European Venus Explorer

An in-situ Venus explorer proposed in Dec 2010 as a Cosmic Vision M3 mission, for launch in 2020 – 2025

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Why Venus?

- Venus should be the most Earthlike planet we know.
  - *Created at roughly the same time*
  - *Apparently similar bulk composition*
  - *Almost the same size & density*
  - *Similar solar energy input*
    - *(due to high reflectivity of Venus clouds)*.

- Early Venus was probably much like early Earth
  - *Hot dense atmosphere rich in CO$_2$ and water*

- Venus also illustrates the probable fate of the Earth.
  - *In ~ 1 billion years, with a brighter sun, the insolation at Earth will be similar to that at Venus today. Will we be able to avoid the runaway greenhouse warming that is found at Venus?*

*Need to understand the ‘life story’ of terrestrial planets*
Why Venus?

- Venus provides the key to understanding terrestrial planets and exo-planets.

Venus allows study of the factors determining planetary habitability:

- **Radiative balance** (greenhouse warming, role of clouds)
- **Dynamics** (role of super-rotation and equator-pole circulations in re-distributing heat)
- **Evolution of atmospheric composition** (surface-atmosphere and atmosphere-space exchanges)
- **Role of magnetic field and solar wind interaction** in governing escape rates.

Which is the most common outcome for terrestrial planets: Venus-like, Earth-like, or Mars-like?

Need to understand the ‘life story’ of terrestrial planets
Why Venus?

**Venus is accessible!**

- Short cruise time (5-6 months)
- Abundant solar power
- Not too far from Earth (\(<\sim 1\) A.U. distance), good data rate.
- Low-cost single-element missions (\(<\欧元 500\) m).
- Well-suited for multi-agency co-operative campaign
  - Balloon mission
  - Next-generation radar / data relay orbiter
- Extensive heritage
- Benign cloud-level environment (\(~20\) deg C)
- Great test-bed for in situ payloads
  - Re-fly at Titan, Saturn, Uranus, Mars ...
A balloon mission in the heart of the habitable layer

- Helium superpressure balloon, 53-57 km float altitude.

- Benefit from benign climate: 10 – 50 °C, atmospheric densities like those found at 0 to 5 km altitude on Earth.

- Explore clouds of liquid water (albeit mixed with sulphuric acid).

- Use high winds of 200-250 km/h to circumnavigate the planet in 5-8 days.
EVE 2010 vs. EVE 2007

• 2007 EVE was for a large multinational mission.
  – Orbiter + Balloon + Lander
  – Russia was to provide launcher, lander, and EDLS components
  – optimistic mass & budget estimates

• 2010 EVE proposal was for an ESA-only balloon mission
  – A more tightly focussed mission, achievable without non-ESA partners
  – A balloon element only
    ▪ Cruise vehicle provides data relay during flyby
    ▪ Thereafter, balloon communicates Direct-to-Earth
  – More robust treatment of mass, power, and cost.

CNES funded a detailed phase 0 mission study in 2009-2010.

• Astrium (Toulouse) was subcontracted for aspects of mission design, including entry system and carrier spacecraft.
EVE – Measurement goals

• Exploring the cloud-level environment
  – Chemistry
  – Microphysical properties
  – Dynamics
  – Radiative Balance
  – Electric properties

• Evolution of Venus & its climate
  – Abundances of noble gases (Ar, Kr, Xe, …) and isotopic ratios of light elements (O, C, N …)
EVE – 15 kg science payload

• Exploring the cloud-level environment
  – Chemistry
    GC/MS with Aerosol inlet; Tunable laser Spec., XRF
  – Microphysical properties
    Nephelometer
  – Dynamics
    p, T, tracking of balloon (winds)
  – Radiative Balance
    6-ch radiometer (↑ and ↓, λ = 0.25 – 25 µm)
  – Electric properties
    Permittivity, conductivity, electric charge of aerosol, lightning

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  – abundances of noble gases (Ar, Kr, Xe, …) and isotopic ratios of light elements (O, C, N …)
    Dedicated mass spectrometer with getters, cryotrap
    Tunable diode laser to resolve ambiguities (e.g. CO vs N₂)
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• **X-ray Fluorescence Spectrometer**
  - Current cloud models have only H₂SO₄ : H₂O.
  - Venera descent probes had XRF which detected S, P, Fe, and Cl in cloud particles.
  - These measurements need to be repeated!
EVE – 15 kg science payload

- Polarising nephelometer
  - Measures scattered light intensity and polarisation as function of scattering angle.
  - Determine refractive index (constraint on composition)
  - Liquid / crystalline / amorphous particles
  - Determine size distribution

Characterize cloud microphysics;
Search for ‘mode 3’ large particles;
Clues to unknown UV absorber
EVE – 15kg science payload

- Electromagnetic wave analyser and permittivity sensor.
  - Measure horizontal and vertical electric field (AC and DC)
  - Measure perpendicular horizontal magnetic field
  - Also, optical and acoustic lightning sensors

Detect & characterise lightning
Study atmospheric electrical circuit
Sound subsurface using Schumann resonances

Figure 1: Forward modeling of MT signatures of different thermal structures and mantle compositions of Venus. Red: Incipient melting, L = 30 km, \( \Delta T = 750 \) K. Blue: Mobile lid, L = 100 km, \( \Delta T = 1000 \) K. Green: Stagnant lid, L = 500 km, \( \Delta T = 1300 \) K. Solid: Dry olivine. Dash: Olivine with 1 ppm H\(_2\)O. Note separation of L curves >> error bar and different frequency slope of water-bearing mantle. Grimm et al., LPI 2009
Mission profile

- Soyuz-Fregat 21-1b launch from Kourou, in 2021 or 2023.
- Six months for Earth-Venus transfer.
- Entry Probe (EP) released from carrier a few days before arrival.
- Flyby craft used as data relay during first 2 hours of mission
Mission profile

• Entry point is visible from Earth and is on nightside.
• First 3-4 days of mission are on visible face of Venus
  – First 2 hours: downlink via flyby craft
  – Then, direct-to-Earth communications
• Next 3-4 days are on far side, not visible from Earth
  – no data downlink via carrier, but carrier-probe link used for Doppler tracking.

(Left) Trajectories of entry probe and flyby vehicle; pale blue lines show probe-carrier line of sight; and (right) visibility of Sun, Earth, and flyby vehicle from balloon.
• Total entry mass is 665 kg.
• Pioneer-Venus like external shape, with a main diameter of 2.3 m, nose radius of 0.575 m.
• Frontshield TPS: Carbon Phenolic (as Pioneer Venus).
• Entry System mass: 300 kg including 81 kg for frontshield TPS.
Balloon & deployment system

- Balloon is helium superpressure balloon, 6.6 m diameter.
- Float altitude 55 km (20°C, 0.5 bar).
- Builds strongly on French/Russian Vega balloon heritage.
- Note that inflation system (gas tank + harness) is 141 kg!
• Octagonal tube structure is space-efficient, and effectively transfer mechanical loads during entry.

• Floating Mass is 159 kg, including
  – 16 kg helium
  – 116 kg gondola, incl. 15 kg science payload.
• Low Gain (~omnidirectional) antenna provides only 5-10 bits per second direct-to-Earth downlink. This is insufficient for many science goals.

• Options considered included:
  – Steerable parabolic dish (2 DOF) – mechanically complex, difficult to accommodate
  – Multi-horn antennae – bulky, difficult to accommodate
  – Phased antenna arrays in X-band – retained solution

• Solution allows > 100bps to 35m Ground Station dishes
  – 8 phased antenna arrays, 12-15 dBi, Medium-Gain antennae, each array has dimension 100 x 100 mm.
  – Total mass on gondola is 5 kg, 25 W power consumption

• Further optimisation is certainly possible!
  – e.g. more directional antenna

Communications system

4x Transmit arrays
4x Receive (and DOA determination) arrays
100 g balloon-deployed microprobes?

Oxford Univ, Qinetiq, ESA
1-2 kg balloon-deployed ‘Miniprobes’?

- Payload as for microprobes, but permitting imaging of surface.
Thanks for your attention

For further details:

C. Wilson et al., The 2010 European Venus Explorer (EVE) mission proposal, Experimental Astronomy, April 2012.

DOI:10.1007/s10686-011-9259-9
Lessons learned  
(about getting entry missions selected)

• Like Mars or Earth, Venus has a large and diverse set of environments
  – Surface, low atmosphere
  – 50-60 km: sub cloud atmosphere
  – 60-75 km: Convective cloud layer
  – Mesosphere, thermosphere, ionosphere...

_Difficult to satisfy all communities with a single modest mission_

• Images help to sell a mission

• A stand-alone _in situ_ atmospheric mission has short lifetime and small data return
  – High cost in € per Mbyte
  – partnering with orbital missions helps to mitigate this.

• Much of the understanding of Venus comes indirectly from modelling
  – Evolution models constrained by noble gas abundances and isotopic ratios
  – Atmospheric circulation and chemistry models
  – Radiative transfer / greenhouse models
  – Interior models
European Venus Explorer –
A logical step in Venus exploration

• **Step 1 (2005-2015)**: European Venus-Express mission and Japanese Venus Climate mission Orbiter
  – Atmospheric and cloud dynamics
  – (Incomplete) global scale chemistry of the low atmosphere

• **Step 2a (2015-2025)**: in-situ mission, with the use of atmospheric probes (balloons, descent probes)
  – Venus climate evolution
  – New data relative to atmospheric isotopic ratios, chemistry of the coupled surface/ atmosphere system, dynamics of the whole atmospheric system.

• **Step 2b (2015-2025)**: Next-generation radar mission
  – Surface evolution
  – Landing site characterisation

• **Step 3 (2025-2035)**: Long-lived landers for the characterisation of the interior structure and dynamics of Venus
Lessons learned?
(about getting entry missions selected)

So: why wasn’t EVE selected? Reasons include:

And, of course, strong competition (47 proposals submitted)! M3 finalists were:

- ECHO (Exoplanet Characterisation mission)
- *Marco Polo – R* (Asteroid Sample Return mission)
- *Plato* (Planetary Transit and Oscillations of starts)
- LOFT (Large Observatory For X-ray Timing)
- STE-QUEST (Space-Time Explorer and Quantum Equivalence Principle Space Tes)