The EvolVe mission concept – unveiling the evolution of Venus

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Introduction

Venus and *Earth* are similar in size, mass, and distance from the Sun; both are located within the habitable zone. However, their surface temperature, pressure and chemical composition reveal they are to very different worlds. As a result, our *sister planet* Venus, unlike Earth, cannot support life on its surface. The aim of the EvolVe mission is to investigate why and how Earth and Venus evolved so differently. This will help us to constrain the conditions necessary for the emergence of life on our planet as well as on others, including exoplanets. The importance of this scientific topic is reflected in its inclusion in ESA's *Cosmic Vision 2015-2025* programme, as well as in NASA's *Vision and Voyages 2013-2022* report.

Venus	Earth
6050 km radius	6400 km radius
5.25 g/cc density	5.53 g/cc density
100 bars of CO2	100 bars of CO2 equivalent
Surface consistent with basaltic volcanism	Basaltic volcanism
Large iron-rich core inferred	Large iron-rich core
0.73 AU	1 AU
Thick atmosphere no water(?)	Thin atmosphere, water ocean
462 °C	14 °C
Stagnant lid / previously mobile?	Plate tectonics
243 day rotation	24 hour day
No intrinsic magnetic field	Internal dynamo

Scientific objectives

To understand the reasons of Venus being so different, 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?

Context

•*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 [1]. This has led to theories of catastrophic global resurfacing [2], and change to a stagnant lid state [3], while others suggest a Stable tectonic regime [4].

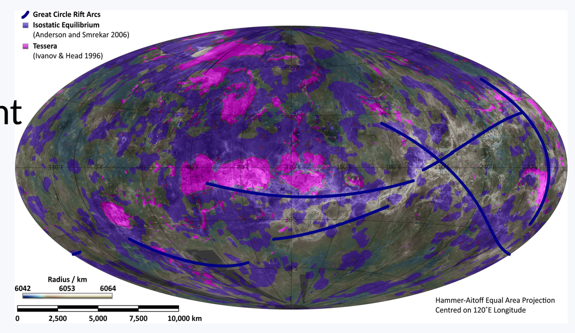


Fig. 1 Tectonic features on Venus © 2015 Richard Ghail.

•*Volcanic activity* on Venus is suggested by surface geochemistry from Venera landers [5], landforms resembling volcanoes and variations in atmospheric SO_2 qabundance. Recently, heat pulses from the surface detected by Venus Express have been interpreted as a sign of magma release (Fig 2) [6].

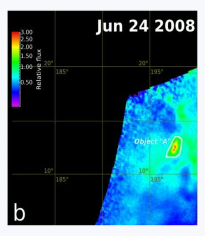


Fig 2 Image taken by VEx VMC, see [6].

•*Initial bulk chemical composition* has a significant effect on the geophysical properties of a planet, such as its internal structure, thermal and tectonic evolution. If Venus and Earth started with different bulk composition, it would mean that they were progressing along different evolutionary paths from the very beginning. It would also tell us about accretion history in the early Solar System. While models suggest this is not the case, we don't have firm knowledge yet.

Surface, by Venera 13. © 2003,2004 Don P. Mitchell

Observations

•1. 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, (Fig 1) [7] with similarities to Earth's mid-ocean ridges. Currently the gravity field is known with a spatial resolution of 700 km [8], 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 (Fig. 3)

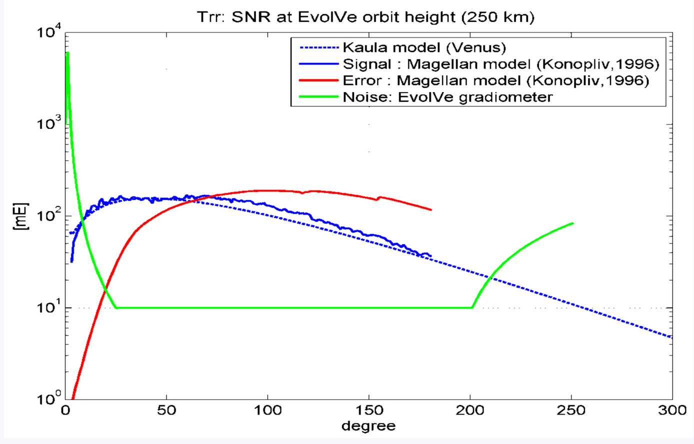


Fig. 3 At an orbital height of 250 km, SNR reaches 1 near spherical degree and order 220, corresponding to a spherical scale of 85 km.

	Magellan	EvolVe
Gravity measurements		
Spatial resolution:	300 - 700 km	80 km
High resolution topography	(SAR stereo)	(SAR stereo / InSAR)
Coverage:	20%	10%
Spatial resolution:	1-2 km	40 m TBC
Vertical precision:	50 m	<4 m
Radar imaging		
Coverage:	global (96%)	20 %
Spatial resolution:	100 m	10 m TBC

Fig. 4 A comparison of Magellan and Evolve

To obtain topographic evidence of tectonics and other geophysical processes, terrain models are to be improved using a synthetic aperture radar (SAR). 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), see Fig. 4.

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 [9].

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 gas chromatograph mass spectrometer, mounted on a balloon that is inserted in the planet's atmosphere.

•2. 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 these measurements, we will select target areas of probable ongoing activity. Changes in morphology and elevation will be detected with 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 and extended mission timeline.

•3. 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 [8]. 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 [10]. 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 [11] will be measured, such as $^{22}Ne/^{20}Ne$ and $^{21}Ne/^{20}Ne$.

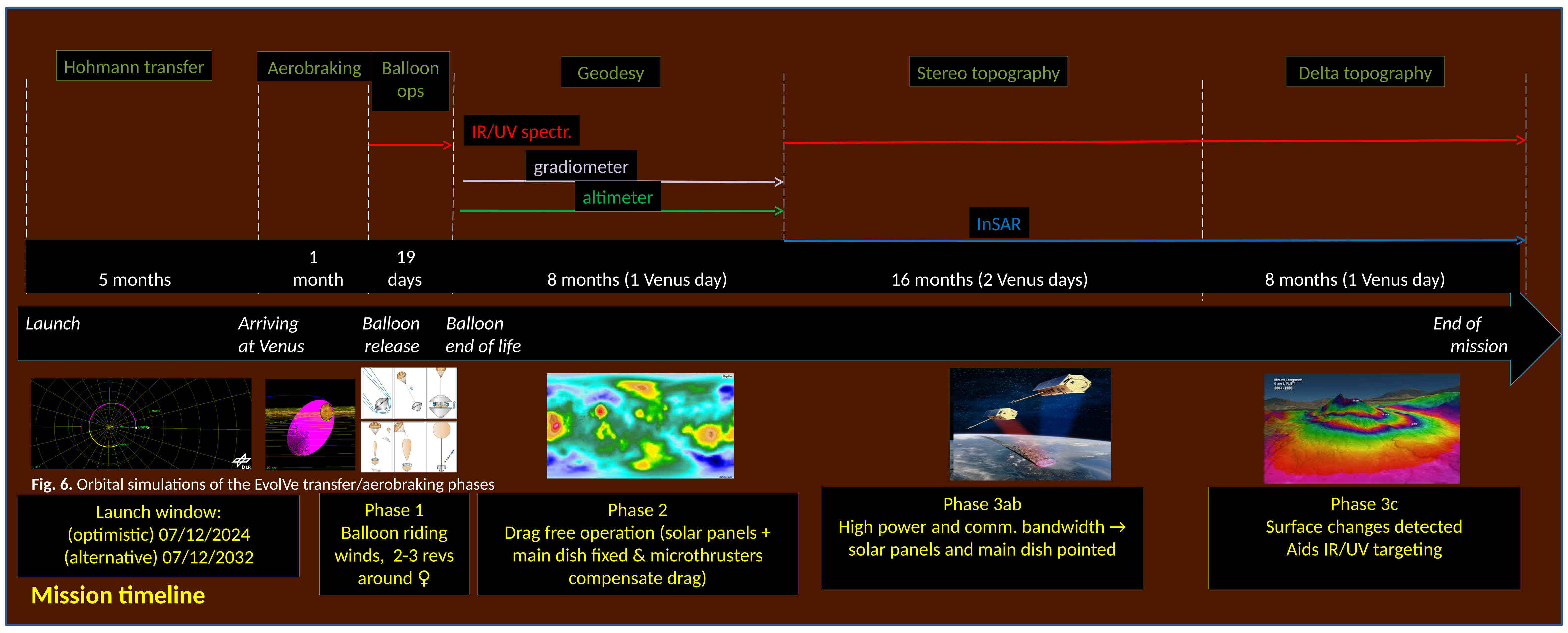


Fig. 6. Orbital simulations of the EvolVe transfer/aerobraking phases

	Instrument	Measurements	Goal	Ranges	Mass Power Data rate
SATELLITE	Gradiometer	Gravity gradient	1	Band with: 5MHz-0.1 Hz Noise: 3mEHz$^{-1/2}$	137 kg 65 W 1.7 kbps
	Radar Altimeter	Altitude	1,2	Sample Frequency: 50 Hz Altitude Accuracy: 1 m	6 kg 1 W 1 kbps
	InSAR	Topography, Delta Topography	1,2	S Band (λ= 12 cm) 10% of surface coverage Look Angle 35-45° SW=40-70 Km Spatial Resolution <40m Vertical accuracy ≈cm	120 kg 800 W 5.3 GB/day
	IR/UV Spectrometer	Detection of SO_2, detect spots with high thermal flux on the surface	2	Spectral Range (μm) 0.11-0.31 and 0.7-5; Spectral Resolution ≈1nm; Spectral Resolving power: λ/Δλ= 100-200 Spatial resolution: 50 Km	20 kg 18 W 6 kbps
BALLOON	Mass Spectrometer	Noble gases ratio in the atmosphere for the accretion questions, bulk chemical composition	2,3	Resolution: 0.1 AMU Range: 2-150 AMU Sensitivity: 0.1 ppb Accuracy ± 1%	18 kg 43 W 1 kbps
	MT sounding	Thickness of crust, lithosphere, thermal gradient for tectonics questions, ground water content	1,3	Frequency: 100 Hz	3.1 kg 2.7 W 5 kbps
	Flux gate Magnetometer	Magnetic field measurement for the bulk composition	1,3	Sample Frequency: 20 Hz	3.1 kg 3.6 W 1.2 kbps

Fig. 5 Payloads on the mission's orbiter and balloon; *goal* refer to the corresponding scientific objectives.

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 (mission *phase 1*). The orbiter conducts a gravimetry campaign *(phase 2)*, and a SAR/InSAR campaign *(phases 3ab/c)*. 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 SAR (drawing high power and producing high data rates). During *phase 2* steerable elements (solar panels and main dish) are fixed, in order to reduce drag and vibrations and the remaining drag is compensated by an electric microthruster taken from LISA. During *phases 3ab* and *3c*, solar arrays are pointed towards the Sun to increase power output and downlink to Earth is made via a 2 m steerable X-band parabolic main antenna. A further challenge is thermal control (because of strong direct solar irradiance and also reflected from Venus), which is maintained by insulation and a radiator on 1 permanently cold face.

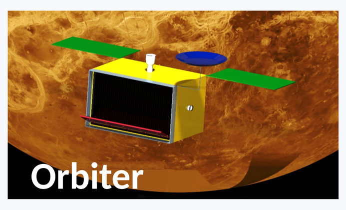
Risk Assessment

Risk assessment shows that even though we used the most pessimistic atmospheric model, its uncertainties (cf. VIRA and Seiff) 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 latest VexADE and other results).

Probability / Severity	*1*	*2*	*3*	*4*	*5*
5	B, M	N	A		
4		E, I	G	H	
3	K	C	F	L	
2	J	D		O	
1					

Severity		Probability	ID
5	Drag in orbit too high for measurements	3	A
5	LV failure	1	B
3	LV injection error	2	C
2	Solar Panel damage	2	D
4	Trajectory failure	2	E
3	HGA pointing error	3	F
4	Loss of Balloon (Reentry, Venus environment)	3	G
4	Insufficient Orbit Determination	4	H
4	Balloon Deployment Failure	2	I
1	Ariane V decommissioned	2	J
3	Solar Array pointing error	1	K
3	Solar Particle Event	4	L
5	Failure to deploy appendices	1	M
5	Pointing accuracy insufficient for gradiometer	2	N
2	Reduced data transmission rate	4	O

Mass, power, communications



- Dry mass: 1099 kg
- Propellant mass: 2042 kg
  - Orbit Injection: 1811 kg
  - Maintenance: 231 kg

1660 W (all systems active)

Antenna size on orbiter: 2.0 m, (to 35 m receiver on Earth)

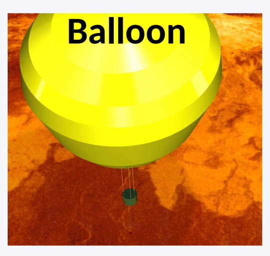
Power: 230 W

Frequency: 8.5 GHz, X-band

Maximum possible Data Rate E/N : 1.924 Mbps

Power (W)	with margin	Data rate (kbps)	With margin
463	**555**	143	**151**
463	**555**	36	**37**
1211	**1423**	341	**358**

Fig. 7 Orbiter power budget and data rates



Superpressure light gas balloon

Gas generated at deployment

Approx. 7 m diameter

292 kg (on spacecraft)

Power: 61 W

ELEMENTS	[M€]
LAUNCHER (Ariane 5)	175
SPACECRAFT (Platform ~xKg + propellant ~ 2100 Kg)	350
ENTRY PROBE (Including balloon, ~290 Kg)	300
SCIENCE OPERATIONS	40
GROUND OPERATIONS	60
PROJECT MANAGEMENT	70
INDUSTRIAL MARGIN (10%)	65
PROGRAM MARGIN (15%)	200
PROGRAM COST TO ESA	1260
PAYLOAD (~500 Kg)	500
TOTAL COST (including margin)	**1760**

Fig. 8 Cost analysis

Summary

We identified a set of fundamental questions regarding the history of Venus, the observations necessary to answer these, and through a gradual process, designed a space mission for this task.

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