DAVINCI+: DEEP ATMOSPHERE OF VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING, PLUS.

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Introduction: The DAVINCI+ mission concept extends prior competed *in situ* mission bids [1-4] by incorporating multiple Venus flybys and an orbital remote sensing phase together with an hour-long probe-based transect of the entire Venus atmosphere to the surface, all within the resource envelopes of NASA's Discovery program. This enhanced 2019 version of the previously developed DAVINCI mission concept [1-4] was formally submitted to the 2019 DISCOVERY mission competition in late June 2019. Here we describe its science motivation and connectivity to long-standing planetary science goals, as well as those relevant to the astrophysical exploration of exoplanets [7]. Our aim is to describe at high-level the scientific rationale and approach for this first-of-a kind *flyby-probe-orbiter* mission to Venus as an example of what the scientific community could implement in the 2020's "Decade of Venus" (e.g., J. Herbert *et al.* [8]; VEXAG GOI [5]). DAVINCI+ was developed in response to VEXAG and Planetary Decadal Survey solar system priorities as a forerunner to an era of advanced landers and orbiting reconnaissance missions involving SAR (and InSAR), IR emission spectroscopy, and lidar, as well as balloons, cube-sats, etc.

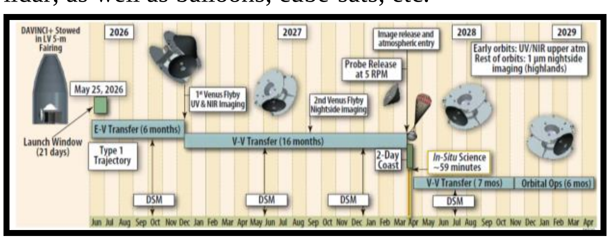

Figure 1: The DAVINCI+ mission concept embraces a carrier/flyby-orbiter and a deep atmosphere "chemistry" probe, with an ensemble of instrument investigations already flight-validated on Mars (MSL) and in deep space at Jupiter (Juno) and Bennu (OSIRIS-Rex).

Primary science goals and objectives are intended to provide definitive boundary conditions for models that explain the Venus water inventory over time, volcanic activity, and the potential for past habitability, as well as how to evaluate Earth-sized exoplanets with atmospheres that could be observed with JWST [7].

Summary of Science Priorities: Traceable to NASEM Planetary Decadal Survey [6] and VEXAG Goals/Investigations [5], the big questions that the DAVINCI+ mission addresses are summarized in **Figure 2**. All of these questions have appeared in recent Decadal Surveys [6], as well as in other framework documents including Dave Crisp's 2002 report [3].

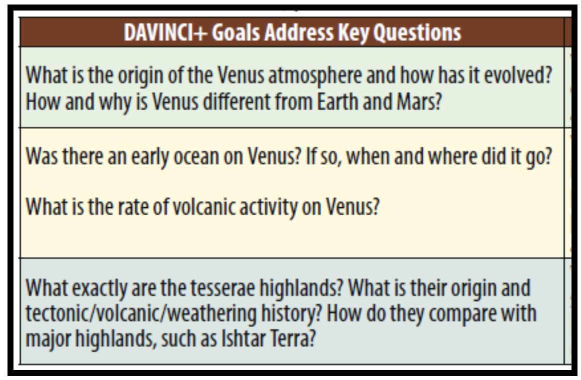

Figure 2: High level questions that are traceable to VEXAG GOI and Decadal priorities [5,6] can be addressed to first-order via the DAVINCI+ approach that integrates in situ definitive chemistry and atmospheric dynamics with flyby/orbital UV and Near IR (1 μm) remote sensing.

Many of the outstanding questions about Venus that emerged after the US Pioneer Venus probe missions and those of the USSR (*Venera*, *Vega*) involve definitive measurements of bulk atmosphere noble gases, the vertical distribution of key trace gases, and the mixing ratio of hydrogen isotopes throughout the atmosphere. Thanks to developments in mass spectrometry, tunable laser spectroscopy, and IR emission spectroscopy, these questions can be addressed via flight-proven sensor systems (developed by DAVINCI+ team-members) in ways that will finally place Venus into its appropriate context within the solar system.

DAVINCI+ Approach: It has been argued that short-lived "probe" missions do not provide adequate sampling of planets bearing large atmospheres, yet results from the *Huygens* probe at Titan and the *Galileo* probe at Jupiter have yielded seminal information from which new models have been developed and published [3]. Moreover, "definitive" atmospheric chemistry via ppbv class sensors such as those operating on the surface of Mars in the MSL SAM suite has not yet been accomplished for any planetary atmosphere. Bringing such 21st century instrumentation to bear on the vertical distribution of traces gases for the deep atmosphere of Venus (lowermost ~16 km) will provide a first examination of the potential disequilibria and surface-atmosphere chemical signatures in this challenging region where CO_2 behaves as a supercritical fluid. DAVINCI+'s probe is equipped with a quadrupole Mass Spectrometer and associated Tunable Laser Spectrometer that will address a preponderance of questions associated with the evolution of the atmosphere all in finely-resolved vertical context. Whether the D/H ratio varies from the upper cloud deck to near the surface will be resolved, as well as vertical gradients in such species as OCS, SO_2, CO, and others.

Connection to the Tessera Surface*:* DAVINCI+ incorporates a high sensitivity (SNR > 100) descent imaging system capable of mapping the 1 μm emissivity of a highlands region at scales as fine as tens of meters to provide "ground-truth" for *VEx* and *Akatsuki*-based 100 km scale assessments of composition via their NIR cameras [3,5,8]. In addition, the DAVINCI+ descent imaging system incorporates a panchromatic band so that dozens of nested images from ~ 5 km to near the surface will be acquired with resolutions adequate to evaluate sedimentary process histories and from which to compute digital elevation models (DEMs) with spatial sampling as fine as meters [4]. These unique imaging-related datasets (i.e., emissivity maps and DEMs) will serve as training sites and ground-truth for the upcoming orbital reconnaissance missions under consideration by NASA, ESA, and ISRO, including the *EnVision* orbiter for the 2030s [8].

The combination of 1-10 m scale DEMs, meter-scale morphologic imaging, and 1 μm emissivity (for compositional assessment) will enable evaluation of formation and modification scenarios for one major tessera region on Venus (*Alpha*), which has been explored from recent orbital missions by DAVINCI+ team-members. **Figure 3** captures one approach for evaluating the tessera surfaces that will be sampled by DAVINCI+'s decent imaging system, from which different evolutionary scenarios and models can be tested.

Connecting the lower atmospheric trace gas chemistry to surface-atmosphere interactions can be accomplished via mass spectrometry, tunable laser spectroscopy (D/H, sulfur species, fO_2), and 1 μm model-based emissivity (from lower altitude narrow-band descent imaging). We believe chemical and emissivity signatures of specific minerals or weather pathways can be established, potentially resolving key aspects of the modification histories of complex ridged terrain regions (tessera) such as *Alpha Regio* [1,4].

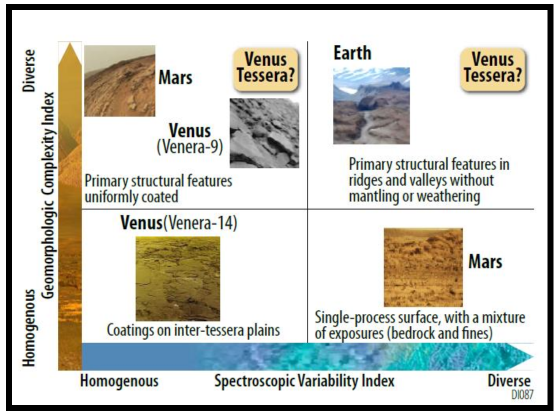

Figure 3: Two-dimensional analysis approach enabled by DAVINCI+ descent imaging data, together with its orbital 1 μm emissivity sampling for *Alpha Regio* [4].

***Flyby/Orbital Remote Sensing*:** The DAVINCI+ mission (**Fig. 1**) includes two Venus flybys and an orbital remote sensing phase to complement and synergize with the *in situ* probe. A multi-band imaging system that includes UV, Near IR (1 um), and an engineering wide-field mode, has been incorporated onto the Lockheed-Martin carrier/telecom/orbiter spacecraft, with opportunities to acquire first-ever vantage points on Venus in the UV (where the mystery absorber is lurking) as well as in night-side 1 μm emissivity. This heritage-based imaging system developed by partners at MSSS (Ravine) builds on the success of the JunoCam and OSIRIS-Rex NavCam to provide scientifically-relevant imaging of aspects of Venus upper atmosphere and surface not well mapped by either *VEx* or *Akatsuki*. Indeed, the flexible orbital phase includes multiple opportunities for night-side NIR imaging of Ishtar Terra, as well as the probe entry site in *Alpha*

SUMMARY: The Discovery-class DAVINCI+ mission builds on ~12 years of investments at GSFC, LM, LaRC, APL, ARC, MSSS and at partnering universities to offer a mission to Venus that embraces all of the highest priority unknowns about Venus [3,5,8]. Its innovative *flyby-probe-orbiter* approach is poised to set the stage in the 2020's for an enduring period of Venus exploration that extends into the 2040's, while new astrophysical observatories leverage its definitive measurements to evaluate Venus-like exoplanets [7].

References: [1] Glaze L. *et al*. (2018) *Space Sci. Rev. 214 (89)*, p. 1-37. [2] Glaze L. *et al.* (2017) *IEEE Aerospace Conf. 2017* (5 pp). [3] Crisp D. *et al.* (2002) *ASP Conf. #272* (M. Sykes, Ed.), p. 5-34. [4] Garvin J. B. *et al.* (2018) *LPSC 49th*, #2287. [5] VEXAG (https://www.lpi.usra.edu/vexag/reports/VEXAG_Venus_GOI_Current.pdf). [6] NASEM Planetary Decadal Survey, 2011 (V&V). [7] Arney, G., & Kane, S. (2018). arXiv:1804.05889 (JWST). [8] Helbert J. *et al.* (2020), in LPSC 51st, *this meeting*.