NEW-FRONTIERS CLASS VENUS IN-SITU EXPLORATION: THE VENUS CLIMATE AND GEOPHYSICS MISSION (VCGM) CONCEPT. K. H. Baines[1], J. A. Cutts[1], L. Dorsky[1], J. Hall[1], A. Akins[1], A. Davis[1], A. Komjathy[1], S. Krishnamoorthy[1], D. Nikolić[1], P. Vergados[1], A. Akins[1], S. Atreya[2], M. Bullock[3], G. Hunter[4], S. Lebonnois[5], P. Lognonné[6], O. Mousis[7], J. O'Rourke[8], J.-B. Renard[9], C, Wilson[10]. [1] Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Dr., Pasadena, CA, 91109, USA) [kevin.baines@jpl.nasa.gov], [2] University of Michigan, Ann Arbor, MI, [3]Science and Technology Corp, Boulder CO, [4]NASA Glenn Research Center, Cleveland, OH. [5]LMD/IPSL, Sorbonne University, Paris, France, [6]Institute de Physique du Globe de Paris, Paris, France, [7]Aix Marseille Universite., CNRS, CNES, LAM, Marseille, France, [8]Arizona State University, Tempe, AZ, [9]LPC2E-CNRS, Université d'Orléans (3A Avenue de la Recherche Scientifique, 45071 Orléans, France), [10]Oxford University, Oxford, UK

Introduction: We present a class of Venus New Frontiers mission concepts that effectively and affordably address the majority of priority science objectives dealing with Venus' formation, evolution, interior, surface, and atmosphere promulgated by the Venus Exploration Analysis Group (VEXAG) [1]. Collectively called Venus Climate and Geophysics Missions (VCGMs), this mission class incorporates both in-situ and orbital elements to obtain an optimum science return within the New Frontiers ~$1B cost constraint. We do not specify a single mission concept, but instead describe a suite of possibilities that could fit in the New Frontiers envelope. A detailed study could be carried out under the auspices of the Planetary Science Decadal Survey to guide the Survey on the potential of such a New Frontiers mission.

Mission Goals: The overarching goal of VCGM is to combine measurements of the atmosphere and near-surface to understand Venus as a planetary system and why its atmospheric circulation/dynamics, evolution and geophysical properties are unique in general and different from Earth in particular. Taking our initial direction from the most recent VEXAG Roadmap [1] supplemented by two Venus community workshops on the science return, complexities, and risks of a variety of aerial platforms [2], we center our mission around a key element: a long-lived, altitude-varying balloon-borne instrumented science platform (hereafter, "aerobot"). Utilizing the large (~60 m s^{-1}) zonal winds found at all latitudes equatorward of ~ 60°, the aerobot would circle the planet more than a dozen times over a notional 90-Earth-day science phase. Global Circulation Model simulations [3] indicate that the aerobot would sample a wide range of latitudes between the equator and 50°.

Approach: Onboard instrumentation would sample the environment over all times of day including (1) the winds in all three dimensions, (2) the pressure/temperature structure, and (3) the composition of the air and aerosols [4], including (A) UV-absorbing material which possibly may be linked to astrobiology [5,6], (B) the reactive sulfur-cycle gases that create the aerosols, and (C) the noble gases, their isotopes and the isotopes of light gases. - key to understanding the formation of the planet and the evolution of its atmosphere (e.g., [7]). The aerobot, capable of multiple altitude traverses of up to 10 km centered near an altitude of 55-km (~0.5 bar, 25C), will enable three-dimensional maps of these environmental characteristics, as well as the dynamically and chemically influenced size distribution of aerosol particles via a nephelometer (e.g., [8]) and/or particle counter [9]. These traverses also reveal the vertically-varying characteristics of atmospheric stability, gravity and planetary waves, and Hadley cells, all important for understanding the mechanisms that power and sustain the planet's strong super-rotation. As well, these altitude excursions enable measurements of the radiative balance and solar energy deposition via a Net Flux Radiometer [10], another key to understanding super-rotation.

As it circumnavigates Venus every 5 days, the aerobot monitors the terrain that it passes over from 50-60 km in altitude. Geophysical investigations of the interior of the planet take advantage of (1) the proximity to the surface relative to an orbiter and (2) the contact with the atmosphere which enables infrasound to be observed in situ. Electromagnetic measurements of the thickness of the lithosphere using excitation by the Schumann resonance [11], surveys of remanent magnetism [12,13] evidence of an early Venusian magnetic field, and an infrasound survey of seismic activity [14] are envisioned.

A supporting near-equatorial orbiter will 1) relay data from the aerobot to greatly increase data return and 2) locate and track the aerobot, particularly on the farside of Venus when out of view of Earth-based radio telescopes [15]. Imagers/spectrometers for both atmospheric and surface science provide synergistic support of aerobot measurements. Near-infrared imaging spectrometers/imagers (e.g., [16, 17]) would spectrally image (1) clouds and trace gases at depth [18], and (2) most of the surface. Seismic investigations of the interior can also be conducted complementary to those provided by the aerobot through the airglow generated by the interaction of infrasound emanating from Venus quakes. [14,19]. Other spectral imagers would map the UV-absorbing clouds and signals of the interaction of the solar wind with the upper atmosphere and ionosphere [20, 21], as well as the thermal structure and tides and waves of the middle atmosphere in the thermal IR [22]. Finally, An INMS [23] would sample the atmospheric loss of hydrogen and oxygen over a wide range of latitudes (likely > 70^{o}) under varying solar wind conditions over the expected orbiter lifetime of several years.

In addition to the two primary platforms, the VCGM may include (1) up to two Cubesats for balloon location support and enhanced radio occultation coverage of the atmosphere [24], and (2) 2-3 dropsondes to provide atmospheric P/T and trace gas profiles, and to image the surface at high resolution. [25]. Another possibility would be to measure the vertical variability of N_2 (via a speed-of-sound/attenuation sensor [26]) throughout the atmosphere down to the surface including within the ~ 7 km-thick surface boundary layer, a critical measurement for understanding the stability and dynamics of the lower atmosphere [27].

Out of the 23 VEXAG investigations [1], VCGM effectively addresses 20 (87%) of them. Superior measurements via aerobot and orbiter instrumentation working in concert cover 7 (30%).

Acknowledgments: Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References: Grimm, R. E., et al. (**1.** VEXAG (2019), Venus Strategic Documents; https://www.lpi.usra.edu /vexag/reports/ Combined _VEXAG_Strategic_ Documents_Current.pdf **2**. Cutts, J. A. et al. (2018). Summary report. JPL D-102569. **3**. Sebastien Lebonnois (2017). Presented at Venera-D Venus Modellng Workshop, IKI, October 5-7, 2017, http://venerad.cosmos.ru/fileadmin/user_ upload/ documents/Workshop2017_ Proceedings .pdf.

4. Baines, K. H., et al. (2018) https:// www.hou. usra.edu/meetings/vexag2018/pdf/8031.pdf. **5.** Limaye, S. S., et al. (2018). *Astrobiology* 18: 1-18. DOI: 10.1089/ast.2017.1783. **6.** Schulze-Makuch, D., et al. (2004) *Astrobiology* 4:11–18. **7.** Baines, K. H., et al. (2013). Tn *Comparative Climatology of Terrestrial Planets* (S. J. Mackwell, A. A. Simon-Miller, J. W. Harder, and M. A. Bullock, Ed). University of Arizona Press, Pp. 137-160. **8.** Banfield, D., et al. (2004). In: Proc. Int. Workshop 'Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science', Lisbon, Portugal, 6–9 October 2003 (ESA Publication SP-544, February 2004). **9.** Renard, J-B., et al. (2016). Atmos. Meas. Tech., 9, 1721–1742 doi:10.5194/amt-9. **10.** Aslam, S., et al. (2015). N*EPSC Abstracts*, Vol 10. EPSC2015-388. **11.** 2012). *Icarus*, *217*(2), 462–473. **12**. O'Rourke, J. et al. (2019). *Geophys. Res. Lett.*46, 5768-5777. **13.** O'Rourke, J.G., et al.(2018). *Earth Plan. Sci. Lett.* 502, 46–56. **14.** KISS: Keck Inst. for Space Studies, Venus Seismology Study Team (2015), Keck Institute for Space Studies, Pasadena, Calif., April 2015, http://resolver.caltech.edu/ Caltech AUTHORS: 20150727-150921873**. 15.** Cheung, K.-M. et al. (2019). Single-satellite real-time 3D positioning of balloon at Venus/ Titan. IAC abstract. **16.** Helbert, J., et al. (2018). SPIE Proc. Vol. 10765, *Infrared Remote Sensing. and Instrument.* XXVI., 107650D., https://doi-org.ezproxy.library.wisc. edu/ 10.1117/ 12. 2320112. **17**. Piccioni, G.et al., (2004). VIRTIS. in SP-1295. **18**. Marcq, E. et al. (2008). *JGR* 113, E00B07. **19**. Garcia, R., et al. (2005). *GRL.* 32, L16205.doi:10.1029/2005GL023558 **20.** Gray, C. L. (2015). PhD dissertation, New Mexico State University. **21.** Gray, C. L. et al. (2014). *Icarus* 233, p. 342347. **22**. Kleinboehl et al. (2019). https://www.cps-jp.org/~akatsuki/pub/venus2019/abstracts/IVC2019 05-3_Kleinboehl_abstract.pdf**. 23.** Waite, J. H., Jr., et al. (2004). *Space Sci. Rev.* 114, 113–23. **24**. Vergados, P., et al. (2018). AGU Fall Meeting 2018, December 10-14, Washington, DC., 2018, Poster number P41F-3795. **25.** Hunter, G. W., et al. (2007). Microsystems, space qualified electronics, and mobile sensor platforms for harsh environment applications and planetary exploration. Presented at Fifth International Planetary Probe Workshop, Bordeaux, FR, June 25-29, 2007. **26.** Petculescu, A., et al. (2006). *J. Acoustical Society America* 120, 1779-1782. doi: 10.1121/ 1.2336758. **27**. Lebonnois, S. and Schubert, G. (2017). *Nature Geosci.* 10, 473-479. DOI: 10.1038 /NGEO2971.