VENUS CLOUD EXPLORER: A LONG-DURATION IN-SITU NEW FRONTIERS MISSION TO INVESTIGATE THE HABITABILITY OF VENUS.

K. H Baines[1], J. A. Cutts[1], P. Byrne[2], L. Dorsky[1], J. O'Rourke[3], S. Seager[4], C. Wilson[5]. [1]Jet Propulsion Laboratory, California Institute of Technology, M/S 183-601, 4800 Oak Grove Dr., Pasadena, CA 91109, kevin.baines@jpl.nasa.gov; [2]Dept. of Earth and Planetary Science, Washington University, 1 Brookings Dr., St. Louis, MO, 63130, USA; [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA; [4]Dept of Physics, Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, MA, 02139, USA; [5]Dept. of Physics, Oxford University, Oxford, UK.

Introduction: Venus is essential to our understanding of the evolution and habitability of Earth-size planets throughout the galaxy. The selection of the VERITAS, EnVision and DAVINCI+ missions by NASA and ESA in June 2021 is an important step in advancing the science. However, addressing the habitability of Venus's clouds in 52-62 km altitude range encompassing the putative Venus Habitable Zone (VHZ) spanning temperatures 20º ± 40º C requires an in-situ aerial platform that can operate throughout this environment for extended periods in order to capture the full complexity of our sister world.

Science Opportunities: An aerial platform is capable of sampling the full inventory of gases and aerosols throughout the VHZ over all times-of-day and over a wide range of latitude in order to gain an understanding of Venus's intricate array of photochemical and thermodynamic processes within the VHZ An aerial platform can also characterize atmospheric kinematics and the in situ radiative environment with unprecedented accuracy and time resolution in order to characterize vertical transport mechanisms such as convection, turbulence, and gravity and planetary waves. These processes govern the rates of supply of surface-emitted materials (such as phosphorus, sulfur, sodium, and calcium) into and out of the VHZ. An aerial platform can be equipped to monitor infrasound signals indicative of seismic and volcanic activity and high resolution subcloud near infrared imaging. These observations would provide increased understanding of the rate and power of surface activity responsible for the flux of surface materials into the atmosphere. Finally, measurements of magnetic field exploiting the proximity of the aerial platform to the surface can provide magnetic measurements of unprecedented sensitivity. These observations would characterize remanent magnetism to test the hypothesis that Venus had a significant magnetic field early in its history [1].

Mission Concept Implementation: A balloon-borne aerial platform or aerobot appears to be the most cost-effective and practical means to conduct such a comprehensive set of investigations. To access the 10-km deep altitude range noted above, the aerobot is able to adjust its altitude by exchanging helium between a super-pressure balloon and a zero-pressure balloon enabling it to climb/descend and float at whatever VHZ altitude is desired. To explore all times-of-day, Venus's "global jetstream" prevalent at VHZ altitudes can be utilized to propel the observatory zonally east-to-west at 55-85 m/s, depending on altitude, to allow it to circumnavigate the planet and sample all times-of-day in 5.3 - 8.1 days. Over the planned one Venus-day (177 Earth days) mission, the gentler (~ 1-5 m/s) meridional winds that are currently known with much less accuracy and hence predictability from orbital observations, will allow the aerobot to visit a wide range of latitudes, currently expected to be > 30 degrees from the initial near-equatorial latitude of deployment. During these travels, radio-tracking via orbiter(s) and the Deep Space Network and other ground-based radio telescopes, supported by an on-board IMU as well as pressure/temperature and 3-D relative-wind sensors, will provide information on wind shear, turbulence, convection, and gravity and planetary waves.

Figure 1 Final stages of deployment of the Venus Cloud Explorer. The gondola with the scientific instruments is being winched down below the balloon envelope following jettison of the inflation tanks in order to reduce blocking of relay signals by the metallic film on the balloon

Orbital support of the aerobot enhances this mission in three ways. Relay of data through the orbiter provides a major increase in data return over what is possible with direct-to-Earth communications and with much less power consumption. Radiotracking of the aerobot as noted above is key for executing efficient mission operations and for characterizing Venusian atmospheric dynamics. Thirdly, orbital remote sensing provides complementary science to that which is obtained with in situ measurements and with UV and NIR imaging provides the context for in situ observations of the Venus clouds.

Science Implementation: Detailed measurements of the chemical compositions of the gaseous atmosphere and its aerosols would be provided by a mass-spectrometer capable of measuring both the gases and aerosols (the Aerosol-Sampling Instrument Package, ASIP [2]) and by a Tunable Laser Spectrometer [3] targeted for specific chemicals of interest, such as PH_3. ASIP has incorporated within it a nephelometer/particle counter [4,5] that provides particle sizing and particle number-density information for assessing the relative abundances of the trace molecular species found inside the particles and to provide detailed particle number and volume densities over altitude for determination of precipitation rates. Utilizing a vaporizer operating at up to 600^{o}C to vaporize the aerosols, ASIP provides a complete accurate inventory of all species mass-separated by 10 milli-Dalton from its neighbors, out to 300 Dalton, for both atmospheric gases and the aerosols.

An array of light sensors would measure the radiation both up and down providing a means to assess radiative balance and energy deposition as a function of altitude and time-of-day within the clouds. An array of sensitive pressure sensors would act as infrasound microphones that detect and characterize Venus-quake-generated soundwaves, as recently been successfully achieved for the Earth [6]. Finally, a magnetometer detects remanent magnetism from terrain being overflown by the observatory at ~ 20-km scales.

The Venus Flagship mission concept studied in support of the Planetary Science Decadal Survey [7] included similar capabilities but our Venus Cloud Explorer team has focused on both refocusing the science that can be accomplished by the aerobot and reducing its physical size compatible with a competitive mission in the New Frontiers class. The new and enhanced scientific capabilities include sub-cloud near infrared night time imaging that would enable investigations of both recent and contemporary volcanic activity and the chemistry of the ancient tessera terrains with a possible record of an early water rich era on Venus.

Cost Reduction Strategy: Key to driving the cost of this mission concept into the range of competitive New Frontiers missions is reducing the mass of the entry vehicle and the instrument science module (gondola) in the aerobot by a factor of two relative to the Flagship study. This reduction impacts favorably the mass and cost of every other system element including the mass that has to be delivered to Venus. These reductions are accomplished by applying small spacecraft technologies under development at JPL, design innovations, power reductions, and stringent cost-benefit analyses as described in more detail in a trade study of the Venus Cloud Explorer concept [8].

Discussion: The Venus Cloud Explorer focuses specifically on things that we don't know about Venus that are significant to the habitability of the Venus Cloud layer, including broader questions of what forms and sustains the Venus cloud layer as well as to events in the very early history of the planet. But while the currently approved missions will provide vast strides in knowledge about Venus geology, geophysics and gas chemistry, they will not contribute meaningfully to addressing the questions raised here. Mission concepts targeting Venus have been part of the New Frontiers program since its inception but no Venus mission has yet been selected. The NF-5 AO is expected in less than three years from now. The Venus Cloud Explorer concept outlined here is a candidate for the NF 5 opportunity and can play a key role in filling the significant scientific gaps that will still remain after the currently approved missions have been executed.

Acknowledgments: The research described in this paper was funded by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References: [1] O'Rourke, J, G et al. (2019). *JGR Let* 10.1029/2019GL092725. [2] Baines K. H. et al (2021). *Astrobiology* 21, 8, DOI:10.1089/ast. 2021. 0001 [3] Christensen, L. E. et al. (2007). Anal. Chem. 10.1021/ac071040p. [4] Renard, J.-B. et al (2016) Atmos. Meas. Tech. 9: 1721-1742. [5] Renard, J.-B. et al (2016) Atmos. Meas. Tech. 9: 3673-3686.[6] Brissaud, Q. et al. (2021) GRL,doi: 10.1029/ 2021 GL 093013. [7] Beauchamp, P. et al. (2021) IEEE Aerospace Conference (50100), 2021, pp. 1-18, doi: 10.1109/AERO50100.2021.9438335. [8] Cutts, J. et al. IEEE Aerospace Conference, 2022 in press