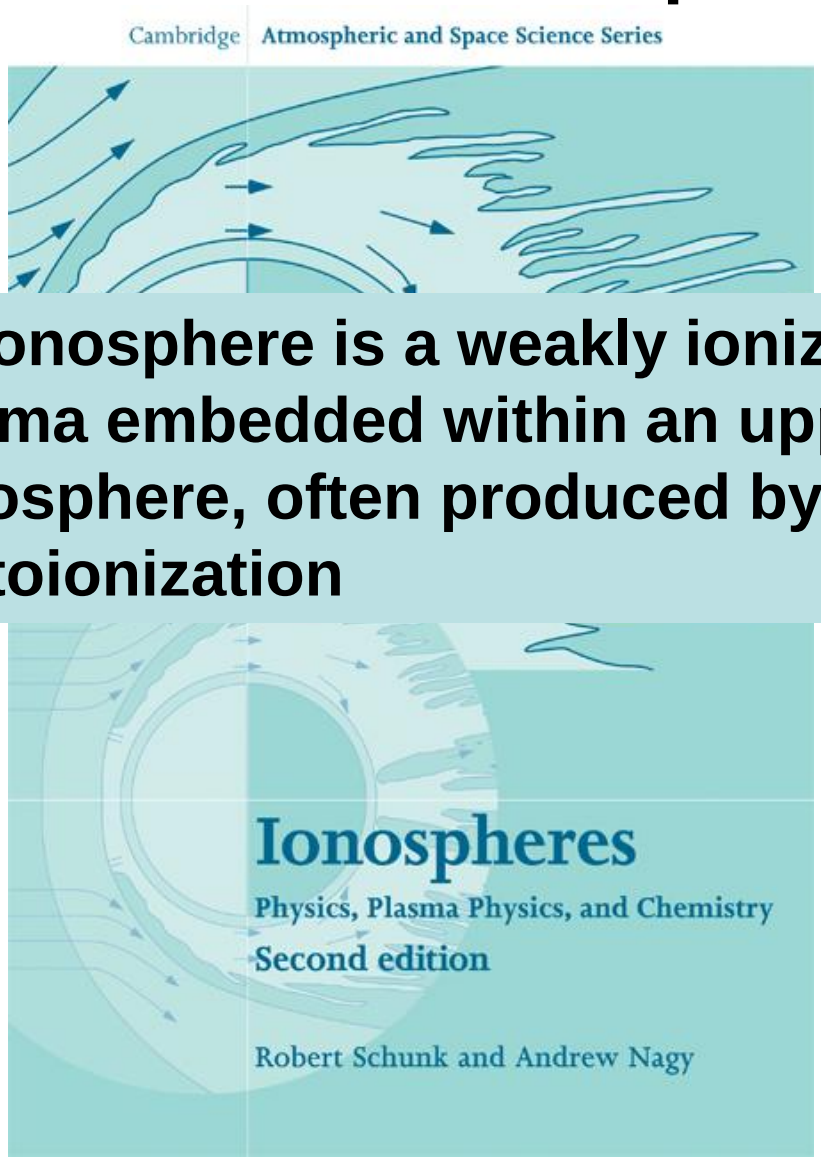
100x smaller surface pressure

Target of many spacecraft in last 15 years

What is an ionosphere?



What is an ionosphere?



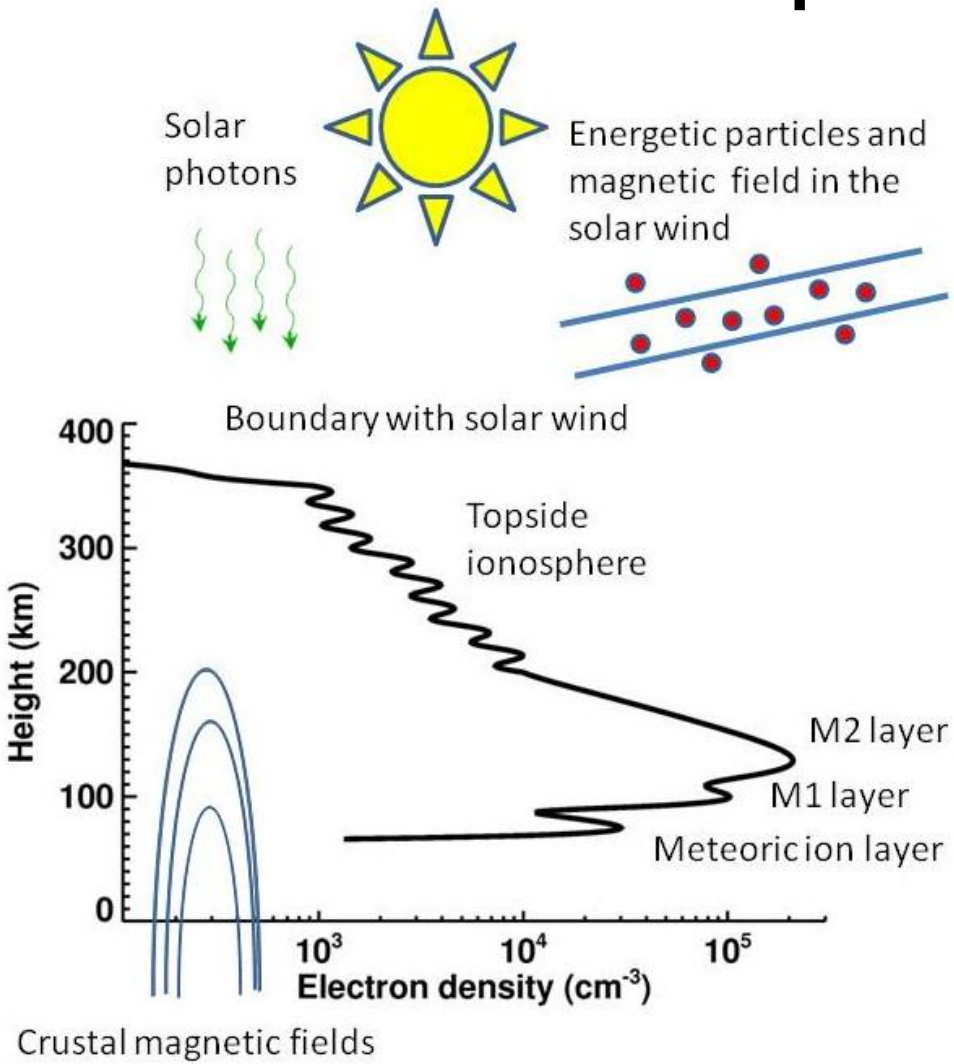
An ionosphere is a weakly ionized plasma embedded within an upper atmosphere, often produced by photoionization

What does that actually mean?

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

✓ Important ✗ Not important ? Perhaps important

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

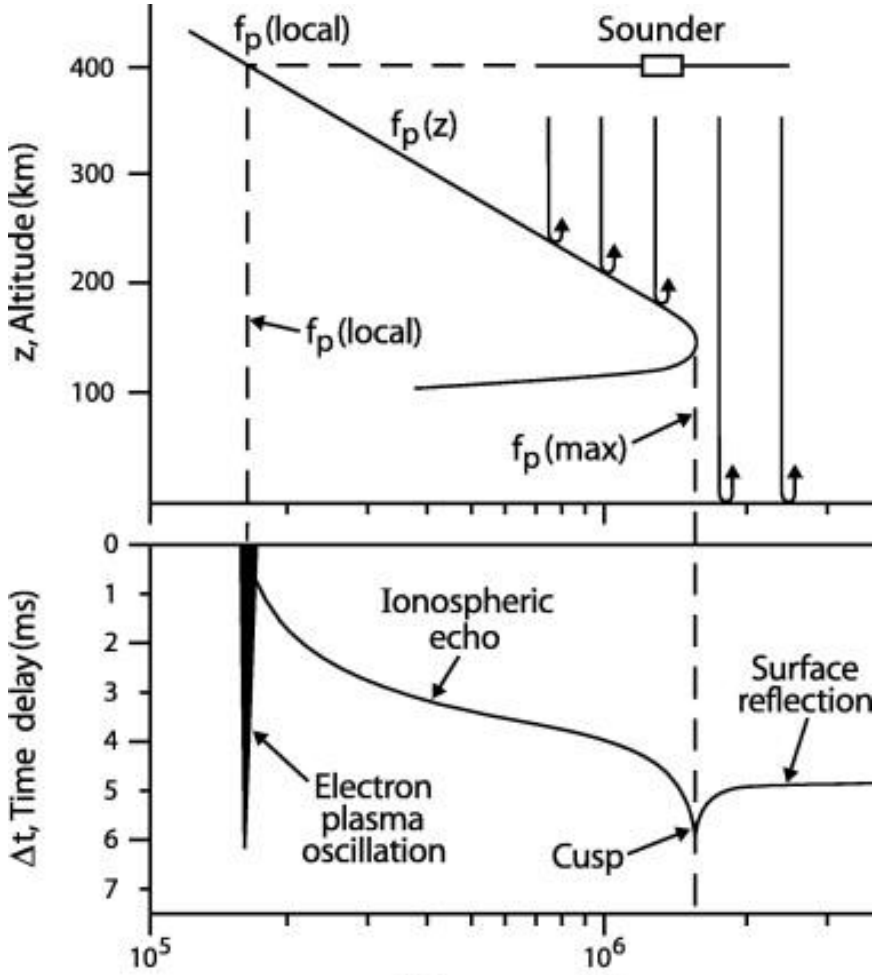
Transport only important in topside ionosphere

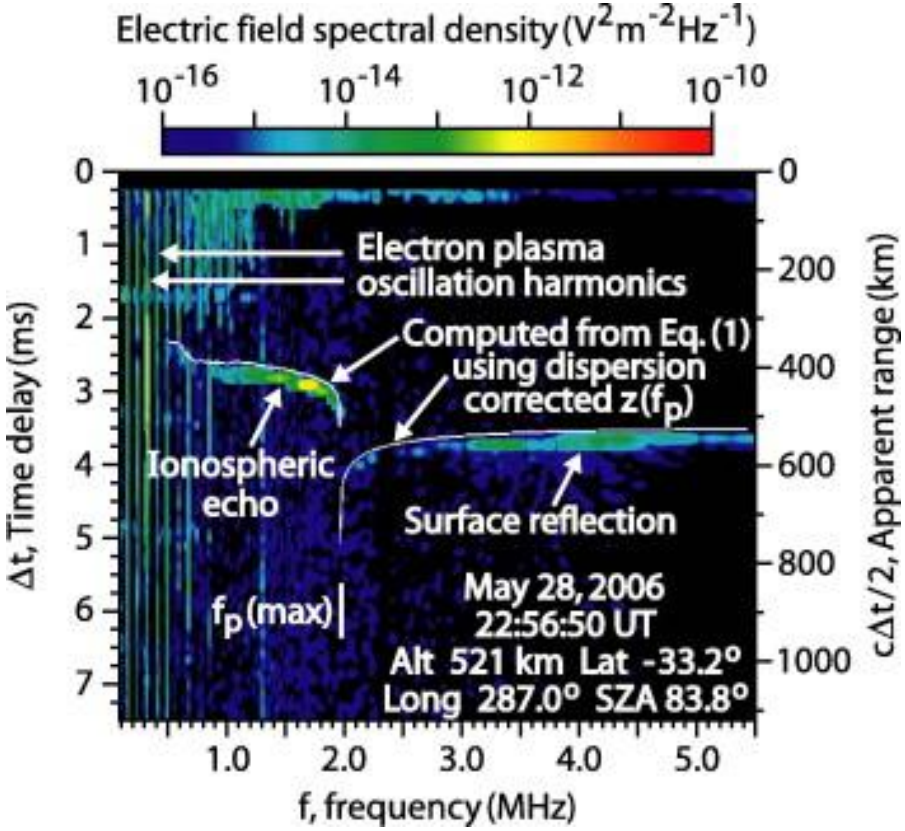
Withers et al. (2009) Decadal Survey white paper

Goal for this talk

- Introduce 2 measurement techniques that are highly complementary to each other
- Explore some effects of magnetic fields
- Show some crazy features

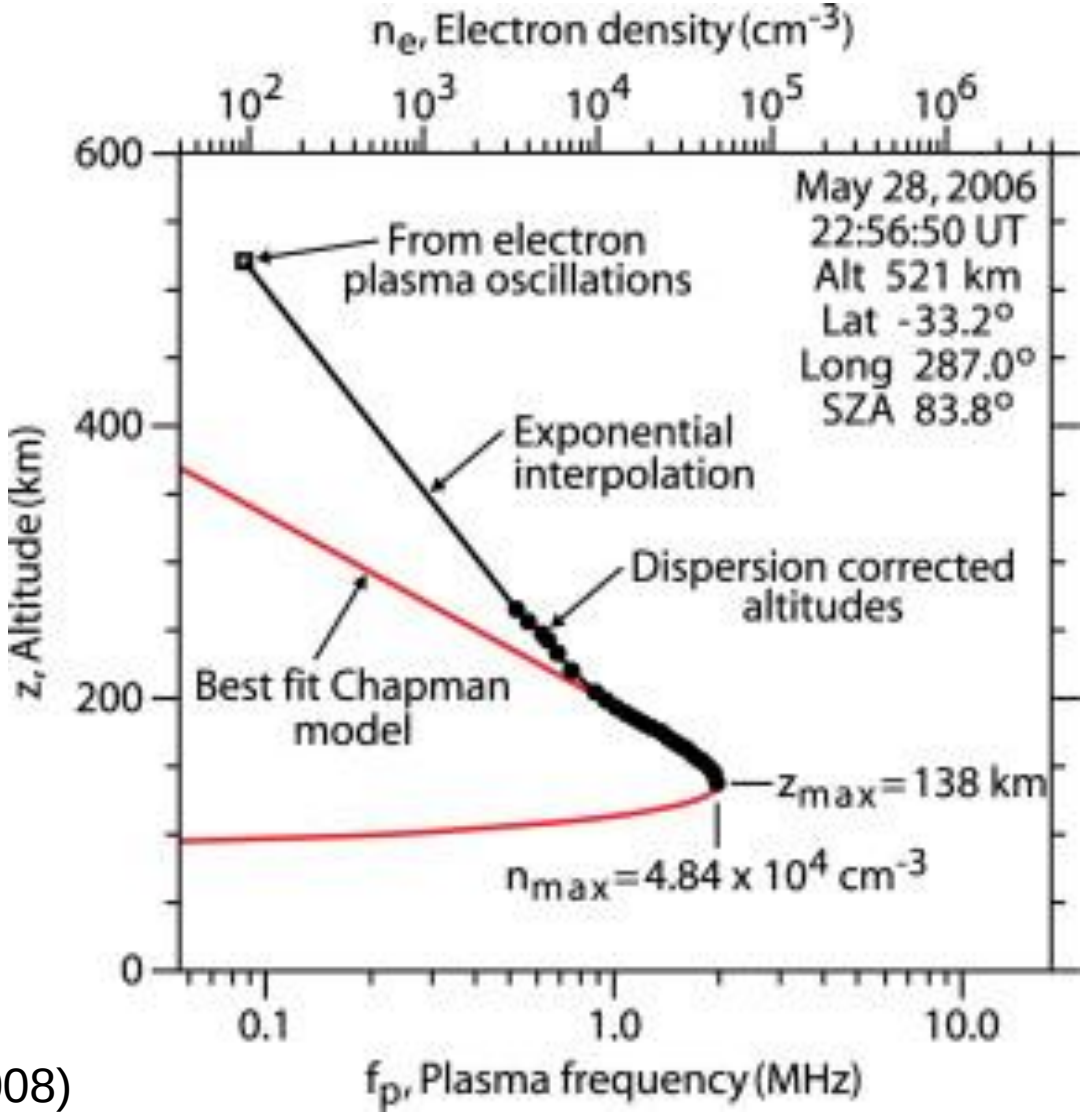
MARSIS radar sounding





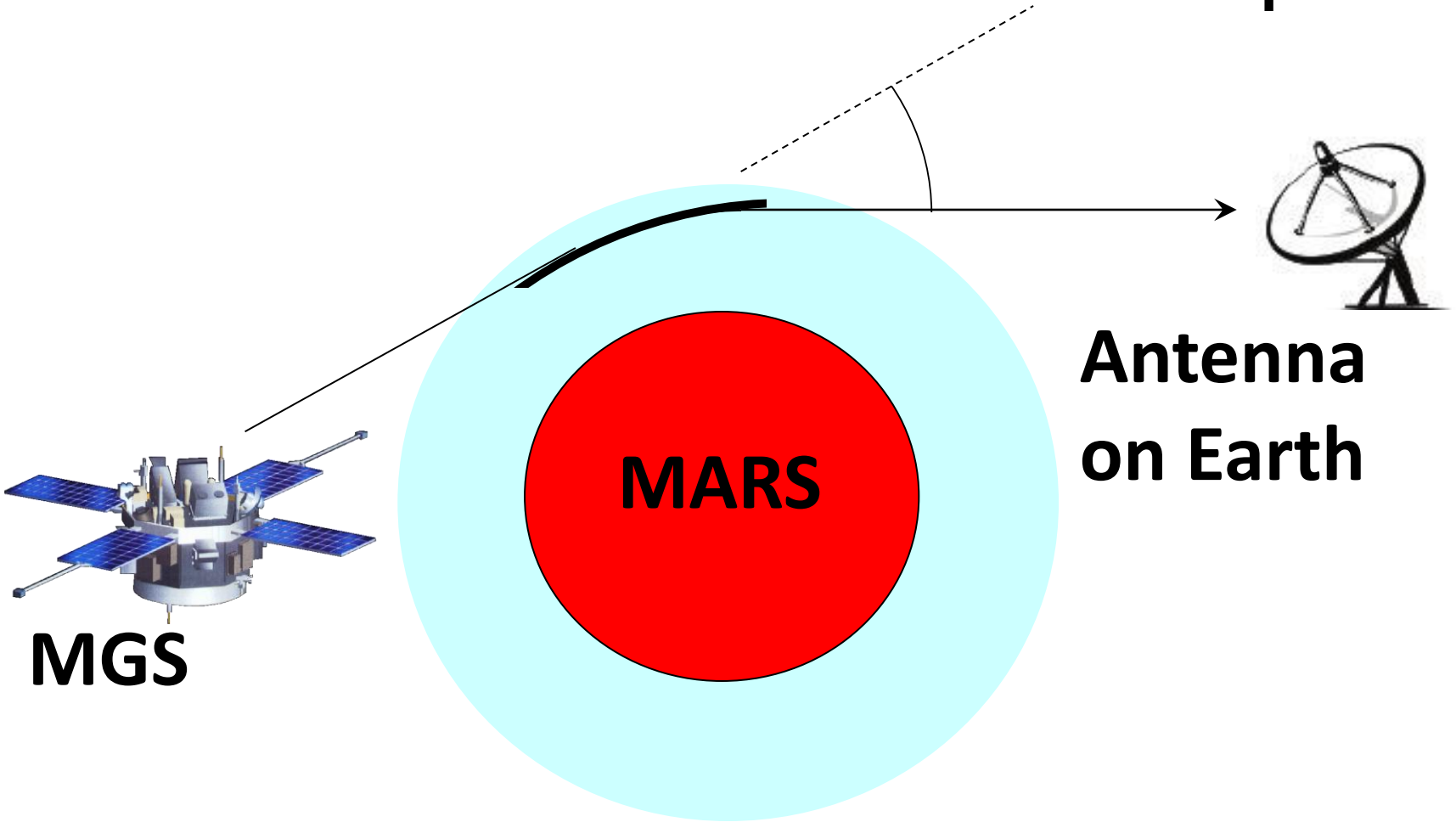
Gurnett et al. (2008)

MARSIS results

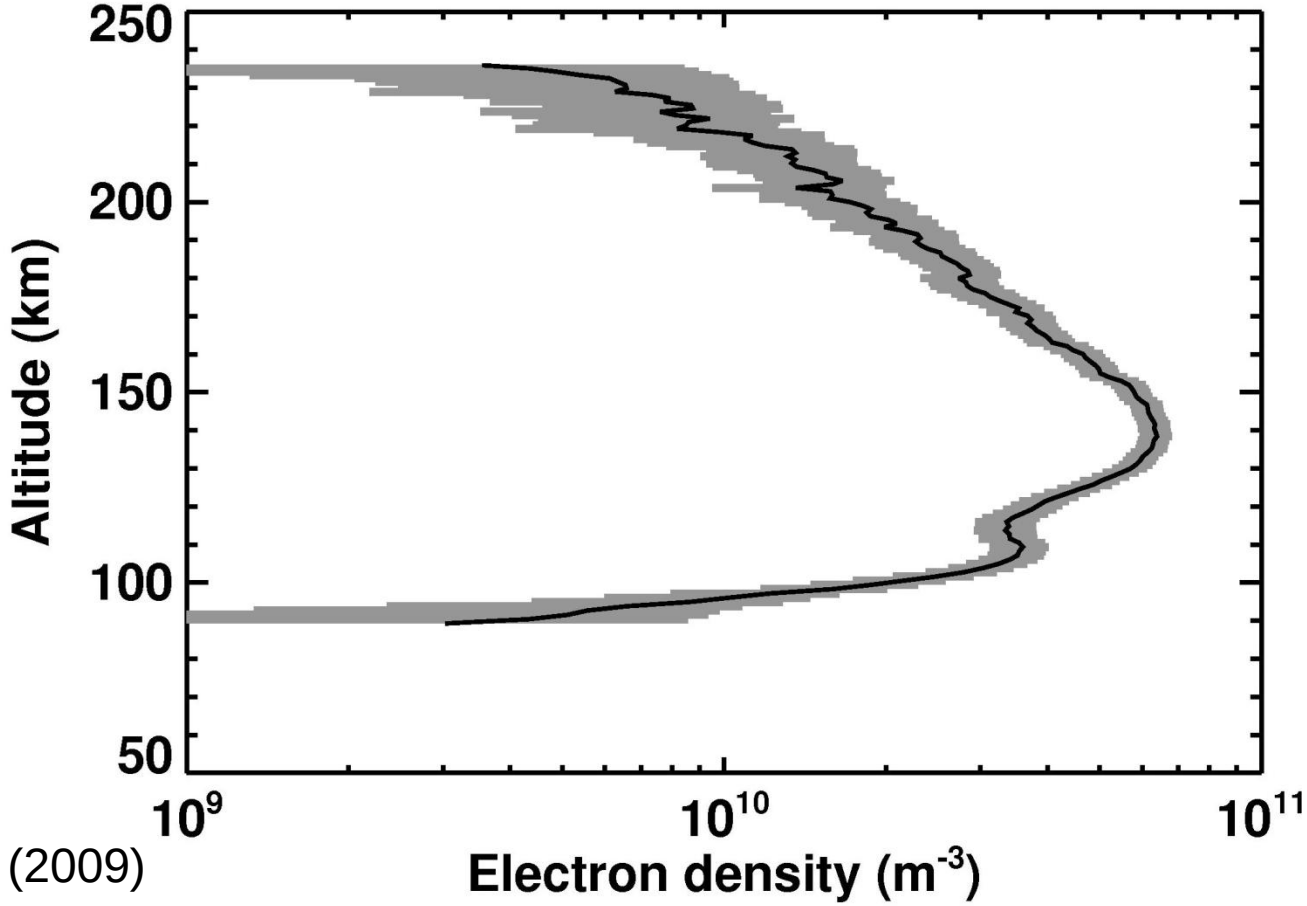


Gurnett et al. (2008)

Radio occultation technique



Radio occultation results



Withers et al. (2009)

Complementary techniques

Radio occultation

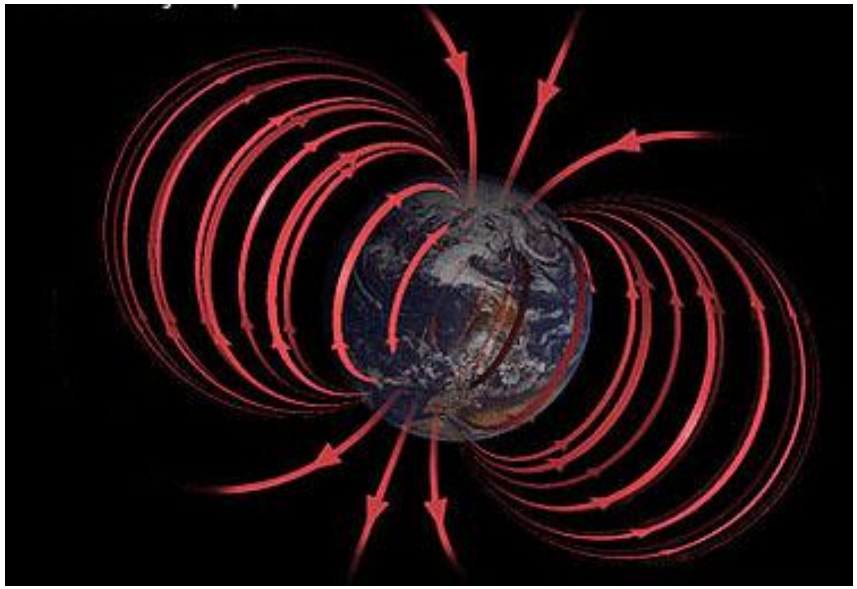
- Precise vertical scale
- 1 km vertical resolution
- Full vertical coverage
- ~200 km horizontal averaging
- Alias horizontal structure to vertical
- Limited opportunities

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

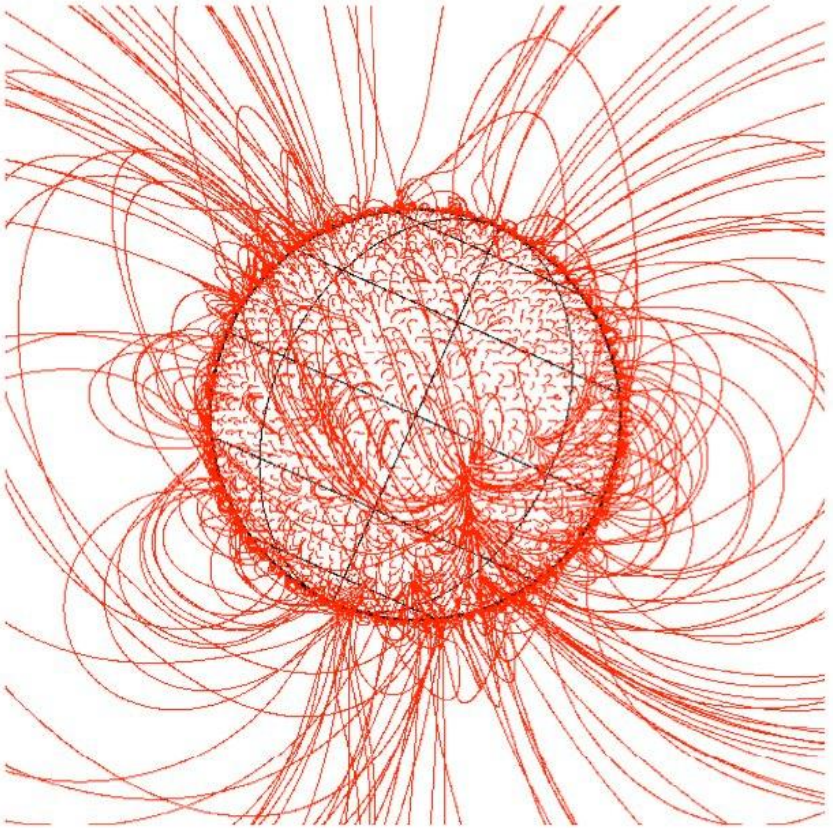
Mars is magnetically crazy

Earth magnetic field



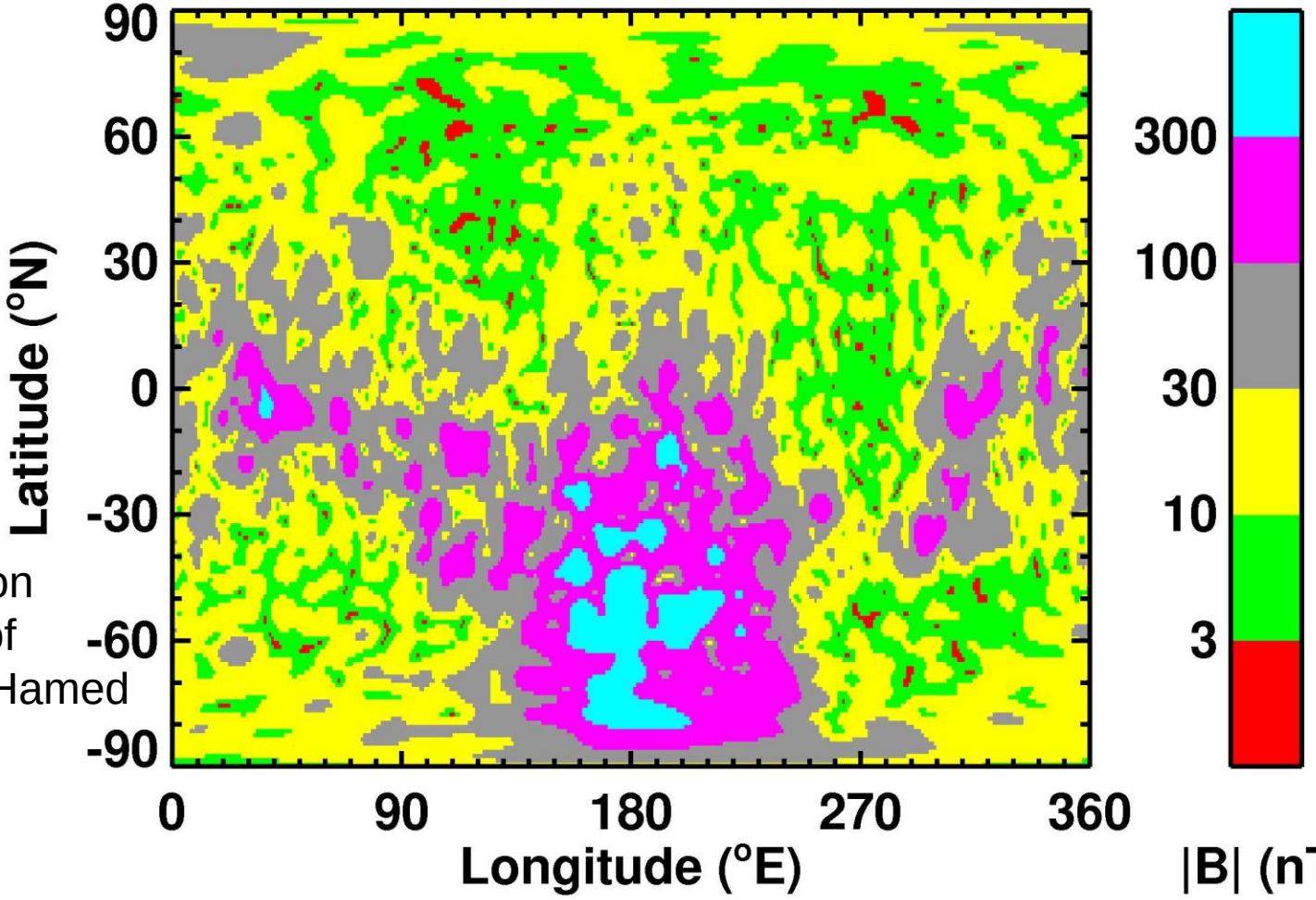
www.windows2universe.org

Mars magnetic field



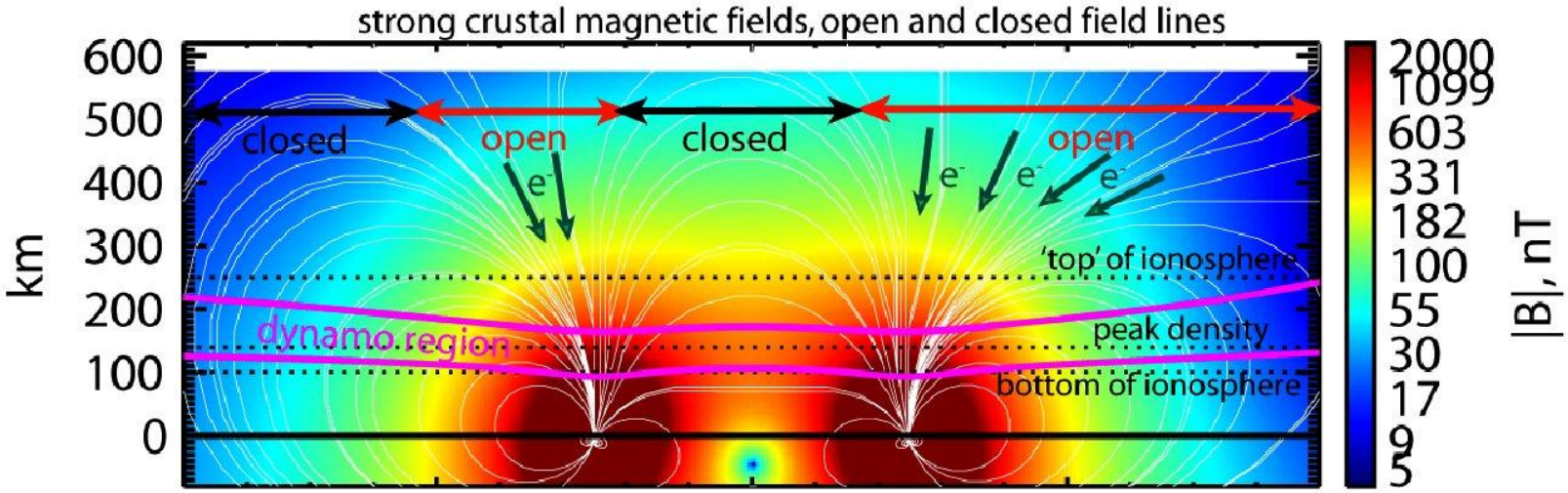
Brain (2002)

Magnetic field at Mars



Based on model of Arkani-Hamed (2004)

“Shield and sword”

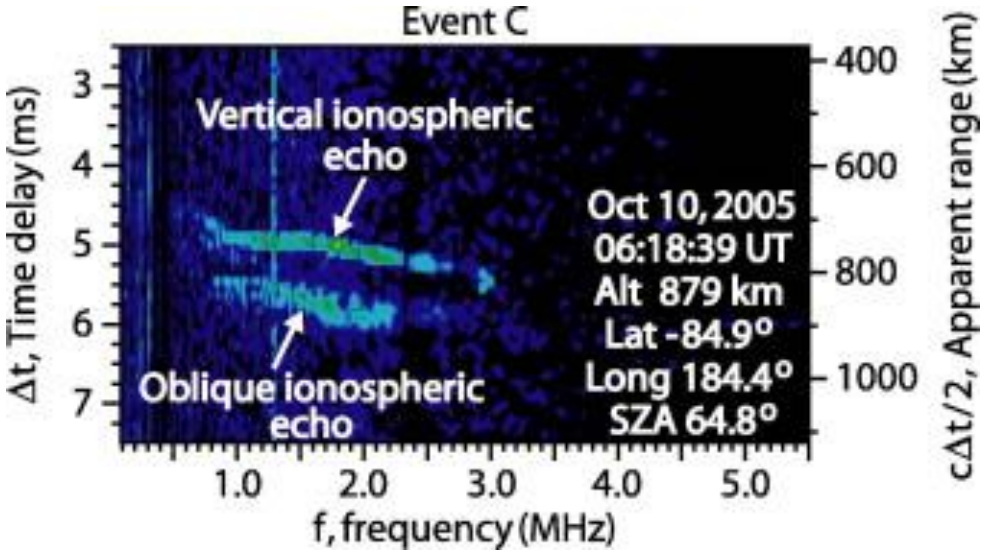


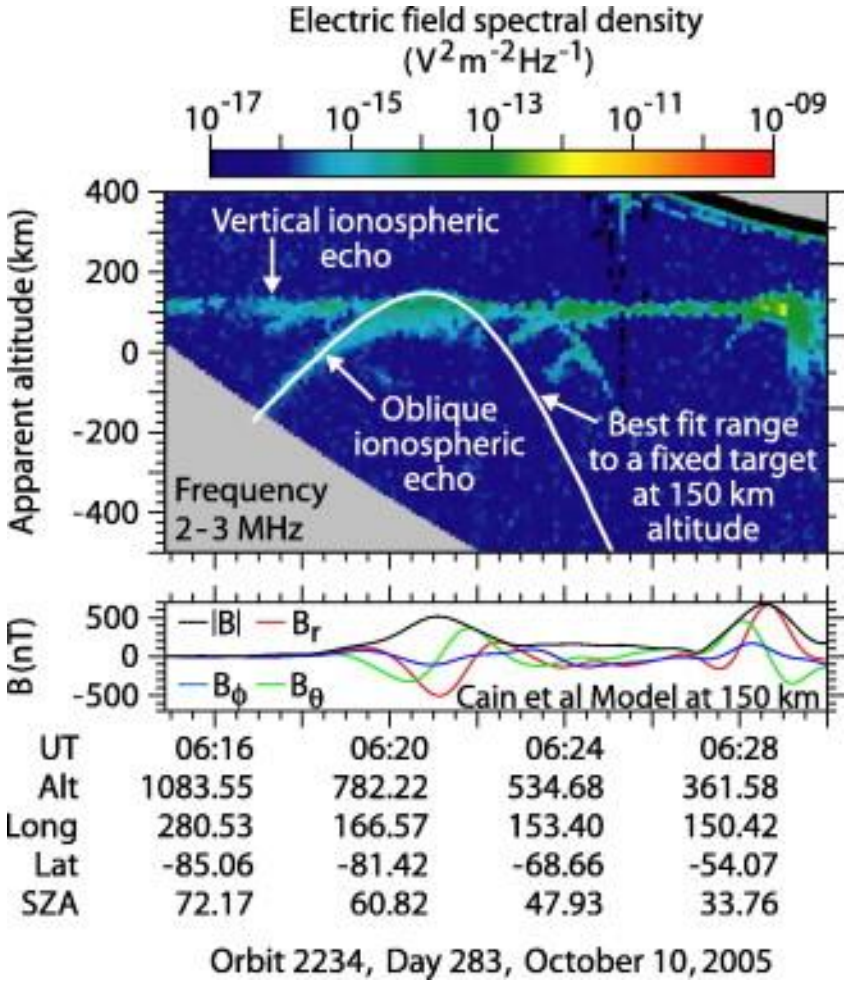
Lillis et al. (2011)

Closed field lines – Both ends anchored on planet

Open field lines – One end anchored on planet, other end connects with solar wind

What is the ionosphere like in strongly-magnetized regions?

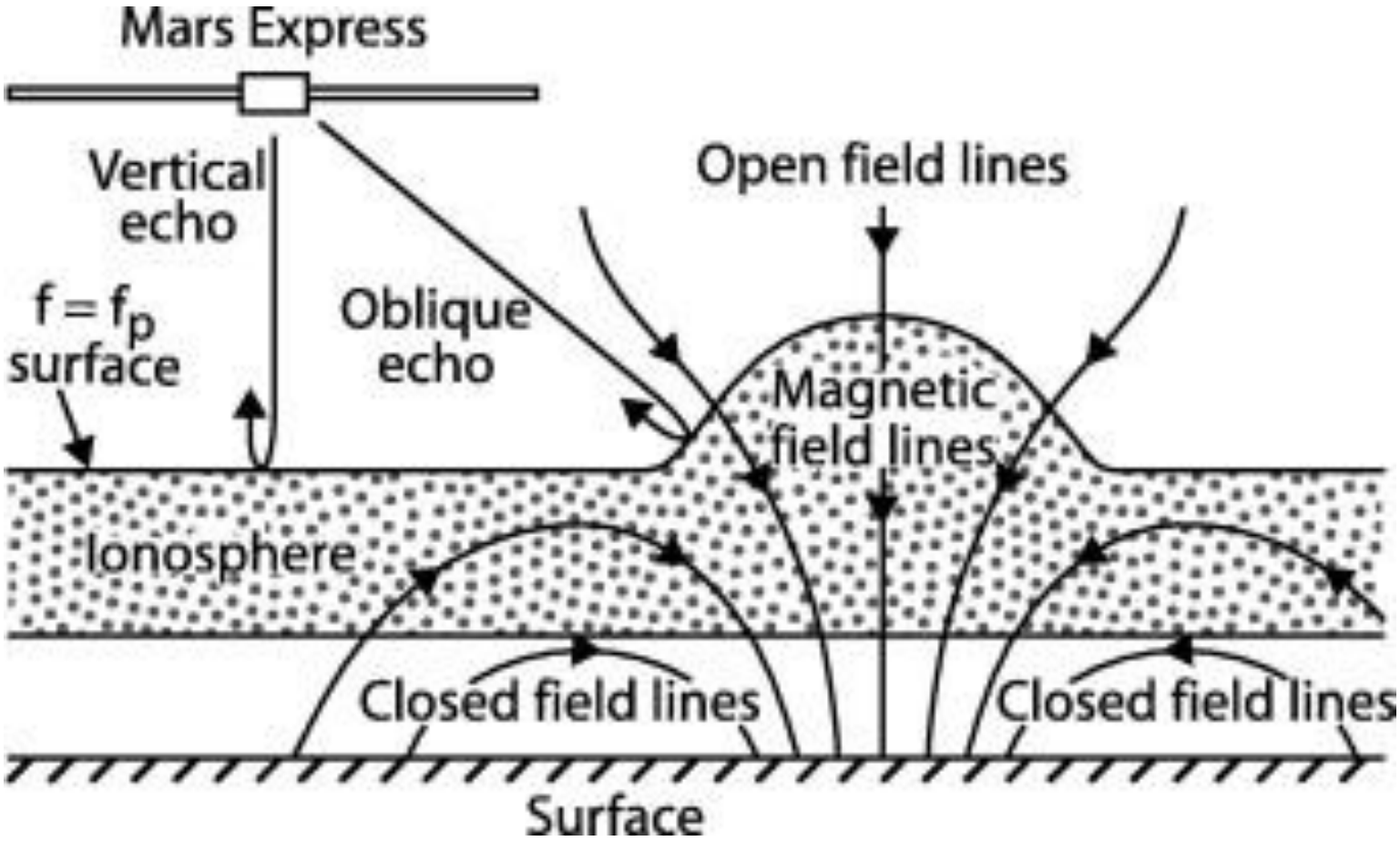




Oblique echoes seen over strong and vertical crustal magnetic fields

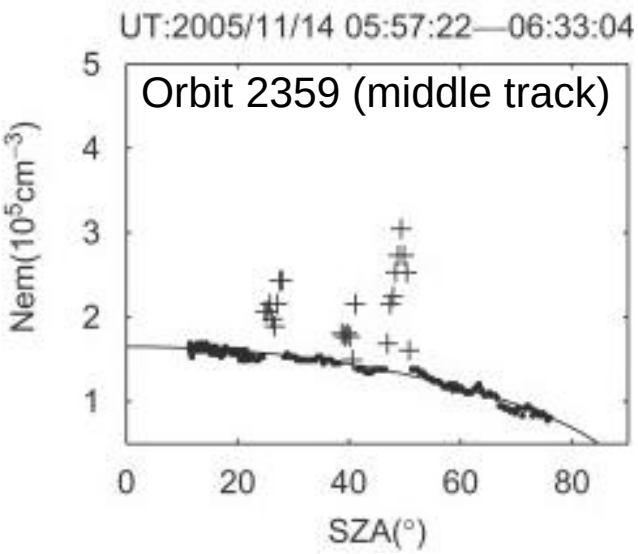
Gurnett et al. (2008)
(both figs)

Ionosphere is “inflated”



Gurnett et al. (2008)

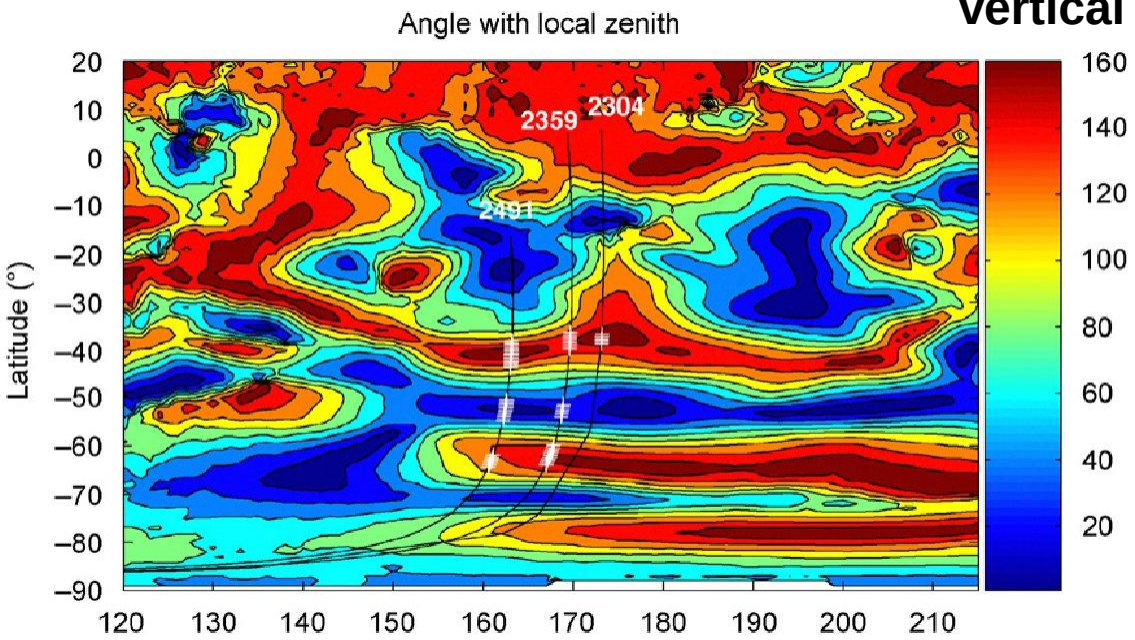
Enhancements are localized



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

Internal effects of **B** as well

$$m_j \frac{\partial \underline{v_j}}{\partial t} + m_j \left(\underline{v_j} \cdot \underline{\nabla} \right) \underline{v_j} = m_j \underline{g} - \frac{1}{N_j} \underline{\nabla} \left(N_j k T_j \right)$$

Gravity and pressure gradients

$$+ q_j \underline{E} + q_j \underline{v_j} \times \underline{B}$$

Electric and magnetic fields

$$- m_j \nu_{jn} \left(\underline{v_j} - \underline{u} \right)$$

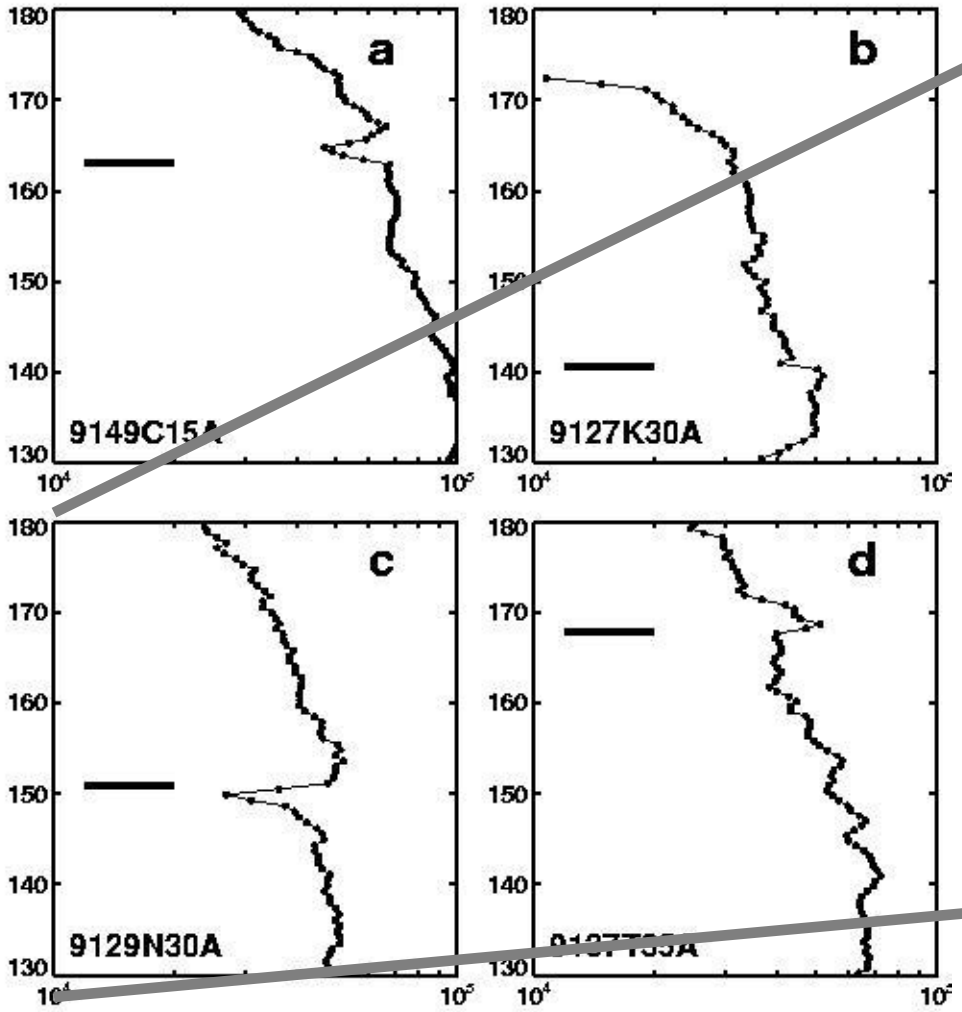
Ion-neutral collisions

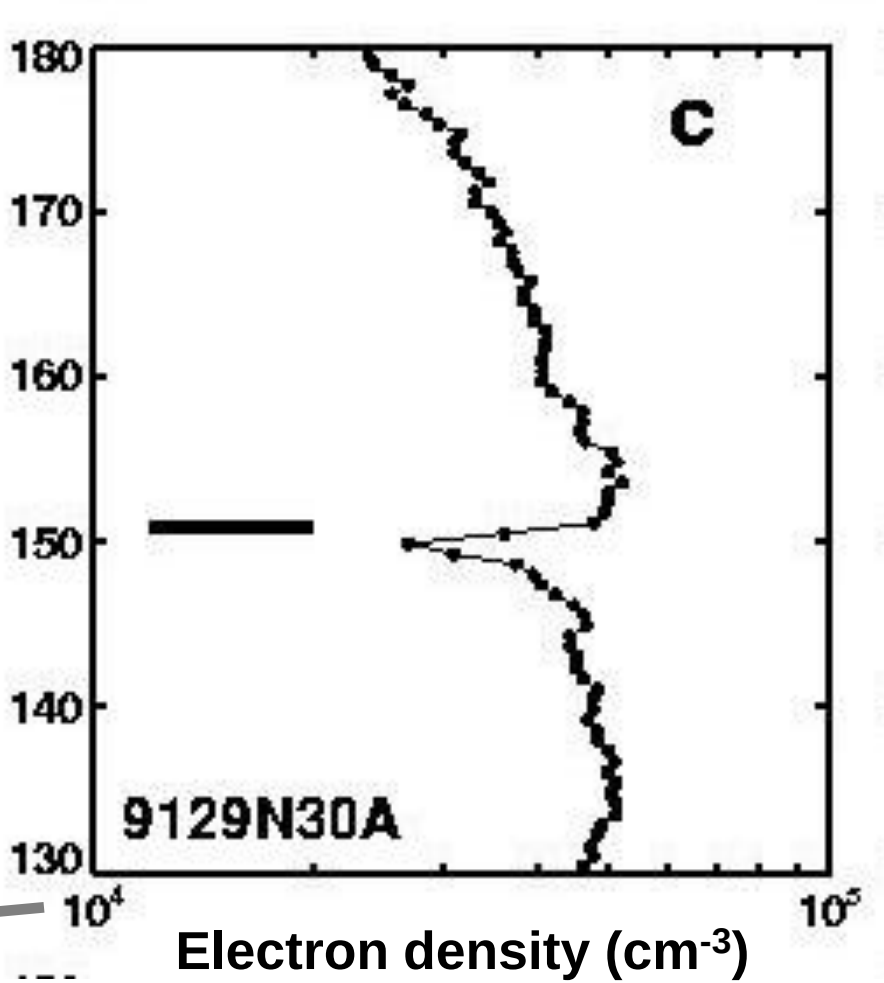
$$\kappa_j = \frac{q_j B}{m_j \nu_{jn}}$$

This is a critical ratio – defines “strong” or “weak” field

Ion gyrofrequency to ion-neutral collision frequency

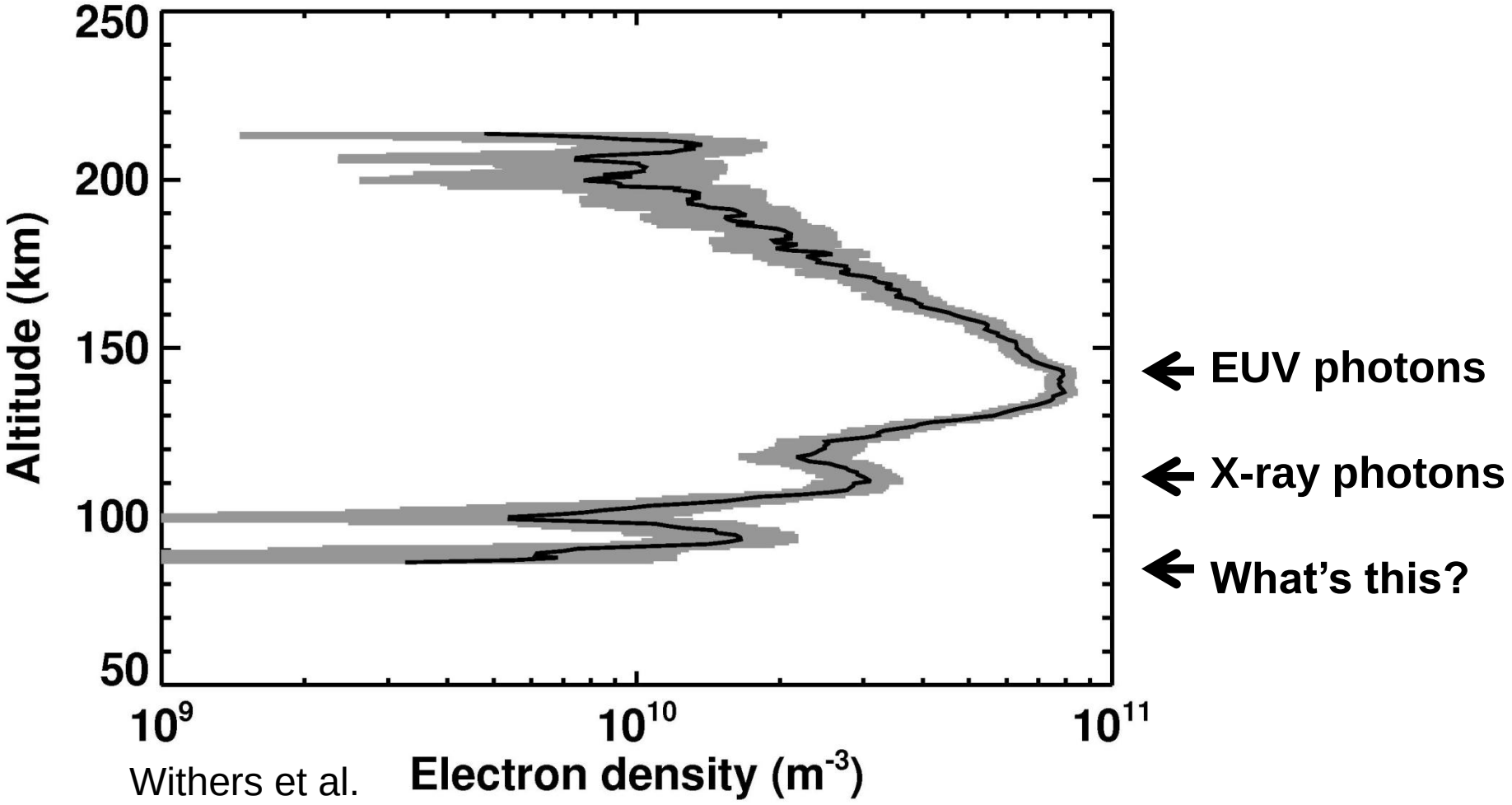
Localized variations seen





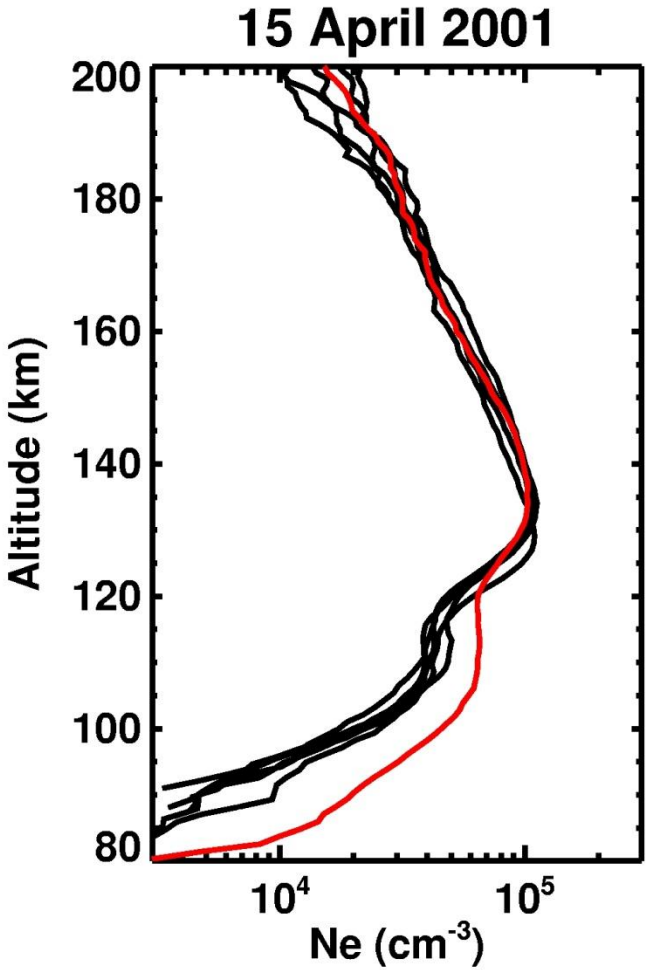
Withers et al. (2005)

Sporadic plasma below 100 km



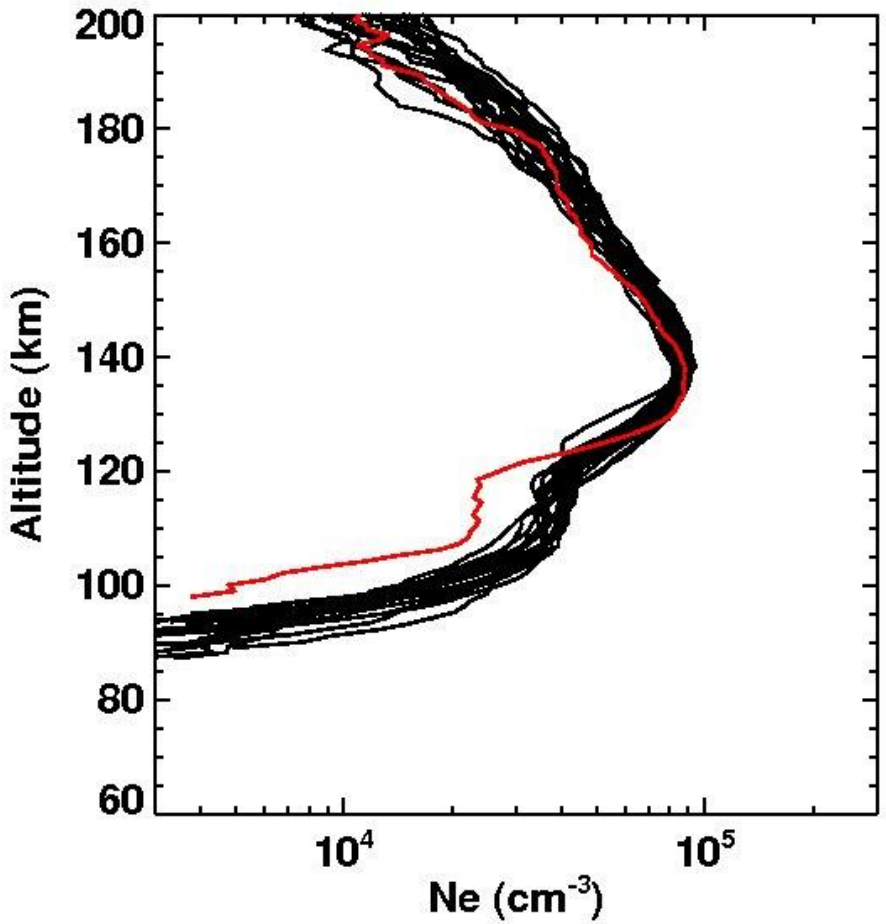
Withers et al. (2008)

At the X-ray-produced layer



Mendillo et al. (2006)

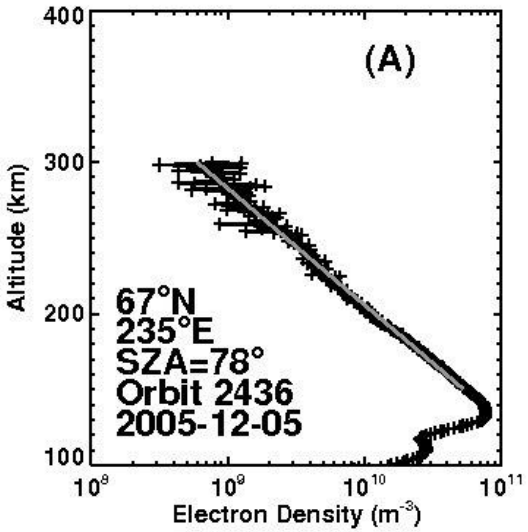
One case of large electron densities

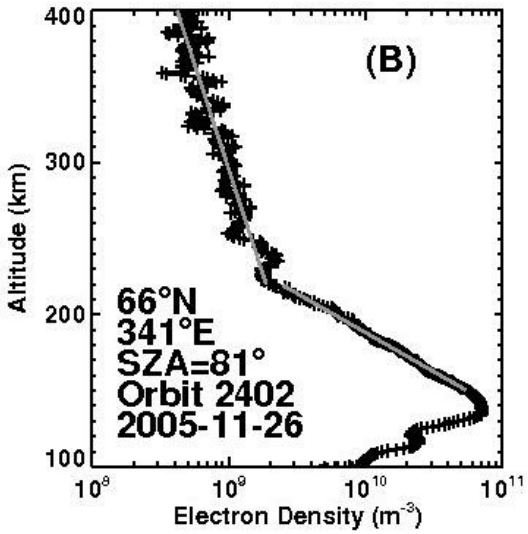


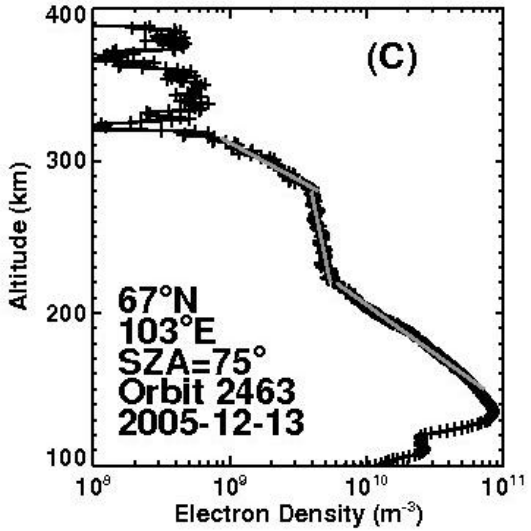
Withers (2009)

One case of small electron densities

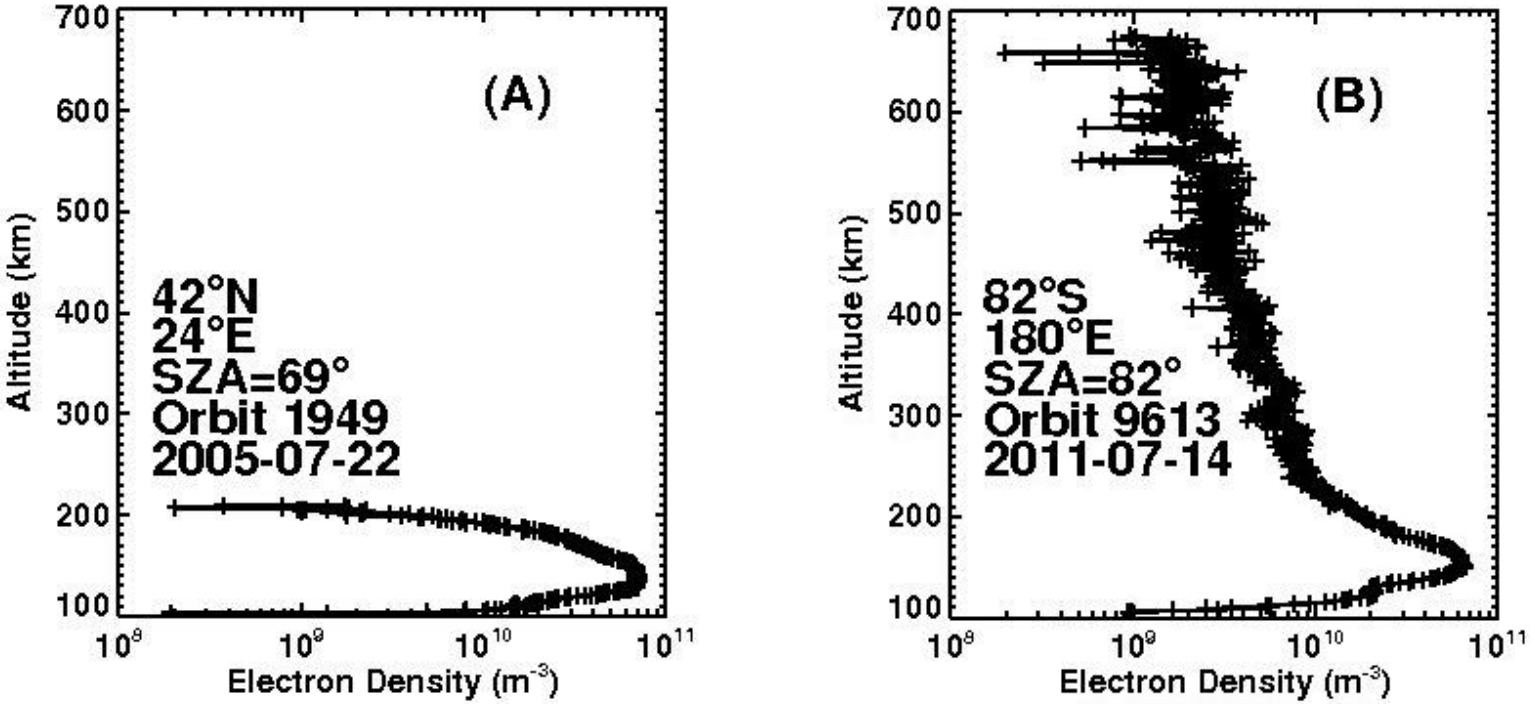
Variations in topside structure

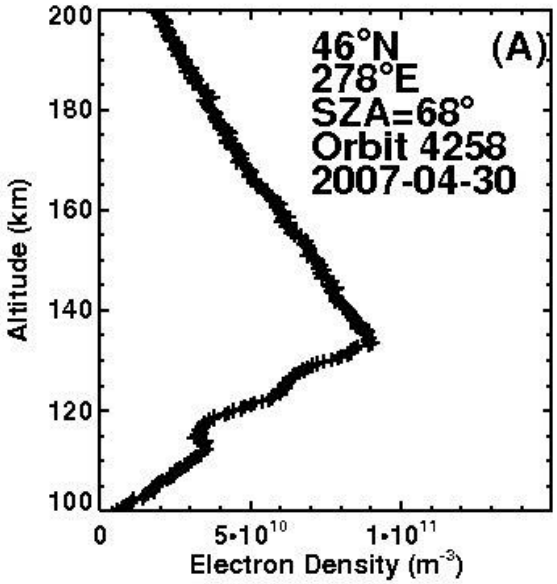


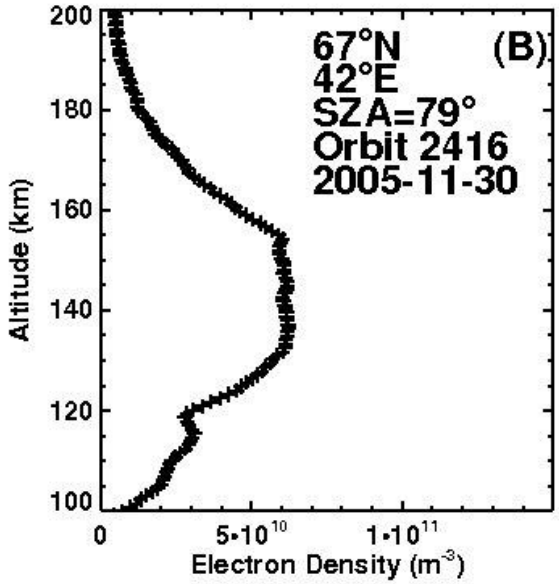


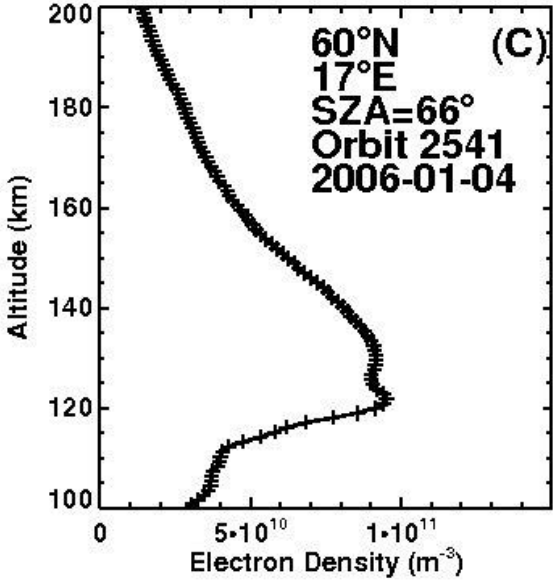


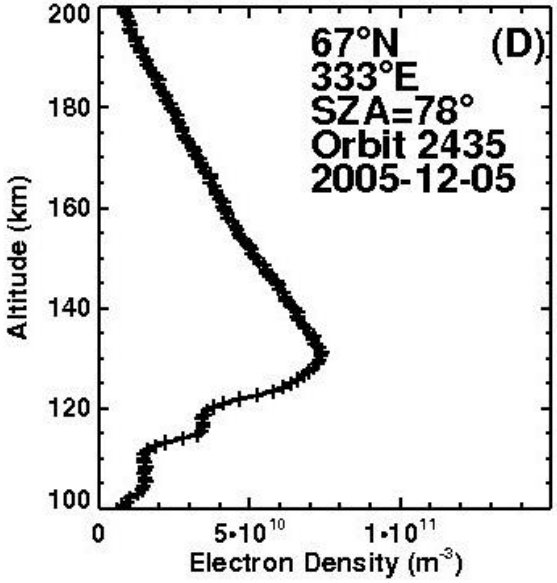
Variations in ionopause altitude

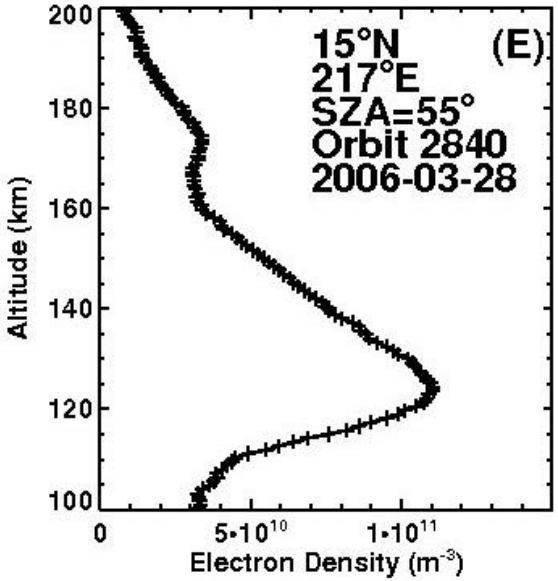


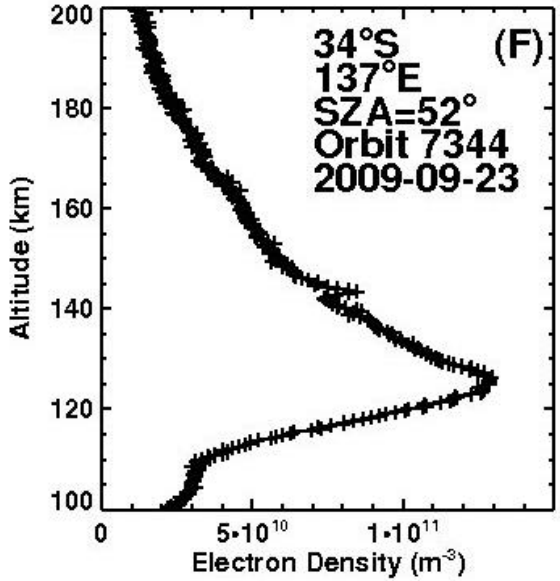

46°N
278°E
SZA=68°
Orbit 4258
2007-04-30
(A)
Altitude (km)
Electron Density (m-3)


67°N
42°E
SZA=79°
Orbit 2416
2005-11-30
(B)
Altitude (km)
Electron Density (m-3)


60°N
17°E
SZA=66°
Orbit 2541
2006-01-04
(C)
Altitude (km)
Electron Density (m-3)


67°N
333°E
SZA=78°
Orbit 2435
2005-12-05
(D)
Altitude (km)
Electron Density (m-3)

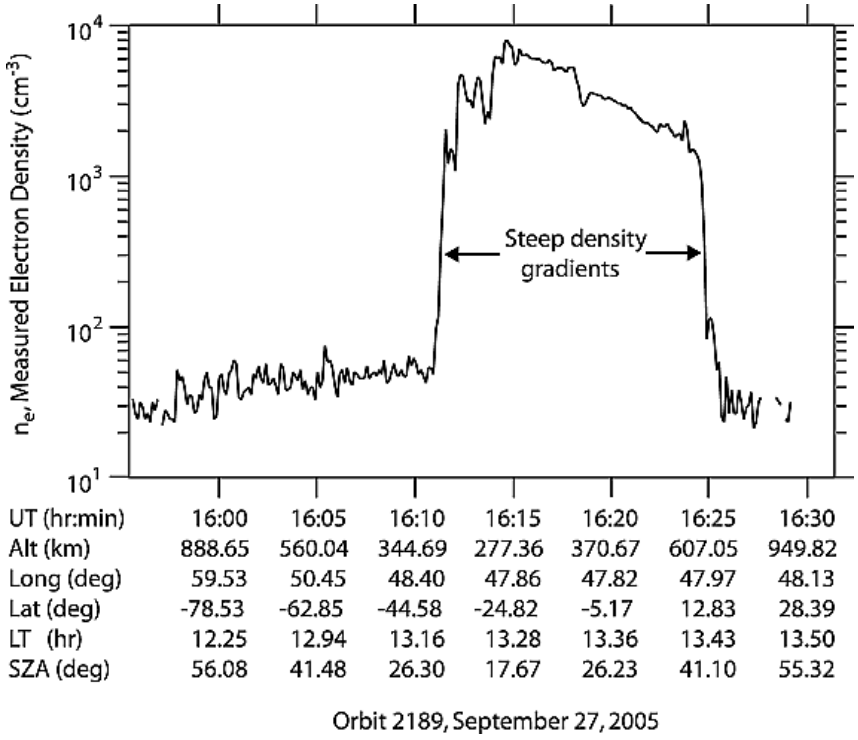

15°N
217°E
SZA=55°
Orbit 2840
2006-03-28
(E)
Altitude (km)
Electron Density (m-3)


34°S
137°E
SZA=52°
Orbit 7344
2009-09-23
(F)
Altitude (km)
Electron Density (m-3)

Conclusions

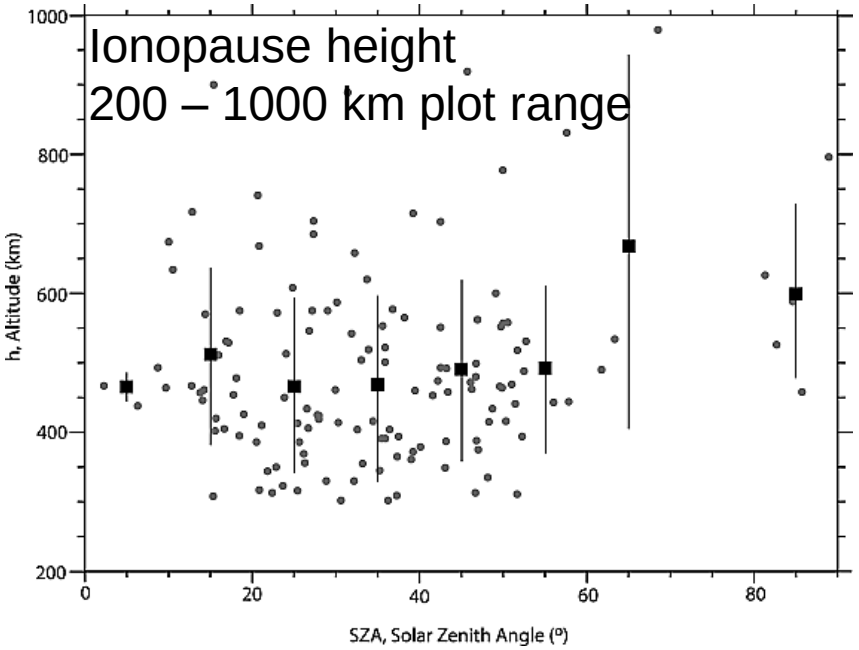
- Radio occultations and MARSIS topside sounder have different strengths and weaknesses
- Effects of magnetic fields on ionospheric properties are substantial, if poorly understood
- Deviations from the basic vertical structure of the ionosphere can be very large

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

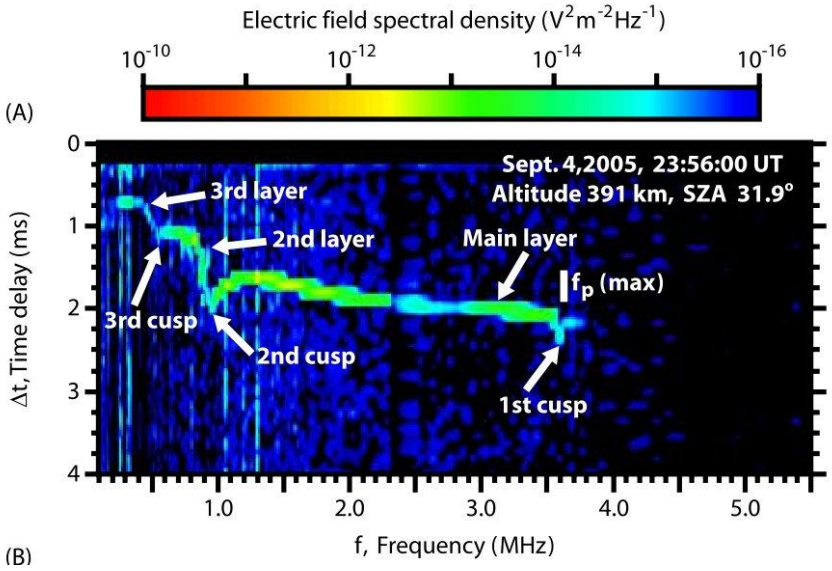


SZA 0 – 90 degrees plot range

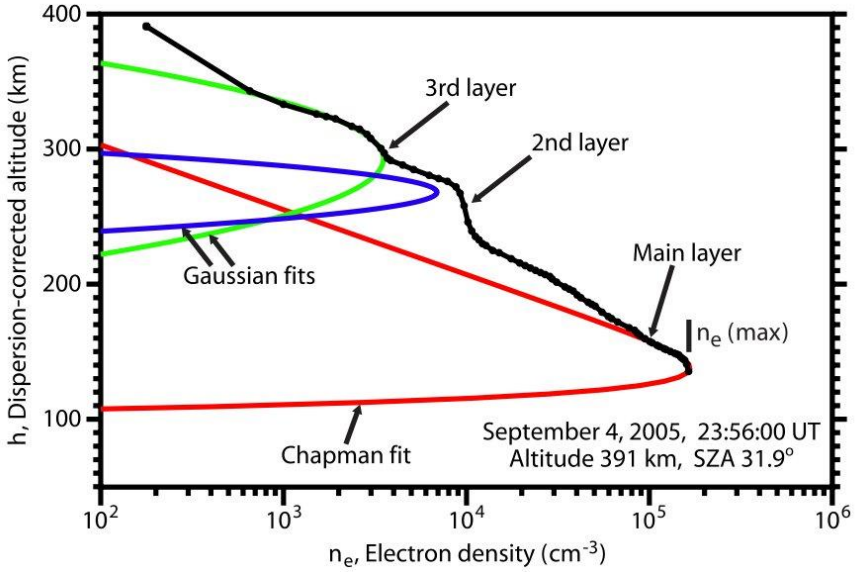
Ionopause is not always present
When present, typically around 400 km

Duru et al. (2009) (both figs)

Structure of topside ionosphere



Kopf et al. (2008)



Kopf et al. (2008)

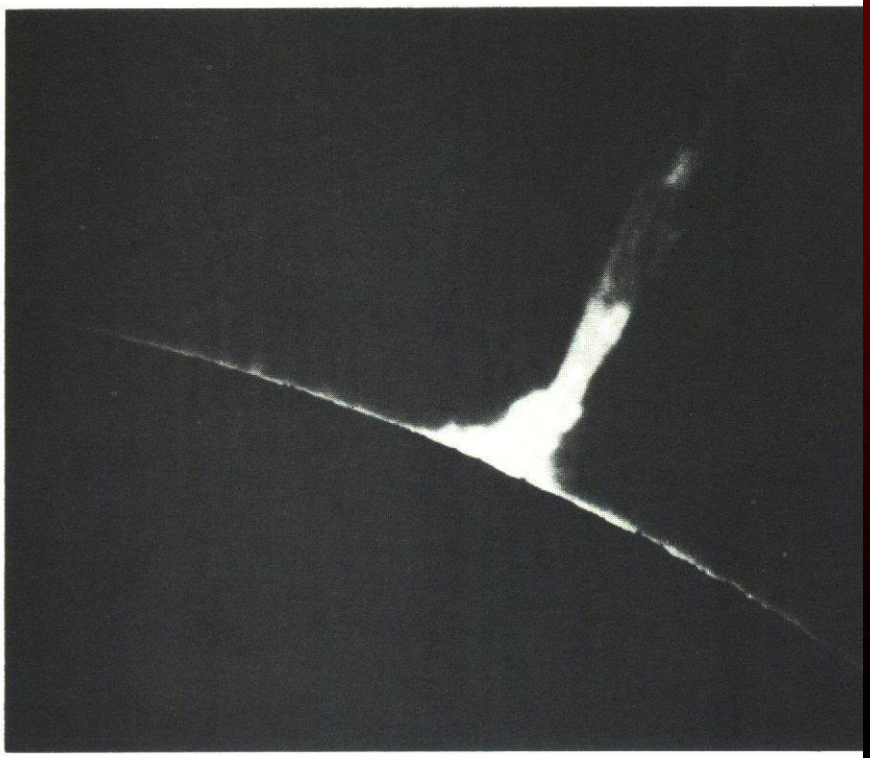
Each observed cusp (dip) means a local maximum in plasma density

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

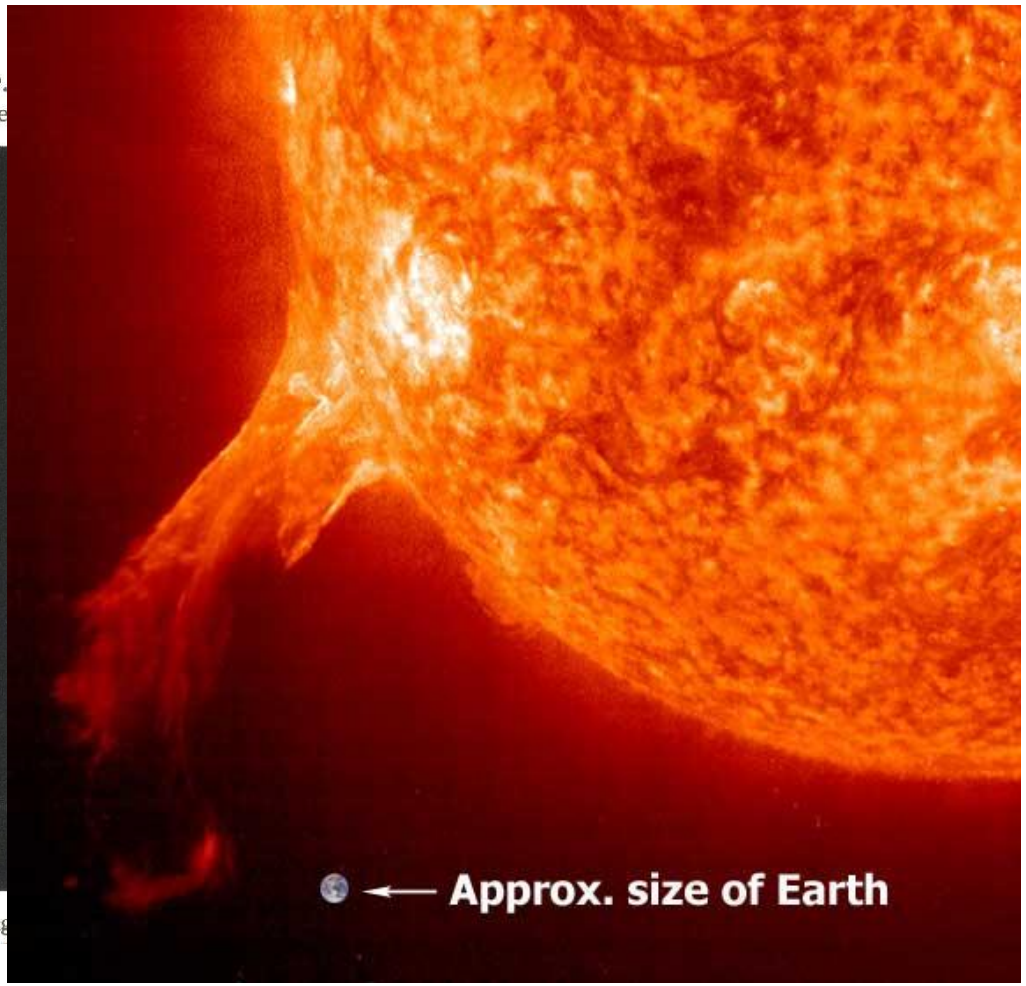
Solar Flares

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



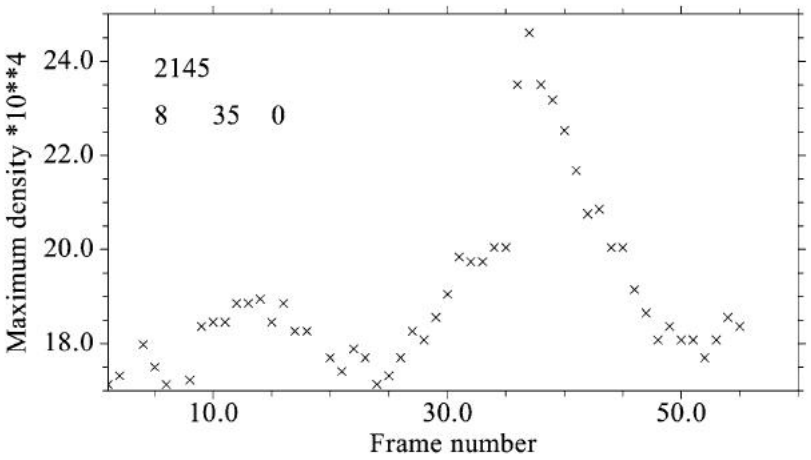
The photograph was taken with a 15 cm aperture solar telescope using



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

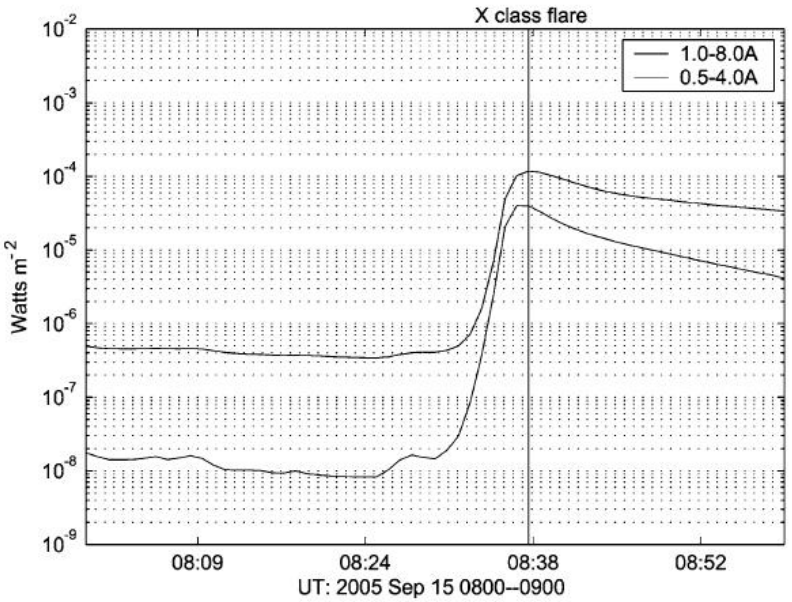
http://rednova.com/news/stories/1/2003/10/24/story002.html

High frequency of MARSIS measurements is invaluable



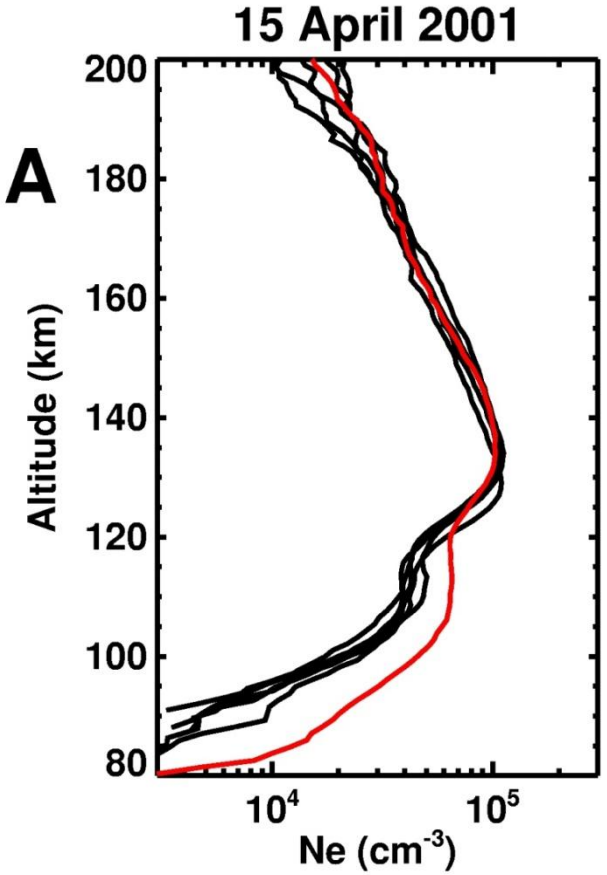
Seven minutes of MARSIS peak electron densities
Increase by 30% for a few minutes

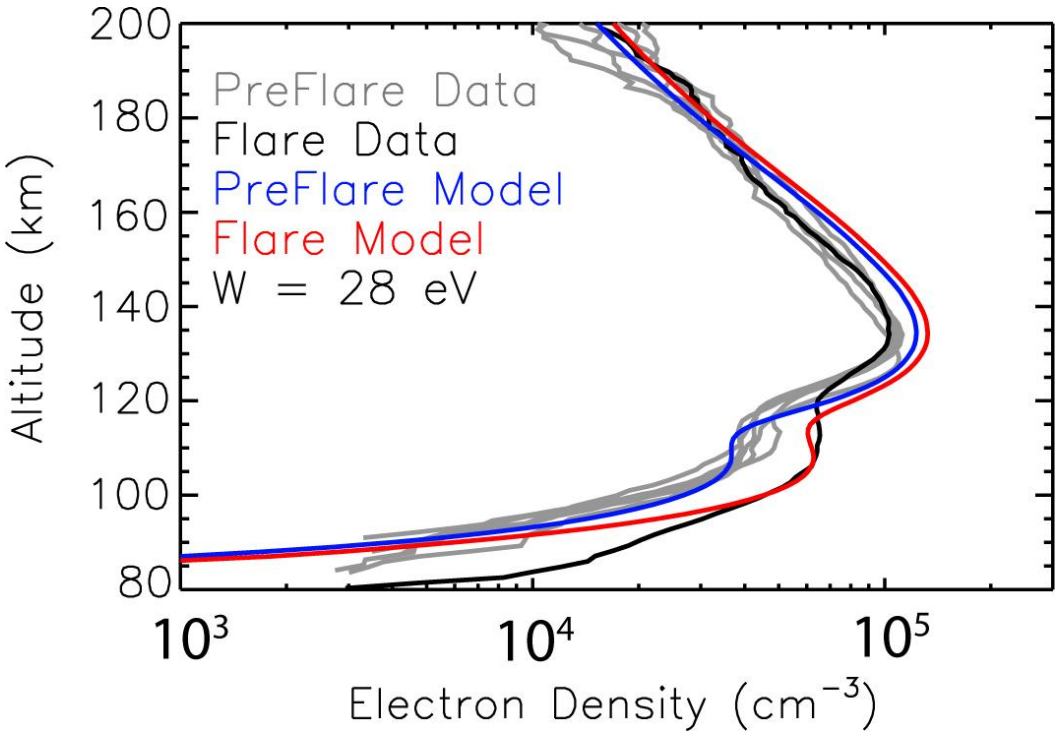
Nielsen et al. (2006)



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)