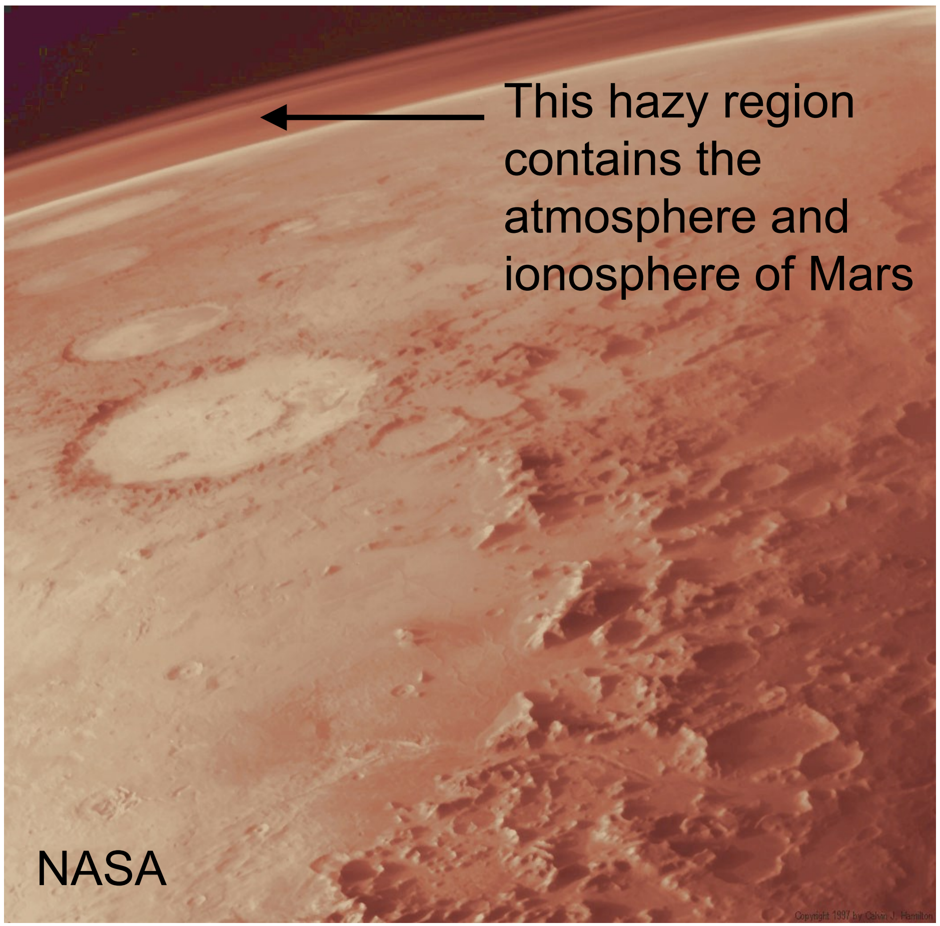
The ionosphere of Mars prior to the arrival of MAVEN

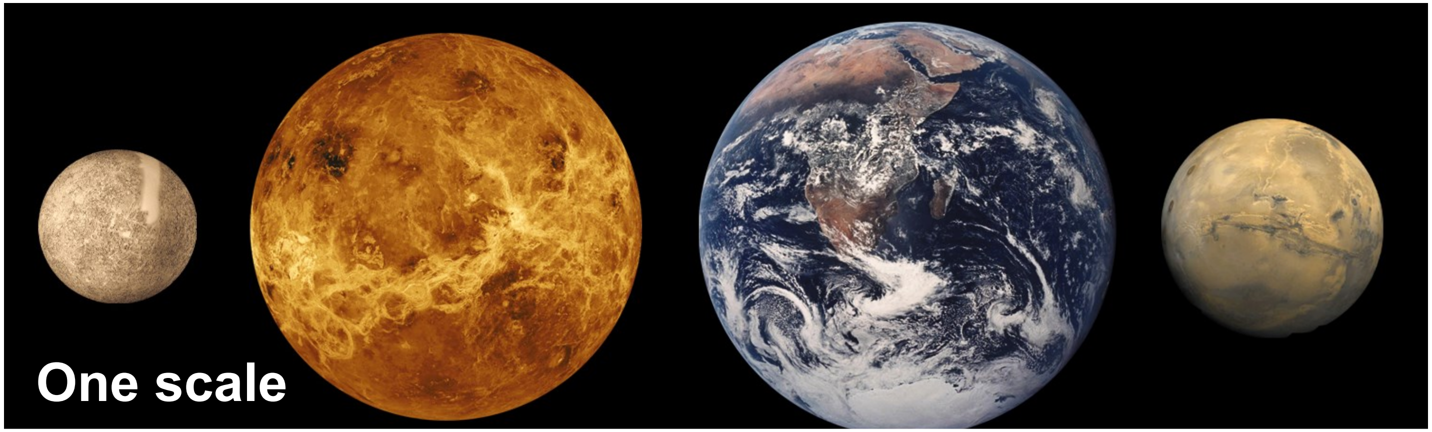


Paul Withers
Boston University
(withers@bu.edu)

MIT Haystack Observatory

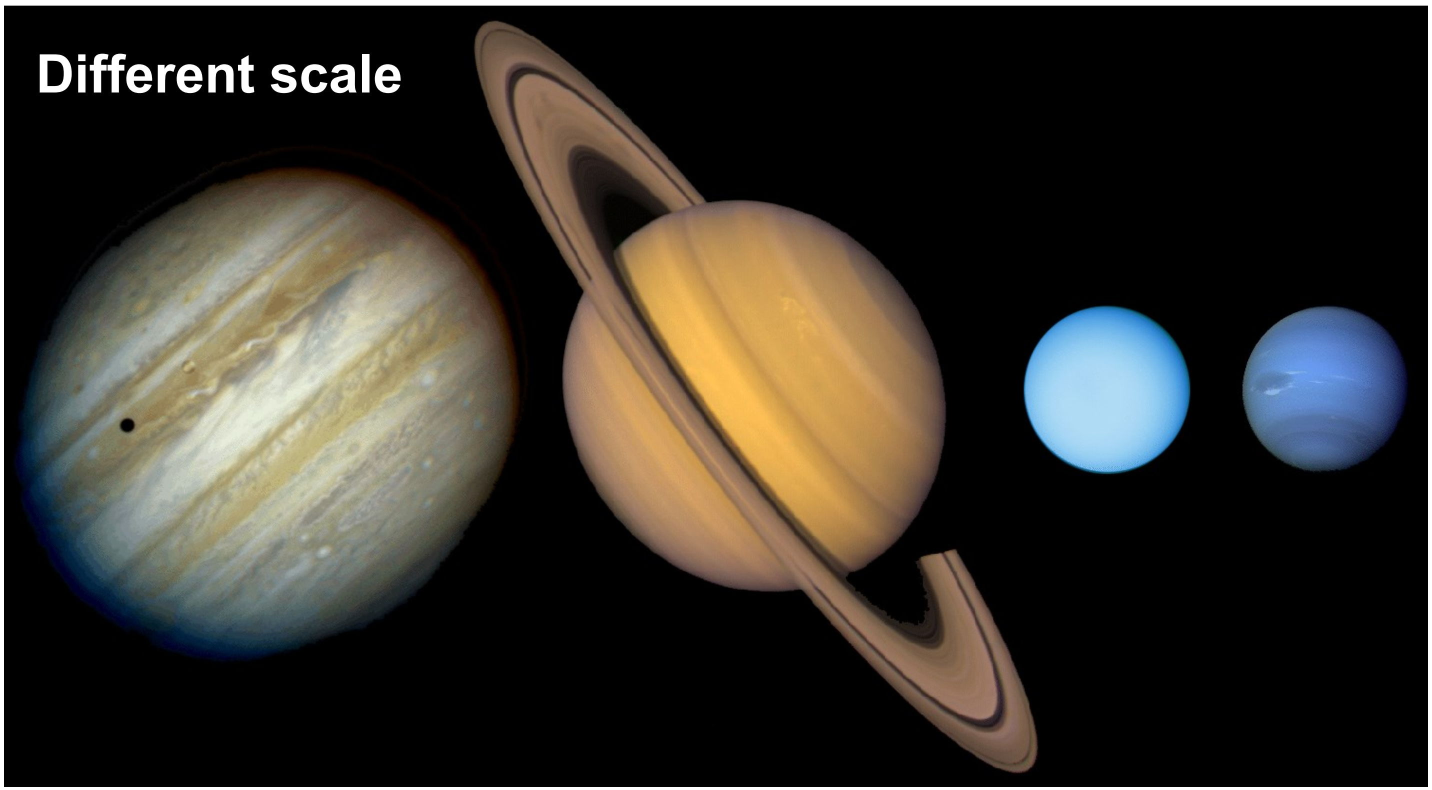
Monday 2014.10.20

Thanks to graduate students
Majd Matta (now postdoc)
Zachary Girazian
Katy Fallows



This is Mars

←



www.solarviews.com

0.5 x R-Earth

1.5 AU from Sun

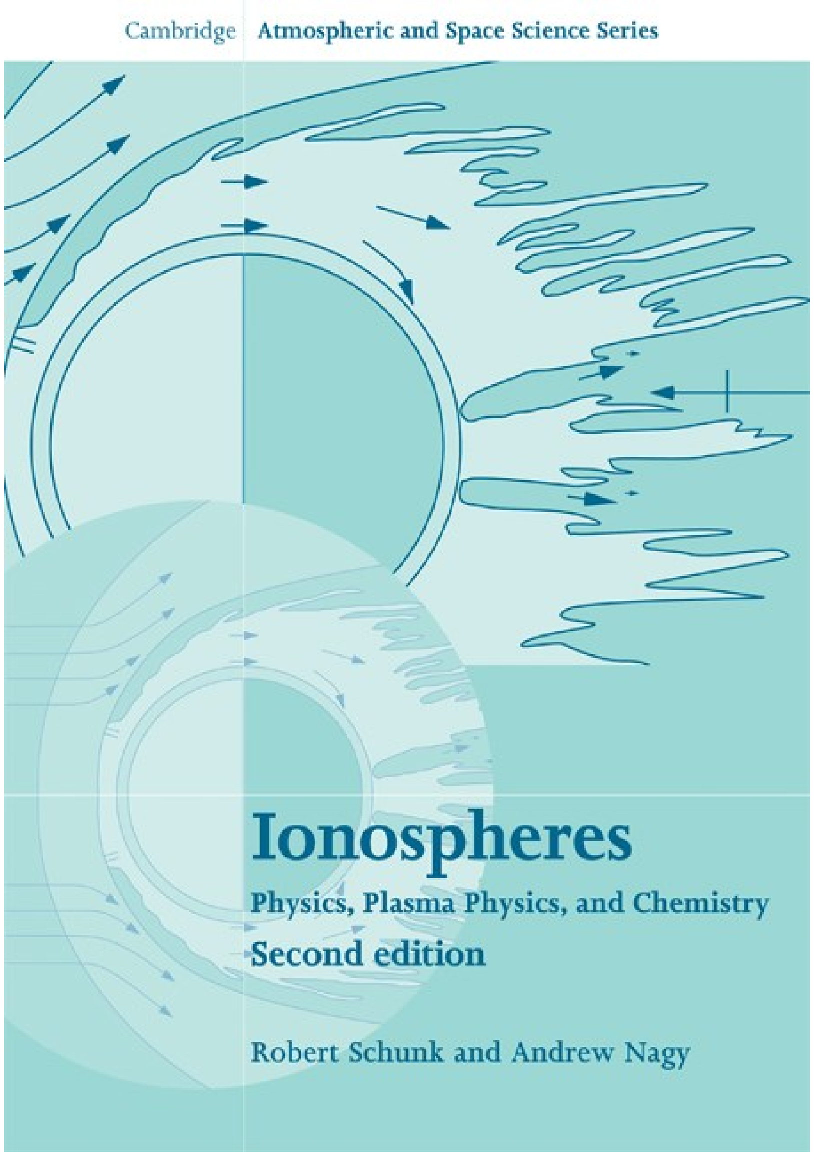
Same rotation rate as Earth

Carbon dioxide atmosphere

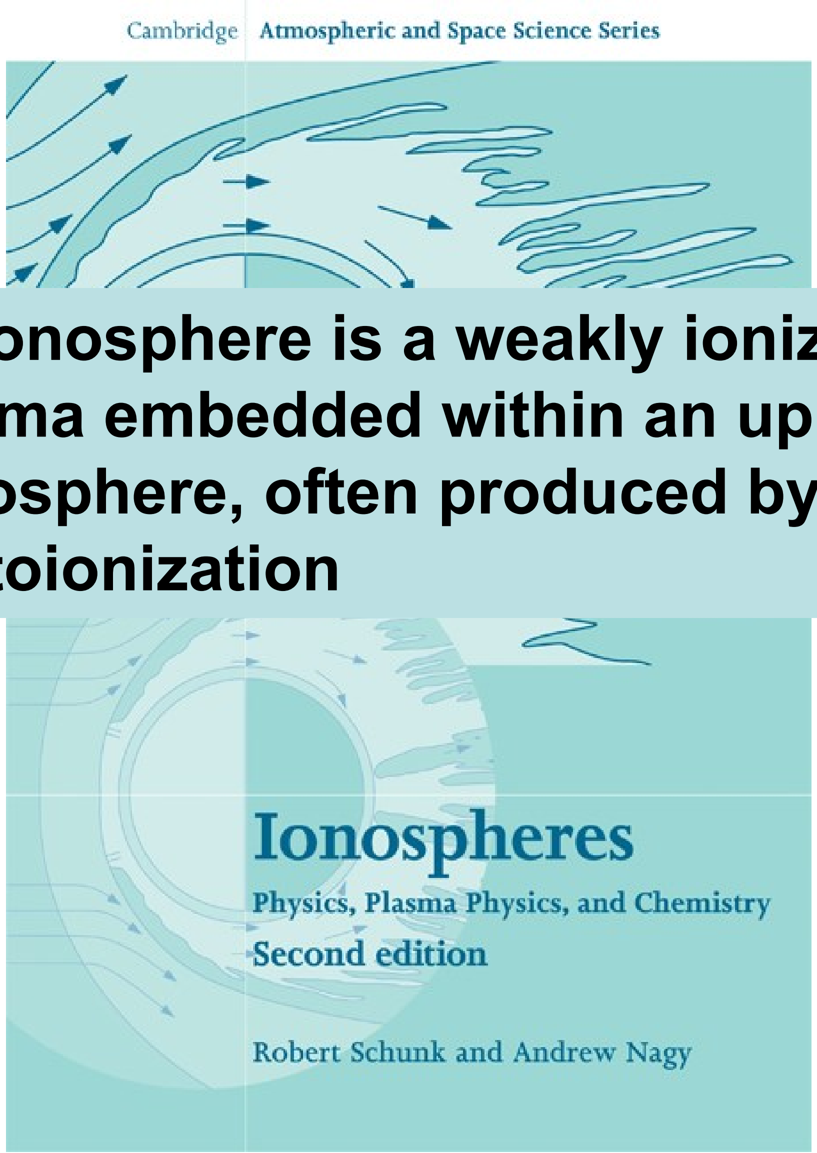
100x smaller surface pressure

Target of many spacecraft in last 15 years

What is an ionosphere?



What is an ionosphere?

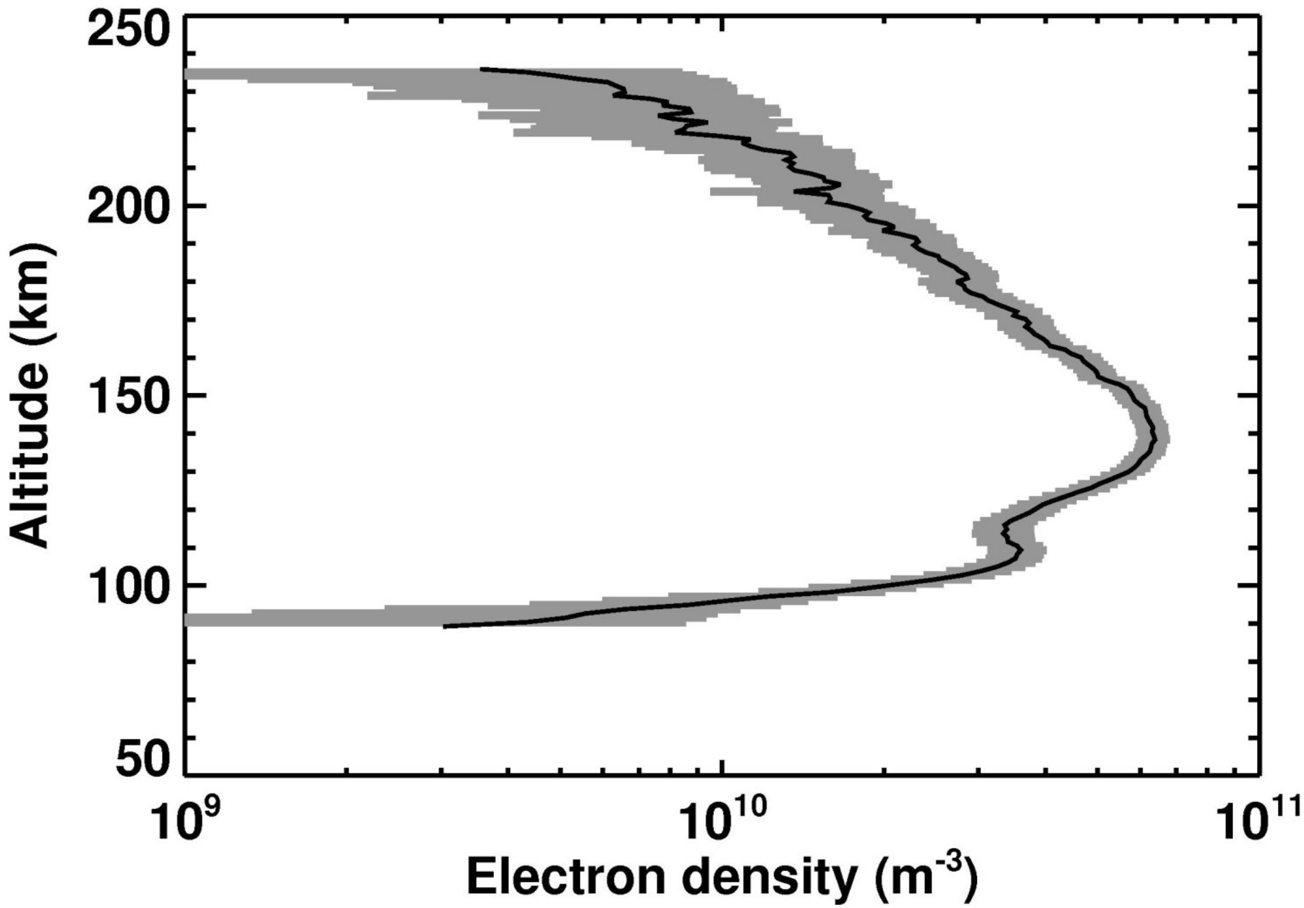


An ionosphere is a weakly ionized plasma embedded within an upper atmosphere, often produced by photoionization

What does that actually mean?

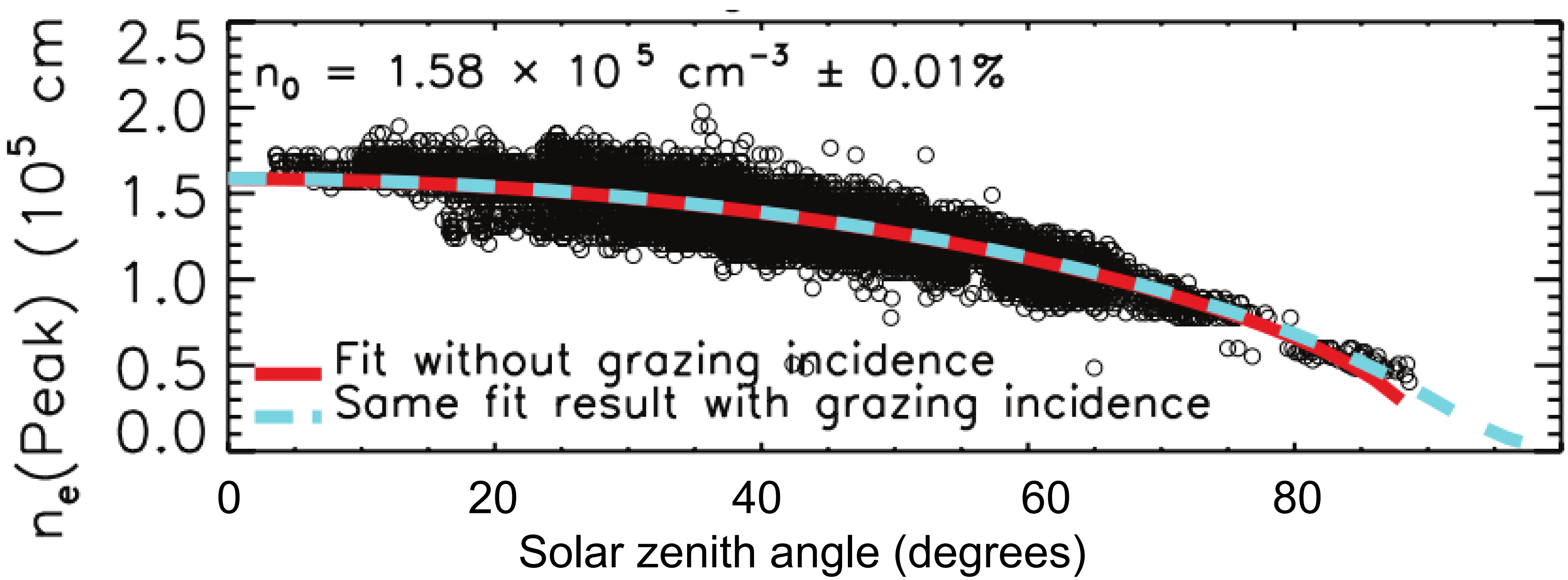
	Atmosphere	Ionosphere	Space physics
Chemistry	✗	✓	✗
Gravity	✓	✓	✗
Sunlight	✓	✓	✗
Magnetic fields	✗	✓ and ✗	✓
Composition	Neutrals	Ions, electrons, and neutrals	Protons and electrons

Typical electron density profile



Withers et al. (2009) – Radio occultation observations

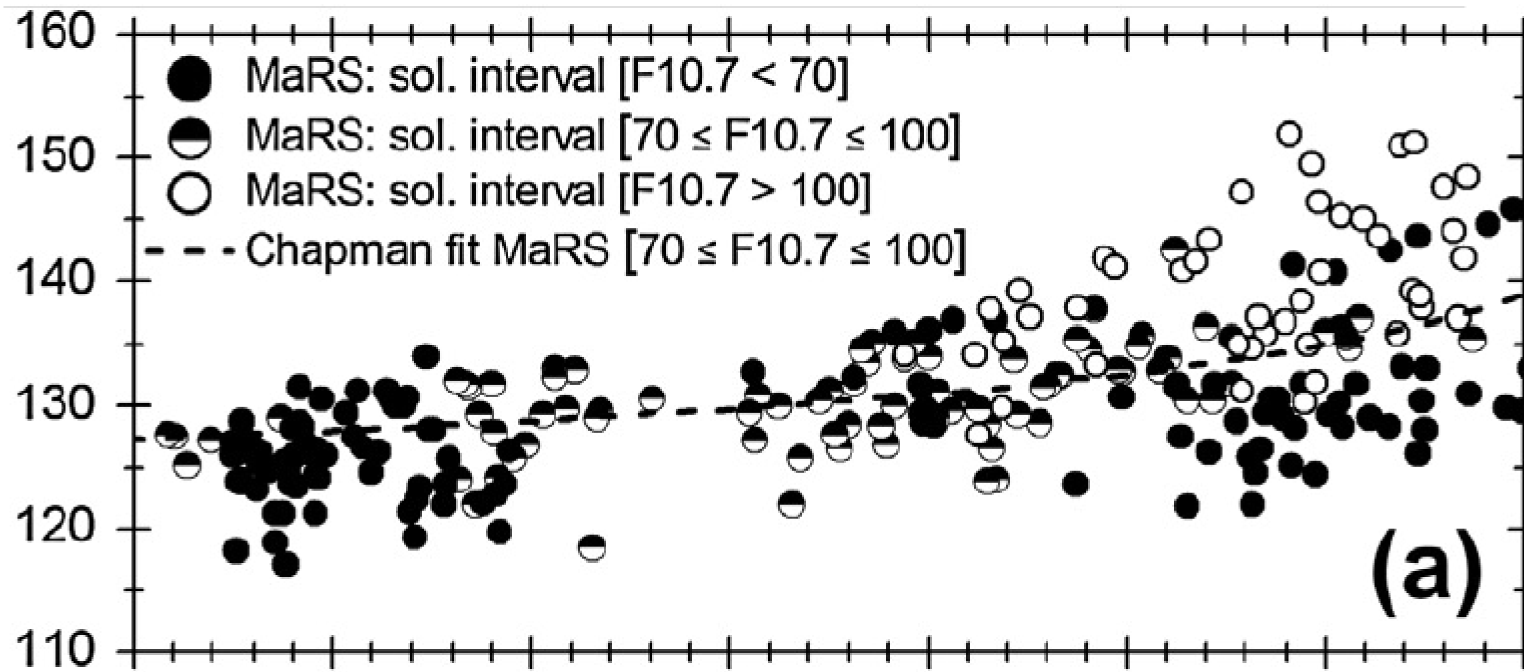
Peak electron density and SZA



Morgan et al. (2008) – Radar sounder observations

Peak altitude and SZA

Altitude (km)

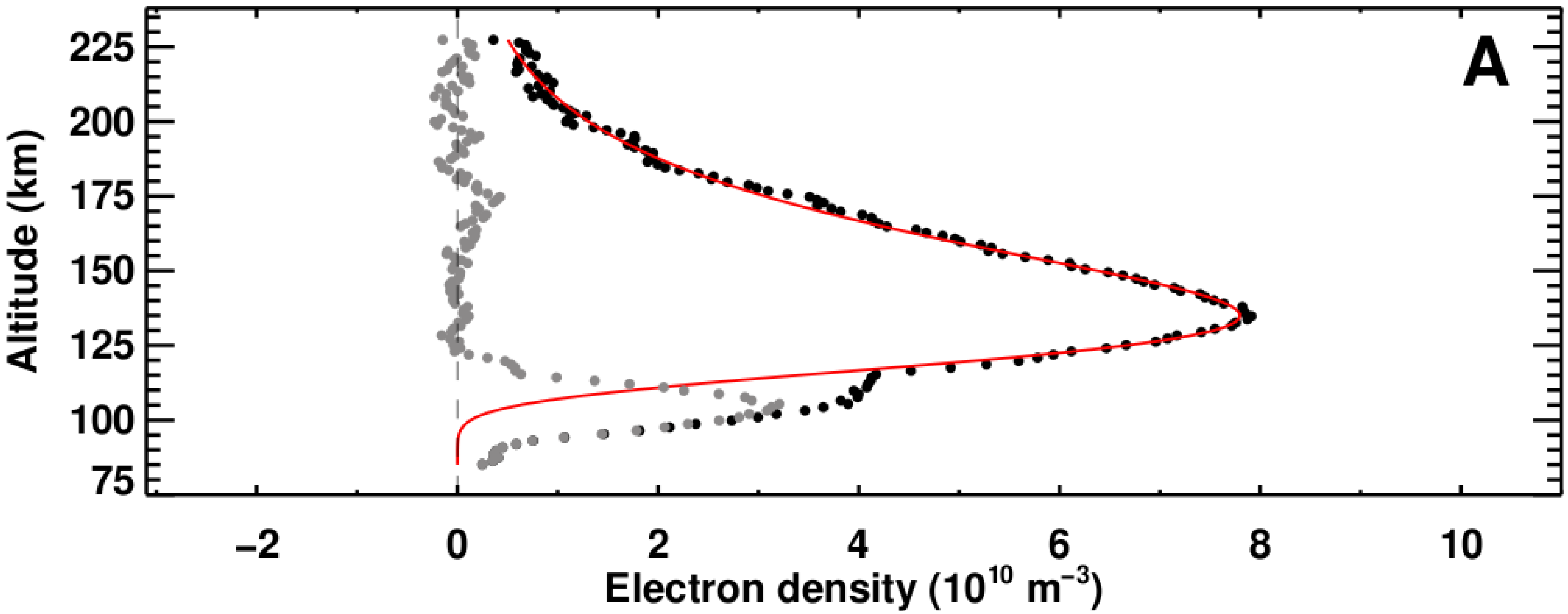


50 60 70 80

Solar zenith angle (degrees)

Peter et al. (2014) – Radio occultation observations

Overall shape



Radio occultation observations

Predictions of simple theory

$$N = N_m \exp\left(\frac{1}{2}\left(1 - \frac{(z - z_m)}{H} - \exp\left(-\frac{(z - z_m)}{H}\right)\right)\right)$$

$$N_m = N_0 / \sqrt{Ch\,(\mathrm{SZA})} \qquad N_0^2 = \frac{F_0}{\alpha \exp(1)\, H}$$

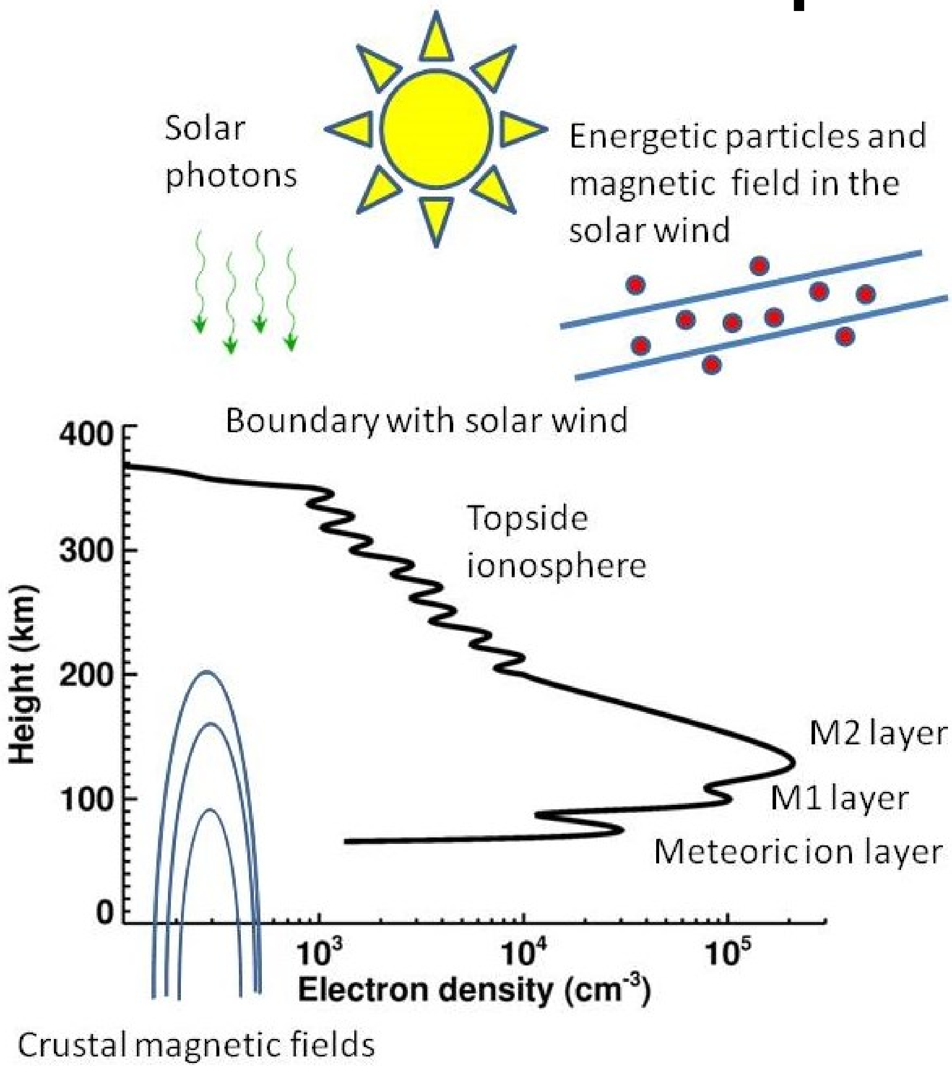
$$z_m = z_0 + H \ln Ch\,(\mathrm{SZA}) \quad \sigma n\,(z_m)\, H Ch(\mathrm{SZA}) = 1$$

$Ch\,(\mathrm{SZA})$ = 1 / cos(SZA) for small SZA

This is Chapman theory

Neutral atmosphere has single constituent and fixed scale height
Each ionization event instantly produces one molecular ion
Molecular ions are lost by dissociative recombination with an electron

The ionosphere of Mars



Withers (2011)

Neutral atmosphere is mainly CO_2, O becomes significant at high altitudes

O_2^+ is main ion at all altitudes

Solar EUV photons responsible for main M2 layer

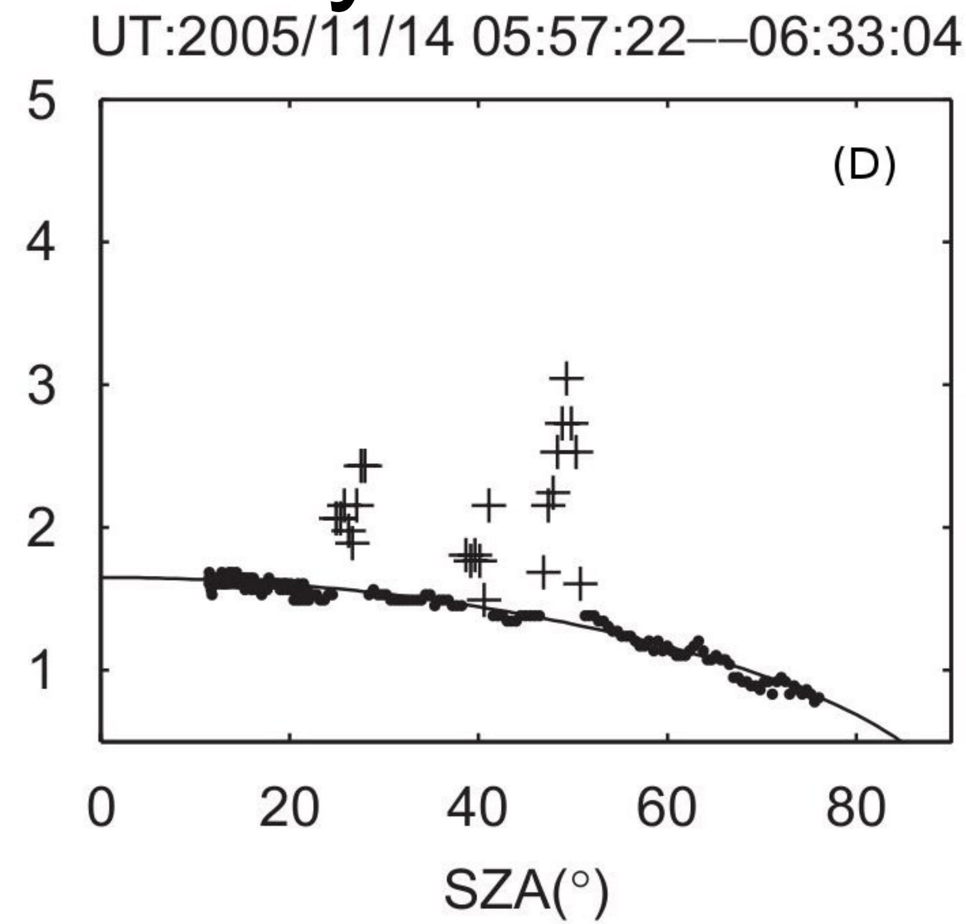
Soft X-ray photons and secondary ionization responsible for lower M1 layer

Does transport, which is ignored by Chapman theory, affect plasma densities anywhere?

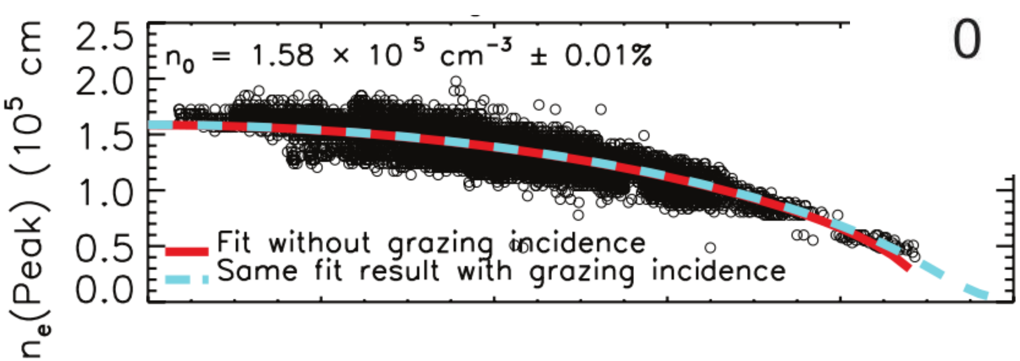
Peak electron density and SZA

Peak density does not always depend smoothly on SZA

$$N_m = N_0/\sqrt{Ch\,(\mathrm{SZA})}$$

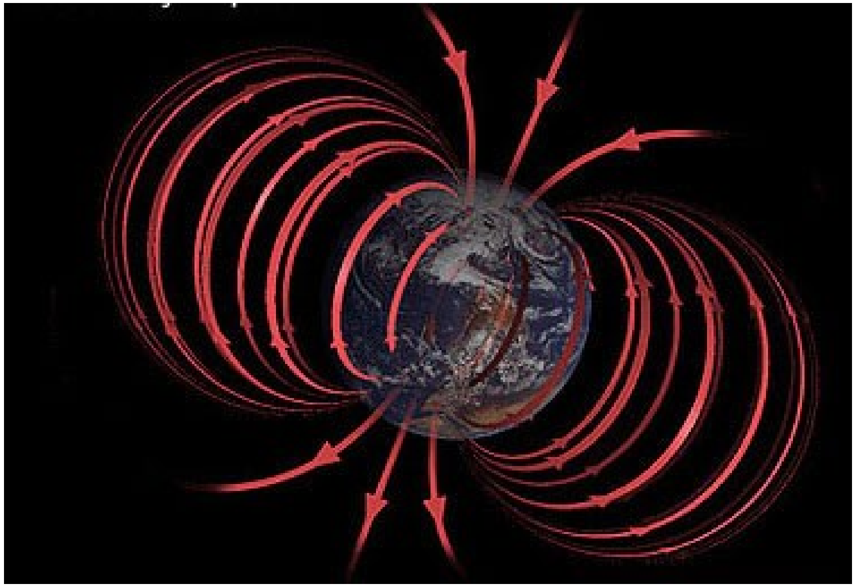


Nielsen et al. (2007)
Radar sounder observations



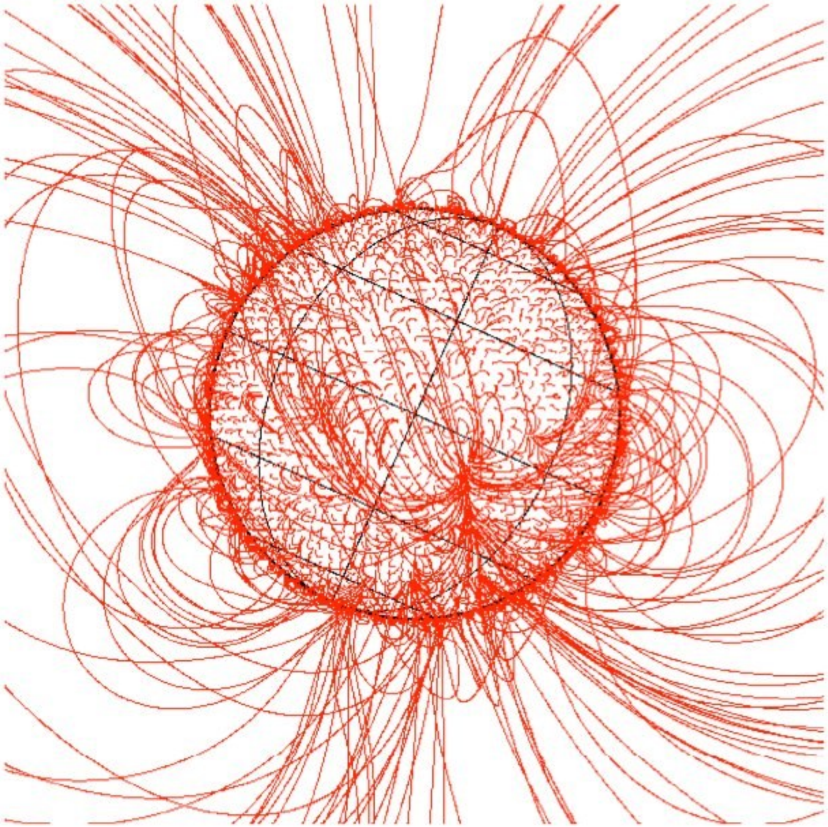
Unique magnetic field is responsible

Earth magnetic field



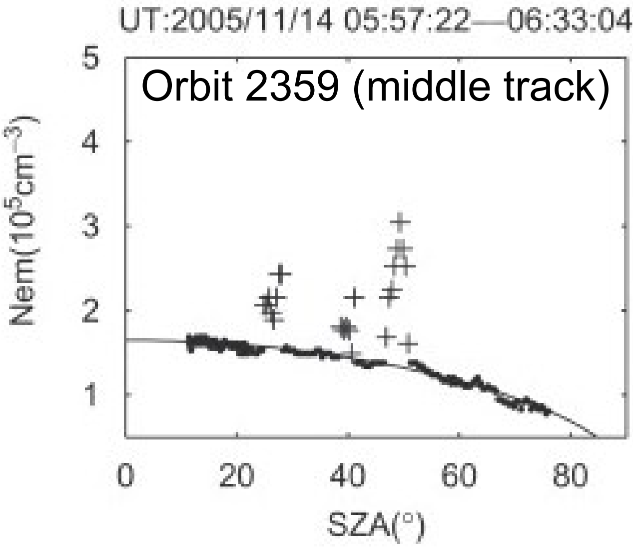
www.windows2universe.org

Mars magnetic field



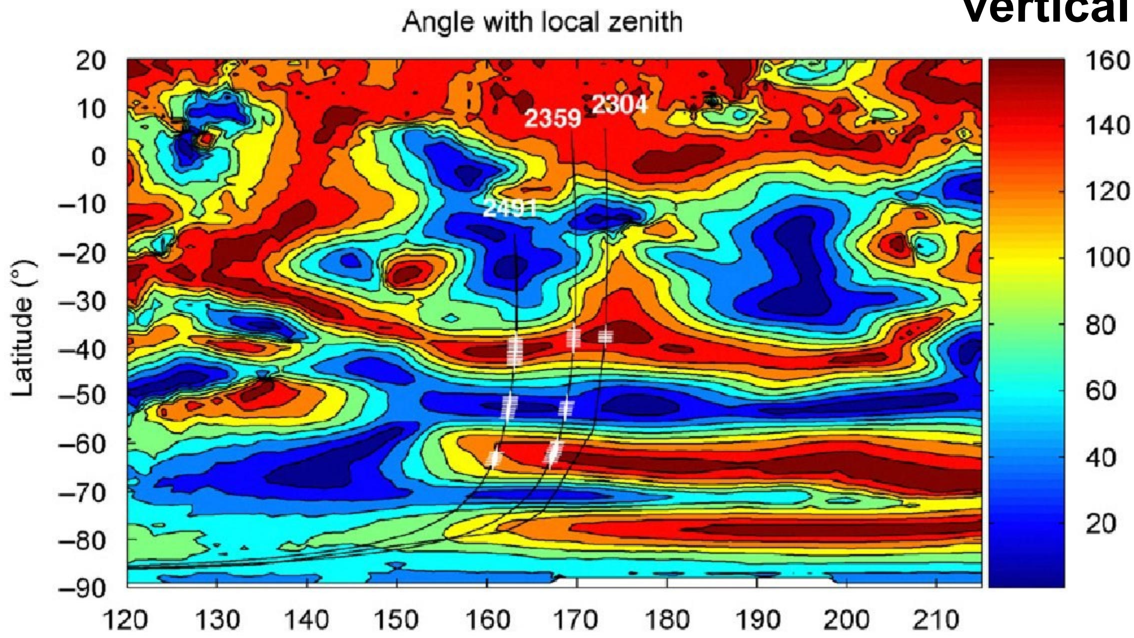
Brain (2002)

Peak electron density and SZA



Nielsen et al. (2007)

Peak electron densities



Angle between field and vertical

Longitude (°E)

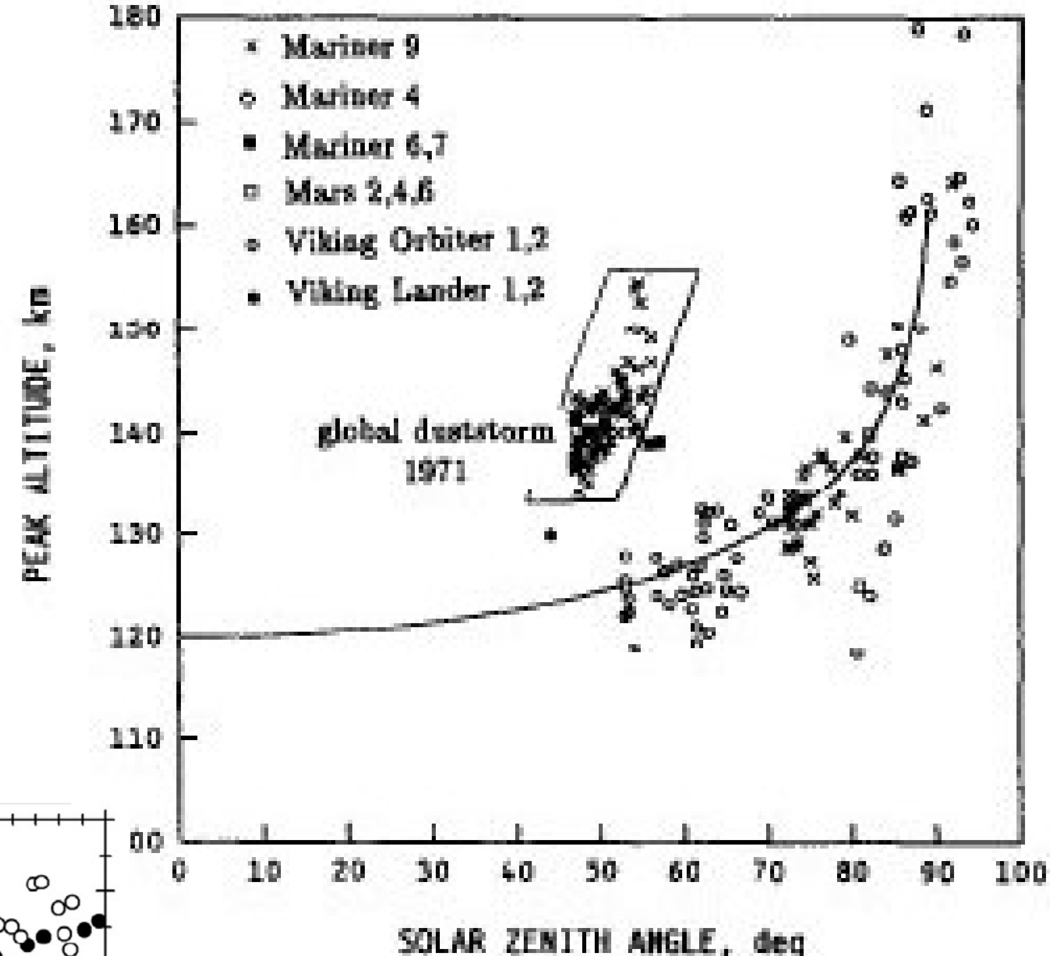
Nielsen et al. (2007)

Enhancements seen over strong and vertical crustal magnetic fields

Peak altitude and SZA

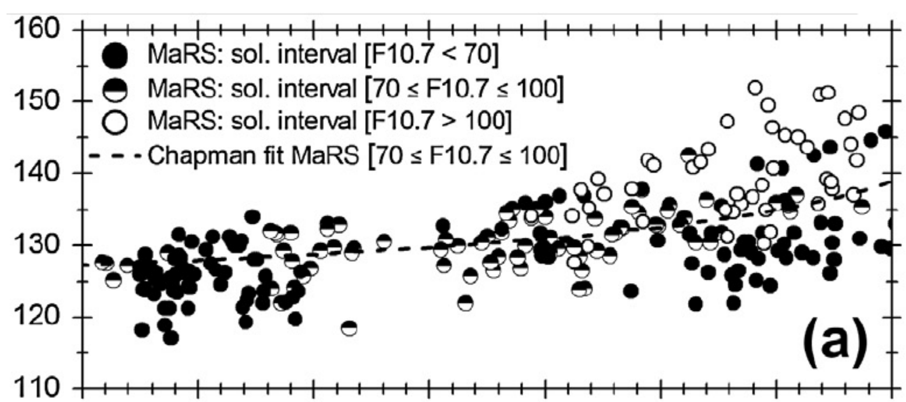
Peak altitude does not always depend on SZA in the usual manner

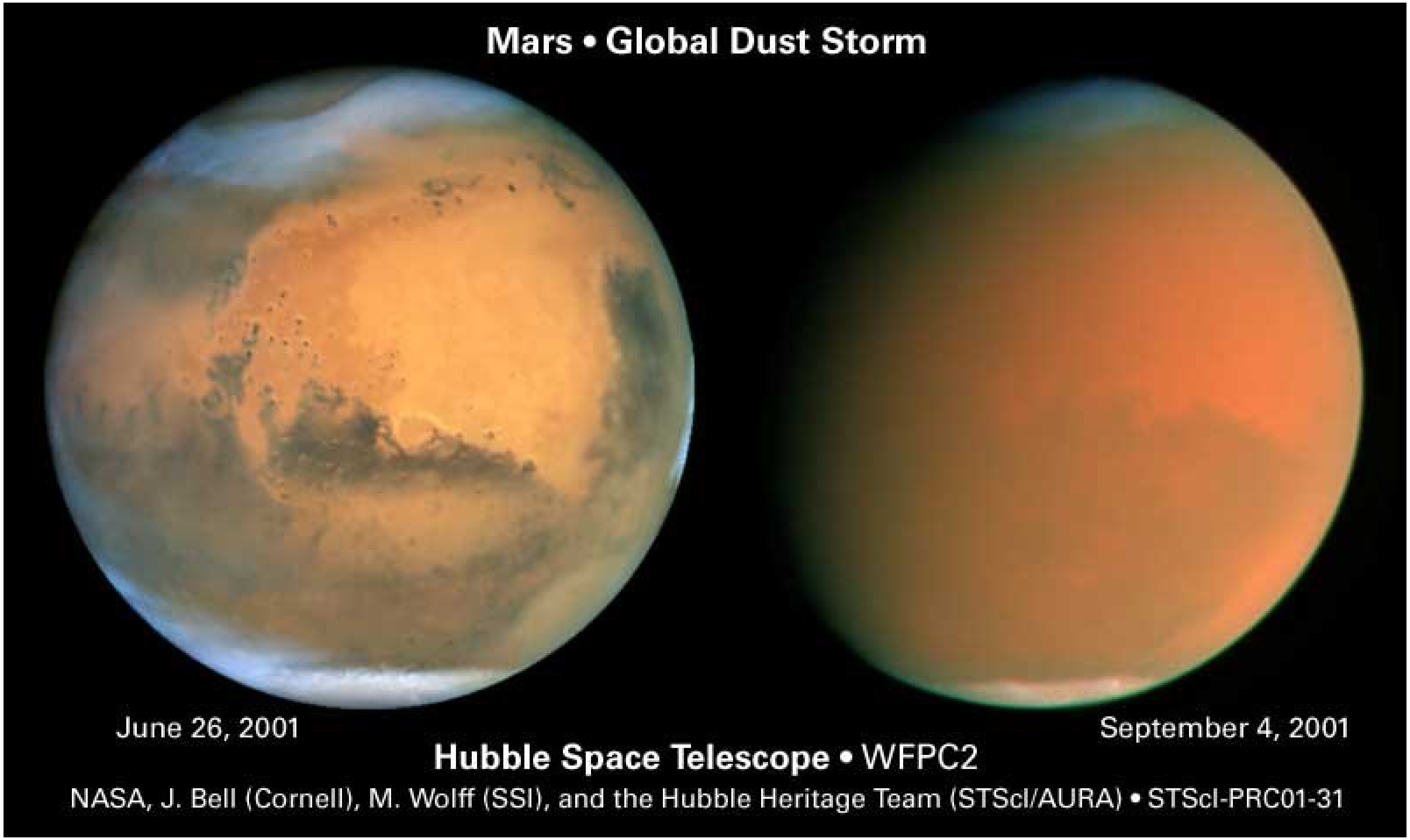
$$z_m = z_0 + H \ln Ch\,(\mathrm{SZA})$$



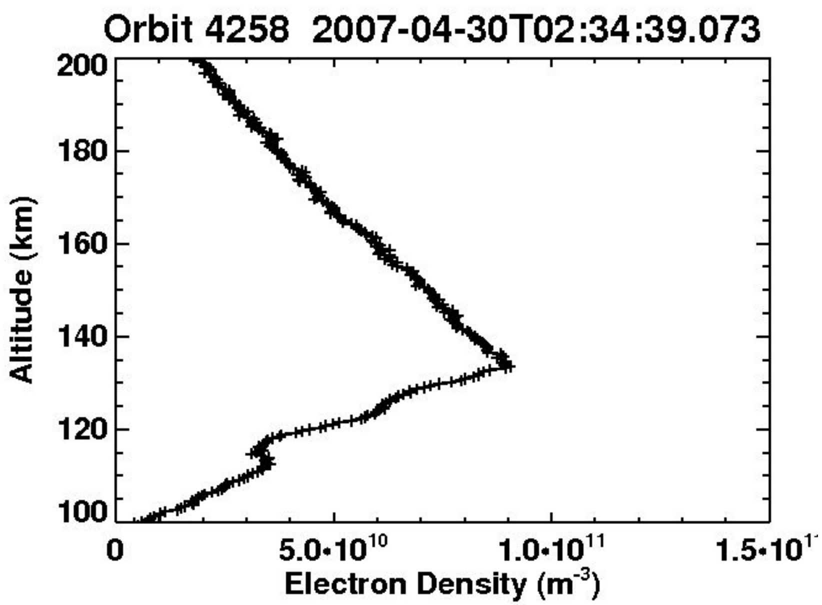
Hantsch and Bauer (1990)

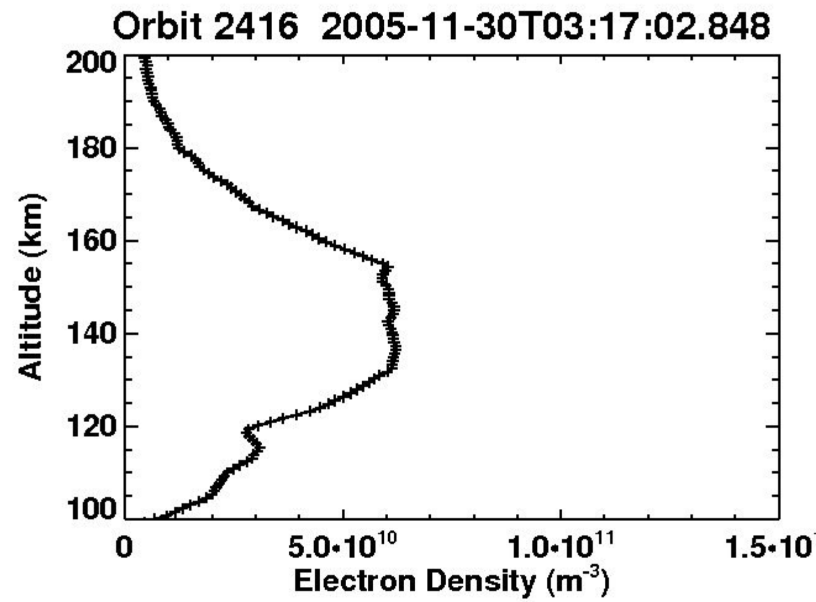
Peter et al. (2014)




Mars • Global Dust Storm
June 26, 2001
September 4, 2001
Hubble Space Telescope • WFPC2
NASA, J. Bell (Cornell), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA) • STScI-PRC01-31

Overall shape

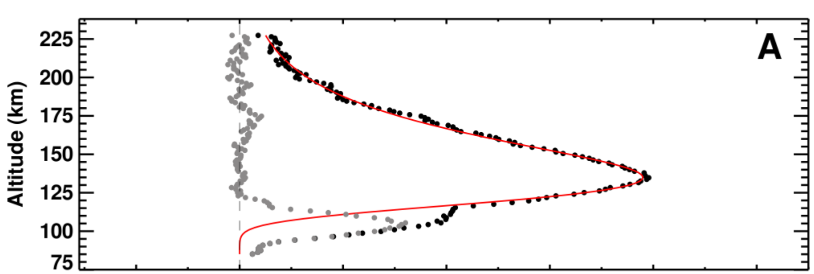




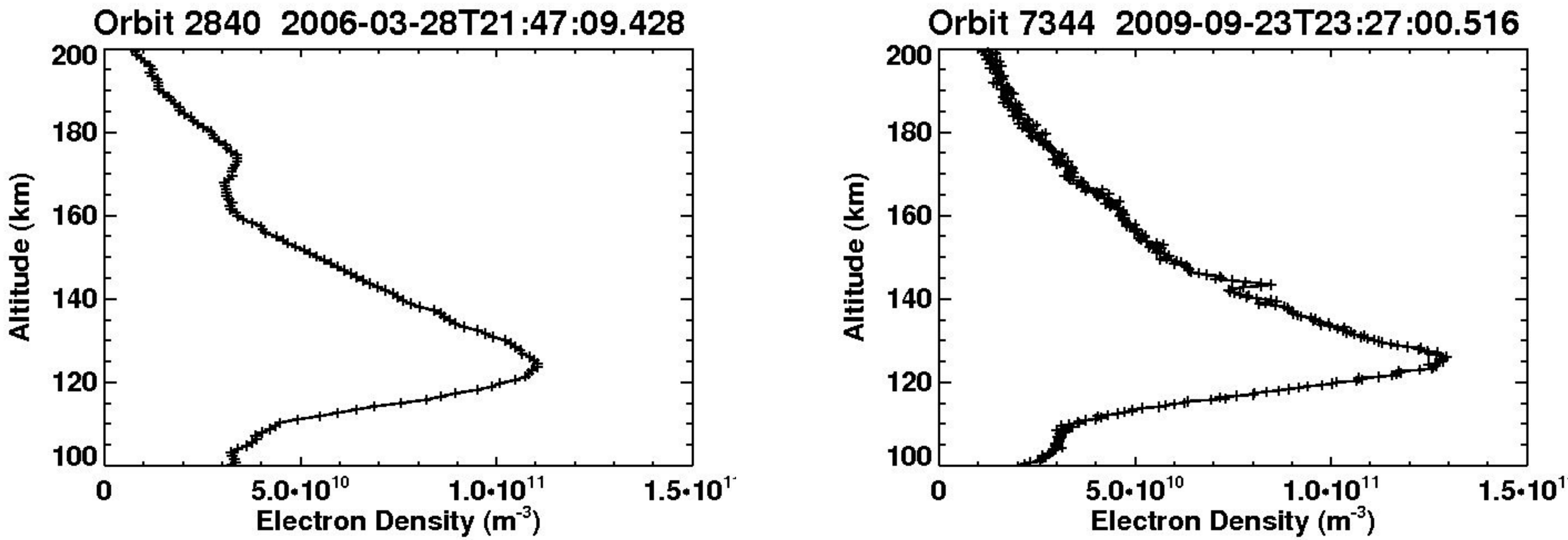
Shape is often not Chapman-like

Withers et al. (2012)
Radio occultation data

$$N = N_m \exp\left(\frac{1}{2}\left(1 - \frac{(z - z_m)}{H} - \exp\left(-\frac{(z - z_m)}{H}\right)\right)\right)$$

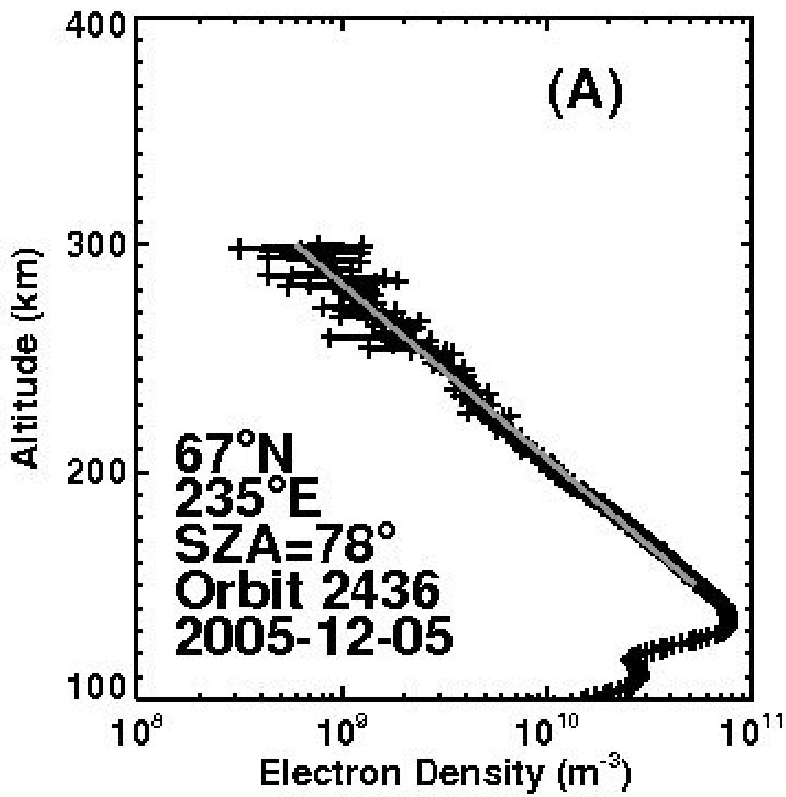


Odd features at slightly higher altitudes

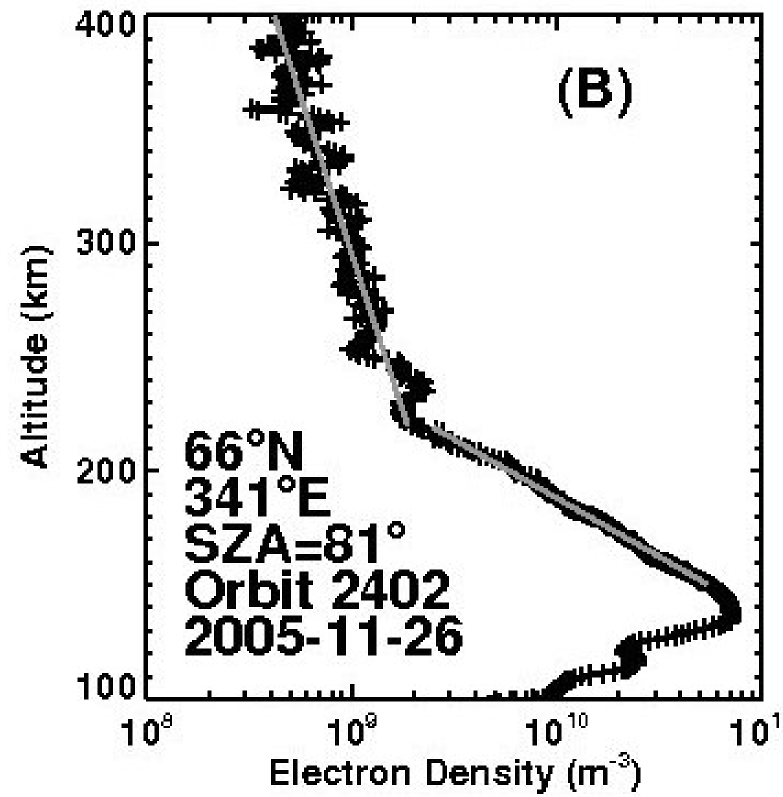


Withers et al. (2012) – Radio occultation observations

How does the topside behave?



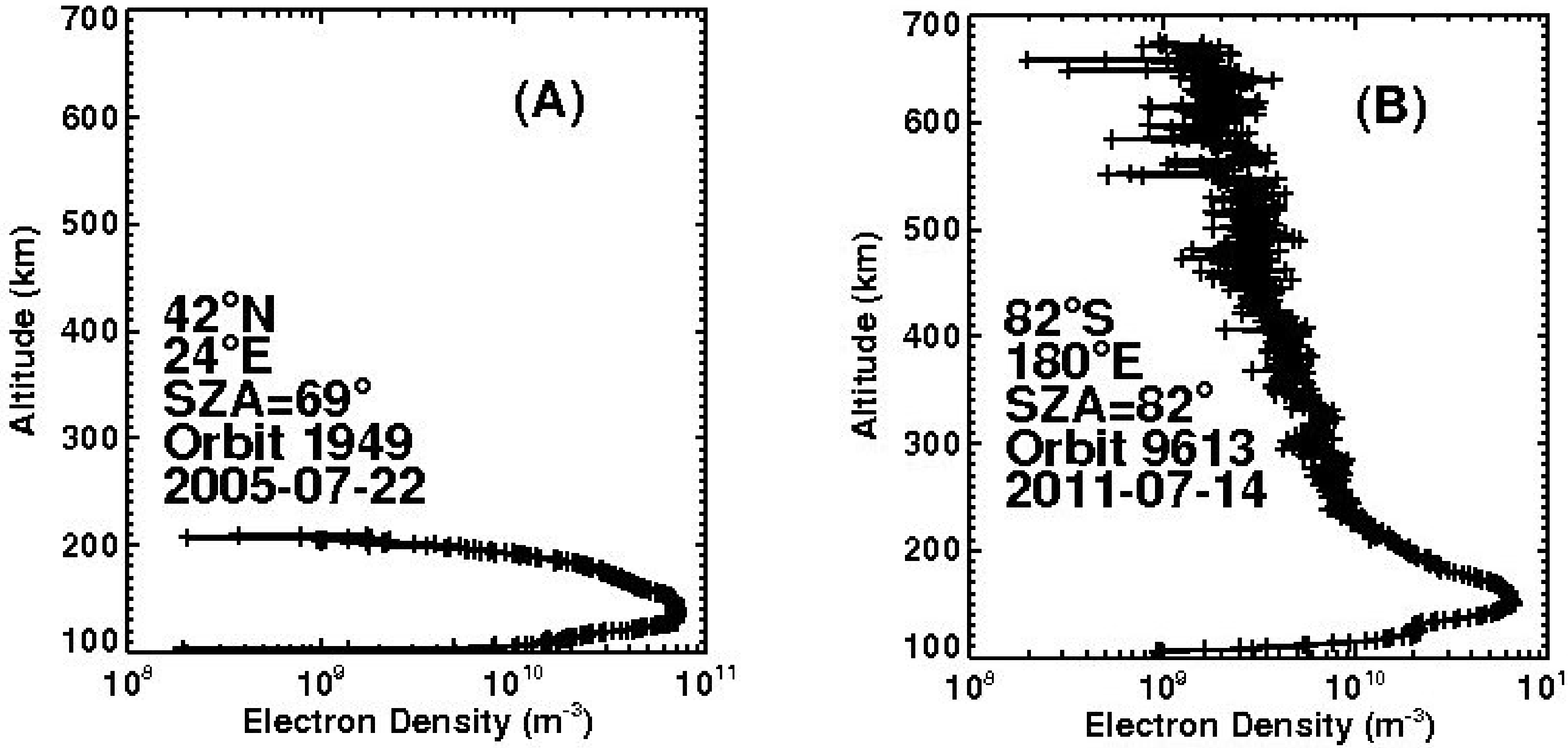
Consistent with
no transport



Consistent with
diffusive equilibrium

Withers et al. (2012) – Radio occultation observations

Where’s the ionopause?



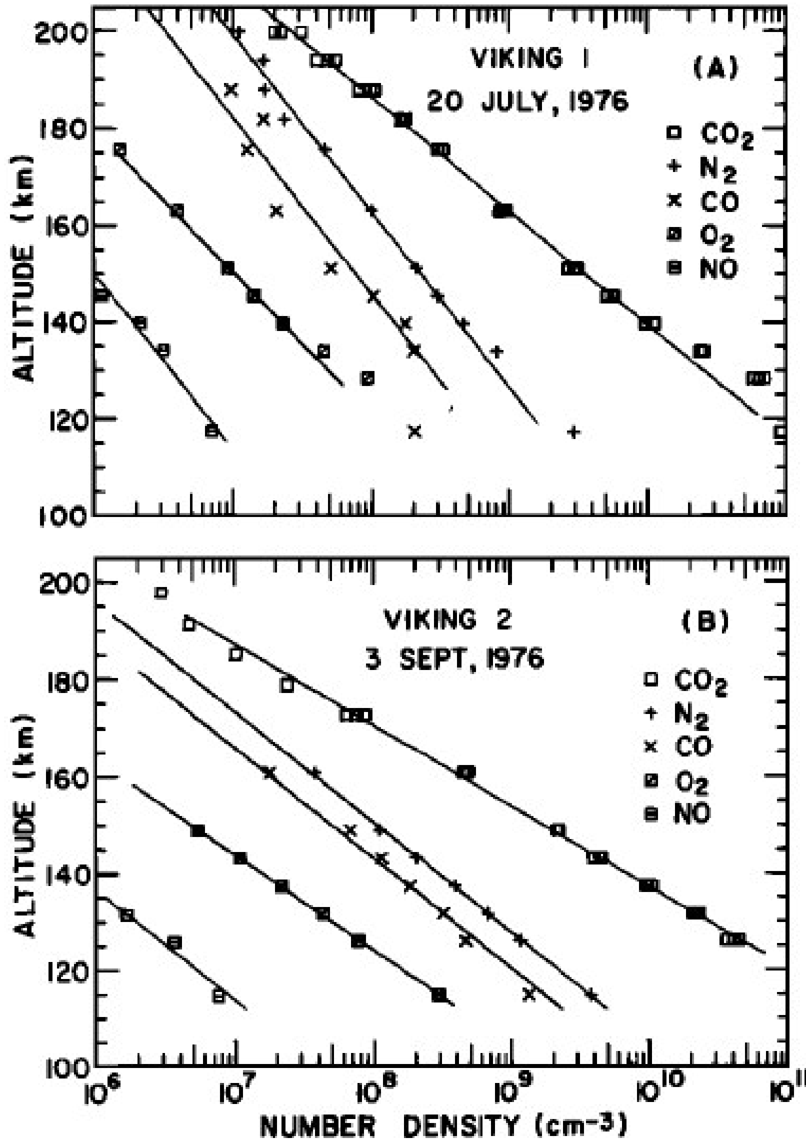
Withers et al. (2012) – Radio occultation observations

Why is it so hard to predict ionospheric characteristics?

Consider existing data on

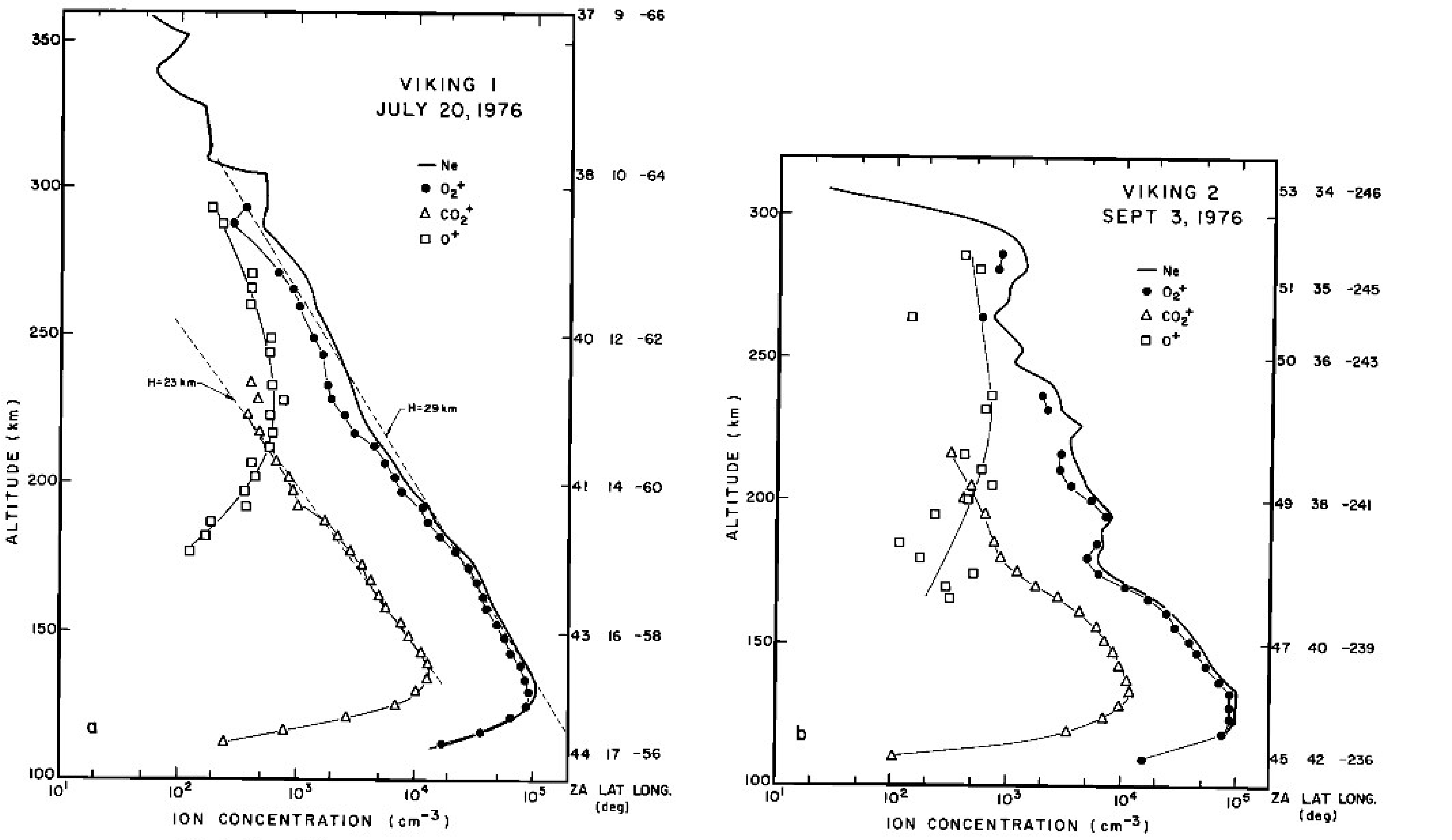
- Neutral composition
- Neutral dynamics
- Plasma composition
- Plasma dynamics
- Plasma energetics

Neutral composition



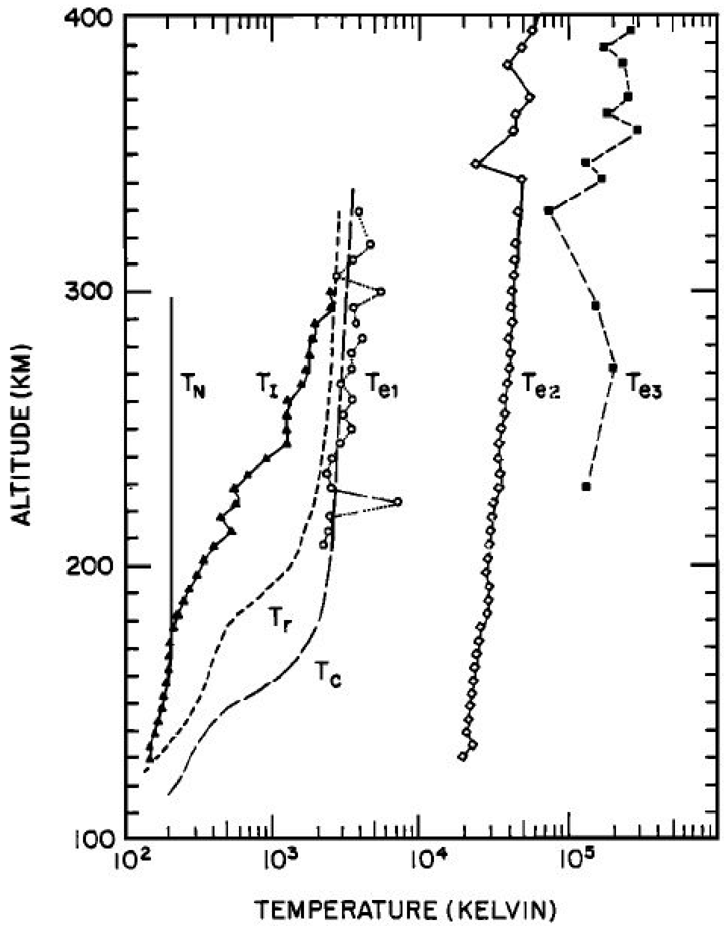
Neutral dynamics

Plasma composition



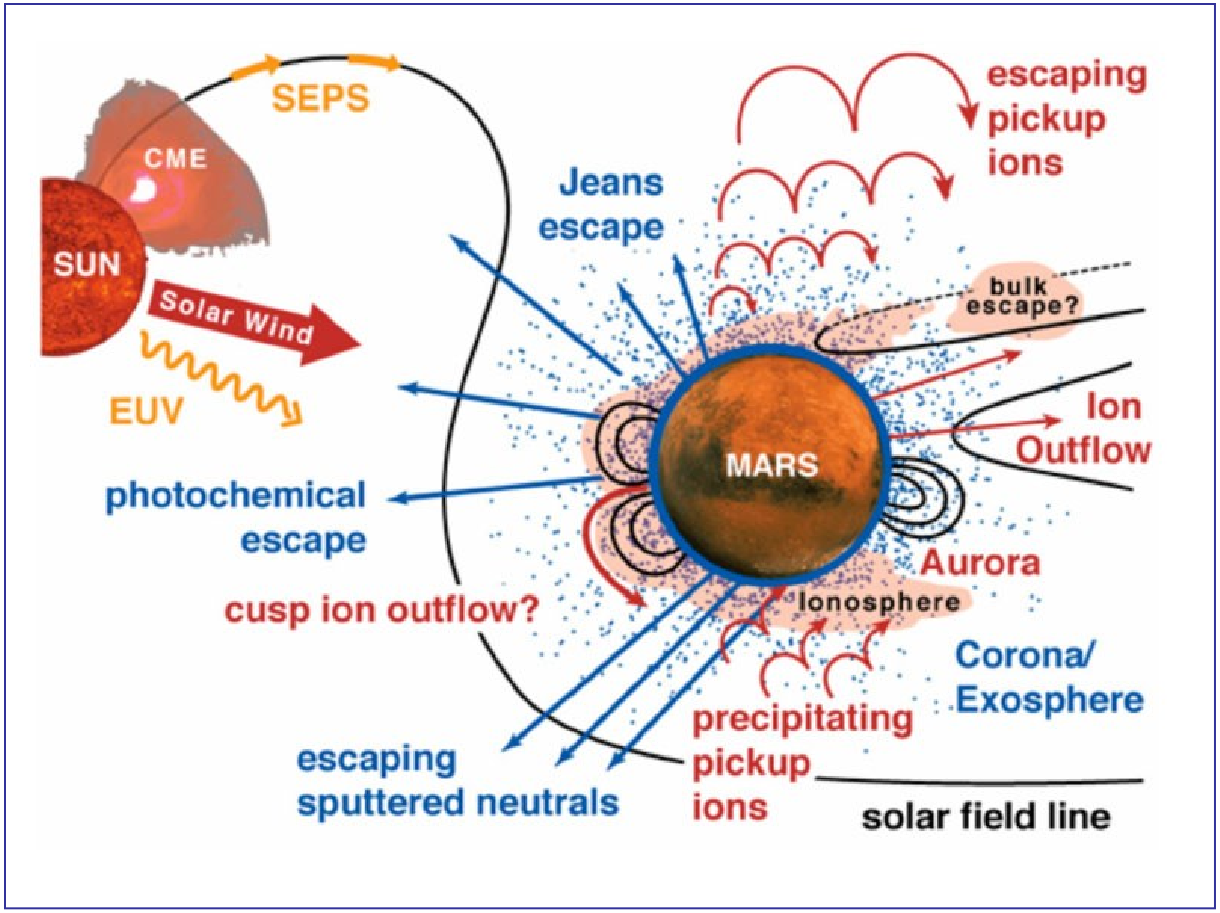
Plasma dynamics

Plasma energetics



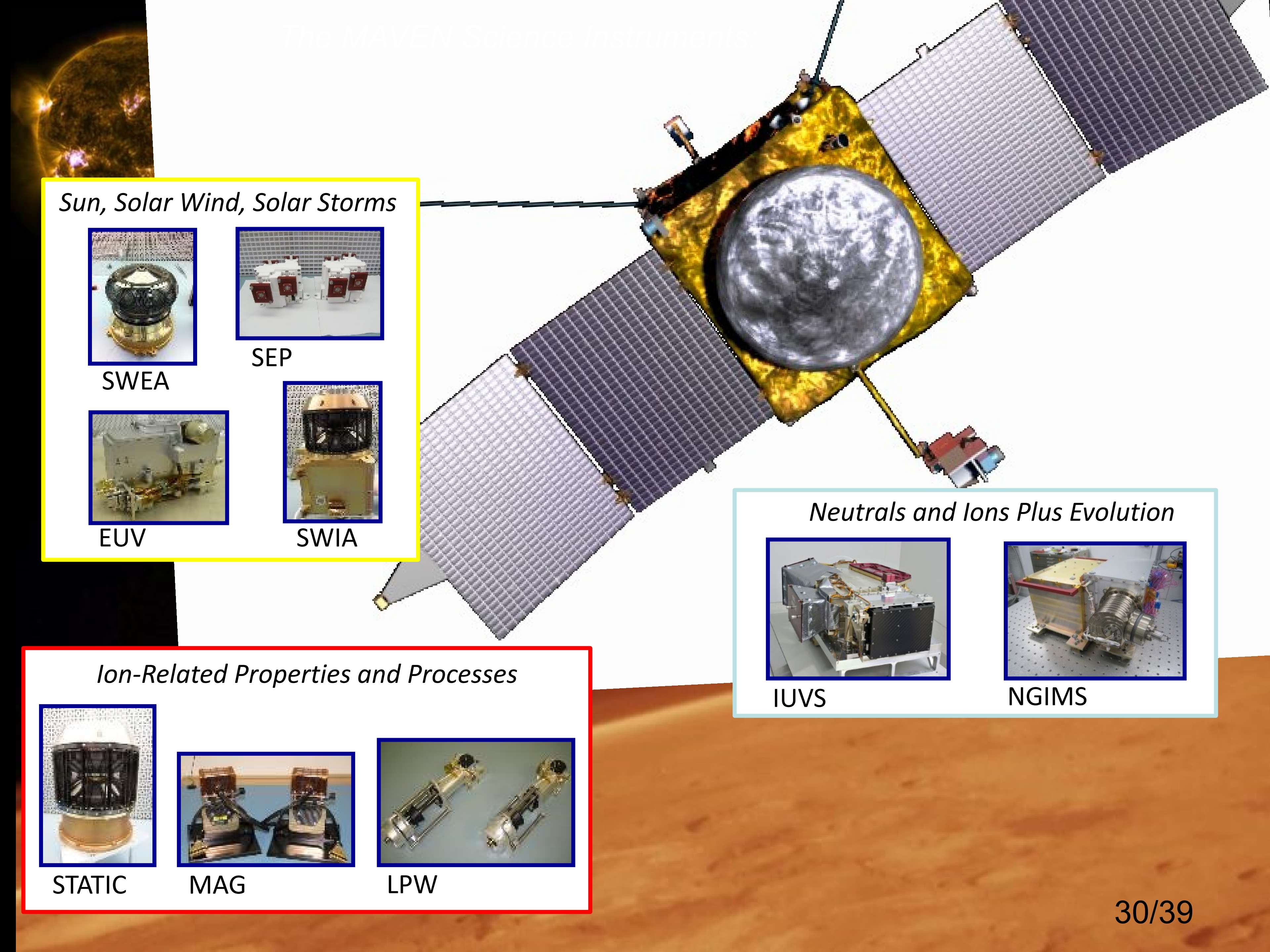
The $500M MAVEN mission was sent to Mars to collect more data for my ionospheric research

MAVEN Will Allow Us to Understand Escape of Atmospheric Gases to Space



- MAVEN will determine the present state of the upper atmosphere and today's rates of loss to space.

- Measurements will allow determination of the net integrated loss to space through time.


The MAVEN Science Instruments
Sun, Solar Wind, Solar Storms
SWEA
SEP
EUV
SWIA
Neutrals and Ions Plus Evolution
IUVS
NGIMS
Ion-Related Properties and Processes
STATIC
MAG
LPW

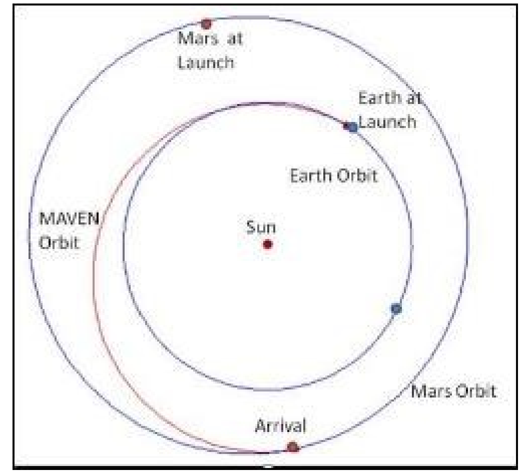
MAVEN instruments

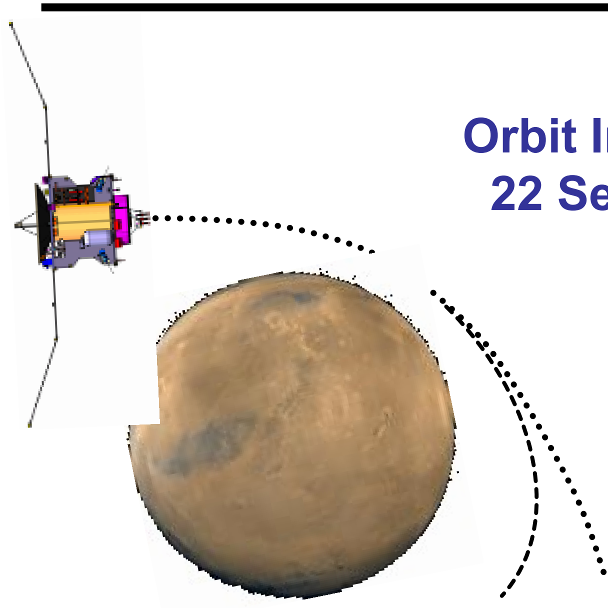
- EUV – Several sensors for EUV fluxes
- IUVS – UV spectrometer
- LPW – Langmuir probe
- MAG – Magnetometer
- NGIMS – Neutral and ion mass spectrometer
- SEP, STATIC, SWEA, SWIA – Electron and ion spectrometers

MAVEN Mission Architecture

Launched on 18 Nov. 2013, first day of its 20-day launch period

Ten-Month Ballistic Cruise to Mars

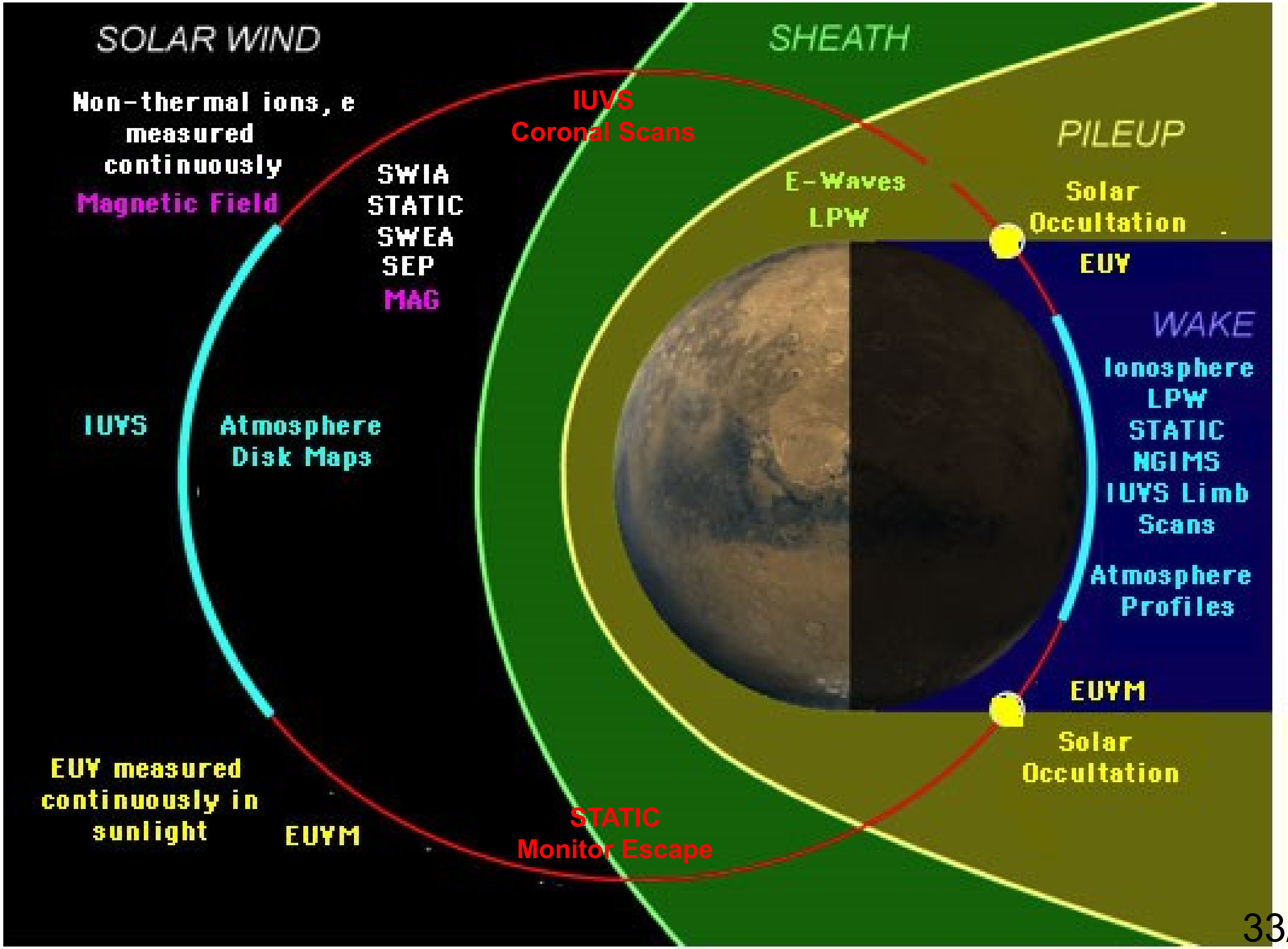




Orbit Insertion: 22 Sept 2014

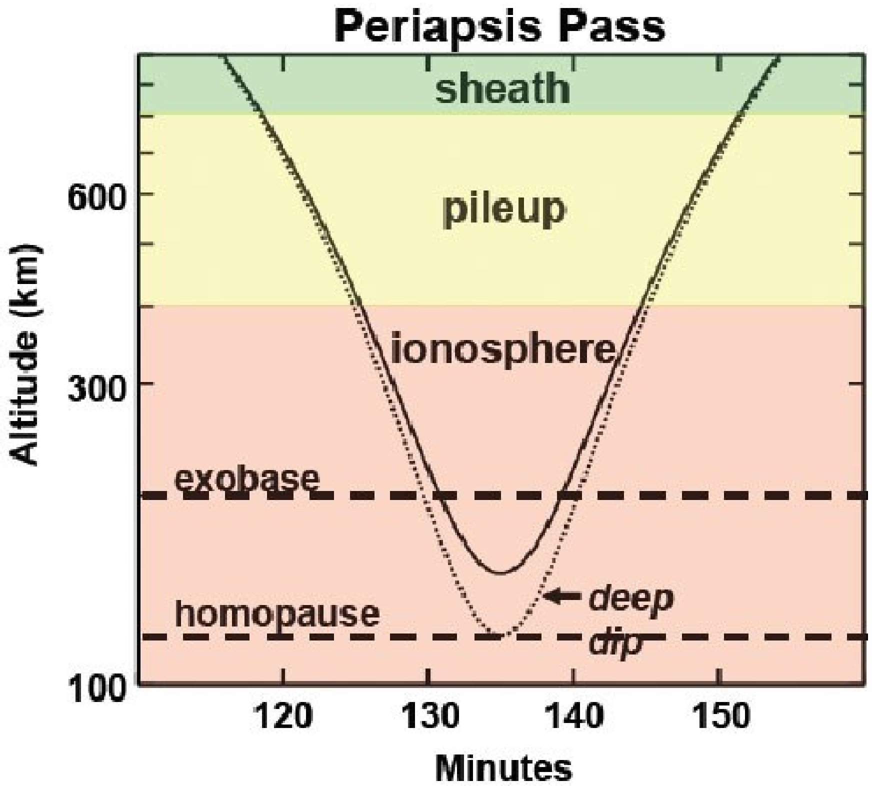
One Year of Science Operations

MAVEN Observes All Regions Of Near-Mars Space Throughout The Orbit



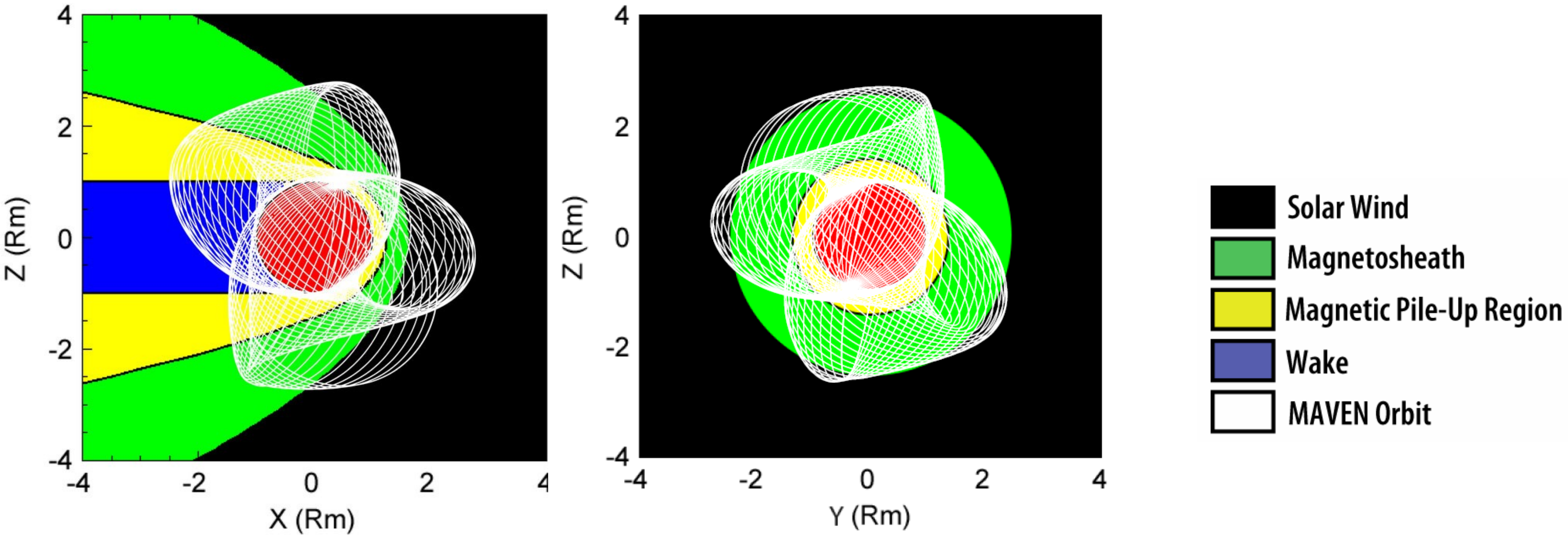
Elliptical Orbit Allows Measurement of All Relevant Regions of Upper Atmosphere

- Nominal periapsis near 150 km.
- Five "deep-dip" campaigns with periapsis near 125 km.
- Provide coverage of entire upper atmosphere

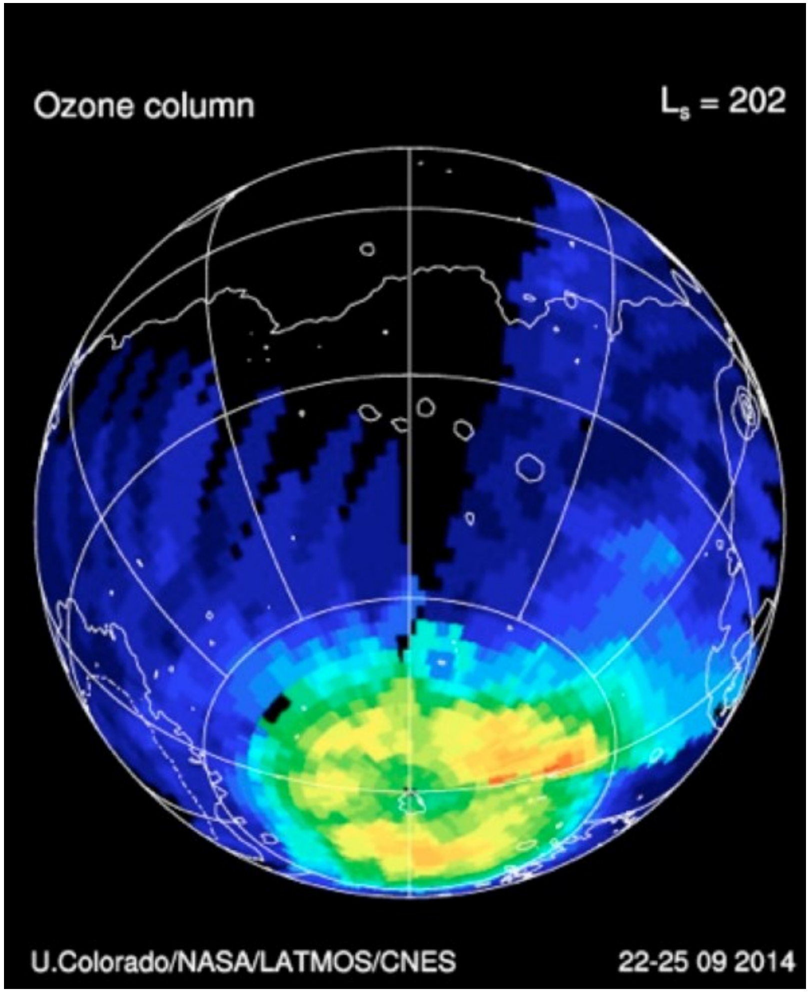


MAVEN Orbit During Primary Science Mission

- Elliptical orbit to provide coverage of all altitudes
- The orbit precesses in both latitude and local solar time
- One-Earth-year mission allows thorough coverage of near-Mars space

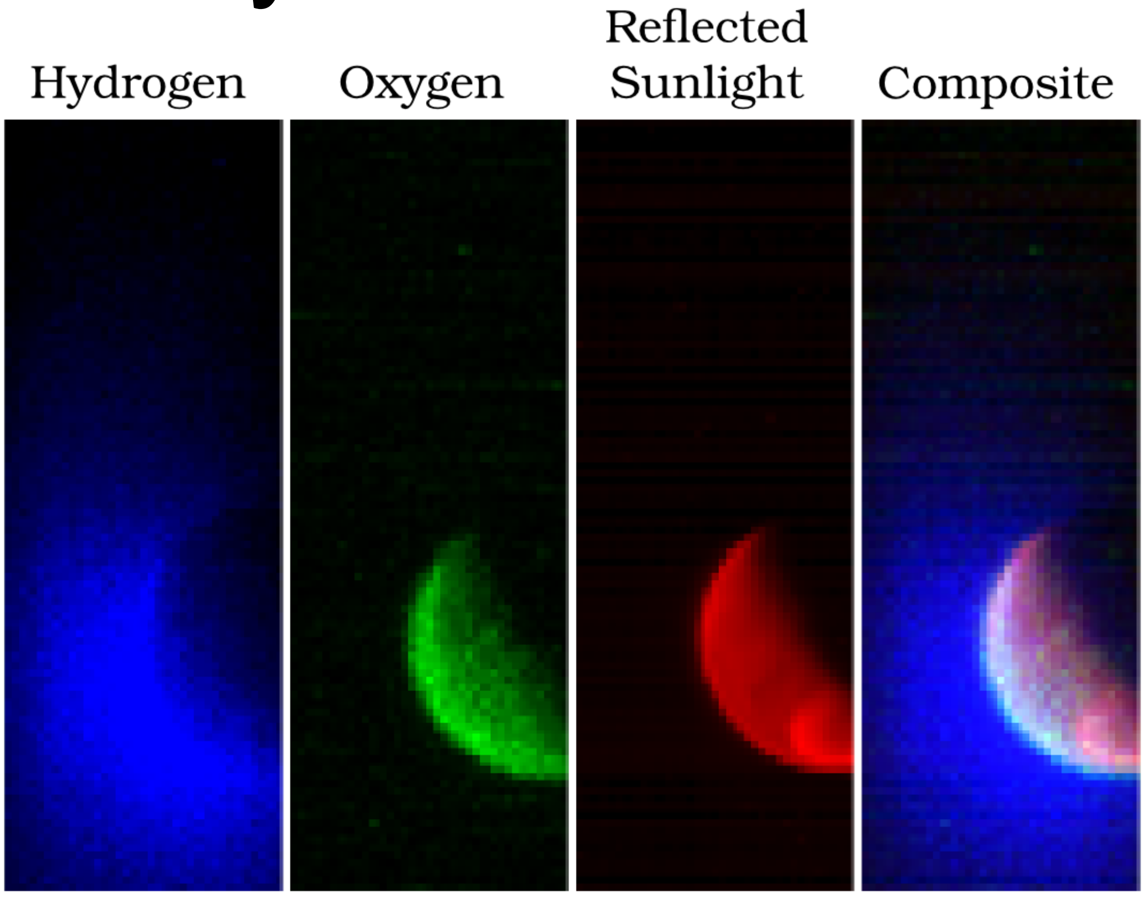


Early media releases



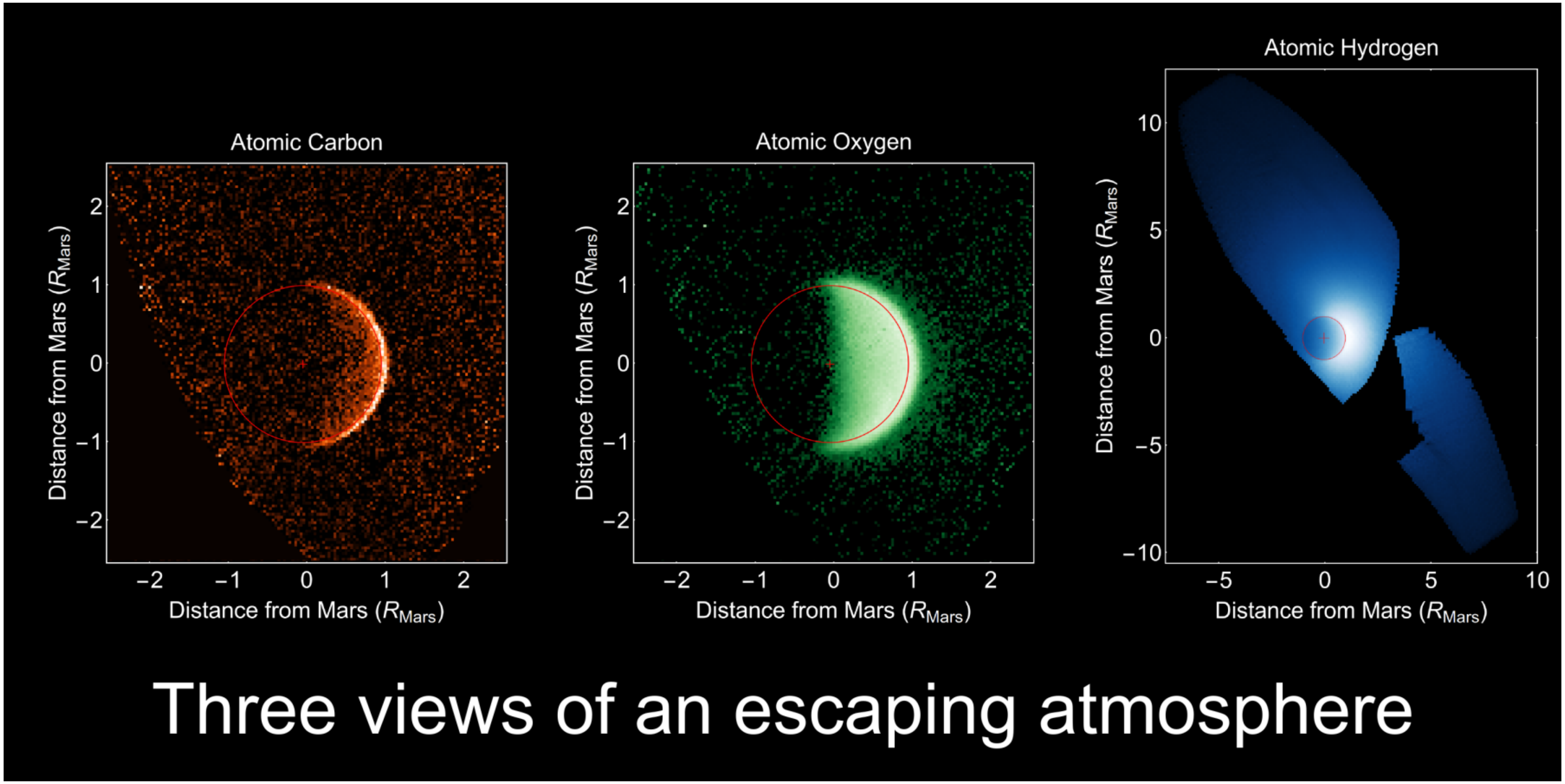
http://www.nasa.gov/sites/default/files/thumbnails/image/ozone_justin2.png

Early media releases



http://lasp.colorado.edu/home/maven/files/2014/09/IUVS-final-image.jpg

Early media releases



http://www.nasa.gov/sites/default/files/thumbnails/image/justincombined.png

Conclusions

- Simple theory explains some ionospheric characteristics…
- …But lots of observations exist that conflict with simple theory
- Explaining them will require data on solar flux, magnetospheric conditions, neutral atmosphere, and ionospheric response
- MAVEN will provide abundant and comprehensive data for space physics at Mars