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Venus: Earth's divergent twin?

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Abstract

Venus and Earth are similar in size and composition, and both may have had liquid water and mobile lithospheres with active surface geology in early Solar System history. However, Venus later evolved to a hot, dry planet with a stagnant surface. The European Space Agency (ESA) medium class mission candidate EnVision would improve our understanding of the divergent evolution of Venus and Earth. NASA is considering potential partnerships with ESA on EnVision, including a possible contributed synthetic aperture radar (SAR).

1. The evolution of Venus

Venus today is a hot, dry world with a stagnant surface, starkly different from Earth's liquid water and mobile lithosphere with active plate tectonics. However, Venus was not always this way. Ishtar Terra consists of a 1800 x 2700 km across, 3.5 km high, flat plateau (Lakshmi Planum) surrounded by folded mountain belts 8-11 km high. This indicates a compressional origin, possibly as fold and thrust belts [7], similar to the Tibetan Plateau and Himalaya Mountains on Earth. The high topography is supported by thickened crust. Producing this crustal thickening requires a minimum of 2000-3000 km of crustal convergence driven by mantle convection [8] at some point in Venus's history. The complexly deformed tessera terrains are the stratigraphically oldest geologic units on Venus, and they too may record a history of collisional deformation [4] associated with an early mobile lithosphere.

The geologically younger portions of Venus show much less evidence for active surface deformation. For example, the stratigraphically young Devana Chasma rift system records only 10-30 km of extensional deformation [10], similar to continental rift systems such as the East African Rift system on Earth. The geologically recent volcanism rate on Venus may be only 10% of the Earth's present-day average rate of effusive volcanism [12]. Ridge belts in the Venus plains, such as Atalanta Planitia or Lavinia Planitia, appear to record an intermediate level of tectonic deformation and thus may trace to a time when Venus had begun to decline in its geologic activity.

This geologic evolution may be due to a loss of liquid water. Water is known to reduce the coefficient of friction on plate boundary faults and thus appears to play a key role in enabling plate tectonics on Earth. The solar-driven climate evolution of Venus [14] could have caused a prolonged epoch of water loss [5], which in turn would lead to a transition from an early mobile, deformable lithosphere to the present-day, relatively stagnant, single-plate planet [15].

Understanding the divergent evolution of Venus and Earth is one of the fundamental issues in planetary science. Among the critical science questions for understanding Venus are therefore (1) How and when did Venus diverge from Earth to reach its present state?, and (2) How geologically active is Venus today? Key measurements for understanding the evolution of Venus are needed both from orbiting spacecraft and from deep atmospheric probes, which provide complementary and essential views of Venus. The evolution of Venus over time from an early mobile lithosphere to the present, less active world is recorded in the geologic record and can be measured by radar imaging and altimetry from an orbital spacecraft. Measurements of the abundances and isotopic composition of atmospheric noble gases and the D/H isotopic ratio by an atmospheric probe can constrain the initial sources and abundance of planetary volatiles as well as the amount of subsequent water loss [5]. Some atmospheric noble gases, such as ^{40}Ar and ^{4}He, are volcanic outgassing products and their abundances can constrain the long-term and geologically recent volcanism rates [9].

2. The EnVision mission concept

EnVision is one of three mission concepts currently in a Phase A study as part of ESA's Medium Class

M5 mission competition. EnVision includes a SAR, a subsurface sounding radar, a spectrometer suite focusing on infrared and ultraviolet observations of the atmosphere and surface, and a radio science experiment. Possible selection for flight could occur in mid-2021, with launch in 2032. EnVision's prime mission includes four 243-day mapping cycles of Venus, with a possible extended mission of two additional mapping cycles.

3. Possible NASA participation in the EnVision mission

NASA is currently considering collaborating with ESA on the EnVision mission. Specifically, NASA is considering providing an S-band SAR with a competitively selected science team that would be open to both US and ESA members. The SAR would be capable of imaging broad regions of Venus at ~30 meters/pixel, which is 4-10 times better than Magellan radar imaging. Selected subsets of these regions would also be imaged at ~6 m/pixel. The radar images could be collected using dual radar polarization (either circular or linear polarization), which would help to identify geologic units with different surface textures, for example distinguishing bare lava flows from weathered lavas and soils [3]. There would also be a passive mode for measuring the microwave emissivity to distinguish regions of differing dielectric constant or permittivity. In most cases, the dielectric constant will depend on the density and porosity of the material, for example distinguishing soil from fresh rock, but in some regions of Venus, the permittivity appears to have a compositional origin [2, 13]. It may also be possible to detect thermal anomalies associated with active volcanism via the microwave emissivity data [1].

Topography of the regions imaged by the SAR would be measured with a horizontal resolution of a few hundred meters per pixel by a combination of stereo imaging, interferometric SAR (InSAR), and nadir altimetry profiling. The horizontal sampling of the topography would be at least an order of magnitude better than that obtained by Magellan. This high-resolution topography would enable quantitative modeling of surface processes, which is difficult or impossible using currently available data. For example, quantitative modeling of faulting and folding in tectonic regions can constrain the magnitude of tectonic deformation and changes in heat flow as a function of time, as has been done on Mars [11]. High-resolution topography would also constrain the evolution of volcanic eruption volumes over time, as recorded for example in the form of post-impact crater fill on the floors of large craters [6]. Selected portions of the surface would be imaged on multiple mapping cycles, allowing possible active surface deformation due to tectonic or volcanic processes to be detected by differential InSAR. Other potential NASA contributions to EnVision that are under consideration include a high wattage telecommunication system and telemetry downlink time on the DSN tracking network to facilitate return of the large volume of SAR data.

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