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Venus, Earth's divergent twin?: Testing evolutionary models for Venus with the DAVINCI+ mission

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Understanding the divergent evolution of Venus and Earth is a fundamental problem in planetary science. Although Venus today has a hot, dry atmosphere, recent modeling suggests that Venus may have had a clement surface with liquid water until less than 1 billion years ago [1]. Venus today has a nearly stagnant lithosphere. However, Ishtar Terra's folded mountain belts, 8-11 km high, morphologically resemble Tibet and the Himalaya mountains on Earth and apparently require several thousand kilometers of surface motion at some time in Venus's past. Loss of liquid surface water increases the coefficient of friction in fault zones, favoring a transition from an early mobile lithosphere to a present-day stagnant lithosphere [2]. Solar-driven climate evolution could contribute to a prolonged epoch of water loss on Venus and may be the ultimate cause of the divergent evolution of both the climate history and the interior dynamics of Venus and Earth.

In addition to being a problem of first-order importance for Solar System evolution, understanding the divergent evolution of Venus and Earth is also important for understanding the temporal and spatial distribution of habitable environments in the Solar System. Understanding the evolution of Venus is also a key test for models that interpret Earth-sized exoplanets. Testing evolutionary hypotheses requires interpreting clues that were left behind in both the isotopic composition of the Venus atmosphere and in the rock record of the Venus surface. Although several mission concepts are currently competing for possible flights to Venus, only the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging Plus (DAVINCI+) mission [3] can examine both the atmospheric isotopic record and the rock record of Venus. DAVINCI+ is therefore a compelling choice for selection in the current NASA Discovery Program Phase A competition.

DAVINCI+ includes an atmospheric entry probe and a carrier spacecraft (Figure 1). The probe measures atmospheric composition using a mass spectrometer and tunable laser spectrometer, performs descent imaging, and measures atmospheric structure. Following completion of the probe mission, the carrier spacecraft enters Venus orbit and images the Venus surface in the 1 micron atmospheric window. This payload is ideally suited for testing models of Venus evolution.

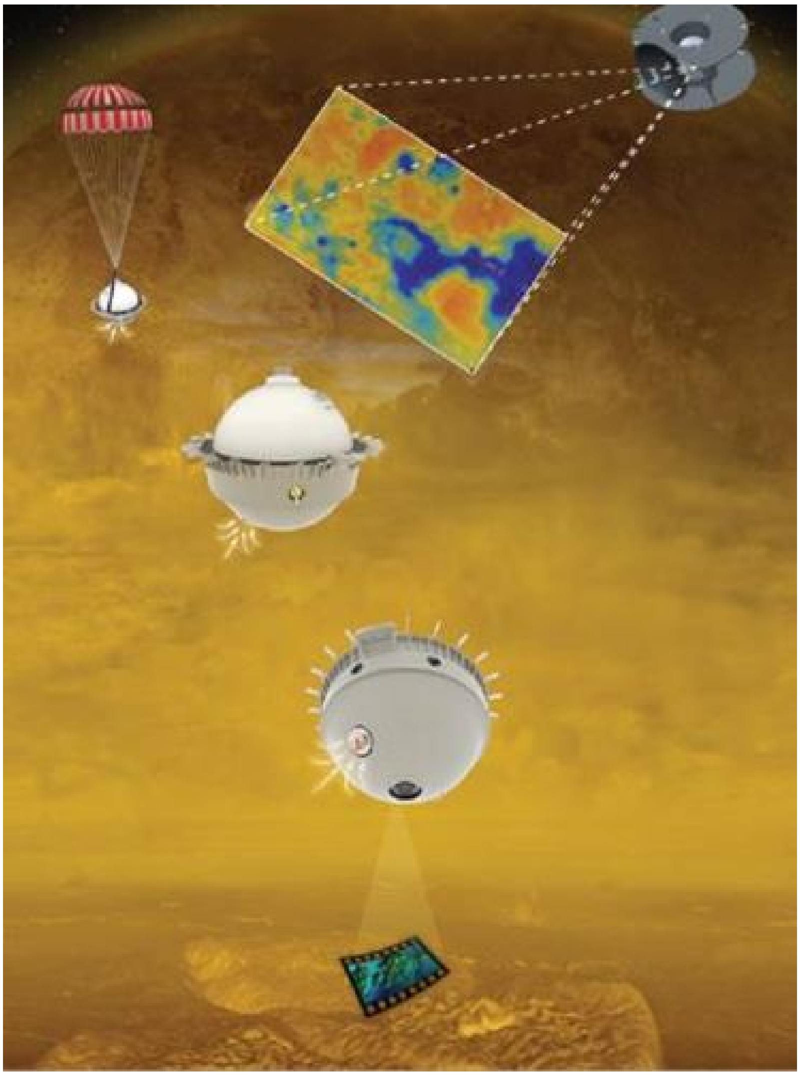

Figure 1: The DAVINCI+ entry probe studies the atmosphere while imaging the Alpha Regio landing site. Afterward, the carrier probe performs infrared imaging of selected targets from orbit.

The History of Water: Isotopic Record

Pioneer Venus measured the D/H value of an H_2SO_4 cloud droplet at ~55 km as 157±30 times the terrestrial value, which was interpreted as the signature of escape of water from the Venus atmosphere [4]. Terrestrial spectroscopy produced a similar range, whereas Venus Express measured a value up to three times larger between 70-90 km [5]. The large value relative to Earth shows that Venus lost a substantial amount of water, but the large uncertainty and the lack of data below the clouds makes it difficult to quantitatively model the history of water loss [6]. DAVINCI+ will measure D/H to high precision from above the clouds down to the surface, greatly improving our ability to interpret the history of water loss on Venus. In addition, the abundance and isotopic ratios of Xe and Kr, together with the Kr/Ar and Xe/Ar ratios, which DAVINCI+ will measure with high precision, will be instrumental in revealing whether Venus and Earth formed in the same way and how their climates diverged.

The History of Water: Rock Record

A key but poorly answered question is the extent to which Venus has produced granitic or felsic (SiO_2-rich) volcanism. Small amounts of felsic magma can be generated by lithospheric processes [7], but large amounts of felsic material requires the presence of water in the melting zone [8], as in terrestrial subduction zones. Tessera, which are regions of old, thick, highly tectonized crust, are widely accepted as the most likely location for felsic material on Venus. Venus Express observations suggest that tessera in Alpha Regio has a felsic composition [9].

DAVINCI+ will explore the presence and distribution of felsic rock in two ways. Comparison of the reflectivity at 1 micron and in panchromatic descent images at the Alpha Regio landing site will test the presence of felsic rock at patch sizes much smaller than can be observed from orbit. Descent imaging will also explore the landing zone geomorphology, and stereo topography will enable quantitative modelling of faulting and folding. Orbital imaging in the 1 micron atmospheric window will test for the presence of felsic rock in other tessera, including Tellus Regio, Fortuna Tessera, Maxwell Montes, Ovda Regio, and Thetis Regio. Our approach is similar to VIRTIS on Venus Express [9] but focuses on regions in the northern hemisphere and near the equator that were not imaged by VIRTIS.

The History of Volcanism: Isotopic Record

Volcanic outgassing releases radioactive decay products such as ^{40}Ar and ^{4}He to the atmosphere. DAVINCI+ measurements of their atmospheric abundance can be used to estimate volcanic outgassing over time. ^{40}Ar provides an integrated record of volcanism over Venus history. Because ^{4}He escapes from the atmosphere to space, its atmospheric abundance constrains geologically recent (last billion years) volcanism. Existing measurements of ^{40}Ar and ^{4}He are too imprecise to strongly constrain the volcanic history of Venus [10] but will be measured with much greater accuracy by DAVINCI+. Because DAVINCI+ will constrain the history of both water and volcanism on Venus, it will provide new insights into the feedbacks that shaped the divergent evolution of Venus and Earth.

References

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