CUPID'S ARROW: A SMALL SATELLITE CONCEPT TO MEASURE NOBLE GASES IN VENUS' ATMOSPHERE. C. Sotin[1], G. Avice[2], J. Baker[1], A. Freeman[1], S. Madzunkov[1], T. Stevenson[3], N. Arora[1], M. Darrach[1], G. Lightsey[3], B. Marty[4]. [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA; [2]California Institute of Technology, GPS division, 1200 E. California Blvd, Pasadena, CA 91125, USA; [3]Georgia Institute of Technology, 270 Ferst Drive, Atlanta, GA, 30332, USA; [4]CRPG-CNRS, Université de Lorraine, 15 Rue Notre Dame des Pauvres, 54501 Vandoeuvre Cedex, France.

Introduction: Getting reliable measurements of noble gases in Venus' atmosphere with a CubeSat-derived mission concept is very challenging. But if feasible it could change how we make this fundamental geochemical measurement in planetary atmospheres and other gaseous environments (e.g., plumes emanating from icy moons or dwarf planets) across the solar system. Venus poses the most urgent and nearby target for such measurements, to fill in a key piece of the puzzle of Venus' origin, evolution, and divergence from Earth's geophysical history. Understanding Venus' geophysical evolution is also key to interpreting observations of "Earth-like" exoplanets in order to assess whether they are Earth-like or Venus-like, which has obvious implications for their habitability potential. Noble gases are tracers of the evolution of planets. They trace physical processes such as the original supply of volatiles from the solar nebula, delivery of volatiles by asteroids and comets, escape rate of planetary atmospheres, degassing of the interior, and its timing in the planet's history. However, a major observational missing link in our understanding of Venus' evolution is the elementary and isotopic pattern of noble gases and stable isotopes in its atmosphere, which remain poorly known [1]. The concentrations of heavy noble gases (Kr, Xe) and their isotopes are mostly unknown, and our knowledge of light noble gases (He, Ne, Ar) is incomplete and imprecise. The Cupid's Arrow mission concept would measure those quantities below the homopause where gas compounds are well mixed.

Science objectives: The objectives of the Cupid's Arrow mission are to determine (1) the origin of the volatiles, (2) the atmospheric loss mechanisms, and (3) the history of volcanic outgassing. These objectives would be achieved by measuring noble gases concentrations and their isotope ratios below the homopause. These objectives partially address two of the five science goals in Planetary Science as they are described in the NASA's 2014 Science Plan. Moreover, the measurements that would be made by Cupid's Arrow correspond to the highest ranked investigation in the number 1 objective of Goal 1 "Atmospheric formation, evolution and climate history" of the VEXAG's Goal, Objectives and Investigation document published in 2014.

The measurements will be made by a miniaturized quadrupole ion trap mass spectrometer (QITMS) that has been developed at JPL. We have conducted measurements in the lab in order to validate the performance model. We demonstrate that the performances exceed the requirements with ample margins [2].

Mission architecture: The mission concept would send an atmospheric probe that skims Venus atmosphere below the homopause to collect samples of Venus atmosphere. These samples are then analyzed by the miniaturized QITMS once the probe is outside of Venus atmosphere. The trade space for the architecture goes from a skimmer that is piggy-backed to Venus (single pass) to an autonomous mission that realizes a Venus orbit insertion (VOI) allowing for multiple passes below the homopause.The nominal mission concept assumes that the spacecraft would approach Venus with an excess velocity of 2.7 km/s, with a closest approach of 250 km. Venus orbit insertion (VOI) would be conducted by the STAR8 motor at periapsis. The spacecraft would then be in a nominally 30 day orbit with a periapsis altitude of 250 km and an inclination of 82°. The high inclination was chosen to minimize the time in which the spacecraft is eclipsed by Venus, and results in an aeropass latitude of approximately 30°. Using a 3σ VOI delta-V error of 6 m/s, the initial orbit period is expected to be between 580 and 915 hours, or 24.2 to 38.1 days. Once the orbit has been refined, the probe would use the ACS thrusters to perform a periapsis lowering maneuver at apoapsis, with a maximum expected delta-V of 0.90 m/s. This will lower the periapsis to 110 km, which is well below the homopause to realize the first atmospheric sampling.

The probe would collect the atmospheric samples at periapsis at 110 km altitude within a few seconds. The probe is below the lowest level of the homopause during more than 100-s leaving plenty of margin for collecting the sample. After the aeropass, the probe would be in a shorter orbit, between 13.3 and 240.5 hours. The large uncertainty in this period is primarily due to the uncertainty in the density of Venus's atmosphere. The probe would perform another apoapsis maneuver with the ACS thrusters to raise the orbit periapsis out of the atmosphere, to 200 km, requiring a maximum of 9.1 m/s. The probe would remain in this orbit while it analyzes and downlinks the collected data from the first aeropass. Once all of the collected data have been returned and the batteries are recharged, the probe would lower its periapsis back to 110 km for the second and final aeropass.

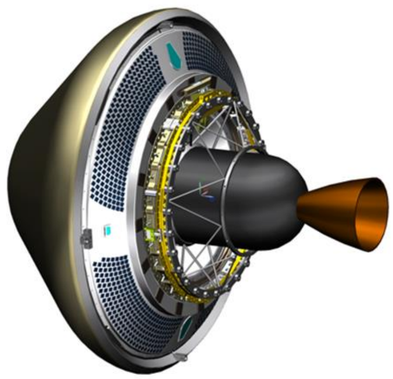

Figure 1: Artist concept of the Cupid's Arrow probe with the STAR 8 motor which would be ejected after VOI.

Spacecraft concept: The Cupids Arrow probe was designed as a modular but highly integrated unit resulting in a compact and lower mass spacecraft (70 kg with margins) that can sample the atmosphere, analyze the samples, and transmit the data to Earth. It consists of two modules, connected by a Lightband separation ring: the probe itself and a detachable STAR 8 solid rocket motor (SRM) that enables orbit insertion around Venus. The probe is a completely self-contained spacecraft and has all the required functionality and performance to fly itself to Venus or be carried to Venus with another spacecraft. The design is flexible and allows for a solid motor, in this case a STAR 8, and its supporting structure to be mated to the probe using an 18.25" Lightband. In the standalone flight mission profile, the probe and the motor remain connected throughout the cruise phase to Venus. The STAR 8 would then be used for the Venus orbit insertion burn, after which the motor and the supporting structure are decoupled from the probe by the Lightband, leaving the smaller upper Lightband ring attached to the probe.

Concept of operations: The nominal mission puts the probe in orbit around Venus with periapis at 110 km, several scale heights below the homopause which has an altitude between 119 km and 138 km depending on the time of day [3.4]. It is higher on the night side past the morning side of the terminator. At this altitude, the ambient pressure is about 0.14 Pa and the dynamic pressure is 1500 times higher due to a velocity of 10.5 km/s. The atmosphere enters the tanks and the QITMS by an inlet located at the stagnation point of the probe. The design is such that one could collect samples at either the ambient pressure or the dynamic pressure which provides an enhancement of 1500 times. The analysis of these different samples would allow us to determine whether fractionation happens due to the dynamic pressure. For each of the four samples (the fourth one is the QITMS chamber in Fig. 2), the QITMS first removes the main components of the atmosphere (CO_2 and N_2) before measuring first He isotopes and then all other noble gases and their isotopes. The performance model suggests integration times of 120 s. A reference gas would also be measured for calibration. The total time for the measurements is about 20 minutes but can be extended to several hours if necessary.

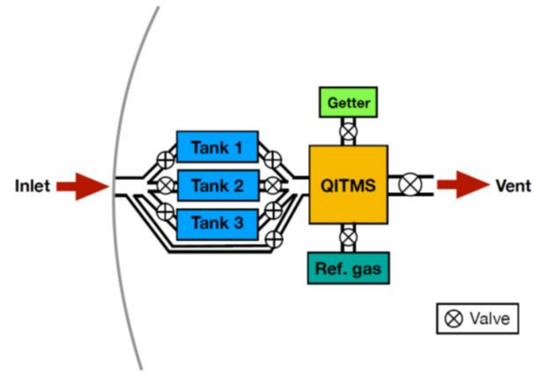

Figure 2: Schematic design of the QITMS and the different tanks in the probe. Using different valves, one can tailor the sampling strategy to best determine the concentration in noble gases in Venus' atmosphere.

Conclusions: The mission concept that has been developed during the present study funded by the PSDS3 NASA program would cost less than the $100M cost cap. Although Venus is the most urgent application, it could also be applied to other places such as Titan where the probe could be piggy-packed by mission such as the Dragonfly mission that was recently selected as one of the two finalists for New Frontiers 4. It could also be used to analyze plumes emanating from icy moons such as Enceladus, Europa, and other icy moons in the outer solar system.

Acknowledgments: This work has been performed at the Jet Propulsion Laboratory (JPL), California Institute of Technology (Caltech), under contract to NASA. The information in this paper is predecisional and is presented for planning and discussion purposes only. The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

References: [1] Chassefière et al. (2012) *Planetary & Space Science, 63-64,* 15-23. [2] Avice G. et al. (2018) *LPSC 49.* [3] Limaye S. et al. (2017) *Icarus, 294,* 124-155. [4] Mahieux A. et al. (2012 *J. Geophys. Res. 117*. doi: 10.1029/ 2012JE004058. [5] Mahieux, A. et al. (2015) *Planet. Space Sci. 113-114,* 309–320.