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Critical components of Venus Lower and Upper atmospheres with FirefOx and Venus Neutron Spectrometer (VeNuS)

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Abstract

We present two instrument concepts for understanding critical aspects of Venus' upper and lower atmosphere. FirefOx is an oxygen fugacity sensor for the lower atmosphere, and The Venus Nuclear Spectrometer (VeNuS) studies composition and volcanic activity signals in the upper atmosphere.

1. FirefOx

Oxygen is a trace gas in the lower atmosphere of Venus, controlled by the CO-CO_2 chemical equilibrium. At mean planetary radius, with temperature of approximately 740 K, fO_2 is calculated to be ~$10^{-21.5}$ bars [1,2]. Lower actual CO values at the surface (i.e. below the 20 ppm measured at 22 km), oxygen fugacity would be higher. Observational and theoretical constraints suggest a CO abundance of 3-20 ppm at the surface of Venus [1], thus a plausible range of oxygen fugacity would be ~ 10^{-20} bars to ~10^{-24} bars.

Direct measurement of fO_2 would both improve understanding of the carbon gas chemistry in the lower atmosphere of Venus. This might change predicted mineral stability regimes, and thus mineral phases present presented at the surface of Venus [2]. Direct measurement of the partial pressure of oxygen would provide robust constraints on gas chemistry and surface mineral stability, and confirmation of carbon gas measurements obtained by other methods.

FirefOx is a metal/metal oxide oxygen fugacity sensor to be mounted on the outside of a Venus descent probe or lander, with electronics to be housed inside a thermally controlled environment. It is a simple, low power and cost sensor derived from common industrial and off-the-shelf ceramic oxygen sensors, with the express purpose of determining the partial pressure of oxygen in the lowest scale heights of the Venus atmosphere, and especially the lowest hundreds of meters and the surface-atmosphere interface, where the atmosphere and surface move to thermodynamic equilibrium.

The primary sensor capability is the detection of the partial pressure of oxygen gas (fO2) in the near-surface environment of Venus, so the sensor must operate in the 710-740K temperature range and at up to 95-bar pressure (predominantly CO2) for sufficient time to obtain a precise, accurate measurement. The baseline sensor objective is survival for at least two hours at Venus surface conditions, and produce accurate measurements (fO2 to 0.5 +/- 0.5x10-24 within the range of 10-18 to 10-24) at a temperature range between 710 and 740K. Mean planetary elevation has a temperature near 735 K, and the operational temperature range covers a range of potential landing elevations. FirefOx requirements are low (~100-200 grams, milliwatt power, several kilobytes total science data), while its potential science return is high.

The FirefOx oxygen sensor is a solid-state, solid electrolyte oxygen concentration cell (henceforth called a ceramic oxygen sensor). Ceramic oxygen sensors have been used to measure oxygen fugacity in hot gases for nearly 50 years [3]. The basic principle relies on a reference material of a known fO_2, a solid electrolyte, and a sample atmosphere or material. The fO_2 differential between the known and unknown materials causes a diffusion of oxygen through the electrolyte, resulting in a small, measurable voltage.

A simple COS fO_2 sensor should follow the Nernst equation [cf. 4,5], and is thus a primary sensor (in other words, one that should not actually need calibration, but whose output is fundamentally related to the inputs). The Nernst equation directly relates the potential generated by the diffusing oxygen atoms through the sensor to the fO_2 via a relationship similar to

$$E = RT/4F \ln(P_{O2}/P_{refO2}) \quad (1)$$

Where E is the open circuit potential across the sensor electrolyte (directly measured by the sensor), R is the universal gas constant, T is the temperature, F is the Faraday constant, P_{refO2} is the reference oxygen pressure on one side of the electrolyte (metal oxide), and P_{O2} is the unknown oxygen pressure of the outside environment [5]

2. VeNuS

Nuclear (gamma-ray and neutron) spectroscopy is a proven technique for measuring the elemental composition of planetary surfaces, including Venus [6]. The technique has also been used to characterize the composition and time variability of planetary atmospheres [7-9]. An orbital Venus Nuclear Spectrometer would address important questions regarding key constituents and events in the Venus upper atmosphere [10].

2.1 Lightning Monitoring:

Lightning is an important dynamical process in atmospheres, and determining the frequency, time-, and spatial-dependence of lightning on Venus is an important goal. Earth-orbiting gamma-ray observatories have detected and mapped terrestrial gamma-ray flashes from upward lightning events across the surface of the Earth [e.g. 11]. A gamma-ray detector on a low-altitude (<2 Venus radii) orbiter would likewise provide real-time monitoring to search for similar lightning-induced gamma rays at Venus [12].

2.2 Atmospheric Composition:

Neutron spectroscopy is sensitive to the abundances of neutron moderating (e.g. H, C, N, O) and absorbing (e.g. Ar, S, Cl, H) elements. A MESSENGER- or Lunar Prospector heritage Neutron Spectrometer on a low-altitude Venus-orbiting spacecraft can be used to derive the bulk abundances of neutron moderating and absorbing elements within the atmosphere at altitudes of 65-80 km. This capability supports two measurements:

1) Derivation of the nitrogen content of the upper atmosphere. Despite being the second-most-abundant compound in Venus' atmosphere, the volume mixing ratio for N_2 is unknown by ±23% [13]. Knowledge of the N content of Venus' atmosphere is crucial for understanding the divergent evolutions of the atmospheres of Venus, Earth, and Mars [14]. Neutron fluxes measured by VeNuS, combined with constraints on the atmospheric composition from prior in-situ experiments [e.g. 13] will provide a precise (<5% uncertainty) determination of the N content of the upper atmosphere.

2) Monitoring volcanic gas concentrations. There is tantalizing evidence for ongoing volcanic activity on the surface of Venus, including from long-term monitoring (1978-1996, 2006-2012) of the SO_2 content of Venus' atmosphere [15-17]. That data shows variability that may be associated with periodic eruptive events that injecting volcanic gas into the upper atmosphere. VeNuS would provide a time-series measurement that is highly sensitive to the bulk concentration of thermal neutron absorbing elements (Ar, S, Cl, and H), which are all expected to be byproducts of volcanic activity. This technique provide time-series measurements of key elements associated with volcanic activity as injected into the upper atmosphere, a crucial constraint on the frequency of present-day volcanic activity on Venus.

References

[1] Fegley, B. Jr. et al., (1997), *Icarus*, *125*(2), 416-439.
[2] Fegley, B. Jr. and Trieman, A. H. (1992), *Venus and Mars: AGU Monogrpah 66*, 7-71.
[3] Nenov, T., and Yordanov, S. P., (1996), CRC Press.
[4] Arculus, R. J., and Delano, J. W., (1981), *Geo. et Cosmo. Acta* 45, 899-913.
[5] Van Setten, E. et al., (2002), *Rev. Sci. Inst.*, *73*, 156-161.
[6] Surkov, Y.A. et al. (1987), JGR 92, E537-540.
[7] Feldman, W.C. et al. (2003), JGR 108, E95103.
[8] Sprague, A.L. et al. (2004), Science 306, 1364-1367.
[9] Prettyman, T.H. et al. (2004), JGR 109, E05001.
[10] VEXAG GOI (2014)
[11] Fishman, G. J et al. (1994), Science 264, 5163.
[12] Lorenz, R.D. and Lawrence, D.J. (2015) PSS (in review).
[13] von Zahn, U. et al. (1983), in Venus (U. AZ. Press), 299-430.
[14] Lecuyer et al. (2000), EPSL 181, 33-40.
[15] Esposito, L.W. et al. (1984), Science 223, 1072-1074.
[16] Esposito, L.W. et al. (1988), JGR 93, 5267-5276.
[17] Marcq, E. et al. (2013), Nat. Geosci. 6, 25-28.