VENUS IN SITU CLOUD EXPLORER: REVOLUTIONIZING KNOWLEDGE OF OUR SISTER PLANET

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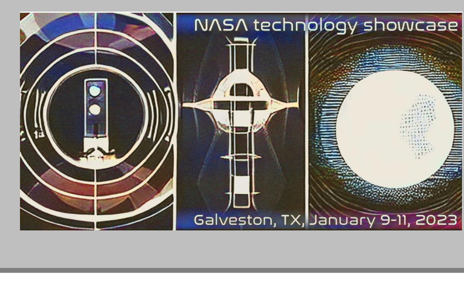


WHY VENUS?

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 (VISCE) Mission Concept described here includes a family of potential missions operating n the Venus clouds that would revolutionize knowledge of Venus [1],[2].

AEROBOT CAPABILITIES:

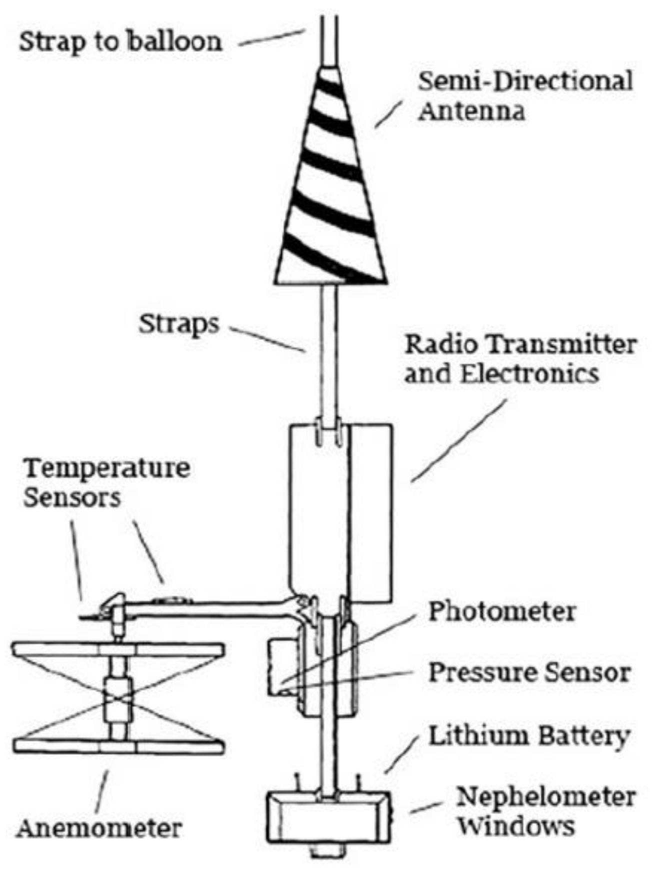
Aerobots are aerial vehicles that exploit buoyancy to achieve long-duration operation in the Venus cloud layer where environmental conditions, relative to the surface are comparatively benign. Buoyancy control allows aerobots to change altitude with little energy expenditure enabling new scientific measurement 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 as described in the VISTA companion concept [3].

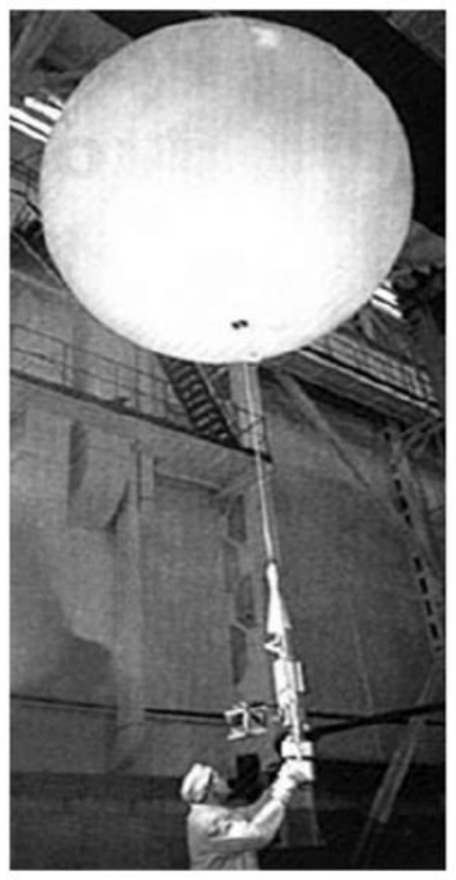
THE VENUS CLOUD ENVIRONMENT

The aerobots considered here operate within the cloud layer where temperatures are moderate enabling the use of conventional electronics and sensors: a thin sulfuric acid mist can be protected against with polymer coatings: and atmospheric density is high enough to allow flight with a balloon compatible with practical entry systems. The aerobot also provides a superb platform for deploying short lived drones that can rise above the cloud tops and descend to the surface expanding the scientific scope. The VISCE mission includes a companion orbiter that tracks the aerobot, relays data to Earth and provides context imaging and synergistic science

HISTORY OF FLIGHT AT VENUS (1985 :

The aerial exploration of the Venus clouds was initiated in the mid-1980s [4] with two small fixed-altitude battery-powered Soviet-era VeGA balloons that each operated for 2 Earth days at a constant altitude near 55 km powered by a primary battery. NASA and JPL have studied concepts for larger versions of a constant altitude battery powered balloon [5].

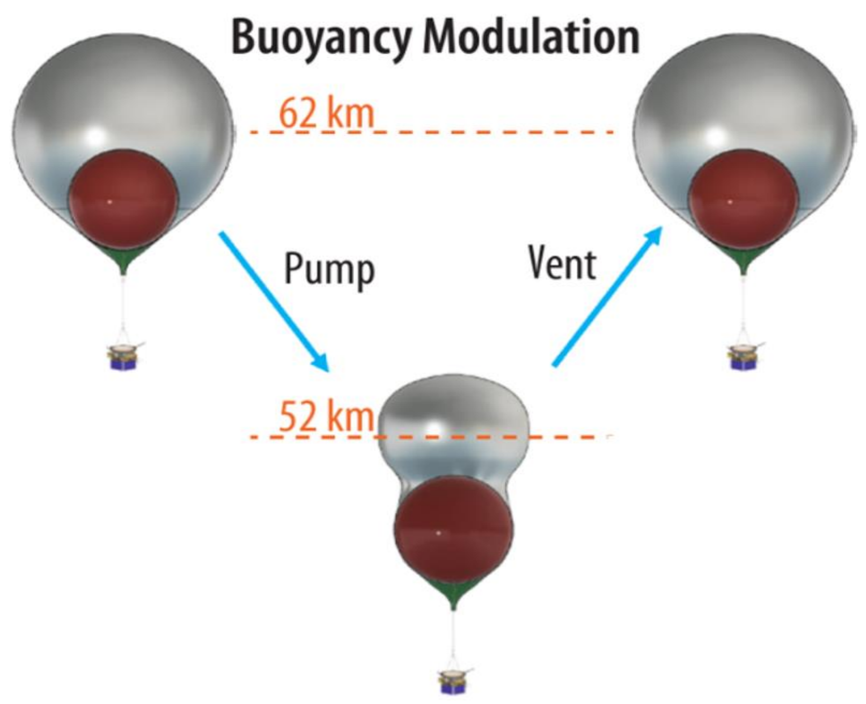




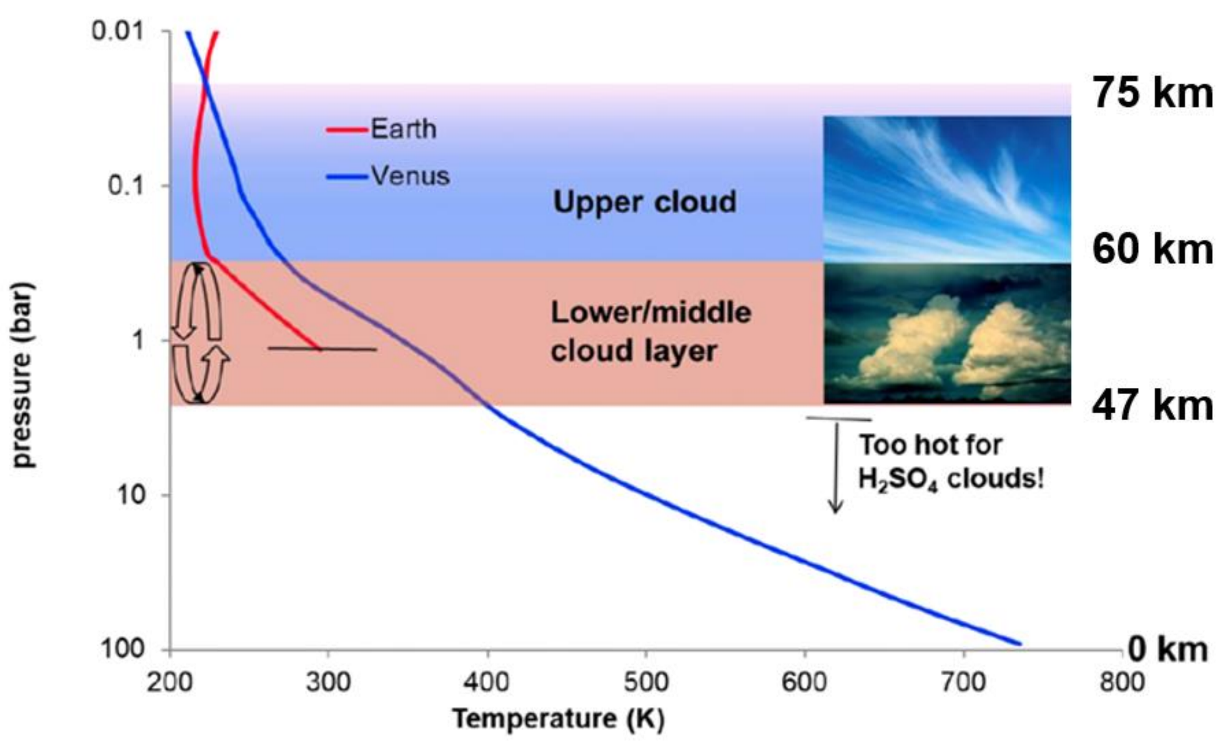
FLIGHT CAPABILITIES – COMING DECADE:

- Long durations – 100 days plus with solar power
- Larger payload 200 kg gondola
- Environmental tolerance – acid clouds temperature
- Variable altitude – mid cloud and cloud base
- Deployable drones and sondes

Venus in Situ Cloud Explorer consists of a variable altitude balloon suspending a gondola packed with scientific instrumentation.



Altitude variation within the Venus cloud layer is enable by alternating pumping and venting helium between an inner and outer balloon [6]



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

Variable altitude aerobot using buoyancy modulation and Venus compatible envelope material was tested in Nevada's Black Rock Desert in summer 2022. Plans are underway for testing a full scale vehicle.

NEW TECHNOLOGIES

A number of technology areas are pertinent to next generation aerobot missions in the VISCE class paving the way ultimately for ambitious missions in the VISTA class

- **Environmental Tolerance:** Advanced balloon materials, tolerant of higher temperatures and acidic aerosols, are needed to enable aerobots that can descend to the base of the cloud layer. Advanced optical coatings that can also tolerate these environmental conditions can help moderate temperature increases under high sun conditions. Energy generation and storage systems tolerant of the environment are required to enable long duration operations in the cloud layer.
- **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
- **Networking:** 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 [7]; long tethers deployed from the aerobot [8] and drones capable of efficient horizontal flight as well as docking with the aerobot [9]. 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 [10].
- **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 [11].

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REFERENCES:

[1] J. Cutts, "Exploring the Clouds of Venus: Science Driven Aerobot Missions to our Sister Planet," in *IEE Aerospace Conference*, 2022.
[2] P. Byrne, "Phantom: Ad Aethera Veneris," 15 September 2022. [Online]. Available: https://twitter.com/ThePlanetaryGuy/status/1570520974902325248.
[3] V. Scott, "Venus In Situ Analysis and Transfer," in *This Workshop*, 2023.
[4] R. Z. Sagdeev, V. M. Linkin, J. E. Blamont and R. A. Preston, "The VEGA Venus Balloon Experiment," *Science*, pp. 1407-1408, 1986.
[5] D. Grinspoon, "Venus Climate Mission: Mission Concepts Study," Planetary Science Decadal Survey, 2010.
[6] J. Hall and J. Izraelevitz, ". "Altitude-Controlled Light Gas Balloons for Venus and Titan Exploration," in *AIAA Aviation Forum*, 2019.
[7] M. De Jong and R. Jacobi, "Extended Range Altitude Control for Venus," in *International Planetary Probe Workshop*, Virtual, 2021.
[8] M. Eirew, L. Arizmendi, S. Mai, B. Lees, D. Smith, M. Tan, B. Hockman and A. Goel, "Development of an Aerodynamically Stable Tethered Payload for Imaging and Atmospheric Measurement Beneath the Cloud Layer of Venus," in *International Planetary Probe Workshop*, 2022.
[9] B. H. Cameron, "A compact drone based instrument for Venus applications," in *International Planetary Probe Workshop*, 2022.
[10] S. Krishnamoorthy, V. H. Lai, A. Komjathy, M. T. Pauken, J. A. Cutts, R. F. Garcia, D. Mimoun, J. M. Jackson, D. C. Bowman, E. Kassarian, L. Martier, A. Sournac and A. Cadu, "Aerial Seismology using Balloon-Based Barometers," *IEEE Transaction on Geoscience and Remote Sensing.* , 2019.
[11] A. Davis, "Imaging of infrared emission from the Venus surface from below the cloud base," *Planetary and Space Science,* 2023, in press.

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