Venus In-Situ Cloud Explorer Mission Concept: Revolutionizing Knowledge of our Sister Planet

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 many of the most challenging questions will require in situ platforms that can operate in the Venus environment for extended periods in order to capture the full complexity of our sister planet. The Venus In Situ Cloud Explorer Mission Concept described here includes a family of potential missions that use the vantage point of the Venus clouds to revolutionize knowledge of Venus.

AEROBOT CAPABILITIES: Aerobots are aerial vehicles that exploit buoyancy to achieve long-duration operation in the Venus cloud layer where environmental conditions are comparatively benign. Buoyancy control (Figure 1) allows aerobots to change altitude with little energy expenditure enabling new scientific measurement opportunities. These include atmospheric chemistry, dynamics, geophysical measurements of the crust and interior and geological investigations enabled by high resolution surface imaging. As the exploration of Venus advances to include return of samples of the clouds and surface materials to Earth, aerobots will also play a key role in these missions.

Figure 1 One-third scale variable altitude aerobot under test in the Black Rock desert in Nevada in July 2022. Exchange of helium between an inner and an outer balloon is used to change the buoyancy of the vehicle and execute altitude changes. (J. Izraelevitz, JPL)

The aerobots considered here operate within the cloud layer (Figure 2) where temperatures are moderate enabling the use of conventional electronics and sensors: a thin sulfuric acid mist can be protected from with polymer coatings: and atmospheric density is high enough to allow flight with a balloon compatible with entry systems. However, the aerobot provides a superb platform for deploying short lived drones that can rise above the cloud tops and descend to the surface expanding the scope of the science. An orbital spacecraft that track the aerobot, relay data efficiently to Earth and provide context imaging and synergistic science.

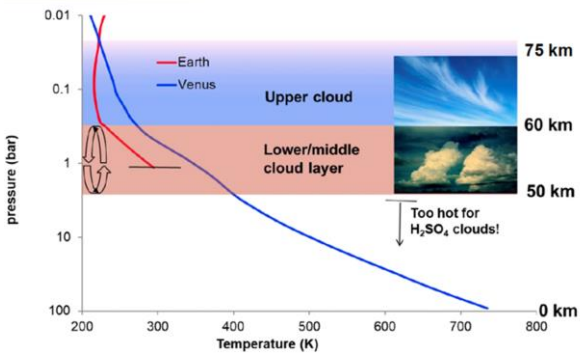

Figure 2 Compared to the surface of Venus, the cloud layer presents conditions that are much more compatible with conventional electronics. Platforms that reaching below the cloud for short periods will required equipment that can tolerate temperatures in excess of 100C

FLIGHT IN THE VENUS CLOUDS: The aerial exploration of the Venus clouds was initiated in the mid-1980s with two small fixed-altitude battery-powered Soviet VeGA mission balloons that each operated for 2 Earth days [1]. However, advances in technology mean that solar powered aerobots are feasible that operate for longer – 100 days or more and deliver larger payloads – 100 kg or more - to the cloud layer. The Venus Climate Orbiter recommended as a Flagship mission by the Planetary Science Decadal Survey of 2013-2022 featured a fixed altitude balloon, orbiter and deployed sondes [2].

Developments in the last decade involve further innovations:

- Variable altitude control within the cloud layer [3]
- Instrumentation to probe the surface and interior as well as the atmosphere [4]
- Sub cloud nightside imaging of surface emitted radiation in the near infrared [5]

FAMILY OF POTENTIAL MISSIONS: A set of concepts for Venus aerial missions feasible as Discovery or New Frontiers proposals were recently proposed [6]. A specific New Frontiers concept called Phantom has now emerged from this study as a candidate for a near term New Frontiers

opportunity. [7]. These concepts are achievable with technologies that are either in hand or currently under development. A focus in this paper is on concepts that would require questions new technologies feasible within the next decade. A companion paper Venus In Situ Transfer and Analysis (VISTA) deals with more ambitious concepts that involve descending deep beneath the cloud layer to the Venus surface [8] that would extend well beyond the next decade.

IMPACT OF NEW TECHNOLOGY: A number of technology areas are pertinent to next generation aerobot missions paving the way for missions in the VISTA class.

Localization: Advanced low mass and low power inertial sensors are needed to determine position of the aerobot in the intervals between tracking by orbiters or ground stations. Knowledge of the zonal, meridional and vertical wind components using the aerobot as a probe is essential to characterizing the global circulation.

Multiple Aerobots: Networks of aerobots are needed to enable measurements to be made simultaneously at a number of different locations in the cloud layer. Technologies for deploying multiple aerobots from a single entry vehicle would be enabling for this application as well as guidance navigation and control technologies for network operation.

Drones and Sondes: Technologies for extending exploration above and below the cloud layer including drones and sondes deployed from aerobots are needed. Approaches identified already include high temperature tolerant balloons [9]; long tethers deployed from the aerobot [10] and drones capable of efficient horizontal flight as well as docking with the aerobot [11]. Unpowered solar balloons capable of rising above the clouds and gliding sondes for targeted close up imaging of the Venus surface are also in this category.

Science Instrumentation: Compact low power instruments capable of chemical, biological, atmospheric and geophysical measurements are needed in the following categories:

- **Cloud physics**: Cloud and aerosol particle number, size, and shape submicron to 50 microns.
- **Infrasound:**. Low magnitude pressure waves with amplitude of 0.003 Pa in the 1 to 10 Hz spectral band.
- **Cloud Astrobiology:** Identification of biological activity and life indicators in cloud particles.
- **EM Radiation Environment:** Flux of UV visible and infrared radiation throughout the cloud layer.
- **Magnetism and Electromagnetism:** Remanent magnetism and induced signals indicative of crustal structure.
- **Infrared Surface Spectral Emission**: Imaging of spectral emission from the surface of Venus in the spectral range 0.8um to 1.2 um.

SUMMARY The Venus cloud layer with its moderate temperatures, abundant solar radiation and earthlike atmospheric density provides an ideal vantage point for conducting in situ investigations of the Venus environment. There is considerable scope for introducing new technologies that will help revolution our knowledge of our sister planet.

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