Observations of the effects of meteors on the ionospheres of Venus, Earth and Mars

Paul Withers[1], A. A. Christou[2], M. Mendillo[1],
M. Pätzold[3], K. Peter[3], S. Tellmann[3], J. Vaubaillon[4]

1 – Boston University
2 – Armagh Observatory
3 – Department for Planetary Research, Cologne
4 – IMCCE, Observatoire de Paris
(withers@bu.edu)

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Observations of the effects of meteors on the ionospheres of Venus, Earth and Mars

- Observations
  - Earth
  - Venus
  - Mars
  - Comparison
- Some factors that affect metal ion layers
  - Meteor showers
  - Sporadic meteoroids
  - Magnetic fields and winds
- Status of theoretical simulations
- Unanswered questions

Metal ions on Earth

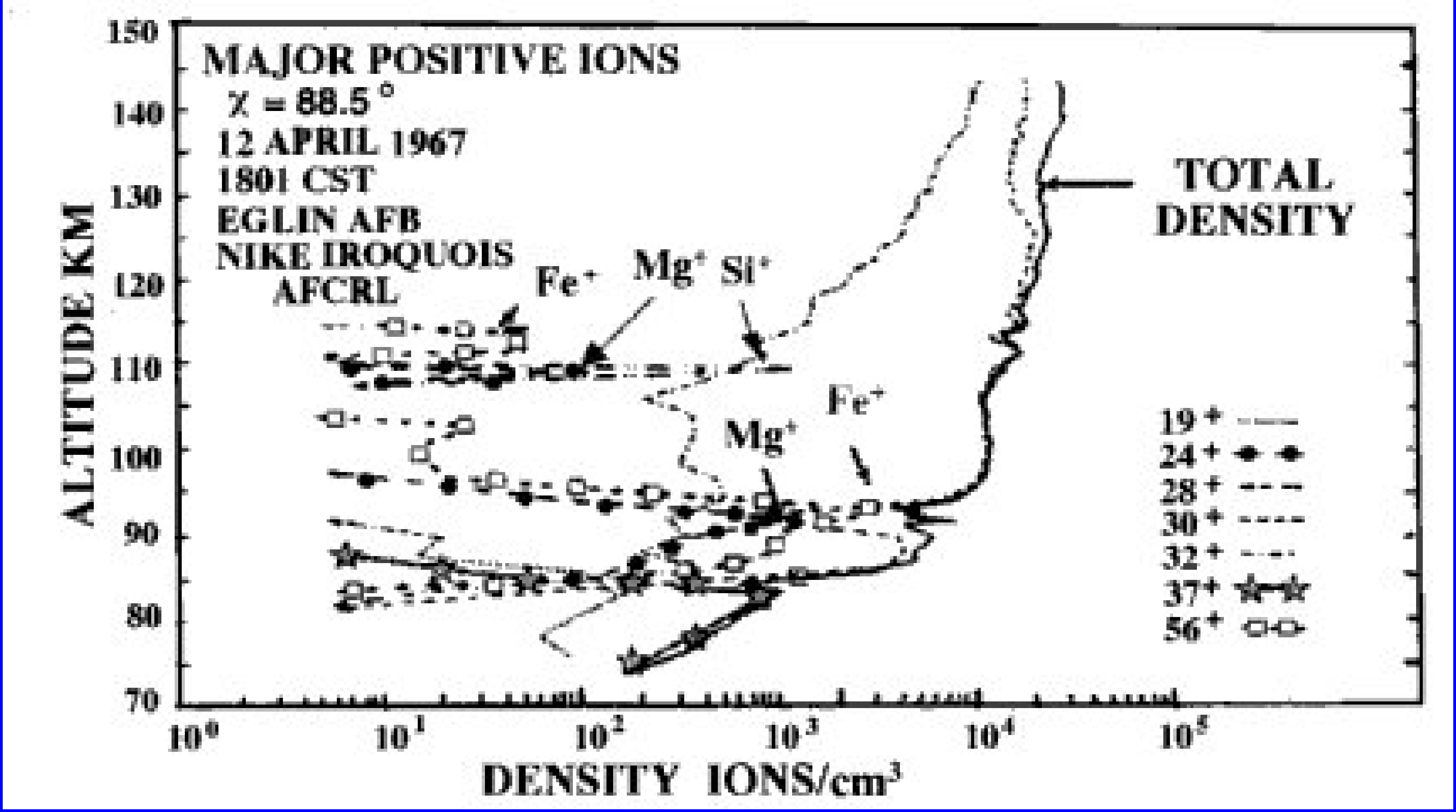


Figure 8.3 of Grebowsky and Aikin (2002)

Sporadic E on Earth

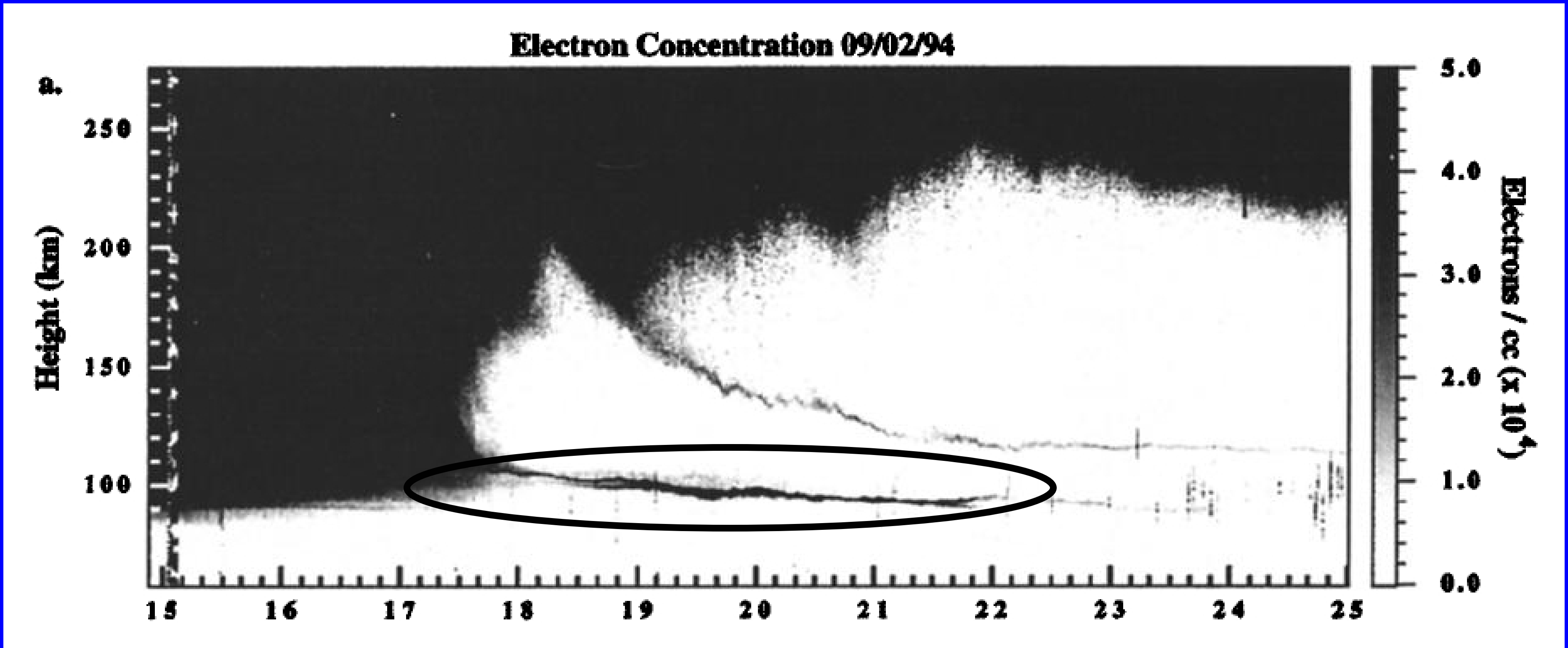


Figure 2a of Mathews et al. (1997)   Ionosonde data from Arecibo

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

Metal ion layer on Venus

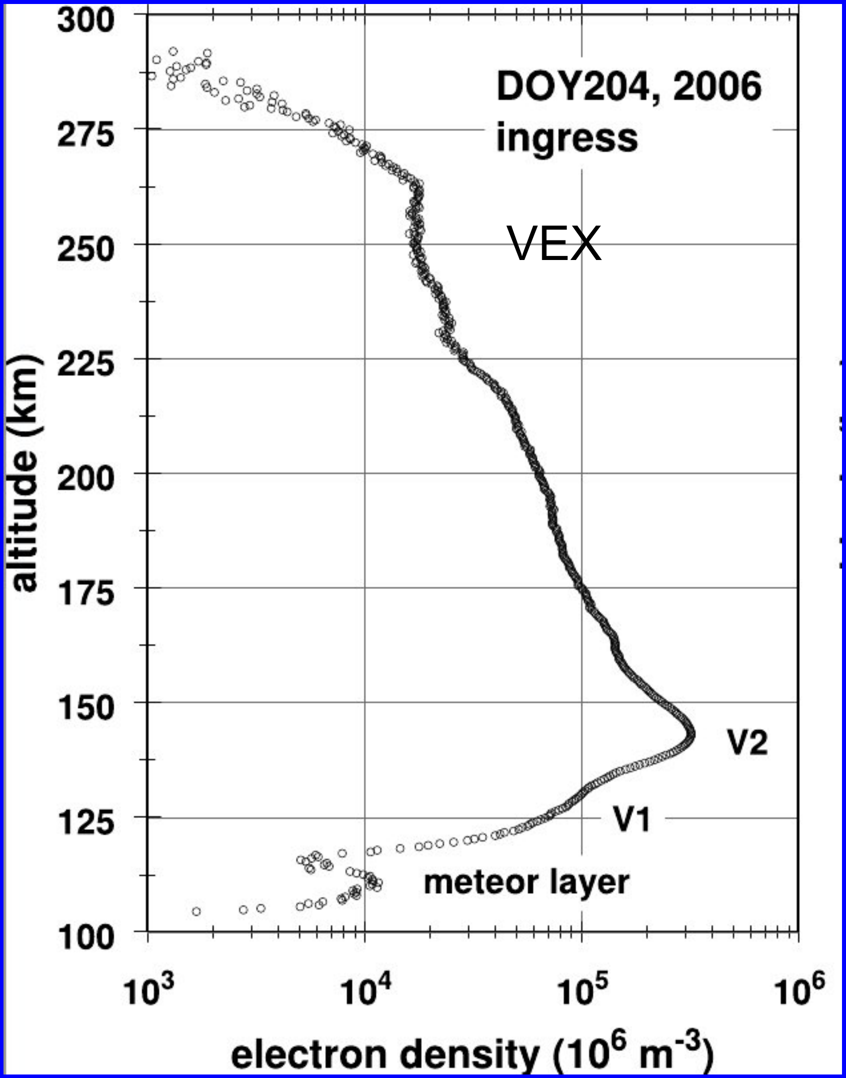


Figure 1 of Pätzold et al. (2009)

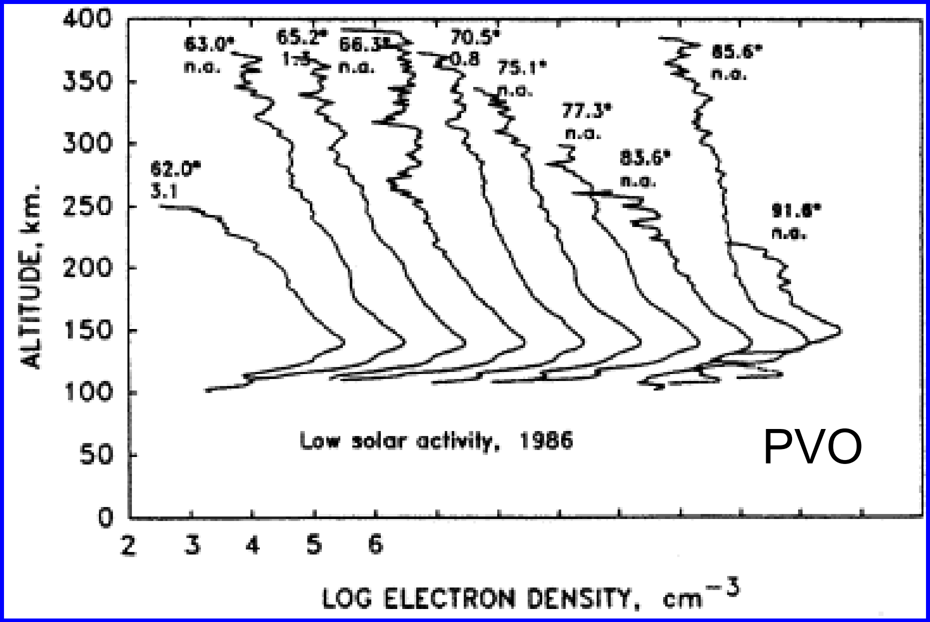
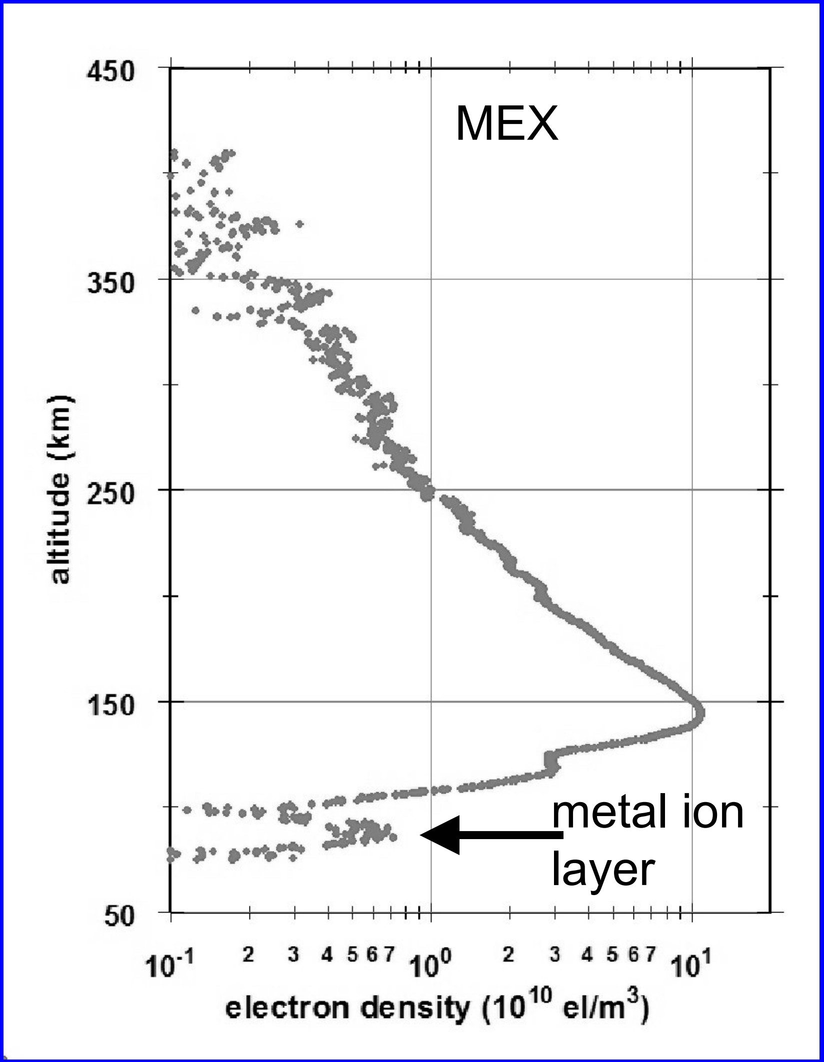


Figure 4 of Kliore (1992)

Candidate layers seen in 18 VEX VeRa profiles from SZA of 60^o to 90^o

Some double layers seen

Metal ion layer on Mars



Withers et al., in prep

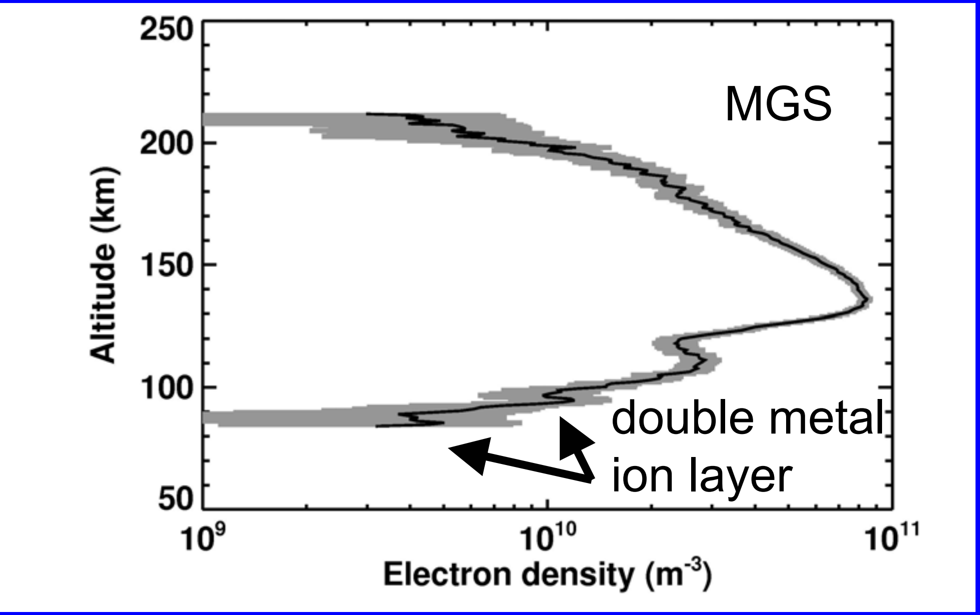


Figure 4 of Withers et al. (2008)

Candidate layers seen in 71 MGS profiles and 75 MEX profiles from SZA of 50^o to 90^o

Some double layers seen

Comparison of observations for Venus, Earth and Mars

Planet	Layering	N (m^{-3})	Height (km)	Width (km)	Pressure (Pa)	Density ($kg\ m^{-3}$)	Scale height (km)	Temp (K)
Venus	Mostly single, some double (radio occ)	1E10	109 – 117	5 – 10	0.1	4E-6	4	190
Earth	Many (rockets), single (Sporadic E)	1E9 (XX)	95 – 100	~2 (rockets)	0.03	5E-7	5	180
Mars	Mostly single, some double (radio occ)	1E10	87 – 97	5 – 15	0.01	5E-7	7	140

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

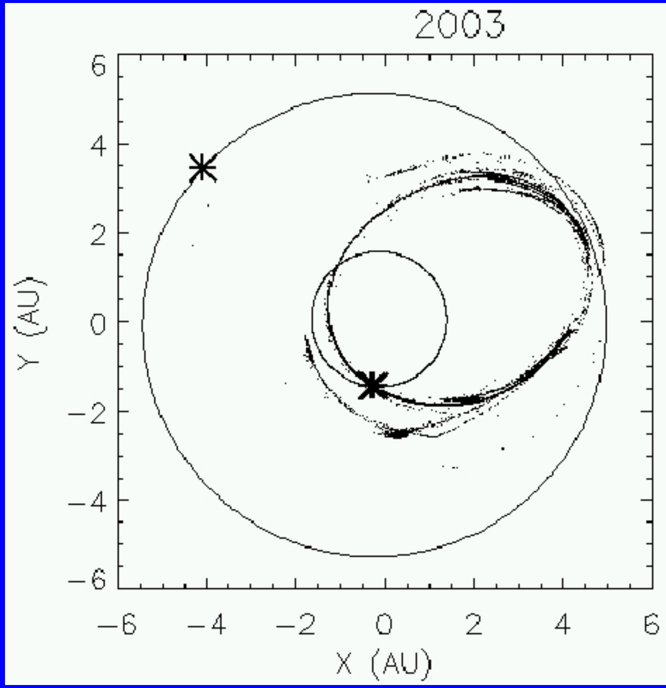
Earth – MSISE-90 model at 100 km for mean solar activities, averaged over local time, season, latitude
Taken from www.spenvis.oma.be/spenvis/ecss/ecss07/ecss07.html

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

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

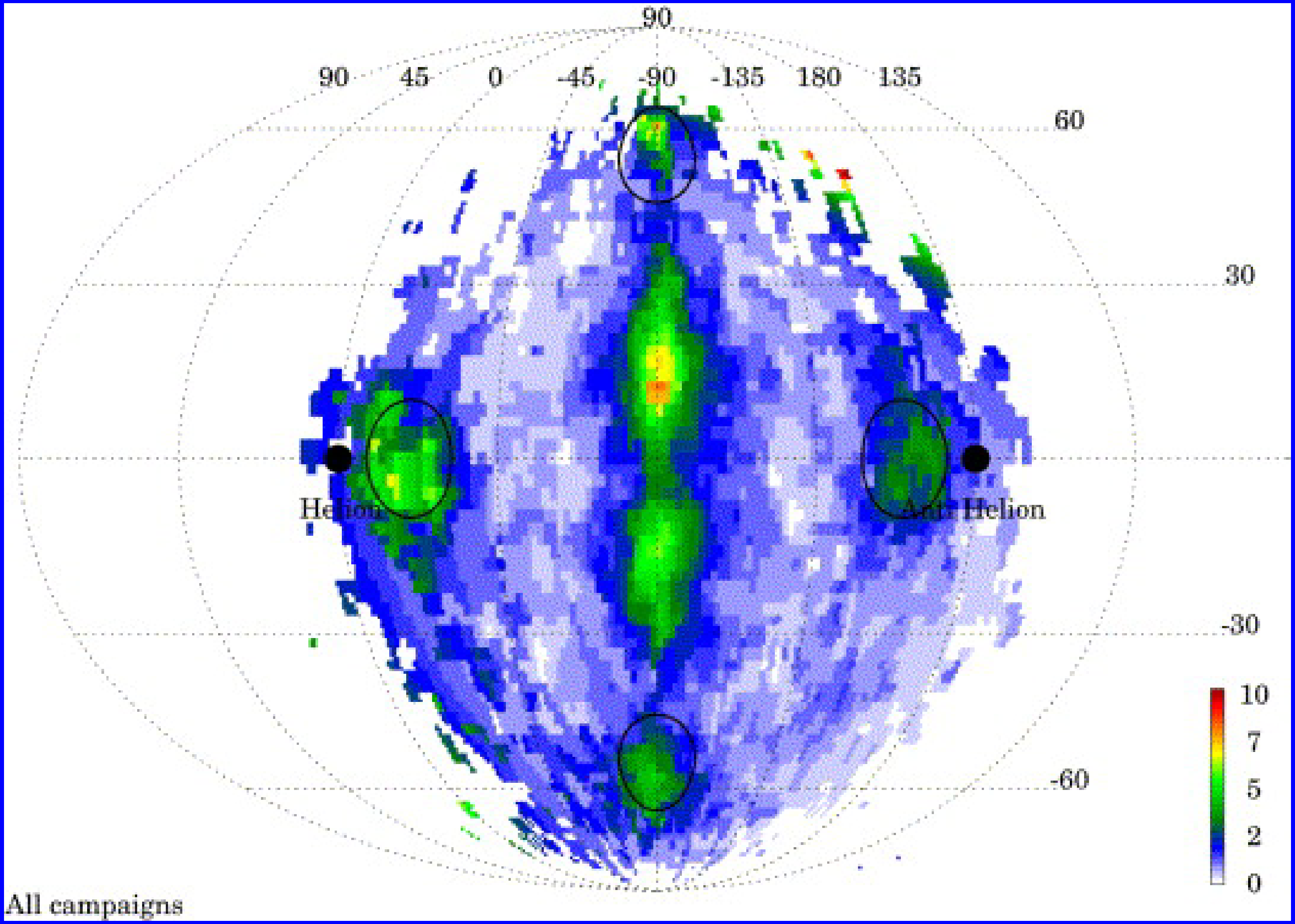
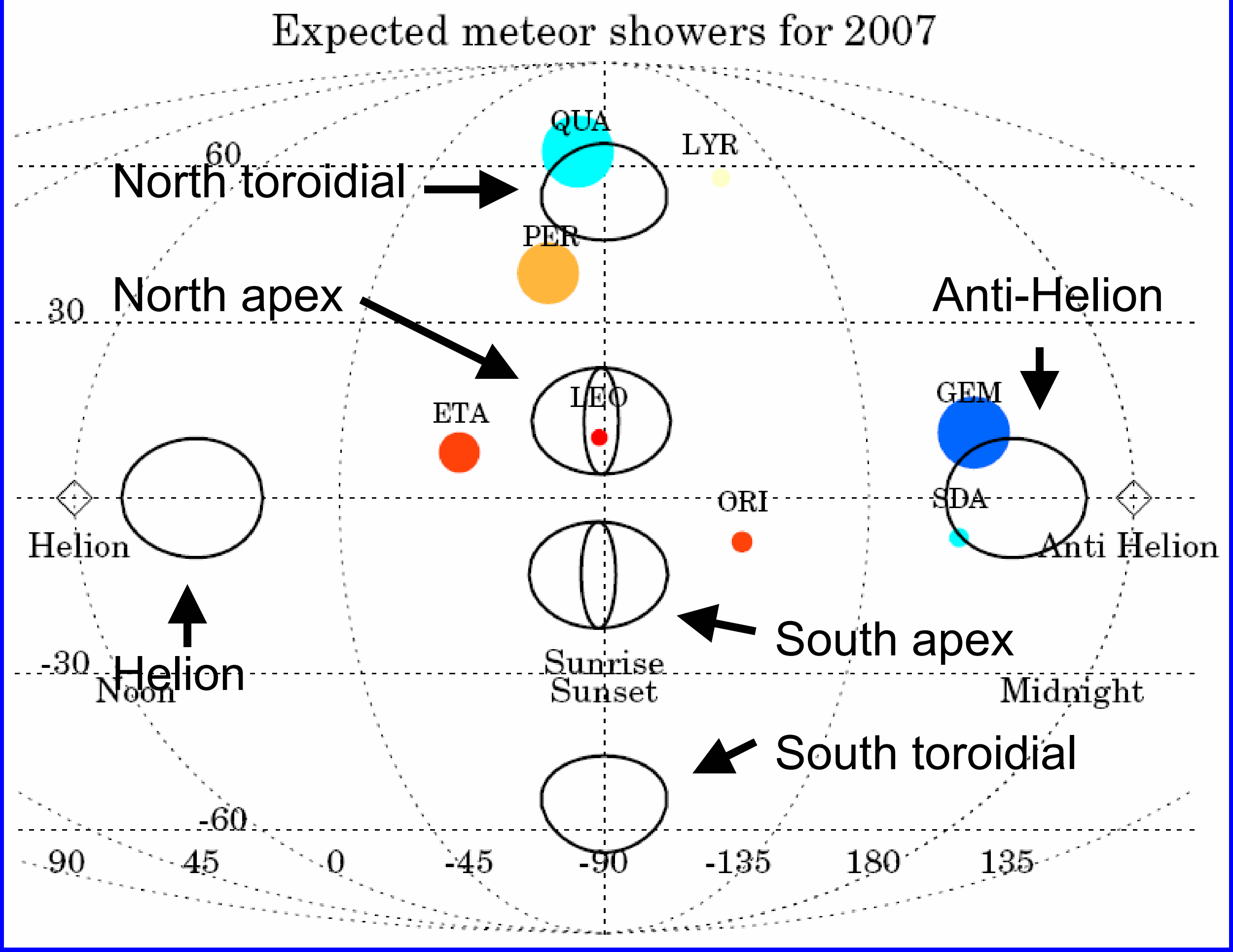


Figure 8 of Chau et al. (2007)

Schematic distribution of sporadic meteors



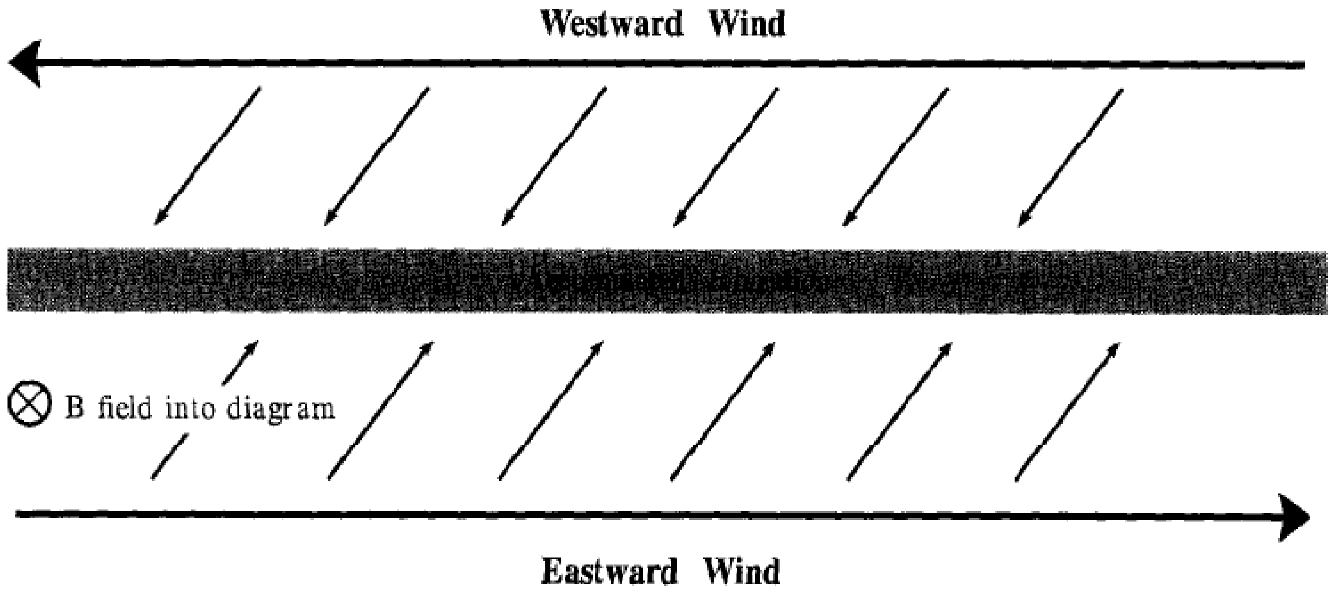
http://jro.igp.gob.pe/newsletter/200902/imagenes/news_meteor2.png

Meteors beyond Earth

- Sporadic meteoroids seen at Earth do not 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?

Magnetic fields and wind shear



1.) $0 = e(\mathbf{v}_i \times \boldsymbol{B} + \boldsymbol{E}) - M\nu_{in}(\mathbf{v}_i - \boldsymbol{V}_n)$	Steady-state ion momentum equation.
2.) $\mathbf{v}_i = (u, v, w)$; $\boldsymbol{V}_n = (U, V, 0)$	Ion and neutral velocity vectors in magnetic south, east, and upward directions.
3.) $\boldsymbol{B} = -B_0(\cos I, 0, \sin I)$	Magnetic field vector (dip angle I; magnitude B_0).
4.) $w = \dfrac{U\cos I \sin I + rV\cos I}{1 + r^2}$	Ion vertical speed for electric field $\boldsymbol{E}$=0.
5.) $r = \nu_{in}/\omega_{ci}$	Ratio of ion-neutral collision frequency (ν_{in}) to ion-cyclotron frequency ($\omega_{ci} = eB_0/M$) for an ion of mass M and electron-charge e.

Important for Sporadic E and metal ion layers on Earth
What about Venus (draped solar wind magnetic field) and Mars (localized crustal fields)?

Figure 1 of Mathews (1998)

Status of theoretical simulations

- Earth
  - Relatively sophisticated models, but geo-centric designs make transfer to other planets difficult
- Mars
  - Two groups have published one paper each
  - 1D model, steady-state, inappropriate conditions for comparison with available observations
  - Critical reaction rate estimated, assumed value is 80x smaller than subsequent laboratory measurements
- Venus
  - Nothing published
  - Several conference abstracts by one group, whose peak electron densities have grown from 10^7 to 10^9 m^{-3}

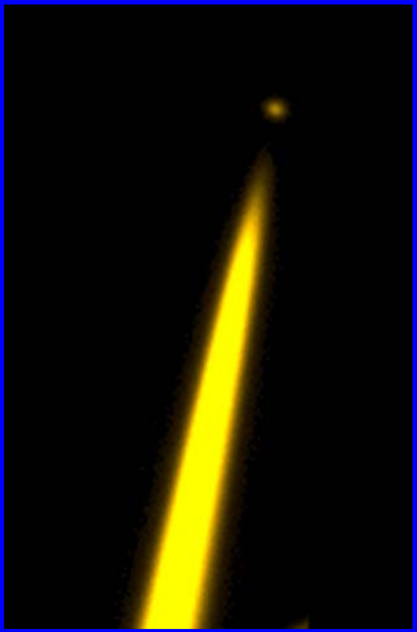
Unanswered questions

- What are the compositions of metal ion layers on Venus and Mars?
- How do different magnetic environments affect the formation of metal ion layers?
- How do fluxes of shower and sporadic meteoroids vary with heliocentric distance?
- What properties and processes control temporal and spatial variations in the physical characteristics of metal ion layers?
- Can a single physics-based model successfully simulate metal ion layers on Venus, Earth and Mars?

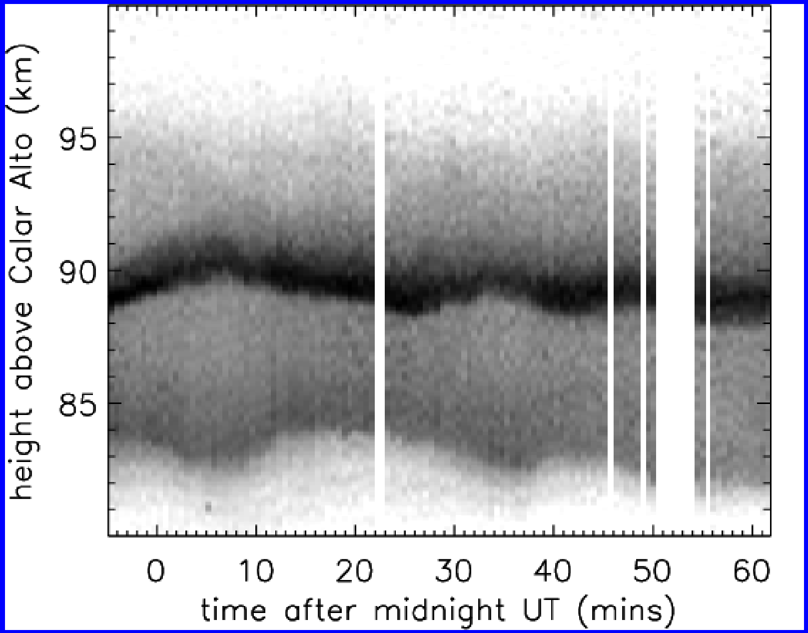
Backup

Meteors and metals in the atmosphere

1966 Leonids, New Mexico



Artificial guide star produced by 589 nm laser



Number density of Na measured by lidar at 589 nm

(Left) http://leonid.arc.nasa.gov/1966.gif
(Centre) http://www.ing.iac.es/PR/newsletter/news2/lsg3.jpg
(Right) Figure 6 of Butler et al. (2003)

Metal ion layers beyond Earth?

- Meteoroids – all planets
- Dominant short-lived (molecular) ions – all planets
- Magnetic field – some planets

- Problem – Available data from radio occultations show electron density, not ion composition.
  - Direct evidence for metal ions impossible

Metal chemistry

- Produce Mg^+ (used here as representative metal species)
  - Directly during ablation
  - Photoionize neutral Mg
  - Neutral Mg charge-exchanges with short-lived molecular ion to form longer-lived atomic ion

- Rate of $Mg^+ + e \rightarrow Mg + h\nu$ is very slow
- Main pathway for loss of metal ions is
  - $Mg^+ + 2X \rightarrow Mg^+.X + X$
  - $Mg^+.X + e \rightarrow Mg + X$

- Three body reaction with two neutrals is often rate-limiting step, proceeds much faster at lower altitudes, so vertical transport of metal ions will be important
- Relevant reaction rate coefficients are poorly known
- Lifetimes ~ days