A VENUS ATMOSPHERIC SAMPLE RETURN MISSION CONCEPT: FEASIBILITY AND TECHNOLOGY REQUIREMENTS.

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Earth's "Twin" Planet: Of all the rocky planets in the Solar System, Venus and Earth come the closest to being similar—at first glance. Both are about the same size, have approximately the same mass, and have orbits that are close to each other. Similarities end there: whereas Earth has a habitable 1 atm pressure and 15°C average temperature on the surface, Venus has an atmosphere at 92 atm and 464°C; Earth has a life-friendly mixture for its atmosphere, while Venus has corrosive clouds.

Figure 1: Venus photo from the Magellan mission. [http://photojournal.jpl.nasa.gov/catalog/PIA00104]

Venus Science Goals: However, exploring Venus will help in understanding how our planet has formed. Considering the similar volumes and orbits, understanding how Venus came to be may lead to a better understanding of how planets are formed. In the Venus Exploration Analysis Group (VEXAG) Goals, Objectives, and Investigations study [1], three goals were identified for future Venus exploration:

- understanding the atmosphere's origins and its evolution, as well as the climate history,
- determining how the surface and interior evolved,
- and understanding the interior-surface-atmosphere interactions over time, as well as if liquid water was ever on Venus.

By measuring the isotopes of nobles gases and oxygen, the origin of the atmosphere can be found. Additionally, the mid-altitude range of Venus (~55 km) has a pressure of approximately 1 atm and 20°C, which has the conditions for habitability and might potentially harbor life forms or evidence of biological processes [2]. The second goal of the VEXAG study looks at the divergence of Venus and Earth from a geological point of view. Although Venus seems to have a young surface, tectonic plates are thought not to exist on Venus. Measuring the outgassing that occurs at the surface, as well as the composition of the surface, can help us understand how Venus's core works and how it has evolved to its current state. Looking into the interactions between the atmosphere, surface, and interior, the third goal cements in place how all three have changed throughout Venus's existence. Surface composition may show some record of hydrated minerals, or volatiles from the interior.

Grabbing Samples from Venus: Future Venus missions should accomplish several of the science goals through in-situ or remote measurements. An atmospheric sample return would accomplish the first and third goals, while a surface sample would accomplish the latter two. Although any samples returned would have a relatively small mass compared to in-situ measurements, having a physical sample in a laboratory has its advantages [3]. Within a lab setting, more accurate and powerful equipment can be used without having to worry about the mass penalties on the spacecraft. With proper storage, these samples could be used again and again with new generations scientists and technologies. Taking advantage of nondestructive techniques, the same sample can be analyzed multiple times through a variety of equipment on the ground; an in-situ science lander rarely has the chance to analyze a sample that has been analyzed by another instrument. With samples returned to Earth, any results can be verified or rejected by reanalyzing the same sample, avoiding some of the issues that have plagued previous missions. As seen with lunar samples, any samples returned can be retested with new hypotheses, without having to send another spacecraft to perform more science measurements.

Price of Thick Atmospheres: Sample returns missions from the Moon and comets were successful, but to return samples from Venus, technology developments and some precursor technology validation missions are essential [4]. These include high-temperature ascent balloons that can be inflated at a temperature of 460°C, guidance and control technology for a Venus ascent vehicle that would be launched from a balloon, and thermal control for a Venus ascent vehicle and lander that is also compatible with the required sample retrieval activities.

Atmosphere Samples vs. Surface Samples: Retrieving surface samples from Venus is notoriously difficult due to the technology development required for the extreme surface conditions. While atmospheric samples can be captured and retrieved with relatively low cost [5], some of the science goals rely on the return of surface samples. Numerous studies have investigated the feasibility of both atmospheric and surface sample returns.

Atmospheric Samples. Two types of atmospheric sample return missions are considered depending on altitude: (1) a single spacecraft can perform a high altitude flyby over Venus and collect samples from the upper atmosphere; (2) lower altitude flyby uses an additional element that dives deeper into the atmosphere to collect gas samples from lower atmosphere and exits the atmosphere to rendezvous with a spacecraft returning to the Earth. The latter concept allows for the collection of particles and aerosols from the clouds in the lower altitudes. Another concept [7] considers a single spacecraft on a free return trajectory and a propulsion burn of 700 m/s at a periapsis altitude of 110 km to compensate for the drag loss.

Surface Samples. Surface sample return missions would require a surface ascent vehicle. Collecting surface samples at the aforementioned extreme environment is complicated enough; the operation becomes even more demanding when one tries lifting the samples off the surface. Three approaches of lifting surface samples were studied and compared [6]. The first approach of using conventional solid rockets has been concluded as unfeasible for Venus Ascent Vehicle (VAV) due to the thick atmosphere. A second approach is to deploy the VAV in the upper atmosphere, which is suspended on a blimp, and using the blimp to rendezvous the VAV with a balloon that lands on the surface and lifts the sample. The third approach is similar to the second but uses an airplane to suspend the VAV and to rendezvous with the balloon carrying surface sample. Figure 2 shows five sample return architectures that have been analyzed for Venus.

A Venus Atmospheric Sample Return Mission: The goal of this work is to 1) reevaluate the feasibility of Venus sample return mission with state-of-the-art or near-term technologies, and 2) propose a new atmospheric sample return strategy. The previous Venus sample return missions have been done with then-current state-of-the-art technology. By revisitng these with modern technologies and other near-term technologies, those mission proposals can be updated and improved. Missions are look at the mid-altitudes, where conditions for habitability exist, will be concentrated on. Revisting the previous architectures proposed, a new Venus atmospheric sample return strategy will be investigated, which can be done using existing technologies or planned in near-term for Earth and other planetary applications. One such technology is a Cubesat launcher. Since Venus and the Earth are similar in size and mass, similar vehicles could be applicable to be launched from the atmosphere. An Earth launcher designed for Cubesats may be useful for raising a Venus cloud sample to low-Venus orbit, which is then retrieved by an orbiter before it propels itself back to Earth.

References: [1] Herrick R. et al. (2016) *Goals, Objectives, and Investigations for Venus Exploration (VEXAG)*. [2] Grinspoon D. H. and Bullock M. A (2007) *American Geophysical Union*. [3] Drake M. J. et al. (1987) *Eos, 68*. [4] Gershman R. et al. (2000) *Aerospace Conference Proceedings*. [5] Sweetser T. et al. (1998) *AIAA/AAS Astrodynamics Conference*. [6] Cutts J. et al. (1999) *AIAA Balloon Technology Conference*. [7] Sweetser T. et al. (2003) *Acta Astronautica, 52*.

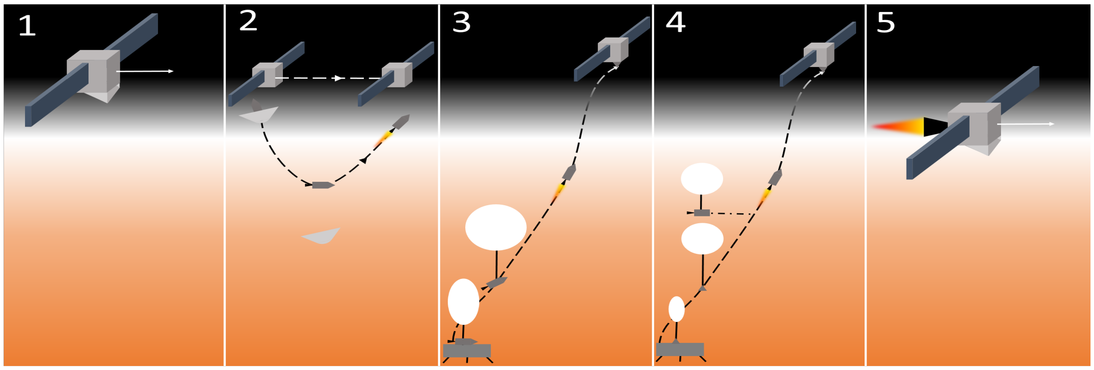

Figure 2: Five architectures that have been analyzed. Architecture 1 is the atmospheric skimmer, using a flyby spacecraft [5]. Architecture 2 uses a low-altitude probe that collects samples at low velocities [5]. Architecture 3 and 4 use a lander to collect surface samples, with a balloon that brings the VAV (in 3) or just the sample (in 4) to the VAV launch height. Once in orbit, it rendezvous with an orbiting tug [5]-[6]. Architecture 5 has a high-altitude spacecraft burn at the flyby periapsis while collecting samples [7].