MAPPING VENUS LIGHTNING USING ULF WAVES IN THE LOWER IONOSPHERE OF VENUS. R. Hart[1], C.T. Russell[1], H. Leinweber[1], H.Y. Wei[1], R.J. Strangeway[1], T.L. Zhang[2], [1]Earth and Space Sciences/Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA, 90095-1567, USA, rhart@igpp.ucla.edu, [2]Space Research Institute, Austrian Academy of Sciences, Vienna, Austria.

Introduction: On Earth, lightning generates electromagnetic waves over a broad spectrum of frequencies from the ULF range below about 10 Hz, to ELF up to 3 kHz, and into the VLF range from 3 to 30 kHz. It also generates radio frequency and optical emissions. The most well studied ULF waves generated by lighting at Earth are the Schumann resonance at about 7 Hz and harmonics thereof. At Venus, we expect and have evidence that these same frequencies are generated in Venus' atmosphere, but the majority of the observations have been made in the planetary ionosphere, and not all signals have equal access to that region. When a lightning flash generates electromagnetic waves in the atmosphere, these waves travel at the speed of light until they reach the ionosphere, at which point they slow down. The slow-down flattens the wave front, and as a result the wave propagates vertically. Since the ionospheric field is usually horizontal, the electromagnetic waves must cross the magnetic field at an angle of near 90°. This can be accomplished easily below about 10 Hz, below a frequency called the lower hybrid resonance frequency which is about 0.65 B(nT) Hz in an electron-proton plasma and about 0.16 B(nT) Hz in a singly-charged oxygen-electron plasma. Since 25 nT is a typical magnetic field in the Venus ionosphere (but it can drop to near zero), the lower hybrid resonance frequency is near 4-16 Hz, and we should expect signals near 10 Hz and below to be able to reach the spacecraft whenever they are generated. Above this frequency, signals should be able to reach the spacecraft orbiting in the lower ionosphere only when the magnetic field line passing through the spacecraft enters the atmosphere at a steep enough angle that the waves can be guided to the spacecraft along the magnetic field.

Pioneer Venus in the 1980's made electric field measurements in four narrow-frequency ranges at 0.1, 0.7, 5.4, and 30 kHz, and discovered, consistent with the above discussion, electromagnetic waves at 100 Hz when the magnetic field dipped into the atmosphere. It provided a map of such signals on the nightside of Venus near the equator, the only place where it was able to measure due to the location of the periapsis of the orbit and the illumination on the antenna which produced noise in sunlight. Venus Express (VEX), beginning in 2006, has been able to make magnetic measurements up to 64 Hz in the Venus ionosphere. VEX has detected two types of electromagnetic waves at all local times, but restricted to the north polar region due to the periapsis location of its orbit. The types of signals seen are illustrated in Figure 1, which shows a dynamic spectrum obtained on April 15, 2007, on the dayside of Venus.

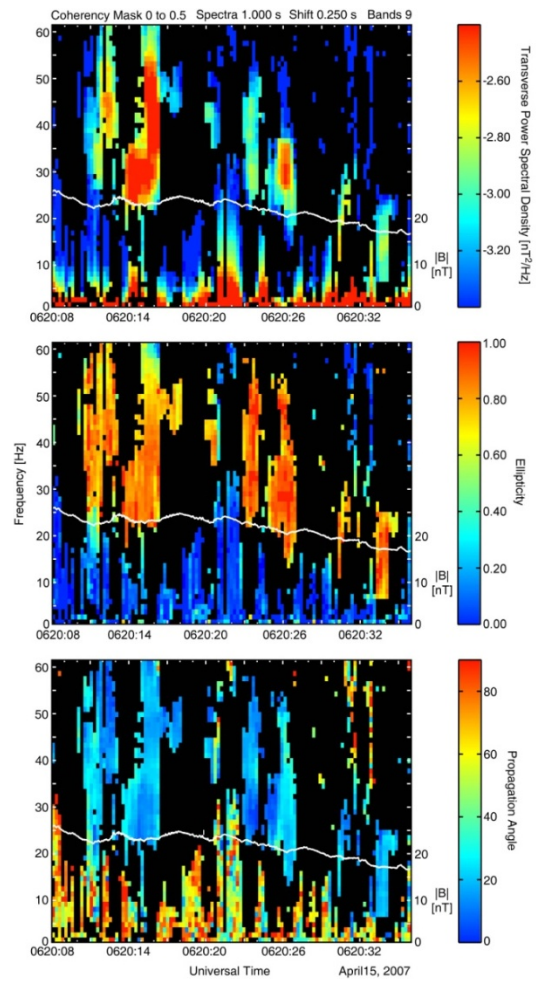

Figure 1. Dynamic spectrum of ULF and ELF magnetic signals observed by Venus Express on April 15, 2007, from 0620:08 to 0620:36 UT. From top to bottom are shown the transverse magnetic field power spectral density from 1 to 64 Hz; the ellipticity of the signal, where red is circularly polarized and right-handed; the propagation angle where blue is along the magnetic field. The white line shows the strength of the magnetic field in nT (see RH scale).

Shown are the powers transverse to the background magnetic field, the direction of propagation relative to the magnetic field and the ellipticity of the signal.

The white line shows the magnetic field strength. We see that, at least initially, there are two types of signals present. The high frequencies are right-handed circular waves guided by the magnetic field. These are the analog of the whistler-mode waves detected in the Earth's ionosphere. The low-frequency waves below about 10 Hz are not guided by the magnetic field.

We can test our hypothesis by examining intervals with low magnetic field strength and high. Figure 2 shows an example of the waves in the same format when the magnetic field is near 8 nT. Here the waves are right-hand circularly polarized over the whole frequency range and propagating along the magnetic field. This propagation is enabled by a magnetic field pointing into the atmosphere on this day.

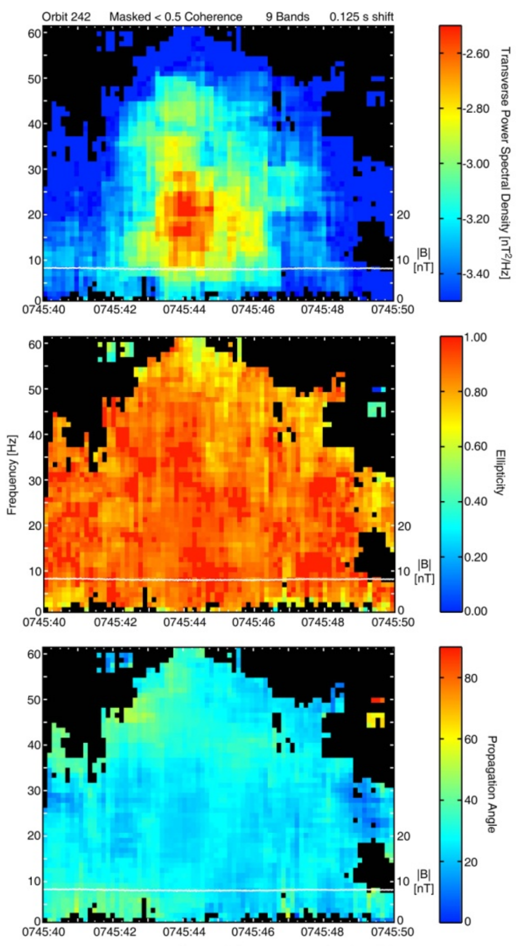

Figure 2. Dynamic spectrum on December 19, 2006, from 0745:40 to 0745:50. See caption of Figure 1. This interval has a low magnetic field strength.

In contrast to this behavior, we examine a similar interval in Figure 3 on a day when the magnetic field is strong, up to over 50 nT. The waves here are linearly polarized and not guided by the magnetic field. The ionospheric magnetic field is nearly horizontal. This is consistent with our expectations. The waves can propagate upward from the atmosphere and cross into the ionosphere when they are below the lower hybrid resonance frequency. This gives us a reliable, frequently available means of obtaining the statistical occurrence of lightning on Venus beneath the VEX spacecraft when it is in the neighborhood of periapsis around 200-300 km above the surface.

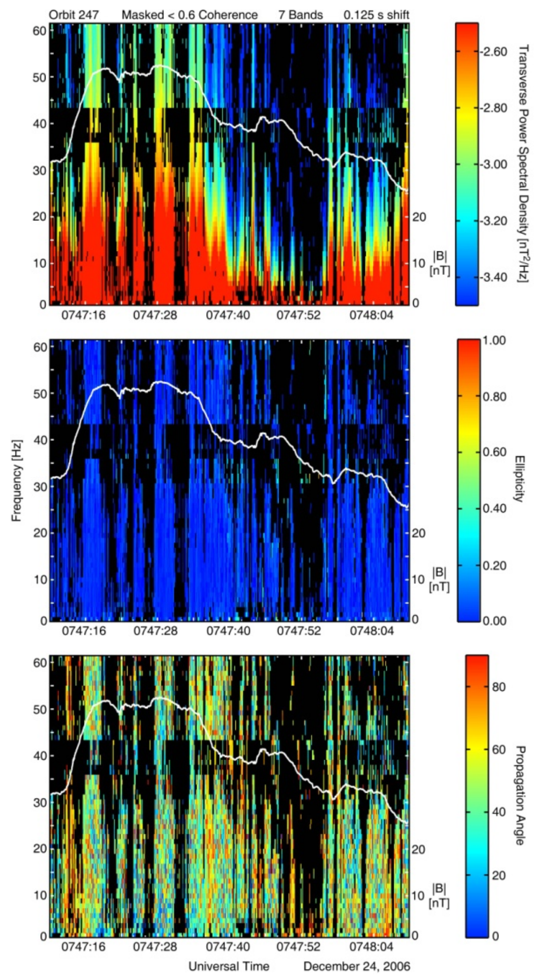

Figure 3. Dynamic spectrum on December 24, 2006, from 0747:10 to 0748:10. See caption of Figure 1. This interval has a high and variable magnetic field strength.

In this study, we exploit these waves to obtain the spatial and temporal occurrence of lightning in the Venus atmosphere in the region near the north pole.

References: [1] Russell et al., (2012) *GRL*, *59*, 965-973.