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The EvolVe mission concept - unveiling the evolution of Venus

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Abstract

Venus and Earth are similar in size, bulk composition and distance from the Sun; both are located within the habitable zone. Nevertheless, their surface conditions reveal that they are two very different worlds; Venus, unlike Earth, cannot support life on its surface. The aim of this mission is to determine how and why Venus evolved so differently by exploring its past and present geologic activity. The concept was designed by young scientists and engineers during Alpbach Summer School 2014.

1. Science objectives, requirements

To understand the reasons of this difference, we address the following scientific questions:

1. What is the tectonic history of Venus?
2. What is the current volcanic activity of Venus?
3. Was the initial bulk chemical composition of Venus and Earth different?

Plate tectonics is ever-present and determines the face of our planet, creating new crust at mid-ocean ridges and destroying it at converging margins. Tectonism on Venus shows differences that are not fully understood, such as features suggesting obduction zones. On a global scale, the surface presents a half billion year record of volcanic activity, but notably, based on impact crater distribution, it appears uniform in age. This has led to theories of catastrophic global resurfacing [1], and change to a stagnant lid state [2], while others suggest a stable tectonic regime [3].

One way to retrieve information on tectonic structures and crustal thickness is by investigating the gravitational field generated by the upper mantle and the lithosphere, including correction with the topography. Venus topography shows rift-like features of 1000s of km length and 10-100 km width along great circles, with similarities to Earth's mid-ocean ridges. Currently the gravity field is known with a spatial resolution of 700 km [4], insufficient to analyse such effects. Our simulations show that using a GOCE-type gravity gradiometer at an orbital height of 250 km, a spatial resolution of 85 km can be reached. Additionally, terrain models are to be improved, and for selected areas (10% of the surface), high resolution (40 m spatial, 4 m vertical) stereo topography shall be obtained (using InSAR, scanning targeted areas twice).

Lithospheric thickness can also be estimated by aerial EM sounding, which shall be achieved by a balloon at 50-60 km altitude, using naturally occurring EM resonances and perturbations. These can penetrate the crust to 50-100 km depth on a dry Venus.

The degassing rate of Venus has implication to its overall tectonic and thermal evolution. Previously measured $^{40}Ar/^{36}Ar$ ratio can be indicative of this, but an independent isotope ratio such as $^{3}He/^{4}He$ is to be measured to better constrain models, calling for a balloon mounted gas chromatograph mass spectrometer.

Volcanic activity on Venus is suggested by surface geochemistry from Venera landers, landforms resembling volcanoes and variations in atmospheric SO_2 abundance. Recently, heat pulses from the surface detected by Venus Express have been interpreted as a sign of magma release.

We plan to monitor long-term SO_2 abundance variations using a UV spectrometer. Secondly, we intend to identify hotspots with an IR spectrometer. Based on those measurements, we will select target areas of probable activity to detect changes in morphology and elevation with an InSAR (spatial and vertical resolution <100 m and <1 cm, respectively). This requires repeated passes over at least one Venerean day, which is met by the designed circular polar orbit.

Initial bulk chemical composition can determine the evolution of a planet. Measuring the currently poorly known size of the core of Venus could constrain its composition. We plan to do so by estimating low-degree gravity field coefficients by Doppler tracking [4]. Additionally, an EM sounding method based on magnetic field observations from the balloon will be used to determine core size, in a manner used before for the Moon [5]. Finally, to compare the source of water on Venus and Earth during their formation, isotopic ratios of noble gases (as a proxy to other volatiles [6]) will be measured, such as ^{22}Ne/^{20}Ne and ^{21}Ne/^{20}Ne.

Table 1: Orbiter and balloon (below) payloads.

Instrument, objective#	Ranges
Gradiometer[1]	BW: 5MHz-0.1Hz
	Noise: 3mEHz$^{-1/2}$;
Radar altimeter[1,2]	sample freq.: 50Hz
	alt. accuracy: 1 m;
SAR/InSAR[1,2]	S-Band, SW=40-70 km
	sp. res.: $\sim$10 m;
IR/UV spectrometer[2]	λ: 0.7-5μ, 110-310μ
	sp. res.: 50km;
Mass Spectrometer[2,3]	2-150, res. 0.1 AMU;
MT sounding[1,3]	freq.: 100Hz;
Flux gate magnetometer[1,3]	sample freq.: 20Hz;

2. Mission Overview

The mission consists the following phases:

Phase 0: Hohmann transfer to Venus (5 months)
Phase 0a: orbit injection, aerobraking (2-6 months)
Phase 1: balloon operation (19 Earth days)
Phase 2a: geodesy (1 Venus day)
Phase 2b: stereo topography (2 Venus days)
Phase 3: delta topography (1 Venus day)
The total mission duration is 3.2 Earth years.

3. System Overview

The mission consists of an orbiter and a balloon. The balloon, travelling passively with the winds, will circle the planet 2-3 times during its short lifetime. The main drivers of the orbiter system and mission design were the conflicting requirements of the gradiometric measurement (needing a drag-free environment) and the InSAR (drawing high power and producing high data rates). During phase 2a steerable elements are fixed to reduce drag and vibrations and remaining drag is compensated by an electric microthruster taken from LISA. During phases 2b and 3, solar arrays are pointed to increase output and downlink to Earth is made via a 2 m steerable X-band parabolic main antenna. A further challenge is thermal control, which is maintained by insulation and a radiator on 1 permanently cold face.

Risk assessment shows that even though we used the most pessimistic atmospheric model, its uncertainties remain the largest risk factor to achieving the primary science objective. This can be mitigated by large margins on the propulsion system and by further investigation of atmospheric models (e.g. incorporation of VexADE and other new results).

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