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The science goals of the EnVision Venus orbiter mission

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If Venus were a newly discovered exoplanet, it would be one of the most Earth-like yet identified. Its similarity in size, bulk density and cloud top temperatures give no clue to the hellish temperatures at its surface. Venus hosts an array of geological features as complex as Earth, but without its organisation, and sustains a chemically reactive atmosphere, but without life. Proposed in response to ESA's M5 call, with enabling support from NASA, EnVision is currently in Phase A study for the next medium-class mission opportunity proceeding towards a final mission selection in summer 2021 for a launch in 2032. Here we discuss the science questions motivating the mission in more detail. Building on discoveries from Magellan, Venus Express and Akatsuki, EnVision will focus on three overarching questions:

- Is Venus geodynamically active?
- How did Venus arrive at its current state?
- How does the Venus climate work and how do the interior, surface and atmosphere interact?

1 – Is Venus geodynamically active?

Venus should be geologically active today and its globally young surface implies extensive volcanic resurfacing, but whether this happened in episodic global events or in a continuous process of small-scale resurfacing is uncertain. Constraining the rate of volcanic and tectonic activity can reveal whether Venus occupies one of these end members, or lies somewhere on the spectrum between.

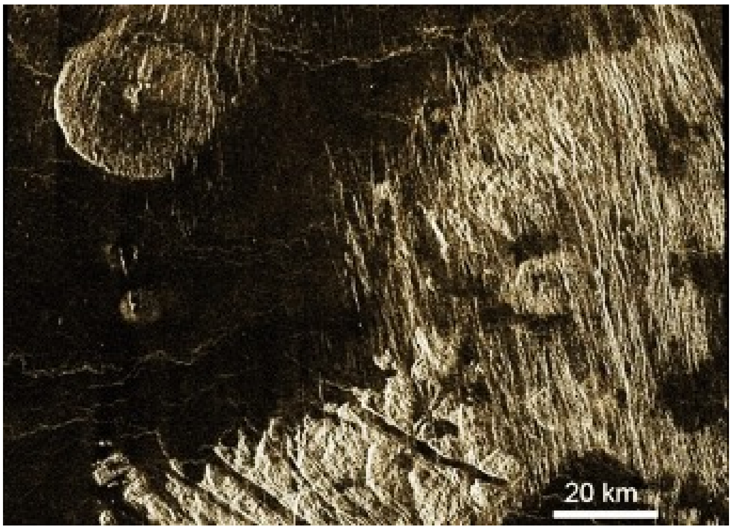
Magellan radar image mosaic of a 550 km wide region of Lada Terra (47°S, 25°E) showing a system of radar-bright and dark lava flows breaching a ridge belt and ponding in a large radar-bright deposit covering 100,000 km². Ammavaru, the source caldera, lies 300 km to the west (JPL/Caltech).

Understanding the tectonic regime driving resurfacing and heat loss is as important as knowing the rate of activity. The surface appears partitioned into areas of low strain bounded by narrow high strain margins. The abundance of steep slopes and landslides implies active uplift in these high strain areas, but existing data provide no constraint on the frequency of landslides or rates of tectonic movement. Are the low strain regions actively created and destroyed, like Earth's oceanic plates, or simply mobilised locally? What is the significance of the global network of elevated rift systems and linear lowland wrinkle-ridged plains? Unique to Venus are coronae, quasi-circular volcano-tectonic features, typically 100–500 km across. Are they the surface expression of plumes, or magmatic intrusions, or subduction zones?

The processes of weathering, mass wasting and aeolian transport are critical for understanding both the geological history and climatic evolution of Venus. Venus Express found anomalously high IR emissivities near suspected active volcanoes, interpreted as fresh, unweathered lava flows, but both their mineralogy and the weathering processes involved are unknown. Magellan detected several, probably impact-related, dune fields at the limit of its resolution, and found indirect evidence for globally distributed smale-scale ripples.

2 – How Did Venus Arrive at its Current State?

The cratering record reveals that the Venus surface is, on average, under 1 Ga old. While some areas are likely active today, other regions, e.g. the tessera highlands, may be considerably older. Magellan data imply a variety of age relationships and long-term activity, with a non-random association between geological features and elevation, e.g. the uplands are consistently more deformed than the lowlands. Impact craters themselves show alteration to dark floors, perhaps from airfall deposits or magmatic resurfacing.



Densely fractured plains (right) abutting tessera (bottom); both are embayed by younger plains (dark areas). A steep-sided volcanic dome (upper left) may be the source of the plains or unrelated to them, and older or younger than the tesserae. Magellan image at 46°N, 360°E, after Basilevsky and McGill (2007).

Constraining the history is critical to understanding not only when and how resurfaced, but whether that activity has changed systematically through time. Were the plains formed in a short period by massive outpourings or by many thousands of small flows over their entire history? Or did many different mechanisms – including sedimentary processes – operate at different times and places? Globally, Venus exhibits perhaps even more tectonic deformation than Earth: what is its role in resurfacing the planet and have the regimes of tectonic deformation changed over time? How did tesserae, especially, accumulate their extraordinary degree of deformation?

The interior of Venus is probably Earth-like, but not the same; its core size is poorly constrained by Magellan gravity data. These data are consistent with an organised pattern of mantle convection but lack the resolution necessary to connect it with geological-scale features.

3 - How does the Venus climate work and how do the Interior, Surface and Atmosphere Interact?

How and why the atmospheres of two Earth-like planets evolved so differently is one of the many compelling reasons to study Venus, directly addressing the question of how our own world became habitable. Understanding its evolution depends on knowing the exchanges between its interior, surface and space.

The lower/middle clouds of Venus as imaged by Akatsuki IR2 camera. Dark areas represent thicker clouds, which may represent volcanic plumes of ash or sulphate particulates. (JAXA/ISAS/DART/Damia Bouic)

Models suggest that the clouds are maintained by a constant input of H_2O and SO_2, both of which vary considerably, perhaps because of volcanic emissions. Elevated D/H ratios indicate the loss of early oceans, but the 'starting' mantle D/H ratio is unknown. Identification of granites in the ancient highlands would support this inference, but the direct detection and characterisation of volcanic volatiles is key to inferring past climate evolution.

Beyond the specific investigations outlined above, however, the most important unknown factor in determining the present day state of Venus and its atmosphere, and how it arrived at that state, is the interaction between the interior, surface and atmosphere: the whole being more than the sum of the parts.

References

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