VADER: Venus Atmosphere, Descent and Environmental Researcher, a NASA Planetary Science Summer School mission concept. P. Sharma[1], D. Nuding[2], P. Ozhogin[3], I. Bell[4], K. Bennett[5], T. Broiles[6], P. Byrne[7], M. Chojnacki[8], E. Frank[9], J. Hanley[10], J. Kay[11], E. Larson[12], M. Pendleton[13], S. Schwartz[14], G. Vixie[15], C.J. Budney[16], L.L. Lowes[16] and K. Mitchell[16], [1]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125; psharma@caltech.edu, [2]Cooperative Institute for Research in Environmental Sciences; Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, [3]Center for Atmospheric Research, University of Massachusetts Lowell, [4]University of Michigan, [5]School of Earth and Space Exploration, Arizona State University, [6]University of Texas-San Antonio/Southwest Research Institute, [7]Department of Terrestrial Magnetism, Carnegie Institution of Washington, [8]Department of Earth and Planetary Science, University of Tennessee, [9]Department of Geological Sciences, University of Colorado at Boulder, [10]Arkansas Center for Space and Planetary Sciences, University of Arkansas, [11]Department of Earth and Environmental Science, University of Illinois at Chicago, [12]Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, [13]Department of Geological Sciences, University of Idaho, [14]University of Maryland/Observatoire de la Côte d'Azur, Nice, France, [15]Department of Physics, University of Idaho, [16]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.

Introduction: In 2011, the Planetary Science Decadal Survey [1] identified a Venus In Situ Explorer as one of the top candidates for a New Frontiers class mission for the decade 2013-2022. In response to this survey and the New Frontiers Announcement of Opportunity (2009) [2], we propose a mission concept, Venus Atmosphere, Descent and Environmental Researcher (VADER), to explore the lower atmosphere and surface of Earth's sister planet, Venus. Following the requirements of the 2009 AO, our proposed lander-probe hybrid would examine the physics and chemistry of the atmosphere and surface, Venus's atmospheric dynamics, and the atmosphere-surface interactions in terms of weathering and hydrology.

Measurements taken during the descent phase would determine the abundances of trace gases, sulfur, light stable isotopes, and noble gas isotopes, as well as temperature/pressure/wind speed profiles from 66 km altitude down to the surface. High resolution images would be taken both during the descent phase and upon landing. The surface composition along with physical properties like mechanical hardness, compressive strength and grain size, would also be examined upon landing. VADER will be constructed to survive temperatures in excess of 450°C for 75 minutes on the ground, following a 60 minute descent.

Although Venus has been explored by robotic missions in the past, all of them were flown more than 20 years ago (except for the European Space Agency's current Venus Express, which is focused mainly on studying the Venusian atmosphere). Consequently, there is a clear need for renewed exploration of Venus, and particularly its surface [3, and references therein]. The proposed mission described here resulted from an intensive one-week mission design exercise, conducted as part of the 2012 NASA Planetary Science Summer School at the Jet Propulsion Laboratory (JPL) (https://pscischool.jpl.nasa.gov/index.cfm).

Science Goals: Investigating Venus's atmosphere and surface would not only answer questions about its origin, evolution, and the dominant processes shaping the planet, it would also provide insights into the fate of Earth's environment under a scenario of increasing greenhouse gas emissions and sustained climate change. The science goals for this mission are to understand: 1) The physics and chemistry of the atmosphere of Venus, 2) The interactions between atmosphere and surface to understand radiative balance, climate dynamics and chemical cycles, 3) The physics and chemistry of the crust of Venus, 4) The properties of Venus's atmosphere down to the surface, and improve our understanding of Venus's zonal cloud-level winds, 5) The weathering environment of the crust of Venus; and 6) To search for planetary-scale evidence of past hydrologic cycles, oceans, and life. To address these goals, VADER would conduct scientific investigations for 60 minutes during descent through Venus's atmosphere and upon landing at a location inside our selected landing ellipse (75 km × 150 km, centered at 8°S, 289°E on the flanks of Phoebe Regio, chosen based on the potential to sample material that has eroded off of the highlands).

Instruments: VADER would carry four suites of instruments to address its science goals.

The *Atmospheric Composition Suite* consists of two instruments: the Neutral Mass Spectrometer (NMS) and the Tunable Laser Spectrometer (TLS). Both the NMS and TLS would measure isotopic ratios of noble gases, D/H ratio, and the abundances of water vapor and sulfur compounds in Venus's atmosphere and surface. The NMS also has an Aerosol Collector to identify the chemical make-up of aerosol particles in Venus's atmosphere.

The *Imaging Suite* consists of three visible cameras (sitecams) and a descent imager. The sitecams would have a field of view (FOV) of 124° × 124°, providing a full panoramic view, with an angular resolution of 2.1 mrad/pixel, allowing the cameras to resolve ~1 cm objects closest to the lander. The sitecams would be mounted on the perimeter of the vehicle bus to image the immediate landing site, providing information on the geology, morphology, and physical characteristics of the surrounding terrain. The descent imager would take images during descent to gather information about cloud structure and to provide context for the landing site by assessing spatial variations in color and inferred surface compositions, evaluating the morphology at a variety of scales, and investigating morphological evidence for past hydrological cycles.

The *Surface Composition Suite* includes a Laser Induced Breakdown Spectrometer (LIBS)/Microscopic Imager, Raman spectrometer, Gamma-ray spectrometer and Impact Penetrometer. The LIBS and Raman spectrometer would evaluate elemental and mineralogical composition, respectively. The microscopic imager would provide textural information on mineral grains, the gamma-ray spectrometer would measure radioactive heavy elements like U, Th and K, and the impact penetrometer would measure the physical properties (e.g., mechanical hardness and compressive strength) of the terrain on which VADER sets down.

Finally, the *Atmospheric Dynamics Suite* consists of the Atmospheric Structure Instrument (ASI), which includes thermocouples, barometers, accelerometers, a nephlometer, and up-and-down spectral radiometers. The ASI would measure the variation of temperature, pressure, density, and wind speeds during the descent phase. The nephlometer would examine the backscattered light from particles in the atmosphere to calculate cloud droplet and aerosol size distribution, and the radiometers would measure visible and infra-red spectra to determine atmospheric composition and to investigate the radiative balance.

Spacecraft description: VADER's spherical shape provides the optimum design to survive the harsh Venusian environment while accommodating the requirements for the scientific payload. Figure 1 shows the placement of all the instruments on and within the spacecraft bus. Phase-change material (H_2O and $LiNO_3.3H_2O$) would fill the walls and the voids between instruments to protect the hardware from the extreme thermal environment. The spacecraft bus would have nine windows for the imaging system and an inlet for the NMS and TLS instruments on the outside. The landing system would consist of three legs, ending with pads of crushable material to help absorb the landing shock. The bottom of the shell would be 0.25 m above the surface to meet the AO rock-hazard avoidance requirement. Its low center of gravity would stabilize the lander and satisfy the 0–10° slope stability requirement of the AO.

A 30% margin is incorporated for mass, power, and propellant, based on JPL proposal phase models. The estimated launch mass is 1,354 kg. Our mission would return ~2 GB of science data by the end of mission life.

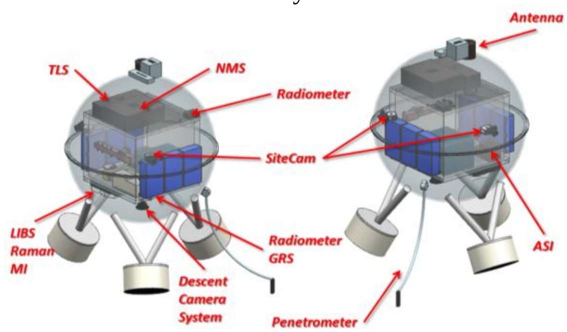

Fig. 1. Instrument placement on spacecraft.

Mission profile: Figure 2 shows a detailed timeline of the mission architecture. The proposed launch date for VADER is July 8th, 2020 with a 20 day launch window. The spacecraft would take 108 days from launch to Venus atmosphere entry interface. Four days before Entry, Descent, and Landing (EDL), a divert maneuver would increase periapsis and position the VADER carrier spacecraft so it is within communication range of the probe for 135 minutes once descent has commenced. Measurements would be taken for 60 minutes during descent and for 75 minutes on the ground.

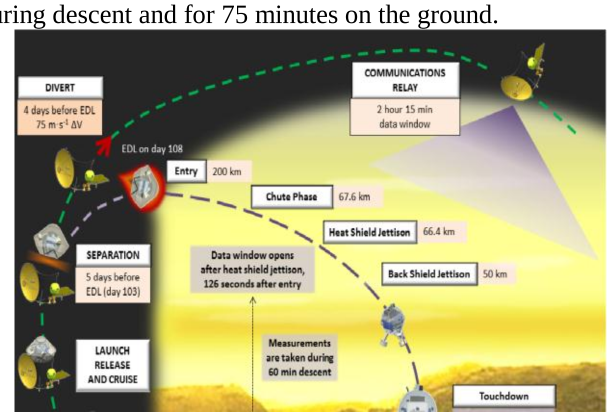

Fig. 2. Mission architecture from launch to landing

Cost: At $1.042B, our proposed mission is below the AO-specified cost cap of $1.069B. This estimate includes a 50% reserve as recommended by the Decadal Survey. This amount was estimated using Team-X/JPL institutional cost models.

References: [1] National Research Council. (2011) Visions and Voyages for Planetary Science in the Decade 2013-2022, *National Academies Press.* [2] NASA (2009) Announcement of Opportunity: New Frontiers 2009. [3] Taylor, F. (2006) *Plan. & Spa. Sci., 54,* 1249–1262.