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VENUS EXPRESS ON THE RIGHT TRACK

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ASTRACT

On October 26th of next year, Venus Express spacecraft will depart from Baikonur on-board the Soyuz/Fregat Launch Vehicle. It will be the very first European mission to the "morning star", two years after the first European trip to Mars. Venus Express will carry 7 science payloads dedicated to global investigation of Venus atmosphere. Three spectrometers covering wavelength range from UV to IR, one plasma analyzer, one magnetometer, one imager and one radio-science experience, most of them derived from similar instruments of Rosetta and Mars Express, will map the whole atmosphere below 200 km, trying to solve some of Venus mysteries. After a 5 months journey, they will operate during at least 500 days, the nominal mission duration.

Built by EADS Astrium, the prime contractor, Venus Express spacecraft is a near copy of Mars Express. It is a square box of honeycomb panels with 2 solar arrays, equipped with a propulsion system derived from the Eurostar Telecom program. However, differences between Venus and Mars environments led to several design changes. The main driver was obviously the need to cope with the severe thermal environment. A dedicated guidance strategy will help to keep the Sun in a narrow area, limited to only 2 faces of the spacecraft, while maintaining the high gain antenna pointed towards the Earth. A high-efficiency MLI was developed to protect those hot faces. In addition, most other external coatings had to be modified. Finally, a new design was deemed necessary for the Solar Array, in order to keep the cells temperature within an acceptable range.

Beside the technical issues, Venus Express is also a challenge in terms of schedule. The whole development phase will be achieved in 3 years, from kick-off to launch. Integration of propulsion system within mechanical bus started in summer 2003 at EADS Astrium UK (Stevenage). Spacecraft integration was continued in Alenia Spazio (Turin) since early April. Environmental tests will shortly begin in Intespace (Toulouse). Development approach, as well as spacecraft status, is depicted in the paper.

Strong heritage from Mars Express, along with efficient cooperation between all European partners, will allow meeting the challenge. Venus Express is on the right track!.

1 INTRODUCTION

In the wee small hours of Christmas 2003, Mars Express was successfully inserted into Mars orbit. Very first European spacecraft to ever orbit a planet, it has been producing outstanding science results since its arrival.

More than two years before Mars Express launch, ESA asked for suggestions on how to reuse the same platform. Guidelines were to use the same units and the same industrial teams, in order to be ready to fly in 2005. Out of 9 promising proposals, ESA selected Venus Express.

Indeed, Venus has been an object of fascination for centuries, but it remained very secret until space exploration began in the early 1960's, in particular because of its very dense atmosphere. It was the first planet to be explored by a spacecraft (Mariner 2) in 1962. Since then, more than 20 spacecrafts have contributed to improve our knowledge of the "morning star". The Russian Venera serie first revealed the severe conditions of the atmosphere, followed by orbiters with a suite of remote sensing instruments. More recently, a complete radar mapping of Venus surface was made by the Magellan spacecraft. Eventually, flyby missions of the Galileo and Cassini spacecraft have explored for short periods the infra-red window in the atmosphere, unveiling very promising insights.

The existence of infra-red instruments developed in the frame of ESA programs Rosetta and Mars Express, combined with the possibility to produce a near copy of the Mars Express spacecraft, provides a unique opportunity to the European scientific community to proceed to the detailed exploration of Venus infra-red window.

Venus Express program was awarded to EADS Astrium/France as prime contractor, and actually began in July 2002, a few months before definitve approval by SPC in November. The spacecraft is now being integrated in Turin, and will shortly move to Toulouse for environmental tests. Launch is scheduled on October 26th, 2005.

2 SCIENCE INSTRUMENTS

Venus Express program will benefit from the existence of instruments which have been for most of them developed in the frame of either Mars Express or Rosetta program.

The payload, with a total mass of more than 88 kg, is composed of seven instruments:

- ASPERA : Analyser of Space Plasmas and Energetic Atoms ;
- PFS : High-resolution IR Fourier spectrometer ;
- SPICAV : UV and IR spectrometer for solar/stellar occultation and nadir observations ;
- VeRa : Venus Radio Science instrument ;
- VIRTIS : UV-Visible-IR Imaging spectrometer ;
- VMC : Venus Monitoring Camera ;
- MAG : Magnetometer.

ASPERA, PFS and SPICAV are inherited from Mars Express. VIRTIS, VeRa and MAG are inherited from Rosetta. Only VMC is a newly developed instrument.

ASPERA is an imager of energetic neutral atoms and analyser of space plasmas. It will allow determining the plasma induced atmospheric escape, as well as interaction of the solar wind with the ionosphere of Venus. Neutral particle imager and electron and ion spectrometer are mounted on scanning platform. The instrument will operate continuously to gather data concerning ion, electron and neutral atom distributions all around Venus.

MAG is an instrument designed to measure the magnetic field in the vicinity of the spacecraft. The instrument will operate continuously to gather data concerning magnetic fields associated with the planet or plasmas.

PFS is a Fourier IR spectrometer optimised for atmospheric studies with two channels of 10 and 20 km footprint respectively. It provides 3D temperature field measurements of the lower atmosphere up to 50 km altitude, minor constituent variations (H_20 and CO_2) and optical properties of atmospheric aerosols, which allow to study the global atmospheric circulation. The instrument also provides data on the thermal inertia of the surface.

SPICAV is a UV spectrometer devoted to the study of the atmosphere with both nadir and limb viewing modes. It will provide important measurements on the ozone content of the atmosphere as well as the coupling of O_3 and H_2. In addition, stellar occultation techniques will provide vertical profiles of CO_2, O_3 and dust. SPICAV also contains an infra-red spectrometer relying on absorption of the Sun's radiation in the infra-red to detect chemical species in the atmosphere such as water, carbon monoxide, hydrogen sulphide and trace gases such as methane and ethane. All these measurements are fundamental inputs to meteorological and dynamic models of the atmosphere. On Venus Express, SPICAV will be complemented by an additional infra-red channel called SOIR.

VeRa is a radio science experiment, which uses the Venus Express orbiter radio subsystem to sound the neutral and ionised atmosphere at occultation, determine the dielectric properties of the surface and observe gravity anomalies.

VIRTIS is a UV-Visible-IR spectrometer which will provide the mineralogical and molecular composition of the surface of Venus at medium resolution and global coverage, through the spectral analysis of the re-diffused solar light and surface thermal emission.

VMC is a specialized visual camera to monitor the Venus disc using a wide angle and multiple narrow band filters to provide imaging in the UV, visible and near IR to produce global spatial and temporal coverage of the Venus disk.

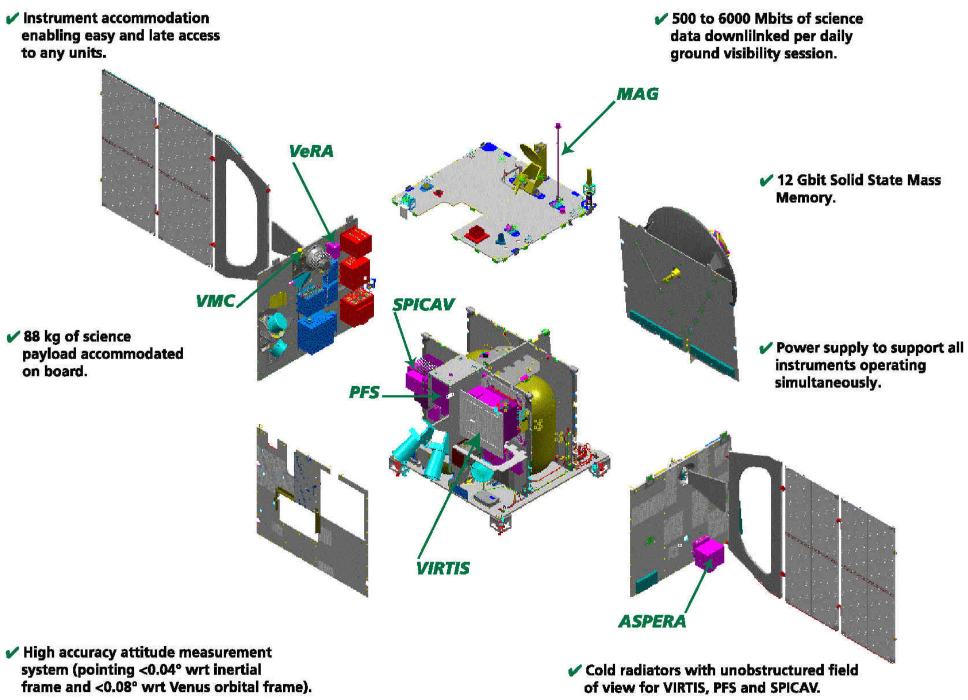
This unique combination of instruments, covering a wavelength range from UV to thermal IR, will allow to map and analyse the entire Venus atmosphere through the fine atmospheric transparency window, from the surface to about 200 km altitude.

Venus Express mission will thus contribute to give answers to the questions raised on the processes sustaining the severe conditions on Venus:

- Is it possible to explain, by in-situ measurements of the various plasma species – from energetic neutrals, to ions and electrons - the drastic evolution of the terrestrial atmosphere of Venus into this wild world of carbon dioxide and sulphuric acid micron size droplets?
- How to explain the global atmospheric circulation, as seen from the typical ultra-violet and infrared markers (from various poorly known constituents), in which the deep atmospheric layer shows a zonal and retrograde super-rotation – 20 times the planet one - with velocities decreasing from up to 120 m/s at the cloud tops down to almost 0 near the surface?
- In fully exploiting the recently discovered near-infrared windows in the high and middle atmospheres, can we close the gap between the low atmosphere vertical composition and the still to be demonstrated surface volcanism?

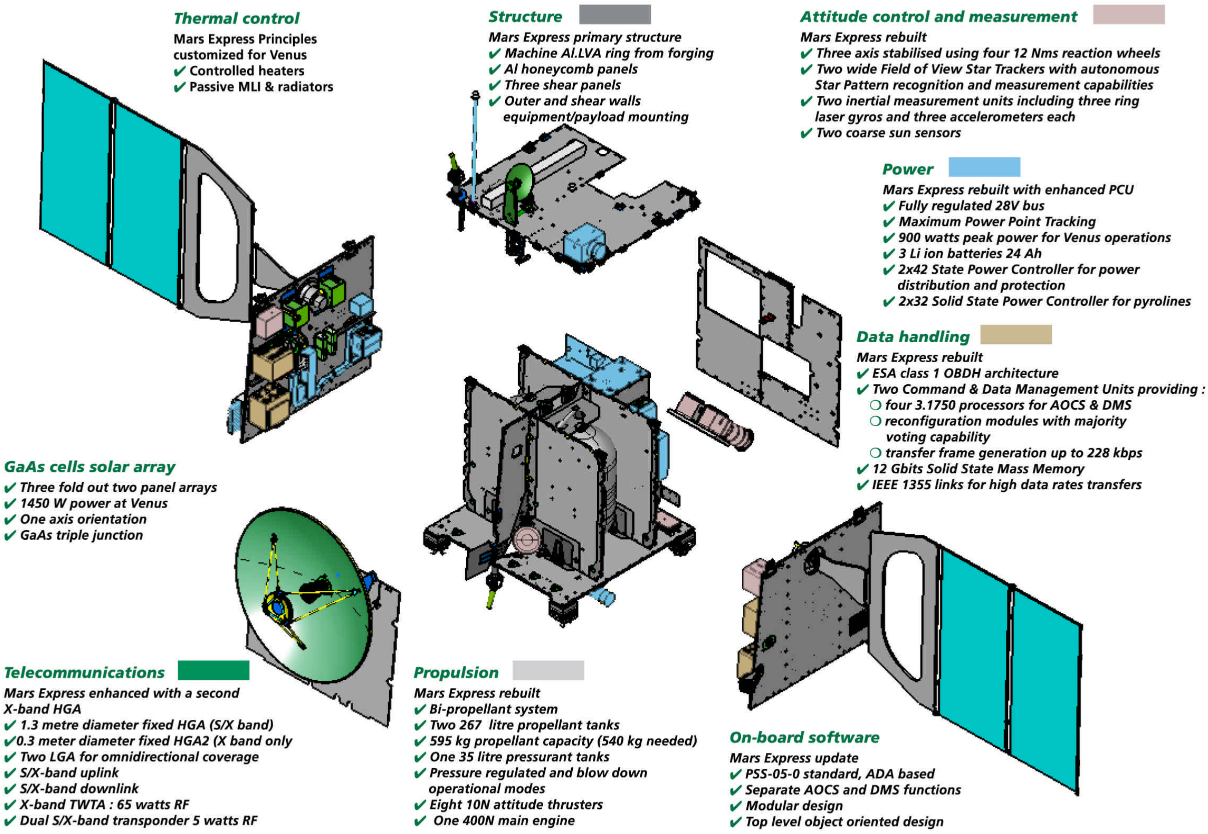
Acronym	*Heritage*	*Principal Investigator*	*Payload Objective*
ASPERA-4	***Mars Express (ASPERA-3)***	***S.Barabash (IRF / Kiruna, Sweden)***	***Neutral and Ionised Plasma Analyser***
MAG	***Rosetta Lander (ROMAP)***	***T.Zhang (OAW / Graz, Austria)***	***Magnetometer***
PFS	***Mars Express (PFS)***	***V.Formisano (IFSI CNR / Rome, Italy)***	***Atmospheric vertical Sounding by Infrared Fourier Spectroscopy***
SPICAV	***Mars Express (SPICAM)***	***JL.Bertaux (SA CNRS / Verrières, France)***	***Atmospheric spectrometry by Star or Sun Occultation in the Ultraviolet to Mid Infrared Range Range***
VeRa	***Rosetta (RSE)***	***B.Haeusler (UniBW / Muenchen, Germany)***	***Radio Sounding of the Atmosphere***
VIRTIS	***Rosetta (VIRTIS)***	***P.Drossart (ObsPM / Meudon, France) and G.Piccioni (IASF CNR / Rome, Italy)***	***Atmosphere and Surface Spectrographic Mapping from the Ultraviolet and Visible to Mid Infrared Ranges***
VMC	***Mars Express (HRSC / SRC) and Rosetta (OSIRIS)***	***W.Markiewicz (MPAe / Lindau, Germany)***	***Ultraviolet and Visible Multi-spectral Camera***

The Venus Express Science Payload



Venus Express Instruments and Accommodation on Spacecraft

3 VENUS EXPRESS SPACECRAFT ARCHITECTURE



The major objective of the Venus Express spacecraft design was to cope with specific mission requirements with extensive reuse of Mars Express design, in order to take maximum benefit of the recurrence, and minimize development risks. Venus Express spacecraft is therefore very similar to Mars Express:

However, there are specific Venus Express mission features that have lead to design changes:

- Science mission: new payloads must be accommodated (VIRTIS, VMC, VeRa and MAG). Two payloads that were design drivers to Mars Express have been removed (BEAGLE and MARSIS).
- Venus thermal environment: since Venus is much closer to the Sun than Mars (0,72 AU instead of 1,5 AU), the thermal flux is four times higher in Venus vicinity than in Mars vicinity, i.e. twice higher than on Earth.
- Venus radiation environment: it is closely related to the distance to Sun, thus quite more stringent for Venus Express than for Mars Express.
- Planets configuration: around Mars, Earth vector is always within +/- 40° of the Sun vector, which is convenient w.r.t. thermal design. Since Venus is an inner planet, this is no longer true.
- Distances to Earth: Venus maximum distance to Earth is smaller than Mars maximum distance to Earth (1,72 AU instead of 2,7 AU).
- Venus gravity: it is quite bigger than Mars gravity (0,81 Earth gravity instead of 0,11). For this reason, more propellant is needed for the capture. Operational orbit duration is thus driven by the tank capability, and is quite longer than for Mars Express (24h instead of approximately 7h).

Main characteristics of the spacecraft design are presented hereafter:

Mechanical design: Mars Express structure concept was fully reused, with only local changes. The core structure is a honeycomb parallelipedic box sizing about 1.7 m length, 1.7 m width and 1.4 m height, reinforced by 3 shear walls, and connected to a cylindrical Launch Vehicle Adapter.

The Solar Array is composed of two wings, providing a symmetrical configuration that minimises torques and forces applied on the arrays and the drive mechanisms during the Venus insertion manœuvres performed with the Main Engine.

Thermal control: the concept of passive thermal control is kept, as for Mars Express. However, external coatings must be modified, in order to minimize the thermal flux entering the spacecraft: high-efficiency Kapton MLI (as for Rosetta) replaces black MLI, white paint replaces black paint, Clear Sulphuric Anodisation replaces alodine. In addition, Optical Surface Reflectors (OSR) are used on the radiators and on the Solar Arrays.

AOCS: as for Mars Express, Attitude Control is achieved using a set of star sensors, gyros, accelerometers, reaction wheels and 10N thrusters.

Propulsion : A bi-propellant Reaction Control System is used for orbit and attitude control. It is composed of one 400 N Main Engine, used only for capture and apocenter lowering, and of 8 thrusters of 10 N for attitude control and orbit maintenance. It is derived from the Telecom Eurostar serie, and is almost the same as on Mars Express. However, propellant load must be increased, because ΔV requirement is more stringent than for Mars Express. Up to 570 kg of propellant may be loaded, leading to a launch mass of 1270 kg, slightly more than for Mars Express (1223 kg).

Electrical design: The Electrical Power generation is performed by Solar Arrays. GaAs cells must be used instead of Silicon cells, because they are less sensitive to temperature and to radiation. Since they are also more efficient, 2 panels per wing are sufficient to meet the power requirements. 820W is achieved in Earth vicinity, which is the sizing case. Nearly 1450W is thus available in Venus vicinity, which is much more than the requirement (1100W). Once around Venus, the spacecraft is thus very tolerant to mispointing of the Solar Array (up to 45°).

Power storage is performed by 3 Lithium-Ion batteries (24 Ah each), as for Mars Express.

A standard 28 V regulated main bus is offered to the payload instruments.

RF Communications: as on Mars Express, it consists of a redundant set of transponders using S-band and X-band for the uplink and the downlink. Depending on the mission phase, the transponder can be routed via RF switches to different antennas.

Two Low Gain Antennas (LGA) allowing an omni-directional reception and emission in S-Band. They will be used in Launch & Early Operation Phase, or in case of emergency.

One dual band High Gain Antenna allowing high rate TM emission and TC reception in S-Band and X-Band. It is very similar to the one of Mars Express, with a smaller diameter (1,3m instead of 1,6m).

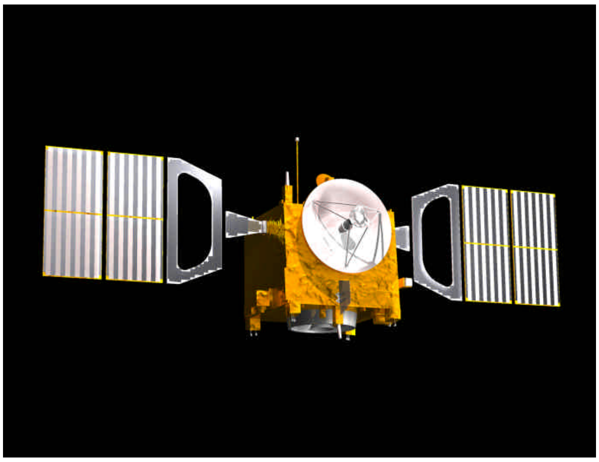
Planets configuration led to implement one additional single band offset Antenna allowing high rate TM emission and TC reception in X-Band. It is derived from the Rosetta Medium Gain Antenna (i.e. offset antenna, 0,3m diameter).

Science data will be transmitted in X-band 8 hours per day in average at rates between 19 and 228 kbps depending of the Venus to Earth distance, through one of the High Gain Antennas.

In the frame of the VeRa experiment, a Ultra Stable Oscillator (USO) will be connected to the transponders, in order to perform Radio-Science operations.

Data Handling: As on Rosetta and Mars Express, it is based on a dual processor architecture embedding standard communication links such as a standard OBDH bus and high rate IEEE 1355 serial data links. It includes a Solid State Mass Memory for data storage, offering 12 Gbits of memory.

From Mars Express…



… to Venus Express

4 MISSION & OPERATIONS

Soyuz/Fregat will launch the spacecraft from Baikonur. The three stage Soyuz brings the nose module consisting of the upper stage with the spacecraft attached to it to an altitude of about 200-km, where the Fregat will circularise the orbit with a first burn. After a coast phase of about 70 minutes in the low earth orbit, Fregat will be re-ignited for the boost into escape trajectory to Venus.

After separation and after the spacecraft has acquired Sun pointing and deployed its solar arrays, spacecraft commissioning will start, followed by payload health checks. As soon as the trajectory is determined on ground, an injection error correction manoeuvre will be scheduled. No routine science operations are planned during the following cruise phase.

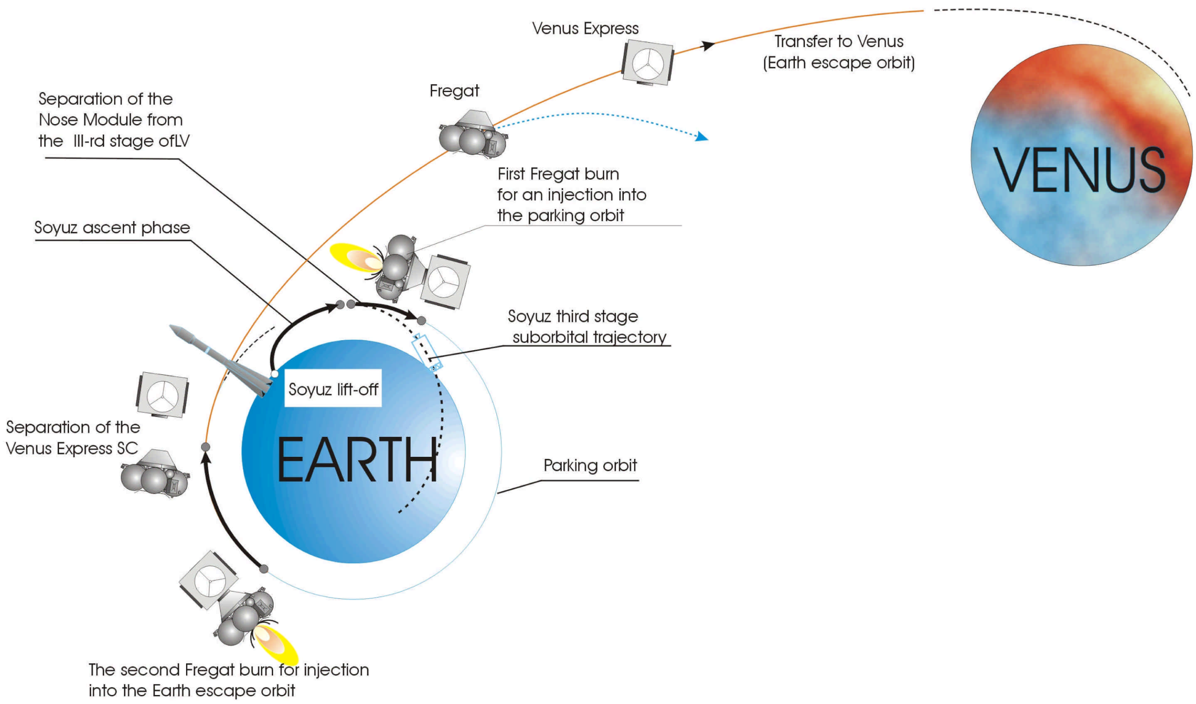
During the cruise to Venus, the spacecraft will be contacted daily for health checks and navigation using the High Gain Antenna. The spacecraft will be put on an arrival trajectory to Venus by mid-course navigation if required and a final course adjustment will be scheduled near the orbit insertion to fine tune the arrival hyperbola.

Insertion onto a Venus capture orbit will be performed five month after launch, i.e. mid-April 2006, by a large propulsion maneuver (1310 m/s). The duration of the burn will be around 53 minutes, which is significantly more than for Mars Express (around 30 minutes). The spacecraft will be injected into a 5,5 days orbit with a very high apocenter (about 220 000 km).

Only one additional Main Engine boost will place the spacecraft on its operational orbit. It will have a near 90^o inclination, a pericentre altitude in the range 250 to 400 km, an apocentre altitude of about 66 600 km, and a period of 24 hours, which allows phasing with Ground Segment.

Once in a stable orbit around Venus, a further commissioning of the orbiter instruments will be performed and the operational phase will start.

The nominal duration of the mission is 500 days, which corresponds to approximately 2 Venus days. An extension of 500 additional days is foreseen.



Launch & Cruise Phase

On final orbit, there are two different phases of operations:

Earth Pointing Phase

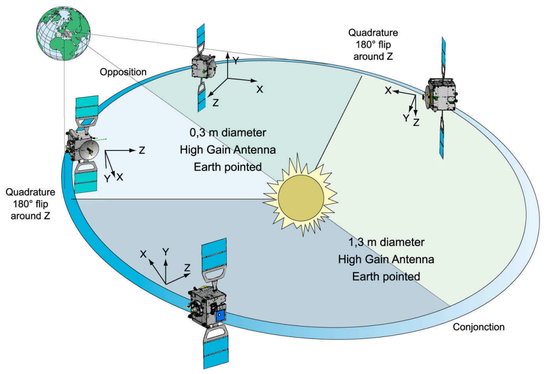
This phase is dedicated to communication with Earth and battery charging. It is used whenever spacecraft is not in Observation phase.

In this phase, one of High Gain Antenna is oriented towards the Earth. It is selected according to the season, so that the “cold face” remains always protected from Sun illumination.

Consequently, the main High Gain Antenna, derived from mars Express with a smaller diameter, will be used during three fourth of the mission, when the spacecraft is the most distant from the Earth. The second High Gain, derived from Rosetta, will be used during one fourth of the mission, when the spacecraft is closer to the Earth.

Rotation angle around Earth direction is optimized in order to avoid any Sun entrance on the side walls radiators.

High rate communication will be performed 8 hours per day in X-band, in order to transmit to Earth all science data stored in the Solid State Mass Memory. An average of 2 Gbits of science data will be downlinked every day to the new ESA ground station of Cebreros (Spain).



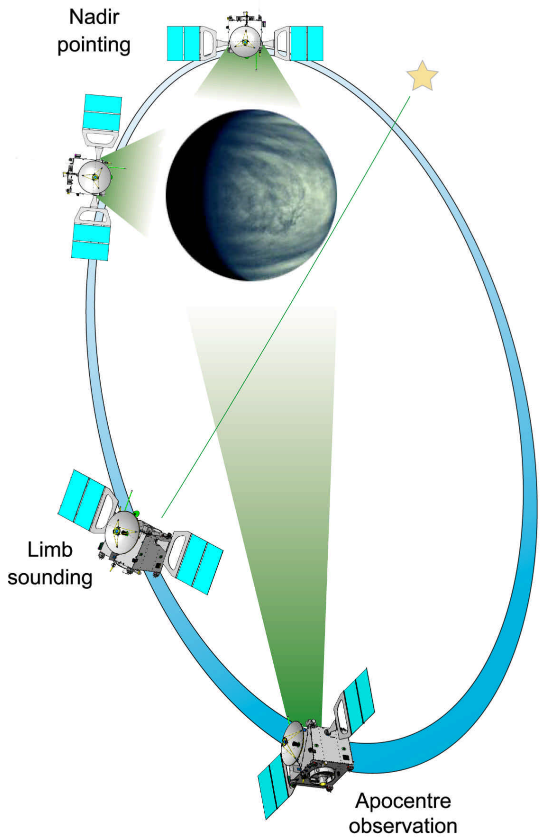
Earth Pointing Communication Phase

Observation phase

There are several different modes of observation, depending on payload configuration and spacecraft orientation:

- Nadir pointing: preferably during pericenter pass, but possibly on any portion of the orbit. Virtis, PFS, SPICAV and VMC may operate in this mode,
- Limb observation. Virtis, PFS, SPICAV and VMC may operate in this mode,
- Star occultation (SPICAV),
- Star occultation (SPICAV/SOIR),
- Radio science (VeRa).

During observation, Sun can illuminate under transient conditions any spacecraft face excepted the “cold face”. The duration of observation is therefore limited by thermal constraints and by battery discharge. The maximum duration of an observation period depends on Sun direction w.r.t. orbit plane, which varies along the mission.



Observation Phase

5 DEVELOPMENT APPROACH

One of the biggest challenge of the Venus Express mission is obviously the schedule. Although kick-off was given in July 2002, a few months before program was officially approved, spacecraft must be delivered to ESA end of June 2005, in order not to miss the launch opportunity, between October 26th and November 24th. This leaves only 3 years for phases B-C/D, which is quite short for a science mission.

This ambitious objective was deemed achievable provided that manufacturing could start immediately after kick-off, which implied several conditions:

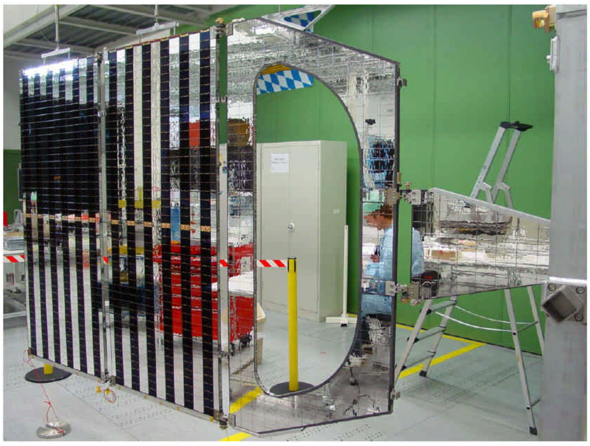
- Reuse of bus units with minimum modifications w.r.t. Mars Express. Therefore, only minor changes driven by Venus mission specific requirements were implemented.
- Adapt payloads that were developed either in the frame of Mars Express or Rosetta. The only exception is VMC, which is a new instrument.
- Reuse Mars Express structure, with only minor modifications imposed by the adaptation of new payloads. This was a mandatory condition to be able to start structure manufacturing, which is clearly on the critical path.

One notable exception is the Solar Array, built by EADS Astrium in Ottobrun (Germany). It had to be redesigned in order to cope with the severe thermal conditions near Venus. Only mechanical design is similar to the one of Mars Express, which was originally derived from Globalstar program. Silicon cells were replaced by Ga/As cells, which are not only much more efficient, but also much less sensitive to temperature and radiation. Electrical layout was therefore completely reworked.

Half of the front face, as well as the whole rear face are covered with Optical Surface Reflectors (OSR), in order to minimise temperature range. Validity of this original thermal concept was firstly proven by exposure of one sample to representative solar flux in the DLR Solar Furnace Facility (in Cologne, Germany). The whole Solar Array was then successfully qualified in Thermal Vacuum over a wide temperature range (-158°C to +158°C).

Qualification was completed by a successfull deployment test.

Finally, Solar Array Flight Model was delivered in July 2004, with still several months of contingency w.r.t. integration schedule. Solar Array is indeed planned to be integrated only for environmental testing.



Solar Array in EADS Astrium/Germany

Main changes w.r.t. Mars Express are imposed by thermal control. In particular, most external coatings had to be replaced to cope with Venus thermal environment. In particular, high-efficiency MLI replaces black MLI.

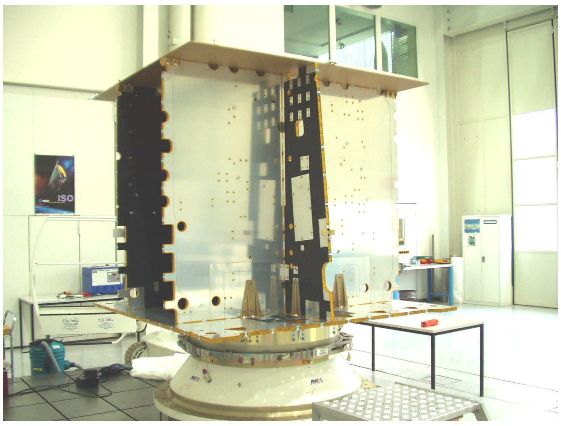
A comprehensive test program was set up to verify the suitability of all new materials. However, it had to be run in parallel to manufacturing process because of schedule. For this reason, well-known technologies were preferred to more innovative solutions.

At first, ageing tests were performed in Estec thermal laboratory. The goal was to measure the evolution of thermal properties after exposure to UV and high temperature. This test campaign is now nearly completed.

In addition, robustness of MLI was tested at DLR Solar Furnace Facility (Cologne, Germany). Two representative samples, one flat and one corner, were exposed to high solar flux. The goal was in particular to evaluate the potential effect of Sun trapping. Tests were completed in September 2004.

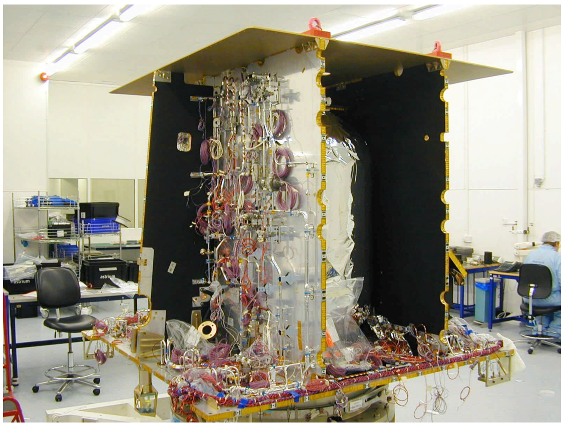
Finally, thermal control validation will be performed at spacecraft level by thermal balance test in Intespace Simles chamber. To that purpose, the Simles solar beam was upgraded up to 2600 W/m², as it is near Venus, instead of 2000 W/m² previously.

As expected, manufacturing of the structure began in Contraves (Zürich, Switzerland) in summer 2002, in parallel to the design activities. Production was optimised in order to cope with the necessary local modifications. Structure was completed less than one year after, in July 2003.



Spacecraft structure in Contraves

Structure was then shipped to Astrium UK (Stevenage, United Kingdom) for integration of the Chemical Propulsion System (CPS), so as to constitute the "mechanical bus". This activity was completed in April 2004, as planned.



Mechanical bus in EADS Astrium/UK

Mechanical bus was then shipped to Alenia Spazio (Turin, Italy) for electrical integration of bus units and payloads, as well as functional tests.

At this point in time, most of the spacecraft units and payloads have been mounted on the structure and tested.

Spacecraft integration in Alenia Spazio

Today, almost one year before launch, adherence to schedule is maintained:

- Major reviews at spacecraft level were held successfully in February 2003 (PDR) and March 2004 (CDR).
- All Flight Models of bus units were delivered and integrated onto spacecraft.
- Most Flight Models of instruments were delivered and integrated.
- Most functional tests have been completed.
- Early validation of Flight Software and Avionics was successfully performed on an Electrical and Functional Test Bench (EFVB, in EADS Astrium, Toulouse).

Main forthcoming activities are:

- Transfer of spacecraft to Intespace (Toulouse),
- System tests,
- Environmental tests.

More than ever, highest priority is given to schedule, with the objective to deliver the spacecraft to ESA at Flight Acceptance Review (FAR) in June 2005. Launch campaign is planned in Summer 2005, in view of launch on October 26th.

6 CONCLUSION

Less than one year after Mars Express was successfully inserted around Mars, its cousin Venus Express is in good shape.

The key success factor for this challenging program, beside all the experience gained on Rosetta and Mars Express, is the team spirit that prevails between ESA, science team and industry.

At the same time next year, Venus Express will be in Baikonur, very close to the launch pad, a few weeks only before one of the most exciting space mission Europe has ever undertaken. Venus Express in on the right track!