Update on Venus Lightning from Observations on PVO and Galileo

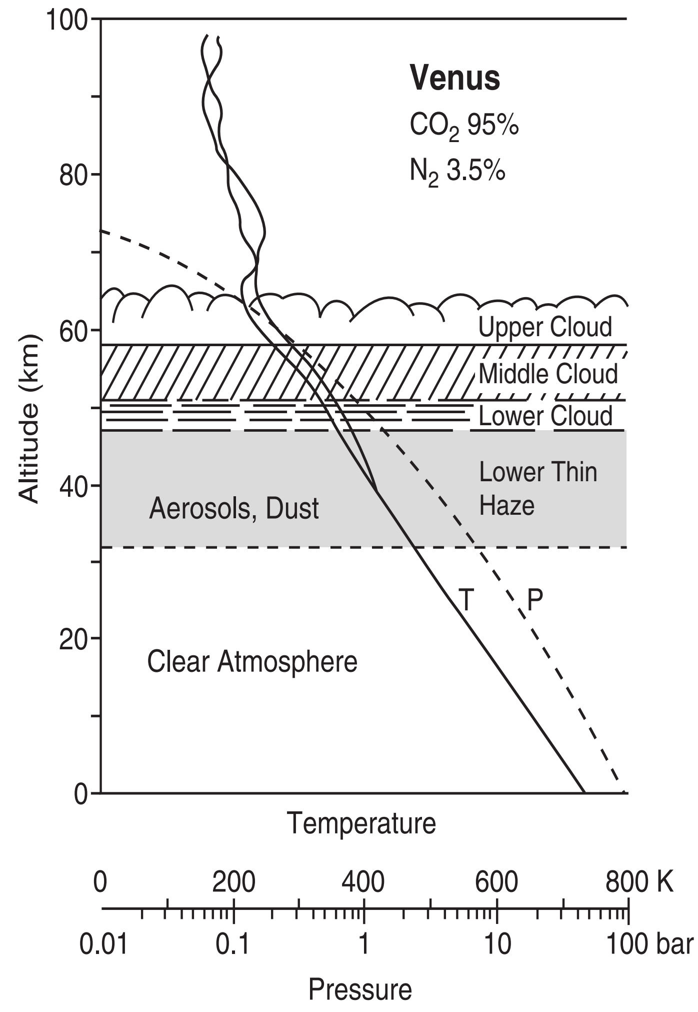
R. J. Strangeway (IGPP/UCLA)
Acknowledgement: C. T. Russell

Outline

- Overview – Venus Atmosphere.
- Lightning pro and con.
- Optical and electromagnetic wave evidence for lightning.
- Cassini and non-evidence for lightning.
- Pioneer Venus Orbiter – whistler-mode emissions.
- Predictions for Venus Express.
- Summary and Conclusions.

The Venus Atmosphere

- Venus' atmosphere differs greatly from that of the Earth. Principally CO_2 (95%) some N_2(3.5%), with a surface pressure of close to 100 bars and a temperature of close to 730K
- The lower atmosphere is clear. The temperature and pressure in the middle cloud are almost Earth like, about 315K and 0.5 bar
- The cloud particles are thought to be H_2SO_4 droplets that like water can be charged. Thus lightning could occur if convection sustained large potential differences within the clouds



Lightning – Issues

Pro:

Venera observations in atmosphere [Krasnopol'sky, Venus, 1983; Ksanfomality et al., Venus, 1983].

Pioneer Venus observations of whistler-mode and broadband emissions [see, e.g., Russell, Space Sci. Rev., 1991].

Venera 9 and Univ. Arizona observations of optical emissions [Grebowsky et al., Venus II, 1997].

Con:

Lack of other confirming visible observations.

Cassini Venus fly-by observations [Gurnett et al., Nature, 2001] (but c.f. Galileo [Gurnett et al., Science, 1991]).

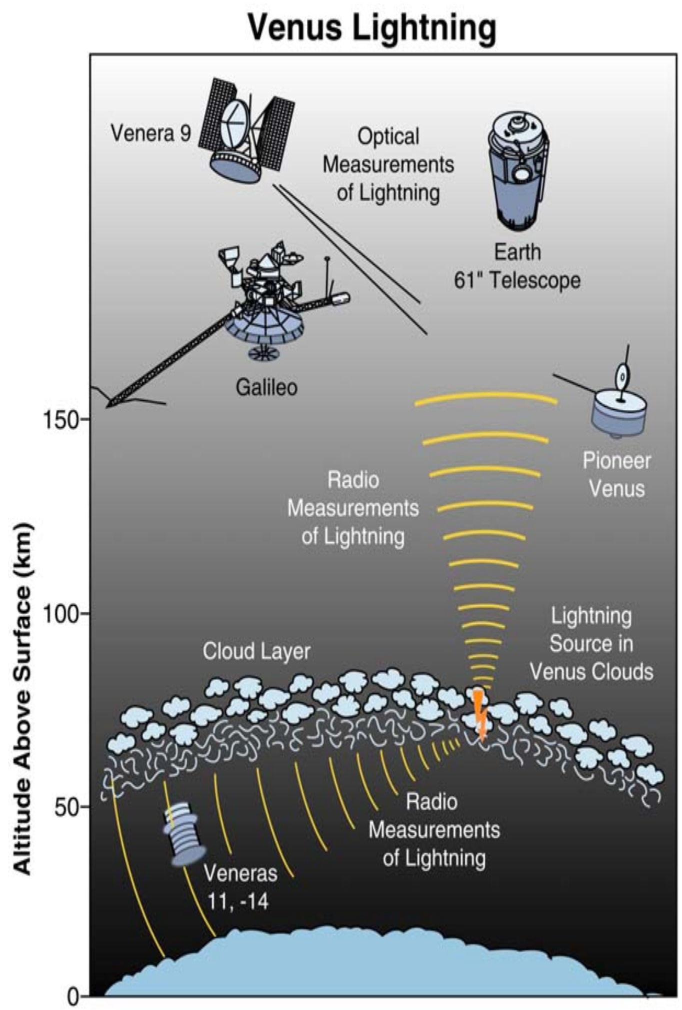
Joule dissipation of whistler-mode waves in lower ionosphere [Cole and Hoegy, JGR, 1996].

Successful Searches for Lightning at Venus

- Atmospheric electricity studies have frequently been the focus of controversy and Venus lightning is no exception. Lightning processes are poorly understood, especially in exotic settings.

- Lightning is most often studied by detecting electromagnetic waves produced by the current surge associated with sudden charge transfer. Such surges also produce heat, light and sound.

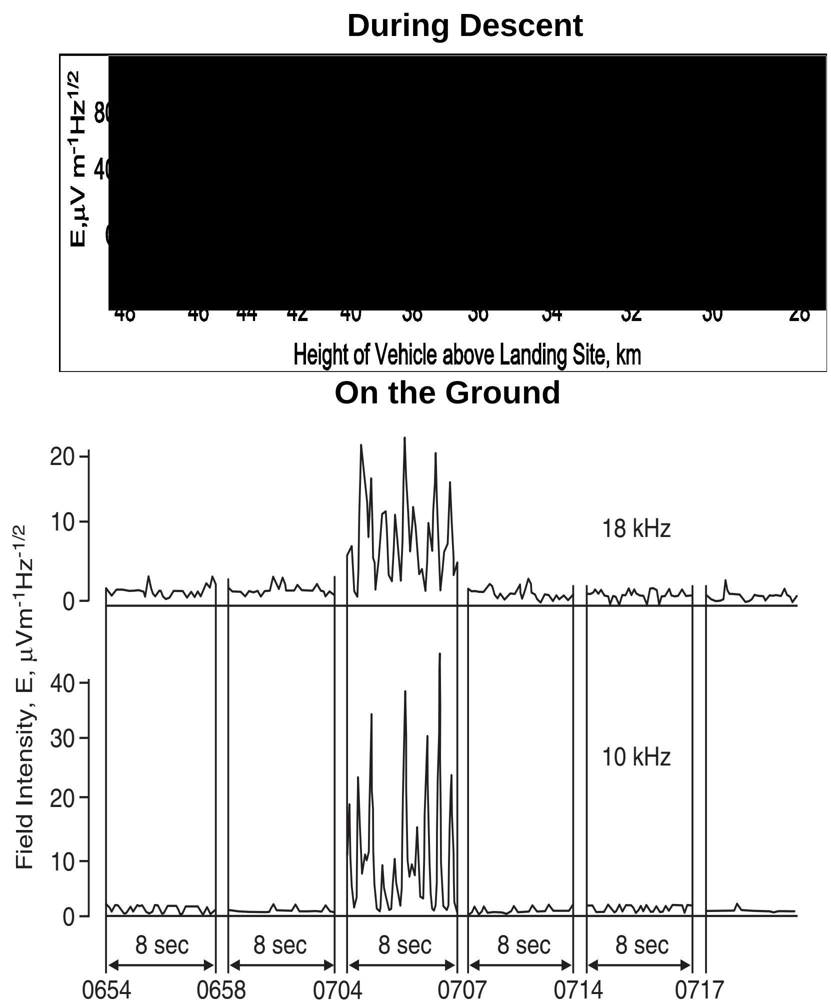
- Electromagnetic waves have been detected both above and below the ionosphere. Lightning has been reported from Venus orbit and from Earth.



Venera 11-14 Landers Detected E-M Waves

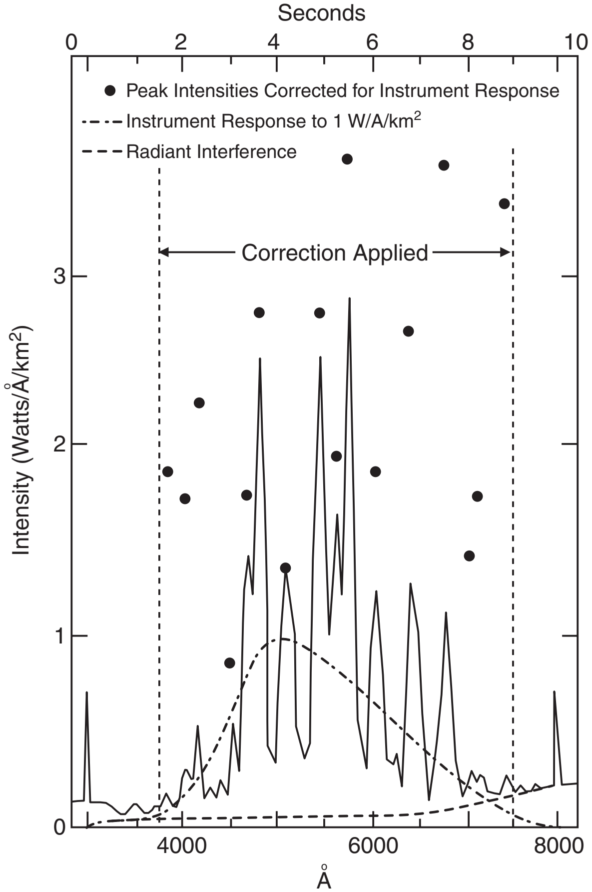
- Venera 11-14 landers were equipped with search coil magnetometers that are usually quite unaffected by spacecraft noise.

- The Venera landers saw noise bursts consistent with lightning discharges both during descent and on the ground.

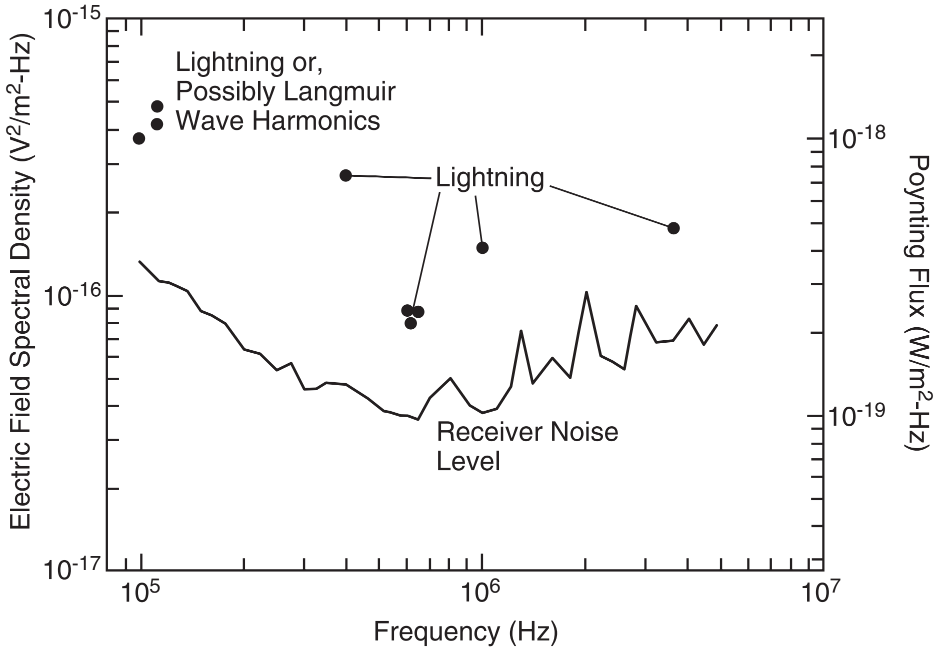


Optical and Radio Measurements

Optical measurements from Venera 9



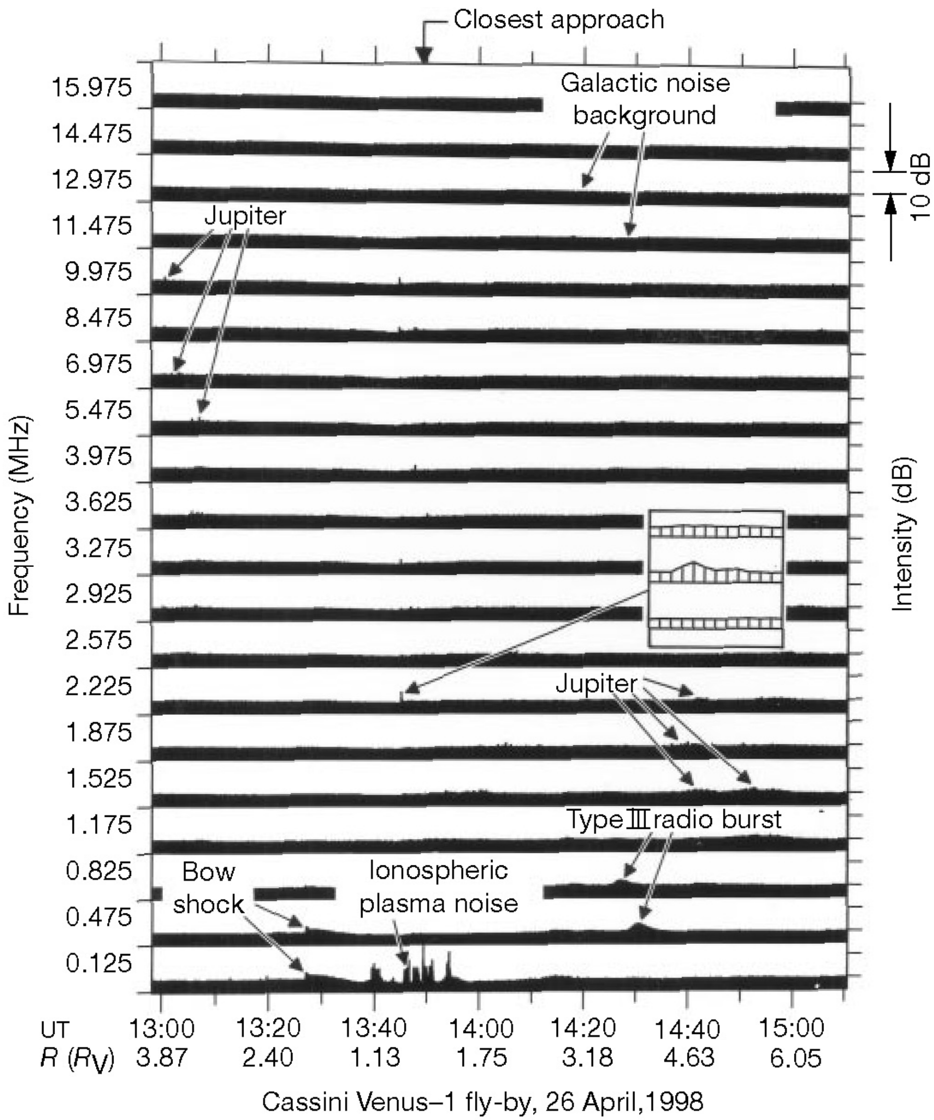
Radio Wave Measurement from Galileo



- From orbit the Venera 9 saw a potential lightning storm. Flash intensity varied as instrument scanned over visible range.

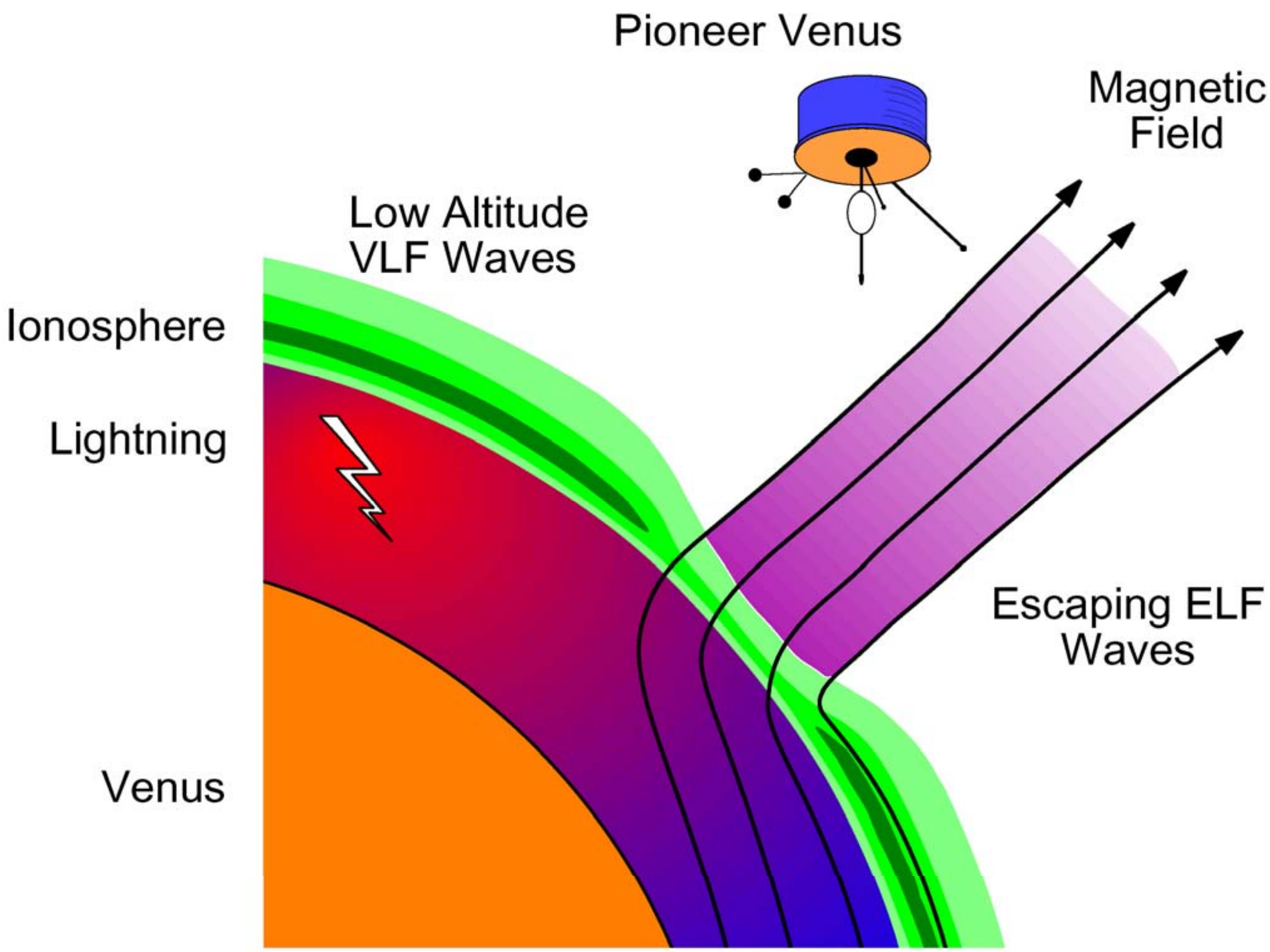
- On its flyby Galileo detected radio sferics symptomatic of lightning.
- Cassini also saw bursts but Gurnett chose not to interpret the bursts as lightning.

Cassini Observations



- From Gurnett et al., Nature, 2001.
- Gurnett argued that the bursts detected near Venus were not due to terrestrial-like cloud to ground lightning – too weak and too infrequent.
- Allowed for possible cloud to cloud or cloud to ionosphere lightning, albeit reluctantly.

Lightning Hypothesis



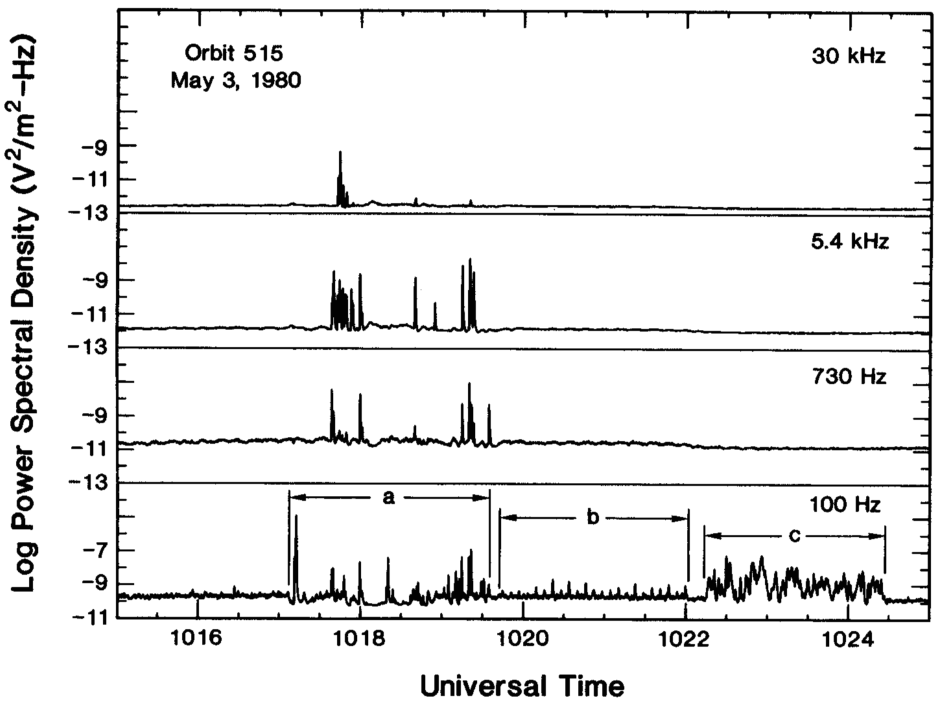
Pioneer Venus Orbiter Measured the Electric Component of Lighting

- Three types of signals were observed in night ionosphere:

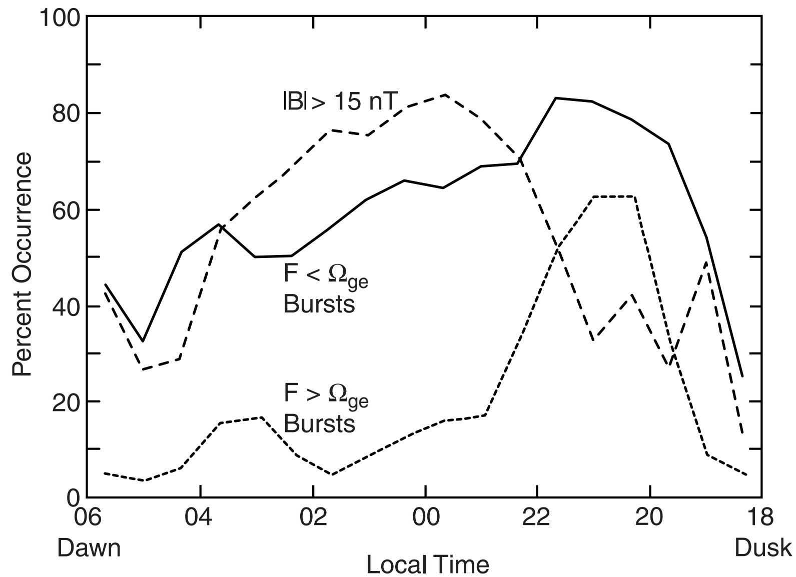
  a. Broadband signals rapidly attenuating with altitude.
  b. Interference, easily distinguishable from natural signal.
  c. Whistler mode signals below the electron gyro frequency with little attenuation with altitude.

- Both broadband noise and whistler mode noise were consistent with a single source, the different bandwidth coming from the propagation to PVO.

Typical Nightside Signals

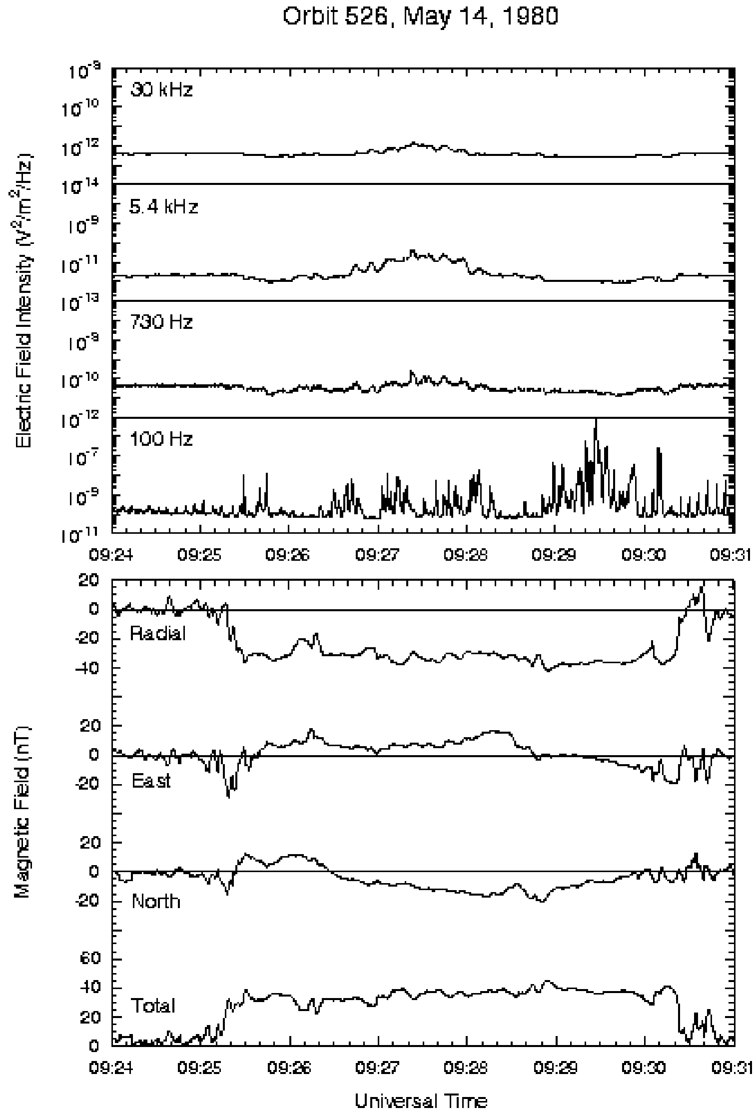


PVO Local Time Distribution

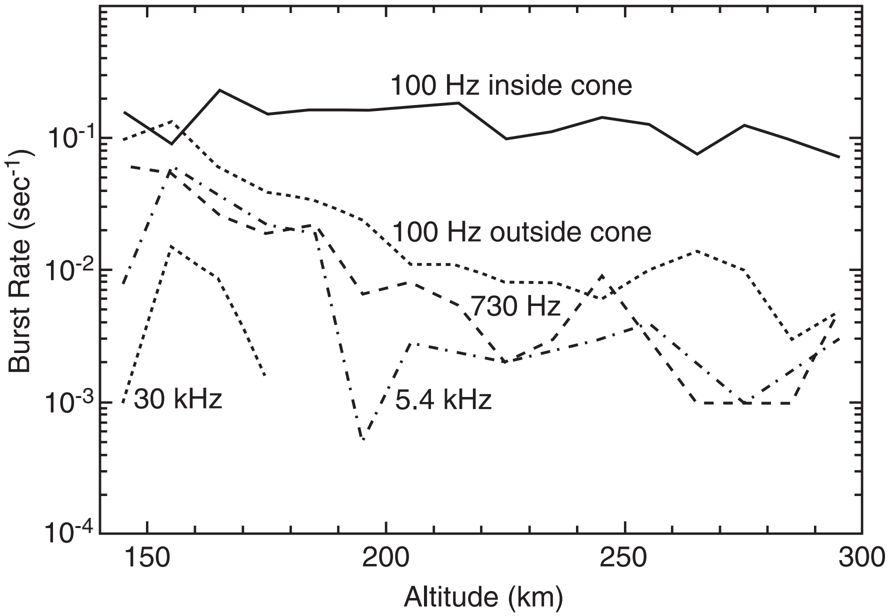


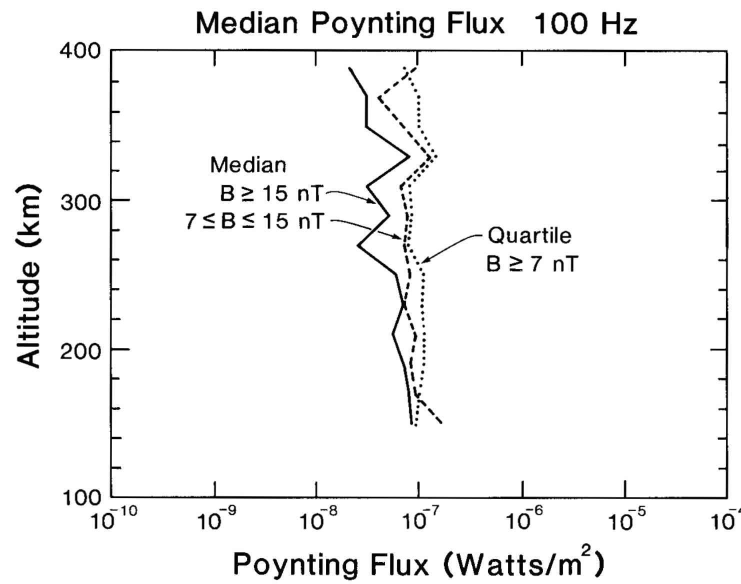
- Both types of signals identified as lightning arose more often near dusk than near dawn.
- Local time distribution was not a reflection of plasma properties.

PVO – 100 Hz Inside Ionospheric Hole



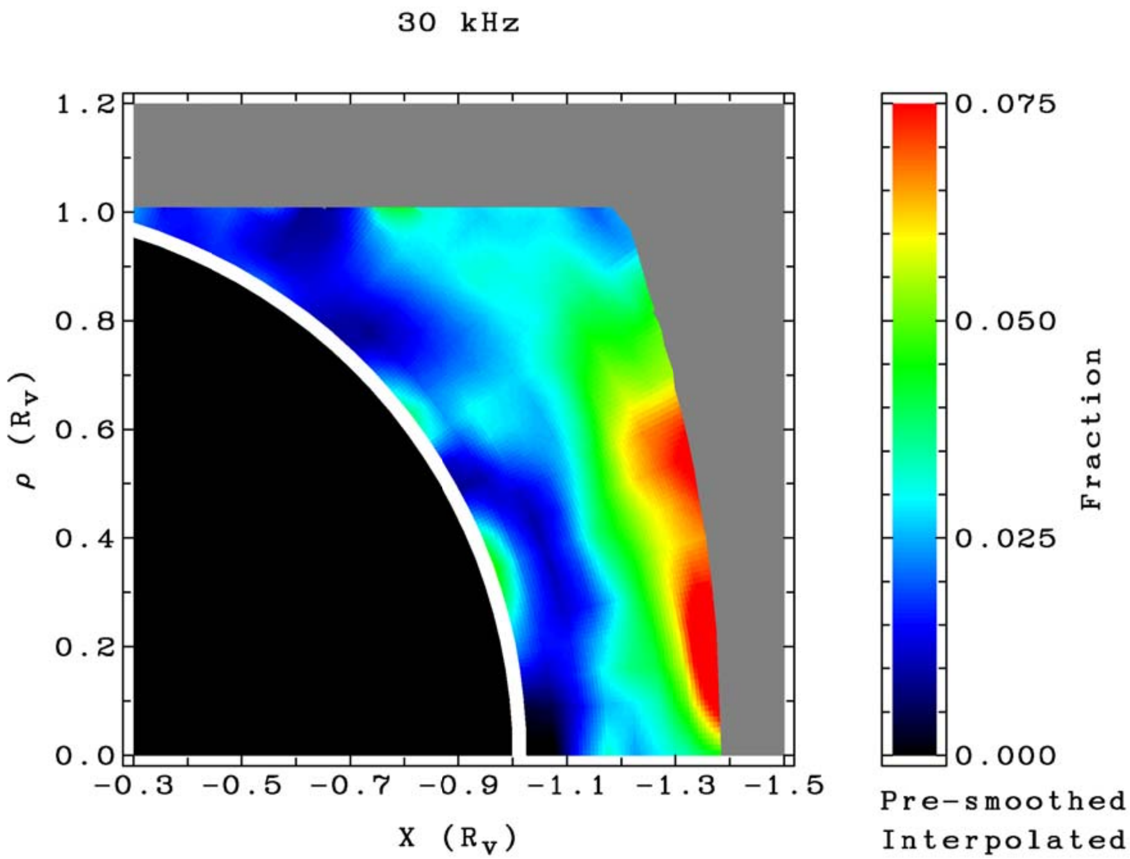
Altitude Dependence of PVO Signals





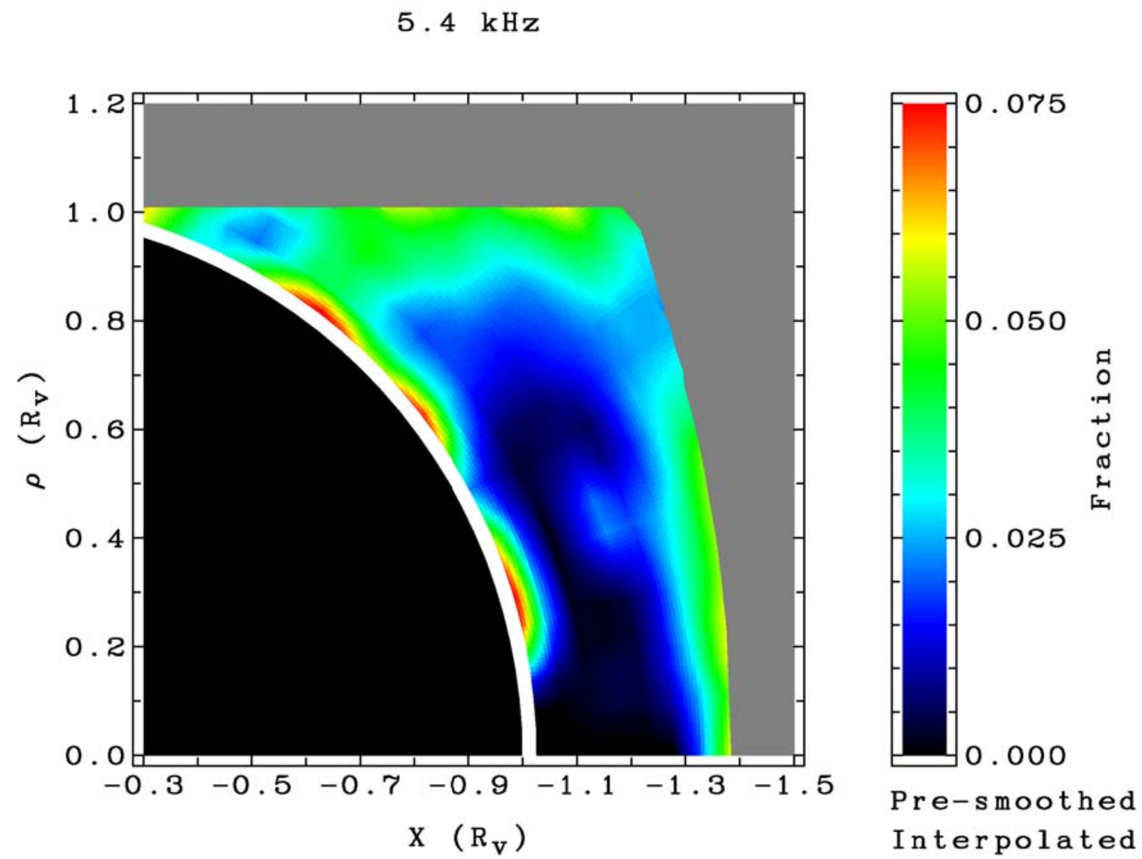
- Whistler mode should propagate vertically above the ionosphere (atmospheric refraction). Thus, the propagation cone can be calculated from the magnetic field direction and strength.
- Inside propagation cone whistler mode burst rates do not vary with altitude. Non-whistler mode frequencies do vary rapidly.
- Poynting flux can be estimated from electric field amplitude and plasma conditions.
- Poynting flux is nearly constant with altitude, decreasing slowly.

Nightside Maps – 30 kHz

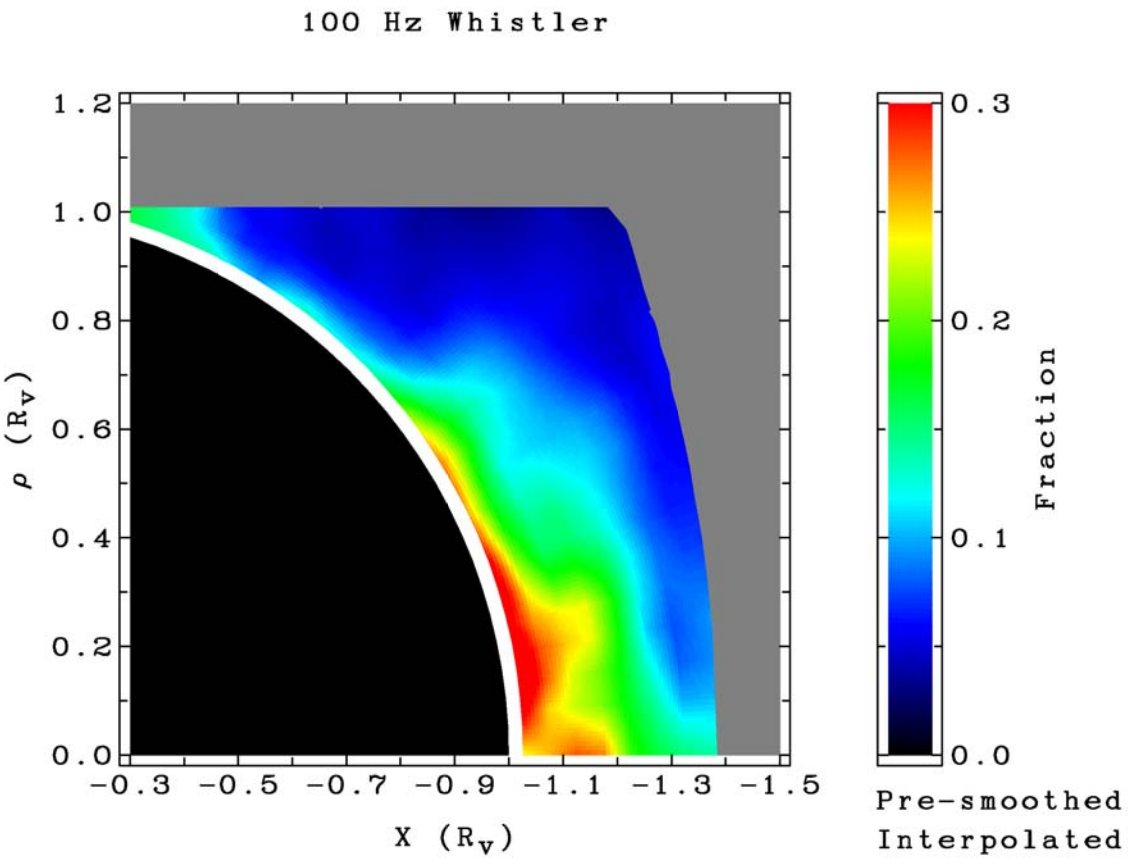


Based on results of Ho et al., P&SS, 1994.

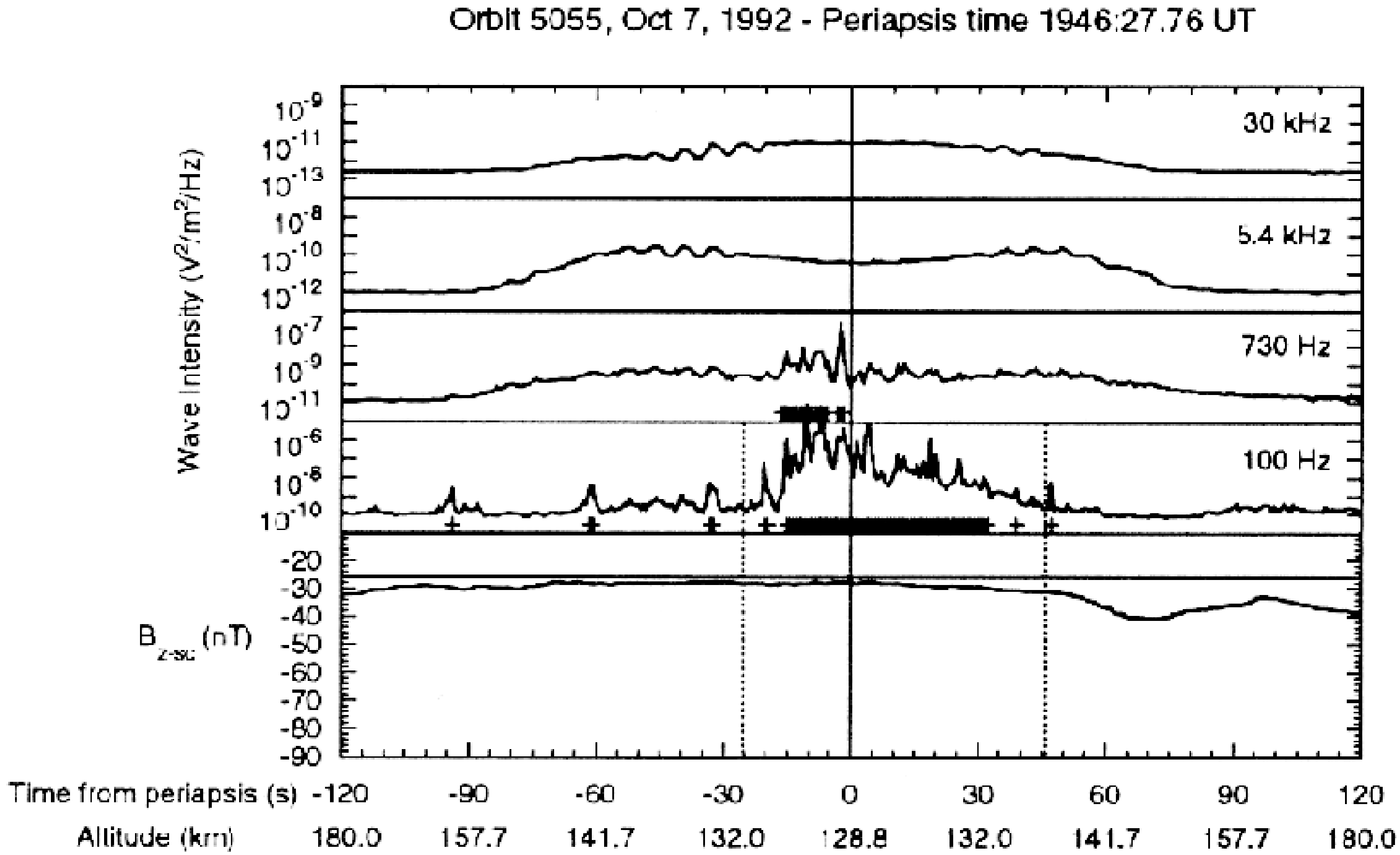
Nightside Maps – 5.4 kHz



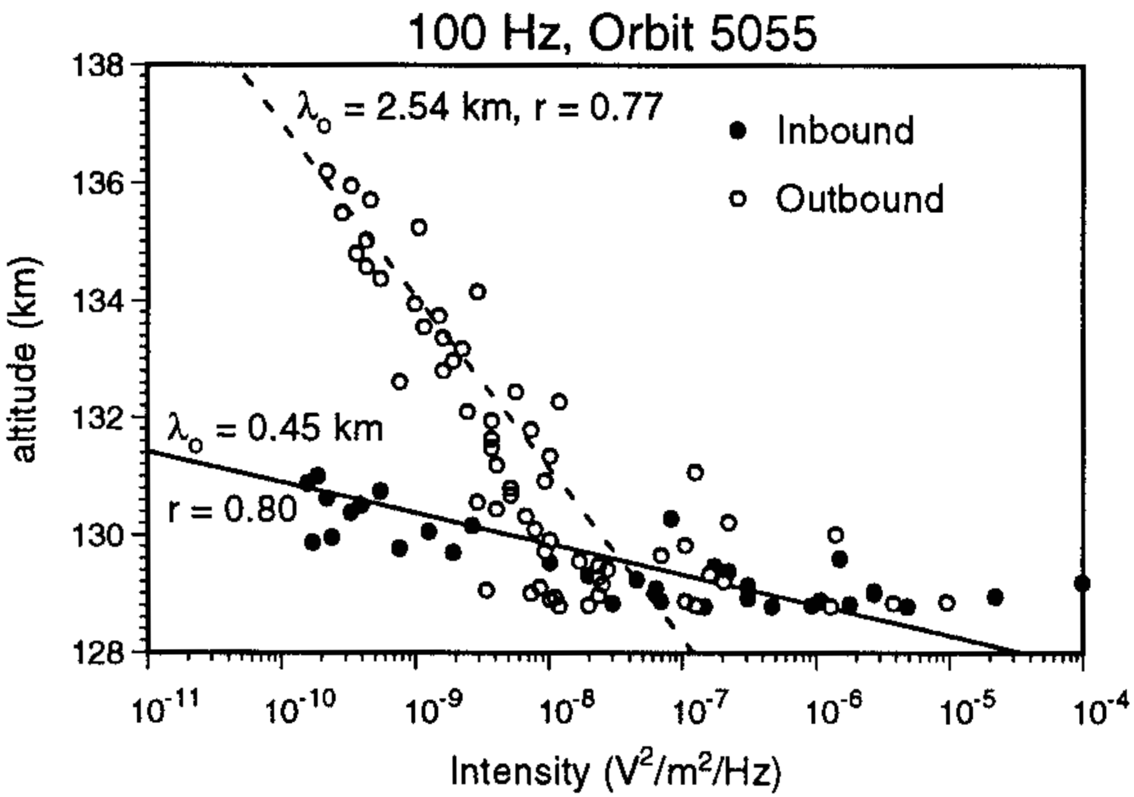
Nightside Maps – 100 Hz Whistler



PVO Entry Phase – Below Ionosphere?



PVO Entry Phase



- On final orbits of PVO when it was entering the atmosphere, measurements were made just below the atmosphere.
- Electric field observations climbed to large values as they should in free spaces as wave phase speed approached speed of light. Median Poynting flux below 129 km was same as above the ionosphere.
- Attenuation scales consistent with propagation through the collisional ionosphere.

Evidence for Whistler Mode

100 Hz wave Poynting flux decreases slowly with altitude [Russell et al., GRL, 1989].

Waves restricted to whistler-mode resonance cone for vertical propagation are polarized perpendicular to the ambient field [Strangeway, JGR, 1991].

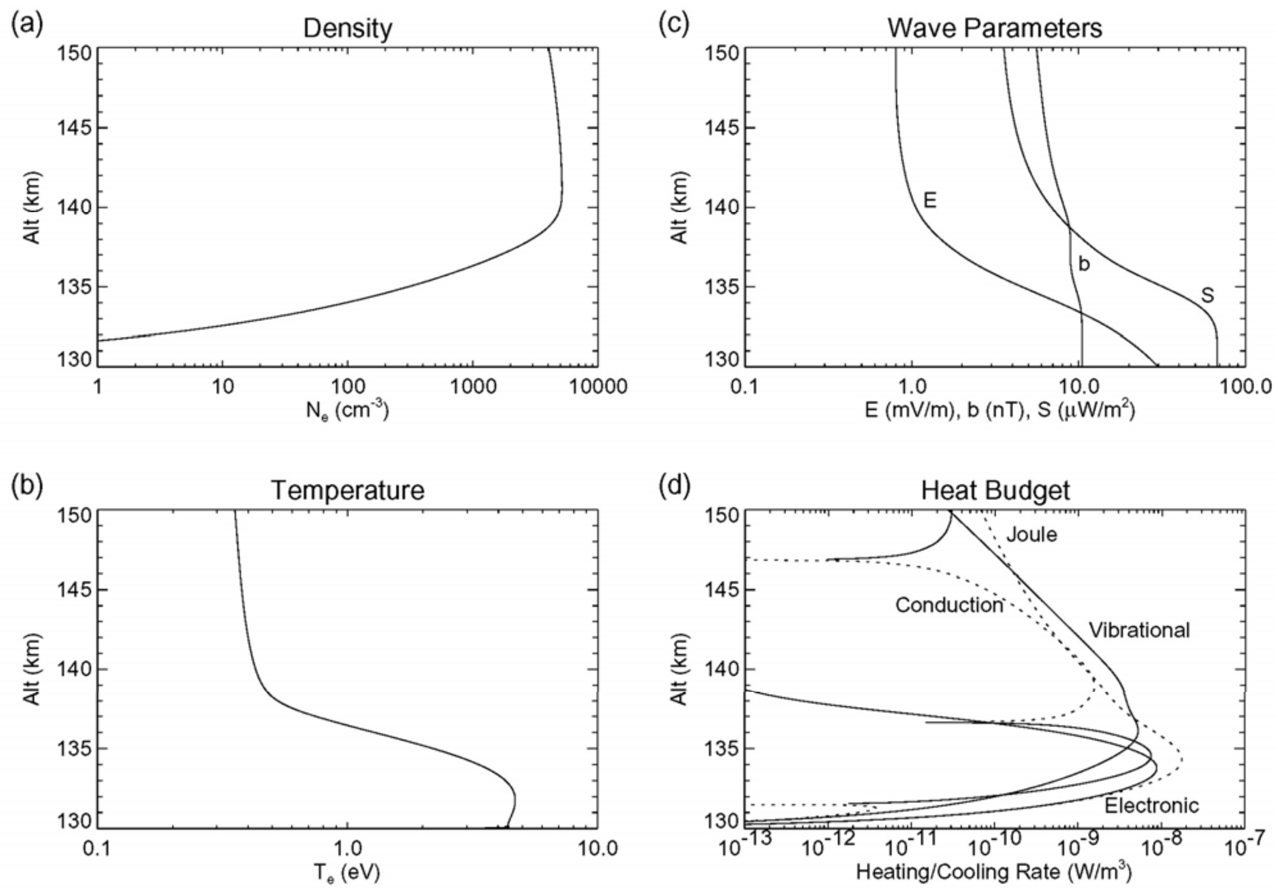
Burst rates highest for vertical magnetic fields [Ho et al., JGR, 1992].

Waves occur for low electron beta [Strangeway, JGR, 1992].

Issues with whistler-mode identification:

- Joule dissipation [Cole and Hoegy, JGR, 1996; Strangeway, 1996].
- Non-linear dispersion [Cole and Hoegy, JGR, 1997], but see Strangeway [JGR, 1997] and Strangeway [Adv. Space Res., 2000]. Wave magnetic fields can be comparable with ambient field – BUT this is why VEX can detect EM lightning signals.

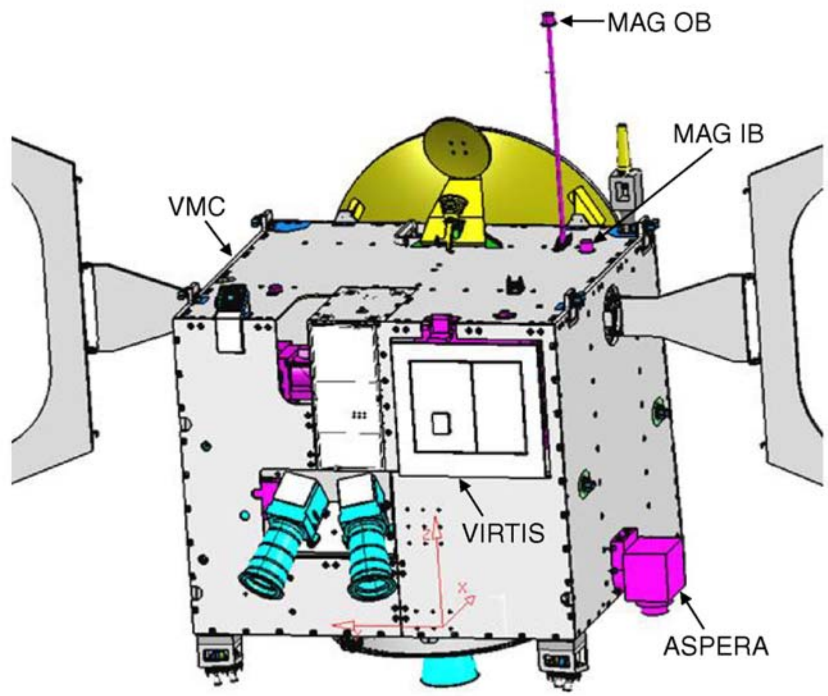
Joule Dissipation



From Strangeway, Adv. Space Res., 2000.

What will Venus Express See?

- Venus Express carries two fluxgate sensors each capable of 128 vectors per second (64 Hz Nyquist frequency).
- The estimated signal strength is well above the noise threshold of these sensors: For μ = 1000, expect signals of order 1 - 10 nT over the bandwidth of the instrument.
- The access of lightning signals to the spacecraft will be modulated by the direction of the magnetic field and the local time of periapsis. Access will also be affected by the presence or absence of ionospheric holes.
- Optical instruments should also detect lightning on the night side: Venus Monitoring Camera (365nm, 935nm, 1010nm) and VIRTIS.
- Optical flashes should be much more frequent near dusk.



Summary and Conclusions

- Atmospheric electricity is a complex phenomenon and at best only poorly understood on Earth.
- Venus lightning contains all the complexity and ambiguity of its terrestrial counterpart and its study was compounded by several intense personal rivalries.
- Evidence for lightning comes from electromagnetic waves above and below the ionosphere; from low frequency and high frequency components, from optical observations in orbit and from Earth.
- The behavior of the signals is consistent with lightning emissions in Venus’ sulfuric acid clouds and propagation (for the EM waves) upward through the ionosphere.
- We expect that Venus Express will detect lightning both optically and electromagnetically.