Comparative meteor science – The effects of meteoroids on planetary atmospheres and ionospheres

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Tuesday 2009.06.30 1930-2130
Zia B+C, Santa Fe, NM
2009 CEDAR Meeting

Motivation

- Recent ionospheric observations at Venus and Mars show low-altitude plasma layers that appear analogous to terrestrial metal ion layers produced by meteoroid ablation

- How can Earth help us understand these extraterrestrial examples?
- How can Venus and Mars challenge and validate Earth-centric theory and models?

Goals of workshop

- To present observations and simulations from Venus and Mars to CEDAR community
- To outline major processes important for terrestrial metal ion layers
- To consider how differences in planetary environment might affect processes that control metal ion layers and hence lead to differences in properties of metal ion layers from planet to planet

- To identify important scientific questions
- To discuss how these questions can be answered

Agenda

- Meers Oppenheim: Introduction (1930-1935)
- Paul Withers: Observations of metal ion layers across the solar system (1935-1950)
- Joe Grebowsky: Simulations of metal ion layers across the solar system (1950-2005)
- John Plane: The chemistry of metal species in planetary atmospheres (2005-2020)
- John Mathews: Metal ions in sporadic E layers, with some speculation about analogous phenomena on other planets (2020-2035)
- Dave Hysell: The electrodynamics of metal ions in sporadic E layers, with some speculation about analogous phenomena on other planets (2035-2050)
- Michael Mendillo: Summary (2050-2100)
- Margin, time available for general discussion and spontaneous presentations from the audience (2100-2130)

Observations of metal ion layers across the solar system

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Metal ions on Earth

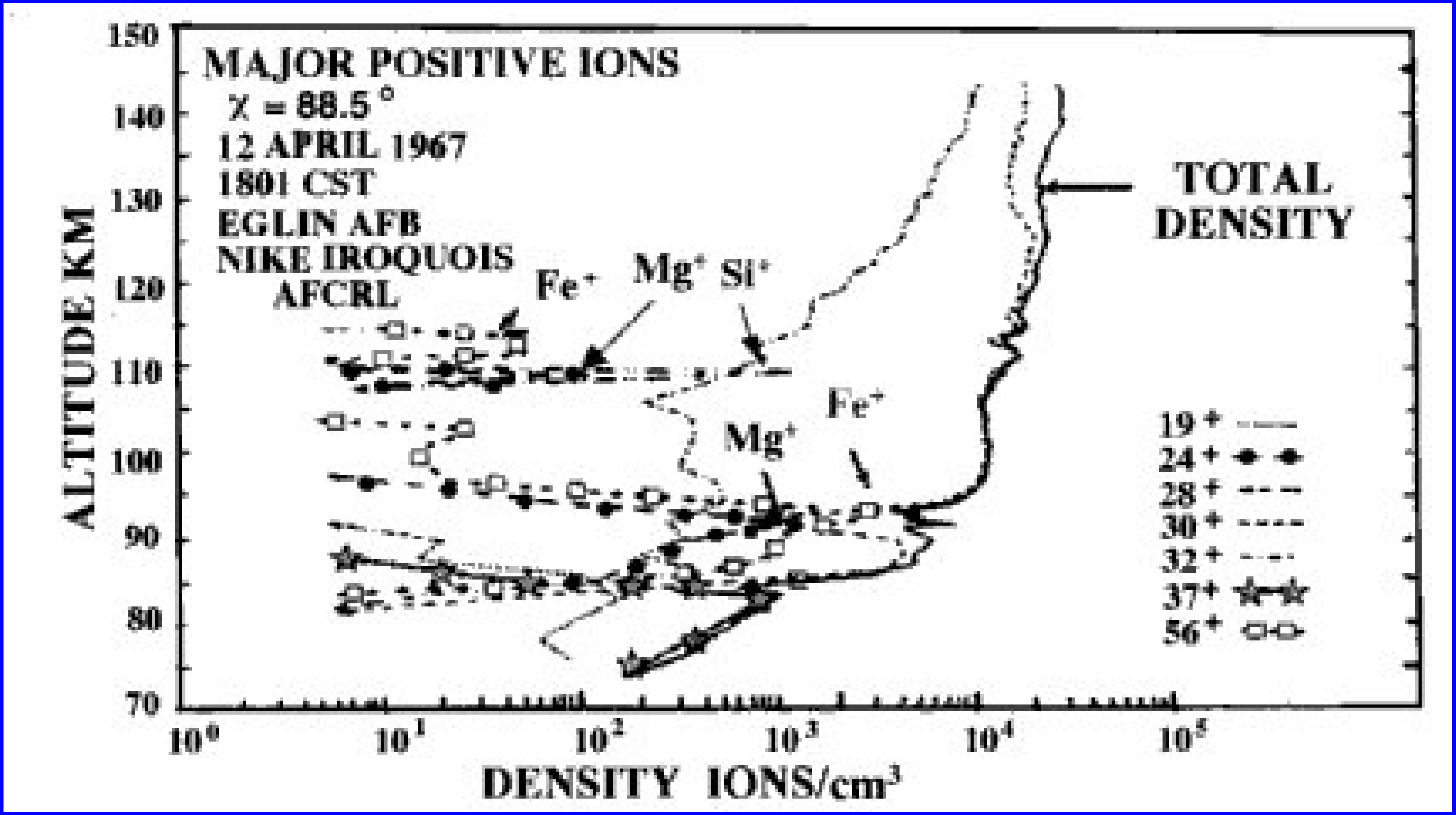


Figure 8.3 of Grebowsky and Aikin (2002)

Sporadic E on Earth

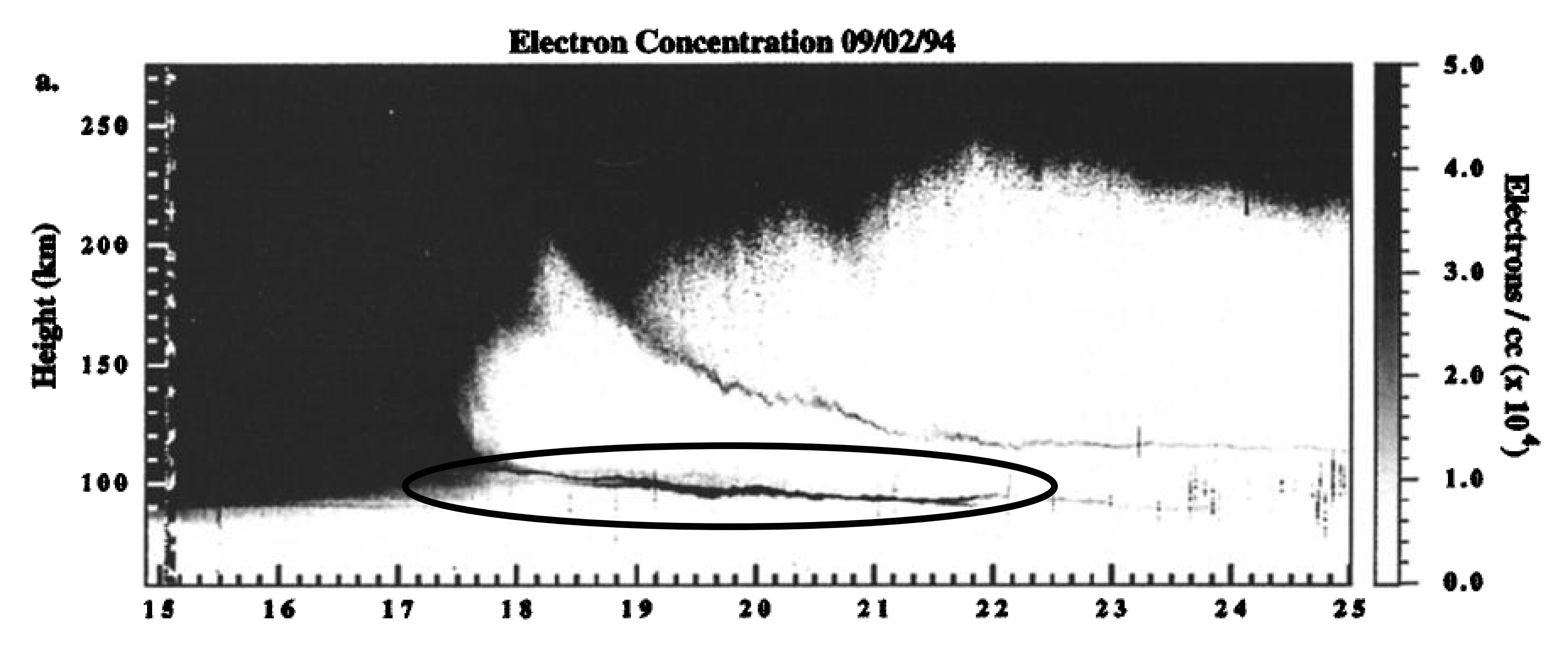


Figure 2a of Mathews et al. (1997) Ionosonde data from Arecibo

Sporadic E = Dense layers of plasma at E-region altitudes that aren’t related to normal E layer

Plasma persists into night, requires long-lived ions – atomic metal ions

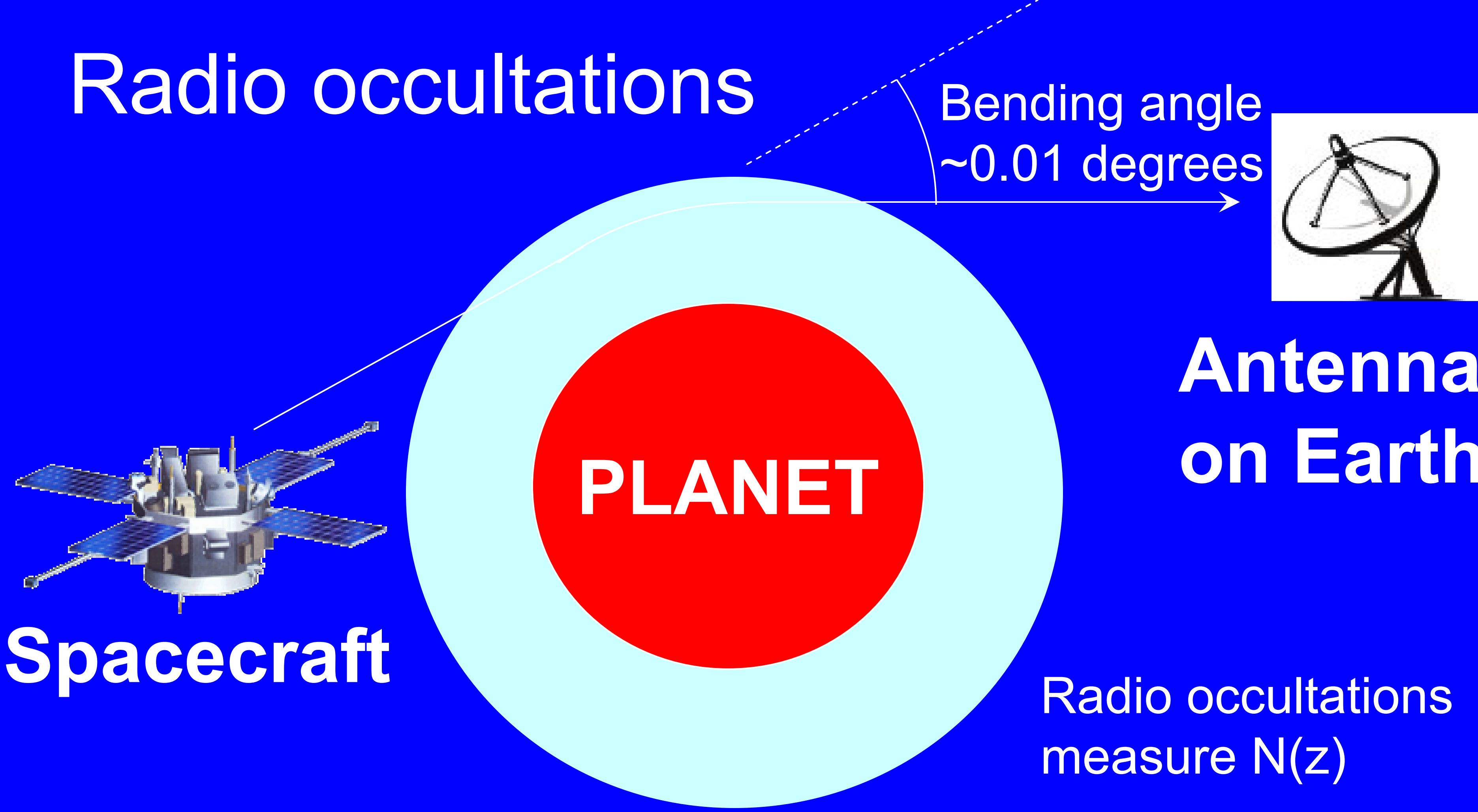
Formed by wind shear in strong, inclined magnetic field

Extraterrestrial observations

- No ion composition data at relevant altitudes
  - No mass spectrometer data
- No surface-based ionosondes or radars making measurements frequently

- Instead, vertical profiles of electron density from radio occultation experiments
  - Thousands at Mars, hundreds at Venus, only a handful at all other planets

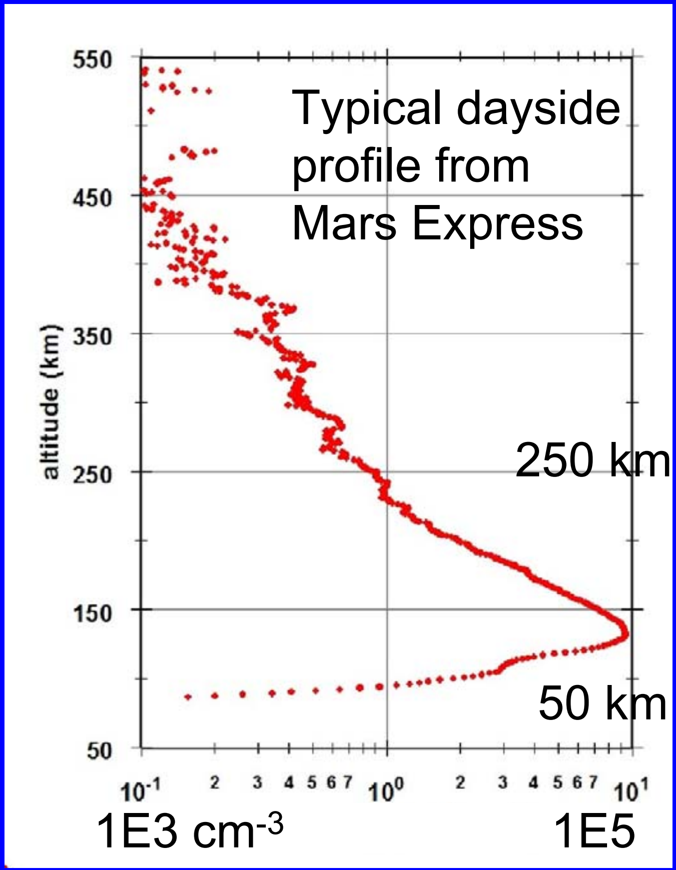
Radio occultations



1. Signal is Doppler-shifted due to spacecraft motion
2. Refraction of signal in planetary atmosphere modifies this Doppler shift
3. Measure received frequency as function of time (or tangent height of signal)
4. Subtract all known causes of frequency shift to obtain residual frequency shift
5. Unique solution for refractive index as function of altitude
6. Obtain electron density profile from refractive index

Workhorse of ionospheric studies

- Venus
  - Mariner 5, Mariner 10, Pioneer Venus, Magellan, Venera 9, 10, 15, 16
- Mars
  - Mariner 4, 6, 7, 9, Mars 2, 4, 5, 6, Viking 1, 2, Mars Global Surveyor, Mars Express
- Jupiter
  - Pioneer 10, 11, Voyager 1, 2, Galileo
- Saturn
  - Pioneer 11, Voyager 1, 2, Cassini
- Uranus and Neptune
  - Voyager 1, 2
- Pluto
  - New Horizons (in flight to destination)
- Comets
  - Giotto, Rosetta (in flight to destination)



Characteristics of radio occultations

Strengths

- Uncertainties ~10^3 cm^{-3}
- Span all altitudes
- Vertical resolution ~1 km
- Observations not limited to spacecraft position or nadir
- Minimal hardware requirements
- Insensitive to quirks of individual instrument

Weaknesses

- No composition data
- Spherical symmetry must be assumed
- Restricted by orbit geometry to locations close to dawn/dusk
- Maximum of two profiles per orbit/flyby

Outer Solar System

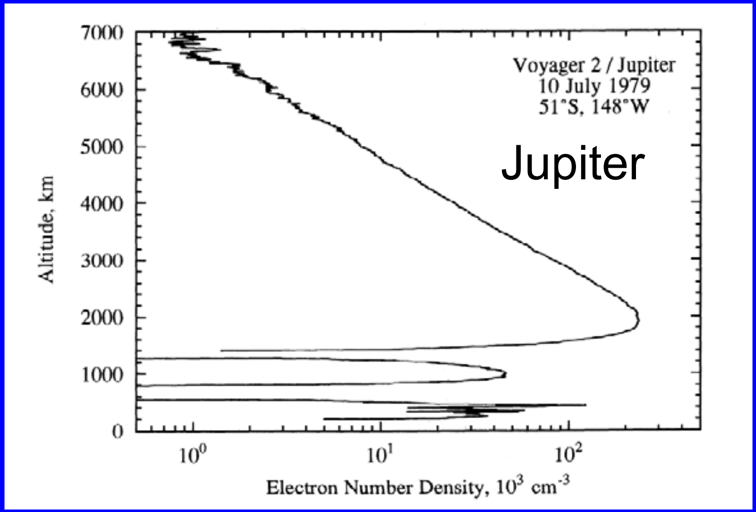


Figure 4 of Hinson et al., 1998

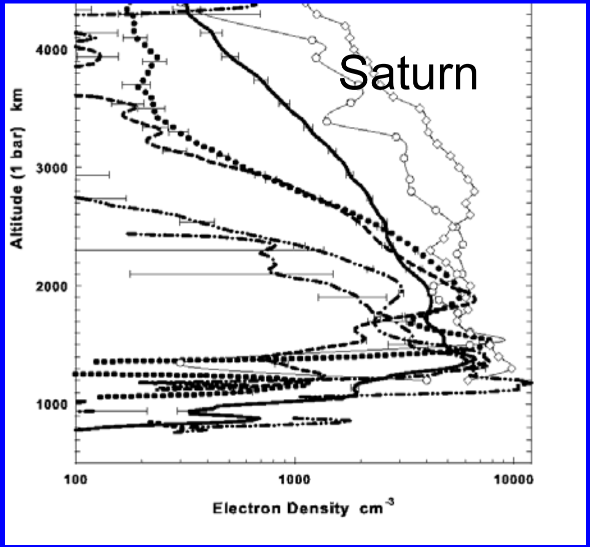


Figure 3 of Nagy et al., 2006

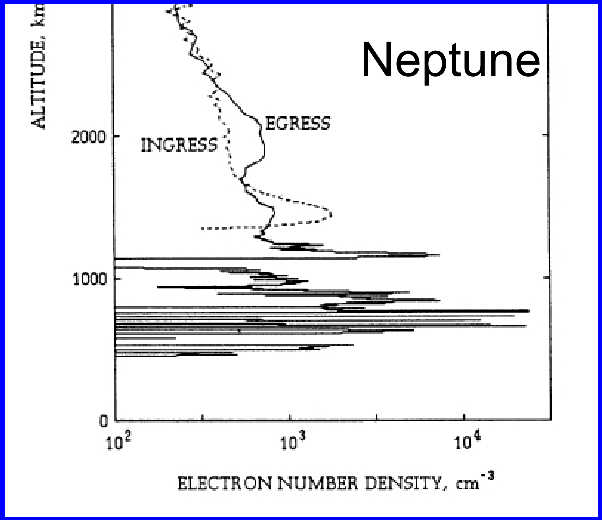


Figure 8 of Lindal, 1992

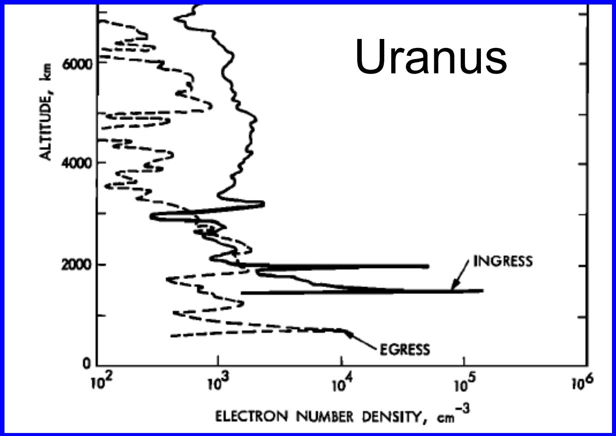


Figure 7 of Lindal et al., 1987

Narrow plasma layers often seen at low altitudes

Poorly understood

Possibly:
- Metal ion layers from meteoroids
- Heavy ion layers from debris of rings or moons
- “Normal” ions layered by gravity waves
- Unreliable data

Metal ion layer on Venus

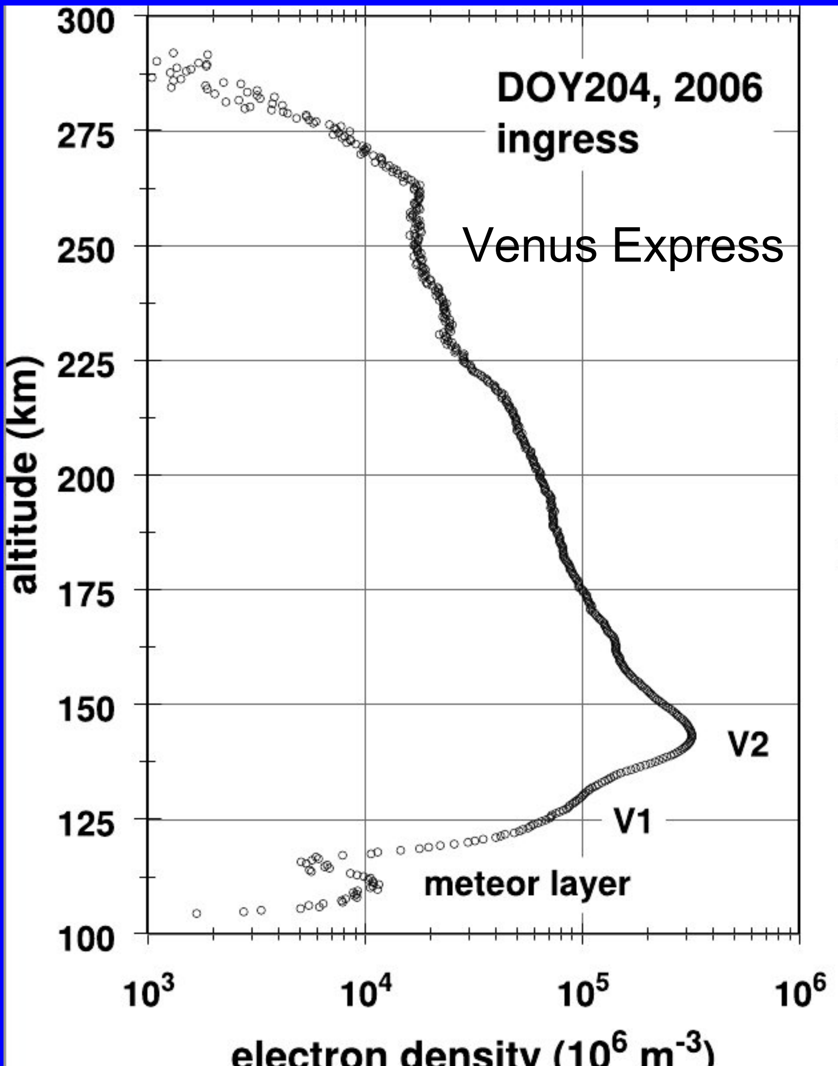


Figure 1 of Pätzold et al. (2009)

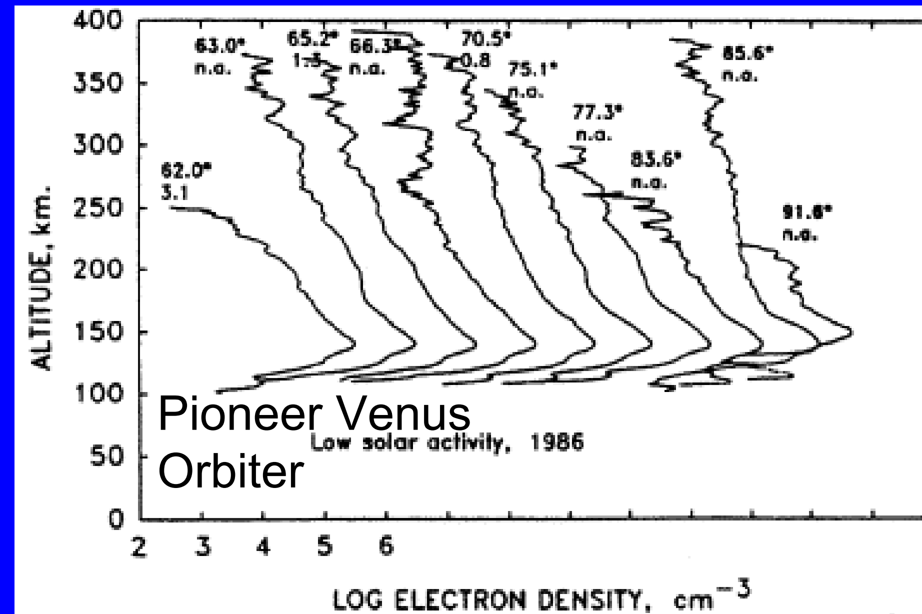


Figure 4 of Kliore (1992)

Candidate layers seen in 18 Venus Express profiles from SZA of 60° to 90°

Some double layers seen

Inferred to be metal ions, but not verified by ion composition data

Three more examples from Venus

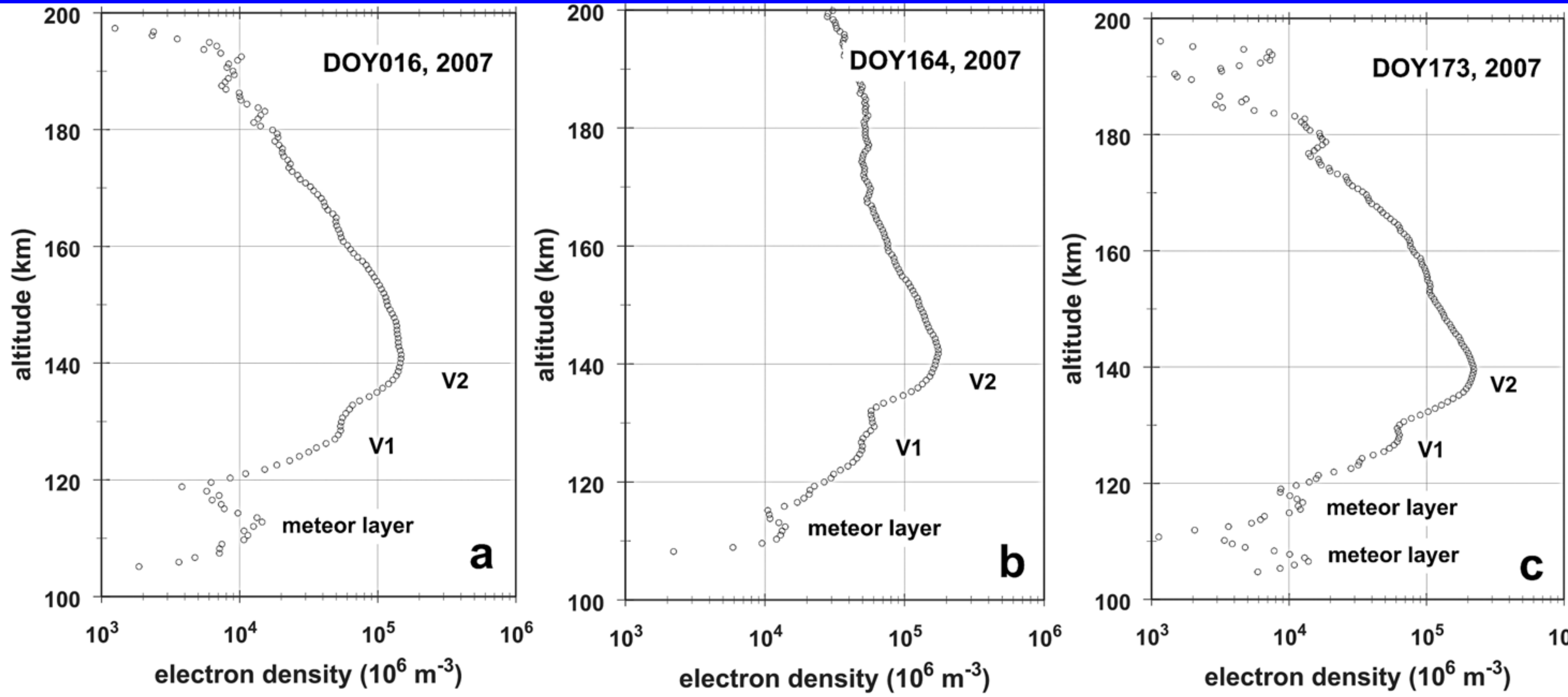


Figure 2 of Pätzold et al. (2009)

Zoom in on three examples

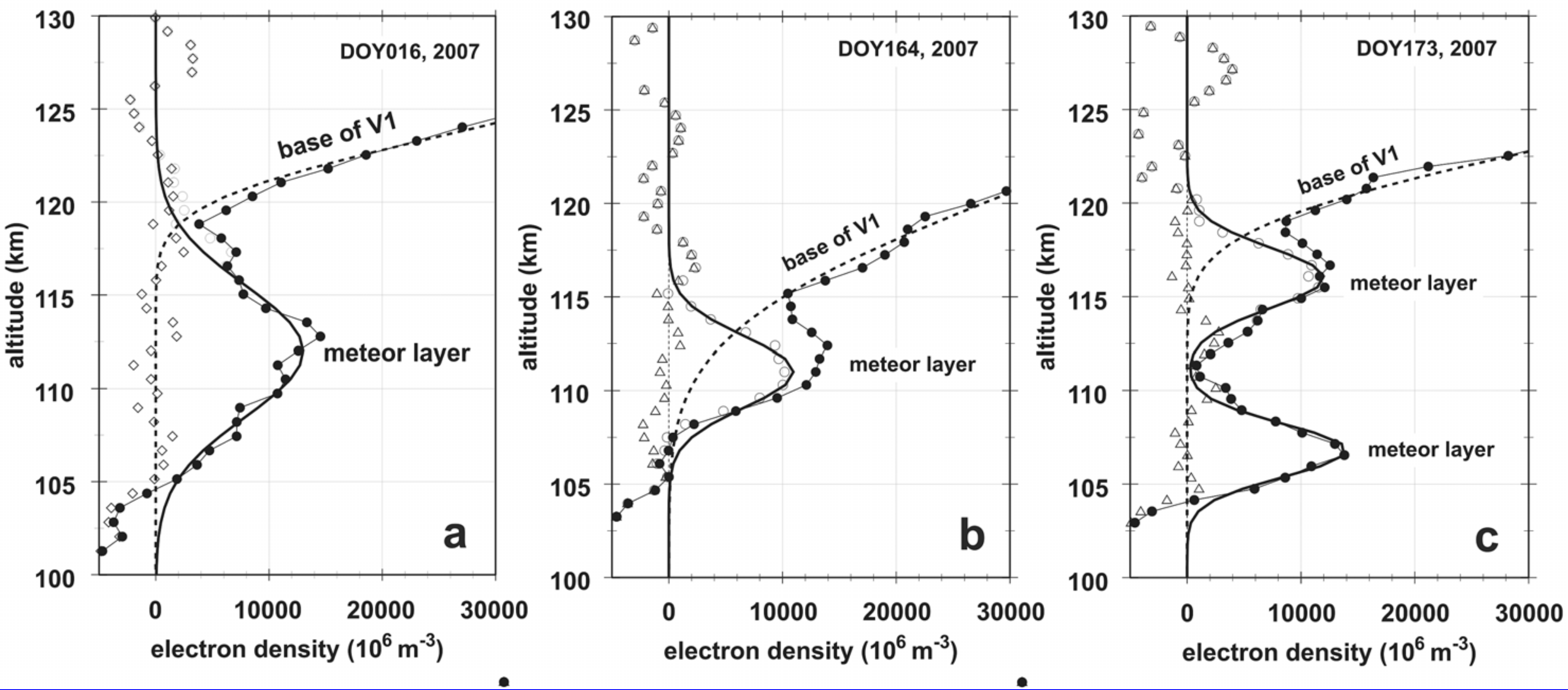
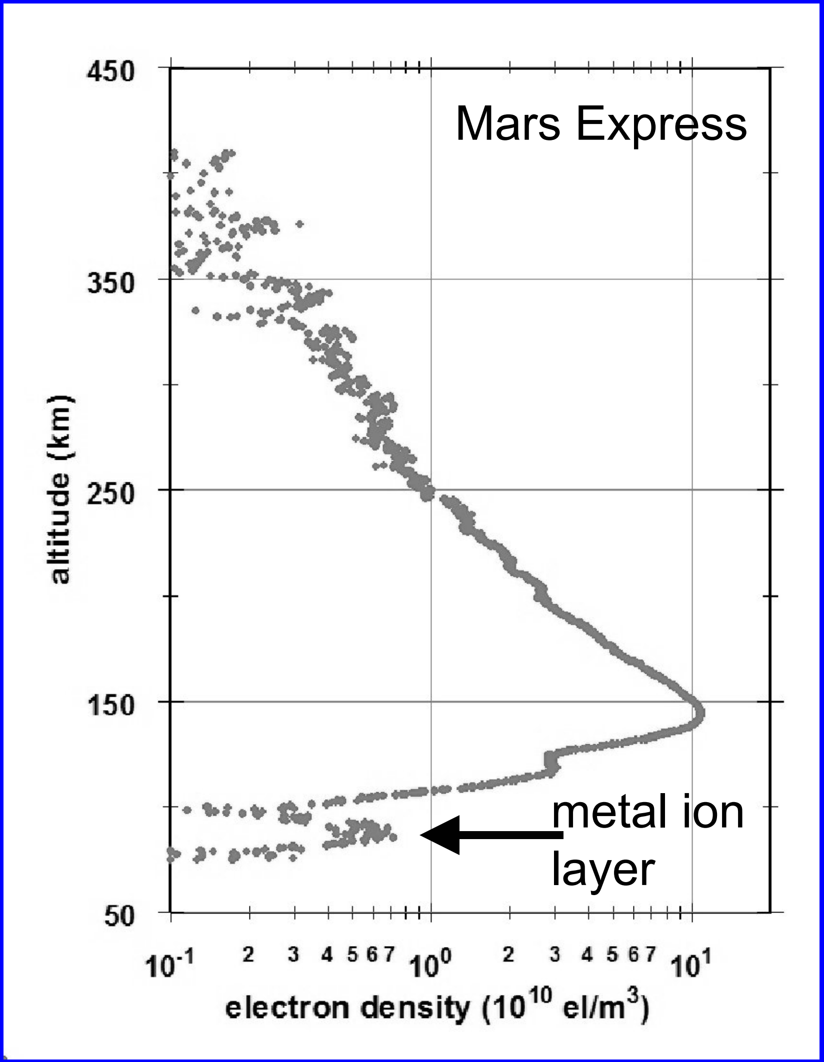


Figure 2 of Pätzold et al. (2009)

Metal ion layer on Mars



Withers et al., in prep

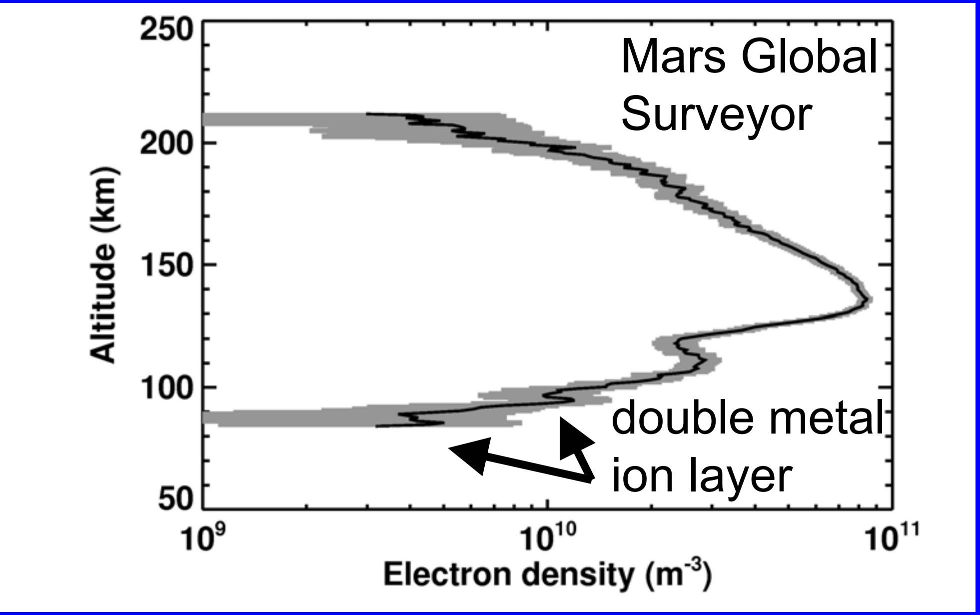


Figure 4 of Withers et al. (2008)

Candidate layers seen in 71 Mars Global Surveyor profiles and 75 Mars Express profiles from SZA of 50° to 90°

Some double layers seen

Inferred to be metal ions, but not verified by ion composition data

Two more examples from Mars Global Surveyor

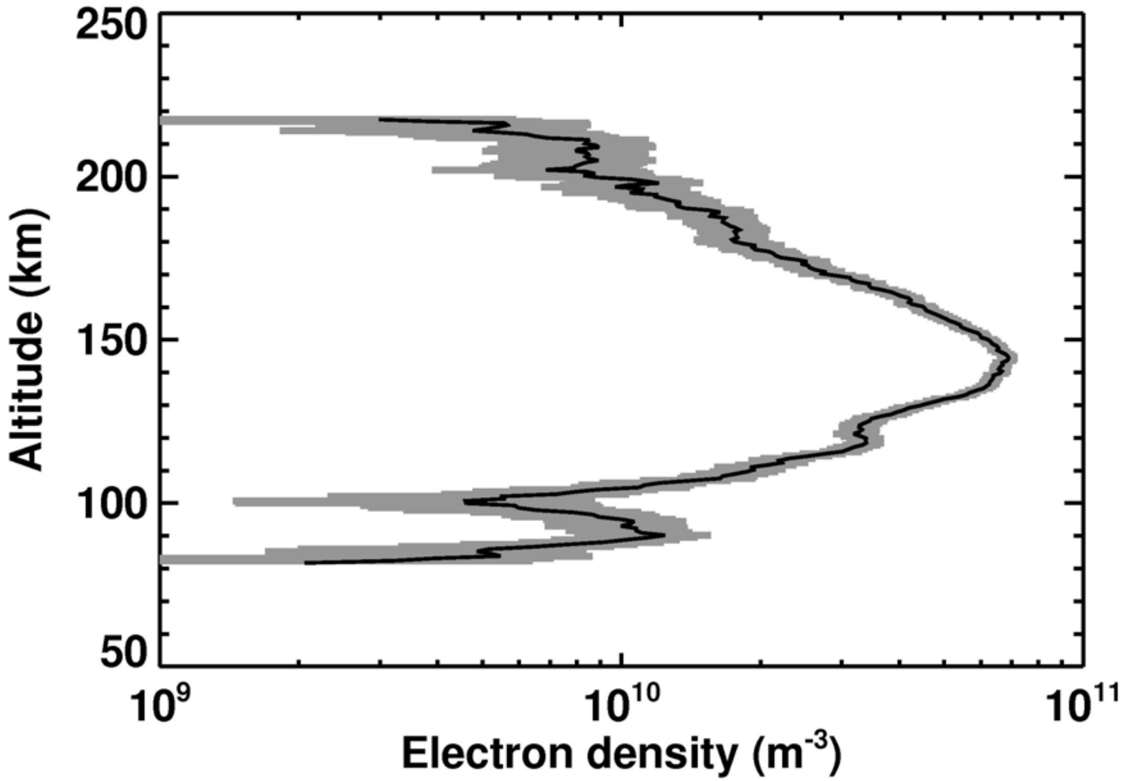


Figure 3 of Withers et al. (2008)

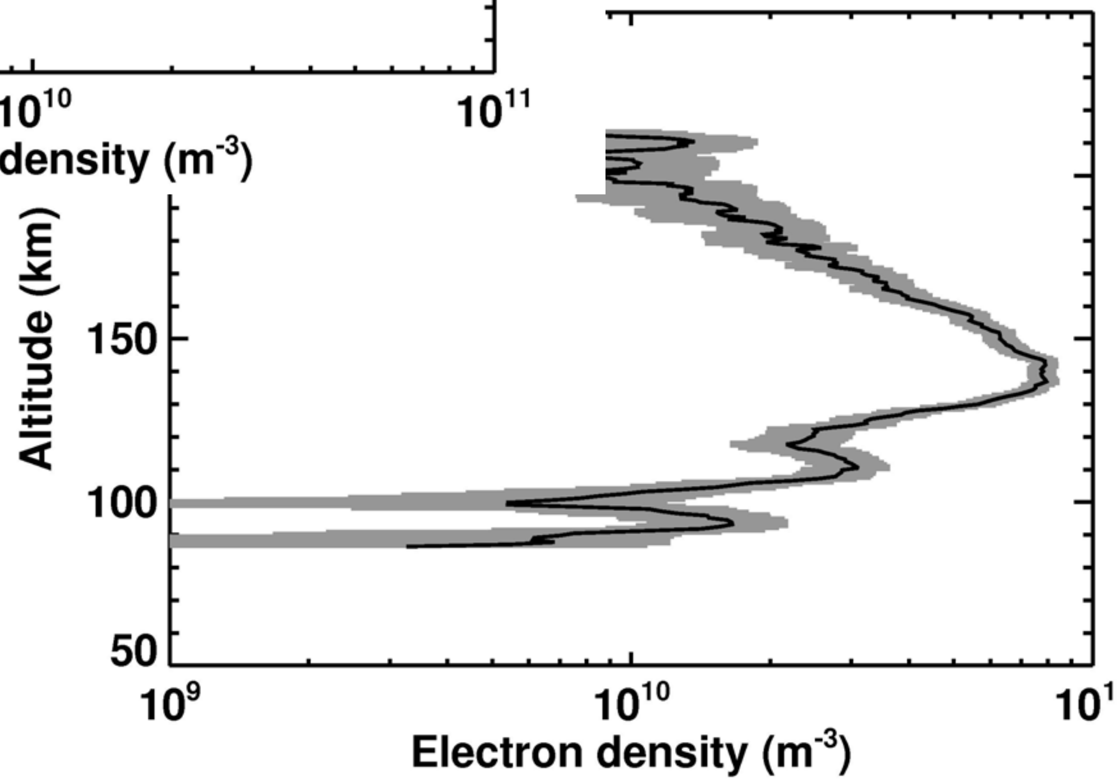


Figure 2 of Withers et al. (2008)

Physical characteristics of metal ion layers from Mars

- Height of 87-97 km
- Width of 5-15 km
- Electron densities of ~10^4 cm^{-3}
- Height, width, electron density of metal ion layers are positively correlated

- These characteristics are not correlated with solar zenith angle, neutral scale height, solar flux
- This is unlike the rest of the ionosphere

Comparison of observations for Venus, Earth and Mars

Planet	Layering	N (cm^{-3})	Height (km)	Width (km)	Pressure (Pa)	Density ($kg\ m^{-3}$)	Scale height (km)	Temp (K)
Venus	Mostly single, some double (radio occ)	2E4	109 – 117	5 – 10	0.1	4E-6	4	190
Earth	Many (rockets), single (Sporadic E)	1E3 (XX)	95 – 100	~2 (rockets)	0.03	5E-7	5	180
Mars	Mostly single, some double (radio occ)	1E4	87 – 97	5 – 15	0.01	5E-7	7	140

Venus – Pioneer Venus Sounder probe data at 112 km from Seiff et al. (1980)

Earth – MSISE-90 model at 100 km for mean solar activities, averaged over local time, season, latitude
Taken from www.spenvis.oma.be/spenvis/ecss/ecss07/ecss07.html

Mars – Viking Lander 1 data at 92 km from Seiff and Kirk (1977)

Planetary properties that may affect metal ion layers

- Chemical composition of atmosphere
  - O_2/N_2 for Earth, CO_2 for Venus and Mars
- Magnetic field
  - Strong and dipolar at Earth, non-existent at Venus, spatially variable crustal fields at Mars
- Rotation rate (duration of nighttime darkness)
  - 1 day for Earth and Mars, hundreds of days for Venus
- Atmospheric dynamics
  - Tides and waves important at Earth, subsolar to anti-solar flow on Venus, possibly a combination at Mars
- Distance from Sun
  - Meteoroid influx will vary from planet to planet

Conclusions

- Plasma layers that appear to be metal ion layers derived from meteoroids have been seen on Venus, Earth and Mars
- Present in ~10% of dayside observations from Venus and Mars ($N>10^3$ cm^{-3})
- Wind shear in strong magnetic field, which is critical on Earth, will be less important on Venus and Mars

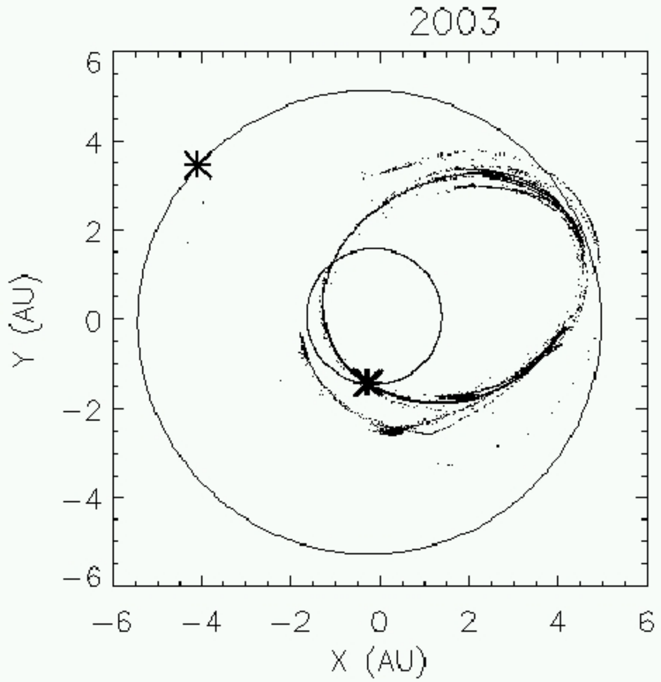
- Don't forget about the ultimate source – meteoroids
- The meteoroid environment at Venus or Mars will not be the same as Earth
  - Relative importance of shower and sporadic meteoroids
  - Seasonal variations in shower and sporadic fluxes

Backup

Comets and meteor showers

Composite image of comet Wild 2 taken by Stardust

Comet West (1975, San Diego)



Positions in 2003 of debris ejected from comet 79P/du Toit-Hartley in 1814. Orbits and positions of Mars and Jupiter in 2003 shown.

(Left) Stardust, NASA
(Centre) http://www.solarviews.com/browse/comet/west2.jpg
(Right) Figure 1 of Christou et al. (2007)

Effects of meteor showers

- Predicted, but not yet definitively detected, on Earth
  - Too many other causes of variability
- If robust repeatable annual variations seen on Venus or Mars, then must discriminate between possible causes
  - seasonal variations in wind shear in magnetic field
  - seasonal variations in sporadic meteoroids
  - meteor showers (insignificant source of mass on Earth)
- The first possibility should be easy to exclude at Venus, which has no magnetic fields and no seasons
- Discrimination between variations in meteoroid influx at Venus or Mars due to changes in showers or sporadics is harder
  - Timescales for changes should be shorter for showers
  - If enhanced metal ion layers seen during expected meteor shower, meteor shower is most likely cause

Observed distribution of sporadic meteors

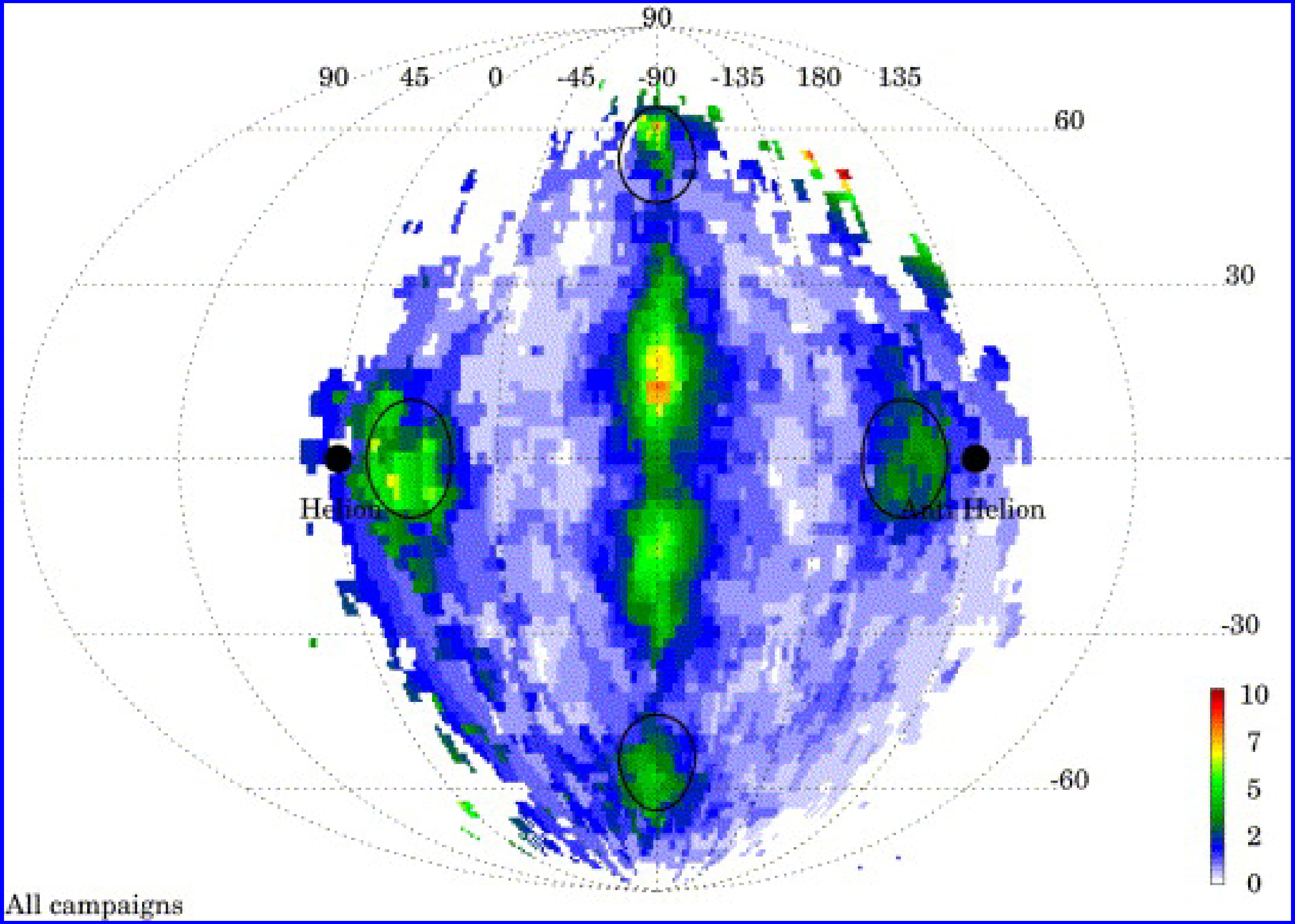
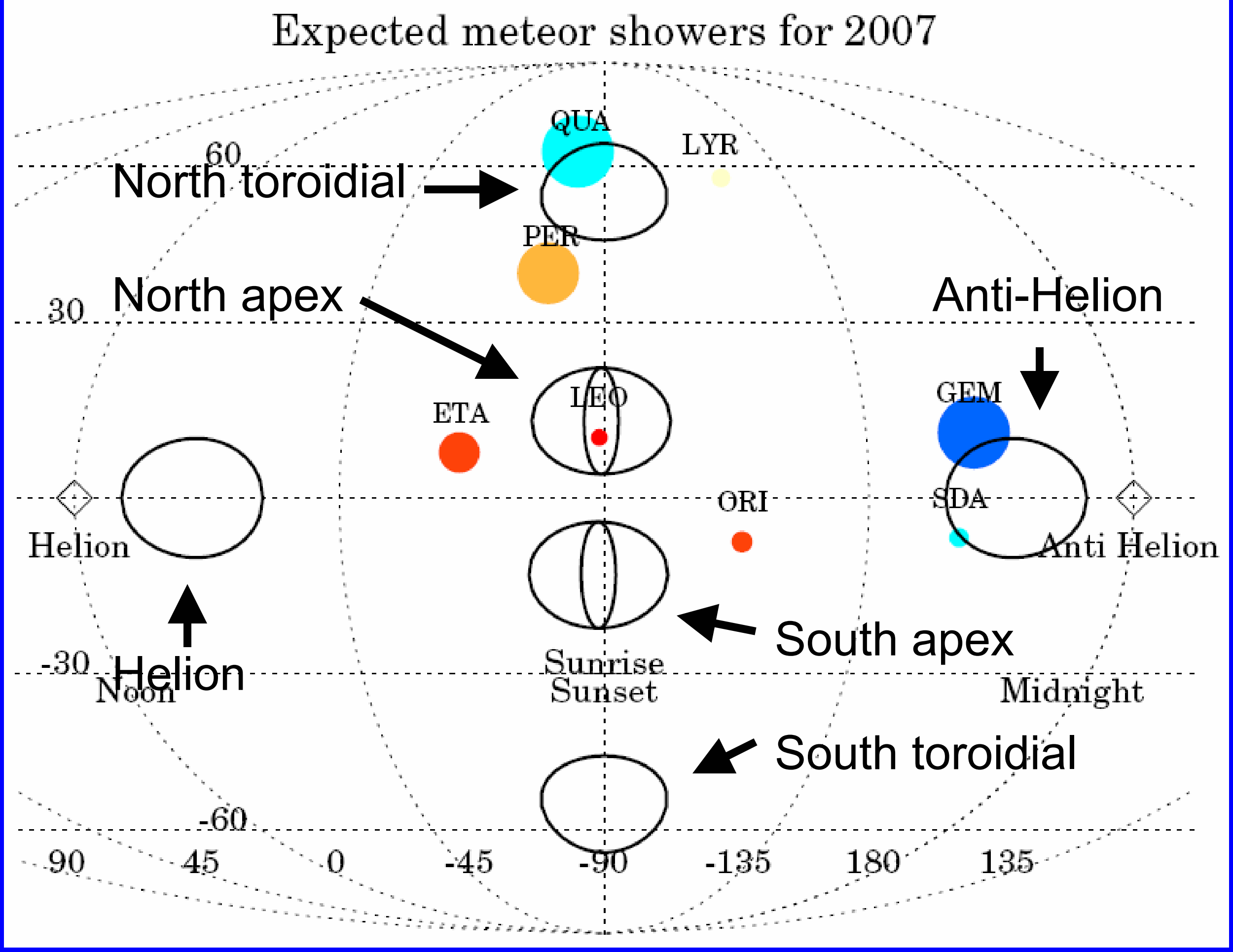


Figure 8 of Chau et al. (2007)

Schematic distribution of sporadic meteors



http://jro.igp.gob.pe/newsletter/200902/imagenes/news_meteor2.png

Meteors beyond Earth

- Sporadic meteoroids seen at Earth do <u>not</u> have uniform distribution of radiants
- Wiegert et al. (2009) showed that sporadic meteoroid distribution at Earth is dominated by debris from Encke and Tempel-Tuttle

- Do sporadic meteoroids at other planets have a uniform distribution of radiants?
- Are sporadic meteoroids at other planets predominantly produced by a small number of comets? Which comets?
- How does ratio of sporadic meteoroid mass flux to shower meteoroid mass flux vary from planet to planet?