The Mars Ionosphere: More than a Chapman Layer

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Images

- www.solarviews.com
- The Cosmic Perspective, Bennett et al. (book)

Aim: Present unusual or unexpected observations of the Mars ionosphere. Show that it is scientifically important to understand and explain them.

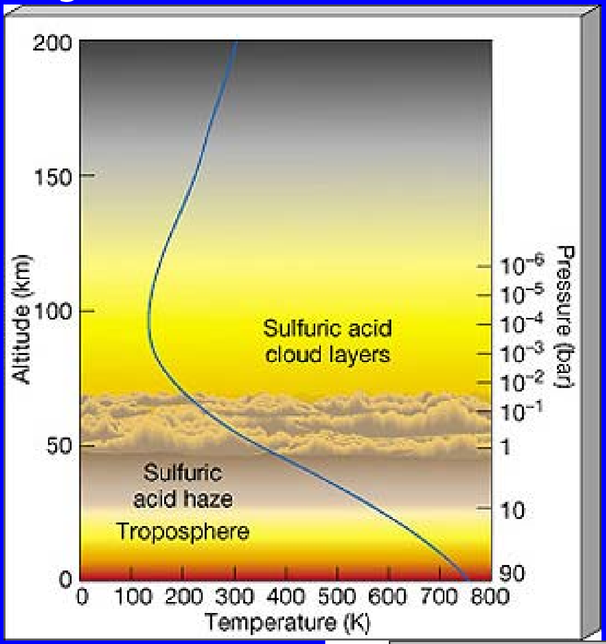
- Describe how properties of Mars relate to properties of Venus and Earth
- Describe the typical Mars atmosphere and ionosphere
- Discuss unusual ionospheric observations and their implications

Atmospheric Compositions

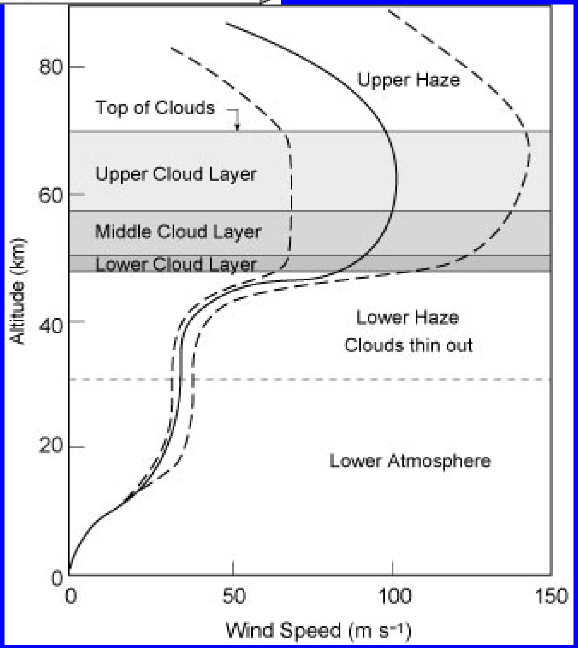
- Venus: 100 bar pressure
  - Mostly CO_2, some N_2
- Earth: 1 bar pressure
  - N_2 and O_2 mixture
- Mars: 0.006 bar pressure
  - Mostly CO_2, some N_2

Present-Day Venus

- Zero obliquity and eccentricity mean no seasons
- Thick atmosphere, slow rotation mean that weather at surface is same everywhere
- 740 K at surface, slow winds, no storms, no rain
- H_2SO_4 clouds at 50 km, where pressures and temperatures are similar to Earth's surface



http://rst.gsfc.nasa.gov/Sect19/Ven-atmos-profile-CM.jpg



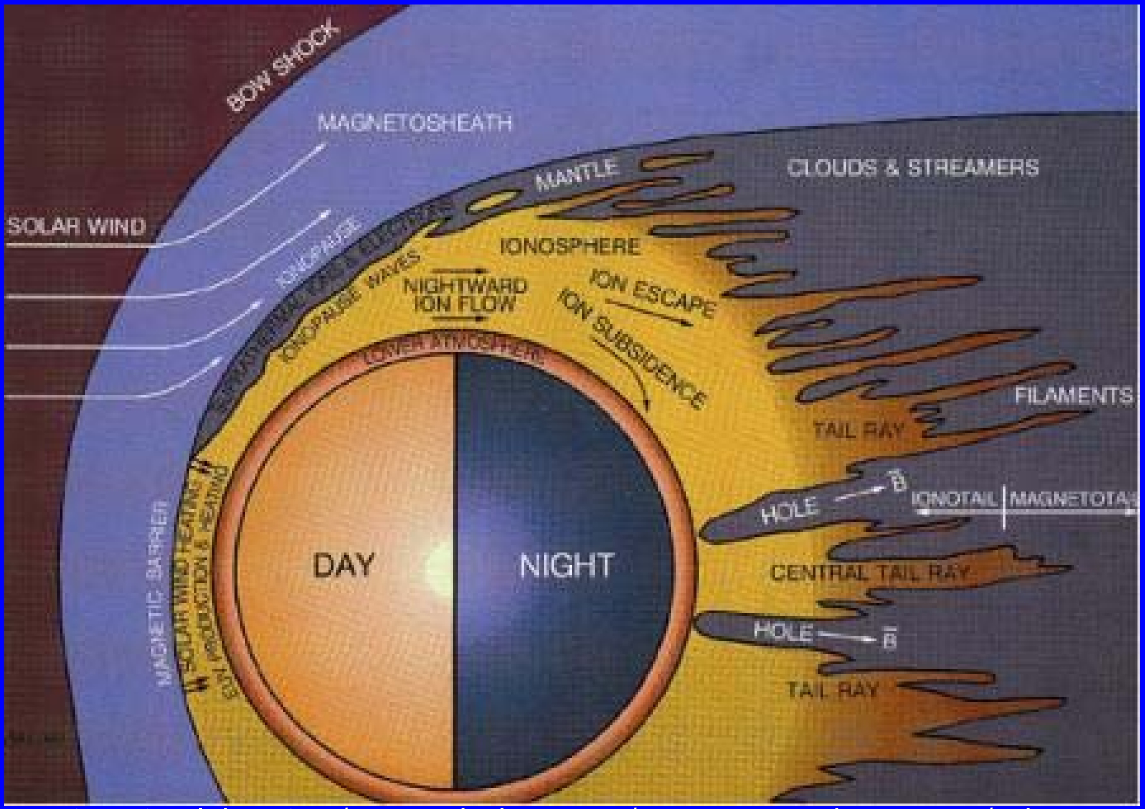
http://ase.tufts.edu/cosmos/pictures/Explore_figs_8/Chapter7/Fig7_3copy.jpg

Venus upper atmosphere

- Reformation of photolysed CO_2 catalysed by Cl, terrestrial implications
- Lots of solar heating, but little day-night transport of energy
- Nightside upper atmosphere is very cold, 100 K, whereas dayside is 300 K
- O / CO_2 ratio plays a major role, more O than CO_2 above 150 km
- Only H is escaping today

Venus ionosphere and plasma

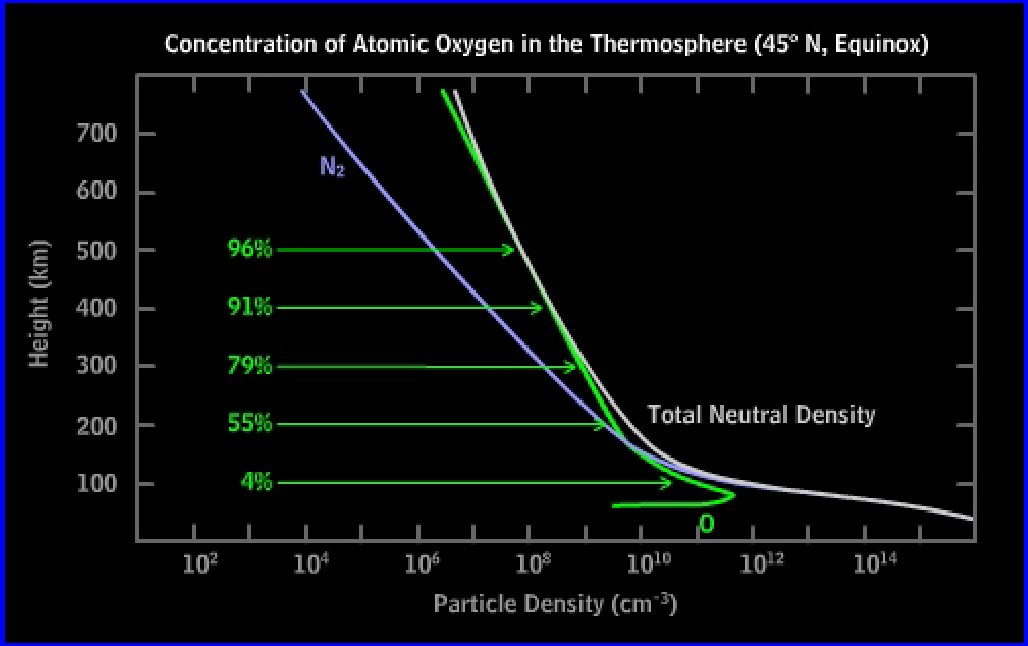
- Ionosphere formed by EUV photoionization of CO_2, but $CO_2^+ + O \rightarrow O_2^+ + CO$
- O_2^+ is dominant at Chapman peak (140 km), O^+ dominant 40 km higher up



http://www3.imperial.ac.uk/spat/research/space_magnetometer_laboratory/spacemissionpages/venusexpresshomepage/science

- Transport important near O_2^+/O^+ transition and above
- Magnetic fields due to draping of solar wind around planet
- Nightside ionosphere and magnetic fields are complex and variable, affected by plasma transport across terminator

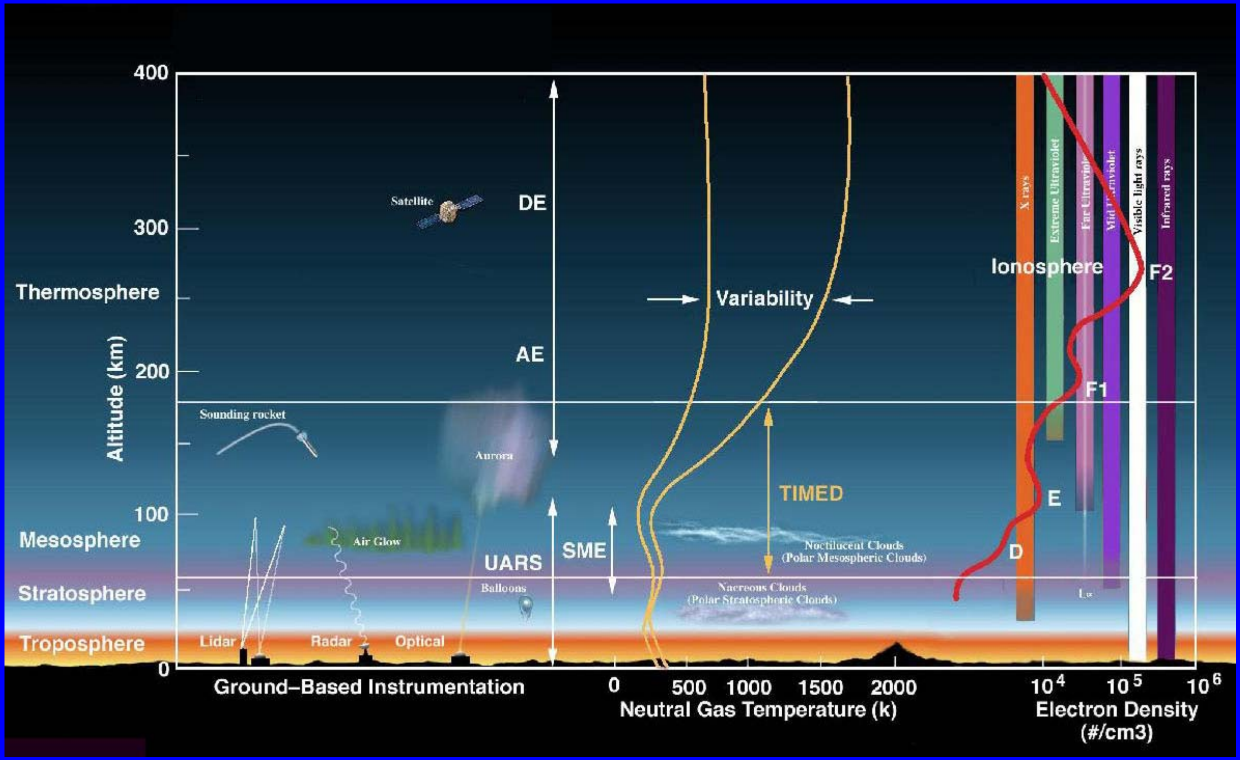
Earth Upper Atmosphere



http://www.meted.ucar.edu/hao/aurora/images/o_concentration.jpg

- O is more abundant than O_2 above 100 km and more abundant than N_2 above 200 km
- T > 800 K above 200 km, much hotter than Venus or Mars. These atmospheres are cooler because CO_2 is very effective at radiating heat, whereas Earth needs higher temperature gradients to conduct heat downwards
- Heating at poles due to magnetic fields guiding solar wind
- Only H is escaping today

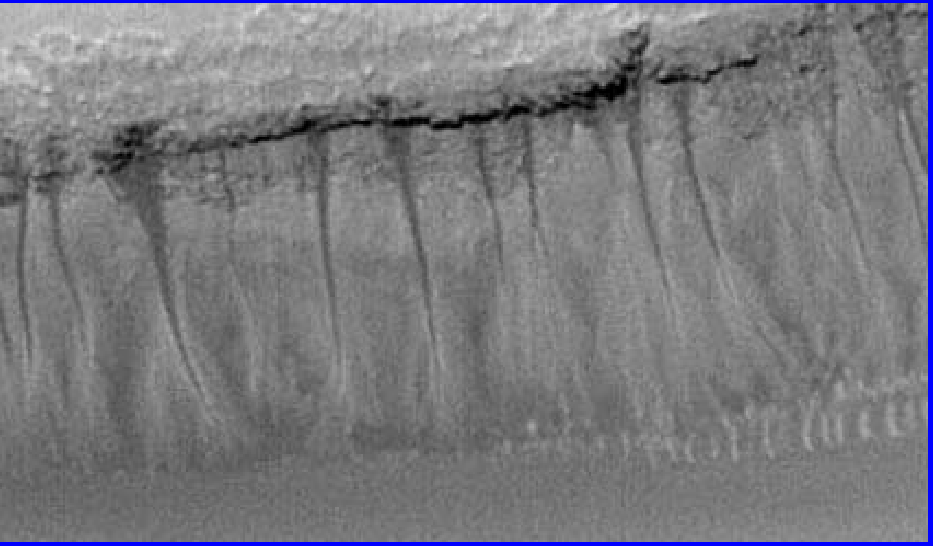
Earth Ionosphere



http://www.bu.edu/cism/CISM_Thrusts/ITM.jpg

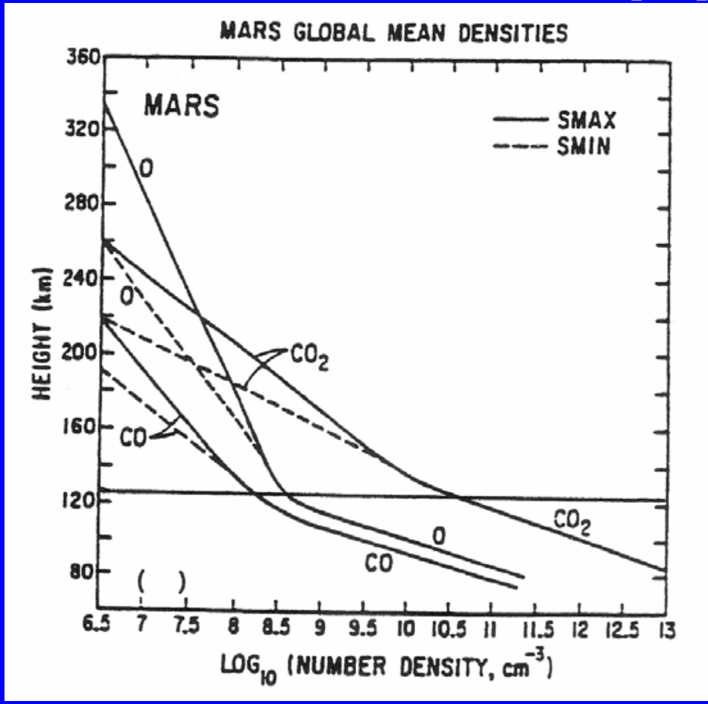
- O_2^+ and NO^+ dominant at 100 km, where EUV absorption peaks
- O^+ dominant at 300 km (overall peak), where transport plays major role
- Changes from O_2^+/NO^+ to O^+ and from N_2 to O make things complex
- Magnetic fields affect plasma transport, especially at equator and near poles

Present-Day Mars

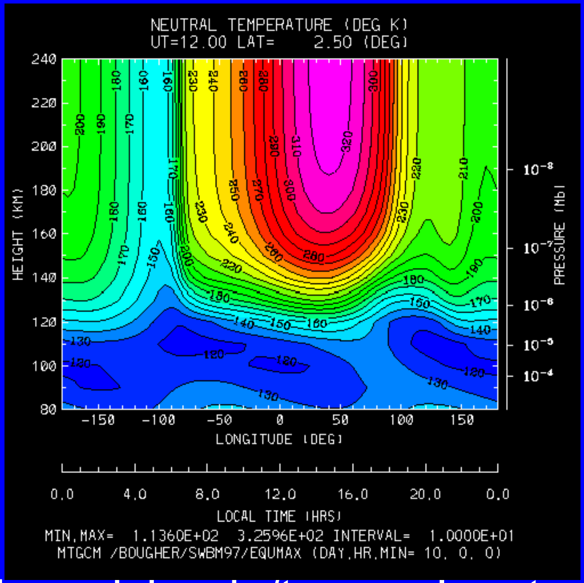


- 1/3 of atmosphere freezes onto winter polar cap
- Global dust storms
- Large day/night temperature differences
- Surface pressure too low for liquid water to be stable, but ongoing gully formation may require liquid water
- Saturated with H_2O, both H_2O and CO_2 clouds are common

Mars Upper Atmosphere



Bougher et al., 2002

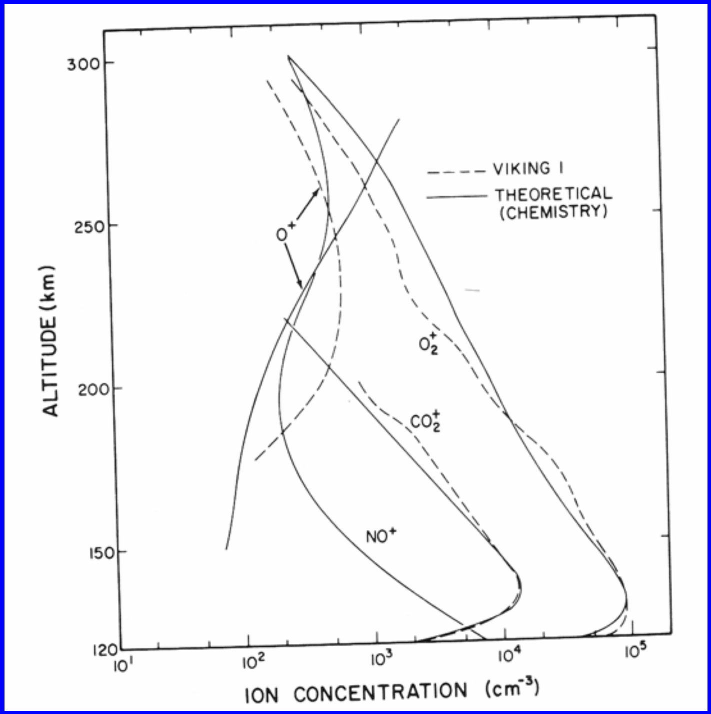


http://data.engin.umich.edu/tgcm_planets_archive/mseasons/equinox/gif/eqtequmax.gif

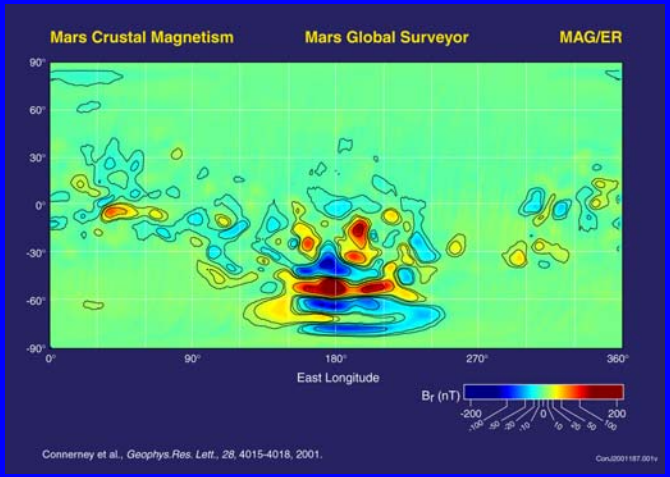
- Species like OH catalyse reformation of photolysed CO_2
- Rapid rotation keeps night/day temperature difference smaller than for Venus
- O / CO_2 ratio is again important, more O than CO_2 above 200 km
- H, H_2, N, and O are escaping today

Mars Ionosphere

- Ionosphere formed by EUV photoionization of CO_2
- $CO_2^+ + O \rightarrow O_2^+ + CO$



Chamberlain and Hunten, 1987

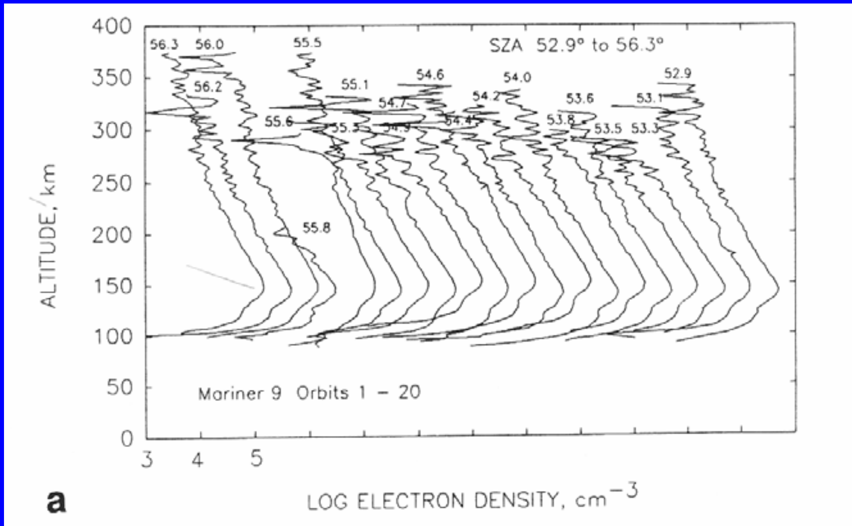


- Transport only important above 180 km, 50 km above peak, so profile is very Chapman-like
- O_2^+ dominant at all altitudes?
- Transport not well-understood
- Effects of magnetic fields not well-understood

Summary

- Venus/Mars have same CO_2 compositions, but lots of differences
- Venus/Mars have similar O_2^+ photochemical ionospheres, but transport processes will be different
- Effects of Mars magnetic fields potentially important

Mars Ionosphere

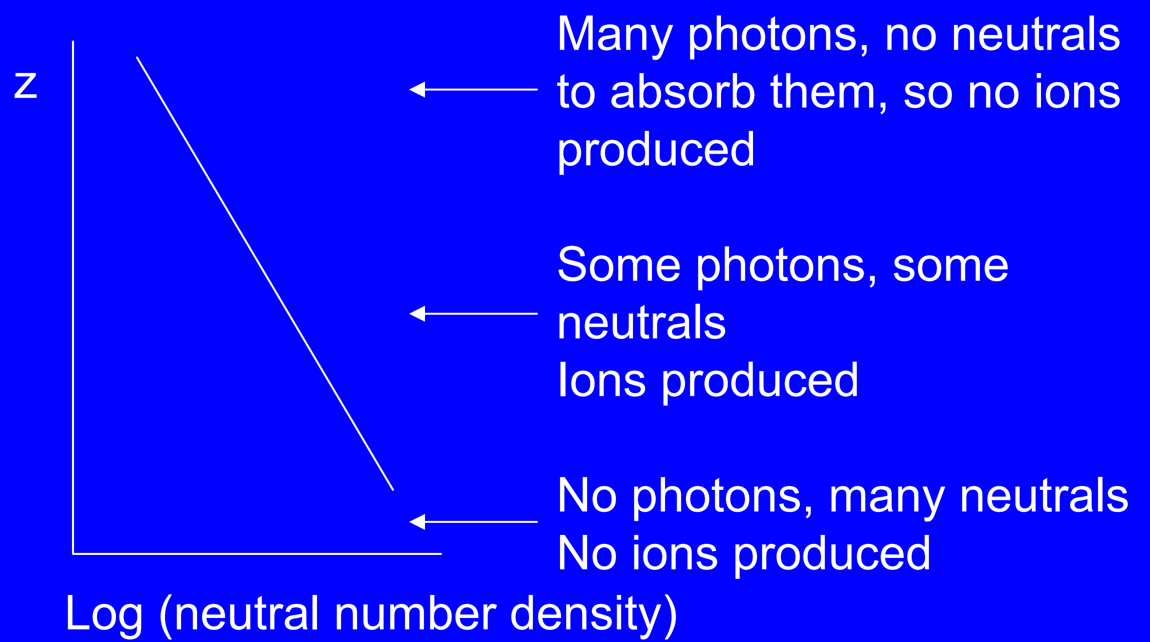


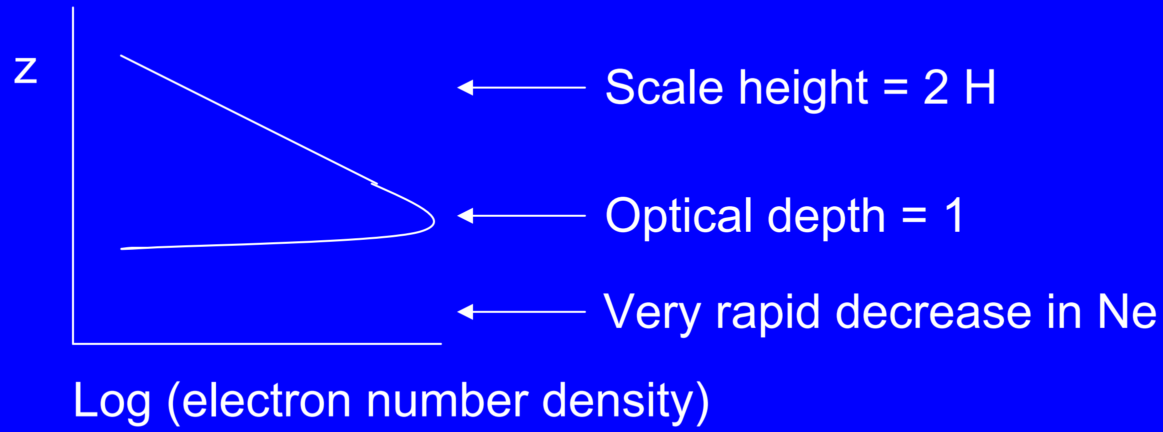
Kliore, 1992

- What do we know?
- Neutral composition – Viking
- Ion composition – Viking
- Electron temperatures – Viking
- Neutral temperatures – Aerobraking data
- Neutral dynamics?
- Plasma dynamics?
- Electron density profiles – Many missions

Very Simple Model - Chapman

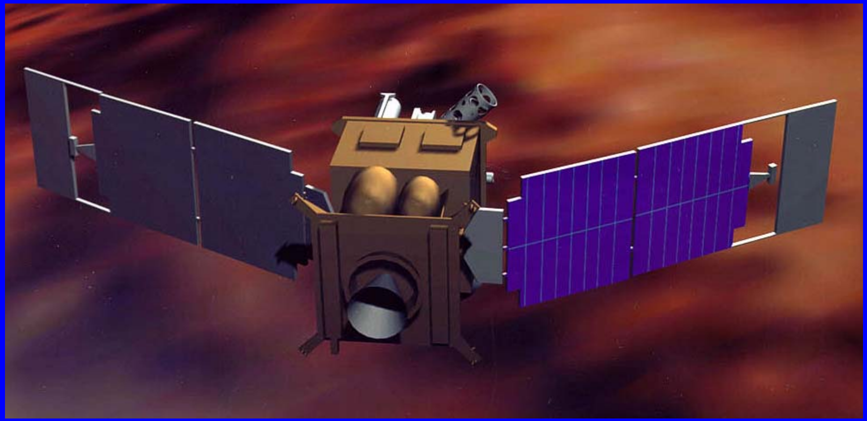
- Neutral atmosphere is CO_2, with constant scale height
- EUV photons create $CO_2^+ + e$ (production)
- $CO_2^+ + O \rightarrow O_2^+ + CO$ (chemistry, fast)
- $O_2^+ + e \rightarrow O + O$ (loss, slower, minutes)
- $P = \alpha N_e^2$

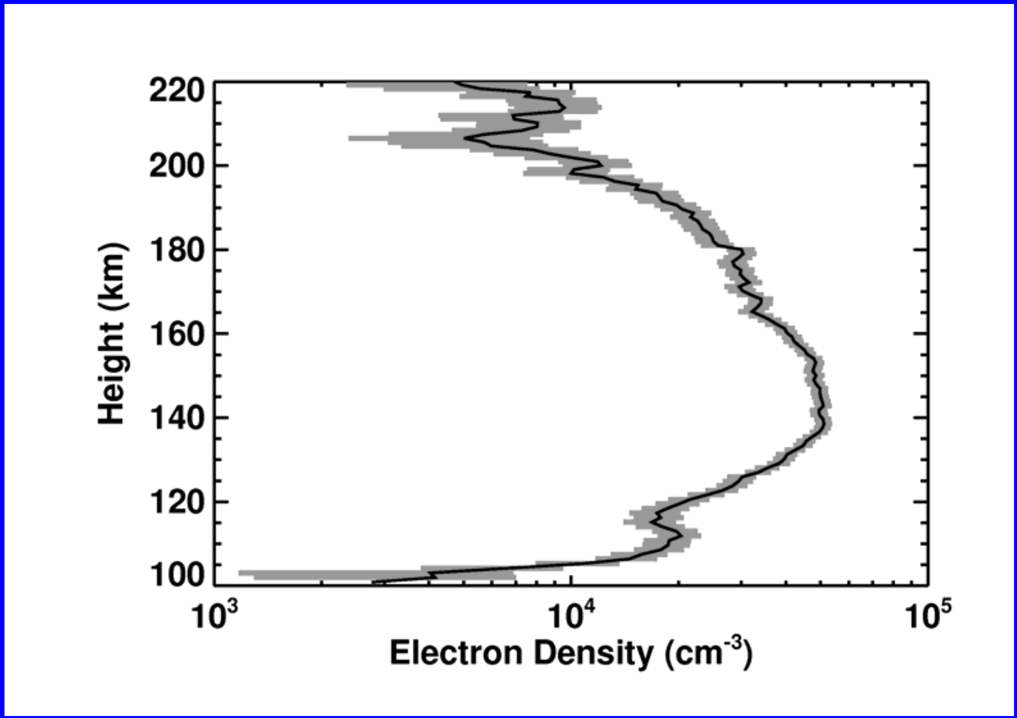




Some Complications

- Typical electron density profile from MGS radio science experiment

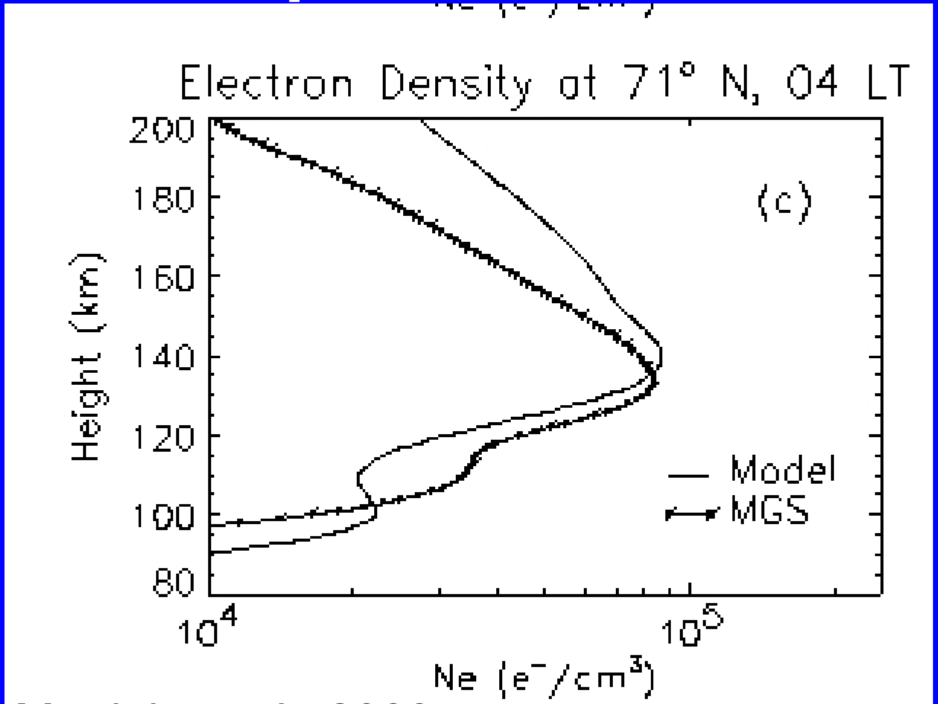




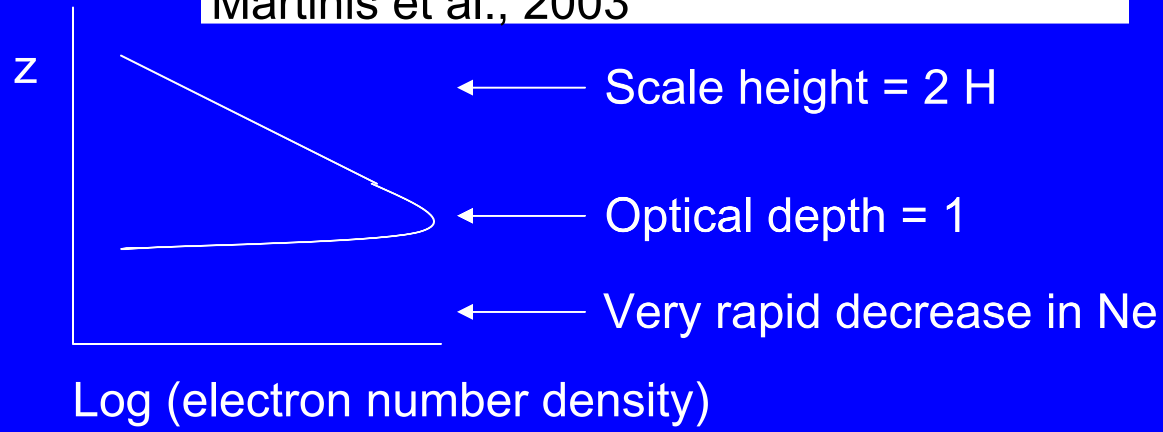
- Neutral chemistry – not just CO_2 absorbing photons and CO_2^+ + O is not only reaction
- X-rays – two competing production functions and multiple ion-electron pairs per photon

Vertical Transport

- Ions move
  - Gravity
  - Pressure gradients
  - E, B fields
  - Drag from winds
- E maintains neutrality
- Topside
  - Large pressure gradients drive plasma upwards
- Bottomside
  - High neutral densities prevent motion of plasma despite pressure gradients



Martinis et al., 2003



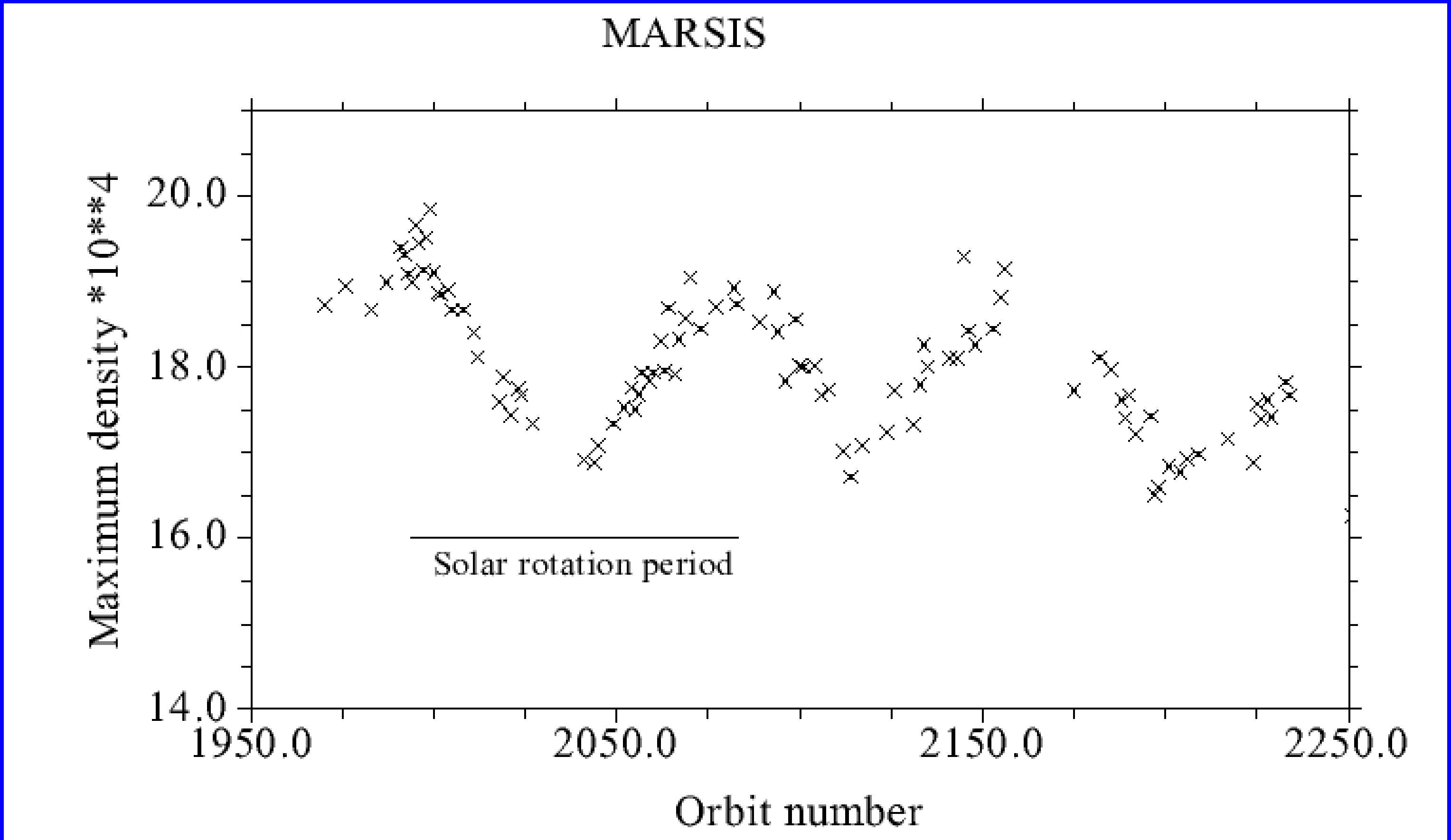
Transport is Complicated

- Models depend on ion and neutral composition, but only Ne(z) known
- Neutral winds not known
- Three-dimensional flow at terminator
- Magnetic fields influence plasma flow

- Basic ionosphere photochemistry is understood, but basic transport is not

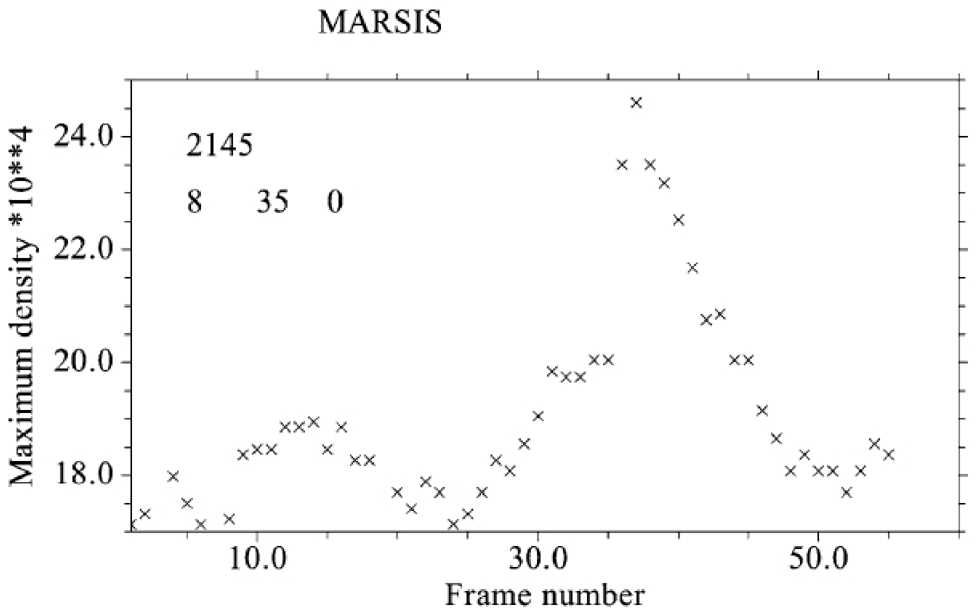
Unusual Ionospheric Observations

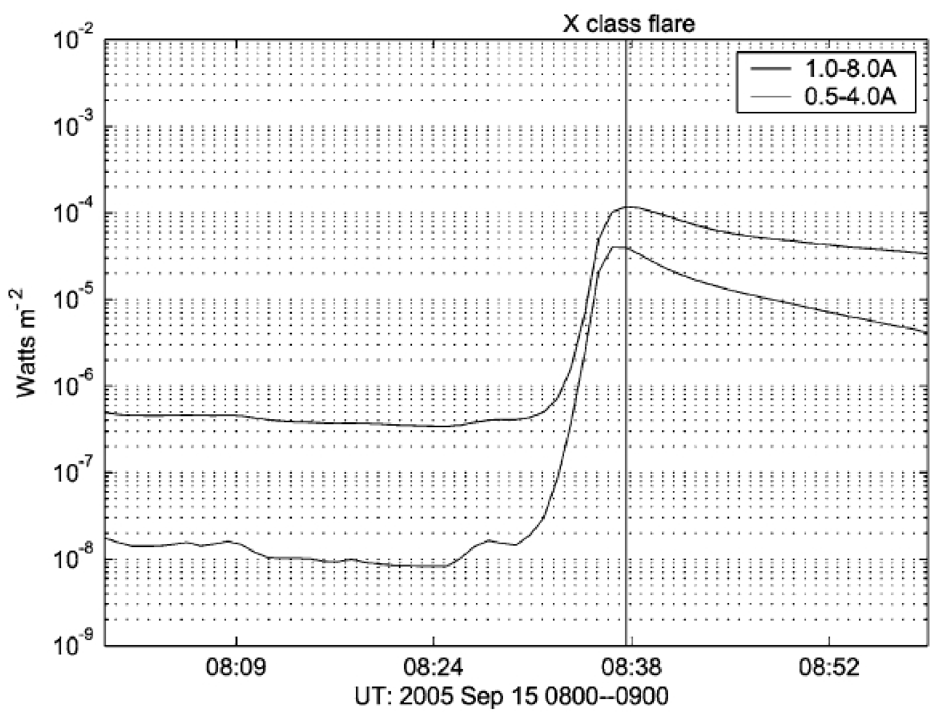
- Unusual -> New science, new discoveries, new interactions
- Unexpected phenomena are powerful tools for testing existing models and developing new models
- A common terrestrial process may behave differently in Mars conditions
- Moving towards more complete understanding
  - Solar flux
  - Meteors
  - Anomalous profiles over magnetic fields

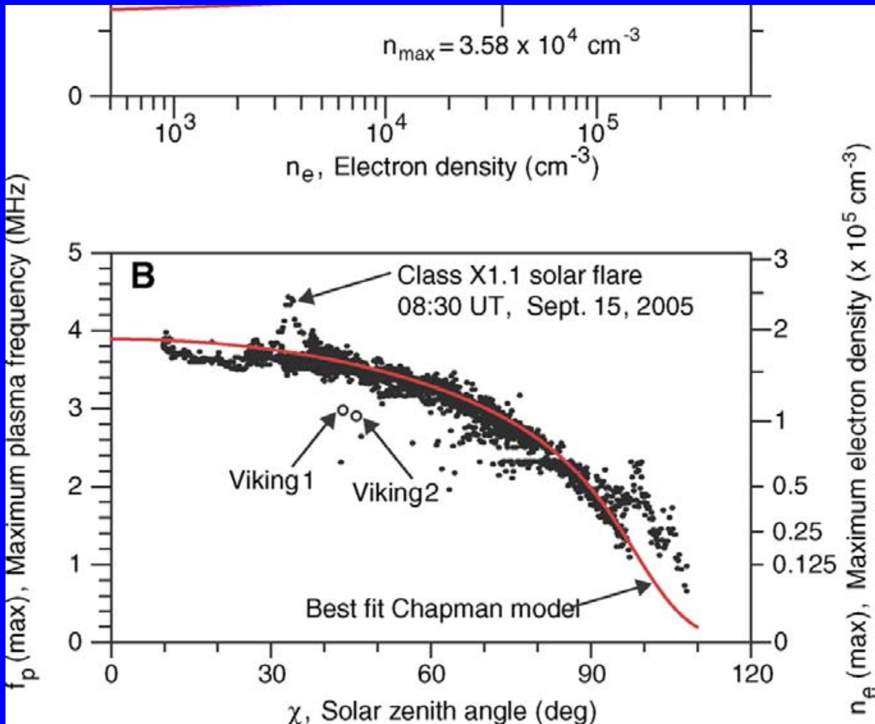


Nielsen et al., 2006

Variation of Nemax with solar rotation period
MARSIS data

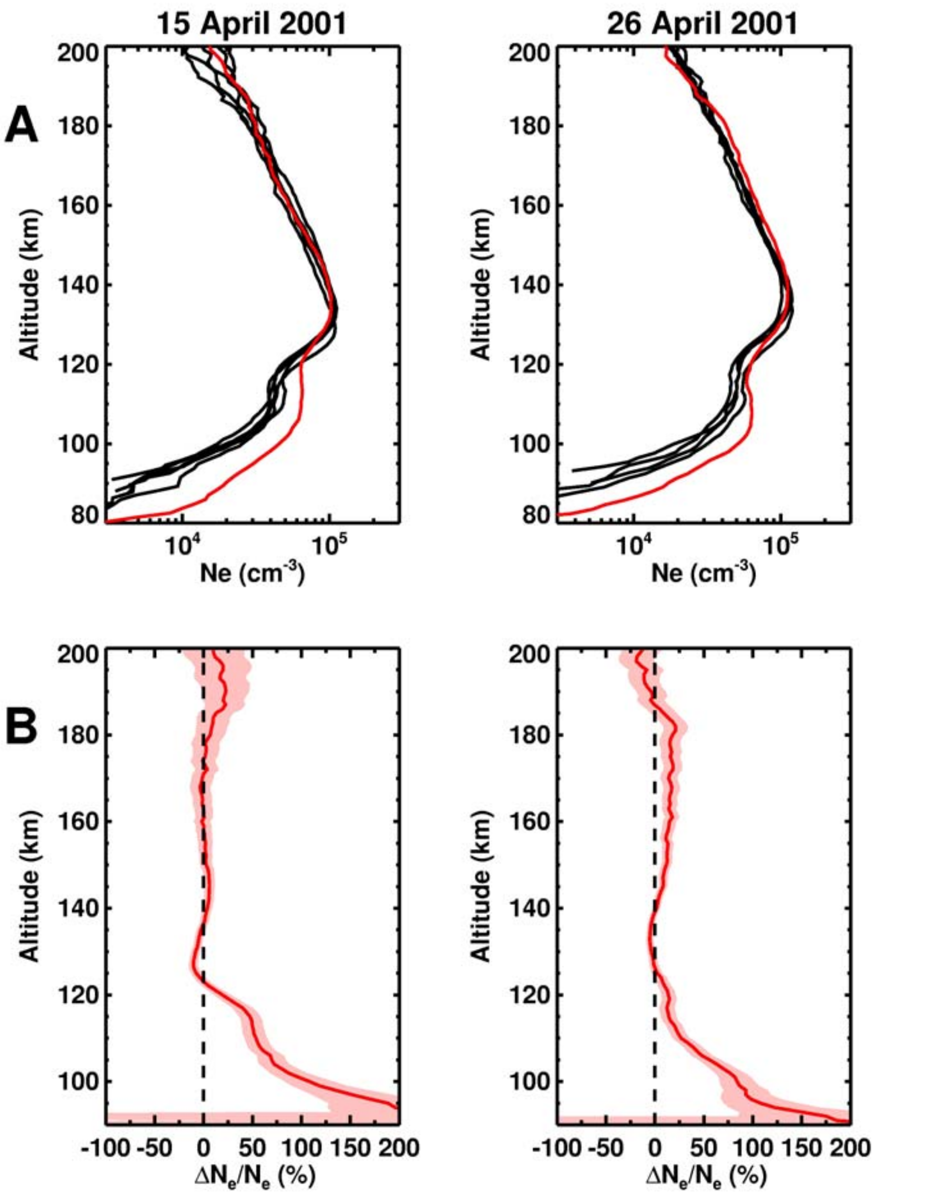


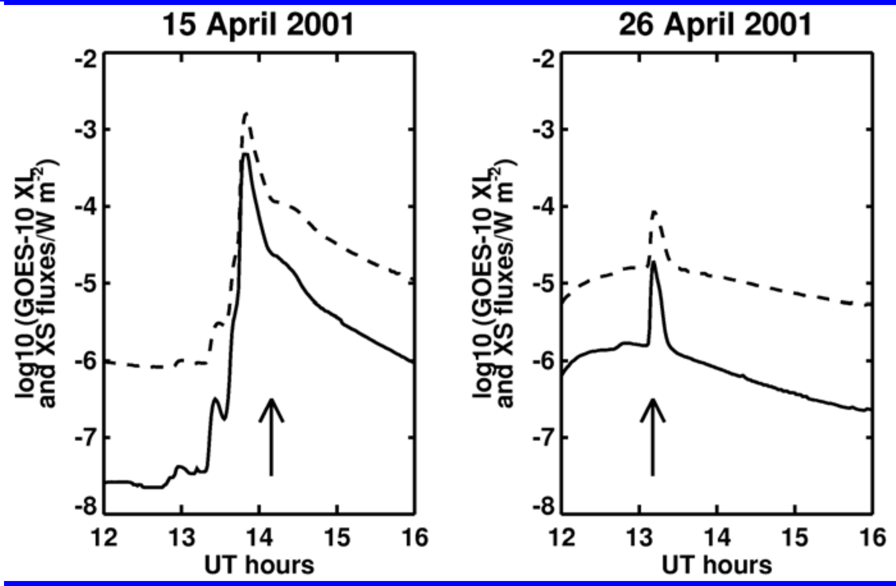




Gurnett et al., 2005

Nielsen et al., 2006





Ionospheric profiles during solar flares

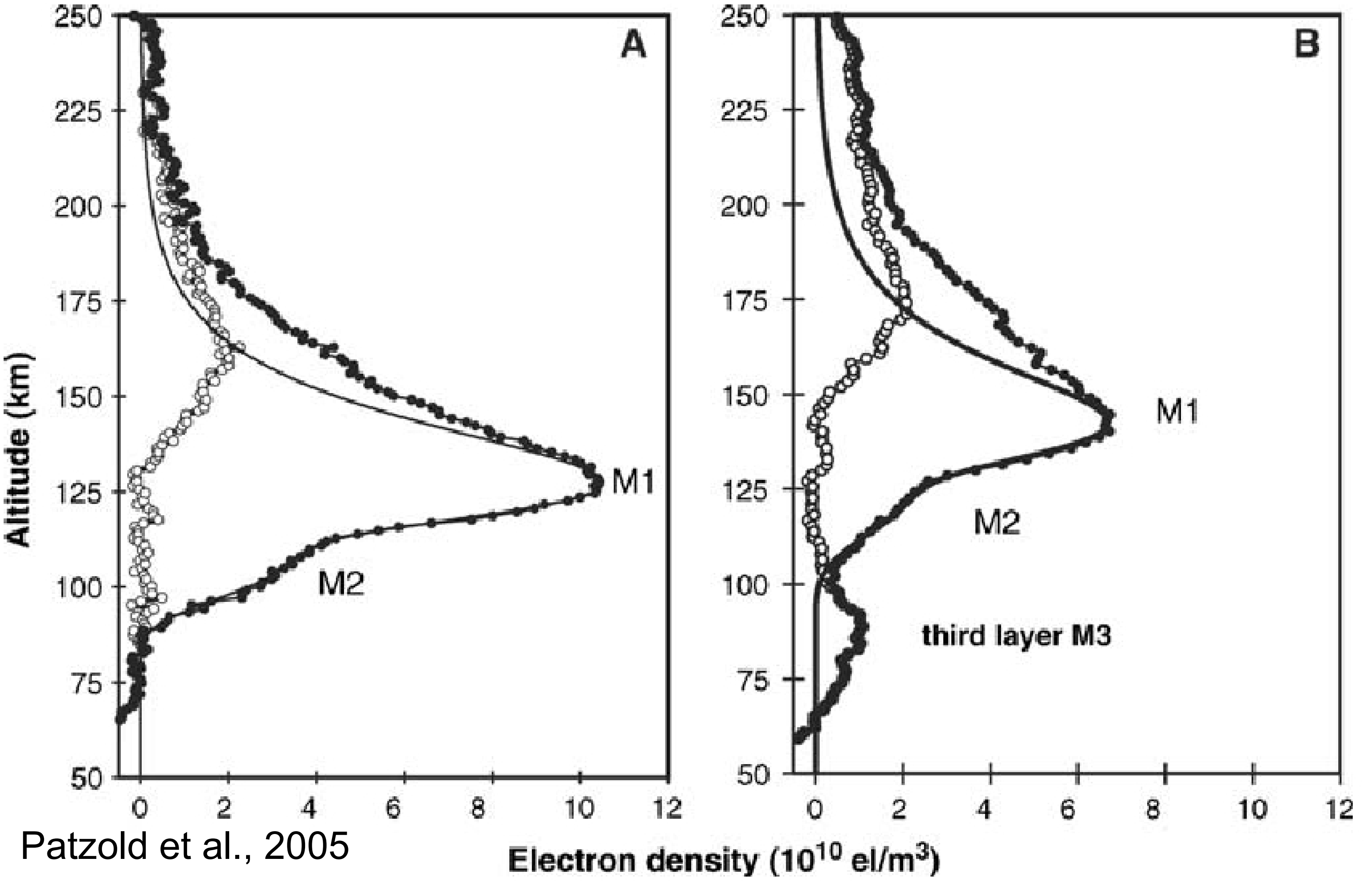
Enhanced electron density at low altitudes

Relative increase in density increases as altitude decreases

Solar Flux

- How many ion-electron pairs per X-ray?
- Separate ionosphere/neutral atmosphere responses to solar cycle with flares
- Are current neutral atmosphere models able to reproduce detailed response to flare? Or is response sensitive to neutral composition?

Low Altitude Ionospheric Layer



Patzold et al., 2005

Meteors at Mars

Typical altitude is 80 – 90 km

Same as models

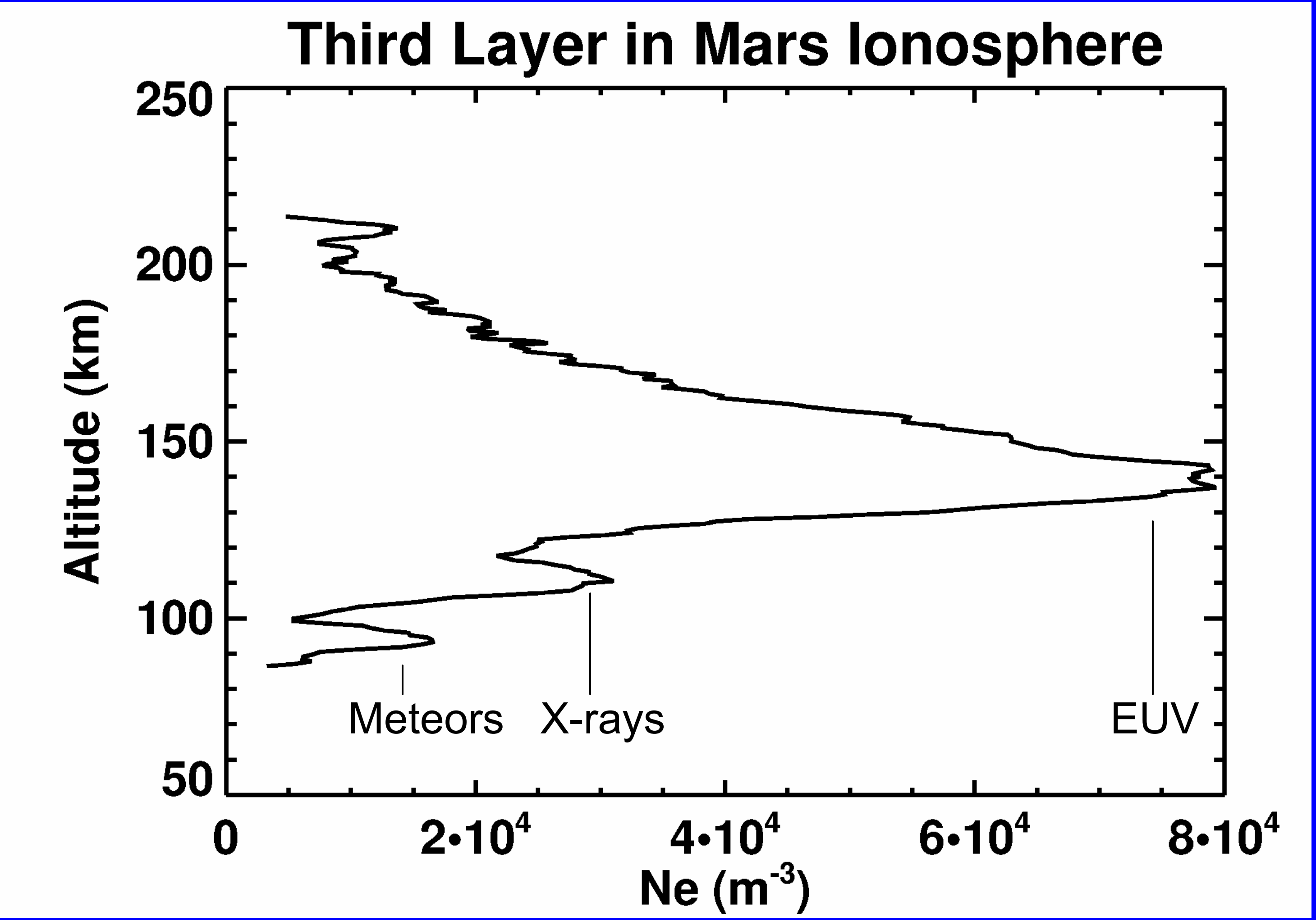
Typical peak electron density is 1 – 2 x 10^4 m^{-3}

Same as models

Typical thickness is 10 – 20 km

Narrower than models predict

Suggests a large eddy diffusion coefficient

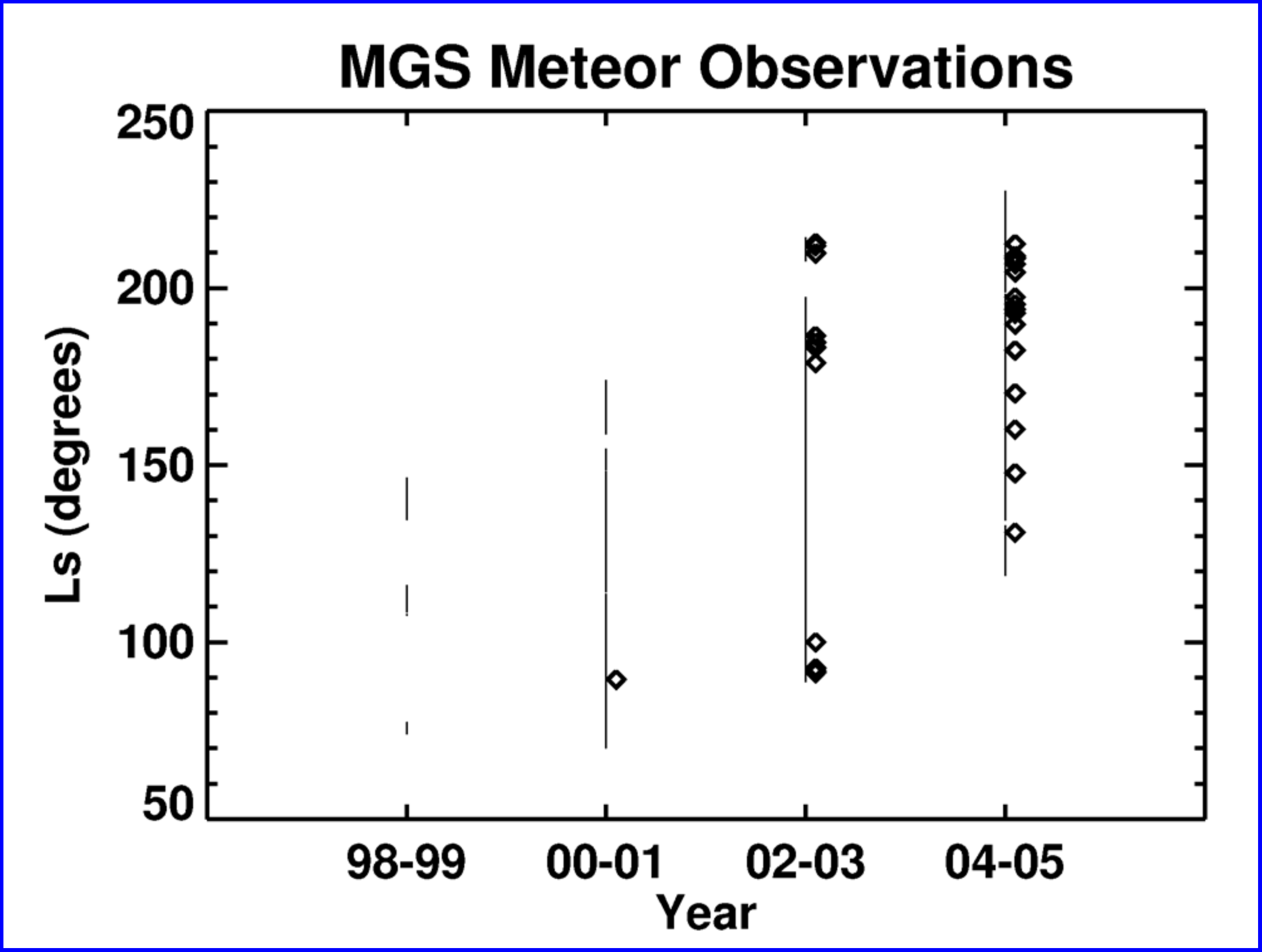


Seasonal Trends

One meteor layer every 200 profiles

Meteor layers are not randomly distributed in Ls

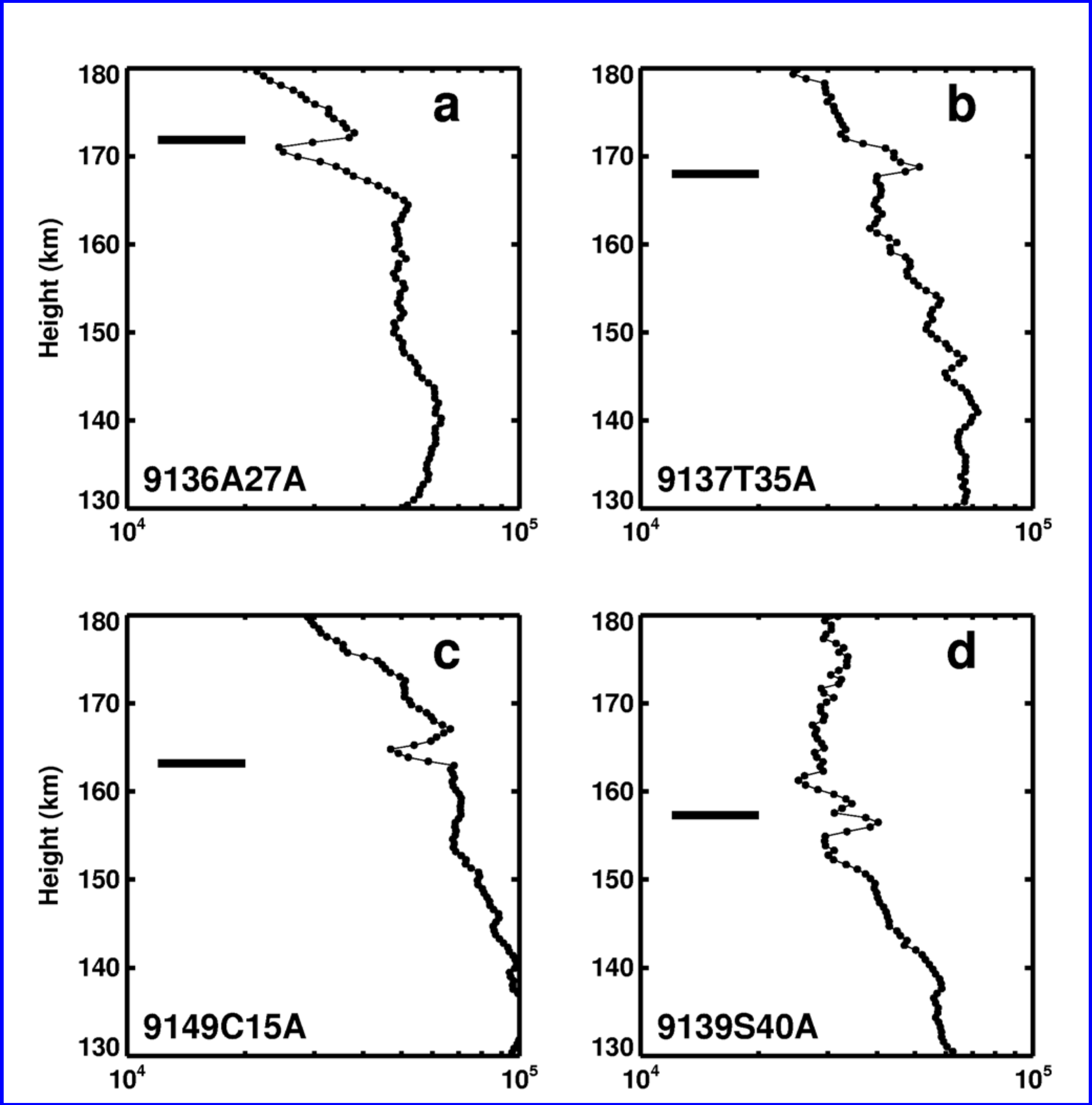
Concentrations at Ls~190 (Asteroid 2102 Tantalus?) and at Ls~210



meteor	0	1	11	16
total	295	1572	1882	1851

Meteors

- Why is meteor layer not always present?
- What comets cause these meteors?
- Why are meteor layer observations not the same in different Mars years?
- Can we model these accurately? Important processes for meteors have only small role for rest of ionosphere

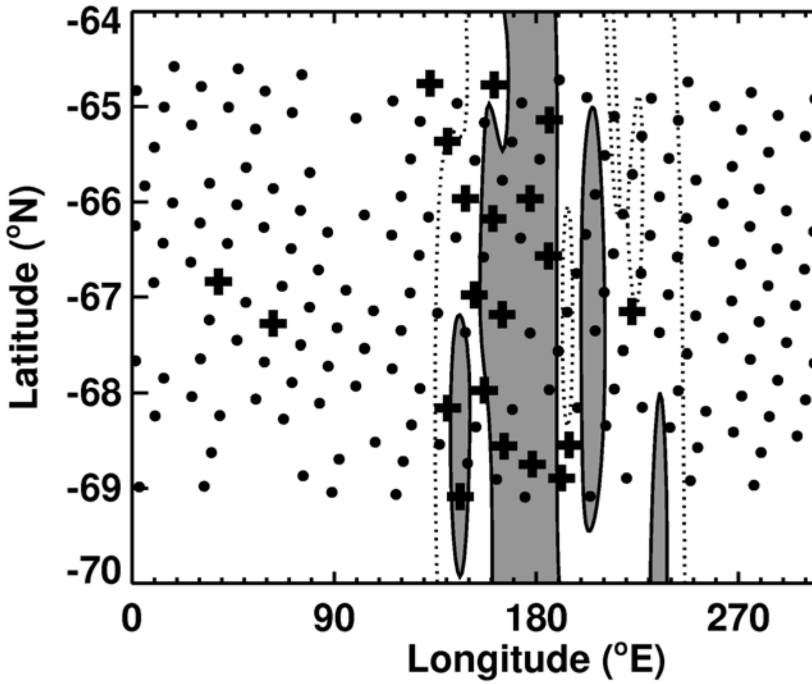


Some MGS profiles show biteouts or bumps

Very short vertical lengthscale

Caution: Data from spacecraft to Earth radio occultation, not from ionosonde

Only found in regions where the magnetic field is strong



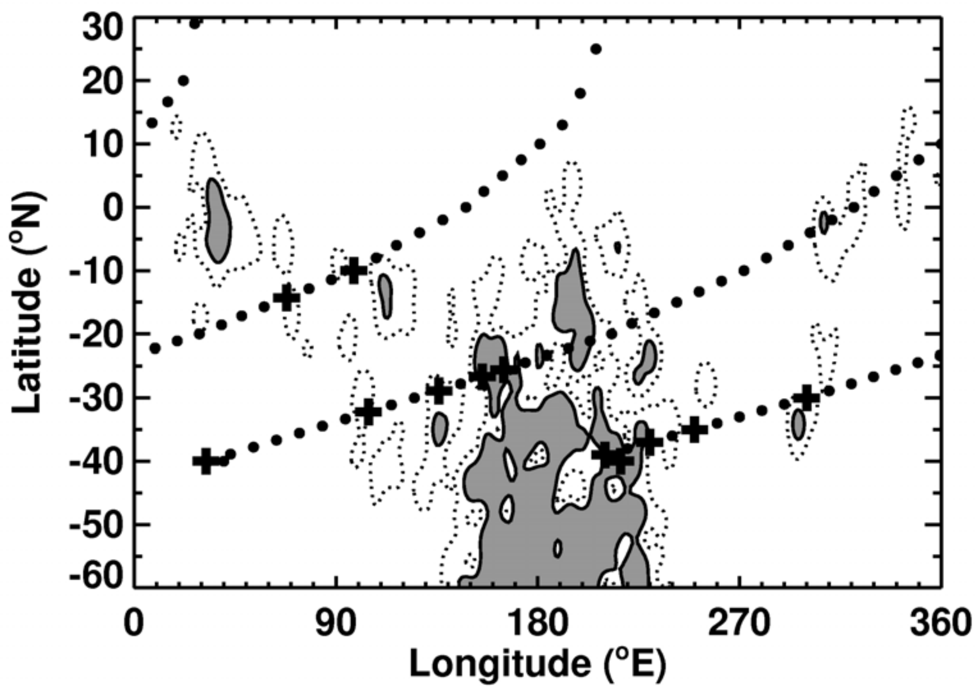
Mars magnetic field is not global dipole. Sources are old crustal rocks.

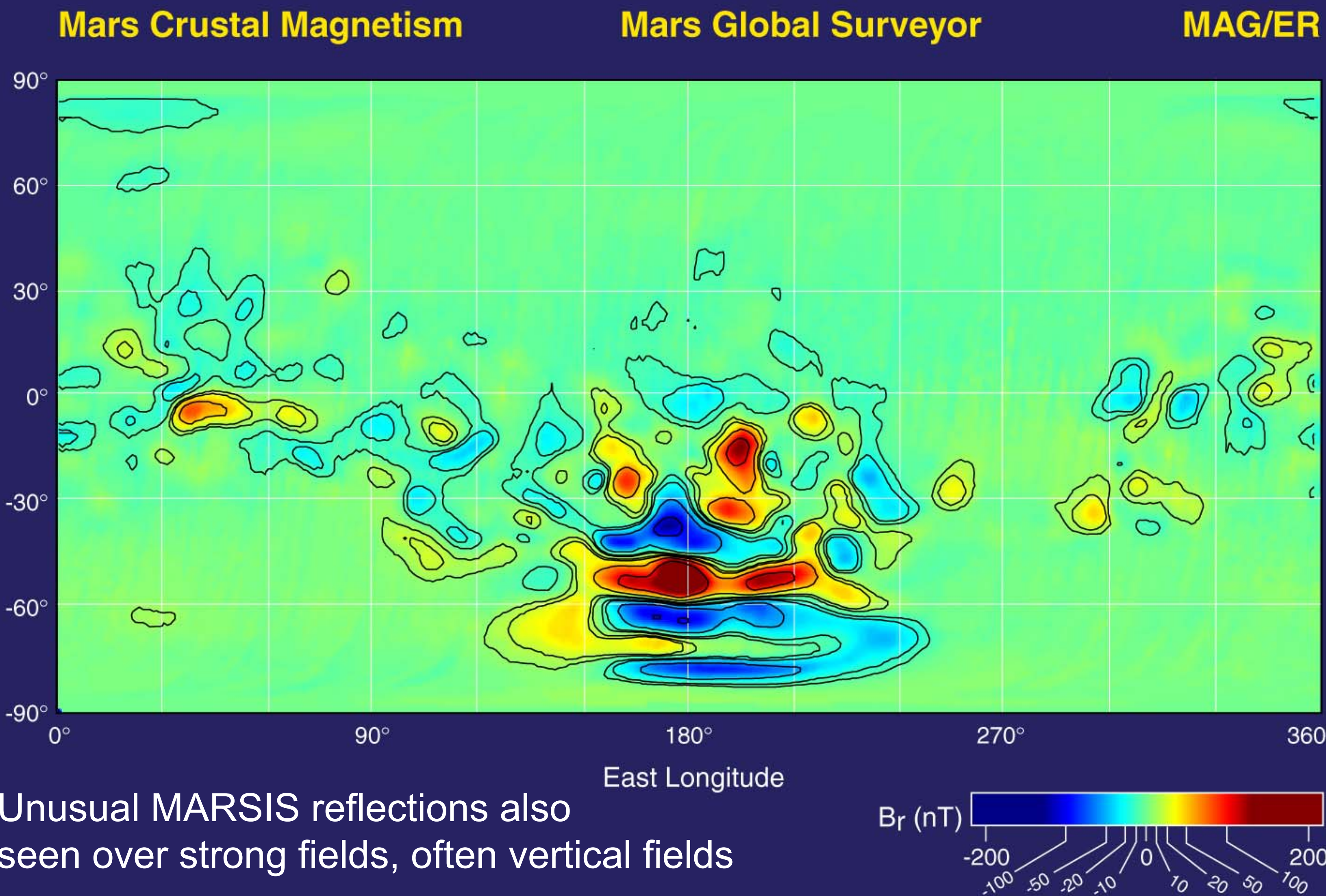
MGS data to the left
Very restricted latitude range

Shaded regions have B>100 nT at 150 km

Mariner 9 data from 1971-2 on right

Same biteouts seen in these data



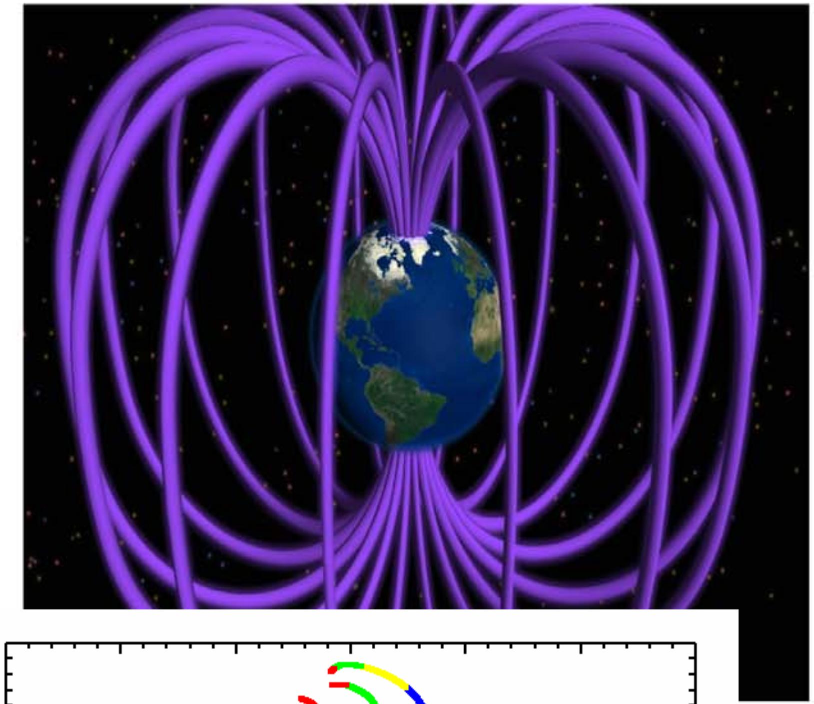


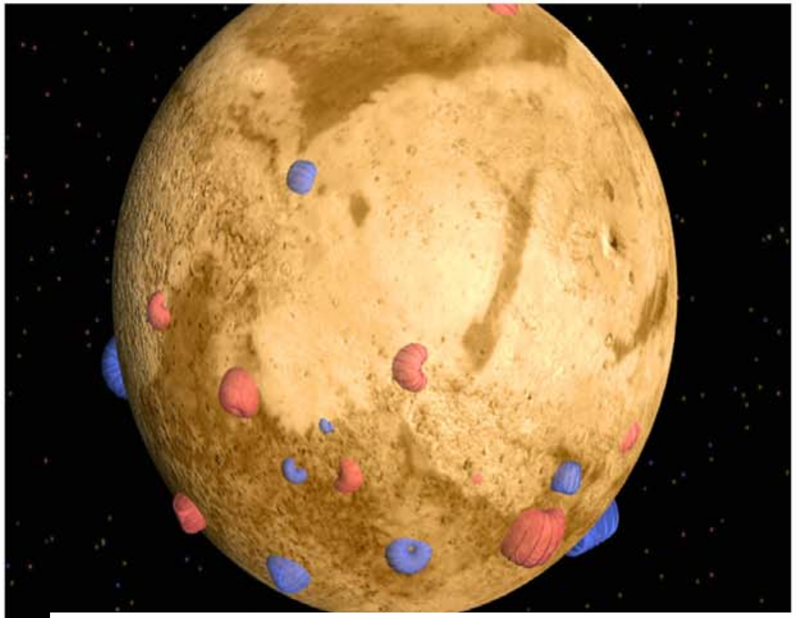
Unusual MARSIS reflections also seen over strong fields, often vertical fields

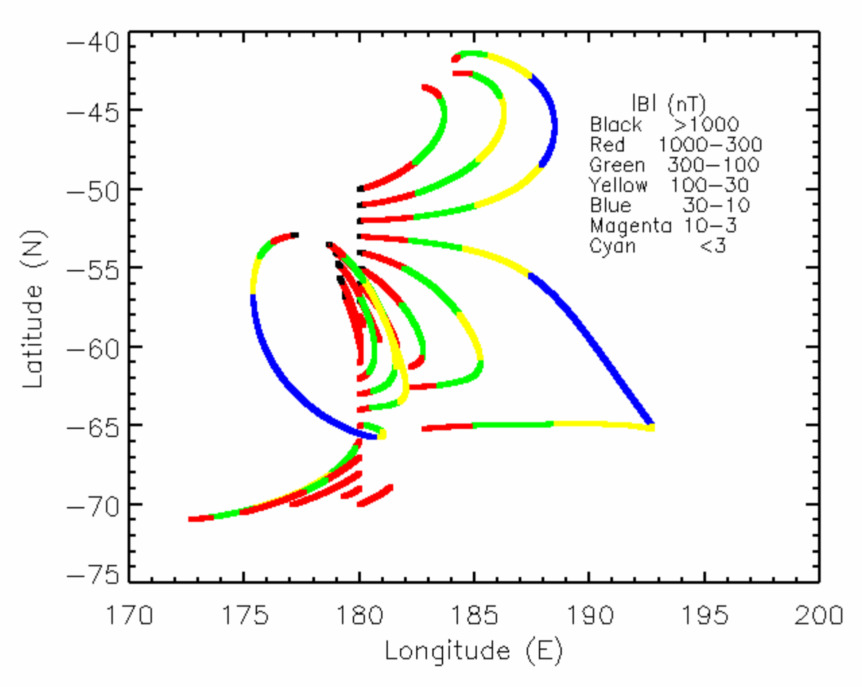
Connerney et al., *Geophys.Res. Lett., 28,* 4015-4018, 2001.

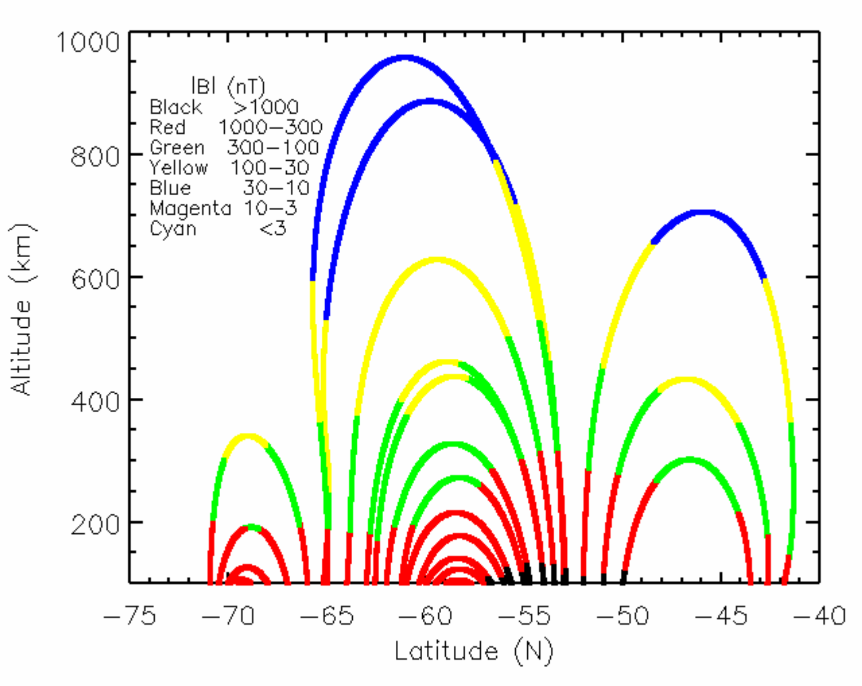
ConJ2001187.001v

Mars magnetism is very complicated









Magnetism

- What plasma instabilities occur on Mars?
- How is plasma transported in non-magnetic regions?
- In strongly-magnetized regions?
- Does the small size of magnetic field regions lead to processes not seen on Earth?

Conclusions

- Mars ionosphere is an important part of the Mars system.
  - It is part of the boundary between the atmosphere and space. Important for escape.
- A natural laboratory to test ideas developed in Earth-centred studies
- Many poorly-understood phenomena are observed
  - They need to be better interpreted and simulated