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EvolVe - A Mission to determine the Evolution of Venus

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Abstract Venus is similar to Earth in many ways, yet the surface of Earth's sister planet is subject to extreme environmental conditions. In this report a mission to Venus is proposed that will investigate the evolution of Venus and address the question of why Venus is so different from Earth. The aim is to investigate, through use of an orbiter and a balloon, the tectonic evolution, the current levels of volcanism and the bulk composition of Venus. The mission will result in a greater understanding of Venus and of planetary formation and evolution in general, which will contribute to understanding of planetary habitability and the conditions that lead to life as we know it.

1 Introduction and scientific background

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 two 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 emergence of life on our planet as well as on others (including exoplanets).

The importance of this scientific topic has been recognized in ESA's and NASA's strategic plans. To answer the first question stated by the Cosmic Vision (ESA, 2005) it is necessary to study what are the conditions necessary for planet formation and emergence of life. Similar questions are raised in Visions and Voyages (NRC, 2011) in the *Building New Worlds* section.

2 Scientific objectives

In order to learn why Earth and Venus evolved differently we will address three following scientific questions.

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

2.1 Primary objective: Venus tectonics

On Earth, plate tectonics are ever-present and determine the face of our planet, creating new crust at the mid-ocean ridges, destroying (and recycling) it at converging margins between ocean and continental plates, and forming towering mountain ranges through orogenesis. It creates long tracks of volcanoes along plate margin. Moving tectonic plates are responsible for earthquakes and in general some of the most striking characteristics of our planet.

Venus' surface exhibits "a half-billion year record of volcanic activity, with visible plains, volcanic rises, coronae, chasmata and crustal plateaus" (Anderson et al., 2004). However, tectonism on Venus shows differences to Earth's plate tectonics that are not fully understood. Some theories suggest that there are obduction zones on Venus that are substantially different from processes on Earth, such as subduction and mountain formation. One of the major question is the state of plate tectonics on Venus. If the *stagnant lid theory* (Solomatov and Moresi, 1996) is correct, the buildup of heat in the mantle will make the mantle hotter than the core preventing its cooling and solidification, and hindering formation of a planetary magnetic field on Venus.

One way to retrieve information about past tectonic activity is by investigating the gravitational field generated by the mass distribution in the upper mantle and the lithosphere. The mass distribution is a result of the response of the lithosphere to the extensional and bending forces as well as to the thermal instabilities (hot spots) in the upper mantle. Gravity information used together with topographic information can reveal thermal instabilities (weak crust) through their association with density anomalies. Venus topography shows rift-like features of 1000s of kilometers length and 10 -100 km width along great circles that have similarities to those known from the bathymetry on Earth (Ghail, 2014). Rifts are common tectonic features and are often associated with upwelling of hot material from the mantle, that become visible because of their negative density with respect to the normal mantle density. The small-scale structures on Earth have a magnitude of 10 - 30 mgals and become visible at scales of 50 - 100 km.
Currently Venus' gravity field (Konopliv, 1999) is known with a spatial resolution of 700 km (over large parts of the planet), and because of that it is not possible to locate and analyse such effects. EvolVe's gravity gradiometer (GOCE-type, ESA-SP-1233, 1999) will fill this gap and provide short-scale gravity information far beyond Magellan's capabilities. Simulations have shown that, at an orbital height of 250 km, the signal to noise ratio of one (SNR=1) will be reached near spherical degree and order 220, which corresponds to a spatial scale of about 85 km. The gravity gradiometer is necessary to achieve this high resolution, because gradients (second derivatives of the gavitational potential) at orbit height, relatively to other gravity functionals, have highest energy at short scales.

Digital models of the topography are another valuable source that can be used to determine litospheric properties such as the elastic behaviour and crustal thickness. Crustal thickness is a major driver for tectonic models and isostatic models, and therefore an important parameter. We plan to retrieve the crustal thickness by two methods with an accuracy of 10 kilometres. First one is based on analyzing Bouger anomalies, which can be understood as gravity anomalies corrected for the topographic masses. In order to do so, topography needs to be determined with a vertical accuracy of 10 m (ESA-SP-1233,1999) at a few tens of meters spatial resolution. Current topography from the Magellan mission is given with 1-2 km spatial resolution and a vertical accuracy of 50 m for 20 % of the planet. Additionally, for the selected areas (10 % of Venus), the InSAR instrument on the orbiter of EvolVe will provide data on the high resolution topography (spatial resolution 40 m and vertical accuracy on the order of meters).

Estimation of the crustal thickness can be also done by the EM sounding from a balloon inserted into the Venus atmosphere at an altitude 50-60 km. Due to the extreme conditions at the surface of Venus, use of a ground-based method is restricted by the amount of time the ground probe could survive. To do EM sounding on Venus, we will make use of the natural EM resonances and perturbations such as the Schumann resonances from lightning, which penetrate the crust to 50-100 km in a dry Venus. The Schumann resonance frequency is expected to be at 9-11 Hz. For this reason we will sample in the range 1-100 Hz to pick up the Schumann resonance frequency and all higher fundamentals. The method is based on a proposal by Grimm et al. (2012) for EM sounding in Venus atmosphere. As an aside, EM sounding is able to provide estimates of water content in the mantle through data inversion and derivation of subsurface conductivity.

The overall extent of Venus tectonic activity expressed by degassing of the interior can be also determined from measurements of radiogenic noble gases in the atmosphere. Measurements of 40Ar/36Ar ratio, performed by Venera 11 and 12, give a value of 1.19 $\pm$ 0.07 and were confirmed by Pioneer Venus to be 1.03 $\pm$ 0.04 (Fegley 1995). Those results indicate that Venus is much less degassed than Earth, Mars or even Titan, where this ratios are in the range of 150-2000 (Owen 1992, Artreya et al. 2006, Pujor et al. 2013). The low degassing rate on Venus has strong implications for the thermal and tectonic evolution of Venus and can support the stagnant lid theory (Solomatov and Moresi 2012). However, since lower amounts of 40Ar can be also caused by significantly lower amounts of 40K (from which radiogenic argon is produced), in order to better constrain stagnant lid theory we need to measure an independent isotope ratio such as 3He/4He. This measurement will be performed with a gas chromatograph mass spectrometer similar to the one that was used on the Huygens Probe (Niemann et al. 1999) or consisting of elements from the SAM instrument on Curiosity Rover (Mahaffy et al. 2012). The scientific requirements for this experiment are: an accuracy of ± 1 % sensitivity of 0.1 ppb, mass resolution of 0.1 AMU and mass range 2-150 AMU.

2.2 Secondary objective: Venus volcanic activity

Volcanic activity is one of the most prominent manifestations of the internal activity of a planet. Determining the degree and characteristics of the present Venus' volcanic activity will help us better constrain the models of its internal, surface and atmospheric evolution that led to the planet being very different from Earth. Multiple lines of evidence suggest that Venus is a volcanically active planet. Venus is similar in size to Earth and its cooling rate should be sufficient to support volcanism. Geochemical composition of relatively fresh rocks measured by Venera landers is consistent with volcanic rocks, namely basalts (Surkov 1997). Their age is not known, but dating performed by crater counting shows that the surface of Venus is very young, likely less than 500 Ma (McKinnon et al. 1997) and covered by numerous landforms that resemble volcanoes (Head et al. 1992). In addition, the measured variation of the atmospheric abundance of SO_2 has been interpreted to be a result of volcanic activity (Esposito et al. 1997, Marcq et al. 2013). However, other explanations such as long term variation in the circulation within the mesosphere (Clancy and Muhleman 1991) are also a possibility. Recently, short-term (order of few days) heat pulses from the surface were detected by Venus Monitoring Camera onboard of Venus Express (Shalygin et al. 2014), they were interpreted to be proof of very recent magma release. However the extent of this process has not yet been determined.

We will determine the extent of current volcanic activity on Venus in four different manners. First, we will perform a long term monitoring (over the entire time-life of the mission) of SO_2 abundance variation in the atmosphere with a UV spectrometer based on the SPICAV instrument onboard Venus Express. Scientific requirements for this instrument are a spectral range of 0.11-0.31 μm, spectral resolution of 0.8 nm, spectral resolving power of $\sim$ 300 and field of view 55x8.7 rad. Secondly, we will be detecting spots with high thermal flux on the surface with an IR spectrometer based on elements of the SPICAV and VIRTIS instruments onboard Venus Express. Scientific requirements for this measurement are a spectral range of 0.7-5 μm, spectral resolution of 0.8 nm, spectral resolving power of $\sim$ 100-200 and field of view 64x64 rad. Based on those measurements we will select areas (up to 10 % of Venus surface area) where active volcanism is the most probable and perform measurements of small scale changes in morphology and elevation with an InSAR. Scientific requirements for this experiment are a spatial resolution of $<$ 100 m, vertical resolution of $<$ 2 cm, and the monitoring of selected locations over a time span of at least one Venusian day (actual changes are expected to happen in within a few days). Due to our orbit the monitoring will happen twice per Venusian day, which is sufficient. Finally, in order to confirm the volcanic origin of SO_2 and other volcanic gases in Venus atmosphere we will perform an in situ atmospheric measurement of their isotopic ratios with a gas chromatograph mass spectrometer described above, but with higher temporal resolution (once every 12 hours).

2.3 Secondary objective: Venus bulk initial chemical composition

The geophysical properties of a planet, such as its internal structure, thermal and tectonic evolution, depend heavily on its bulk chemical composition. If Venus and Earth have a different bulk composition, it would mean that these two planets were proceeding along different evolutionary paths from the very beginning. This discovery would significantly alter our definition of the habitable zone.

The bulk chemical composition of the terrestrial planets is not well-determined due to lack of samples from deeper part of the mantle and the core, but some inferences can be made from analysis of meteorites (Hutchison 2007). General comparison of Venus and Earth's bulk chemical composition can be performed in two ways: by comparing the sizes of their cores and by comparing isotopic ratios of noble gases in their atmospheres. The current estimation of the size of the Venus core (R=3200 km; Yoder 1995) is based on downscaling of a model for the interior of the Earth (R=3480 km; Dziewonski and Anderson 1981) to fit the radius and previously measured gravity field of Venus. This estimation is correct only in the case where the two planets have an identical chemical composition - if the matter from which Venus accreted included more iron, then the core of Venus would be larger. We will measure the size of the core of Venus by estimating the low-degree gravity field coefficients by Doppler tracking (dynamic orbit analysis, e.g. Konopliv et al. 1999) from which the moment of inertia of the planet can be determined. The low degree coefficients (especially J2) shall be determined with a better accuracy than current knowledge from Magellan, taking advantage of our low (circular) near-polar orbit configuration shows a higher sensitivty for those coefficients. Additionally, we attempt to determine core size with an electromagnetic sounding method based on magnetic field observations from a balloon as applied in a similar manner previously for the Moon (Shimuzu et al. 2013) and Europa and Callisto (Khurana et al. 1998). This method was also recently proposed for Venus (Grimm et al. 2012, Russel et al. 2014). It requires night-side observations and at least one solar wind event to measure its induced effects on the ionosphere on Venus. The magnetometer has to be able to measure variations in the order of 0.1 nT.

Evolution of early bulk chemical composition (including volatiles) of a planet can be also studied using the analysis of noble gases released from the planet's interior during volcanic activity or deposited on its surface by collisions with comets and incorporated into the atmosphere. Noble gases are thermochemically and photochemically inert and their ratios undergo predictable changes that can be modeled relatively easy. For this reason, they preserve information on how planets formed and evolved over time (Mukhopadkyay and Steward 2014). For example, if the 22Ne/20Ne and 21Ne/20Ne ratios measured in Venus atmosphere fall on the terrestrial fractionation line (Mukhopadkyay 2013), it means that Ne on Venus and Earth was delivered from the same source (Baines et al. 2007). Since during the phase of Solar System formation noble gases were associated with other volatiles, we can use them as a proxy to infer the sources of water on Venus and Earth. During the EvolVe mission, we will perform in situ atmospheric measurements of noble gases' ratios and aFbundances (He, Ne, Ar, Kr and Xe) with the gas chromatograph mass spectrometer described above.

3 EvolVe Payloads

The instruments necessary to achieve the scientific goals of the EvolVe mission are listed in Fig. 1, together with their link to the respective scientific goal, observable, accuracy, mass, power consumption and required data rate.

4 Mission Design

4.1 Top-Level Requirements

The Top-Level Requirements are derived from the scientific requirements defined in Section 2.

Tectonics

a) The mission shall use a 0.15 rad precisely pointed Gravity Gradiometer to determine Venus gravity field up to short scales (80 km) at 250km orbital altitude with 5mGal accuracy. During the measurement the spacecraft has to be in drag-free environment.

b) Additionally a nadir pointing radar altimeter will be needed in order to improve the orbit determination accuray by cross-track analyses.

c) Repeated pass to obtain the stereo topography of

	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. 1 Payloads mounted on the orbiter *ISHTAR* and the balloon *TAMMUZ* of EvolVe mission; the column goal refers to the major scientific objectives: 1 = tectonics, 2= volcanism, 3= bulk composition

Venus with a single InSAR (Interferometric Synthetic Aperture Radar) antenna. Spatial resolution and accuracy shall be 40 m and in the order of meters, respectively.

d) An MT sounding device should be used to measure the thickness of the lithosphere and the water content doing a 1-100 Hz sampling.

Volcanism

a) The mission shall employ a mass spectrometer to measure the atmospheric isotopic composition of noble gases. At minimum, every noble gas isotopic ratio shall be measured at least once.

b) Recent volcanic activity shall be detected using an IR/UV spectrometer. Sulfur, ash, and water crystals shall be detected with a spatial resoltuion of about 50 km, with a field of view of 64 x 64 rad.

c) An InSAR shall be supported by the mission to detect changes in topography due to volcanism. The vertical and spatial resolutions are less than 2 cm and less than 40 m, respectively.

Bulk Composition

a) A fluxgate magnetometer shall be used to estimate the size of the core. It should have an accuracy of 50 pT and requires the knowledge of the attitude of the balloon.

4.2 Mission phases and orbit scenario

EvolVe will consist of the following four defined mission phases:

- **Phase 0 :** transfer to Venus (5 months)
- **Phase 0a:** orbit injection (2-6 months)
- **Phase 1 :** balloon (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 estimated 3.2 years.

Date	07-12-2032	07-12-2040
C3 (km^2/s^2)	10.61	10.09
Travel time(days)	159.62	157.52
Injectable mass (kg) (ARIANE5)	4496	4650

Table 1 Launch window scenario

The orbit design of the transfer to Venus is primarily based on optimizing launch energy (DeltaV1+ DeltaV2) and time of transfer to Venus orbit. We also required the transfer time to be shorter than 200 days and a launch window of 10 days (with a 5 % margin on launch energy). Considering a time frame between 2030 and 2040, we come up with the first possible launch window on 06.12.2032. The optimal trajectory based on our constraints has a flight time of 155 days and travels approximately a half revolution around the Sun. Additional launch windows are periodically available, with a similar configuration occurring on 06.12.2040.

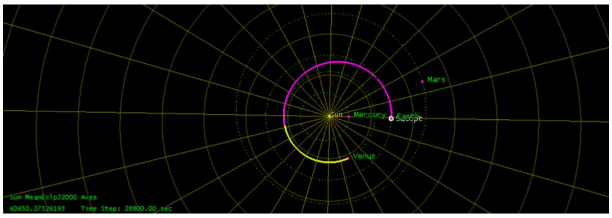

Fig. 2 Hohmann transfer to Venus (type 2)

The choice of the Ariane 5 launcher was operated taking into account the mass it could inject into Venus orbit as a function of the C3 (solution of the Lambert problem) as well as the payload required for the mission (see Section 3). To respect the mission requirement of a low orbit and a global coverage, we opt for a polar quasi-circular orbit around Venus at 250km, with a period of 91 minutes. It is indeed not possible to set a Sun-synchronous orbit around Venus, because of its low flattening. Such an orbit shall allow the full coverage of the planet surface after a Venusian day (or 243 Earth days), with a ground track separation of approximately 10 km.

The arrival in Venus orbit at 10.6 km/s is followed by thrusters ignition to get into the polar elliptical orbit with a periapsis altitude of 130km. We computed several scenarios to get in the requested science orbit: chemical propulsion, aero-braking, and aero-capture

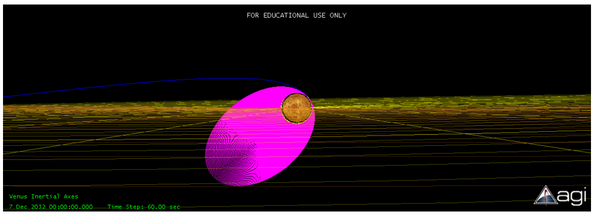

Fig. 3 Aerobraking at 130km (last 2-6 months)

Orbit parameters	Value
Periapsis altitude	250
Eccentricity	0.001
Period	91 minutes
Inclination	90.02

Table 2 Science orbit parameters

respectively. It turned out, that the aero-braking is the best solution within the framework of our mission: more fuel-saving than chemical propulsion and more technically ready compared to aero-capture. We used the most pessimistic atmospheric model from [Seiff], in order to consider the atmospheric-drag on the spacecraft. Uncertainties in the atmospheric models (cf. VIRA and Seiff) and results of the latest VexADE experiments should be considered and investigated in detail. Throughout the mission design we considered Venus gravity field up to degree and order 4 as well as the third body influence of the Sun.

Aero-braking allows to get to a quasi-circular (e= 0.001) polar orbit after approximately 2 to 6 months from the initial injection at 130 km of altitude. The maximum wet mass inserted to the final orbit is 2690 kg, to be compared to 1472 kg using standard chemical propulsion. During the aero-brake, with the spacecraft on an elliptical orbit around Venus, several preliminary operations will be performed: calibration of the onboard instruments, a first phase of measurement using the SAR and the IR/UV cameras.

The balloon *Tammuz* is to be released into Venus atmosphere during the last few days of the aero-braking maneuver, to assure the communications with the satellite. The initial velocity needed for the deployment is provided by the entry flight system. The shielded entry flight system separates the balloon, after drogue parachute opens. The main parachute in combination with the balloon inflation let the balloon float at an altitude of about 55 km. Final orbit is to be reached on 25.06.2032, while orbit maintenance at the final altitude of 250 km will require a DeltaV of 0.179 km/s/year,

Launcher	Ariane 5
Launch mass	4496 kg
Launch date	07-12-2032
C3	10.09
DeltaV orbit insertion	1.49 km/s
DeltaV raise periapsis	0.03 km/s
DeltaV orbit maintenance	0.5 km/s
DeltaV total	2.02 km/s
total dry mass	1467 kg

Table 3 Relevant values for orbit design of EvolVe

corresponding to approximately 220 kg/year of fuel. The relevant values for orbit design of the EvolVe mission corresponding to the first launch window, is shown in table. Visibility from Earth is assured for 35 % of the mission time, considering coverage of 8h/day by one single ESA Estrack ground station.

4.3 Mission elements

4.3.1 Orbiter - Ishtar

In this section the structure and subsystems of the main spacecraft of the mission - *Ishtar* - will be described.

Structure

The primary structure of the orbiter carries the main loads over the course of the mission. In particular, the launch loads are being supported by it. Calculations, including a large safety factor and empirical estimations by SMAD indicate a primary structure mass of 170 kg. The secondary structure supports instrument and subsystem placements. This mass has been calculated to be 67 kg. Lastly, mechanisms have been addressed. The two solar arrays and the high-gain antenna require pointing mechanisms. Deployment mechanisms can be simple one-way systems. This results in a mass of 15 kg, and an operating power of 61 W.

Propulsion

Two types of propulsion will be used.In order to get to Venus and for the orbit maintenance during the Science phase, the orbiter will have one 400N bi-propellant and twelve 10N bi-propellant thrusters. 2050kg of fuel will be needed for the orbit operations: 90% will be used to reach the planned quasi-circular polar orbit, while the rest is needed for orbit maintenance. Morever, during phase 2a, the main requirement is to fly with minimal drag. The necessary propulsion has been estimated at around 270mN, using the most pessimistic atmospheric models. To provide such a low force we have chosen to use an electrical propulsor developed for LISA (miniRIT).

Power

Solar power is an abundant and reliable source of energy around Venus. We estimated the longest duration of an eclipse to be 1h. The power consumption has been estimated for each phase of the mission, the most expensive being the last phases that involve SAR measurements and will require 595W. A foreseen constrain is that the solar panels will have to be fixed during phase 2a. Moreover, the duration of the mission will be limited by the deterioration of the elements. Following these considerations, we planned to have 4 m^2 of triple junction Ga As and two possible configurations for the solar panels and 6kg of rechargeable Li-ion batteries.

AOCS (Attitude and Orbital Control Systems)

In order to operate, the gradiometer requires the attitude to be controlled at 0.15 rad, the angular velocity at 3×10^{-5} rad and angular acceleration at 9×10^{-7} rad. To satisfy these requirements, we will use 3 A-STR star trackers, 2 gyroscopes and 3 Sun sensors. Thus, we can also guarantee a redundancy and a safe mode. To control the orbit we have chosen to have three axes stabilized by 4 reaction wheels.

Thermal

The extreme thermal conditions to which the spacecraft will be exposed during its mission around Venus is one of the main design drivers for the spacecraft. The solar flux near Venus is almost double than near Earth ($\approx$ 2.6 kW/m^2 vs. $\approx$ 1.4 kW/m^2), while the extremely high reflectivity of Venus, $\approx$ 0.8, makes the albedo contribution of the same order as the solar one. The Ishtar spacecraft is therefore designed to control temperature under operational conditions. In the worst hot case scenario, the energy input to the spacecraft is the sum of: 2.6 kW/m^2 (solar flux), 2.1 kW/m^2 (Venus albedo) and the internal power dissipation of 1150 W. To maintain an operational temperature of 297 K, Ishtar is covered by 20 layers of Multi-Layer Insulator (MLI) on 5 of its faces, and one of the faces is maintained always cold by periodically maneuvering the spacecraft. A 4 m^2 silvered Teflon radiator ($\alpha = 0.78$, $\epsilon = 0.05$), which is the calculated size needed to dissipate the heat in the worst case, is placed on this face of the spacecraft. On the other hand, the Tammuz balloon will face a total energy input of $\approx 600W/m^2$ (solar insolation), $525W/m^2$ (background thermal environment) and an internal power dissipation of 50 W. At a cruise altitude of 55 km, the atmospheric temperature is around 300 K. Based on previous studies on the thermal environment, a worst case temperature of 85°C has been considered for the solar array sizing.

4.3.2 Balloon - Tammuz

A balloon diameter of 7 meters will be required, assuming hydrogen inflation gas, a cruise altitude of 55 km and a total mass of Tammuz of 160 kg with 28kg of payload. It will fly passively for 19 days (traveling with the winds and circling Venus 2.5 times near the equator) with 3 experiments on board.

The power consumption of the balloon will be 60W/h. At this altitude the solar radiance is about 600W/m^2, so for extending its life time without increasing its weight too much we chose to use solar panels in addition to lithium-thionyl chloride batteries. With cells of amorphous silicon we expect to have at least 11% of efficiency and 2m^2 is available on the gondola. The size of the battery was designed to last 8 Earth days, keeping the instruments running on the night side.

To save the battery data will be sending to the orbiter only during the day. We will use an antenna working in band S at 2GHz

The balloon envelope is designed to resist the atmosphere of Venus by having its envelope coated. The thermal system will be passive as the temperature at this altitude is about 300K.

4.3.3 Communication

Three parabolic antennas are being used in this mission as well as a ground station. A parabolic antenna is an antenna that uses a parabolic reflector, a curved surface with the cross-sectional shape of a parabola, to direct the radio waves. The main advantage of parabolic antennas is that they can produce the narrowest beamwidths , that is,they have some of the highest gains, of any antenna type. The data collected by the balloon is transferred (uplink) via a 0.1m antenna to an identical receiver on the orbiter at the rate of 35.5kb/s. This uplink only runs for the lifetime of the balloon. This data is transferred over the UHF band at 0.45GHz. Due to the high data rate of the InSAR instrument in cycles 2, 3 and 4 the downlink to Earth is made via a 2m parabolic reflector operating in the X-band (8.5GHz). The ground station is remotely operated from the Estrack Control Centre (ECC) at ESOC. The 35m station provides the improved range, radio technology and data rates required by current and next-generation exploratory missions such as Mars Express, Venus Express, Rosetta and BepiColombo.

Task Name	Duration	Start	Finish
EvolVe Mission Development Plan	**5676 days**	**Mon 7/14/14**	**Mon 4/14/36**
Phase 0 - Mission needs and first assessments	110 days	Mon 7/14/14	Fri 12/12/14
MDR - Mission Design Review	0 days	Fri 12/12/14	Fri 12/12/14
Phase A - Feasibility Assessment	397 days	Mon 12/15/14	Tue 6/21/16
PRR - Preliminary Requirements Review	0 days	Tue 6/21/16	Tue 6/21/16
Phase B - Preliminary Definition	786 days	Tue 6/21/16	Tue 6/25/19
SRR - System Requirement Review	0 days	Wed 8/1/18	Wed 8/1/18
PRD - Preliminary Design Review	0 days	Tue 6/25/19	Tue 6/25/19
Phase C - Detailed Definition	1170 days	Tue 6/25/19	Mon 12/18/23
CDR - Critical Design Review	0 days	Mon 12/18/23	Mon 12/18/23
Phase D - Production & Qualification	2093 days	Mon 12/18/23	Wed 12/24/31
QR - Qualification Review	0 days	Sat 12/1/29	Sat 12/1/29
AR - Acceptance Review	0 days	Wed 12/24/31	Wed 12/24/31
Phase E - Operations	854 days	Tue 12/7/32	Fri 3/14/36
Phase F - Disposal	22 days	Sat 3/15/36	Mon 4/14/36

Fig. 4 EvolVe - Mission development plan

4.4 Mission development plan and costs

EvolVe is planned to be launched on the 7th of December 2032, and the Phase 3 of the mission is expected to finish in the first quarter of 2036 (see Fig. 4 for details). A preliminary study of the project development plan shows its feasibility, taking into account longer development phases for the enabling technologies for the mission. The following table outlines an estimation of the total costs foreseen for the mission, based on previous missions and industry standards.
An educational and public outreach program has been considered to produce exhibits and plain-text books to transmit the scientific results to a broader public.

ELEMENTS	[M€]
LAUNCHER (Ariane 5)	175
SPACECRAFT (Dry mass ~ 1115 Kg + propellant ~ 2450 Kg)	350
ENTRY PROBE (Including balloon, ~290 Kg)	300
SMOC	110
PROJECT MANAGEMENT	80
INDUSTRIAL MARGIN (10%)	65
PROGRAM MARGIN (15%)	136
PROGRAM COST TO ESA	**1216**
PAYLOAD (~500 Kg)	500
TOTAL COST (including margin)	**1716**

Fig. 5 EvolVe - costs overview

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

Fig. 6 Mapping of different risk IDs (A to O) according to their severity and probability (five is highest, one is lowest).

4.5 Risk assessment

Fifteen top-level risks have been identified. Mapped by probability and severity they revealed that the mission faces two major risks. Identifier A relates to the probability that the drag of the atmosphere might be higher than expected. Although validated models of the atmosphere of Venus exist, and have been used in the mission design, high-altitude density can vary a lot. This would severely hinder answering the primary science objective of the mission. Risk mitigation can be applied by including large margins on the propulsion system, and further investigation of Venus atmosphere models. The second major risk (identifier H) indicates a possible insufficient orbit determination. The primary mission objective strongly relies on precise knowledge of the orbit. If the spacecraft position during the gradiometer measurements cannot be accurately determined, the measurements will yield no scientific return. A longer development time for tracking systems and the instrument can mitigate this.

5 Conclusions

Our mission has a high potential to improve our understanding of the evolution of the planet Venus. Our mission consists of an orbiter and a balloon. The payload of the orbiter comprises a gradiometer, an IR/UV spectrometer and an InSAR. Attached to the balloon there is a gas chromatograph mass spectrometer, and an MT sounding device with a fluxgate magnetometer. The duration of the total mission is 3.2 Earth years with an estimated total cost of 1760 million Euro.
The received data from these instruments will greatly improve on existing models, in particular the interior structure, tectonic models and atmospheric density models. With this knowledge, we will learn more about our "sister" planet, and in addition we will find out more about processes that might have led to the different evolution of the two planets. By comparing these two worlds, we will learn which conditions led to a hostile environment for life as we know it.

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FACTSHEET : EvolVe – Evolution of Venus

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MISSION OVERVIEW

EvolVe is a scientific mission to Venus, dedicated to the observation of important geophysical parameters of the planet. Despite of many similarities between the neighboring planets Earth and Venus, both planets exhibit extremely different environmental conditions. Understanding the evolution of Venus and of planetary formation in general, will help to define the conditions during the terrestrial planets formation that lead to planetary habitability and make life possible.

The mission's orbiter (Ishtar) will orbit Venus in a low polar orbit at ~250 km above the surface, while a balloon (Tammuz) will descend to the Venusian atmosphere to perform in-situ measurements that cannot be taken from space.

The total mission duration is 3.2 years. Risks are assessed and EvolVe is estimated to cost 1700 M€.
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EvolVe is designed to answer three main scientific questions:

1. Is the tectonic history of Venus comparable to Earth's?
2. What is the current volcanic activity of Venus?
3. Was the bulk initial chemical composition of Venus and Earth different?
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EvolVe will have 6 different mission phases

1. Phase 0 : Transfer to Venus. (5 months)
2. Phase 0a: Science orbit injection. (2-6 months)
3. Phase 1 : Balloon will be deployed for in-situ measurements in the atmosphere at an altitude of 55 km. (19 days)
4. Phase 2a: Geodesy - global gravity field determination by parallel operation of gradiometer and altimeter. (1 Venus year)
5. Phase 2b: InSAR onboard the orbiter will measure 10-20 % of the Venus ' topography with high resolution. (2 Venus years)
6. Phase 3: Continued InSAR observations to detect vertical and horizontal displacements . (1 Venus year)
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<td rowspan="2">Payload</td>
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Ishtar orbiter:

o Gradiometer: measures the mid- to short-wavelengths part of the gravity field.
o InSAR: maps the topography and detects changes in the topography.
o Spectometer (IR/UV): detects hot spots on the Venus´ surface.
o Radar Altimeter: provides surface height and is used to improve orbit determination via cross-track analysis
</td>
<td rowspan="2">S/C</td>
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Spacecraft characteristics:

- Passive thermal design and periodic re-orientation for thermal control.
- Mechanic solar arrays allow different configuration for different mission phases.
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Tammuz balloon:

o Gas Cromatograph Mass Spectrometer (GCMS): measures the noble gases ratio in the atmosphere.
o Double Star Magnetometer (RACH-DSM): measures local magnetic field.
o Magnetotelluric Sounding Device (MSD): maps the radial lithosphere structure
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Balloon characteristics:

- Solar arrays along the surface allows hybrid power supply.
- A dedicated entry probe shields the balloon components during the atmosphere entrance.
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Mission Summary	
Launch: 07/12/2032	Venus arrival: 14/05/2033
Launch vehicle: Ariane 5	Science orbit injection: 24/06/2033