Venus' Upper Atmosphere: Before and After Venus Express
Early lightning detections: Venera

- Venera 9 visible spectrometer detected flashes (Krasnopolsky, 1983).
- Extremely low frequency (ELF) detectors on Venera 11 and 12.
- Temporally varying signal along similar trajectories suggest lightning.
- Venera 13 and 14 made similar detections and also found no coronal discharge.

Ksanfomaliti et al. 1983
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Early lightning detections: Pioneer

- ELF signals detected near 130km in altitude during Pioneer's last orbit.
- Non-symmetric about periapsis, indicates it is not due to collisions

Strangeway et al. (1993)
Early lightning detections: Galileo

- Galileo had a Venus flyby in February of 1990.
- Much more suited for plasma radio observations.
- Several low frequency bursts, with strength, occurrence rate, and spectrum characteristic of terrestrial lightning, originally observed by Gurnett et al. (1991).

Russell (1995)
Mechanism

- Cloud layer is too far from ground for cloud to ground discharges.
- Early work found the signals were concentrated near Phoebe, Beta, and Alta, potential sources of volcanic activity (Scarf and Russell, 1983). Later work, however, showed little geographical correlation (Russell et al., 1988).
- Intra-cloud discharge with electrified sulfuric acid is the most likely candidate.
- The method of charge separation is not fully solved, but ionization by cosmic rays is a suggested mechanism (Wilson, 1929; Russell et al., 1980; Phillips and Russell, 1987).

http://apod.nasa.gov/apod/ap140420.html

Taylor et al. (1987)
Recent evidence

- Absorption seen near 1853.742 cm\(^{-1}\) NO line.

- Krasnopol'sky (2006) argues that lightning is the only potential source of NO with flash energies of \(10^9\) J.

Krasnopol'sky (2006)
Recent evidence

- The dual fluxgate magnetometer on Venus Express (MAG) detected frequent ELF signals throughout its mission (Hart et al., 2015). The majority were observed at 250 km.

Hart et al. (2015)
Remaining issues

- More data is required to create a spatial map of the storms. Hopefully Akatsuki allows this.
- Lightning could cause significant heating in the atmosphere (Strangeway, 2000). This has not been appropriately accounted for yet.
Early predictions depended on remote observations of spectral lines and exospheric temperatures (Barth, 1968).

Little in situ measurements were available from Pioneer Venus other than atmospheric drag (Keating, 1980).

Single latitude profile from Sieff et al. (1980).
Enter SOIR on Venus Express

- Infrared channel of SPICAV, allowed measurements of atmosphere across several orbits (Mahieux, 2015a).
Min and max temperatures

- “The succession of a warm layer (230±30 K, 1σ standard deviation) at a pressure level of 3.2 x 10^{-7} mbar (140 km), a very cold layer (125±32 K) at 2.5 x 10^{-5} mbar (123 km), a warm layer (204±17 K) at 0.01 mbar (102 km) and finally a colder layer at 0.4 mbar (171±34 K, 87 km).” (Mahieux, 2015a)
Enter SOIR on Venus Express

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Cool regions

Mahiuex (2015a)
Cool regions

- Confirmed with measurements made from transmission spectra to create “rotation temperatures” (Mahieux, 2015b).
Venus Thermospheric General Circulation Model (VTGCM)

- Early models predicted local minimum (Bougher, 1995), they were updated to include the Venus Express data (Bougher et al. 2015); suggests the structure is caused by radiative rather than dynamical processes, possibly aerosol heating in the upper haze layer.
- The difference between VTGCM and SOIR could possibly be accounted for with tidal heating or planetary waves.