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bulletin

SPACE FOR EUROPE

Venus Express Launched

ESA bulletin 124 - november 2005

European Space Agency
Agence spatiale européenne

european space agency

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(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

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agence spatiale européenne

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ESRIN, Frascati, Italy.

Président du Conseil: Sigmar Wittig

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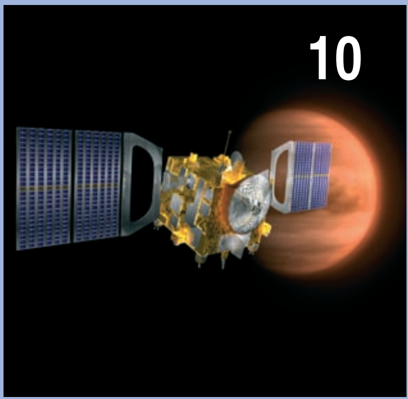
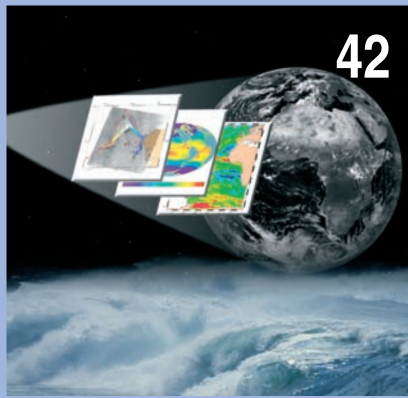
Cover: Venus Express on the launch pad – see page 8



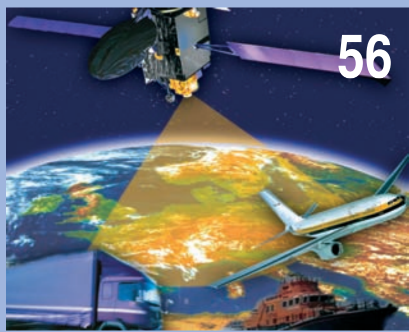
The Venus Express Mission

ESA's New Cebreros Station Ready to Support Venus Express

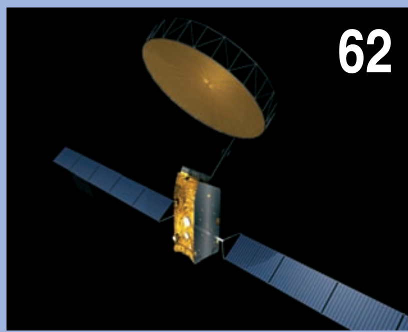


The Roadmap for a GMES Operational Oceanography Mission

A Tsunami Early-Warning System



EGNOS Operations and Their Planned Evolution



The BGAN Extension Programme

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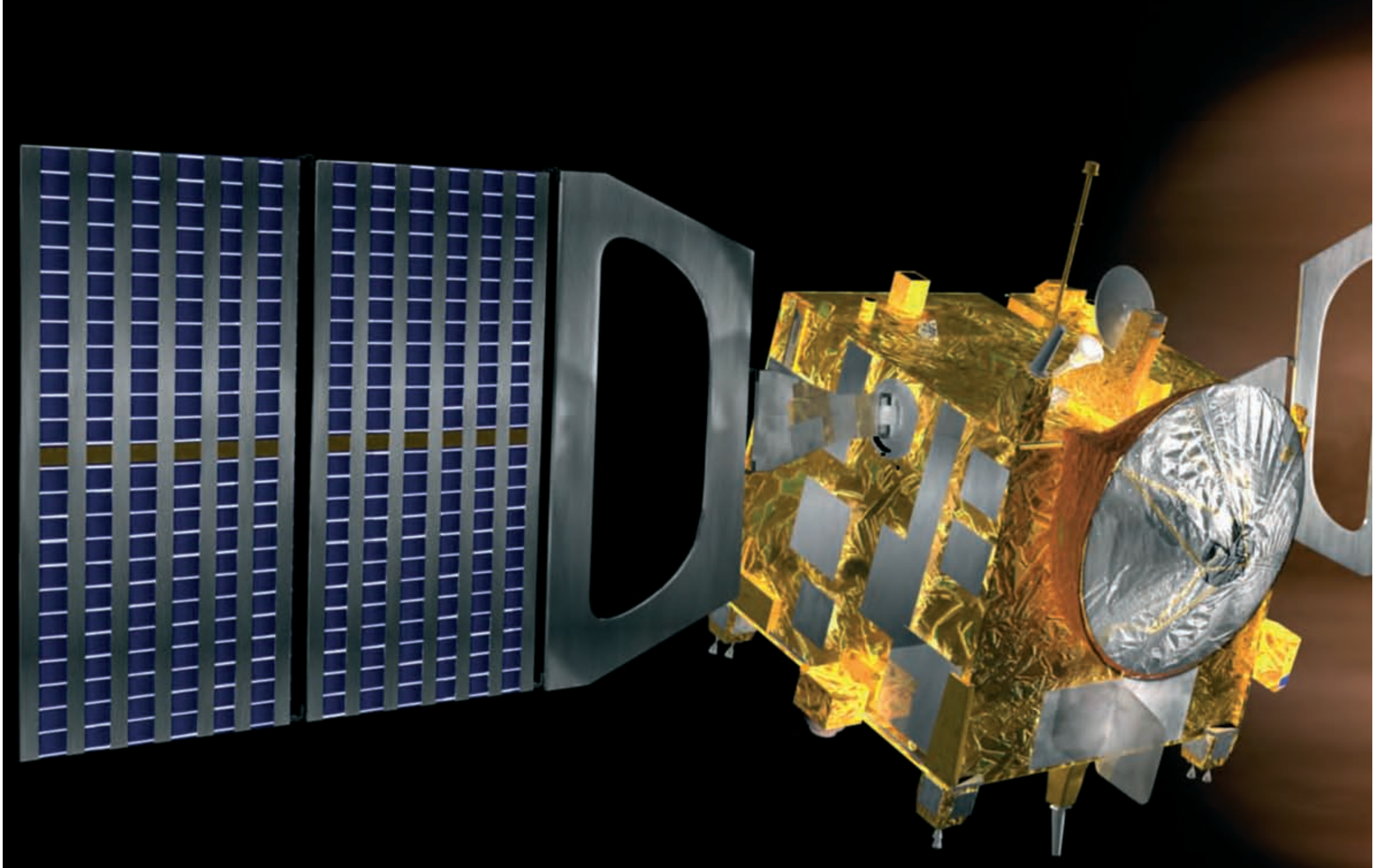
Venus Express: The Mission Begins

The Venus Express spacecraft was launched successfully at 04:33:34 CET on 9 November, by a Soyuz-Fregat Launcher from the Baikonur Cosmodrome in Kazakhstan. The launch and subsequent Fregat operations were picture perfect, giving the satellite exactly the boost it needed to start its journey to Venus, with only a 3 m/sec error in its velocity against a relative speed with respect to Earth of some 2.7 km/sec!

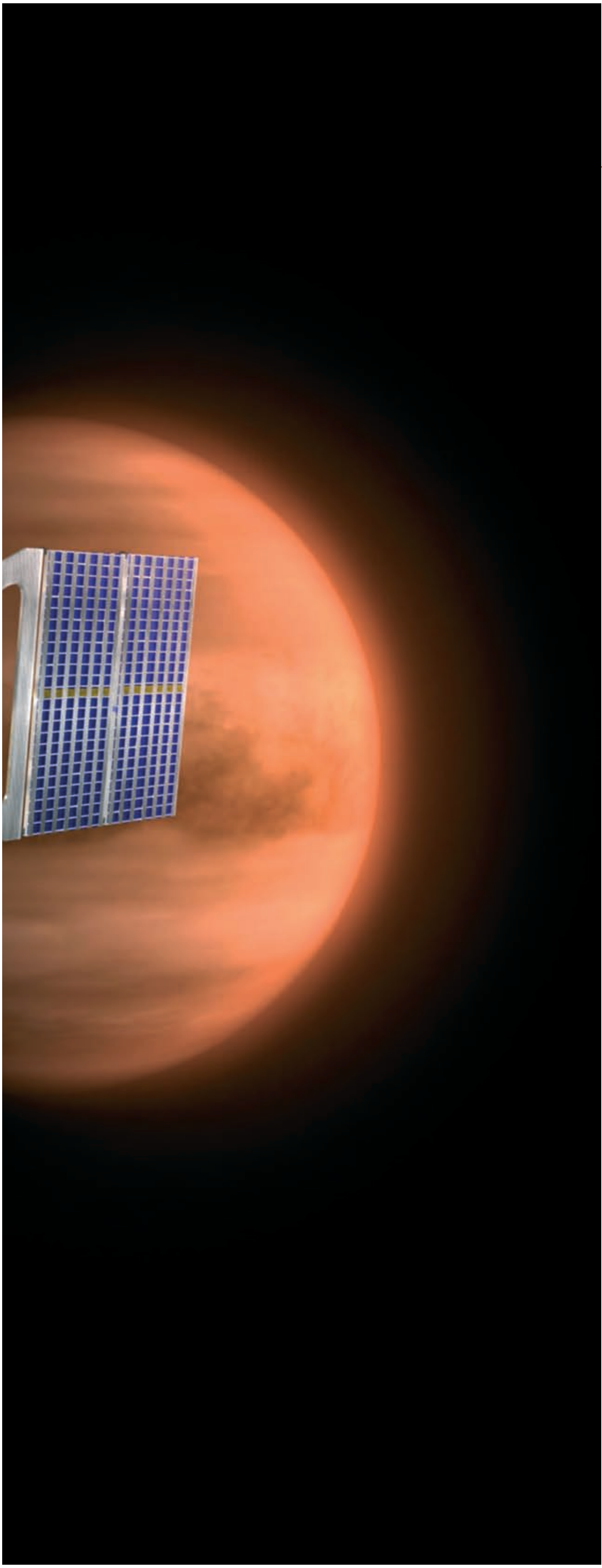
The satellite was activated automatically after the Fregat upper stage commanded separation and the ESA ground station at New Norcia in Western Australia picked up the radio signal from Venus Express at precisely the expected time and with the expected strength. From there the spacecraft performed flawlessly with deployment of the solar arrays and acquisition of the Sun's rays in order to achieve a positive power balance.

The Venus Express Mission Operations Centre at ESA's European Space Operations Centre (ESOC) in Darmstadt then put the spacecraft through its paces by configuring it for normal operations and turning on the high power X-band transmitters. The Launch and Early Orbit Phase (LEOP) of the mission was completed on time without incident on 11 November and the spacecraft is now on its way to Venus, travelling an average of one million kilometres every four days during the initial part its the voyage. The 'cruise phase' will continue until the spacecraft reaches Venus on 11 April 2006, and during this period the spacecraft platform and the experiments that it carries will be exercised to confirm correct performance and operability. The very critical Venus Orbit Insertion (VOI) manoeuvre will also be practised to ensure that operation is successful. Once the satellite is in orbit around Venus, the final experiment commissioning will take place in order to start routine science operations in early June 2006.

The Soyuz fairing being moved over the horizontally tilted stack of the Venus Express spacecraft and the Fregat upper stage



The Venus Express Mission



Donald McCoy, Thorsten Siwitza & Roy Gouka
Venus Express Project, ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Venus evokes the ever-attractive image of a goddess from antiquity, and yet our sister planet, although attractive, is far from hospitable. The reasons for such a great difference between Earth and Venus have still to be understood and so, considering that they are very close in terms of astronomical distances, a mystery is invoked. Whether Earth is a unique planet, for which life was destined, or whether both planets were created under similar circumstances and subsequently evolved in different manners, is fundamental to the understanding of our place in the Solar System and, indeed, perhaps the Universe.

Introduction

Building on what we know from the Russian and American spacecraft that visited Venus in the seventies and eighties, Venus Express will continue the quest to understand the fundamental mysteries of the planet, but now using the latest state-of-the-art scientific instrumentation. Similar to Mars Express, the technical precursor of the Venus Express mission, the information produced around Venus will allow scientists to compare our nearest neighbour with our home planet. The link to Mars Express goes beyond the science, since the satellite is essentially derived from the same design.

Venus Express is a mission that was proposed to ESA in response to a Call for Ideas to re-use the Mars Express platform, issued in March 2001. The Venus Express proposal competed with nine others and was selected as one of three candidates for a preliminary three-month study by industry to establish the feasibility of re-using the Mars Express spacecraft bus. That study, performed in the period July-October 2001 by ESA, Astrium and a team of scientific institutes, demonstrated that an orbiter mission to Venus could indeed be carried out by adapting the Mars Express satellite. At the completion of the study, ESA's Solar System Working Group and Space Science Advisory Committee recommended to the Science Programme Committee (SPC) in November 2001 that the Venus proposal be chosen for further investigation. As a result, the SPC recommended that a Pre-Phase-B study be implemented to prepare the Venus Express mission for an implementation decision in 2002. Finally, on 4 November 2002 the Venus Express project was fully accepted by the SPC for implementation, with a modification to exclude the VENSIS radar experiment due to lack of financial support.

An enabling factor for embarking on the Venus mission was the availability of instruments from previous missions such as Mars Express and Rosetta, both of which were projects already managed by the Scientific Projects Department. The spacecraft design modifications were kept to an absolute minimum to satisfy the Venus Express mission requirements. As a consequence, the Venus Express spacecraft maintains large similarities to Mars Express. The system concept, such as the structural design, propulsion subsystem, avionics units and operational concept, have been maintained while some Venus Express mission characteristics, such as the proximity to the Sun, the constellation of planets, and the distance to Earth, have led to unavoidable design changes, primarily in the areas of thermal control, communications and electrical power.

The following articles in this Bulletin describe the spacecraft, the ground system and the payload in more detail. This introductory article is intended to provide the reader with an overall impression of the mission and how it was created in a resource-critical environment with a short development time and limited budget.

Science

Venus, Mars and Earth, which represent three out of the four inner or rocky planets of our Solar System, have much in common: a solid surface of comparable composition, an atmosphere, a weather system and a location in space where the solar energy flux is moderate. However, the differences between the planets themselves are striking, particularly in the case of Venus, which is very similar to Earth in terms of size and gravity, and there are radical differences in the environments of the planets. Surface pressures on Venus are 90 times greater than those on Earth and surface temperatures reach 470°C (about ten times higher than the hottest temperatures on Earth), although the Sun's energy falling on Venus is only double that of the Earth's. Clearly, the 'greenhouse effect' is at work on Venus! The evolution and behaviour of the Venusian atmosphere must be of keen interest to us, if we believe that the same effect is beginning on Earth. The ESA mission will therefore study Venus in greater detail than ever before, using it as a 'living laboratory' to gain better insight into the life cycles of planets like our own and perhaps help us predict the future for the Earth's environment.

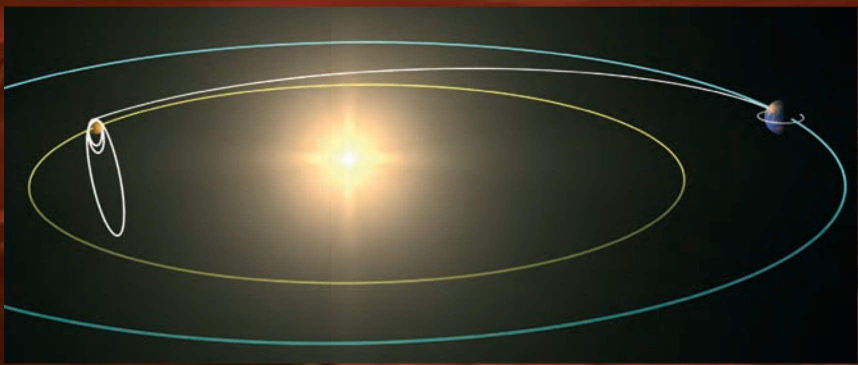
Although the distances to our planetary neighbours, Mars and Venus, are huge relative to those experienced in our daily lives, they are not so great when compared to the distances to the giant planets orbiting our star. Why then is there such a great difference between the environments of our planets? Mars is cold with a very thin atmosphere composed primarily of carbon dioxide, while Venus is very hot with a massive atmosphere also consisting primarily of carbon dioxide. Earth, on the other hand, balances the composition of its atmosphere with a small amount of carbon dioxide mixed in with a large amount of oxygen in an atmosphere dominated by nitrogen.

Through a regular and extended period of global observations, the Venus Express instruments will provide scientists with a broad range of spectral data in the infrared and ultraviolet spectral bands. Furthermore, in-situ measurements of atomic particles at the boundary between the Venusian atmosphere and space will provide insight into the interaction with the solar wind. Magnetometer measurements will support the measurements of plasma around the planet.

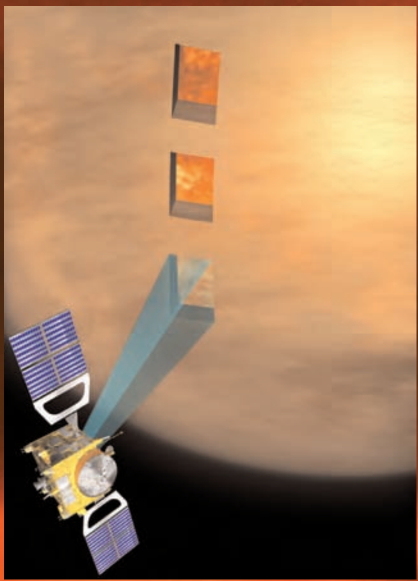
The multi-disciplinary science package onboard Venus will enable scientists to correlate many physical phenomena affecting the planet and will provide cross-correlation of these phenomena to help them understand why Venus is so radically different from its neighbours.

The Mission

The Venus Express spacecraft was launched by a Soyuz-Fregat launcher from the Baikonur Cosmodrome in Kazakhstan on 9 November at 04:33 CET. The launcher put the combined spacecraft and Fregat upper stage onto a trajectory that



Venus Express's journey to Venus



By digging into the atmosphere, Venus Express will provide clues about the whole planet

allowed the Fregat to circularise the orbit into a temporary parking orbit about 190 km above the Earth. After about one revolution around the planet, the upper stage was reignited to put the composite on an interplanetary trajectory towards Venus. Separation of the spacecraft from the upper stage was commanded by the Fregat 90 minutes after launch and this action initiated the deployment sequence onboard the spacecraft. Once the solar arrays had been deployed and the propulsion system primed, the spacecraft was controlled by the Venus Mission Operations Centre at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany.

Venus Express will spend approximately 150 days on its interplanetary journey, during which time any necessary trajectory corrections will be made using the spacecraft's thrusters. At least one correction, planned to take place about sixty days after launch, will be required. On arrival at Venus, a significant deceleration manoeuvre will be made using the spacecraft's own engine. The 53 minute burn will reduce the spacecraft's arrival speed by about 1.3 km/sec, sufficient for it to be inserted initially into a highly elliptical polar orbit around the planet, with a pericentre altitude of about 250 km and a period of about ten Earth days. Smaller engine burns will then be used to lower the apocentre and reach the operational orbit.

The nominal arrival of the spacecraft at Venus is planned for 11 April 2006. After some time for trimming the orbit parameters to achieve the required 24 hour polar orbit, the commissioning of the spacecraft and the scientific payload will start. Full nominal operations will then commence for a period of 2 Venusian days, corresponding to 486 Earth days. A mission extension beyond this time is a possibility since the onboard consumables have been sized to cope with that.

The major events of the mission are listed in the accompanying panel, together with the nominal planning dates for each event.

The Ground Segment

The concept for controlling Venus Express is based on the use of a single control centre in conjunction with ESA's new Cebreros 35 m station near Madrid (Spain). The New Norcia 35 m station near Perth (W. Australia) will be used to support the Venus Orbit Insertion phase and for data acquisition in support of the Radio Science investigations. The baseline operations philosophy is to acquire scientific data primarily during the 95 minute pericentre planetary passes, store it onboard, and downlink it during a single pass each day.

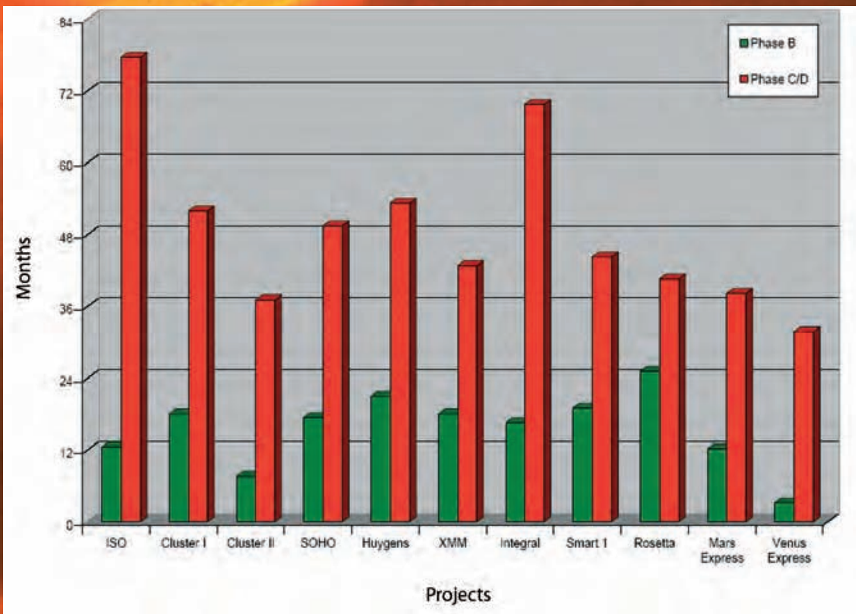
All phases of the mission will be controlled from the Venus Express Mission Operations Centre (VMOC) located at ESOC. The Launch and Early Orbit Phase (LEOP) will use the Main Control Room (MCR) at ESOC and will be supported for tracking, telemetry and commanding by the ESA ground stations in Kourou (French Guiana) and New Norcia.

The VMOC is the primary interface with the spacecraft through the ground station(s) and will be responsible for monitoring and control of the complete mission. The principal mode of operations is that all routine payload operations must be pre-planned and executed according to an agreed Science Activity Plan (SAP). There are no real-time payload operations foreseen, other than the near-real-time interactive operations at the time of commissioning (initial turn-on, calibration) and/or during contingency situations. The respective procedures are contained in the Flight Operations Plan (FOP). Following launch, the performance of each spacecraft subsystem will be checked out, followed by a sequential switch-on/commissioning of each experiment. Cruise operations will follow this checkout phase.

From launch until the end of the mission, facilities and services will be provided to the scientific community for the planning and execution of scientific data acquisition. This will include the generation and provision of complete raw-

Main Events and Mission Phasing

Event/Mission phase	Nominal date(s) or typical duration
Launch window	26 October 2005 to 24 November 2005
Launch and Early-Orbit Phase (LEOP)	~3 days
Near-Earth Commissioning Phase	~21 days
Interplanetary Cruise Phase	~3.5 months
Orbit Insertion Phase	About 5 weeks starting in March 2006
- Venus Capture Manoeuvre	11 April 2006
- Venus Apocentre Lowering	~15 days
Venus Payload-Commissioning Phase	~45 days
Routine Operations Phase	2 Venusian days (486 Earth days)
- End of nominal mission	September 2007
Extended Operations Phase	September 2007 to January 2009
Total Mission Duration	1185 days



ESA scientific mission development times

data sets and the necessary auxiliary data to the Principal Investigators (PIs).

A Venus Express Science Operations Centre (VSOC) will support scientific mission planning and experiment command request preparation for consolidated onward submittal to the VMOC. The VSOC is managed by the Research and Scientific Support Department at ESTEC in Noordwijk (NL). The VSOC undertakes the short-term science coordination and mission planning, and the Data Handling and Archive Service (DHAS) will make pre-processed scientific data and the scientific data archive available to the scientific community.

Express-Mission Experience

The Venus Express mission's feasibility was totally reliant on making maximum reuse of already developed spacecraft elements and subsystems. For Venus Express, ESA had the unique opportunity to reuse a complete spacecraft bus. Contrary to previous Announcements of Opportunity to the scientific community, this one specifically asked the question: 'What science can be done with a Mars Express-type spacecraft and within a very short period of time?' The reuse concept was even extended to the ESA and industrial personnel involved, with some teams working on both Mars Express and Venus Express, for more than a year during an overlapping period.

While the reuse approach certainly has many advantages, there are also some side-effects: at the programmatic level, reduced cost and shortened development time are traded against a repetition and consequent amplification of deviations in the geographical-return targets. The commensurate reduction of team sizes and partly simultaneous working allows a maximum of knowledge transfer, but can at times lead to an overload on the teams. Finally, the concept of reusing entire spacecraft and offering them to the science community cannot compete with a programme approach of setting scientific objectives that drive state-of-the-art payload instruments along with mission-specific spacecraft.

The limitations of the Express approach have also to be recognised when considering a programmatic approach in which larger missions pave the way for technological development of spacecraft and payload units that cannot be accommodated on fast, low-cost missions. For example, the very compressed Venus Express schedule probably represents the limit in terms of reducing development time. Any attempt at further reduction require a much different approach to the way of building scientific spacecraft. This is demonstrated by the accompanying graph, which shows a number of ESA science missions and their relative development times divided into the duration of the Phase-B, which is typically a design phase, and of the Phase-C/D, which is typically a phase of building hardware models and the final flight spacecraft. This plot clearly shows that the Venus Express development schedule was the shortest for science missions conducted to date. More interestingly, however, it shows that the time for the Phase-C/D over the family of missions upon which the Express approach was applied is not drastically different. Thus Rosetta, which was the source spacecraft for the units of Mars Express and Venus Express, shows a Phase-C/D manufacture and verification time only a few months longer than Mars Express, while the Venus Express Phase-C/D is shorter by about 7 months. More significant reductions are demonstrated in the Phase-B design duration from Rosetta to Venus Express.

The three projects had quite different approaches in terms of model philosophy, with Rosetta being the most extensive, Mars Express a modified proto-flight approach, and Venus a pure proto-flight approach. Clearly, the lower limit of time for building a spacecraft has been approached while still following the standard practices for good spacecraft manufacturing and testing. This is indeed further reinforced when comparing with the other science-project development times.

The rebuilding of the Cluster-II spacecraft shows a similar development time to the Express missions, while singular one-off missions show a range of development times similar to Rosetta. Particular exceptions to this are ISO and Integral, which suffered from very particular technological problems that resulted in stretched development schedules. In the case of ISO, it was the technology for handling the cryogenic fluids, while for Integral it was the

Combined spacecraft and launcher teams from Alenia, Astrium, ESA, Europe Assistance, Lavotschkin and Starsem in front of the Venus Express spacecraft mounted on the Fregat upper stage prior to encapsulation

complex sensor technologies needed for the instruments.

The development of the instruments for scientific satellites is a very demanding task by virtue of the need to exploit cutting-edge technologies to meet advancing scientific goals. The Express missions have had the benefit of reusing existing instruments through controlled modifications in most cases. This is a key point in the setting of programme goals where a series of spacecraft are planned to be produced. For any follow-on spacecraft, a series of instruments based on those developed for a first mission is virtually obligatory if the development times are to be maintained at the level of the Venus Express mission.

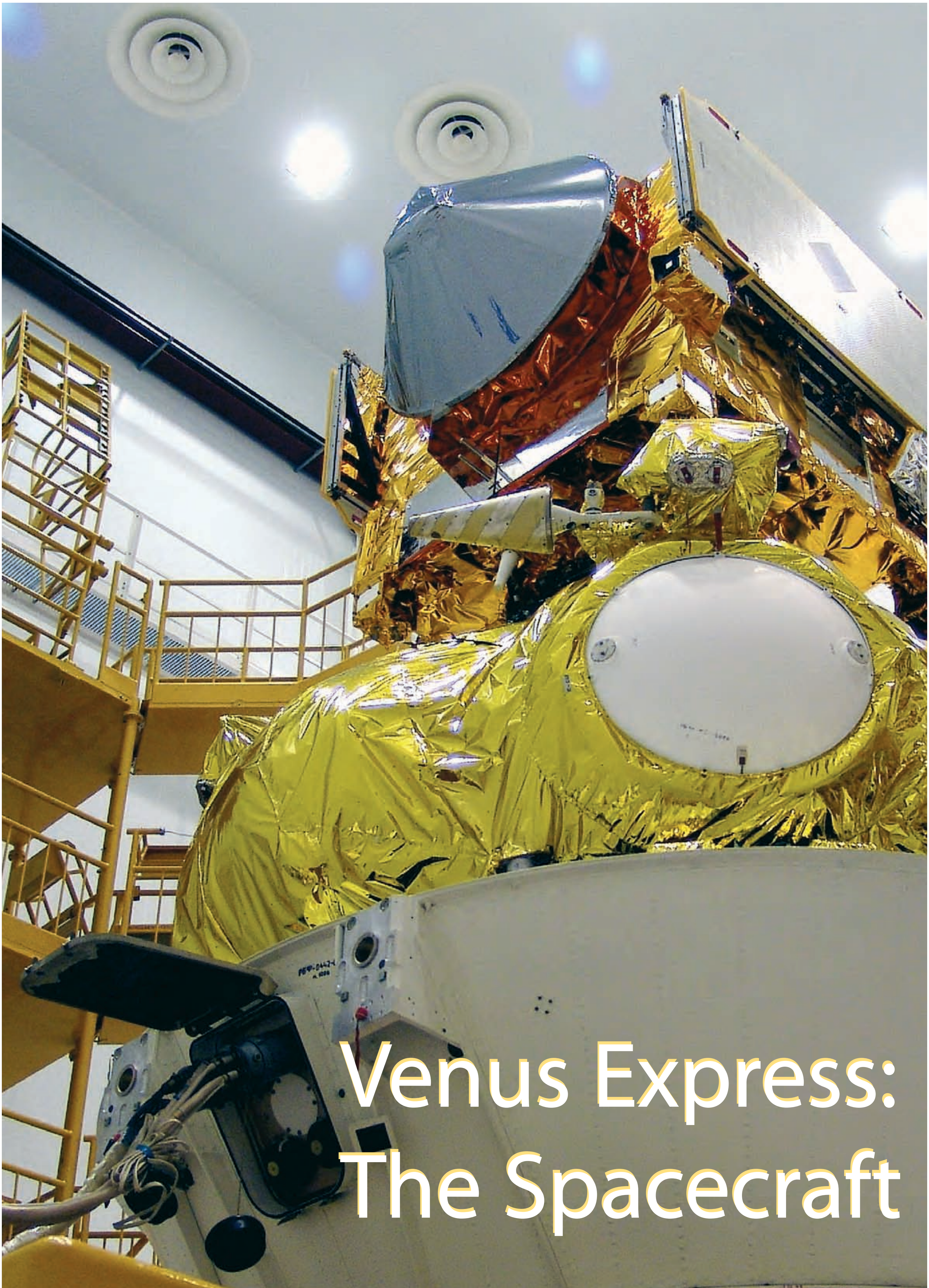
In conclusion, the Express experience, which the Agency has just completed, can be a future model for a programme approach with multiple spacecraft developments, if the programme carefully plans instrument and unit pre-developments along with multiple copies of the flight models. It is highly unlikely that, using the current best-practices approach for a scientific mission, the time to build the satellite can be further compressed. Attempts to further reduce the development duration will require a different approach, without increasing the risk for mission success. The proven integration and verification methods should therefore not be sacrificed for the sake of time savings.

Some possibilities for improving the development for a series of spacecraft could look at having several units with rather large requirement envelopes built concurrently even without the mission being selected. This would be a true off-the-shelf approach, which would also require careful review of mission differences and of whether delta qualifications are needed for utilisation in follow-on missions.

All in all, the Mars and Venus Express projects have allowed the ESA Science Directorate to procure two interplanetary missions with minimal resources while still providing a world-class scientific return.

Acknowledgement

The challenging development of the Venus Express satellite and its ground segment has been successfully achieved within a tight schedule and budgetary envelope thanks to the efficient teamwork by ESA, the scientific Principal Investigators and Industry. It was their skill and dedication that turned this challenge into a success.



Venus Express: The Spacecraft

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The Venus Express project began with the fortunate inheritance of a set of spare spacecraft units and an industrial setup from the Mars Express mission, as it was clear that this second 'Express' mission would only be possible both financially and schedule-wise if new developments were kept to a minimum. Likewise for the payload, the strong legacy from Rosetta and Mars Express in terms of the scientific instruments was equally essential for mission success. Another critical factor was strict adherence to the spacecraft Assembly, Integration and Test campaign schedule, to ensure that the fixed launch window would be met.

Introduction

The main technical challenges faced with Venus Express have been the demanding mission requirements coupled with the need to make maximum reuse of the Mars Express spacecraft design in order to reduce the development risk. Equally challenging was the fact that everything had to be completed within a very short time frame, with the project getting the go-ahead in the autumn of 2002 for a launch in the autumn of 2005.

Consequently, the Venus Express spacecraft is very similar to Mars Express in the following areas:

- Unchanged system concept, with body mounted instruments, fixed antennas and a pair of solar arrays mounted on one-degree-of-freedom drive mechanisms.
- Similar structure with only local changes.
- Fully recurrent propulsion-subsystem and avionics units.

- Similar operational concept, with steady-state Earth-pointing for communications alternated with Venus observations during specific portions of the 24-hour orbit.

There are, however, a number of mission features specific to Venus Express that have required several design changes:

- Some payload instruments not flown on Mars Express had to be accommodated (VIRTIS, VMC, VeRa and MAG), whilst two instruments that were major design drivers for Mars Express are not present on Venus Express (Beagle-2 and MARSIS).
- The thermal environment at Venus is quite severe, with twice the solar flux compared to Earth, which greatly restricts the choice of external materials for the spacecraft.
- Since Venus is an inner planet, the Earth–spacecraft–Sun angle can be up to 360 deg, leading to the need for a dual High-Gain Antenna (HGA) design to ensure that a cryogenic radiator cold surface on the spacecraft can always be pointed away from the Sun.
- The gravity on Venus is 0.81 times that of the Earth (on Mars it is 0.11) and hence a greater velocity increment (delta-V) is needed for the spacecraft's injection into orbit around the planet, requiring the onboard propellant mass to be increased up to the tank limit.
- Venus is closer to Earth than Mars, allowing a proportional reduction in the size of the HGA whilst still maintaining the same performance.

Mechanical Features

The mechanical requirements were driven by the need to reuse the same mechanical spacecraft bus as for Mars Express, with minimal design changes to accommodate the body-mounted 88 kg payload. The interface to the Soyuz-Fregat launcher was unchanged. The maximum spacecraft mass for this launcher was 1270 kg.

Structural Features

The spacecraft's core structure is a honeycomb box 1.7 m long, 1.7 m wide and 1.4 m high, reinforced by three shear-walls and connected to a conical Launch Vehicle Adapter. The solar array is composed of two symmetrical wings to ensure that balanced forces are applied to the arrays and drive mechanisms during the main-engine firing for Venus orbit insertion. This array design would also permit aero-braking if required, for orbit reduction and circularisation.

Four main assemblies were produced in such a way as to simplify the spacecraft development and integration process as much as possible, namely:

- The propulsion module with the core structure.
- The ±Y lateral walls supporting the spacecraft avionics and solar array.
- The shear wall and lower and upper floors supporting the payload units.
- The ±X lateral walls supporting the HGA and radiators.

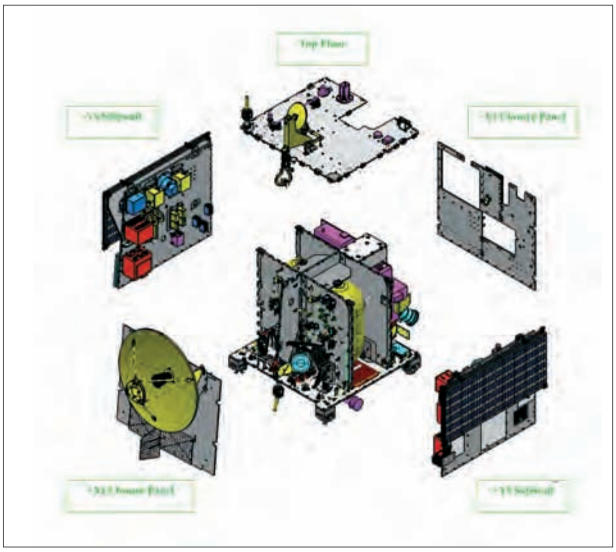
Propulsion Features

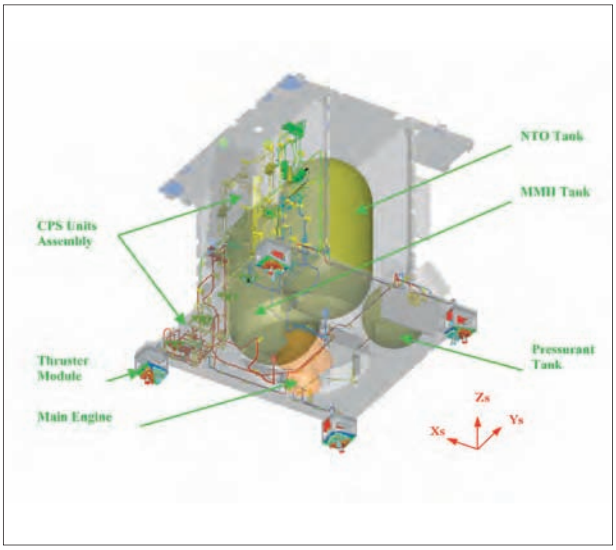
A helium-pressurised, bi-propellant, reaction-control system is used for orbit and attitude manoeuvres by either the 400 N main engine or banks of 10 N thrusters. This is very similar to Mars Express, except for some pipe routing, which was modified due to a change of pyrotechnic valves. In addition, the propellant load at launch was increased to 570 kg due to the increased delta-V requirement; most of it will be used during the 53-minute main-engine burn for Venus Orbit Insertion.

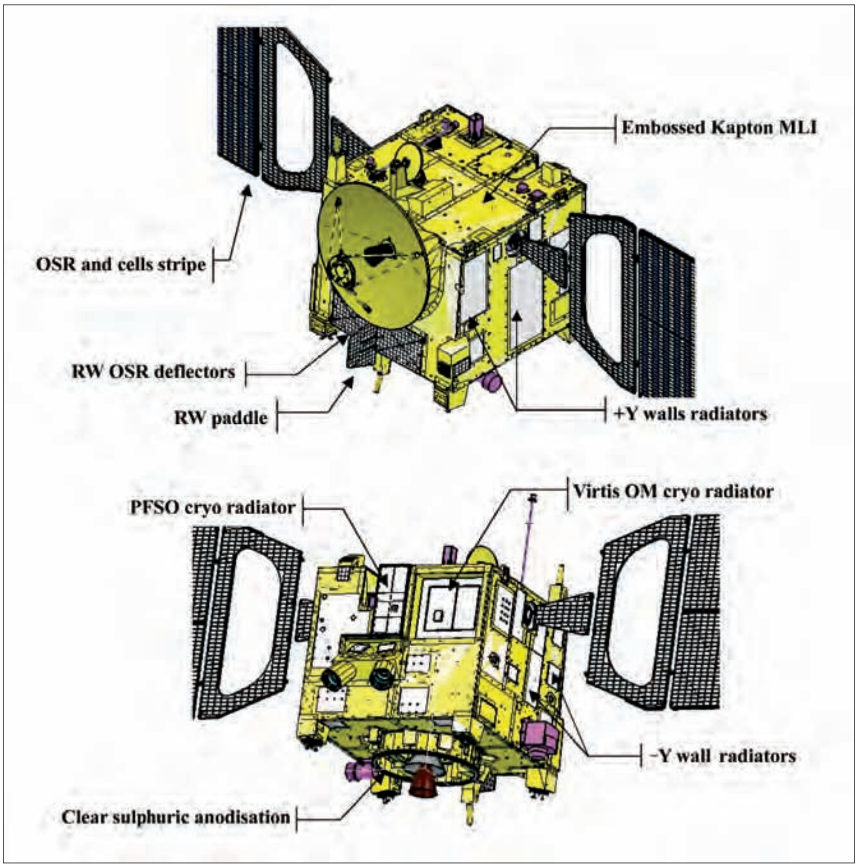
Thermal Features

It was clear from the outset that the Venus Express mission would be very much dominated by the unique thermal design required for this inner planet mission. The thermal requirements were driven by the worst-case cold conditions when in eclipse and the worst-case hot conditions when orbiting the planet, whilst also taking into account the fact that the solar flux would vary from 1320 W/m^2 near Earth to 2655 W/m^2 at Venus. Due to the high

Exploded view of the Venus Express spacecraft and its propulsion system







Views of the top (nadir-facing) and bottom (cryo-radiator) faces of the spacecraft

predicted surface temperatures (up to 250 deg), together with an intense ultraviolet environment, a rapid programme of thermal design, material selection and demonstration was instigated. Because of the severe schedule constraints, it was decided to adopt a conservative margin for the thermo-optical properties of the chosen materials.

The passive thermal control used on Mars Express has been retained, but the spacecraft's external coatings have been modified to eliminate multiple reflections and avoid solar flux entering the spacecraft directly. In particular, Kapton multi-layer insulation (MLI) covers most of the spsacecraft, while optical solar reflectors (OSRs) are used on the lateral radiators and solar arrays, and sulphuric anodisation on the launch-vehicle adapter (LVA) ring's external surface. The heater power has been increased compared to Mars Express, which at first sight would appear counter-intuitive for a mission to an inner planet, but due to the passive thermal design there is a cold bias to the satellite. The additional heating is particularly required during the mission's early cruise phase and during eclipse.

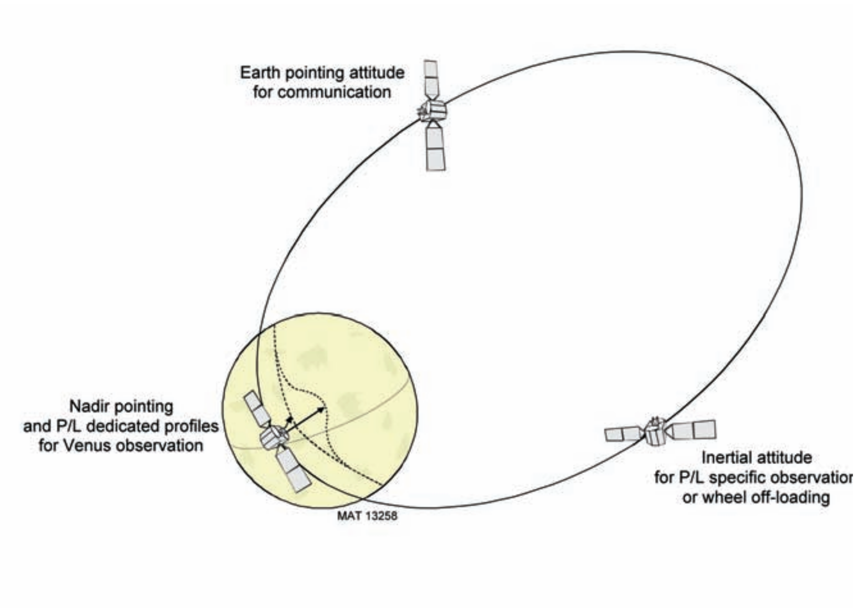
Electrical Features

The Venus Express electrical architecture satisfies the needs of an interplanetary mission driven by high-autonomy requirements due to the lack of real-time control, and the highly variable environment in terms of distance, aspect angle, spacecraft attitude, orbit insertion and maintenance, together with the need to collect and format large volumes of science data for return to Earth.

Power subsystem

The spacecraft's onboard power is managed and regulated by the Power Control Unit (PCU) to provide a +28V regulated main supply for use by both the platform and payload units. Power is distributed to all spacecraft units via a Power Distribution

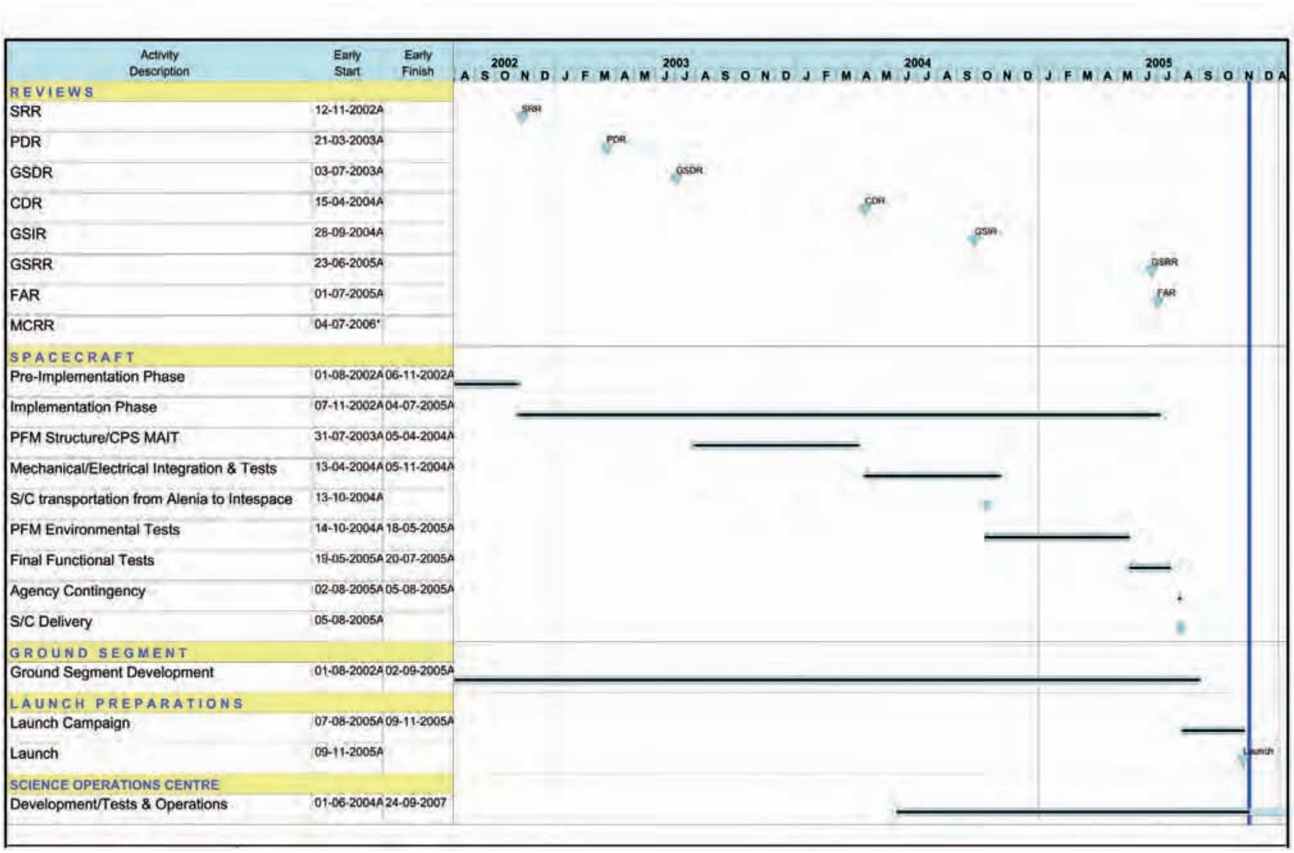
One of the solar-array wings after a successful deployment test at Intespace in Toulouse (F)



Pointing manoeuvres in the Venus orbit

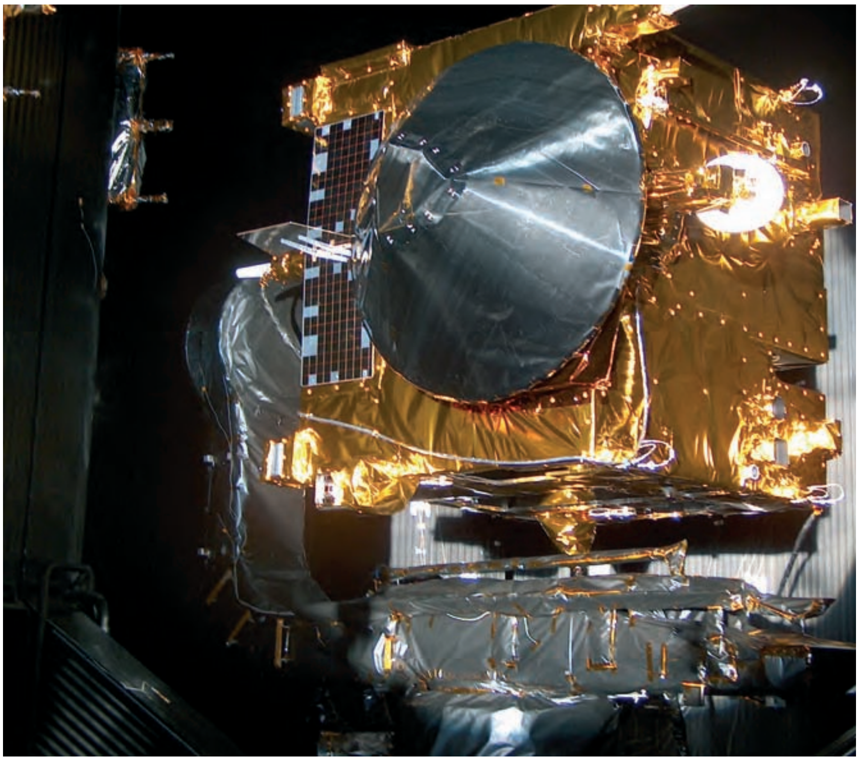
Unit (PDU) that features current limiters for all units. Energy is stored in three low-mass 24 Ah Lithium-Ion batteries for use primarily during eclipse. The pyrotechnic firing circuits are also within the PDU, with the necessary power drawn from the spacecraft's batteries.

The solar-array power output needed near the Earth is 800 W, while at Venus it is 1100 W. It was decided at an early stage in the project that the silicon-based solar cells used on Mars Express would be unsuitable for Venus Express due to the wide range of temperatures that would be experienced by the arrays, leading to a large voltage range incompatible with the PCU. A trade-off study showed that gallium-arsenide triple-junction ($GaInP_2$/GaAs/Ge) solar cells would be the most suitable for Venus Express. A total of 1056 are mounted on the two wings, each with two panels of two sections, giving each wing a mass of 20.7 kg.



The overall schedule for Venus Express

The spacecraft undergoing integration at Alenia in Turin (I)



The spacecraft in the SIMLES facility at Intespace in Toulouse (F)

Communications subsystem

The mission's Telemetry, Tracking and Command (TT&C) requirements were driven by the total volume of scientific data to be returned, and the operational requirements for spacecraft command and telemetry, spacecraft navigation and radio science. Compatibility with both the ESA TT&C Standards and the NASA Deep-Space Network (DSN) was mandatory to allow cross-agency support.

The configuration of the planets during the mission and the need to maintain a cold spacecraft face pointing away from the Sun led to the inclusion of a second smaller High-Gain Antenna (HGA2) that will be used for approximately one quarter of the mission, centred around inferior conjunction when the spacecraft will be at its closest to the Earth.

The TT&C subsystem has at its core two redundant dual-band transponders and two high-power 70 W travelling-wave-tube amplifiers interconnected with a radio-frequency (RF) switching network.

The spacecraft communications system also hosts the VeRa radio-science experiment's high-performance Ultra-Stable Oscillator (USO), which is essential for the one-way downlink experiments.

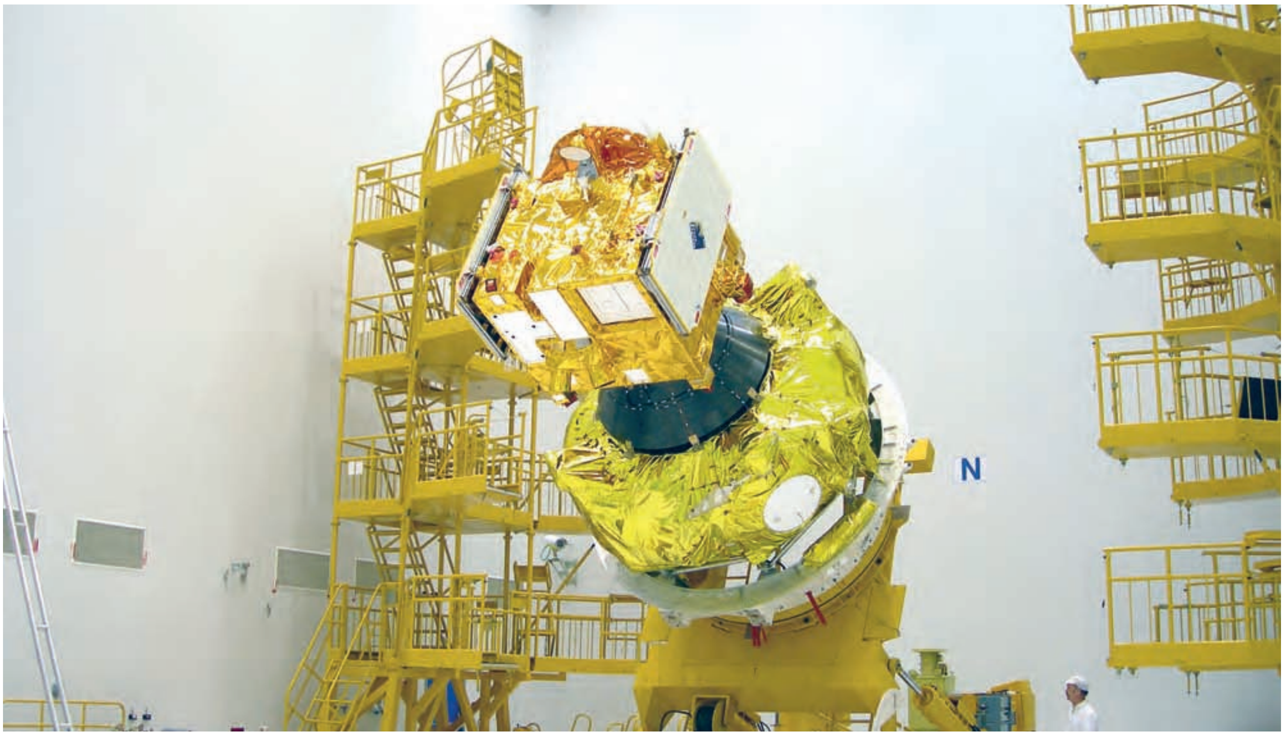
Data-handling subsystem

The spacecraft's data-handling architecture is centred on two Control and Data Management Units (CDMUs), which together constitute the Data Management System (DMS), a Remote Terminal Unit (RTU), an AOCS Interface Unit (AIU) and a Solid-State Mass Memory (SSMM).

The main tasks of the CDMUs are:

- Decoding of the telecommands from the ground and ensuring their execution, onboard housekeeping and science-data telemetry formatting for transmission.
- Execution of DMS software for overall data management, including the mission timeline.
- Execution of the attitude and orbit control system software.

The RTU is the interface between the DMS system and the payload and platform units. Instructions to these units are passed over one of the two redundant OBDH busses. In



The combined stack of the Venus Express spacecraft and Fregat upper stage being readied for launch at the Starsem facilities in Baikonur

the return direction, telemetry from the payload or platform units is gathered by the RTU for return to the DMS.

The SSMM is a file-based 12 Gbit mass-memory store for housekeeping and science data collected by the DMS system. However, two of the payloads, VIRTIS and VMC, generate such large volumes of data at high speed that they have their own dedicated direct links to the SSMM.

Attitude and Orbit Control Subsystem

As the spacecraft is of a fixed-antenna and body-mounted-instrument design and there is the need for a main-engine burn to achieve orbit insertion around Venus, the Attitude and Orbit Control System (AOCS) has to provide a high degree of attitude manoeuvrability. Attitude estimation is therefore based on star-tracker and gyroscope data. There is also a Sun-acquisition sensor for initial orientation of the spacecraft after its separation from the Fregat at launch and for safe modes. Reaction wheels are used for most attitude manoeuvres, thereby reducing fuel consumption.

Testing

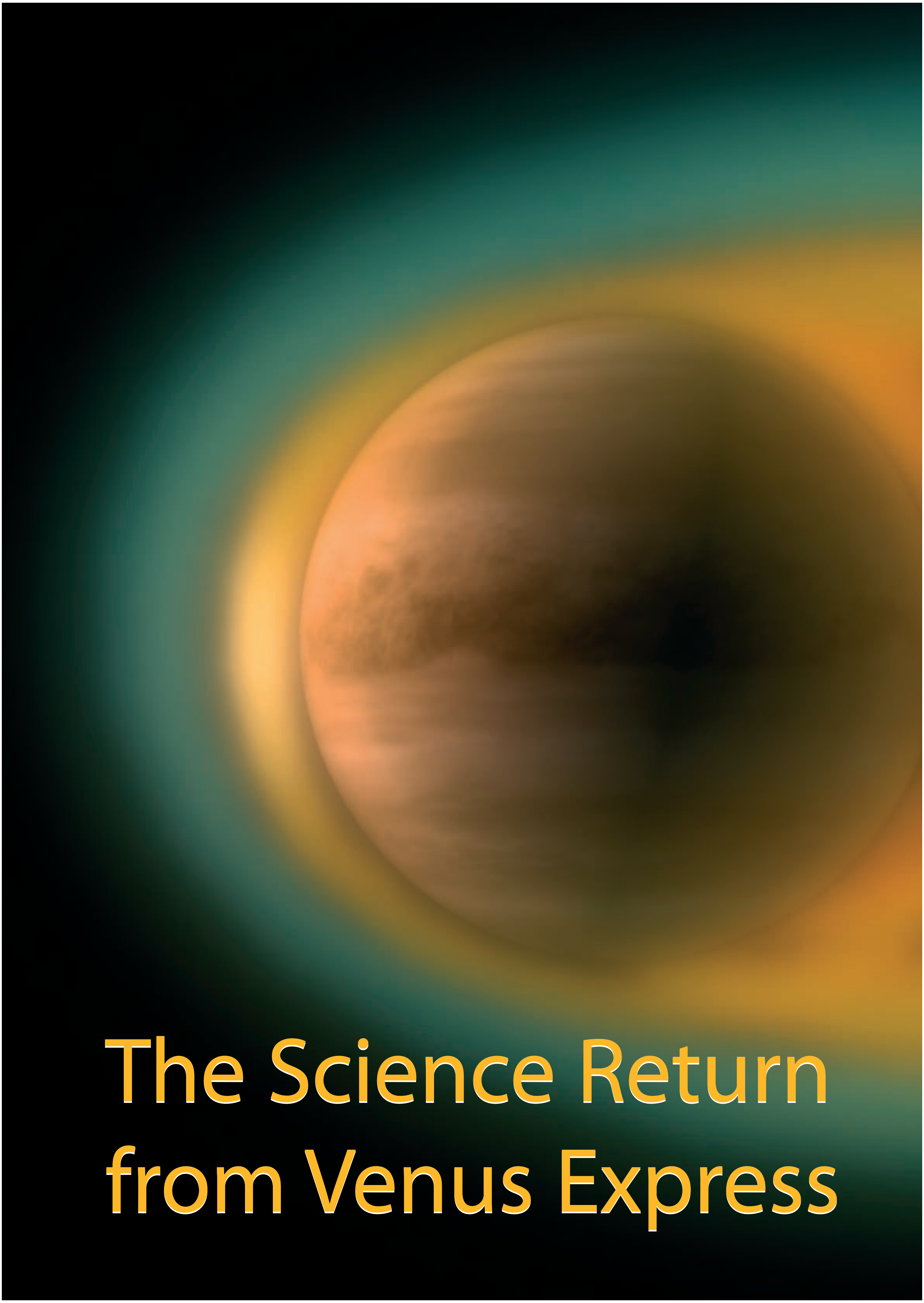
The true ‘express’ nature of the Assembly, Integration and Test (AIT) activities can be appreciated from the fact that the spacecraft structure was delivered to Alenia’s integration facility in Turin (I) on 5 April 2004 and the environmental test campaign was successfully completed just 15 months later, on 2 July 2005.

Following the initial integration of all of the platform units, payload units, thermal hardware, spacecraft harness, RF waveguides and antennas, an Integrated Subsystem Test was first completed. The spacecraft was then moved to the Intespace facility in Toulouse (F) in order to complete the system and environmental testing close to Astrium, the Venus Express prime contractor.

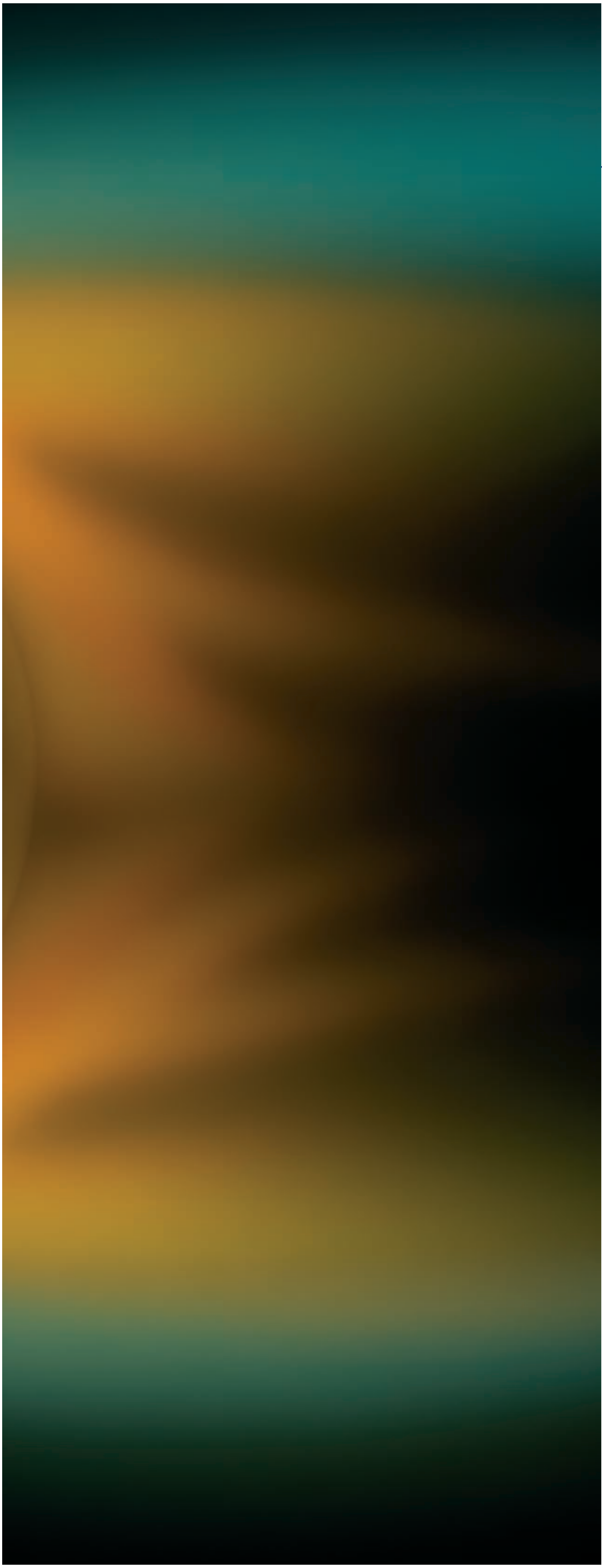
Owing to the unique characteristics of a Venus mission and the high solar flux experienced, it was necessary to upgrade the solar simulator facility (SIMLES) at Intespace. The solar flux was temporarily increased by introducing a removable lens into the optical path of the simulator, thereby concentrating the solar beam into a smaller area to illuminate the spacecraft with the higher flux representative of the flight environment.

The first spacecraft Integrated System Tests were run at Intespace at the end of November 2004, and the mechanical vibration and acoustic testing was performed immediately after Christmas. These tests showed that the spacecraft should perform as expected after its ride into space aboard the Soyuz/Fregat launcher.

By the spring of 2005, Venus Express was ready for the Thermal Balance/ Thermal Vacuum test campaign. The results of these tests successfully demonstrated that the spacecraft would perform as predicted in the harsh thermal environment to be expected around Venus. The spacecraft underwent radiated Electromagnetic Compatibility (EMC) testing, including an auto-compatibility test to demonstrate that when the spacecraft is transmitting to Earth none of its other functions will be affected. In late spring, the System Verification Test performed by ESOC, and a further Integrated System Test, rounded off the successful Environmental Test Campaign.



The Science Return from Venus Express



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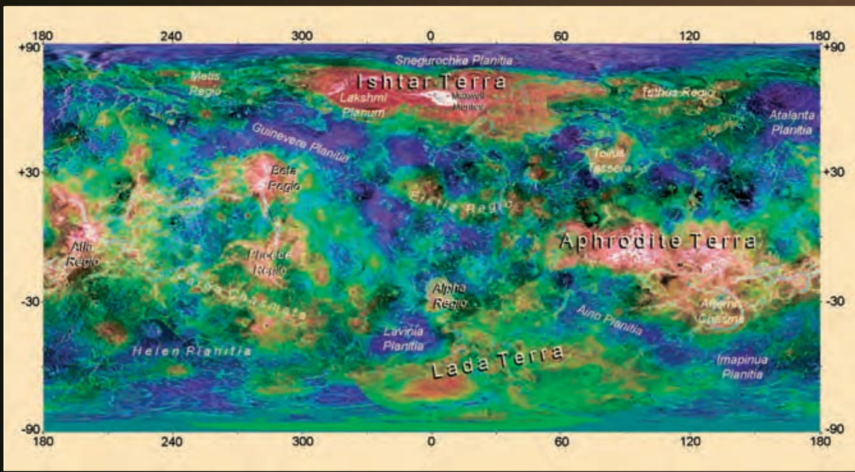
Since the beginning of the space era, Venus has been an attractive target for planetary scientists. Our nearest planetary neighbour and, in size at least, the Earth's twin sister, Venus was expected to be very similar to our planet. However, the first phase of Venus spacecraft exploration (1962-1985) discovered an entirely different, exotic world hidden behind a curtain of dense cloud. The earlier exploration of Venus included a set of Soviet orbiters and descent probes, the Veneras 4 to14, the US Pioneer Venus mission, the Soviet Vega balloons and the Venera 15, 16 and Magellan radar-mapping orbiters, the Galileo and Cassini flybys, and a variety of ground-based observations. But despite all of this exploration by more than 20 spacecraft, the so-called 'morning star' remains a mysterious world!

Introduction

All of these earlier studies of Venus have given us a basic knowledge of the conditions prevailing on the planet, but have generated many more questions than they have answered concerning its atmospheric composition, chemistry, structure, dynamics, surface-atmosphere interactions, atmospheric and geological evolution, and plasma environment. It is now high time that we proceed from the discovery phase to a thorough investigation and deeper understanding of what lies behind Venus' complex chemical, dynamical, and geological phenomena.

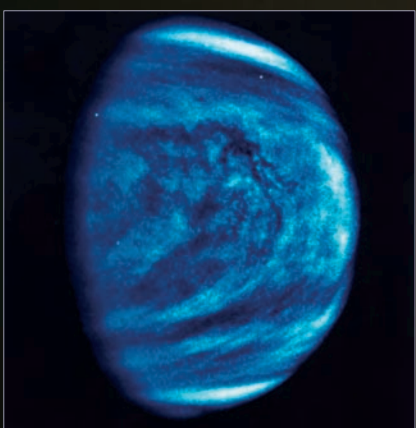


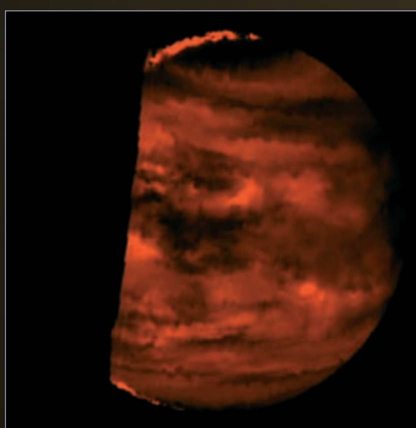
A topographic map of Venus based on radar data from the US Magellan mission (1990-1994). The purple/blue areas correspond to the lowest elevations and the red/white areas to the highest. There are several regions with dramatic features, but a large portion of the planet is dominated by smoothly rolling plains. 90% of the surface lies within an altitude range of only 3 km. At the top centre is the large highland area of Ishtar Terra with the highest mountain on the planet, Maxwell Montes, rising to an altitude 11000 m above the mean surface level. Due to the planet's low rotation speed, Venus is almost perfectly spherical

The Russian Venera 13 lander and its twin Venera 14 returned the first colour images from the surface and allowed investigation of the surface composition. Basaltic rock and soil dominate these landing sites. These panoramic images from Venera 13 (top) and 14 (bottom) show a very flat landscape and a part of the horizon at the upper corners

The data from ground-based observations and previous space missions are very limited in term of their spatial and temporal coverage and, prior to the discovery of the near-infrared 'spectral windows' in the planet's atmosphere, lacked the ability to sound the lower atmosphere of Venus remotely and to study from orbit the phenomena hidden below the thick cloud deck. A survey of the Venusian atmosphere is therefore long overdue. The Pioneer Venus, Venera 15 and 16, and Magellan missions provided global comprehensive radar mapping of the surface and investigated its properties.

While a fully comprehensive exploration of Venus will require, in the long term, in-situ measurements from probes, balloons and sample return, so many key questions about Venus remain unanswered that even a basic orbiter mission, carrying an appropriate combination of modern instruments to the planet, can bring a rich harvest of high-quality scientific results. Venus Express, based on the Mars Express spacecraft bus and equipped with selected instruments designed originally for the Mars Express and Rosetta projects, together with two new instruments, is very appropriate in this regard. It offers an excellent opportunity to make major progress in the study of the planet.





(Left) mage of Venus in daylight, taken by the NIMS instrument onboard the Galileo spacecraft during its fly-by en route to Jupiter. The image was taken with a violet filter to show the structure of the upper cloud layer. The contrast, which is not visible at other wavelengths, is produced by a still unknown substance

(Right) This image from the Galileo/NIMS instrument was taken over the nightside of Venus at an infrared wavelength of 2.3 µm. At this wavelength, the atmosphere is partly transparent to light and so the radiation from the hot lower part of the atmosphere can penetrate the upper atmosphere and the cloud layer. Brightness distribution shows cloud patchiness: the darker the region the higher the cloud opacity

Previous Successful Missions to Venus*

Year	Mission	Country	Type of mission
1962	Mariner 2	USA	Flyby
1967	Mariner 5	USA	Flyby
1967	Venera 4	USSR	Atmospheric probe
1969	Venera 5 & 6	USSR	Atmospheric probes
1970	Venera 7	USSR	Lander
1972	Venera 8	USSR	Lander
1974	Mariner 10	USA	Flyby
1975	Venera 9 & 10	USSR	2 orbiters and 2 landers
1978	Venera 11 & 12	USSR	Landers
1978-1992	Pioneer Venus 1 & 2	USA	1 orbiter and 4 atmospheric probes
1981	Venera 13 & 14	USSR	Landers
1983	Venera 15 & 16	USSR	Orbiters
1985	Vega 1 & 2	USSR	Flyby + 2 balloons + 2 landers
1990-1994	Magellan	USA	Orbiter (radar)
1990	Galileo	USA	Flyby
1998, 1999	Cassini	USA	Flyby

** The exploration of Venus started in the early days of space exploration and several missions failed at different stages.*

Venus before Venus Express

The ground-based observations made before space exploration began could provide only very limited information about Venus. From the first flyby of Venus, by Mariner 2 which discovered that the planet has no magnetic field, to the most recent brief visit, the Cassini flyby on its way to Saturn in 1999, we have come to a point of at least a basic understanding. So what do we really know about Venus today?

The major planetary parameters are indeed very similar to those of the Earth. The radius of Venus is 6051 km (versus 6378 km for the Earth) and its average density is 5.25 g/cm^3 (versus 5.52 g/cm^3 for the Earth). Consequently, the masses, volumes, surface gravities, and escape velocities are also similar for the two planets. The distance to the Sun is 0.72 Astronomical Units (AU) for Venus, versus 1 AU for the Earth (where 1 AU = 150 million km and is the average distance from the Earth to the Sun).

Here, however, the similarities end. Venus rotates very slowly, once in 243 Earth days, and in the opposite direction to Earth (so-called retrograde rotation). The length of a Venusian year is 224 Earth days. The planet's atmosphere is composed mainly of carbon dioxide (96.5%), with molecular nitrogen as a minor constituent (3.5%). Water vapour, sulphur dioxide, carbon monoxide and other compounds also exist in small amounts. The average surface temperature is 464°C, and the atmospheric pressure is 92 bars. Clouds mainly made up of sulphuric-acid droplets cover the whole planet. Venus is indeed an inhospitable world!

The surface: Venus is one of the most geologically active planets in the Solar System. Its surface is rather young and it appears that it has been completely altered by a global outburst of volcanic activity about 500 million years ago. The surface therefore does not carry any record of the first 90% of the planet's life, and is roughly divided into plains covering 80% of the planet and highlands. Geological features such as mountains and canyons are also found, as well as craters larger than 2 km. Smaller craters have not been formed due to the destruction of small meteorites by the dense planetary atmosphere. It is likely that there is still active volcanism. Earth-like plate tectonics have not been observed. Our knowledge about the surface has benefited dramatically from the Magellan radar sounding; only a very limited number of optical images of the surface exist, but a few such panoramas were sent back by the Venera landers (see accompanying images).

The lower atmosphere and cloud layer: The physics and the chemistry of the first 60 km of the atmosphere are largely unknown. This is especially true as far as the atmospheric dynamics and the composition of the lower atmosphere and the cloud layer are concerned. The nature of the UV-absorbing substance at the cloud tops that produces patterns on the Venus disc (see accompanying figure) and absorbs a large fraction of the solar radiation, and the origin of the large solid particles detected by Pioneer Venus, are also poorly understood.

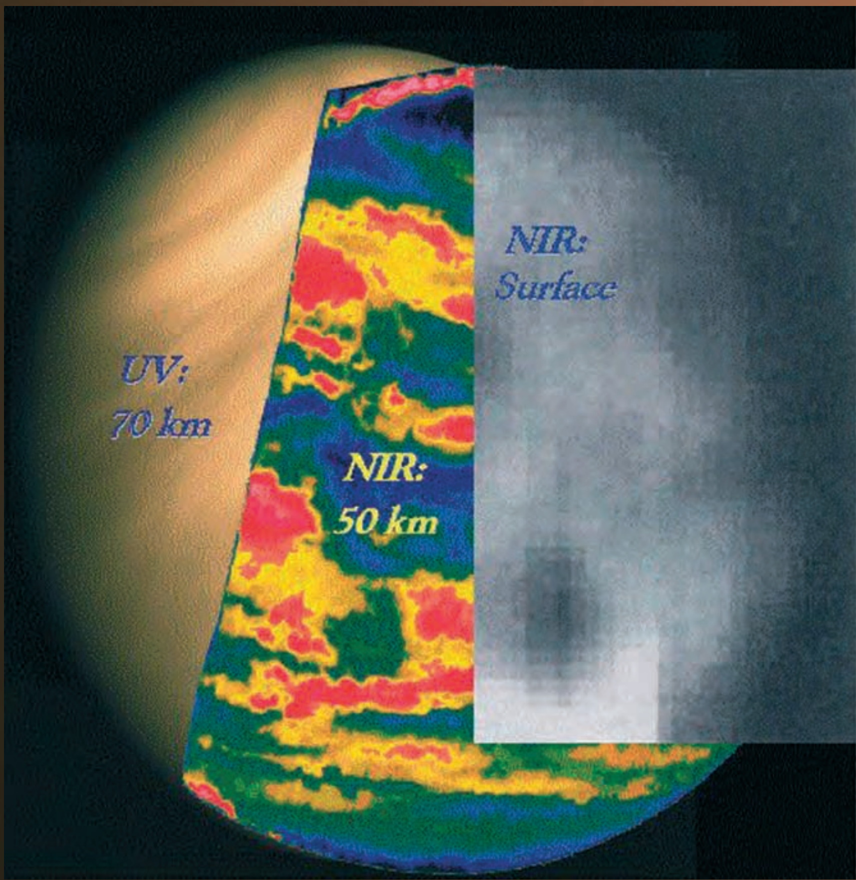
The winds at an altitude of about 70 km exceed 100 m/s, which makes the atmosphere at this level circulate the planet in only four days, whilst the planet itself rotates very slowly, with a period 60 times longer. This 'super-rotating' wind gradually reduces with decreasing altitude, becoming approximately zero at the surface. The process generating these strong winds cannot presently be explained. Polar vortices, observed by earlier missions but also not explained, may well have some link with this super-rotating atmosphere.

The cloud layer extends between 50 and 70 km altitude and is possibly made up of two or more distinctly separate layers governed by different processes. The transparency is strongly wavelength-dependent and at a few wavelengths in the near infrared it is possible to see through to the lower cloud layers and even down to the surface (see figure).

Venus's climate is strongly driven by the 'greenhouse effect' produced mainly by the high content of CO_2, which is transparent to incoming solar radiation in the visible range, but blocks the outgoing thermal-infrared radiation from the surface and the lower atmosphere. This causes the surface of Venus to be the hottest place of all in the Solar System.

The middle and upper atmosphere: Also above 60 km altitude, the processes in the atmosphere are poorly known. In the middle atmosphere (60 to 110 km), carbon dioxide and sulphur dioxide are photo-dissociated by the solar flux, leading to an interesting chemistry that is important to understand in order to grasp how the clouds are formed below. The temperature and cloud structure show significant latitudinal variability. Strong day/night contrasts exist above 110 km in the thermosphere. These differences should lead to much stronger differential winds than are currently observed.

The plasma environment: Since Venus lacks an internal magnetic field, the upper atmosphere is interacting directly with the solar wind. As a result, via a complex process, part of the atmosphere is escaping to space. This may have been the mechanism that has removed the water and other volatiles, which are likely to have been present after the formation of the planet. The deuterium abundance is much higher on Venus than on the Earth, which indicates that large amounts of hydrogen have been lost in the past. This point is particularly important for understanding the evolution of the atmosphere.



A collage of the sorts of imagery that can be produced by Venus Express's VMC camera using three of its four filters. The altitude in the atmosphere from which most of the radiation originates in each case is indicated. The rightmost element, which shows the surface, is extracted from an Earth-based telescope image taken at 1.0 µm and therefore both the contrast and resolution are limited

Key Questions and Mission Objectives

The information we have has certainly advanced our knowledge about Venus, but it has also enabled us to more precisely formulate what we do not know, and in particular what it is important to understand next. Some of the key questions that have been identified are:

- What is the mechanism and what is the driving force of the super-rotation of the atmosphere?
- What are the basic processes in the general circulation of the atmosphere?
- What is the composition and chemistry of the lower atmosphere and the clouds?
- What is the past and present water balance in the atmosphere?
- What is the role of the radiative balance and greenhouse effect in the past, present and future evolution of the planet?
- Is there currently volcanic and/or tectonic activity on the planet?

The answers to these questions, together with the comprehensive studies under the different themes described below, will lead to an improved understanding of perhaps the most fundamental question of all, namely: *Why has Venus evolved so differently compared to the Earth, in spite of the similarities in terms of size, basic composition and distance to the Sun?*

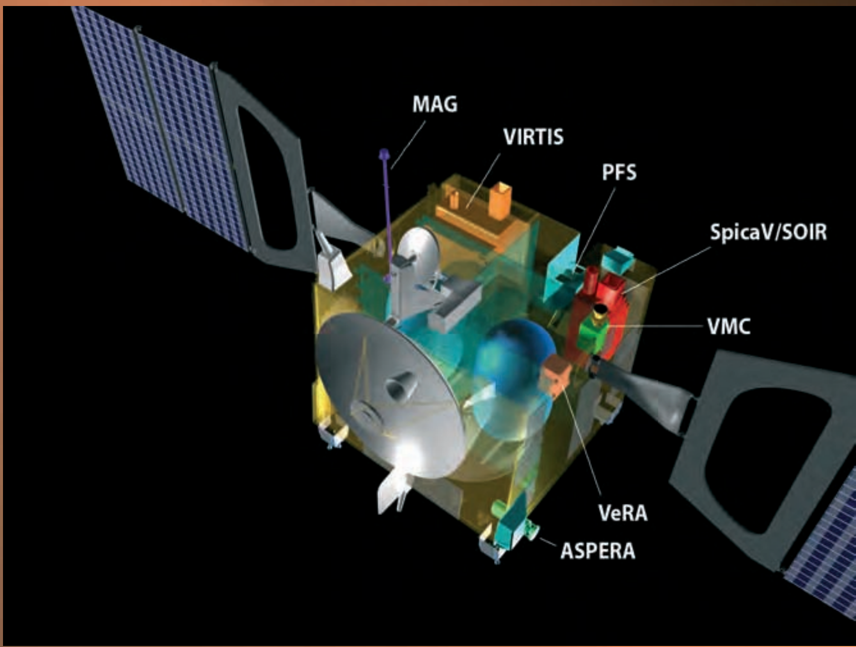
The scientific objectives of the Venus Express Mission have been concisely expressed within seven 'Scientific Themes'. The aim is to carry out a comprehensive study of the atmosphere of Venus and to study the planet's plasma environment and its interaction with the solar wind in some detail. Dedicated surface studies will also be performed. The seven Scientific Themes are:

- Atmospheric Dynamics
- Atmospheric Structure
- Atmospheric Composition and Chemistry
- Cloud Layer and Hazes
- Radiative Balance
- Surface Properties and Geology
- Plasma Environment and Escape Processes.

The first three themes are divided into sub-themes that refer to the upper, middle and lower parts of the atmosphere. The corresponding approximate limits for these regions are, above 110 km, between 110 and 60 km, and below 60 km. The scientific requirements within the sub-themes are broken down into units that can be directly addressed by individual measurements.

The Scientific Payload

As there were already strict requirements on the payload in the 'Call for Ideas' in that



Locations of the seven scientific instruments on the Venus Express spacecraft

the individual instruments had to be available to match the challenging schedule of the mission, the list of instruments that could be chosen was fairly restricted. The obvious candidates were the spare models from the Mars Express and Rosetta projects. After a detailed assessment, three Mars Express instruments were chosen together with two Rosetta instruments, enhanced with a newly developed miniaturised four-band camera and a new magnetometer (with heritage from the Rosetta lander). In addition, a very high-resolution solar-occultation spectrometer was added to one of the original Mars Express instruments. This resulted in a payload complement including a combination of different spectrometers, an imaging spectrometer and a camera, covering the UV to thermal-IR range, along with a plasma analyser and a magnetometer. The Radio Science team will utilise the communication link to the Earth, enhanced with an ultrastable oscillator, to conduct atmospheric investigations with high vertical resolution. This payload can sound the entire atmosphere from the planet's surface to 200 km altitude.

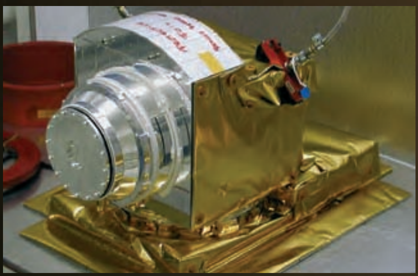
The elements of the scientific payload and their respective Principal Investigators are listed in the adjacent table. As it turned out, despite the limitations on the freedom of choice, the payload is close to optimal for the mission, with all of the scientific objectives able to be addressed in the proper depth. The payload has shown excellent performance in pre-launch testing, with accurate calibration being achieved for all instruments.

ASPERA

The ASPERA-4 experiment is designed to study the solar-wind/atmosphere interaction and to characterise the plasma and neutral-gas environment in near-Venus space through the imaging of Energetic Neutral Atoms (ENAs) and local charged-particle measurements. The studies to be performed address the fundamental

Venus Express Scientific Payload

Instrument	Description	Principal Investigator
ASPERA	Ion and electron analyser and energetic neutral atoms imager	S. Barabash, IRF, Kiruna, Sweden
MAG	Magnetometer	T. Zhang, IWF, Graz, Austria
PFS	High-resolution infrared Fourier spectrometer	V. Formisano, IFSI-INAF, Rome, Italy
SPICAV	UV and IR atmospheric spectrometer for solar/ stellar occultation and nadir and limb direct observations	J.-L. Bertaux, SA/CNRS, Verrieres-le-Buisson, France
VeRa	Radio-science investigation of the ionosphere, atmosphere, surface, and interplanetary plasma	B. Häusler, Universität der Bundeswehr, München, Germany
VIRTIS	UV/visible/IR imaging and high-resolution spectromery	P. Drossart, CNRS/LESIA, Observatoire de Paris, France G. Piccioni, IASF-CNR, Rome, Italy
VMC	Venus Monitoring Camera with filters in four wavelength bands	W.J. Markiewicz, MPS, Katlenburg-Lindau, Germany



The main unit of the ASPERA-4 instrument

question: How strongly do the interplanetary plasma and electromagnetic fields affect the Venusian atmosphere?

The ASPERA-4 instrument has four sensors: two ENA sensors, an electron spectrometer and an ion spectrometer. The Neutral Particle Imager (NPI) provides measurements of the integral ENA flux (0.1 - 60 keV) with no mass and energy resolution, but with a relatively high angular resolution of 4 deg x 11 deg. The Neutral Particle Detector (NPD) provides measurements of the ENA flux, resolving velocity (0.1 - 10 keV) and mass (hydrogen and oxygen) with a coarse angular resolution of 4.5 deg x 30 deg. The Electron Spectrometer (ELS) is a top-hat electrostatic analyser of very compact design, to measure electron fluxes in the energy range 1 eV - 20 keV with an 8% energy resolution. These three sensors are located on a scanning platform providing full sky_ coverage. The fourth sensor is a spacecraft-fixed Ion Mass Analyser (IMA), providing ion measurements in the energy range 0.01 - 36 keV/q for the main ion components H^+, H_2^+, He^+, O^+, O_2^+, and CO_2^+ ion group with M/q > 40 amu/q.

MAG

The magnetic-field observations are intended to define the plasma boundary and to study the solar wind's interaction with the Venusian atmosphere. The magnetic field data will also provide important information to other instruments onboard, for example ASPERA, for combined studies of the Venus plasma environment.

The Magnetometer is a miniaturised digital fluxgate magnetometer that uses two fluxgate sensors to measure the magnetic field's magnitude and direction. One sensor is mounted on the tip of a 1 m-long deployable boom, and the other on the top surface of the spacecraft. This sensor configuration enables the ambient magnetic field, which is the scientific parameter of interest, to be separated from stray spacecraft fields and disturbances. This very-high-sensitivity instrument can detect magnetic variations as small as a few pico-Tesla.

The MAG instrument

PFS

The Planetary Fourier Spectrometer (PFS) is an infrared spectrometer optimised for atmospheric studies. Its two channels together cover the spectral range from 0.9 to 45 µm. The relative spectral resolution ranges from 200 at the longest wavelength to 8000 at the shortest. The field of view is about 1.6 deg for the short-wavelength and 2.8 deg for the long-wavelength channel.

The PFS instrument

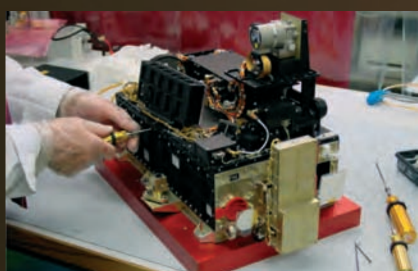
PFS addresses several atmospheric and surface goals on Venus by measuring:
– temperature and cloud structure from 60 to 100 km altitude
– abundance of several important trace molecular species at the cloud tops and in the lower atmosphere
– pressure at the cloud tops
– cloud opacity and its variations
– thermal surface flux at several wavelengths near 1 micron, with concurrent constraints on surface temperature and emissivity (indicative of composition)
– oxygen airglow near the 100 km level.

It will also search for and characterise current volcanic activity by measuring spatial and temporal anomalies in both the surface thermal flux and the abundances of volcanic trace species in the lower atmosphere.

SPICAV

SPICAV is a suite of three optical spectrometers designed to study the present state of Venus's atmosphere and provide clues to its evolution. On the nightside, the near-IR thermal emission emanating from the deep atmosphere will be analysed (0.7 to 1.65 µm, resolution ~1500) to learn more about the composition of the lower atmosphere and H_2O content, and to detect hot spots on the surface. In the UV range (measured by an imaging spectrometer with intensified CCD at 110-320 nm, resolution 1.5 nm) upper atmosphere natural emissions will be studied. NO and O_2 emissions are tracers of the thermosphere global circulation. Precipitation of energetic electrons produces emissions of atomic oxygen at 130.4 and 135.6 nm. On the dayside, Lyman-α hydrogen and oxygen emission will allow the escape of H and O atoms to be studied. The UV spectrometer will probe the vertical distribution of SO_2 and haze layers using the star-occultation technique.

The SOIR (Solar Occultation in the Infra-Red) channel is a new type of high-resolution spectrometer ($\lambda/\Delta\lambda$ = 20 000) to measure many atmospheric constituents, in particular HDO and H_2O, above the clouds together with their vertical distributions; this will have a direct impact on our understanding of how water has escaped from Venus. The instrument consists of a



The SPICAV instrument

high-dispersion grating spectrometer (2.2 to 4.4 μm) working in high diffraction orders, combined with an Acousto-Optic Tuneable Filter (AOTF).

VeRa

The Venus Express Radio Science Experiment (VeRa) will use radio signals at X- and S-band (3.5 cm and 13 cm wavelengths) from the spacecraft's telecommunications system to probe the planet's surface, ionosphere and neutral atmosphere, the gravity field and the interplanetary medium. An Ultra Stable Oscillator (USO) will provide a high-quality onboard frequency reference to the spacecraft transponder. Instrumentation on Earth will sample the amplitude, phase, propagation time and polarisation of the received signals. Simultaneous coherent measurements at the two wavelengths will allow separation of the dispersive effects caused by the solar-wind plasma and the Earth's ionosphere. The USO is a direct derivative of the Rosetta USO.

VeRa science objectives include:

- determination of neutral atmospheric structure from 40 to 100 km altitude and derivation of vertical profiles of neutral mass density, temperature, and pressure as a function of local time and season
- study of the H_2SO_4 vapour absorbing layer in the atmosphere via signal intensity variations
- investigation of ionospheric structure from approximately 80 km altitude to the ionopause (< 600 km)
- observation of back-scattered surface echoes from high-elevation targets with anomalous radar properties (such as Maxwell Montes) to determine surface roughness and dielectric properties
- investigation of dynamical processes in the solar corona and the solar wind.

VIRTIS

VIRTIS (the ultraviolet, visible and infrared imaging and high-resolution spectrometer) will map Venus from the surface to the mesosphere. Its scientific objectives cover a wide field, ranging from the meteorology of the middle atmosphere to the surface mineralogy. It will make ample use of the recently discovered infrared 'windows' enabling the atmosphere to be sounded at different depths down to the surface, and three-dimensional mapping of the region between the surface and 150 km altitude. These maps, regularly repeated to provide a temporal dimension, will be used to study the dynamics of the atmosphere with unprecedented precision. The scientific studies will address the atmospheric super-rotation, the cloud structure along with the specific question of the UV absorbers, and the dynamics of the mesosphere, together with specific questions related to atmospheric escape. Volcanism, atmospheric composition and surface–atmosphere interactions will also be addressed.

Particular VIRTIS scientific goals are:

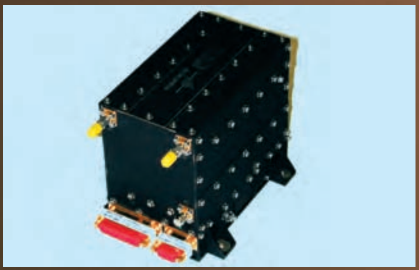
- study of the lower atmosphere composition (CO, OCS, SO_2, H_2O)
- study of the cloud structure, composition and scattering properties
- cloud tracking in the UV and IR, to retrieve the wind velocity field
- sounding of the mesospheric temperature and cloud structure
- search for lightning
- search for variations related to surface/atmosphere interaction
- temperature mapping of the surface and search for volcanic activity
- search for seismic-wave activity (tentative).

VIRTIS will also provide true-colour images of Venus for science communication and education purposes.

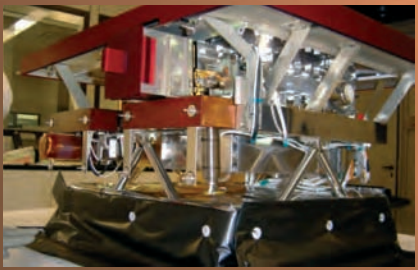
VMC

The Venus Monitoring Camera (VMC) is an innovative compact design with four independent lenses (channels) that share a single CCD. The four channels have individual narrow-band filters at wavelengths chosen for specific science objectives.

A collage of possible outputs from three of the VMC channels is shown in the figure on page 28. An ultraviolet (UV) channel is centred on 365 nm. At this wavelength the top layer of the Venus clouds exhibits an absorption feature due to an unknown substance. The yellowish part at the left of the figure shows a UV image of Venus captured by Mariner-10. Tracking motions of these features will be used to study the atmospheric dynamics at the cloud tops (at about 70 km) with the goal to understand the mechanism of the super-rotation, the mysterious polar vortex and to observe atmospheric waves and other small-scale phenomena. VMC has also two near infrared filters. The first, centred at 1.01 μm, will be used to study the nighttime emission from the hot surface of Venus. This channel will map the surface brightness temperature distribution, allowing for a search for "hot spots" associated with possible volcanic activity. Brightness variations and their motions across the disc in this channel will also give a clue about cloud patchiness and atmospheric dynamics at 50 km altitude. The second near infrared filter, centred at 935 nm, will be used to study the global distribution of water vapour at the cloud top and in the lower atmosphere. A visible wavelength filter, at 513 nm, will observe O_2 nightglow. Mapping its spatial distribution and temporal variations will contribute to the study of the circulation of the lower thermosphere (100 - 130 km). In

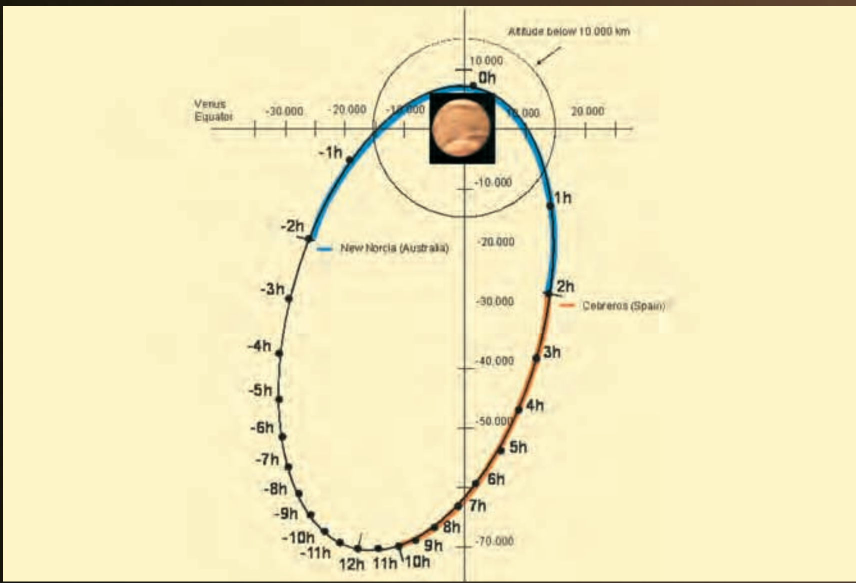


The VeRa instrument



The VIRTIS instrument

The VMC instrument's four lenses



The operational orbit of Venus Express. The ticks mark every hour of the 24 hour orbit. The main scientific observations will be made at the orbit's pericentre, below 10 000 km, close to apocentre, between 10 h and –10 h, and at the ascending branch, between –10 h and –2 h. Communication with the Earth and data downlinking will occur between 2 h and 10 h orbital time each day. The timing of the orbit is such that this period coincides with the spacecraft's visibility from the ESA station at Cebreros in Spain

addition, the VMC observations will also continue the search for lightning, and limb imaging will be used to study the high-altitude haze layers.

Operations and Scientific Observations

To capture a spacecraft into orbit around Venus from an interplanetary trajectory requires a significantly higher velocity increment (delta-V), and thus more fuel, compared to orbit insertion at Mars. This is due to the fact that the differential speed between the spacecraft and the planet is higher at Venus than at Mars. In addition, Venus has significantly more mass than Mars and therefore a greater delta-V is required to lower the orbit to the desired operational altitude.

With the fixed size of the fuel tanks on the spacecraft, the choice of possible orbits was limited. After studying several options, an elliptical polar orbit with a period of 24 hours and a pericentre at about 80°N was selected. This orbit has a pericentre altitude of 250 km and an apocentre altitude of 66 000 km. This is an ideal orbit for combining global studies of large-scale phenomena from the apocentre part of the orbit with detailed studies at high resolution at pericentre. An operational advantage of such an orbit is that the communication with the Earth can be achieved with only one ground station and that the time slot will be at the same time of day throughout the mission (see figure).

On arrival at Venus, the spacecraft will, for technical reasons, be inserted into a temporary 10-day orbit by a first burn with the main engine. This first orbit will be used for scientific observations at very high altitudes during which a first set of pictures of the southern hemisphere of Venus will be made and the dynamics around the South Pole will be studied for an extended period.

The Venus Express science operations will include observations at pericentre with the spacecraft in nadir pointing mode, off-pericentre observations, limb observations, observations in stellar- and solar-occultation geometry, and Earth radio-occultation observations. When operational constraints allow, different kinds of observations will be combined in one orbit in order to use the spacecraft and payload capabilities most effectively and thereby maximise the scientific return. The planned duration of the nominal mission is 2 Venus sidereal days (~ 500 Earth days), during which with about 1 Terabit of science data will be returned to the ground. The spacecraft design and available resources will also allow for a mission extension of another 500 days.

With the chosen orbit and the high performance of the spacecraft and its payload, Venus Express mission will achieve the following scientific 'firsts':

- *First global monitoring of the composition of the lower atmosphere via the near-infrared transparency 'windows'.*
- *First coherent study of the atmospheric temperature and dynamics at different levels of the atmosphere from the surface up to ~200 km.*
- *First coherent observations of Venus in the spectral range from the ultraviolet to the thermal infrared.*
- *First application of the solar/stellar occultation technique at Venus.*
- *First measurements of the global surface temperature distribution from orbit.*
- *First study of the middle and upper atmosphere dynamics from O_2, O, and NO emissions.*
- *First measurements of the non-thermal atmospheric escape.*
- *First use of a 3D ion-mass analyser, high-energy-resolution electron spectrometer, and energetic neutral-atom imager at Venus.*

Conclusion

Venus Express has triggered a worldwide revival of scientific interest in Venus. After more than a decade of being the 'forgotten' planet, Venus is again receiving the attention it deserves. This comes just in time since many of the scientists and engineers involved in the early missions now are coming to the end of their careers, while a large group of young people are prepared to take up activities in the field. The newcomers can therefore still benefit by learning from the experts who were active during the early days of Venus exploration. Old and new Venus explorers all over the world are therefore looking forward with great interest to Venus Express arriving at the planet and seeing the first data on their computer screens.

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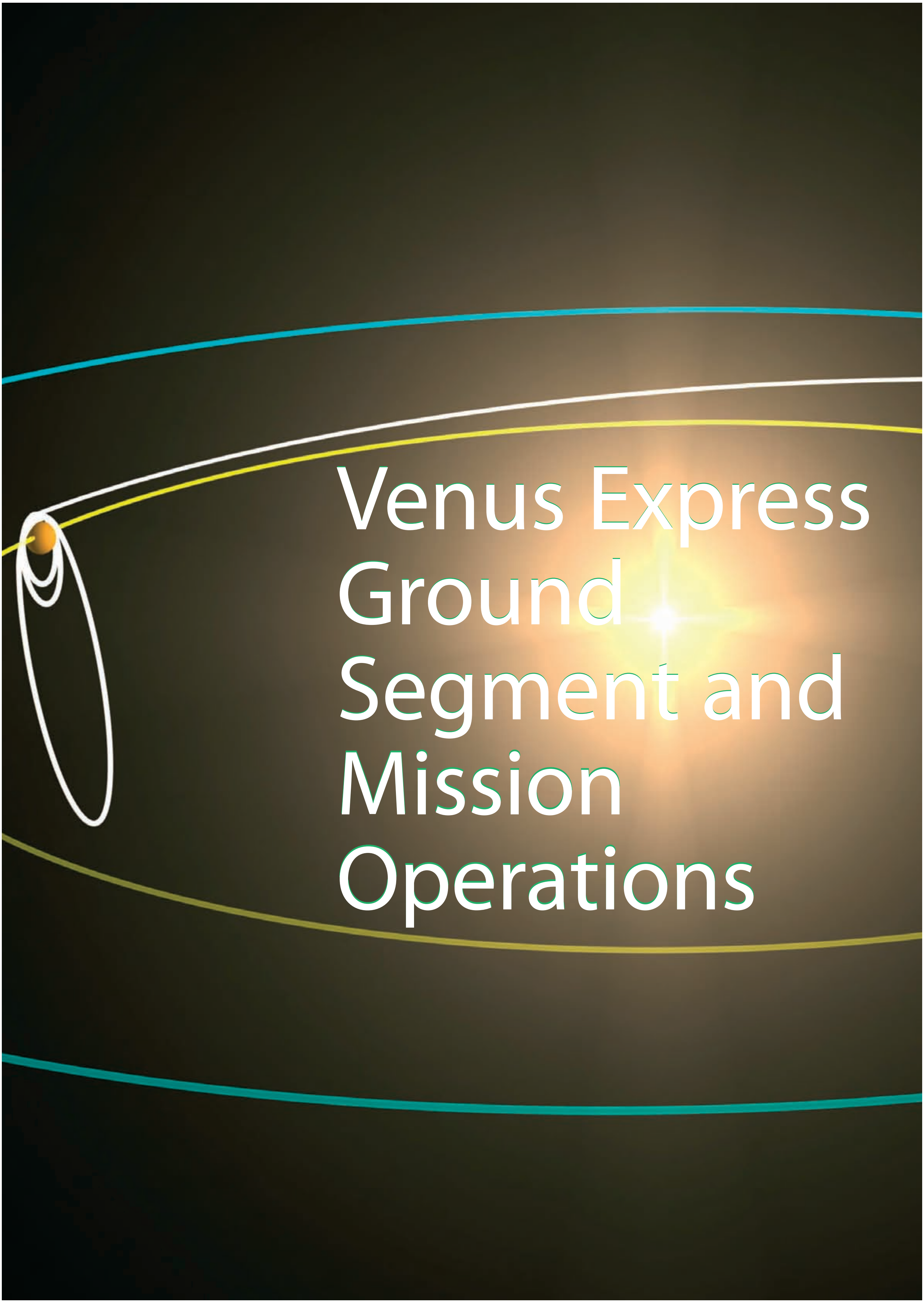
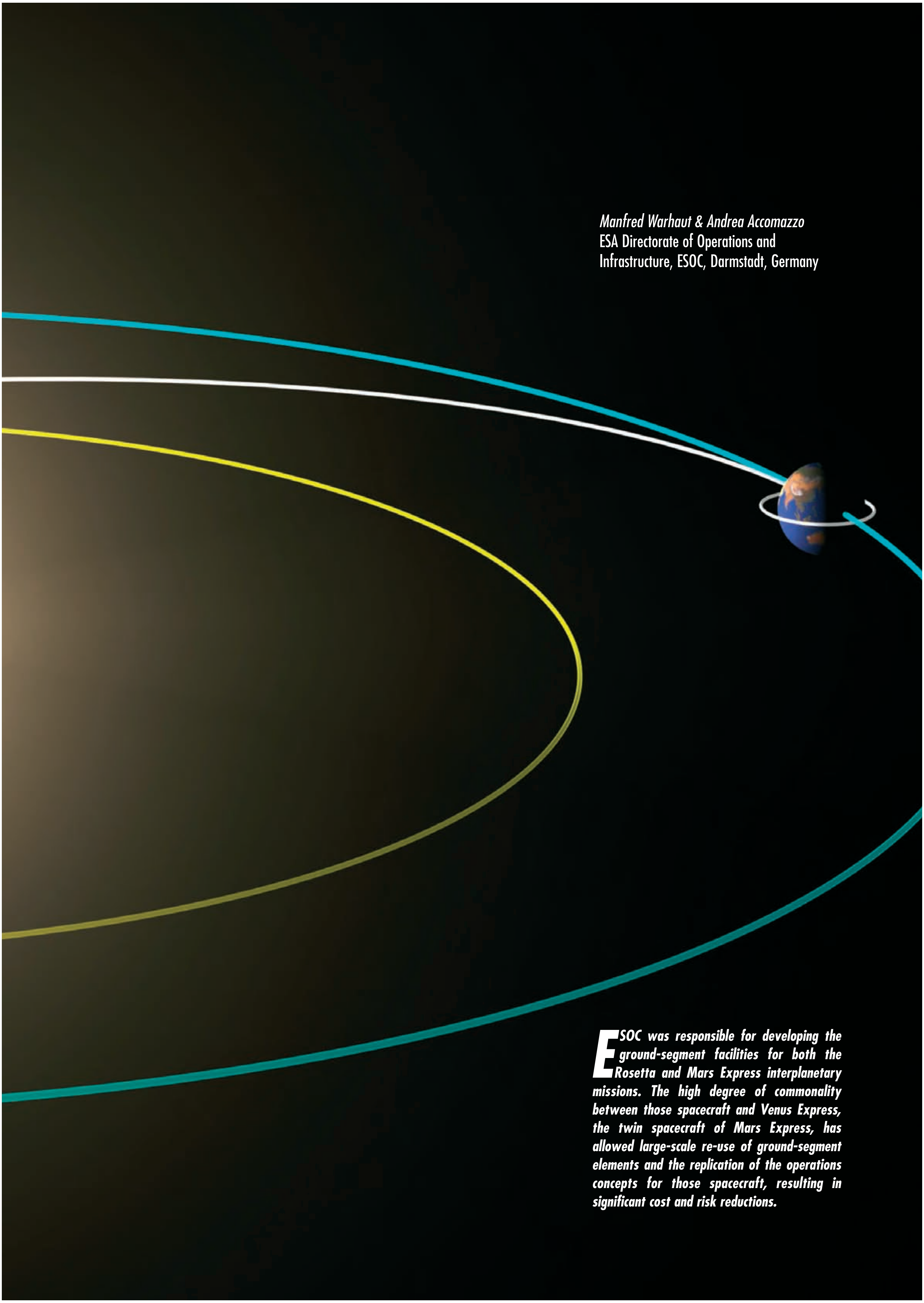
Venus Express Ground Segment and Mission Operations





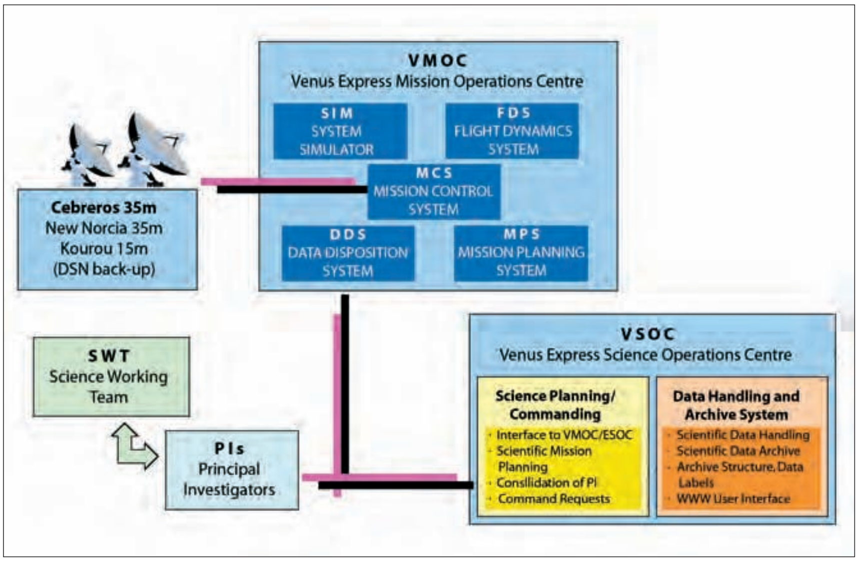
Manfred Warhaut & Andrea Accomazzo
ESA Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

ESOC was responsible for developing the ground-segment facilities for both the Rosetta and Mars Express interplanetary missions. The high degree of commonality between those spacecraft and Venus Express, the twin spacecraft of Mars Express, has allowed large-scale re-use of ground-segment elements and the replication of the operations concepts for those spacecraft, resulting in significant cost and risk reductions.

Ground Segment Systems/Facilities

The Venus Express Ground Segment provides the capabilities for monitoring and controlling the spacecraft and payload during all phases of the mission, as well as for the reception, archiving and distribution of the data gathered by the payload instruments. It therefore consists of (see figure):

– a Ground Station and Communications Network
– a Mission Operations Centre, and
– a Science Operations Centre.



The Venus Express Ground Segment

The Ground Station and Communications Network

These elements are responsible for performing the telemetry, telecommand and tracking operations for Venus Express, using S/X-band frequencies. Tele-commands and telemetry are sent in either the S- or X-bands, with the possibility to transmit simultaneously in both frequency bands, only one of which will be modulated. The S-band up/downlink is used only during the Launch and Early Operations Phase (LEOP), in support of the Radio Science Instrument (VeRa) campaigns, and in case of an emergency. The ground station used throughout all mission phases will be the new ESA 35 metre installation at Cebreros, near Madrid (Spain) (see accompanying article), complemented by the ESA New Norcia 35 metre station in Western Australia to support the Venus Orbit Insertion and VeRa campaigns, and the Kourou 15 metre station during the LEOP. NASA DSN tracking support is provided as a back-up.

The Communications Network also provides the support services needed for accessing test data obtained during the spacecraft's integration and test programme, for the submittal of command requests to the ESOC/VMOC, for the retrieval of quick-look mission products kept at ESOC, and also for supporting the electronic exchange of scientifically processed data if required.

The Mission Operations Centre

The Venus Express Mission Operations Centre (VMOC) located at ESOC in Darmstadt (Germany), includes:

- the Mission Control System, to support, with both hardware and software, the data-processing tasks essential for controlling the mission, as well as spacecraft performance evaluation
- the Data Disposition System, supporting the acquisition and interim storage of raw scientific data, to be accessible together with raw housekeeping and auxiliary data from the instrument Principal Investigators at remote locations, and to provide for production of all data on a raw data medium for archiving purposes
- the Mission Planning System, supporting command request handling and the planning and scheduling of spacecraft/payload operations
- the Flight Dynamics System, supporting all activities related to attitude and orbit determination and prediction, preparation of slew and orbit manoeuvres, spacecraft dynamics evaluation and navigation in general
- the Spacecraft Simulator, to support procedure validation, operator training and the simulation campaign before each major phase of the mission (LEOP, VOI, etc.).

The Science Operations Centre

The Venus Express Science Operations Centre (VSOC) supports the scientific mission planning and experiment command request preparation for consolidated onward submittal to the Mission Operations Centre (VMOC). The VSOC, which will be co-located with the VMOC during critical mission phases, will make pre-processed scientific data and the scientific data archive available to the scientific community through its Data Handling and Archive Service (DHAS).

The existing ESA/ESOC ground-segment elements and facilities available through the Rosetta and Mars Express missions have been reused to the maximum extent possible, both in terms of hardware and software, for Venus Express.

Flight Operations Concepts and Principles

The Mission Operations Department at ESOC is responsible for the Venus Express mission operations preparation, planning and execution. All Venus Express Operations will be conducted by ESOC according to procedures laid down in the Venus Express Flight Operations Plan, a comprehensive document prepared by the ESOC Venus Express Flight Control Team based on Project/Industry deliverables (User Manual and Database), the Science Operations Plan, and Agreements with the Principal Investigators.

Spacecraft operations during all active mission phases – lasting about 2 years in total, with a possible extension of 1.5 years – will be carried out following an 'off-line'

The Venus Express Mission Control Room at ESOC during the Launch and Early Operations Phase (LEOP)

approach, with all activities being pre-planned and the appropiate telecommands being uplinked to the spacecraft for time-tagged execution (via the onboard mission timeline). The evaluation of telemetry data will also mainly take place off-line, with the possibility of quasi-real-time intervention restricted to certain critical phases and cases of major contingencies.

There will be several communication-blackout periods of up to two weeks duration during the mission, due to the spacecraft-Earth-Sun geometry preventing radio-frequency signal transmission. The round-trip communication time between the ground and the spacecraft will be up to 30 minutes. Contact between the Venus Express Mission Operations Centre at ESOC and the spacecraft will not be continuous and the periods of contact will be primarily used for the pre-programming of autonomous operations functions on the spacecraft, and for data collection for subsequent offline status assessment. The downlink will normally be configured such that most of the bandwidth is dedicated to the dumping of onboard stored telemetry, with limited housekeeping and/or event telemetry transmitted in real-time during the passes according to spacecraft monitoring requirements.

The Institutes who have developed the scientific instruments are responsible for defining their operation onboard the spacecraft, with the primary responsibility for developing the payload operations strategy for the scientific mission resting with the Venus Express Science Working Team (SWT).

Mission Products

The mission products made available to the Principal Investigators will include all spacecraft and experiment telemetry data and auxiliary data. Under nominal conditions, all data acquired will be available at the VMOC in engineering format just 1 minute after their reception at the ground station.

ESA's New Cebreros Station Ready to Support Venus Express

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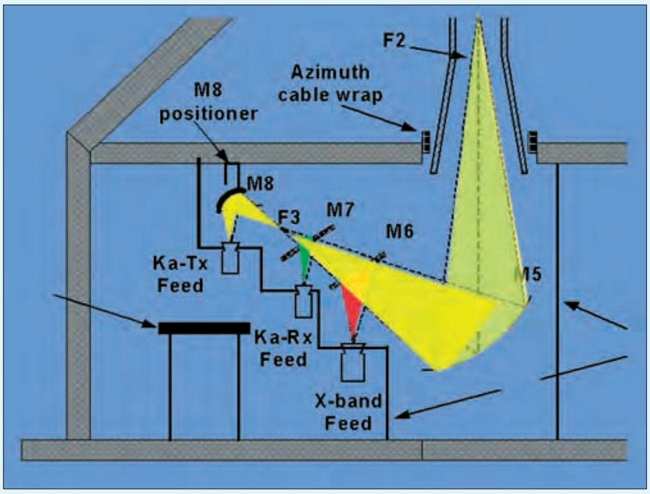
ESA's new deep-space radio antenna at Cebreros (near Avila) in Spain was officially inaugurated on 28 September. The new 35 metre antenna is the Agency's second facility devoted to communications with spacecraft on interplanetary missions or in very distant orbits; the first is at New Norcia in Western Australia. Cebreros's first task is the tracking of ESA's Venus Express spacecraft, launched on 9 November.

Introduction

The construction of ESA's deep-space antenna at Cebreros was completed in record time. The site-selection process began in April 2002, the procurement activities began in February 2003, and the building work began in Spring 2004 on the site of a former NASA ground station. After successful assembly of the antenna structure in November 2004 and the almost flawless acceptance testing of the various infrastructure elements and the radio-frequency components, the new antenna was completed in August 2005, which provided just sufficient time for final testing before being used for the first time to support Venus Express.

Technical Specifications of the Cebreros Antenna



The novel Cebreros antenna feed concept

REFLECTOR DISH

Diameter:	35 metres
Depth:	8 metres
Surface contour:	shaped parabola
Number of panels:	304 on 7 rings
Surface accuracy:	0.3 mm rms
Weight:	100 tons

ANTENNA PEDESTAL

Height:	40 metres
Weight movable part:	500 tons
Total weight:	620 tons

OPERATING ENVIRONMENT

Temperature:	-20°C to + 50°C
Relative humidity:	0 – 100% including condensation
Wind:	up to 50 km/h constant, gusting to 70 km/h
Rain:	up to 35 mm/h
Solar heat:	up to 1200 W/m^2

MECHANICAL PERFORMANCE

Slew range:	
Azimuth	0 to 540 deg
Elevation	0 to 90 deg
Slew rate:	
Both axes	1.0 deg/s max.
Acceleration:	
Both axes	0.4 deg/s^2 max.
Pointing error:	0.006 deg

RF PERFORMANCE

- X-band (8 GHz) transmission/reception with right- and left-hand polarisations
- Ka-band reception
- Beam-waveguide concept
- G/T at 10 deg elevation ≥ 50.8 dB/K at X-band
- G/T at 10 deg elevation ≥ 55.8.0 dB/K at Ka-band
- Transmit EIRP >107 dBW at X-band

SPECIAL FEATURES

- Temperature-measuring system incorporating 230 sensors on antenna structure
- Compensation of pointing errors
- Steerable sub-reflector
- Helium-cooled amplifiers (LNAs) with very low noise temperature
- 20 kW de-ionised water-cooled primary high-power amplifier
- 2 kW air-cooled secondary low-power amplifier
- Fully digitised receive system with ranging function
- Hydrogen-maser timing system with very high accuracy
- Designed for unmanned and full remote-controlled operation
- Completely power self-contained with back-up power diesel generators.

The supporting structure of the Cebreros antenna

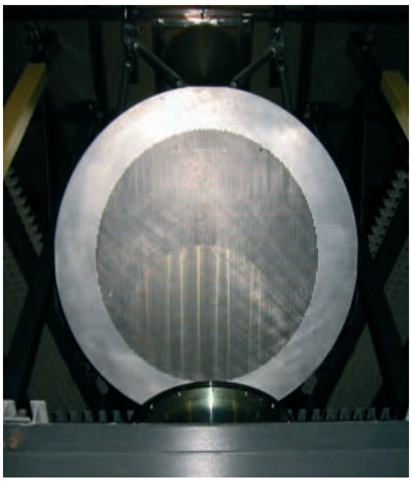
Cebreros was chosen as the site on which to build ESA's second deep-space antenna for several reasons. To achieve the required coverage, this antenna had to be positioned 120 degrees East or West of the antenna in Australia and an ideal location would have been ESA's European Space Astronomy Centre (ESAC) at Villafranca near Madrid. However, active urban development in the surroundings of ESAC could be a source of interference. The Cebreros location is equally good from a technical point of view and is also well away from densely-populated areas, but still sufficiently close to ESAC for purposes of operating efficiency. Like all other ground stations within ESA's ESTRACK network, Cebreros will be remotely operated from ESOC in Darmstadt, Germany, and will only be manned during especially critical mission phases, such as launches.

The entire antenna-carrying structure is 40 metres high and weighs about 630 tons, making it one of the World's largest TT&C antennas. It has been built by an industrial consortium led by the Canadian company SED Systems. The Spanish firms Esteyco and Necso built the antenna-tower infrastructure, and LV Salamanca was responsible for the building refurbishment.

Novel Features of Cebreros

Future deep-space missions will transmit increasing amounts of data from positions hundreds of millions of kilometres from Earth and require higher frequencies to increase data return. ESA's new Cebreros ground station therefore features a Ka-band reception capability, significantly enhancing the performance of the ESA Station Tracking Network (ESTRACK).

The Cebreros antenna incorporates the latest technology, which provides some advantages compared to the New Norcia facility. For instance, the Cebreros data acquisition capacity is higher, due to the fact that it will receive signals in the Ka-band (31.8 – 32.3 GHz). Cebreros also has a higher pointing accuracy, with a state-of-the-art pointing/calibration system with a maximum error of 6 milli-degrees, which is ten times better than a standard ESA 15 metre antenna. This exceptional mechanical accuracy is required due to the higher frequencies of the Ka-band compared to X- or S-band. It is achieved through the combination of a very stiff mechanical structure and 250 temperature sensors mounted throughout the antenna structure to automatically compensate for expansion and contraction due to temperature changes. Cebreros offers enhanced wind resistance compared with the New Norcia dish, can operate over a wider temperature range, and can rotate further in azimuth and at a higher speed.



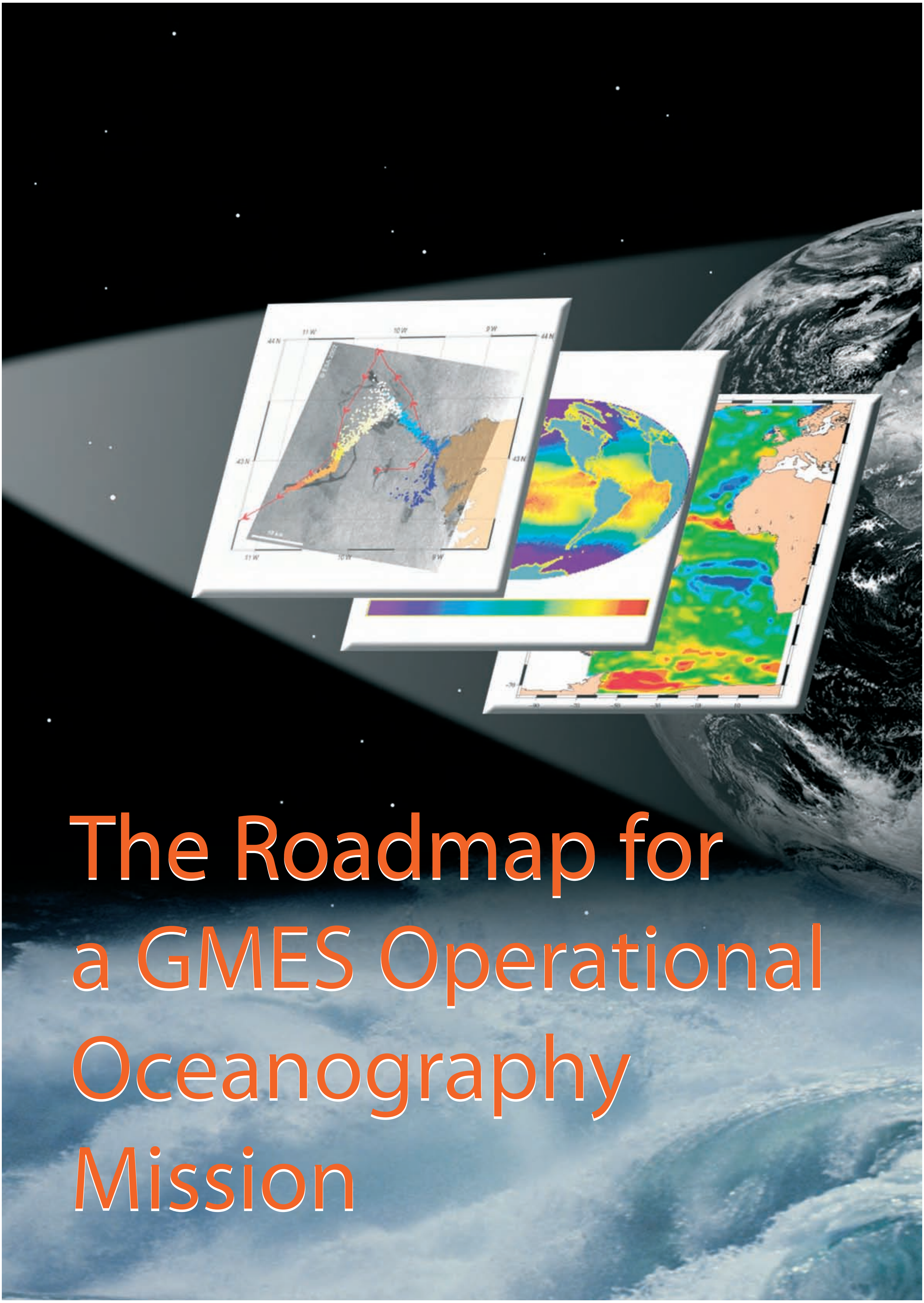
The novel dichroic mirror used in the Cebreros antenna

The heart of Cebreros' antenna is the beam waveguide concept and the Ka-band reception capability featuring a 1.2 m x 1.1 m dichroic mirror. This mirror is just 7.9 mm thick but contains several thousand rectangular holes drilled to an accuracy of 10 microns. It therefore reflects radio signals in the X-band (7.1 and 8.5 GHz) and allows those in the Ka-band to pass through its surface, thereby channelling the signals of different wavelength received by the main antenna dish to the correct receivers. Like New Norcia, Cebreros relies on Low-Noise Amplifiers cooled to 15K (-258°C) to reduce the system noise temperature to facilitate the reception of faint signals, and 20 kW amplifiers are used to transmit instructions and commands.

Conclusion

Cebreros and New Norcia are the first two of ESA's three planned 35 metre deep-space antennas. The third is likely to be built later in the decade and will be sited at an American longitude. As an integral part of a nine-station ESTRACK ground-station network, these three ground stations located 120° apart will be able to provide continuous coverage for any ESA mission despite the Earth's rotation.

In addition to being the dedicated ground station for Venus Express, Cebreros is also providing back-up support for the Mars Express and Rosetta missions. In the coming years, it will also be involved in tracking the Herschel/Planck, Lisa Pathfinder and Gaia spacecraft, as well as BepiColombo, ESA's first mission to Mercury.



The Roadmap for a GMES Operational Oceanography Mission

Oceans cover approximately 70% of the Earth's surface and, with about 60% of the World's population living within 200 km of the coast, they have an untold impact on all of us. Not surprisingly, for people living close to the coast or those who depend on the ocean for their livelihood, regular forecasts of ocean conditions are just as important as traditional weather forecasts. Therefore, development of the infrastructure needed to support and sustain independent, European operational ocean forecasting, and the associated coastal and marine information services, are key priorities of the joint Global Monitoring for Environment and Security (GMES) initiative by the European Commission and ESA.

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Operational Oceanography

The development and maturation of operational weather forecasting during the last century has resulted in its ascendancy from broad public awareness to its common acceptance in everyday use. We can view 'operational oceanography' as the equivalent suite of forecasting and assessment capabilities for the state of the World's oceans. The development of these capabilities to a similar level of maturity and the same widespread use as meteorology is a major challenge for the 21st century. The near-term objective is to provide an integrated service to intermediate and end-users and decision makers in support of safe and efficient offshore activities, pollution monitoring, environmental management, security and sustainable use of marine resources. A routine integrated assessment of ocean state will also be extremely beneficial to weather forecasting, and ocean, ecosystem and climate research.

A Roadmap for GMES and the Sentinel-3 mission

Several major efforts have been initiated over the last five years to develop Europe's capacity in global operational oceanography. These efforts are now being integrated and pursued through the joint EC/ESA GMES initiative. Within the EC's Framework Programme, the Marine Environment and Security for the European Area (MERSEA) project is developing a European system for operational monitoring and forecasting of the ocean physics, biogeochemistry, and ecosystems, on both global and regional scales (www.mersea.eu.org). In parallel, the ESA GMES Services Element (GSE) is developing complementary 'downstream' marine and coastal environmental information services to end-users (www.esa.int/gmes). These EC and ESA initiatives will be coordinated with the implementation of the ocean-observing spaceborne component by the GMES Programme Office, to allow the development and deployment of the ocean component of GMES by 2015.

To develop a truly operational oceanography infrastructure that responds to the GMES requirements, a long-term commitment to ocean satellite-measurement systems must, however, be guaranteed. Without such global satellite measurements, these integrated systems will not be sufficiently supported by observations to provide routine, robust and reliable products. These thoughts are behind the development of the ESA GMES Sentinels, for which preparatory activities have now begun. These activities will pave the way for a decision on the full implementation of the GMES space component. The Roadmap described here targets the preliminary definition of the GMES ocean mission, Sentinel-3.

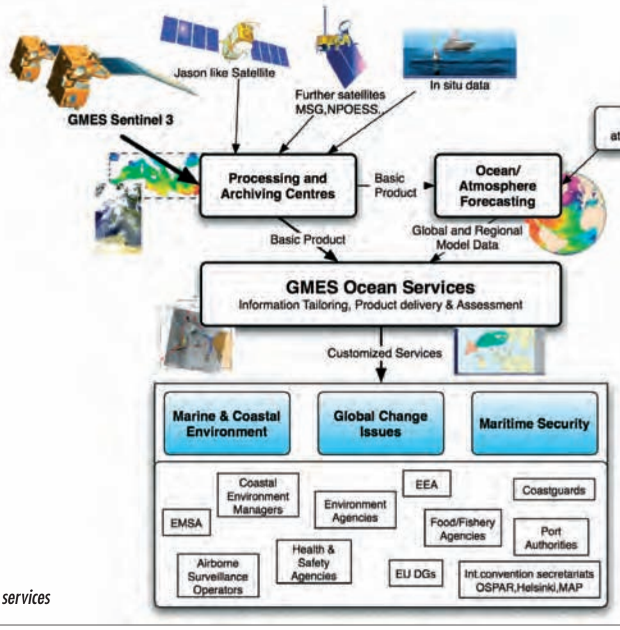
From February 2004 to March 2005, an ESA study titled 'Definition of Scenarios and Roadmap for Operational Oceanography' was carried out by a consortium led by CLS. The team consisted of eleven partners from six European countries: CLS, IFREMER, INGV, MERCATOR Ocean, NERSC, Satellite Observing Systems, Southampton Oceanography Centre, STARLAB, the UK Meteorological Office's National Centre for Ocean Forecasting, the University of Hamburg, and Alcatel Space. This article summarises the main results of this study, as essential background to the GMES Sentinel-3 preparatory study activities.

GMES Marine Services and Users

GMES marine services have been established that support, reinforce and improve European capacities linked to:

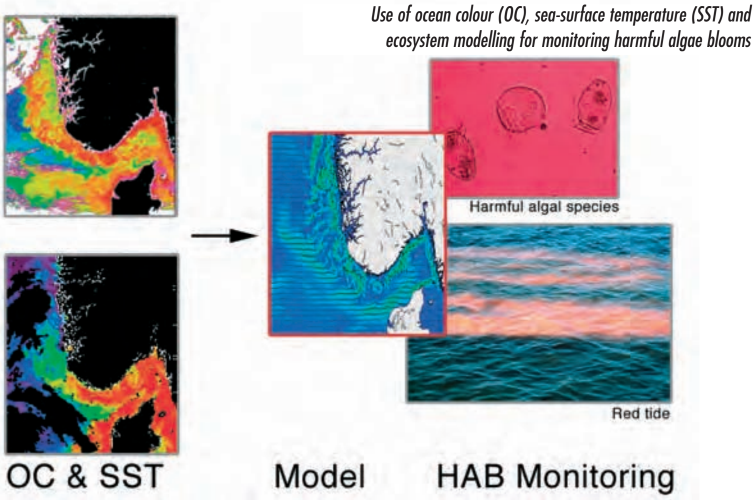
- Verification and enforcement of international treaties, and assessment of European policies.
- Sustainable exploitation and management of ocean resources (offshore oil-and-gas industry, fisheries, etc.).
- Improvement of safety and efficiency of maritime transport, shipping, and naval operations, as well as of national security and reduction of public-health risks.
- Anticipation and mitigation of the effects of environmental hazards and pollution crises (oil spills, harmful algal blooms, etc.).
- Advanced marine research for better understanding of the ocean ecosystems and their variability.
- Contribution to ocean climate variability studies.
- Contribution to seasonal climate prediction and its effects on coastal populations.
- Coastal management and planning services.

GMES marine services need to be able to rely on core services in global and regional operational oceanography with a mandate for remote sensing and in-situ data processing and distribution, modelling and data assimilation, and finally product distribution. These products will be exploited by end-user services tailored for specific applications and user communities (see figure). The core services that form the backbone of European operational oceanography will



GMES marine services

address the requirements from national and European policies, international conventions (e.g. OSPAR, HELCOM, UNCLOS), as well as European and international agencies (e.g. EEA, ICES, WCRP, UNFCC), for data, information products and indicators on the environment. Users will also include operational agencies responsible for marine meteorology, weather forecasting, maritime safety, and environmental monitoring. Companies from the private or public sectors providing ship-routing services, offshore operation support, environmental impact studies, coastal structure design or coastal management studies will also benefit from these core services. End-user services will successively build on these core services to address specific applications (e.g. for oil spills and illegal discharges, or harmful algae blooms) (see accompanying figures).



Use of ocean colour (OC), sea-surface temperature (SST) and ecosystem modelling for monitoring harmful algae blooms

Operational Oceanography Requirements

The backbone of operational oceanography is formed by global/basin-scale/regional modelling and data assimilation systems that use remote sensing and in-situ measurements to provide a regular, robust, comprehensive description and forecast of the ocean state. A core objective for the Sentinel-3 mission is therefore to provide the space-based observations required by these 'integrated' systems.

The primary operational Earth Observation (EO) satellite observation requirements specified by the GMES MERSEA project, the ESA GSE studies, and the Global Ocean Data Assimilation Experiment (GODAE) are as follows:

- Global, near-real-time, high-accuracy and high-resolution observations of sea surface topography. The minimum requirement is at least two (preferably four) altimeter-bearing missions including one long-term and highly accurate mission for climate applications.
- Global, near-real-time, high-resolution sea-surface-temperature (SST) products as specified by the GODAE High Resolution SST Pilot Project (GHRSST PP). These products, based on the merging of satellite and in-situ data, are needed at time intervals of less than 24 hours and at a spatial resolution of better than 10 km for the global ocean, and better than 2 km for regional seas and coastal areas.
- While some R&D activities are still needed to develop the effective use of satellite ocean-colour (OC) data in ocean forecasting models, it is foreseen that by 2008 MERSEA operational models will routinely use ocean-colour data as an input to ecosystem models. Resolution requirements should be close to those specified for SST, though many near-shore coastal applications require spatial resolutions better than 1 km.
- Global sea-ice concentration and sea-ice drift (daily, with resolution better than 25 km) and possibly sea-ice-thickness fields.

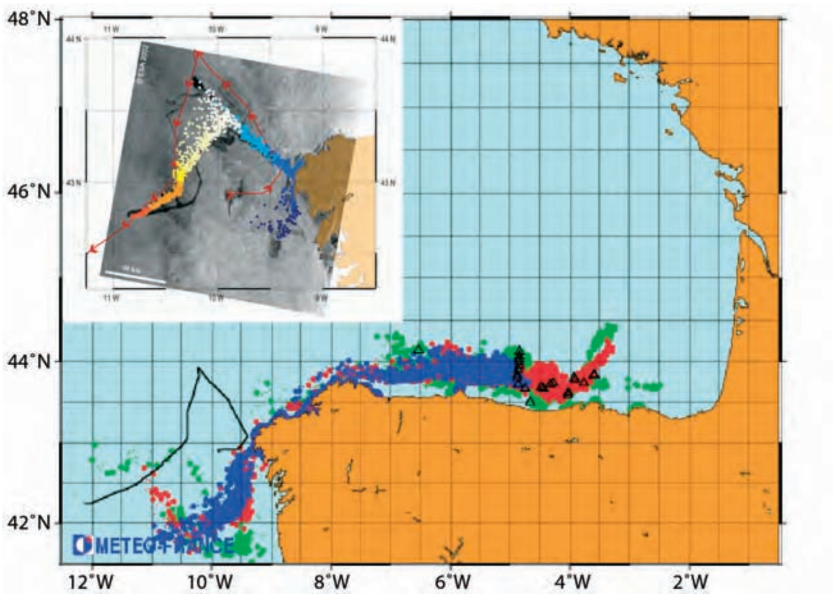
In addition to the above EO data requirements, meteorological forcing fields from Numerical Weather Prediction systems are required as inputs to the operational ocean models. These should be complemented by vector winds from at least two wide-swath wind scatterometers (including the Advanced Scatterometer on MetOp, planned for launch in 2006). Though ocean-surface salinity is also a very important parameter that should ultimately be monitored from space, the feasibility of salinity retrievals must first be demonstrated by ESA's SMOS and NASA's Aquarius missions.

Requirements for the Sentinel-3 Mission

As explained above, sea level, sea-surface temperature, sea ice, ocean colour and wind vectors are the key prognostic quantities in operational oceanography. The European contribution to ocean wind measurements is already addressed by the Advanced Scatterometer (ASCAT) instrument on the MetOp series of satellites. Existing and planned missions should additionally provide the required information on sea-ice edge, concentration and drift, but not the ice thickness. An ocean altimeter mission could, however, be adapted to address the sea-ice thickness requirement.

There is also a strong requirement for Synthetic Aperture Radar (SAR) data expressed by the marine user community, in connection for instance with oil-spill monitoring. The SAR marine requirements are addressed in principle by Sentinel-1, but will nonetheless benefit from forecast information provided by ocean models constrained by Sentinel-3 observation data. Other more critical marine services, such as oil-spill drift forecasting, would not be possible without Sentinel-3 data, since wind, wave and ocean current forecasts are required.

Existing EO data requirements for ocean surface-wave modelling and forecasting must also be addressed by the Sentinels. This calls for access to surface wind fields as well as satellite observations of sea state currently provided by altimeters (in the form



The Prestige accident in November 2002 demonstrated the importance of ocean model forecasts of large-scale currents, essential for accurate oil-spill spread prediction

of significant wave height) and SARs (as wave spectra). New concepts for effective global measurements of these parameters need to be developed, but in the meantime a combination of multiple altimeter and SAR-bearing EO satellite missions would provide a suitable alternative.

The main conclusion drawn from a detailed study of the requirements is thus that Sentinel-3 should be the first of an established series of operational, long-term ocean-monitoring satellites providing core measurements of ocean altimetry, sea-surface temperature and ocean colour. The Sentinel-3 measurement requirements summarised below have been distilled from the analysis of existing and planned missions (see tables).

Ocean/Ice Altimetry

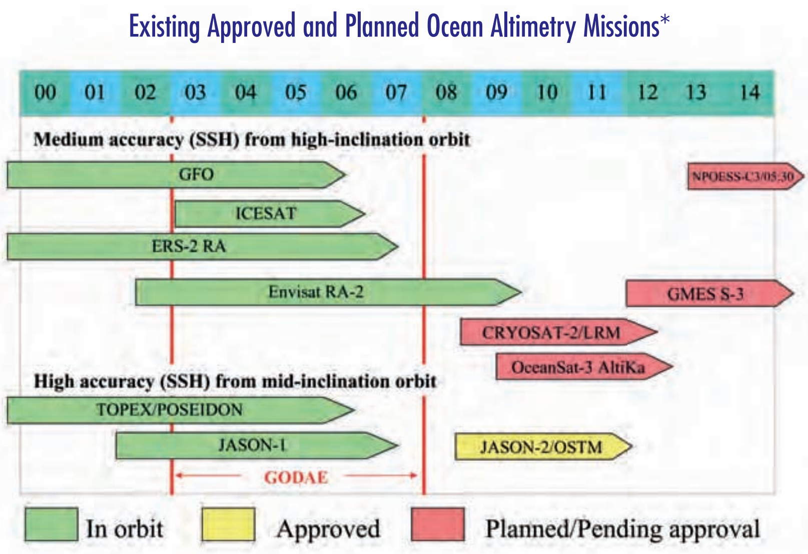
The most urgent requirement is to fly a post-Envisat, radar-altimeter-bearing mission, while in the longer term a high-resolution altimeter measurement system should be in place for the operational GMES phase. It would also provide useful data both for operational ocean-wave forecasting and sea-ice-thickness monitoring.

Altimetry provides the ocean topography in the form of precise sea-surface height measurements. Such data are required to adequately represent ocean eddies and associated currents (the 'ocean weather') in models. Most operational oceanography applications, such as marine security and pollution monitoring, require high-resolution surface-current data, which will not be adequately reproduced without a high-resolution altimeter system.

The altimeter system that is being proposed should complement the Jason series, which we assume will continue to provide precise long-term data. The European Commission's GAMBLE study (www.altimetrie.net) recommends a constellation of three optimised altimeter missions in addition to the Jason series.

Sea-Surface Temperature and Ocean Colour

Analysis of planned missions shows that the basic operational oceanography requirements should be fulfilled from 2011 onwards with the VIIRS optical and CMIS microwave sensors that will fly on all NPOESS satellites. Europe has, however, developed a strong heritage and leadership in the highest-precision measurement of climate-quality SST with the ERS and Envisat ATSR and A/ATSR sensors. These sensors have so far been the 'gold standard' for high-quality ocean-surface-temperature measurements, and a successor would provide an extremely important complement to the planned NPOESS and MetOp missions. Similar logic holds for precise/high-resolution ocean-colour monitoring applications using Envisat data,



*Whereas three altimeters (including one high inclination and one lower inclination) are required for effective operational oceanography, the number of altimeter missions falls below three from 2007 onwards. Unless the Envisat RA-2 and Jason Instruments remain operable, there may potentially be a gap in altimetric measurements until the launch of Jason-2 (expected in late 2008). The only planned altimeter mission in the post-2011 timeframe is the NPOESS C3 altimeter.

whereby the MERIS instrument channels provide specific benefits for GMES marine and coastal services. The important synergies between SST and ocean-colour measurements also make a strong case for a combined SST/OC sensor capability on the same platform.

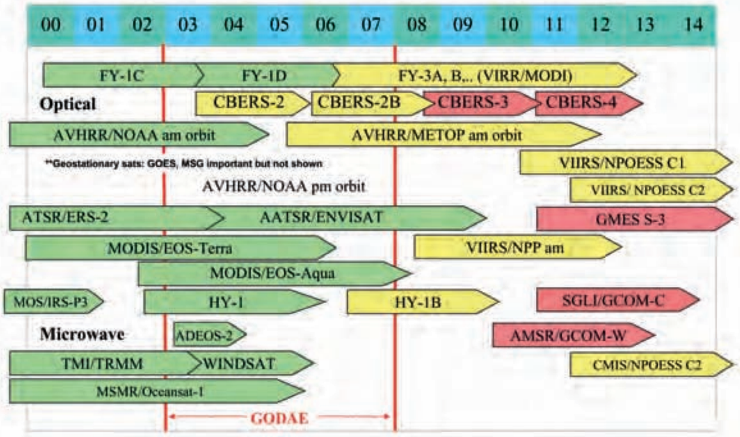
The Sentinel-3 Concept

Two concepts have been analysed as part of the Sentinel-3 Roadmap exercise:

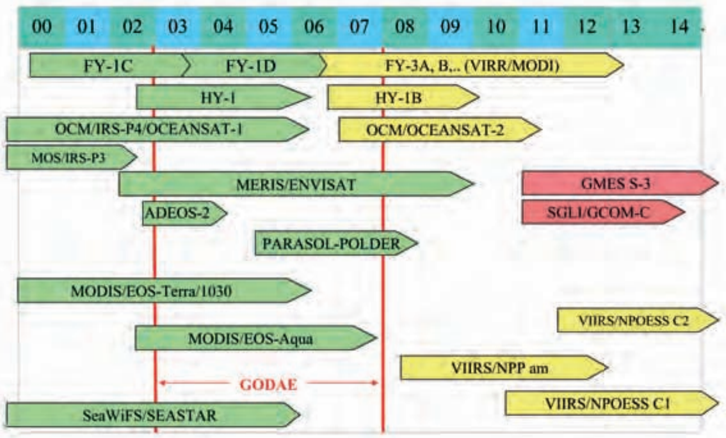
– Concept 1: Altimetry/SST/Ocean Colour on single platform in a polar orbit.
– Concept 2: Altimetry and SST/Ocean Colour on two independent polar orbiting platforms.

While co-located SST, ocean-colour and altimetry observations show scientific potential in the context, for example, of ocean-atmosphere exchanges and coupling between physical and biochemical components of the upper ocean, there are currently no specific GMES requirements for flying an altimeter and an SST/OC payload on the same platform. Concept 2 would allow optimisation of the orbit choices (e.g. repeat/non-repeat orbit, altitude, minimisation of Sun-glint effects, etc.) and to have different observing schedules for the altimeter and the SST/OC missions.

Sea-Surface Temperature*



Ocean Colour*



* Overall outlook appears to ensure good available of SST and OC observations from space, but the European contribution to OC monitoring is very limited and calls for readjustment. The main issue for SST is to continue to provide high-quality products for climate applications.

Altimetry

A high-inclination altimetry mission is recommended to cover high-latitude regions. The orbit could be Sun-synchronous, preferably using the same repeat track as Envisat. The main requirement for high-resolution ocean altimetry would be to fly three altimeters in addition to the Jason series, either directly as a constellation or built up progressively with a launch every 2 to 3 years. The preferred option would be to phase the orbit of each satellite to improve the sampling interval as much as possible. Swath altimetry is an attractive means for improving the spatial/temporal coverage, but a demonstration of the concept prior to entering operational status is required. In the longer run, use of Global Navigation Satellite System (GNSS) reflected signals should also be considered to supplement conventional radar-altimetry data.

Sea-Surface Temperature/Ocean Colour

The primary requirement is to retrieve SST with AATSR instrument-type accuracy. In this case, an along-track view (bi-angular observation) is mandatory to compensate for atmospheric-dust and aerosol-induced errors. Ideally, the system should thus provide high-quality SST measurements over a wide swath, as well as a dual view over a narrower swath as a 'gold standard' for all other SST measurements. The objective of the ocean-colour instrument is to monitor the global open ocean, whilst also supporting several important applications in coastal areas. This will require a selection of wavelengths similar to MERIS. A revisit time of 1 day at European latitudes should be a goal for the SST/OC mission and this requires large swath widths (>2000 km). Orbit time and/or phasing should be optimised versus NPOESS and MetOp.

Time schedule

The timetable for Concept 1 could be to fly the first mission as early as possible (2010/2011) and to ensure continuity of the data streams currently provided by Envisat. One should allow some overlap between the missions for a precise inter-calibration of the different sensors. The schedule for Concept 2 might be slightly different. One should first start as early as possible (2009) with the first altimeter component (post-Envisat 'gap filler') and then fly new altimeter missions every two years or so in order to have at least two simultaneous missions by 2011 (assuming a lifetime of 4/5 years). The SST/OC component could follow the same schedule as for Concept 1.

Sentinel-3 Mission Characteristics

Altimeter payload

The altimetry payload must include an altimeter, a radiometer for atmospheric-moisture correction, a precise navigation receiver for orbit determination, and a laser retro-reflector for absolute calibration of the orbit. Nadir altimeters are proposed as the baseline for the ocean mission and the following possibilities have been identified:

- Poseidon-3 recurrent altimeter: this dual-frequency (Ku+C bands) altimeter is the main instrument on the Jason-2 mission.
- SAR Radar Altimeter (SRAL): this is a dual-band (C+Ku) altimeter operating in conventional radar-altimeter mode as on Poseidon-3, and in SAR mode over sea ice and coastal regions. As a secondary objective, the SRAL will provide sea ice-thickness measurements of the same quality as the SIRAL payload on CryoSat.
- Alti-Ka: this instrument includes a single-frequency Ka-band (35 GHz) altimeter and a dual-frequency radiometer. Due to its compactness, it is particularly well-suited for implementa tion on a micro satellite. The first implementation of Alti Ka should be on the Indian OceanSat-3 mission in the framework of a CNES/ISRO partnership.

SRAL is a mature concept supported by the strong heritage from Poseidon-3 and the CryoSat SIRAL instrument, and would provide the required ocean and sea-ice thickness measurements, as well as inland-waters and coastal measurements. It is therefore favoured as the baseline for the first Sentinel-3 mission.

A recurrent radiometer derived from the Envisat MWR is considered the baseline solution for the microwave radiometer.

SST/OC payload

A first optical payload trade-off exercise has highlighted a preference for two separate instruments, one optimised for SST and the other for ocean colour.

The SST requirement for a dual-view and large-swath (1800 km) instrument calls for very specific scanning assemblies. The in-beam dual scanner, with a dual-mirror arrangement using a single scanner, continuously rotating at a moderate and constant speed, is preferred for its simplicity and reliability. The main drawback is the need to duplicate the calibration sources, but this solution should provide the required radiometric accuracy, thanks to the excellent calibration blackbodies available.

For the ocean-colour instrument, two possible solutions have been identified:

- Push-broom instruments based on MERIS cameras or using a new spectro imaging camera with larger field-of view than MERIS, providing a 1100 km swath.
- A high-performance scanner allowing large swath (1800 km) and along-track dynamic tilting to avoid Sun-glint problems; a high-transmittance spectro-meter is used for superior spectral and radiometric performances.

The latter solution is the preferred baseline for the ocean-colour instrument as it provides a larger swath to meet the coverage requirements.

Satellite

In the Concept 1 scenario, the altimetry, ocean-colour and sea-surface-temperature missions are accommodated on a single platform, compatible with a 1 tonne-class launch vehicle such as Rockot. A local observation time of 12:00 hrs would be preferable for the ocean-colour mission in order to avoid morning haze, while an early afternoon orbit should be avoided for good SST retrieval. Optimisation of the local time with regard to the NPOESS local time will probably lead to the selection a local time of around 11:00 hrs. The satellite's overall mass is 942 kg and the maximum power budget is 1100 W, which can be satisfied by a 9.6 m^2 solar array. The data volume budget is compatible with state-of-the-art telemetry and mass memory hardware without any need for compression.

Concept 2 foresees dedicated spacecraft for the altimetry and SST/OC missions, with the development of a common platform probably the most cost-effective option. The accommodation of large-swath (1800 km) instruments forms the baseline for both concepts.

Owing to the compactness of the French Alti-Ka altimeter, an alternative for the altimetry mission's implementation would be to use micro-satellites and multiple launches. This solution is particularly well suited to ocean mesoscale requirements, and would offer flexibility in the maintenance of an altimeter constellation.

Conclusions and Recommendations

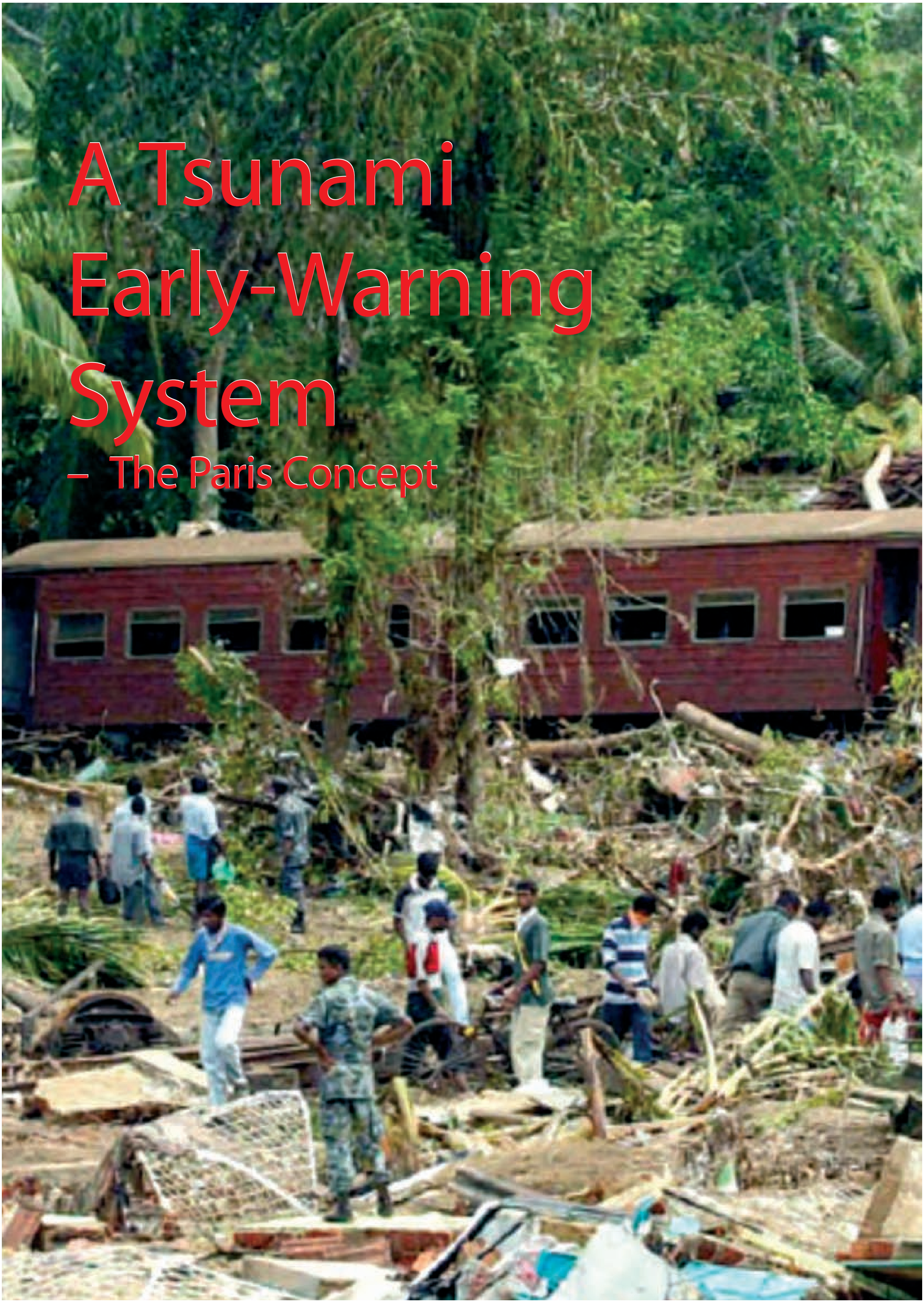
The GMES Sentinel-3 mission will provide the core observations required for the operational global and regional ocean monitoring and forecasting systems that Europe is setting up. Given the expected gaps in altimetry and precise SST and ocean-colour measurements in the post-Envisat timeframe (2009-2011), a decision on its implementation is urgently needed and any delay poses a major risk for the future of operational oceanography and GMES in Europe.

A long spacecraft lifetime (~10 years) should be targeted to reduce the number of satellites needed for the overall duration of the mission. This is helped by the fact that the solutions identified for the altimeter, ocean-colour and SST instruments use mature technologies and concepts with a low development risk and high reliability.

The final choice between the two candidate mission concepts will depend on many criteria, including refined requirements, operational needs, reliability, lifetime, development risk and schedule, and overall life-cycle costs. Taking cost alone as the overriding criterion, Concept 1 would be the preferred solution, but Concept 2 would allow the long-term requirements for high-resolution altimetry to be addressed more effectively.

A Tsunami Early-Warning System

– The Paris Concept



Manuel Martin-Neira & Christopher Buck
Directorate of Technical and Quality Management, ESTEC, Noordwijk, The Netherlands

Last December a tsunami generated by an earthquake, with its epicentre in the Indian Ocean to the west of Indonesia, resulted in a devastating human catastrophe throughout the region. Several proposals for establishing a network of sensors for tsunami detection have since been put forward, including the concept proposed here. The Passive Reflectometry and Interferometry System (PARIS) makes use of Global Navigation Satellite System (GNSS) signals reflected from the ocean's surface to perform mesoscale ocean-altimetry measurements, but it can equally well be applied to the task of rapid tsunami detection.

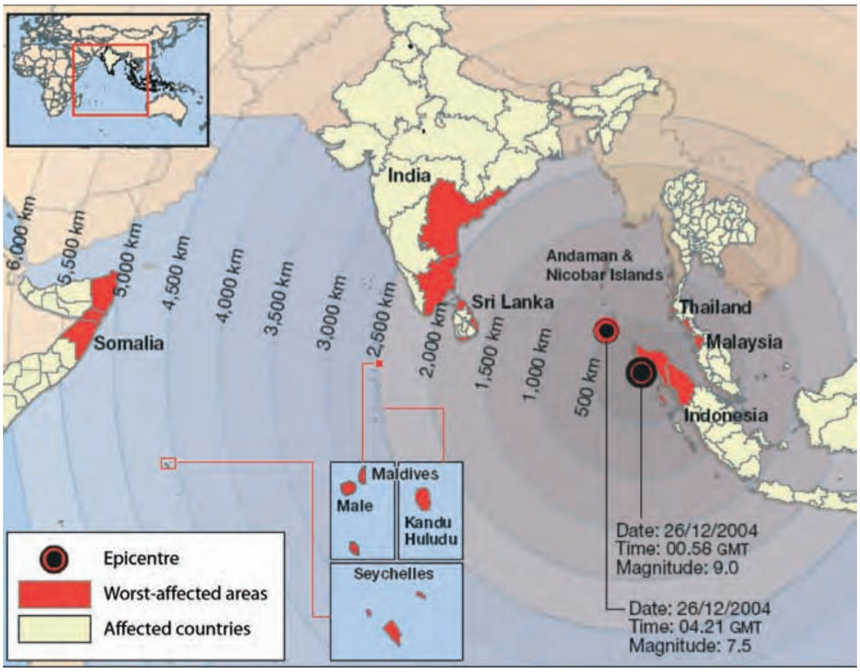
"Our mastery of major technology projects must lead us to reflect on how we can place our expertise and technology at the service of all the world's citizens, in particular those who are suffering today or who may one day suffer from the various scourges that afflict our Earth. There are of course limits to what we can do, but we must do whatever we can.…
… this plan will concern both the reconstruction phase in South-East Asia and a further phase devoted to the detection and prevention of such events."

Jean-Jacques Dordain,
Director General, ESA
15 January 2005

Need for a Global Tsunami Detection System

On Boxing Day 2004, the entire World was shocked to learn of the sub-oceanic earthquake off the coast of Sumatra and the subsequent tsunamis that devastated shoreline communities from Indonesia to Thailand and from Sri Lanka to Somalia.

Since then, governments and policy makers around the World have looked to seismologists and oceanographers for at least the means to provide a substantiated warning in the event of any such occurrence happening again in the future.



The region affected by the tsunami (source Nature)

The PARIS Concept

ESA and European industry have been working since 1993 on the idea of using navigation-satellite (GNSS) signals reflected from the ocean's surface to perform altimetry measurements. The validity of this technique, dubbed 'PARIS', was first established via experiments over a large pond on the ESTEC site, then from the Zeeland bridge in the southern part of The Netherlands, and most recently from an aircraft flying over the Mediterranean Sea near Barcelona. All of these experiments have produced convincing, suggesting that a spaceborne PARIS instrument would be capable of detecting sea-surface height with a precision of the order of a few centimetres.

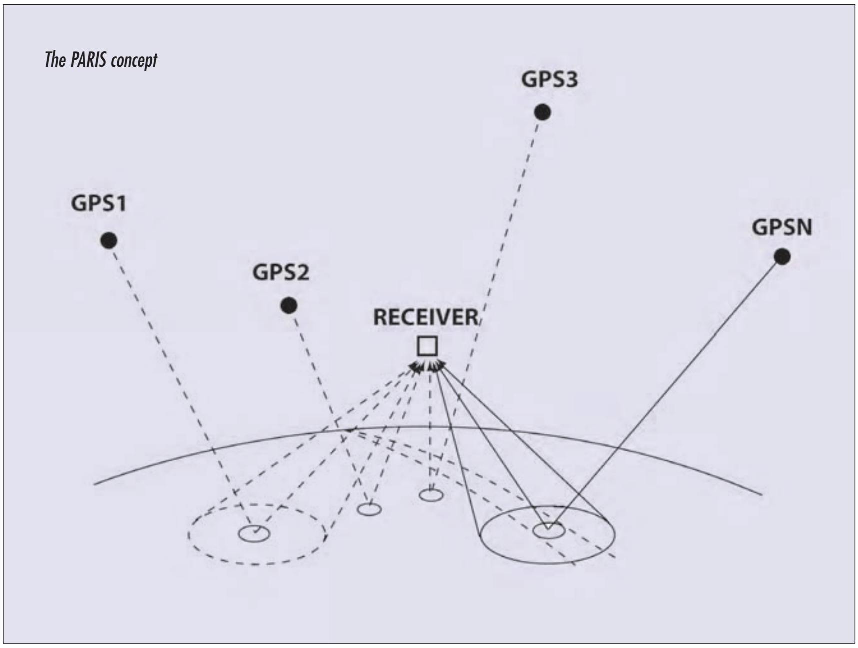
PARIS serves as a very-wide swath altimeter, capable of achieving swaths of 1000 km or more, depending on orbital altitude, as it picks up ocean-reflected (and direct) signals from several GNSS satellites (typically six GPS and six Galileo satellites when available). This wide swath means that a constellation of ten PARIS satellites with an orbital inclination of 45 degrees could cover the most populated central part of the Earth (from 45°S to 45°N in latitude), with a revisit time of less than an hour. As PARIS has a typical height resolution of 5-10 cm and a spatial resolution of 20-50 cm, a 30-60 cm high, 100 km-wavelength tsunami wave occurring in this region would be easily observable.

Global and Long-Term Coverage

The beauty of using PARIS for tsunami detection is that it is passive technique, requiring only a relatively low-cost instrument and, unlike conventional altimeters, it can measure and monitor the sea-surface height at a large number of locations simultaneously, depending on the number of GNSS signals within the antenna's field of view. Current ideas for a space-based PARIS sensor envisage the antenna having 12 independently tracking beams. This means that with a single instrument, coverage of the World's oceans would already be improved by a factor of 12, compared to a conventional altimeter.

The continued development of GNSS

The PARIS concept

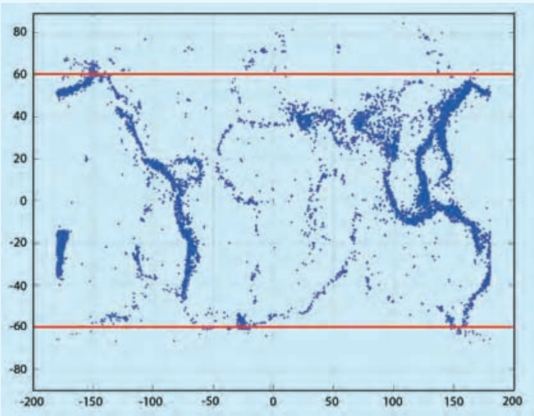


The Tsunami Phenomenon

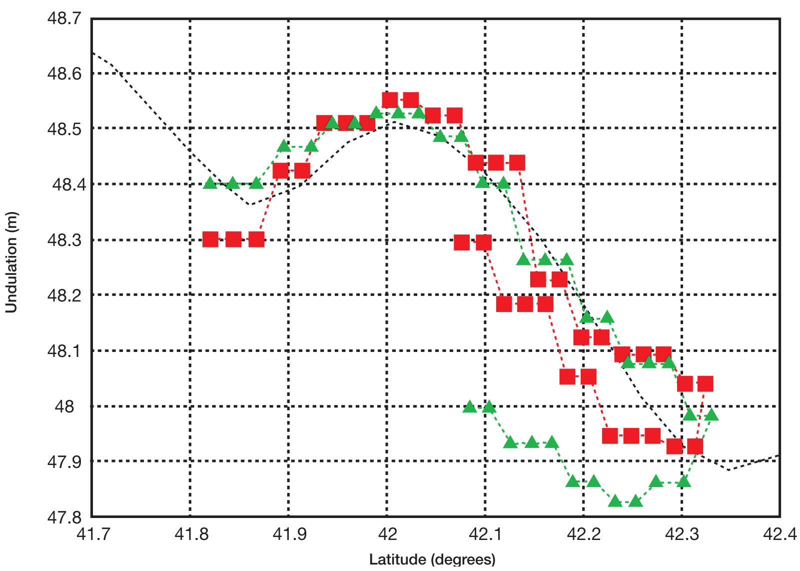
A tsunami is a wave train generated in a body of water by an impulsive disturbance such as an earthquake, which vertically displaces a column of water. Tsunamis have historically been referred to as tidal waves, because as they approach land they take on the characteristics of a violent onrushing tide. The tsunami is generated when the vertically displaced water mass moves to regain its equilibrium and radiates across the mass of water. The size of the resultant tsunami's waves is determined by the degree of deformation of the sea floor. The greater the vertical displacement, the larger the waves will be. As the tsunami crosses the deep ocean, its wavelength may be a hundred kilometres or more and its amplitude will typically be in the order of 30-60 cm. Because a tsunami has an extremely long wavelength (> 100 km), it behaves like a shallow-water wave even in deep ocean waters (5000 m), and its speed v depends only on the Earth's gravitational pull and the water depth D via the relation:

$$V = (g \times D)^{1/2}$$

Consequently, a tsunami travels relatively slowly in very shallow water (about 50 km/h) but very quickly in deep water (more than 500 km/h).



Around 18,000 earthquakes of magnitude 6 or greater occurred from 1 January 1900 to 31 December 1995 (from "Seismicity Catalogue" of the National Geophysical Data Centre)



Retrieved sea-surface height from the PARIS aircraft flight at 1000 m altitude over the Palamós Canyon Green triangles = C/A code; Red squares = P-code

systems in the future also guarantees the availability of the 'transmitter segment' for decades – an important feature for tsunami detection – with continuous improvements in transmitted power, bandwidth and frequencies also assured.

Airborne Demonstrations of PARIS

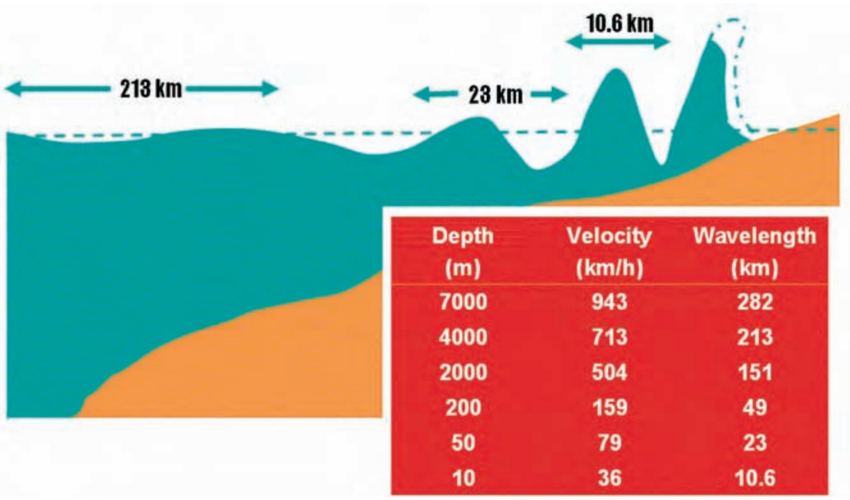
On 25 September 2001, under contract to ESA, the Institute of Space Studies of Catalonia (IEEC), Spain, flew a PARIS altimeter over the Mediterranean off the Costa Brava. In this region, a trench in the sea floor (Palamós Canyon) disturbs the water current and produces a 30 cm dip about 100 km long in the mean sea level. The amplitude and wavelength of such a topographic feature are similar to those of a tsunami in the open ocean.

The aircraft over-flew a Topex satellite ground track, which provided the reference sea-level profile, and several GPS-buoys were deployed to provide in-situ measurements. GPS stations were installed at several places along the coast as well, and kinematic differential GPS was used to retrieve the plane's trajectory (the C/A code was processed by IEEC, and the encrypted P-code by NASA/JPL for IEEC). The Palamós Canyon 30 cm dip was observed in both the C/A and P-code derived profiles. The topographic profile due to the continental shelf was also recovered. The closeness of the P-code solution to the Topex profile was remarkable.

The same flight was repeated one year later, on 27 September 2002, using the same PARIS altimeter over an extended track, by Starlab (Barcelona, Spain), acting as a fully independent data processor. Only the C/A code was processed and the retrieved profile looked very similar to the original one, confirming the robustness of the PARIS technique. The Palamós Canyon dip was again observable, as were the gentle surface slopes above the continental shelf. The deviation between the PARIS and Jason-derived sea-surface heights was less than 10 cm rms.

Towards a Satellite Demonstration

In September 2003, the UK-DMC (UK contribution to the Disaster and Monitoring Constellation) satellite was launched into a



Depth (m)	Velocity (km/h)	Wavelength (km)
7000	943	282
4000	713	213
2000	504	151
200	159	49
50	79	23
10	36	10.6

Velocity and wavelength of a tsunami in open ocean and near the coast

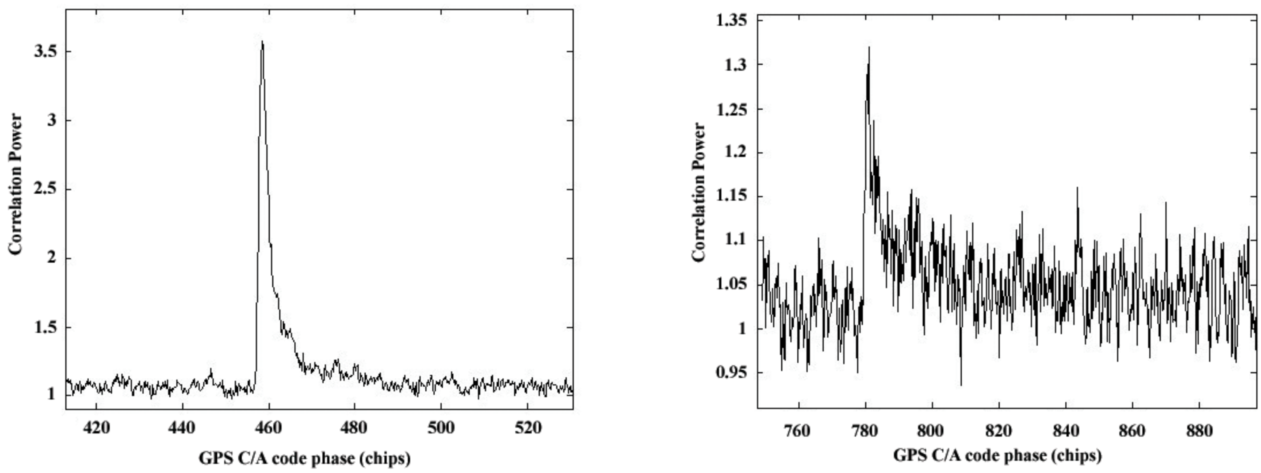
685 km, Sun-synchronous orbit to provide quick-response imaging for disaster situations such as the earthquake and tsunami that subsequently devastated Southeast Asia. It included a pioneering PARIS-based experiment, realised by Surrey Satellite Technology Ltd. with support from the British National Space Centre, in the form of a downward-looking, medium-gain antenna, a link to an onboard data recorder, and enhanced delay-Doppler mapping processing. Even at this high altitude and with modest antenna gain, the results to date have been remarkable, with ocean-scattered signals found in every data collection under a wide range of ocean conditions. The accompanying figure shows two signals detected under very different ocean conditions: on the left is a strong sea-reflected signal when the wind speed was 2.5 m/s (2 Beaufort – derived indirectly from wind models), whereas the much weaker signal on the right corresponds to a QuickSCAT measured wind speed of 11m/s (6 Beaufort).

A Tsunami Early-Warning Satellite System

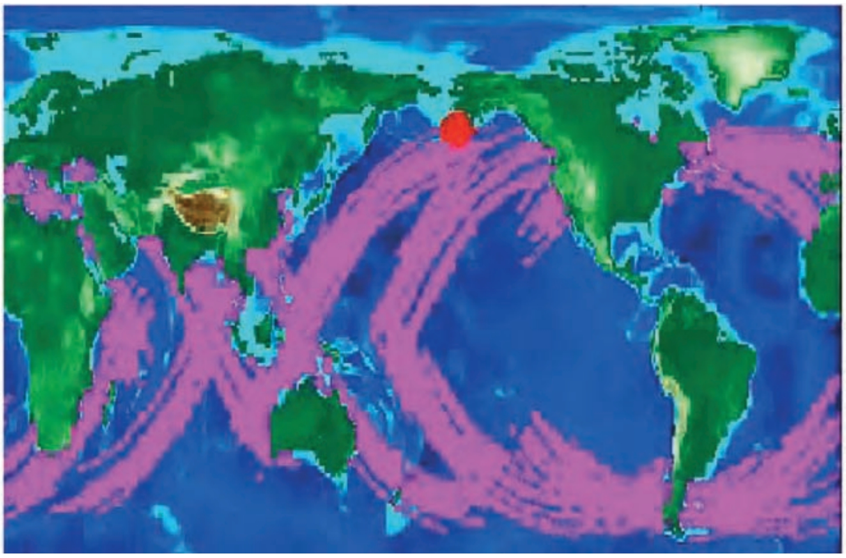
The physical characteristics of a tsunami and the capabilities of the PARIS altimeter are perfectly matched. The PARIS concept provides a synoptic view of an extremely large portion of the ocean's surface: in just 150 seconds, a 1000 km x 1000 km area is swept by typically 12 quasi-parallel tracks (reflection points) with random spacing. In that time, a tsunami may have travelled some 30 km, which is of the order of the spatial resolution of PARIS, i.e. it will look almost like a static wave in the ocean during a satellite overpass. A constellation of ten PARIS satellites would be able to detect a tsunami with a time to first alarm of less than 45 minutes, with real-time onboard processing and appropriate data down-linking.

The strength of the PARIS concept lies in the fact that, by providing a synoptic view of the ocean surface, the probability of a false alarm is low. The wave structure will clearly reveal itself as a tsunami rather than an artifact due to other reasons (instrument error, ionospheric delay, etc.), and a low false-alarm rate is important to ensure that the population takes it seriously when an alarm is actually raised.

As tsunamis fortunately happen only very seldom, the constellation of PARIS altimeters can serve various other oceanographic and scientific purposes during normal operation. Also, in this way the constellation will be maintained and updated on a regular basis and, even if it is many years before the next major tsunami, will still be fully functional and capable of warning the many thousands of people at risk.



Measured reflected GPS signals, for low (left) and high wind conditions (right)

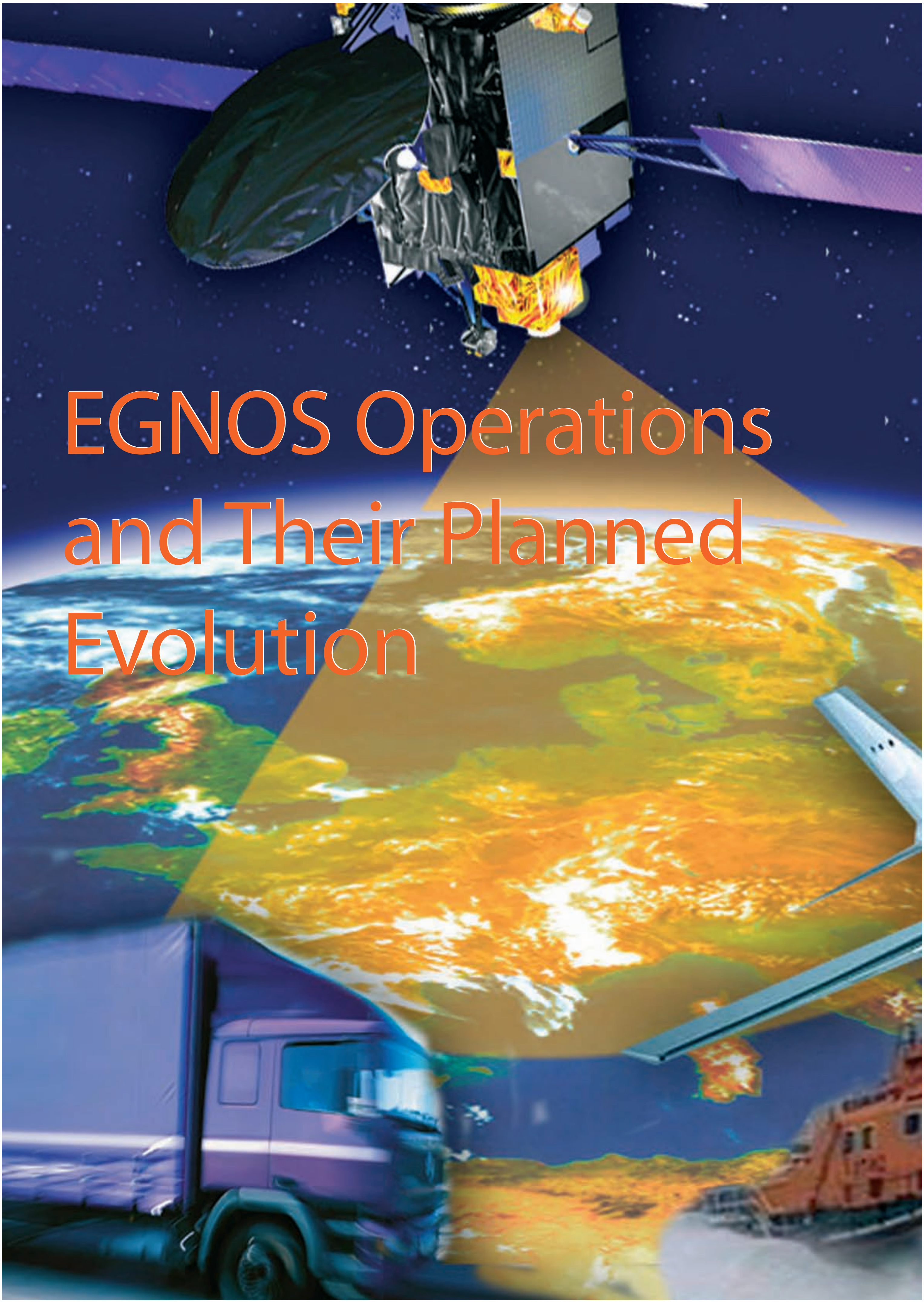


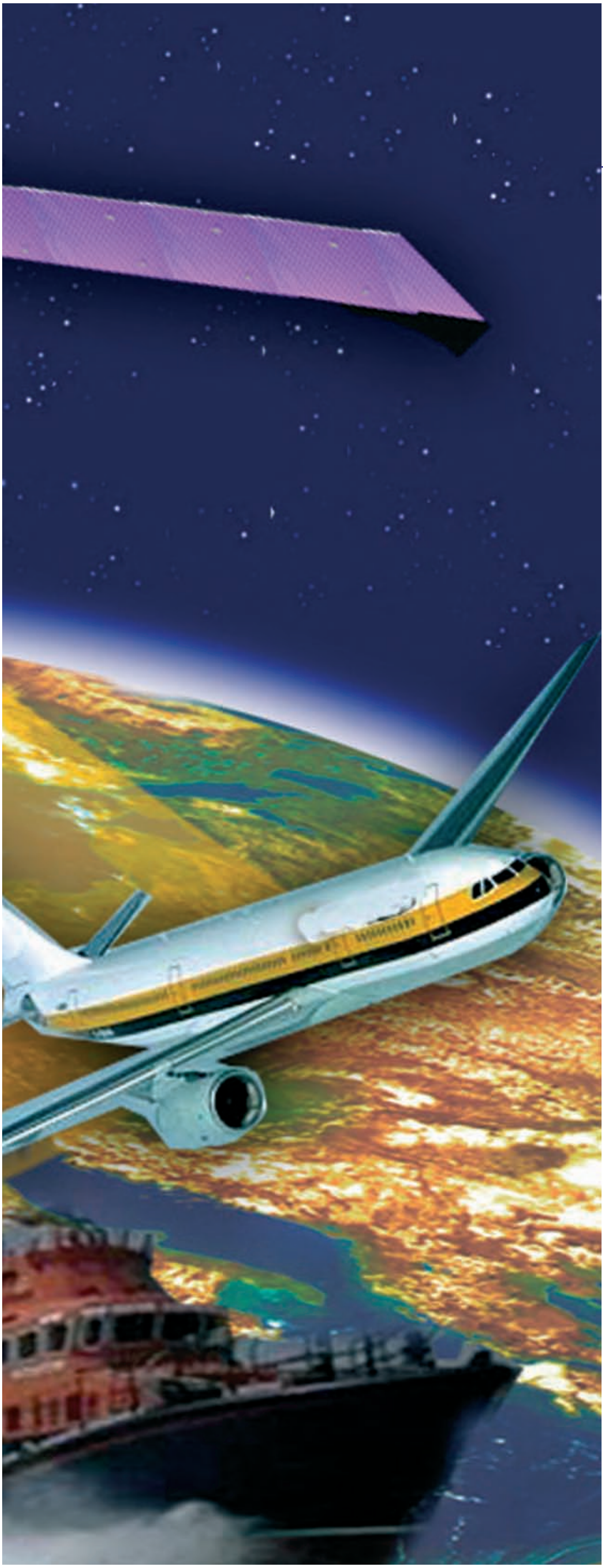
A simulated tsunami detection system, with the wave (in red) tracked by ten PARIS-carrying satellites in low Earth orbit (LEO: ground tracks in purple). The tsunami is detected in 33 minutes

Conclusion

From the work already performed, it is clear that a constellation of satellites equipped with PARIS altimeters can provide an extremely useful tsunami early-warning system. Tsunamis and PARIS are a perfect match, with the fast-developing, high-amplitude (>10 cm) mesoscale ocean features being well recognizable in the extremely wide-swath altimeter system's synoptic views of the ocean's surface. The probability of false alarms is also likely to be very low due to the very specific characteristics of a tsunami, and this is a key parameter for any early-warning system. The challenges of the onboard real-time processing and the data downlinking and dissemination to the population as risk will be addressed by future ESA studies. At first glance, a space-based system looks expensive when compared to ground-based systems, but the cost of establishing (and maintaining) a global network of buoys and pressure sensors is by no means trivial, not to mention the enormity of the task in terms of planning and execution. The PARIS-based solution would also provide a wealth of other data of immense benefit to oceanographers and other scientists.

EGNOS Operations and Their Planned Evolution





Laurent Gauthier, Javier Ventura-Traveset, Felix Toran
Navigation Department, ESA Directorate of European Union and Industrial Programmes, Toulouse, France

Chantal de Lesthievent, Jean-Yves Bedu
Alcatel Alenia Space, France

This summer, after more than 8 years of intensive work by ESA and European Industry, the European Geostationary Overlay Service (EGNOS) achieved two major programme milestones, with the successful completion of the formal technical-qualification process (Operational Readiness Review) and the start of initial operations. The measured performance of the system has already been shown to exceed requirements in several respects.

Via the EGNOS project, the European Tripartite Group – constituted by ESA, the European Commission and Eurocontrol – has implemented the European contribution to the first-generation Global Navigation Satellite System (GNSS-1). ESA has been responsible for the system design, development and qualification of the advanced operational system, also known as EGNOS V1.

In parallel with the start of operations, the EGNOS system will now be enhanced to enlarge the service area, to provide additional services, to further improve performance and to follow the global evolution in Satellite-Based Augmentation Systems (SBAS) that is taking place, leading up to the introduction of the European Galileo system.

Place	Paris	Toulouse	Madrid	Brussels	Geneva	Palma de Mallorda	Lisbon	Cork	Berlin
HNSE (95%)	1.0	1.0	1.1	0.8	0.9	1.1	1.1	1.3	1.1
VNSE (95%)	1.3	1.6	1.4	1.6	1.5	1.5	1.7	1.9	1.6

The horizontal and vertical positioning performance of EGNOS

Today's Situation

The EGNOS ground infrastructure currently consists of four Mission Control Centres (MCC), six Navigation Land Earth Stations (NLES), and thirty-one Reference stations (called RIMS). Since December 2003, when the first transmissions were made, three geostationary satellites – Inmarsat-3 AOR-E, Inmarsat-3 IND-W and ESA''s Artemis – have been successfully transmitting EGNOS signals. To complete the formal qualification process of the EGNOS V1 development programme, an Operational Readiness Review (ORR) was held in May/June 2005 involving more than 60 peers, including ESA, Civil Aviation, Galileo Joint Undertaking and Eurocontrol reviewers. Meeting on 16 June, the Board concluded that:

- EGNOS technical qualification was successful, subject to the completion of some review actions and recommendations.
- EGNOS Advanced Operational Capability (AOC) requirements were verified and are largely met.
- The system was ready to enter the Initial Operations Phase as EGNOS V1.

The Initial Operations, managed by ESA, have therefore started in July 2005, following the successful conclusion of negotiations between ESA and the ESSP (European Satellite Services Provider). The main objectives are to ramp-up and stabilise the technical operation of the EGNOS Ground Segment and Support Facilities, then to conduct an Operations Qualification Review (OQR) in order to arrive at an operationally qualified system able to support safety-of-life services (e.g. aviation). Each phase (ramp-up, stabilisation and qualification) is planned to last six months, with the OQR planned to take place by end-2006. Thereafter EGNOS system operations will be directly controlled by the Galileo Concessionaire.

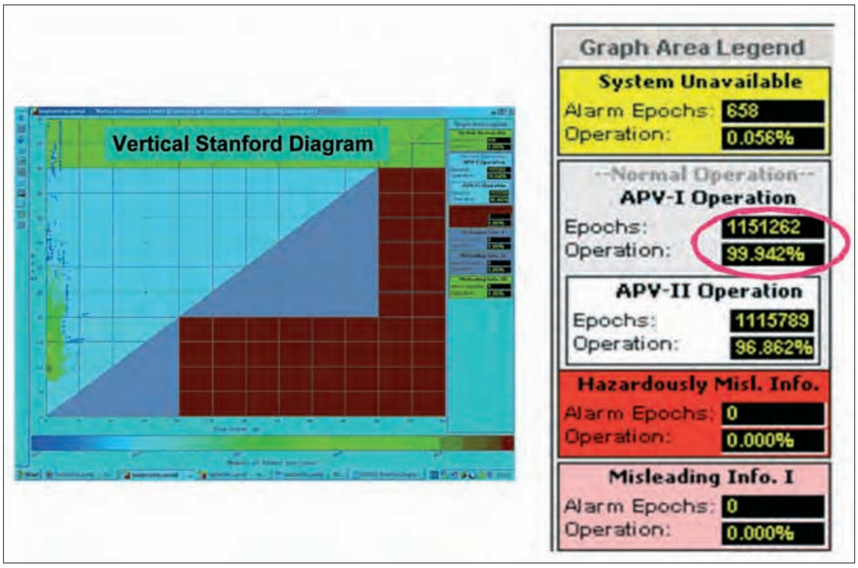
System Performance

The performance review panel that conducted the ORR concluded that all EGNOS system performance targets, extrapolated to operational conditions, are fully met in terms of accuracy, integrity and availability. As an example, the accompanying figure shows the horizontal and vertical navigation-error accuracies as measured at nine different European cities during the performance-qualification phase. Being in the order of 1 m and 1 to 2 m, respectively, they are much better than the specified requirement of 7.7 m.

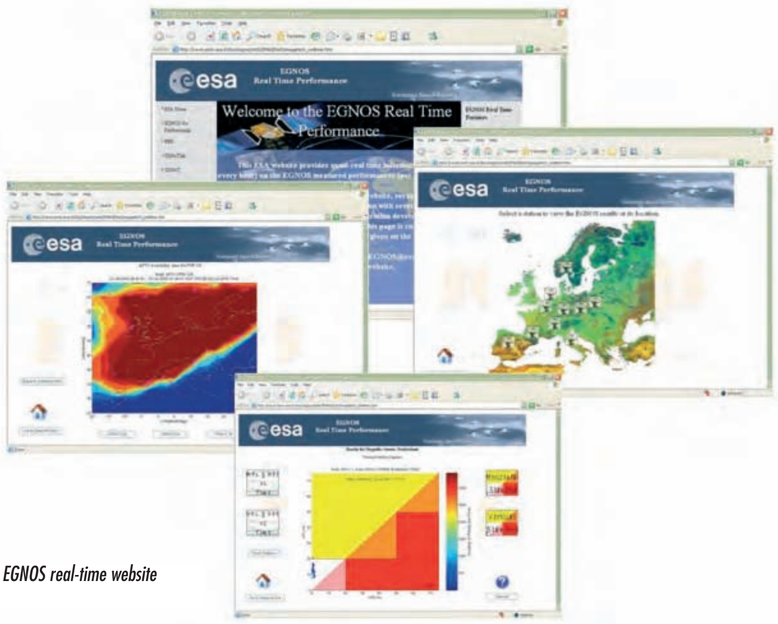
The second figure shows the cumulative availability of the system as measured at the Project Office facilities in Toulouse in February 2005 during the qualification campaign. The measured availabilities were 99.94% for APV-1 and more than 95% for APV-2, thereby exceeding the formal requirements of 99% and 95%, respectively.

The Integrity of EGNOS V1 was also assessed during the qualification campaign by both ESA (through the IMAGE Project) and Industry. With over 20 000 0000 samples analysed, it confirmed that not a single 'misleading information' event was observed at any location in Europe and that comfortable safety margins exist. Even during the severe solar storm that occurred in October 2003, which was one of the largest ever recorded, EGNOS would have provided a totally reliable service at all of the 17 locations checked with full vertical-guidance capability (APV) and with no 'misleading information events' at user level. Knowing that the US WAAS system had to interrupt its service during this storm, this is an extremely encouraging result that further boosts confidence in the safety of EGNOS.

To promulgate such information on EGNOS's performance, and to support



The EGNOS availability figures (APVs) measured at ESA in Toulouse



The EGNOS real-time website

application development, ESA has created a dedicated website (at http://www.esa.int/navigation/egnos-pro) where the performance data are updated hourly for several European cities.

EGNOS Evolution 2006-2010

The Context

The original EGNOS mission requirements were defined in 1998, but since then the Global Navigation Satellite System (GNSS) environment has expanded considerably, with the launch of the Galileo Programme and the planned modernisation of the Global Positioning System (GPS), with for example the introduction of the GLPS L5 civil frequency and WAAS systems. In this global context, the Council of the European Union confirmed in June 2003 that:

– EGNOS is an integral part of the European Satellite Navigation Policy
– EGNOS should be adapted as needed to follow the SBAS International Civil Aviation Organisation (ICAO) international-standard upgrades, and
– EGNOS services should be resolutely extended to other parts of the World on a long-term basis.

In addition, several studies indicate that modernised SBAS systems in combination with the European Galileo services, could lead to GNSS being the 'preferred solution' for even the most demanding life-protecting safety applications.

In response, a GNSS Support Programme has been defined by ESA and the European Commission. It is designed to further maximise the benefits of GNSS for Europe's citizens, and in particular to define and implement the most appropriate EGNOS developments, paving the way for the expected boom in Galileo services from 2010 onwards. It is being implemented in two steps: Step 1, covering 2005-2006, and Step 2 the 2006-2010 time frame.

The drivers behind the planned EGNOS evolution are essentially:

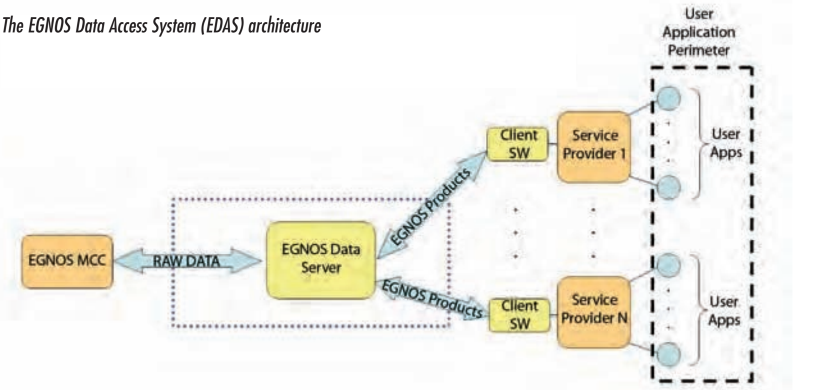
– its extension beyond the European (ECAC) service area
– the follow-up of International Standards, so that EGNOS always remains interoperable with WAAS and MSAS
– targeting of 'sole-means' status for EGNOS safety-of-life applications when combined with Galileo
– fostering Galileo multimodal service penetration
– maintaining European Industry excellence in GNSS/SBAS technologies.

The Infrastructure

In June 2005, ESA launched an EGNOS Evolution definition phase to establish a viable plan for infrastructure development plan so that the EGNOS mission-evolution concepts identified as desirable can be successfully implemented in the 2006-2010 time frame (see figure). These concepts currently include:

STEP 1	STEP 2: EGNOS Evolution Programme		
EGNOS V2.1 in 2006	EGNOS V2.2 in 2007/8	EGNOS V2.3 in 2008/9	EGNOS V3 in 2010/11
EGNOS Data Server Extension to MEDA Region Critical technologies assessment Consolidation of EGNOS Infrastructure Evolution Plan	Regional Extension Module (REM) concept Extension in Africa ESA ALIVE concept	L5 Message standards and initial L5 GEO broadcast GPSL1/L5/Galileo /Glonass enhanced RIMS receivers	MRS Concept (Multi-constellation Regional System) • GPS L5 augmentation Service • Galileo Augmentation (TBC) • Glonass modernisation augmentation (TBC)

Proposed EGNOS Infrastructure Evolution plan



The EGNOS Data Access System (EDAS) architecture

– The EGNOS Data Access System (EDAS: EGNOS V2.1).
– The Regional Extension Module (REM: EGNOS V2.2).
– The ESA Alert Interface via EGNOS (ALIVE: EGNOS V2.2).
– The Multi-constellation Regional System (MRS: EGNOS V3).

EDAS

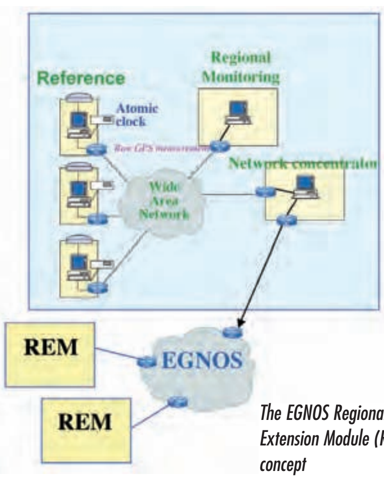
The EGNOS Data Access System (EDAS) will provide a controlled on-line interface to multimodal Service Providers, to provide real-time EGNOS products within guaranteed delay, security, and safety performance boundaries. Application Service Providers will exploit these EGNOS products to provide added-value services to end-users though broadcast means other than geostationary satellites.

The EDAS Data Server will perform the following primary functions via the INSPIRE interface:
– Provide the necessary security mechanisms to protect the INSPIRE interface and the EGNOS system from external interference.
– Transform the EGNOS raw products to internationally accepted open standards.
– Allow the connection of an almost unlimited number of users.
– Allow the definition of different levels of data provision (from raw data to more elaborate products).

A large assortment of navigation-based added-value services can be based on such EGNOS Data Server products.

EDAS will be developed, in cooperation with the Galileo Joint Undertaking, via the GNSS Support Programme Step 1 with a view to having an operational server in place before end-2006, to enable its commercial exploitation by the Galileo Concessionaire. As shown in the accompanying figure, EDAS obtains the EGNOS raw data from one of the EGNOS Mission Control Centres (MCC) in real time. The Data Server then performs two main operations on the raw data:
• it converts it into EGNOS products, which are provided following internationally accepted open standards
• it provides a robust security layer, protecting EGNOS from external attack.

The EGNOS products are then made available to the Service Providers using client-specific software (to be provided by ESA). These Service Providers then exploit the EGNOS products for their added-value services, which are supplied to the end-users by means other than geostationary satellites.



The EGNOS Regional Extension Module (REM) concept

REM

One of the clear paths for EGNOS Evolution is the extension of coverage beyond the original European ECAC area. There are several possible extension target areas, including North Africa (MEDA region), the Middle East, Eastern Europe, or even the whole of the African continent. Given the large number of possible extension scenarios, and to avoid costly dedicated, a la carte solutions, ESA and EGNOS Industry have developed a generic extension concept (see figure) known as the EGNOS Regional Extension Module (REM). It consists of a number of dedicated reference stations, a local monitoring centre, a network concentrator and a clean and unique interface with EGNOS core system.

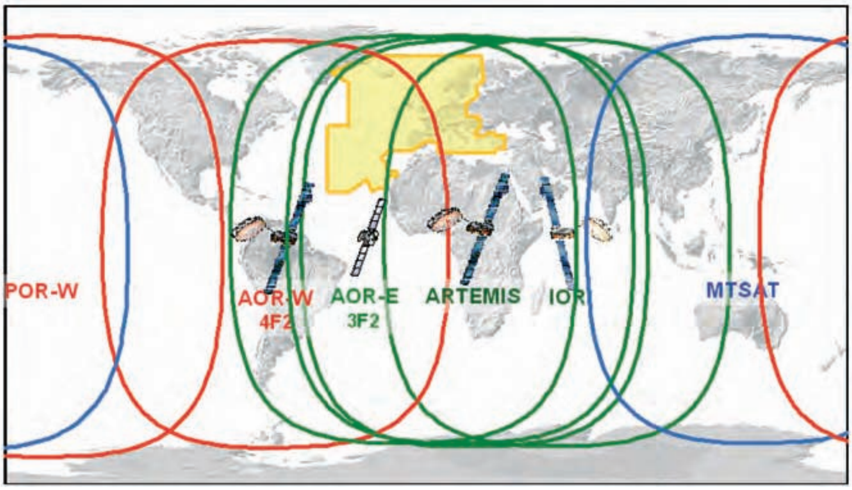
Two major benefits expected from this generic concept are:
– Future EGNOS coverage extensions will be based largely on a recurrent extension design concept.
– Extension is performed in multiple steps, through the connection of several REM units, allowing controlled system scalability.

For example, only 3 to 4 REM modules are currently envisaged for providing full service coverage for the whole of Africa.

ALIVE

Disaster prevention and mitigation is a topic that is currently receiving a great deal of attention. One of the main goals is to identify ways to inform people at risk from, for instance, natural events such as earthquakes, tsunamis, hurricanes, storm surges, extreme precipitation and flooding, or volcanic eruptions, so that specific actions can be taken to mitigate the impact of the disaster and ultimately save lives. The same information channels would be valuable tools for supporting rescue and aid operations in the aftermath of disasters, thereby also reducing loss of life.

Those most affected by such disasters are often the poor and the socially disadvantaged in developing countries, who are the least equipped to cope. In countries like Africa and the Indian Ocean states, for instance, lack of communication is a severe limitation for efficient warning

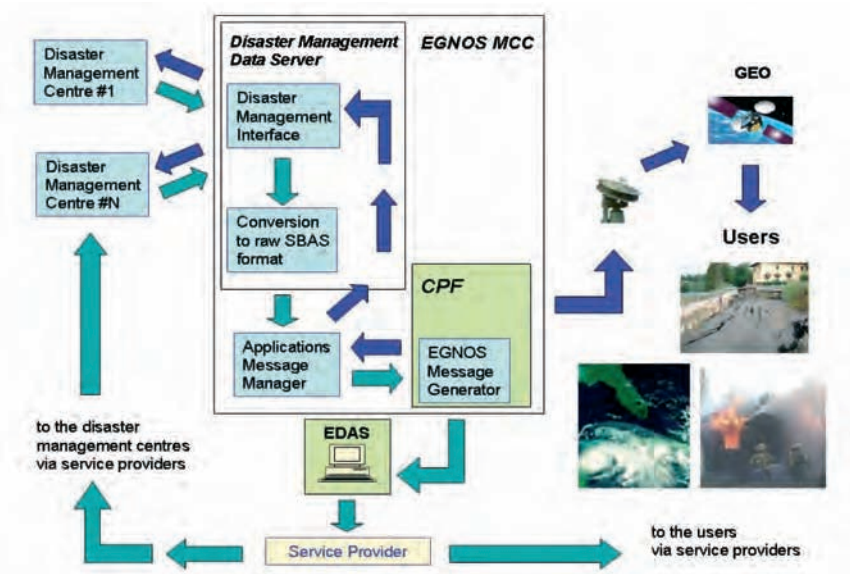


The broadcasting areas of the three existing operational SBAS systems: EGNOS / WAAS / MSAS

systems, and additional means of communication paired with a positioning service could be of great help. Using the message broadcast capacity of Satellite-Based Augmentation Systems (SBAS), i.e. EGNOS for the case of Europe, is of considerable interest, not least because:

- The three existing SBASs together provide global coverage (see figure).
- All navigation receivers are becoming SBAS-compatible and share the same worldwide accepted standards.
- It combines the possibility of warning with the ability to determine the location of the user via the same equipment (key feature).
- SBAS systems have been conceived for the 'safety-of-life' environment and are institutionally controlled and thus include the built-in design and operating features needed to guarantee integrity of message broadcasts and acknowledgments.

ALIVE is based on the more general concept of using the available spare EGNOS message broadcasting capacity for transmitting low-rate, spatially related information from an originator to EGNOS users through dedicated SBAS messages. National and international organisations responsible for disaster management or the provision of civil-protection services already make use of special infrastructures for monitoring, communication and control. These infrastructures are indicated as 'Disaster Management Centres' in the possible architectural implementation of the ALIVE concept within the EGNOS system (see figure). These Centres then have the task of collecting/generating critical information (e.g. event, location, status, action), interfacing with the EGNOS system to provide the required broadcast conformation and receive an acknowledgement that the information has been sent. All users within the EGNOS satellites footprint equipped with an EGNOS receiver capable of processing these additional messages are then made aware of the nature of the problem, its location, the current status and the actions being taken.



Architecture for the implementation of the ALIVE function

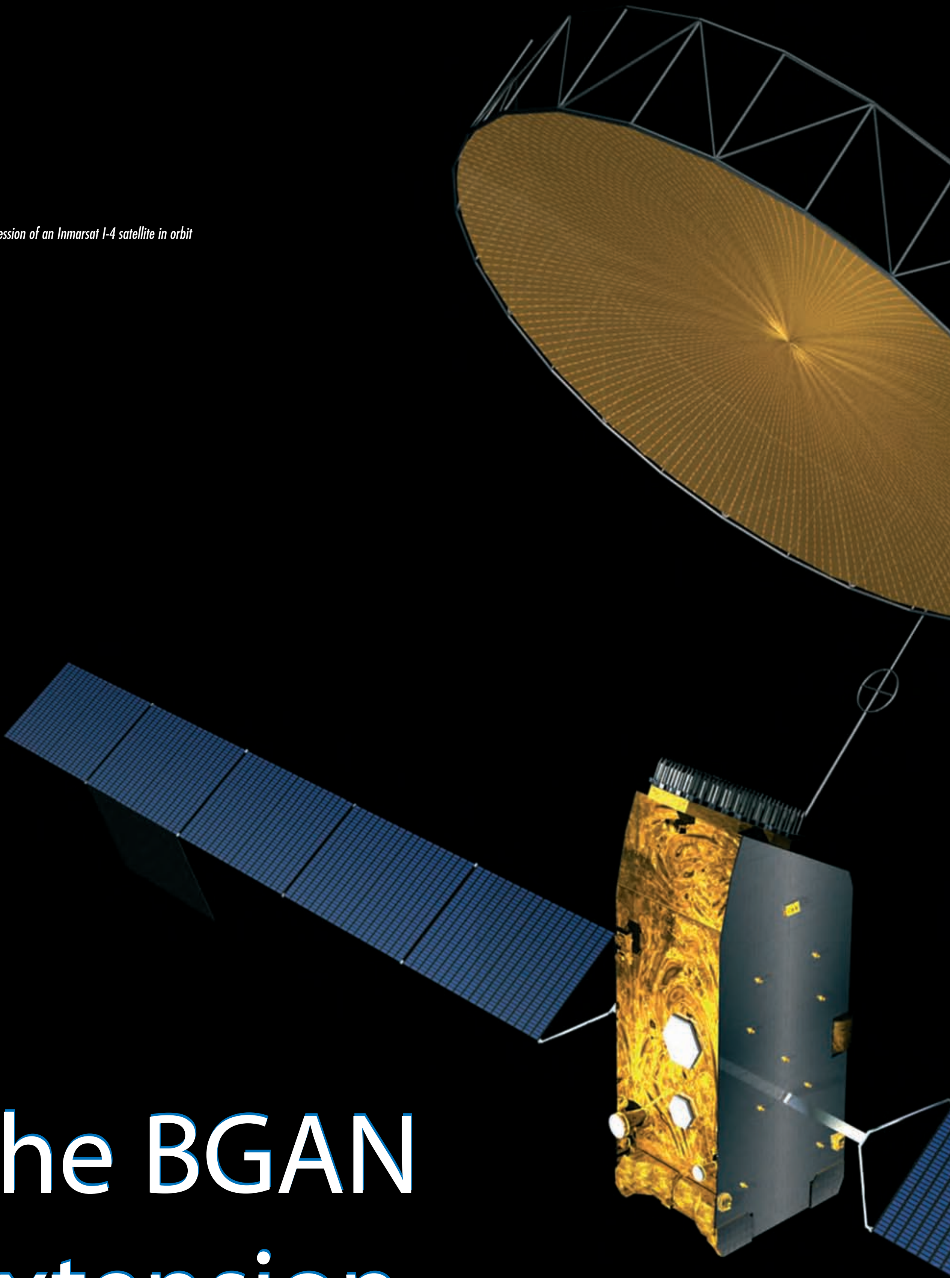
Conclusion

As the first-generation European GNSS System, EGNOS represents the first step towards Galileo, the second-generation operational system based on an independent European satellite constellation. The start of the Initial Operations phase in July 2005 marked the successful completion of more than 8 years of intense work by ESA and European Industry.

The evolutionary versions of EGNOS that will result from the EGNOS V2 and EGNOS V3 'modernisation' initiatives will enlarge the service area covered, provide additional services, and further improve system performance. Step-1 of this modernisation plan (2005-2006) has been approved and is already underway. The EGNOS Evolution Definition studies that are proceeding in parallel will produce a concrete EGNOS infrastructure Evolution Plan for 2006-2010 for ESA and EU members' endorsement.

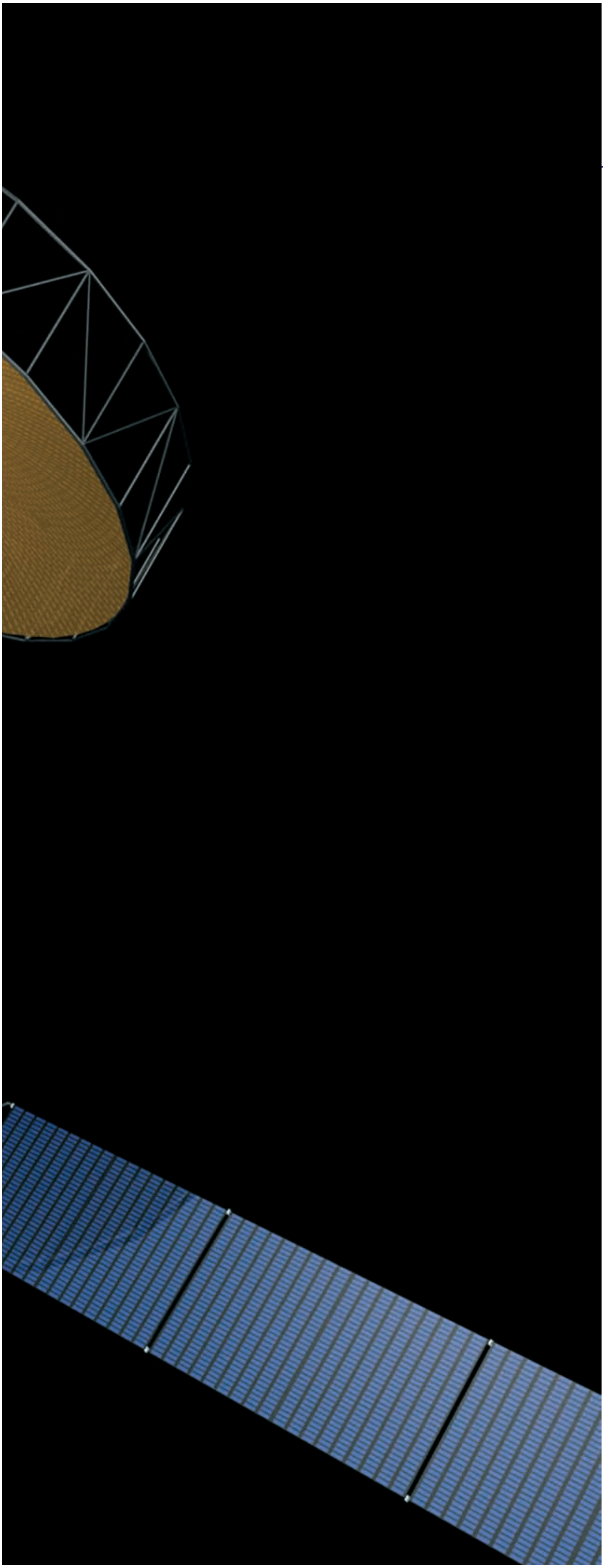
Acknowledgement

The EGNOS Project Office would like to acknowledge the excellence of the work conducted by the European Industry staff involved in the EGNOS development effort over the last 8 years.



Artist's impression of an Inmarsat I-4 satellite in orbit

The BGAN Extension Programme



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Mobile satellite telecommunications systems have undergone an enormous evolution in the last decades, with the interest in having advanced telecommunications services available on demand, anywhere and at any time, leading to incredible advances. The demand for broadband data is therefore rapidly gathering pace, but current solutions are finding it increasingly difficult to combine large bandwidth with ubiquitous coverage, reliability and portability. The BGAN (Broadband Global Area Network) system, designed to operate with the Inmarsat-4 satellites, provides breakthrough services that meet all of these requirements. It will enable broadband connection on the move, delivering all the key tools of the modern office.

Recognising the great impact that Inmarsat's BGAN system will have on the European satellite communications industry, and the benefits that it will bring to a wide range of European industries, in 2003 ESA initiated the 'BGAN Extension' project. Its primary goals are to provide the full range of BGAN services to truly mobile platforms, operating in aeronautical, vehicular and maritime environments, and to introduce a multicast service capability. The project is supported by the ARTES Programme which establishes a collaboration agreement between ESA, Inmarsat and a group of key industrial and academic institutions which includes EMS, Logica, Nera and the University of Surrey (UK).

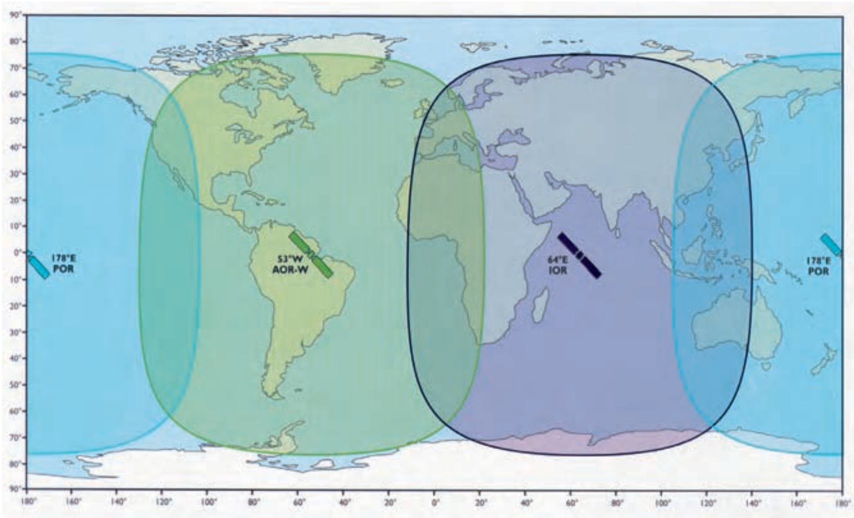
Introduction

Since its creation in 1979, Inmarsat has been operating pioneering global mobile satellite communication systems. The company came into being as an intergovernmental organization to provide global safety and other communications for the maritime community. Starting with a customer base of 900 ships in the early 1980s, it grew rapidly to offer similar services to other users on land and in the air. It now supports links for phone, fax and data communications to more than 287 000 ships, vehicles, aircraft and other mobile users in every part of the World except the polar regions.

Inmarsat's current strategy is to pursue a range of new data-dissemination opportunities at the convergence of information technology, telecommunications and mobility, while continuing to serve the traditional maritime, aeronautical, land-mobile and remote-area markets. A cornerstone of this strategy is the new Inmarsat fourth generation satellite (I-4) constellation, which is expected to begin providing commercial services late in 2005. These satellites will form the backbone of Inmarsat's BGAN system.

BGAN is designed to provide a portfolio of packet-mode and circuit-mode-based services, offering speech telephony, ISDN calls and 'always-on' Internet/Intranet IP-based mobile data communications at up to 492 kbps for Internet access, mobile multimedia and many other advanced applications. Data rates and connection options provided to BGAN users are dependent on the design and class of user equipment, encompassing in its fully deployed configuration up to 12 different types of user terminals. The BGAN Mobile Satellite Service will share the scarce radio resources available in the L-band with a wide range of existing Inmarsat services, which are carried over 2nd and 3rd-generation satellites in addition to I-4s.

The agreement established between ESA and Inmarsat in 2003 on the 'BGAN Extension' Programme pursues the enhancement of the BGAN system and marks the first collaboration on system engineering activities between the two organizations. The Programme identifies two main areas of research and development:

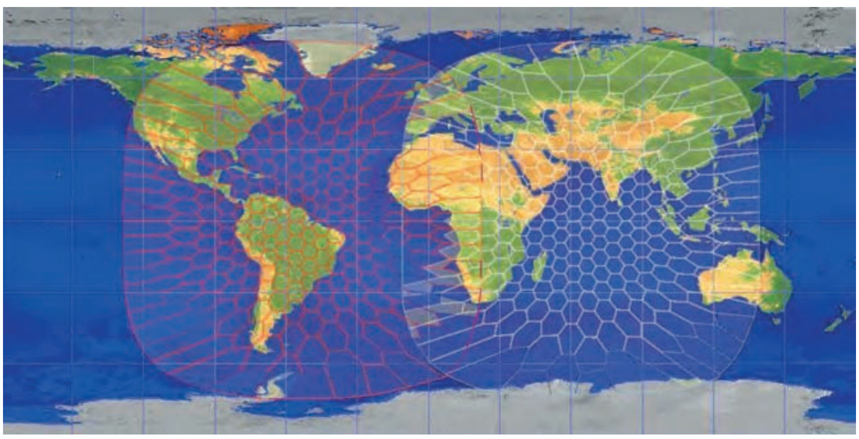


Inmarsat BGAN coverage

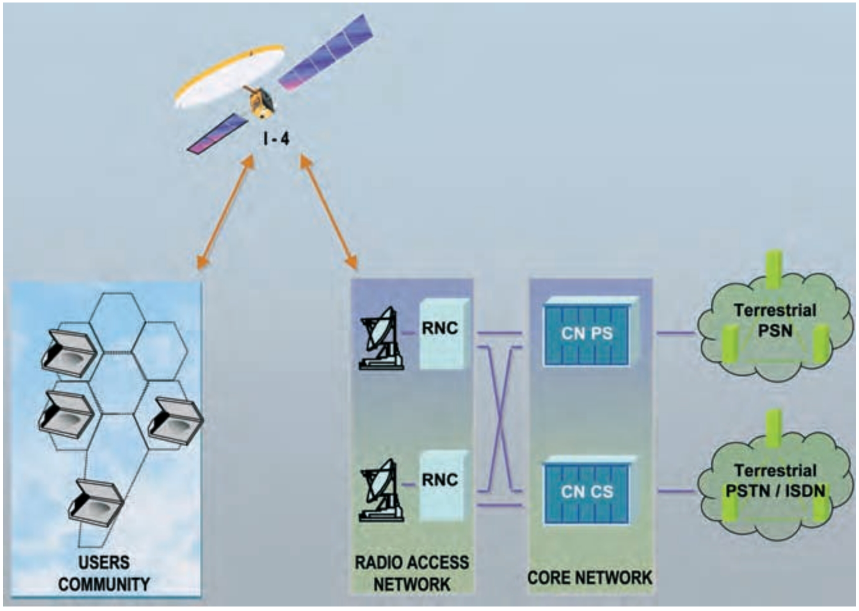
- The baseline system is optimised for static land-portable terminals. The 'BGAN Extension' Programme will extend the capabilities of the system to new directional as well as omni directional BGAN platforms and services for truly mobile maritime, aeronautical and land vehicular applications, extending the number of user-terminal classes from 3 to 12.
- The baseline system has been designed to support point-to-point telecommunica tions services. BGAN Extension also aims to diversify the service portfolio through the development of multicast service capabilities, i.e. point-to-multipoint or multipoint-to-multipoint communication services, thereby exploiting the natural strength of satellites for delivering multicast services at the global level.

The BGAN System

The Inmarsat BGAN system is intended to form part of the satellite component of the Third Generation (3G) IMT-2000/ Universal Mobile Telecommunications System (UMTS). It constitutes the first new Inmarsat service to be launched on its geostationary I-4 satellites and will be the first mobile satellite system to deliver broadband data and voice simultaneously through one device, to almost anywhere on the planet. After the launch of the first I-4



The spot-beam coverages of the first two I-4 satellites



System overview

satellite, the service will initially be available across Europe, the Middle East, Africa and Asia late in 2005; it is expected to be launched in North and South America in the second quarter of 2006, after the launch of the second I-4 satellite. The future of the third satellite, which is required to provide full global coverage, will be decided after the launch and initial testing of the second satellite. The accompanying figure shows the BGAN service area after deployment of the first two satellites.

The BGAN user terminals provide a set of services that mirror those available with terrestrial UMTS. Based on IP technology, BGAN will deliver data rates of up to 492 kbps. At launch, the service will be accessible via three classes of satellite terminals: Class-1 a briefcase-like terminal, Class 2 a notebook-like terminal, or Class-3 a pocket-sized terminal. The Class-1 terminal is meant for the fixed office environment, whilst the Class-2 and -3 variants are intended to serve professional users who require packet- and circuit-switched services whilst on the move. The system architecture is shown in the accompanying figure.

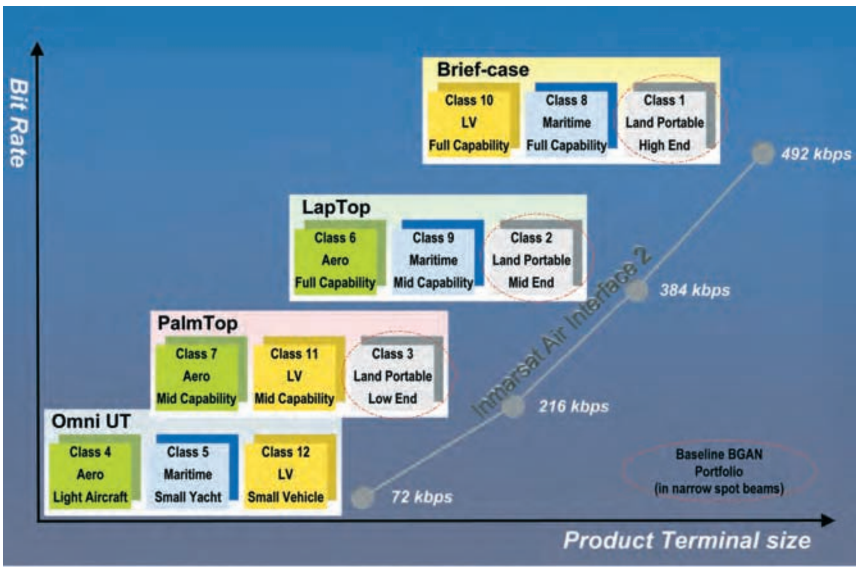
The BGAN Core Network is a suite of UMTS network nodes. It is aligned with a so-called 3GPP release-4 architecture, having separate packet- and circuit-switched domains. Media Gateway/MSC Server nodes (for user and control plane transmission, respectively) are provided for circuit-switched communication, including ISDN. GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) services are provided for Internet Protocol (IP) packet-switched communications.

The Services

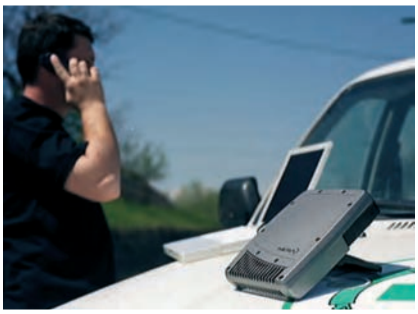
The 21st century office is increasingly dependent on the availability of high-speed communications. Mobility is an intrinsic part of working life for many people and expectations are now higher regarding what can be done whilst on the move. The demand for broadband data 'anytime, anywhere' is gathering pace, but current solutions don't always hit the mark in combining high bandwidth with ubiquitous coverage, reliability and portability. BGAN is the breakthrough system that can meet all of these requirements, by enabling broadband on the move, delivering all the key tools that the modern office needs.

In some locations, BGAN may be the user's only means of connectivity with the rest of the world, and so must be totally dependable. The 16-fold increase in network capacity that the new Inmarsat-4 satellites bring will ensure that, and customers will be able to choose from a range of robust mobile satellite terminals designed to cater for different application needs.

BGAN will support innovative packet-switched IP-based services as well as traditional circuit-switched voice telephony and ISDN data via SIM-card-associated telephone numbers. In addition, the voice service will include all the standard enhanced features offered by terrestrial fixed-line and mobile networks,



Long-term vision towards BGAN platform extensions such as voice mail, caller ID, call forwarding, call waiting, conference calling and call barring. The Standard IP data service will offer variable rates up to 492 kbps, typically used for transferring files, accessing e-mail, the Internet or corporate network applications.



A BGAN terminal (courtesy of Nera)

The Streaming IP data service, available on selected BGAN terminals, will offer guaranteed bandwidth on demand, enabling live video applications like video conferencing or video streaming. On the other hand, non-real-time video can also be transmitted based on store-and-forward mechanism, thereby making efficient use of available capacity.

In making a voice call, users will have a choice between using wired and wireless connections, including standard fixed-line telephones and Bluetooth headsets or handsets, depending on the satellite terminal being used. The BGAN system will serve both native BGAN users and roaming customers, provided there is the necessary roaming agreement between their home network and Inmarsat.

Other available services include: short messaging services (SMS), multimedia messaging services (MMS), and UMTS location-based services offering maps, local travel information, etc. Other chargeable content and applications services may be built on top of these many BGAN telecommunications services using Industry-standard toolkits.

The Users

BGAN can greatly extend the boundaries of the 'broadband mobile office', which emerging 3G services have only just started to deliver. Its performance and versatility will appeal to a diverse range of industries with vastly different operational needs, but who all share a need for reliable mobile communications. Key customers for existing Inmarsat services who are expected to be core users of BGAN include:

- Media companies, who use mobile satellite services to file their reports from disaster-hit areas, war zones, sports events and remote regions. Here BGAN can offer high speed, portability and easy to use means of communication, which will enable journalists, broadcasters and photographers to respond even more rapidly and with greater flexibility.
- Governments and the military, who require time-critical communications with an exceptional level of reliability, availability and security. The significant increase in network capacity that the I-4 satellites bring will ensure that BGAN meets these requirements, whilst also offering a high-speed, flexible alternative for voice and data communications on the move.
- Aid agencies and Non-Governmental Organisations (NGOs), who typically create 'temporary offices' for small teams of aid workers in areas of desperate need, which must be quick to set up and dismantle. BGAN can offer small, lightweight terminals that are simple to use, either for basic voice and e-mail communications or life-saving video applications such as telemedicine.
- Oil and gas companies, who usually require mobile satellite services during the initial exploration phase, before a

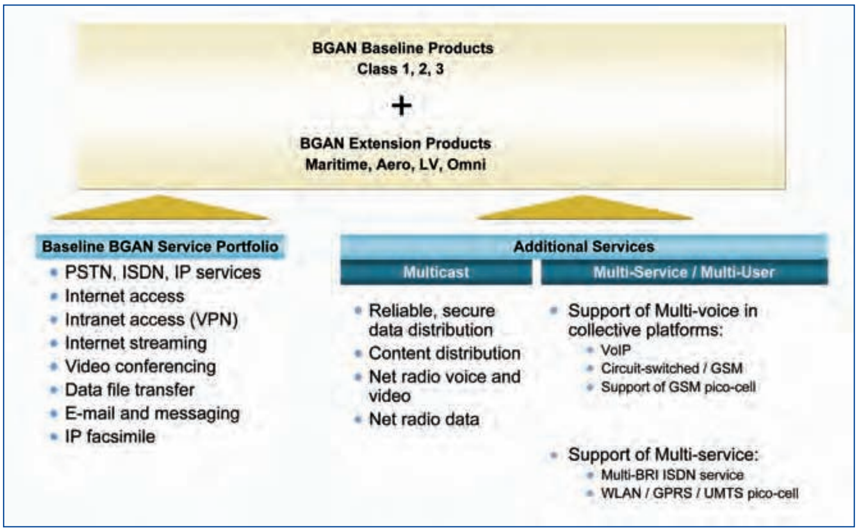
The Inmarsat I-4 Satellites

This new generation of super-satellites will usher in an era of vastly enhanced broadband mobile satellite services. Built by an international team of space engineers from the United Kingdom, France, Germany, the USA and Canada, the I-4's are the biggest and most powerful commercial communications spacecraft ever built. The body of the satellite approaches the size of a double-decker bus, its solar panels span an immense 45 m, and it has a 9 m antenna reflector that unfurls in orbit. The I-4's solar cells efficiently combine silicon technology with advanced gallium-arsenide cells. Its thrusters employ both chemical and plasma-ion technologies.

An Inmarsat I-4 satellite being made ready for testing at Astrium's factory in Toulouse, France

The I-4's can provide a 16-fold increase in the traffic-bearing capacity of the Inmarsat network, with each I-4 capable of generating hundreds of high-power spot beams. These beams can quickly be reconfigured and focused anywhere on the Earth to provide extra capacity where needed. Each satellite can generate 19 wide spot beams and more than 200 narrow spot beams, compared with the seven wide spot beams available on Inmarsat-3. It also illuminates the Earth with a single global beam, which provides an initial signalling link for all services.

EADS Astrium is the industrial prime contractor entrusted with building the three spacecraft, using its tried-and-trusted Eurostar spacecraft bus as the basis.



Scope of follow-on BGAN Extension activities

permanent extraction site is established. Exploration teams, together with those conducting oil-well and pipeline maintenance, will benefit from more portable BGAN terminals that are easier to use, with network coverage across most of the World's land mass.

- Construction companies, who need connectivity during 'rolling' construction projects involving pipelines, power lines, roads and railways, where the team is constantly on the move. Increased bandwidth will enable project teams to send more comprehensive progress reports that also include photographs and video.

The BGAN Extension Programme

Air-Interface and Platform Extension

The BGAN baseline system was optimized for a land-portable channel, which is relatively time-invariant while the truly mobile User Terminals have to operate under dynamically varying channel conditions depending on the specific environment. The baseline portfolio of BGAN terminals will therefore be complemented by three classes – Aeronautical, Maritime and Mobile Vehicular – embracing high-gain, intermediate-gain, and omni-directional terminals.

As these new classes of terminals will have to operate under very different dynamic conditions, careful investigation was required, which involved developing a set of representative propagation models from established databases and theory, and extensive computer simulations of typical environments of each mobile category. The modifications required on the aeronautical channel have proved especially challenging due to the frequency-selective fading that occurs. In addition, numerous changes were needed to the upper protocol layers for handover support, definition of new user terminal classes, management of new bearer types, user-terminal fade recovery mechanisms, management of initial acquisition of omni-terminals, etc.

The evolved specifications and solutions are currently being implemented by Inmarsat and its BGAN Extension programme partners, EMS Technologies and Nera, in the radio access network and the mobile satellite user terminals.

Multicast Service Extension

The BGAN baseline system has been designed to support point-to-point telecommunication services. The BGAN Extension aims to provide a multicast service capability, to exploit the inherent strength of satellites for delivering such services at the global level. Multicast has also been identified as a primary requirement for government and security operations in the field. The BGAN multicast service will support mobile operations in a more efficient manner and with much lower airtime cost for the end-user than today's unicast mode. It is also seen as an attractive proposition for the development of new applications and business opportunities for value-adding resellers.

The BGAN Multicast Service will support both real-time and non-real-time applications. It will be scalable and rely on IP-based standard protocols for interfacing to the end users and content providers, who can be connected to the BGAN System through the Internet. It will be capable of supporting reliable and secure multicast transport protocols ensuring quality of service for individual multicast flows.

The end user will also experience a high degree of flexibility, being able to receive multiple multicast flows simultaneously. Additional functionality provided to the service provider or network operator will enable them to authenticate the user's identity prior to authorising the reception of the multicast content, based on such criteria as membership status, geographical location, user status, mobile capabilities, and network resources.

Future Extensions

The scope of the work covered by the ARTES 'BGAN Extension' programme may be extended in the future to include other attractive features. For instance, the multi-service and multi-user detection capability can build on the complementary role of Mobile Satellite by seamlessly extending GSM, UMTS and WLAN services to users of terrestrial mobile networks when operating out of reach of cellular coverage.

The BGAN System can be extended with multi-service and multi-user support capabilities to provide a reliable means of communication for nomadic and mobile collective platforms like trains, planes or ships, by allowing seamless inter-working between the BGAN mobile satellite communication system and terrestrial wireless access technologies. The multi-user service enhancement will also allow the collective platform users to access the full range of BGAN services via the BGAN mobile terminal serving that platform.

Despite the considerable spectrum-utilisation efficiency offered by the Inmarsat I-4 narrow-spot-beam technology, the growing demand for spectrum arising from ever-increasing multimedia applications may still outstrip the spectrum pool. Narrow-band multi-user detection (MUD) technology has emerged as a promising candidate to alleviate such a scenario, but is very demanding in terms of processing power. Inmarsat therefore intends to prototype an MUD unit in the framework of the BGAN Extension programme to demonstrate the improvements in spectrum utilisation efficiency. In addition to spectrum savings of up to 30% on the return link, the BGAN omni-directional prototype demonstrator may also pave the way for new technology central to the next generation of highly efficient, broadband, mobile user terminals.

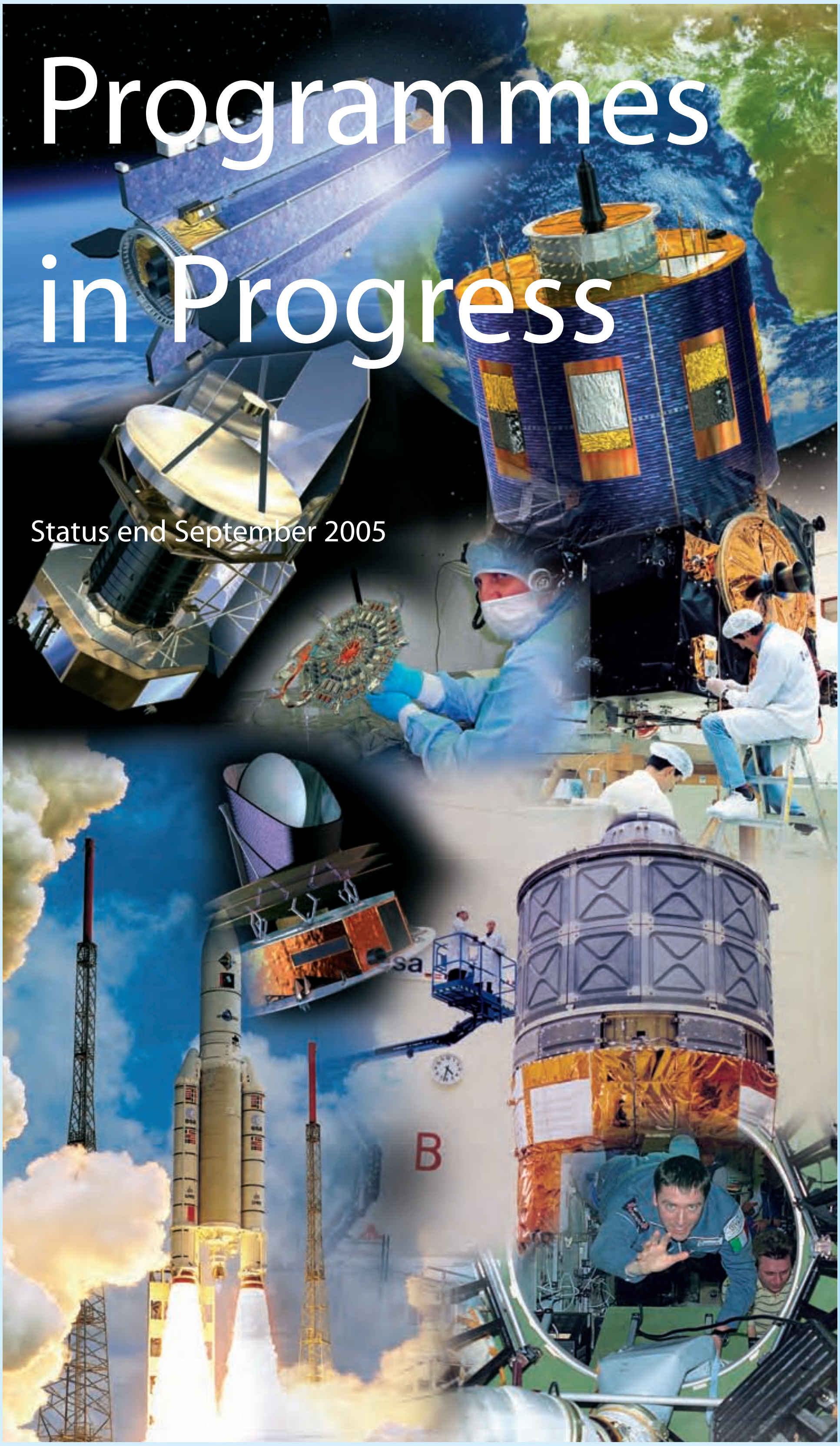
Open Standard Approach

The BGAN Extension programme has adopted an open standard approach and intends to standardise the BGAN system and air interface as a satellite component of the UMTS. The range of BGAN design specifications are expected to produce significant inputs to various European and International standardisation bodies, which are involved with air-interface and signal-in-space definition, protocol optimisation for mobile satellite operation, and spectrum allocation and sharing recommendations.

Conclusion

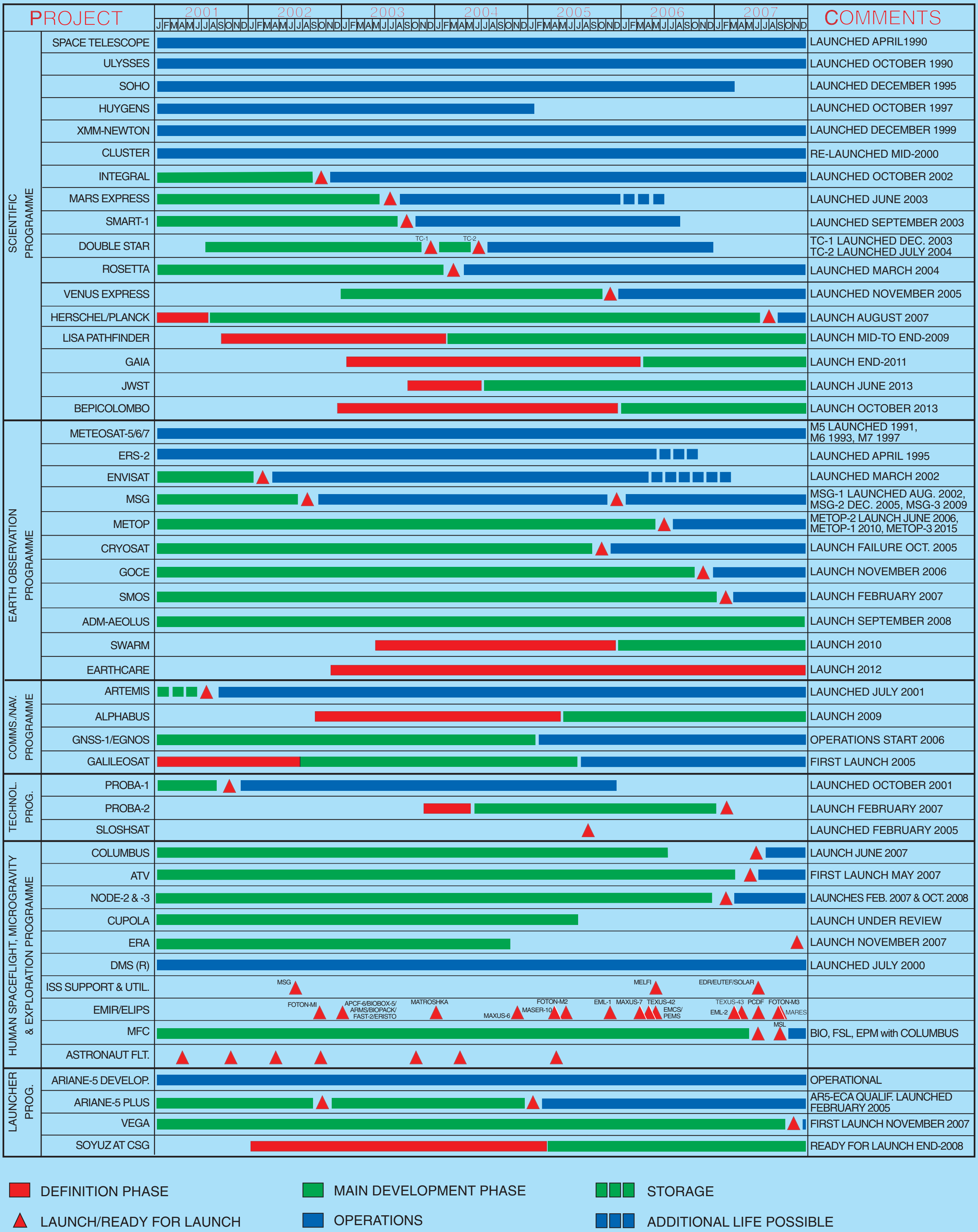
Enabled by the state-of-art Inmarsat-4 satellites, BGAN will usher in the next generation of mobile satellite communi-cations services, which will provide ubiquitous wideband access beyond the reach of the latest terrestrial telecommunic-ations. As the initial services approach role-out by the end of 2005, the BGAN service portfolio is already being enhanced under the auspices of ESA's ARTES Programme. The BGAN extended capabilities provided by the new platforms to the aeronautical, maritime and land-mobile environments, together with the service extension to multicast, will be ready for service at the end of 2006 and early 2007. These new services aim to serve a wide range of user communi-ties, including governmental and non-governmental organizations, aid agencies, the military sector and private companies.

The BGAN Extension Programme therefore responds to the key strategic objective of ESA's Telecommunications Long-Term Plan by contributing to maintaining the competitiveness of both the European Industry and Satellite Operators, and ensuring Inmarsat and its partners a leading position in the global market.



Programmes in Progress

Status end September 2005

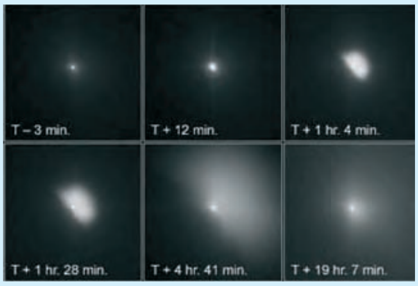

PROJECT
2001 2002 2003 2004 2005 2006 2007
J F M A M J J A S O N D
COMMENTS
SCIENTIFIC PROGRAMME
SPACE TELESCOPE — LAUNCHED APRIL1990
ULYSSES — LAUNCHED OCTOBER 1990
SOHO — LAUNCHED DECEMBER 1995
HUYGENS — LAUNCHED OCTOBER 1997
XMM-NEWTON — LAUNCHED DECEMBER 1999
CLUSTER — RE-LAUNCHED MID-2000
INTEGRAL — LAUNCHED OCTOBER 2002
MARS EXPRESS — LAUNCHED JUNE 2003
SMART-1 — LAUNCHED SEPTEMBER 2003
DOUBLE STAR — TC-1 LAUNCHED DEC. 2003 TC-2 LAUNCHED JULY 2004
TC-1
TC-2
ROSETTA — LAUNCHED MARCH 2004
VENUS EXPRESS — LAUNCHED NOVEMBER 2005
HERSCHEL/PLANCK — LAUNCH AUGUST 2007
LISA PATHFINDER — LAUNCH MID-TO END-2009
GAIA — LAUNCH END-2011
JWST — LAUNCH JUNE 2013
BEPICOLOMBO — LAUNCH OCTOBER 2013
EARTH OBSERVATION PROGRAMME
METEOSAT-5/6/7 — M5 LAUNCHED 1991, M6 1993, M7 1997
ERS-2 — LAUNCHED APRIL 1995
ENVISAT — LAUNCHED MARCH 2002
MSG — MSG-1 LAUNCHED AUG. 2002, MSG-2 DEC. 2005, MSG-3 2009
METOP — METOP-2 LAUNCH JUNE 2006, METOP-1 2010, METOP-3 2015
CRYOSAT — LAUNCH FAILURE OCT. 2005
GOCE — LAUNCH NOVEMBER 2006
SMOS — LAUNCH FEBRUARY 2007
ADM-AEOLUS — LAUNCH SEPTEMBER 2008
SWARM — LAUNCH 2010
EARTHCARE — LAUNCH 2012
COMMS./NAV. PROGRAMME
ARTEMIS — LAUNCHED JULY 2001
ALPHABUS — LAUNCH 2009
GNSS-1/EGNOS — OPERATIONS START 2006
GALILEOSAT — FIRST LAUNCH 2005
TECHNOL. PROG.
PROBA-1 — LAUNCHED OCTOBER 2001
PROBA-2 — LAUNCH FEBRUARY 2007
SLOSHSAT — LAUNCHED FEBRUARY 2005
HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME
COLUMBUS — LAUNCH JUNE 2007
ATV — FIRST LAUNCH MAY 2007
NODE-2 & -3 — LAUNCHES FEB. 2007 & OCT. 2008
CUPOLA — LAUNCH UNDER REVIEW
ERA — LAUNCH NOVEMBER 2007
DMS (R) — LAUNCHED JULY 2000
ISS SUPPORT & UTIL.
MSG
MELFI
EDR/EUTEF/SOLAR
EMIR/ELIPS
FOTON-M1
APCF-6/BIOBOX-5/ ARMS/BIOPACK/ FAST-2/ERISTO
MATROSHKA
MAXUS-6
FOTON-M2
MASER-10
EML-1
MAXUS-7
TEXUS-42
EMCS/ PEMS
TEXUS-43
PCDF
FOTON-M3
EML-2
MARES
MFC — BIO, FSL, EPM with COLUMBUS
MSL
ASTRONAUT FLT.
LAUNCHER PROG.
ARIANE-5 DEVELOP. — OPERATIONAL
ARIANE-5 PLUS — AR5-ECA QUALIF. LAUNCHED FEBRUARY 2005
VEGA — FIRST LAUNCH NOVEMBER 2007
SOYUZ AT CSG — READY FOR LAUNCH END-2008
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
STORAGE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE

HST

The Hubble Space Telescope is operating nominally, with the exception one of the five on-board science instruments, namely the Imaging Spectrograph (STIS), which failed on 3 August 2004.

To extend the expected scientific lifetime of HST, preparations were made over the last year to switch-off one of the gyroscopes and operate in a two-gyro configuration. The two-gyro mode was tested with the four operational scientific instruments in February and, given the excellent results, HST was transitioned to two-gyro mode on 28 August. All indications are that performance in this mode is excellent. Measurements of the point-spread function (PSF) with the Advanced Camera for Surveys (ACS) show extremely small differences, if any, between two-gyro and three-gyro mode. Measurements of the PSF of the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) are consistent with the ACS results, and a first look shows that the NICMOS coronographic performance is unchanged. The performance of the magnetometer guiding has also been excellent, with relatively small errors (typically 1-2 degrees) accumulating during occultations and slews. This early introduction of the two-gyro science mode is expected to extend the observing lifetime of HST with the current set of gyros by at least 9 months to late-2008, corresponding to 2400 to 3000 more orbits of useful science.

Plans for a Space Shuttle SM4 servicing mission continue, but the final decision will only be made after a successful second flight of the Shuttle, now scheduled for early spring 2006. In the meantime, the NASA Administrator has decided that it is not necessary to include a de-orbit module on this mission. Current estimates indicate that HST will not re-enter the atmosphere before 2020, and that provides ample time to find alternative means for a controlled de-orbiting. Removing the de-orbit module will significantly simplify the next mission, as well as reduce the risk associated with a new development and the associated risk to the astronauts.



Collision of Deep Impact's projectile with Comet Tempel 1 on 4 July

The Hubble Space Telescope captured the dramatic effects of the collision on 4 July between an 820-pound projectile released by NASA's Deep Impact spacecraft and comet 9P/Tempel 1. The accompanying sequence of images shows the comet before and after the impact. The visible-light images were taken by the ACS instrument's High-Resolution Camera.

Ulysses

A major milestone for Ulysses was reached on 6 October with the 15th anniversary of its launch from Cape Canaveral on-board the Space Shuttle 'Discovery'. After 15 years of operations, the spacecraft and its scientific payload remain in remarkably good health. No anomalies have occurred during the last quarter, and the data coverage has been excellent, with a mission average of 97% to date.

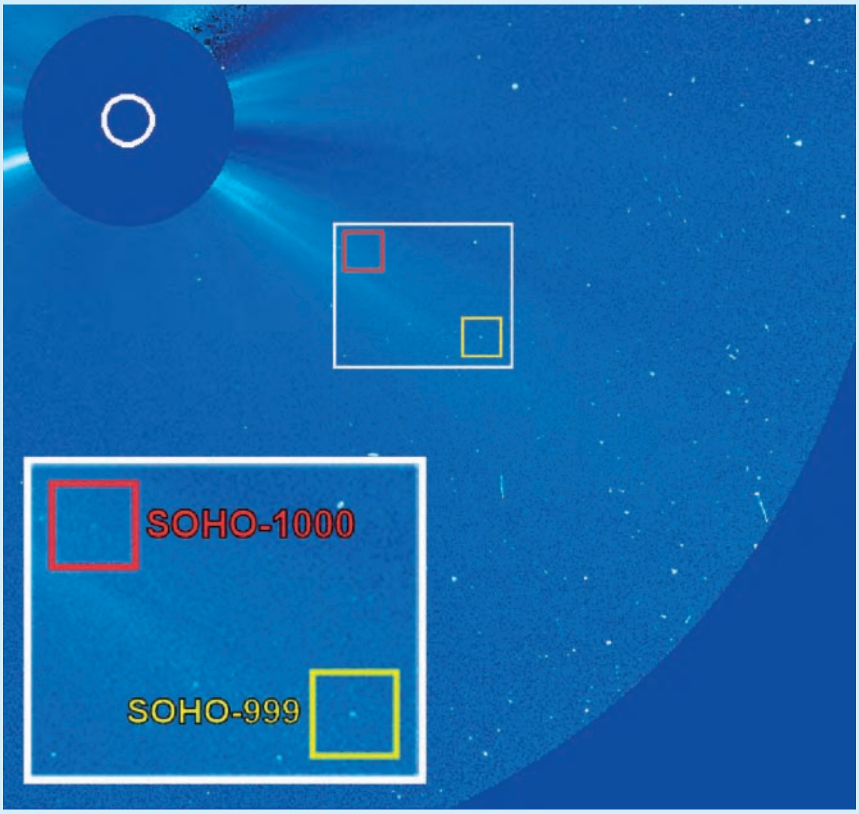
On the programmatic front, the situation regarding NASA's continued participation in the mission, which was a concern earlier in the year, has shown significant improvement. The NASA budget for mission operations and data analysis for Sun-Solar System Connections missions like Ulysses that are currently in their extended operational phase has largely been restored. Nevertheless, the outcome of the next Senior Review, to be held on 14-15 November, will still be important.

All science operations during the reporting period have been nominal, with the payload being operated according to the pre-determined power-sharing plan. The current configuration will be maintained until Spring 2007, when the spacecraft will be close enough to the Sun to allow the heater needed to keep critical parts of the spacecraft platform at a safe temperature to be switched off. Ulysses is presently ~35° south of the solar equator, 4.5 AU from the Sun.

In early September the Sun, although far into the declining phase of the current sunspot cycle, produced a display of major activity. This included one of the largest solar flares of cycle 23, an X 17+ on 7 September, which occurred as the active region responsible rotated into view of the Earth on the Sun's east limb. A very large and very fast Coronal Mass Ejection (CME) was also associated with this flare. At the time, Ulysses was positioned almost directly behind the Sun as seen from Earth, giving it a unique view of the source of the activity for several days prior to its appearance on the visible (from Earth) solar disk. Based on observations from the Ulysses radio experiment, it is likely that region 10808 produced at least 4 intense flares while on the far side as viewed from Earth. The X 17+ flare produced an unusually intense radio burst observed by Ulysses, and the shock driven by the CME was observed *in-situ* at Ulysses on 14 September, implying a transit velocity of ~1210 km/sec over a distance of almost 5 AU! The radio bursts associated with some of the X-class flares occurring after the X 17+ flare had surprisingly low intensities. This is consistent with what was seen for the 2003 'Halloween' events. A possible explanation is that the entire inner heliosphere was filled with energetic electrons to a flux level sufficient to block the plasma instability that would otherwise initiate the radio-emission process.

SOHO

On 5 August, Toni Scarmato, a high-school teacher from San Costantino di Briatico, Calabria, Italy, discovered SOHO's 999th and 1000th comets. Scarmato, an astrophysics graduate of Bologna University, said *"I am very happy for this special experience that is possible thanks to the SOHO satellite and*



Comets SOHO-999 and SOHO-1000. Note that although SOHO-1000 is 'ahead' of SOHO-999, and they appear in the same images, it was so inconspicuous that it was not spotted and reported until a few minutes after SOHO-999

NASA-ESA collaboration. I want to dedicate the SOHO 1000th comet to my wife Rosy and my son Kevin to compensate for the time that I have taken from them to search for SOHO comets".

To help publicise cometary science, the SOHO project held a contest in the months before the discovery that allowed the public to guess the date and time of perihelion passage for SOHO-1000. The winner of this contest, which attracted nearly 10 000 participants worldwide, was Andrew Dolgopolov from Dublin, Ireland, who guessed the time of the comet's closest approach to the Sun (perihelion time) to within 22 minutes!

Nearly half of all comets for which orbital elements have been determined since 1761 have been discovered by SOHO, over two thirds of them by amateurs accessing LASCO data via the web. The current catalogue of 1000 SOHO comets (and counting!) forms a treasure trove of data for years to come for researchers investigating the nature of our Solar System.

Huygens

The analysis of both the engineering and scientific data sets is progressing well, and the main post-flight engineering data analysis is now complete. A follow-up study with the main aim of documenting Huygens 'lessons learnt' will be initiated in November. A coordinated set of Huygens results is being finalised to appear in the journal *Nature* in late November/early December. A preliminary trajectory in the International Celestial Reference Frame (ICRF) has been derived from the Huygens VLBI data set. At the time of writing, work is still in progress to reconcile the VLBI-derived probe trajectory and the trajectory reconstructed from the coordinated analysis of the scientific payload measurements, which is in a Titan Reference Frame.

XMM-Newton

A major solar flare commencing on 8 September interrupted XMM-Newton operations for three and a half revolutions, implying some 380 ksec of lost science time.

The completion status of the Announcement of Opportunity (AO) based observing programmes is as follows:

– AO-3: 99.5%
– AO-4: 50.3%.

Completion of the above programmes is expected by March 2006, in line with the planned start of AO-5 observations. The fifth Announcement of Opportunity (AO-5) was issued on 5 September as planned, with a deadline of 14 October (at 12:00 UT). First indications are that this AO is, once again, heavily oversubscribed.

A new version of the XMM-Newton Science Analysis System (SAS) (Version 6.5) was released on 17 August. Most importantly, the new version allows better modelling of spatial and temporal response dependencies of the MOS cameras and therefore leads to a much better cross-calibration between the EPIC instruments.

Version 2.8 of the XMM-Newton Science Archive (XSA) was released on 2 August. Among other improvements, the new version allows access for the first time to a sample of multi-colour optical images from the XMM-Newton Survey Science Centre X-ray Identification follow-up programme and provides a data-quality report for each observation. The archive has 1550 external users as of 23 August. In July, a total of 960 separate data sets were downloaded by 132 external users.

Over 350 scientists attended the XMM-Newton-organised conference 'The X-ray Universe 2005' on 26-30 September at the Euroforum in San Lorenzo de El Escorial, Spain. The meeting served to highlight the many contributions that XMM-Newton has made to our understanding of this topic, but also clearly illustrated that, for example, the question of the origin of the galactic-ridge emission in hard X-rays is not yet resolved and certainly warrants more observations.

Cluster

The four spacecraft and their instruments are operating nominally. The largest constellation manoeuvres ever performed with Cluster were successfully executed in June-July, with the spacecraft achieving their largest ever separation distance of 10 000 km. It was one of the most complex manoeuvres ever conducted, with 49 individual manoeuvres executed with a total of 21 hours of thruster firings. The spacecraft are now in a multi-scale configuration with three spacecraft (C1, C2, C3) at 10 000 km separation and two spacecraft (C3, C4) at 1000 km.

Work is progressing for the switch from the Villafranca (E) to the Perth (W. Aus.) ground station in early 2006. The data return between March and early September was more than 99.4%.

During the past months, the Cluster Active Archive (CAA) team has been working towards the opening of the Archive this autumn. The ESTEC team has concentrated on the ingestion software and the user interface, and the instrument teams on the delivery of data. The CAA system now has about 12 Tbytes of available storage, of which nearly half is currently used.

A Cluster–Double Star Symposium took place at ESTEC on 19-23 September. This was a special occasion to celebrate Cluster's 5th Anniversary in space. More than 160 scientists from China, Europe, Japan, Russia and Japan participated. Sessions on the latest Cluster and Double Star results and multi-spacecraft analysis tools, as well as on future magnetospheric missions from China, Europe, Japan, Russia and USA, were organised during the week-long Symposium.

The first direct measurement of electric current in the 'ring current' has been published in Annales Geophysicae. The ring current is part of the radiation belts that increases dramatically during geomagnetic storms. The curlometer method (measurement of the magnetic field at the four Cluster spacecraft and computation of current) was not expected to give good results in the ring current because the spacecraft tetrahedron is greatly deformed. However, having the four Cluster at small distances (below 200 km) showed that the current could still be estimated with good accuracy.

Two papers have been published in *Nature* in August and September based on Cluster data. The first one presented the first observations of short-scale Alfven vortices in the polar cusp; these are produced in turbulent plasma and, although theory predicted their occurrence, they had never before been observed in space. The second presented the changes in the radiation belts during the October-November 2003 storms. The belts disappeared from their usual location and then reformed much closer to the Earth, in a region where high-energy particles are usually not found. Looking at Cluster and Antartica data, it was found that an electromagnetic emission called 'chorus' was responsible for the acceleration of electrons. Radiation belts can be a hazard to satellites and humans in space and such studies are crucial to understanding their formation.

Integral

Integral has discovered the fastest-accreting X-ray pulsar known to date. This remarkable object, called IGR J00291+5934, rotates more than 500 times a second and contains a mass comparable to that of our Sun compressed into a sphere only 20 kilometres across. These highly compressed stars, called 'neutron stars', are created in stellar explosions and are the remnants of stars that were once at least eight times more massive than the Sun. The pulses indicate the presence of an intense magnetic field and are produced as beamed gamma-rays which sweep past us as the neutron star rotates, similar to a lighthouse beam. Neutron stars are thought to be born rapidly spinning and then to gradually slow down, losing energy over a few hundred thousand years. Neutron stars in binary star systems, however, can reverse this trend and speed up with the help of material that flows from the companion star. This finding supports the theory that the fastest-spinning isolated pulsars get that fast by devouring a nearby star, with gas ripped from the companion fuelling the pulsar's acceleration. IGR J00291+5934 is the sixth such system known, and it represents a 'stepping stone' in the evolution of slower-spinning binary pulsars into faster-spinning isolated pulsars.

The Integral observations have provided new insights into just how such a rapidly rotating, magnetic, neutron star emits so much energy. As well as providing unprecedented spatial resolution, the Integral imager, IBIS, also provides good spectral resolution. This has enabled the emission associated with the accretion disk and the hot-spots above the magnetic poles to be separated. Indeed, the pulsed emission from above the polar caps is seen to contribute around 80% of the total flux, emphasising the importance of observing these objects in the gamma-ray region while the X-ray monitor onboard Integral simultaneously studies the X-rays from the accretion disk.

Mars Express

The spacecraft completed its 2000th orbit around Mars on 5 August.

The third quarter of 2005 saw the start of commissioning of the now fully deployed MARSIS instrument, and its integration into the routine mission planning and operations cycle. Initial scientific results from the radar's ionospheric and subsurface measurements look very good, with a number of papers intended for the journal Science already in preparation.

Overall operations are proceeding well. The recent proximity of Mars and the favourable illumination conditions resulted in the return of unprecedented amounts of science data from Mars Express in the last three months. Mars Express's distance from Earth decreased from 150 to 79 million km, reducing the one-way signal propagation delay from 8 to 4 minutes, and the maximum operational telemetry bit rate of 182 kbps was exploited throughout the period.

Following problems encountered in operating the PFS instrument, test operations have been performed since mid-July. Recently, the first signs of a possibility for returning to nominal operations have been identified. Since 15 August, the Aspera team has reported disturbances on one of the instrument's high voltages. Investigations show the impact on operations and science data-taking is minimal. The August issue of Planetary and Space Science was dedicated to PFS results, and a special edition of ICARUS dedicated to Aspera results is in preparation.

On 15 September, ESA's Science Programme Committee (SPC) agreed to extend the Mars Express mission for a second Martian year (1 December 2005 to 31 October 07).

Double Star

The two spacecraft and their instruments are operating nominally. The spin-axis drift is as predicted and should not cause problems before July 2006 for TC-2 and December 2006 for TC1.

The perigee of TC-2 has been decreasing due to the Sun-Earth perturbations (height now around 250 km), and atmospheric drag is slightly changing the orbit. Mission planning has been affected in that orbit predictions four weeks in advance can have a shift of up to one hour. This affects the commanding of the PEACE instrument, which has to be switched-off when in the radiation belts, and a temporary work-around solution is being put in place. The perigee altitude reached its minimum in September and will increase again in the next few months.

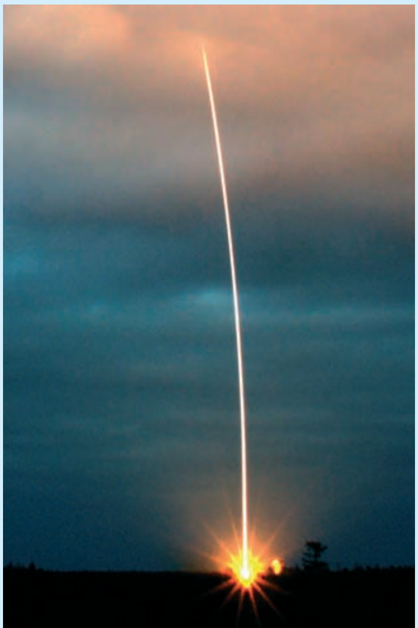
The European Payload Operation System (EPOS) that co-ordinates the operation of the seven European instruments on TC-1 and TC-2 and is running smoothly. ESOC has been acquiring an average of 3 hours of data per day using the Vilspa-2 antenna, with an availability rate of 99.94% during the summer.

A total of 24 papers have been accepted for the special *Annales Geophysicae* issue on the first results from Double Star. A special session on Double Star and Cluster results is scheduled at the American Geophysical Union meeting in San Francisco.

Early in 2005, the Double Star and Cluster spacecraft observed a flux transfer event (FTE) produced when the solar-wind magnetic field reconnected with the magnetospheric magnetic field. The FTE could be observed at small scale with the Cluster spacecraft (200 km separation) and at large scale with Double Star (18 000 km away from Cluster). It was elongated along the vertical z-axis and a preliminary estimate of its motion is consistent with the reconnection model.

CryoSat

The CryoSat launch campaign began on 31 August when a large Antonov 124 cargo plane took off from Munich on route to Archangelsk carrying some 60 tons of equipment. The satellite and the nine containers were then ferried to the Plesetsk cosmodrome by a special train.



The launch of CryoSat from the Plesetsk cosmodrome on 8 October

The launch campaign itself went very smoothly thanks to the excellent cooperation between the Eurockot/Khrunichev and EADS-Astrium/ESA teams. On 5 October, the satellite was declared ready for launch after a successful rehearsal of the countdown procedure. The tracking stations and the ESOC flight- operations team were also ready.

The launch took place on 8 October as planned, at 15:02 hrs. After a successful lift-off, the Rockot launcher disappeared out of sight from the Plesetsk cameras. It was later announced that the mission had been lost due to a failure in the Russian launcher.

The resulting disappointment throughout the entire science community has been enormous, as the mission objectives of CryoSat are becoming ever more important for achieving a better understanding of the mechanisms of global warming. The ESA Executive is therefore working very hard on a proposal to build a replacement satellite and recover the CryoSat mission.

GOCE

The GOCE system-level Critical Design Review (CDR) was completed on 13 July. The Board concluded that the satellite's development had progressed significantly, and consequently it formally released the integration programme for the satellite flight model (FM). The Board also noted, however, the critical issue of the manufacture and verification of the Accelerometer Sensor Heads (ASHs), recommending that an overall schedule-reconsolidation exercise be undertaken to mitigate the consequences of the delay incurred in the production of the flight accelerometers. The Board requested that the Project issue a close-out report on the above issues by the beginning of December.

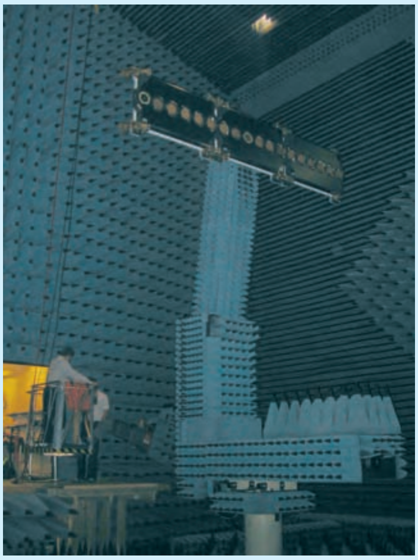
Good progress has also been made on resolving the stiffness anomaly detected in three ASH FMs integrated at ONERA. A new ASH FM, integrated using special cleanliness precautions, was successfully tested and showed no stiffness anomaly after acceptance testing, which included both vibration and thermal-vacuum tests. All of the components needed to build the remaining five ASH FMs plus one spare are ready. The stiffness of the next batch of ASH FMs will also be extensively verified to confirm the repeatability of the good results. As regards the Gradiometer FM electronics manufacturing activities, two Front-End Electronics Unit (FEEU) FMs have been delivered, and the third FEEU FM and the Gradiometer Accelerometer Interface Electronic Unit are undergoing final acceptance testing. The first two FEEU FMs have already been used by ONERA during 'drop tower' tests performed at Zarm (Bremen, Germany). The various tests have demonstrated the performance of the ASH demonstration model and first flight model under microgravity conditions.

In the Platform area, Astrium GmbH is continuing the functional testing of the Test Bench engineering model (TBh EM), with special emphasis on closed-loop testing of the drag-free attitude-control system. Moreover, the integration of the Payload EM (i.e. the SSTI EQM and the Gradiometer EM) on the Platform TBh EM has been completed and the debugging of the platform-to-payload interfaces is in progress. In addition, the Platform FM integration activities have advanced at a good pace and full integration of all FM units (except the Ion Propulsion Assembly) is expected by the beginning of October. Testing of the Ion Propulsion Assembly (IPA) EM has also started, which will verify the overall IPA performance and, in particular, the compatibility between the EQMs of the Ion Thruster, the Ion Propulsion Control Unit and the feed system. In the solar-array area, the flight photovoltaic assembly has been installed on all panels and acceptance testing is in progress.

On the Ground Segment side, the Flight Operations Segment (FOS) and the Payload Data Segment (PDS) activities have progressed according to plan at ESOC and ESRIN. In particular, the first part of System Validation Test 0 (SVT-0) has been successfully performed by sending commands from ESOC to the satellite (i.e. platform plus payload) EM TBh at Astrium GmbH and receiving back the related telemetry. Several reviews have also been successfully performed during the reporting period, including the Payload Data Segment (PDS) Acceptance Review 1, the Calibration and Monitoring Facility Critical Design Review (CDR) and the Reference Planning Facility Preliminary Design Review (PDR). Activities are also progressing nominally at the European GOCE Gravity Consortium responsible for the development of the High-Level Processing Facility (i.e. Level-1 to Level-2): the CDR for this facility was successfully performed in July.

SMOS

The Critical Design Review/ Qualification Results Review for the payload is currently in progress. Except for one schedule-critical subsystem, no major issues have been identified so far.



SMOS antenna arm mounted in the Antenna Test Facility at the Technical University of Denmark

Flight-unit production has started for nearly all subsystems, with many units (filters, antennas, receivers, structure, mechanisms) already delivered. Preparations are being made for the antenna-pattern measurements with the first arm at the Technical University of Denmark.

Platform assembly, integration and testing at Alcatel will start as soon as personnel and equipment are back from the Calypso (another CNES Proteus-platform-based project) launch campaign.

A number of activities have started in industry related to payload operations. Work on tailoring the generic Proteus Mission Operations Control Centre to SMOS's needs is expected to start after the Calypso launch.

The development of the data-processing ground segment has started under an 'Authorisation to Proceed'.

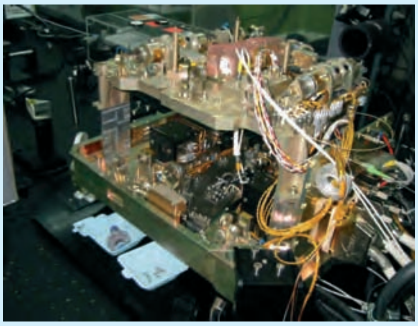
ADM-Aeolus

The structural-model satellite has been disassembled following the successful test campaign. The platform structure has been returned to the supplier, Contraves, who will refurbish it for flight before the end of the year. The thermal hardware, including the radiators and heat pipes, has been returned to Astrium Toulouse to be built into the flight-model instrument.

The qualification model of the laser has been completed at Galileo Avionica and is producing adequate bursts of ultraviolet laser pulses for flight.

Good progress has been made in understanding and characterising laser-induced-damage phenomena. Almost all components and coatings for flight have been selected, including the piezo mirror and master oscillator YaG rods. Some difficulties still remain, however, with the YaG slabs of the power amplifier and the frequency-tripling crystal; alternatives are being evaluated.

The satellite Critical Design Review (CDR) was conducted in August and September. The Board concluded that the satellite's development status was satisfactory and that the CDR objectives had been met. There were some difficulties, however, particularly with the definition of failure detection, isolation and recovery with the Coarse Earth-Sun Sensor, with the GPS and with product assurance at prime-contractor level. These issues will be addressed by the Project in the next few months. The Board also noted the significant



Qualification model of the Aeolus laser producing the appropriate pulsed bursts

advances in high-power laser technology in Europe made within the framework of the project.

Launch is still planned for September 2008.

MetOp

Following a detailed review of the current state of readiness of all elements of the EPS/MetOp System, Eumetsat has announced the launch date for the first Metop as 30 June 2006.

The MetOp-2 satellite (first to be launched) is currently stored in the clean room at Astrium Toulouse awaiting resumption of final preparation activities in early January next year, and subsequent shipment to the Baikonur Cosmodrome in early April. Included in these final preparations is the reintegration and testing of the AMSU-A instruments, which were recently removed for repair due a generic manufacturing problem discovered in a sister instrument in the USA. During this same period, the final ground segment to satellite validation testing will also be performed both with the Launch and Early Operations Phase (LEOP) operator (ESOC) and the routine-operations entity (Eumetsat).

Final system validation and verification testing of the ground segment at Eumetsat is progressing well, with completion of all core activities scheduled for early next year, leading to a series of rehearsals and simulations starting in March 2006. The LEOP preparation activities at ESOC are proceeding according to plan.

As regards the new Soyuz ST launcher, the mechanical qualification activities necessary for the new fairing, intermediate bay and upgraded Fregat orbital-transfer vehicle are in progress, with completion scheduled towards the end of this year. In parallel, modifications to the facilities at the Baikonur Cosmodrome have started with installation of the checkout equipment needed for the new digital avionics and modification of the launch tower, and the associated handling equipment, to accommodate the larger diameter fairing.

Meteosat Second Generation (MSG)

MSG-1

The first north-south station-keeping manoeuvre was successfully performed on Meteosat-8 (formerly MSG-1) in June. It has now been in orbit for 3 years and operations have been nominal during the reporting period, with excellent instrument performance. of Eumetsat)

MSG-2

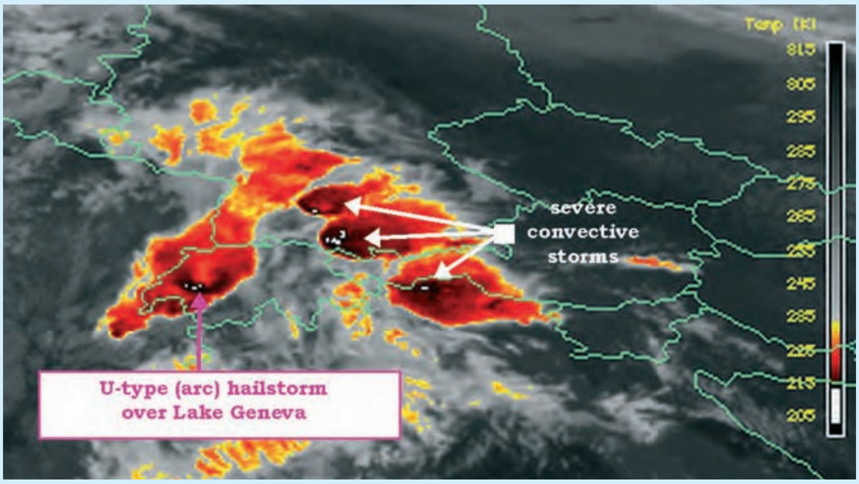
The MSG-2 launch campaign started on 21 June with the satellite's transportation to Kourou (Fr. Guiana), but was stopped when it became clear that an August launch could no longer be supported by Arianespace. The MSG-2 spacecraft was then put into a storage configuration in the clean room at CSG. The MSG team returned to Europe to resume the assembly, integration and test (AIT) activities on MSG-4, while two team-members stayed behind in Kourou with MSG-2. The planned launch date is currently 20 December, which means that the launch campaign should be re-started by the end of October.

MSG-3

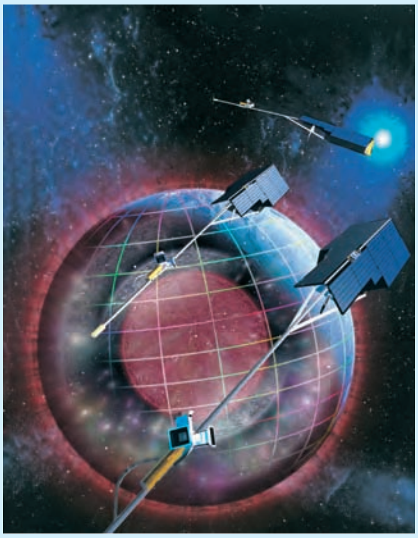
MSG-3 remains in short-term storage in the Alcatel clean room. It will be kept available as a source of spares for MSG-2 during its launch campaign. Thereafter, it will be put into long-term storage, awaiting its own launch, which is currently foreseen for 2009.

MSG-4

The MSG-4 AIT activities are proceeding according to plan. Electrical integration activities were started after the industrial team returned from the aborted MSG-2 launch campaign, with the integration of the Electrical Power System (EPS), and will continue until the MSG-2 launch campaign restarts. The thermal/optical vacuum test on the SEVIRI instrument will be performed as soon as the Focal V facility at CSL (B) becomes available. The instrument's final delivery is now planned for January 2006. Delivery of the Mission



On 18 July, a cold front approached Switzerland from France. In the pre-frontal air mass of tropical-maritime origin, lines of severe thunderstorms were forming. On the satellite image from Meteosat-8, one can derive many details of the thunderstorm cell. In particular, as evidenced by the infrared window channel (IR 10.8) after 12:45 UTC a cold arc was developing on top of the cell with temperatures around -60°C indicating a possible penetration into the stratosphere (see red-black to white colours) (Image courtesy of Eumetsat)



Artist's impression of the Swarm satellite constellation (Courtesy of EADS Astrium)

Communication Package (MCP) is planned for December 2005.

SWARM

Swarm is the fifth ESA Earth Explorer Mission. The mission concept involves placing a constellation of three satellites in three different near-polar orbits at altitudes of between 450 and 530 km, which will provide high-precision and high-resolution measurements of the Earth's magnetic field. (Courtesy of EADS Astrium)

Swarm will provide much-needed continuity with such geopotential research-oriented missions as Ørsted, SAC-C, and Champ. It will carry state-of-the-art magnetometers, and will be able to make measurements over different regions of the Earth simultaneously. An electric-field instrument and an accelerometer on each of the satellites will provide additional measurements to help understand the interaction between the Earth's magnetic field and other physical variables. The mission's primary aim is to provide the best-ever survey of the geomagnetic field and the first global representation of its variation on time scales ranging from hours to several years. The more challenging aspect, however, is to separate the contributions from the various sources. Swarm will simultaneously obtain a space-time characterisation of both the field sources inside the Earth and ionospheric-magnetospheric current systems.

The primary research objectives assigned to the Swarm mission are:
- studies of core dynamics, geo-dynamo processes, and core-mantle interaction
- mapping of lithospheric magnetisation and its geological interpretation
- determination of the 3-D electrical conductivity of the mantle
- investigation of electric currents flowing in the magnetosphere and ionosphere.

In addition to the above sources, the ocean currents produce a contribution to the measured magnetic field. The magnetic field not only contains evidence of the planet's evolution, but also directly controls the dynamics of the ionised and neutral particles in the upper atmosphere, and possibly even has some influence on the lower atmosphere. This has led to the identification of the two secondary research objectives of:
- identifying the ocean circulation by its magnetic signature
- quantifying the magnetic forcing of the upper atmosphere.

Analysis of the Swarm data will greatly improve existing models, and also provide new models of the near-Earth magnetic field with much higher resolution and greater authenticity than previous single-satellite missions. This provides the prospect of investigating hitherto-undetected features of the Earth's interior.

The Phase-B contract for the satellite is planned to start this November.

PROBA

The PROBA-1 spacecraft will complete four years in orbit on 22 October. It is still working very well, supporting a variety of Earth-observation campaigns (examples of which can be found at http://earth.esa.int/workshops/chris_proba_05/) with its main instrument CHRIS (Compact High-Resolution Spectrometer) and the HRC (High-Resolution Camera). Data on the in-orbit radiation and space-debris environments are also routinely provided by the spacecraft's SREM and DEBIE instruments.

During its four years in orbit, PROBA-1 has generated 10 700 CHRIS multi-spectral images (mainly 4- or 19-band), and 8300 HRC black-and-white images. CHRIS instrument images are currently being used by 116 scientific Principal Investigators (PIs) around the World for such local applications as soil, aerosol, forestry, agriculture and water monitoring. CHRIS is also contributing to the International Charter on Space and Major Disasters, while the HRC is being used for public-relations, educational and scientific purposes.

A further one-year extension of PROBA-1 operations conducted from ESA's Redu facility (B) is envisaged.

Human Spaceflight, Research and Applications

Highlights
The Shuttle Return-to-Flight mission (LF-1) took place between 26 July and 9 August. Whilst the overall mission was successful, the External Tank suffered foam loss from a number of different areas. Consequently, the next Shuttle launch has been postponed to no earlier than May 2006.

With regard to the ISS Assembly Sequence, the NASA group evaluating Shuttle-flight options has completed its task. The results are that NASA intends to have 18 Shuttle flights to the ISS, and all main ISS elements will be launched, with the exception of the Centrifuge Accommodation Module and the Russian Solar Power Module.

The Russian Progress Cargo spacecraft (19P) docked to the ISS on 10 September, carrying supplies for the crew. This was the 50th flight

Node-2 activities at the Kennedy Space Center (photo NASA)

of a vehicle to the ISS starting with that of Zarya in November 1998.

Space infrastructure development
The final round of Columbus module system acceptance testing has been completed and integration and testing of the external payload EuTEF (the European Technology Exposure Facility) has started. Operations validation on the Electrical Test Model continues and the Preliminary Acceptance Review (PAR), which covers the module without payloads, has started, and the procedure for the Final Acceptance Review (FAR1), which covers the module outfitted with its payload complement, has been agreed.

During contamination tests earlier in the year, failure of an ATV latch valve occurred during vibration. Following detailed fatigue analysis, it has been decided to refurbish all 44 of the ATV Jules Verne latch valves. The latch-valve replacement, combined with various problems that are being discovered with the Functional Simulation Facility (FSF), has impacted the target ATV launch-readiness date, which is now spring 2007. In the meantime, qualification testing, de-bugging and functional testing continue with the flight-application software, Qualification Reviews have been held for avionics and for the videometer, and the delta-qualification of the ATV/Ariane-5 clamp-band design, to prevent rotation, has started.

Node 2 is currently undergoing ground testing and preparation for flight at the Kennedy Space Center; integration of Node 3 in Europe is continuing, with verification and close-out activities due to start late in 2005.

The European Robotic Arm (ERA) flight model, flight spares and Mission Preparation and Training Equipment (MPTE), a version of which was previously shipped to Russia, remain in storage in Europe. Contractual negotiations for ERA's launch on the Russian Multipurpose Laboratory have been successfully completed.

Operations and related ground segments
The Pulmonary Function System (PFS) was successfully launched in NASA's HRF-2 with Shuttle flight LF-1 and is now accommodated in the 'Destiny' laboratory.

In October, during the Soyuz Taxi Mission (11S) to the ISS to replace both the docked Soyuz vehicle (10S) and the Expedition 11 crew, visiting Crewman Greg Olsen successfully performed three ESA experiments.

Previously, during his stay onboard the ISS as an Expedition 11 crew member, the Russian Cosmonaut Sergey Krikalev successfully conducted three ESA experiments, samples and data for which were successfully downloaded with the Soyuz 10S return to Earth flight in October. During the Expedition 12 activities, a further three ESA experiments will be performed by Cosmonaut Valery Tokarev.

Matroshka, a radiation experiment that was mounted externally on the ISS for 18 months, was recovered during a space walk in August. The passive radiation sensors have been removed from the facility and returned to Earth with the Expedition 11 crew. New passive radiation sensors, which will be uploaded to

Soyuz Taxi Mission 11S approaches the ISS on 3 October (photo NASA) the ISS in December, will be installed by the Expedition 12 crew.

Qualification of the ATV Control Centre (ATV-CC) continues on schedule. Interface testing with external facilities (e.g. Houston, Moscow, Columbus Control Centre, and Kourou) is progressing well, and acceptance of the facility is planned for January 2006.

The Columbus Control Centre (COL-CC) Qualification Review Part 1 (QR-1) has been completed; QR-2 is now planned for the first quarter of 2006. System qualification testing is continuing and a further Columbus System Validation Test has been carried out.

Utilisation planning, payload developments and preparatory missions

The second stage of the Women's International Space Simulation for Exploration (WISE) Bed-Rest Study started in September.

Definition studies are in progress for the human-physiology project proposals that were received following the 2004 Announcement of Opportunity (AO 2004).

Preparations for the 41st ESA Parabolic Flight Campaign planned for 3-14 October, during which 12 physical- and life-sciences and technology experiments will be carried out, are continuing. The Foton-M2 post-flight review will be held from 24-27 October. New payload developments for Foton-M3 are ongoing; confirmation of the launch date, which is currently planned for September 2007, is expected during a review in October.

Experiment-module development efforts for the sounding rockets Texus-EML, whose launch is scheduled for November 2005, and Texus-42 and Maxus-7, whose launches are scheduled for spring 2006, are progressing on schedule.

The Columbus payload rack facilities (Biolab, European Physiology Modules, and Fluid Science Laboratory) as well as the European Drawer Rack (EDR) are all on schedule for delivery of the flight models to Columbus for final integration and integrated testing including the ground segment. The European Modular Cultivation System (EMCS), the -80 degC Freezer (MELFI) and the Percutaneous

Matroshka with ISS Expedition 11 Commander Sergei Krikalev (left) and ISS Expedition 11 Flight Engineer John Phillips. (NASA)

Electrical Muscle Simulator (PEMS) are still integrated in the Multi-Purpose Logistics Module (MPLM) ready for launch on ULF-1.1. The need for pre-flight refurbishment, due to the current Shuttle delay, is under discussion.

Launch of the Portable Glovebox is planned with ATV-1 as an ESA upload; the training models have been delivered and interface testing is currently being performed at NASA.

The Columbus external payloads EuTEF (European Technology Exposure Facility) and SOLAR have been delivered for integration with Columbus and testing is now underway.

The Atomic Clock Ensemble in Space (ACES) Mission System Requirements Review (M-SRR) has been successfully completed.

ISS education

There is still a substantial demand from Member States for education products such as the Education Kits and DVDs.

The selection of future student experiments for the European Long Duration Mission and the ATV Jules Verne mission has been finalised.

The third cycle of the Erasmus/Life in Space Programme (part of the EC projects) was completed in September, with ESA lectures and e-learning links. There have been preliminary contacts with the University of Kiruna (and others) for a possible collaboration on an EC/Erasmus Mundus Masters degree.

Commercial activities

A promotion campaign to attract companies to the ISS Business Club has resulted in three new members.

Commercial proposals for the TERESA project (telemedicine) and the utilisation of ESA assets for training and corporate events, have been received.

Astronaut activities

ESA astronauts T. Reiter and L. Eyharts participated in the Long Duration Mission (Astrolab) Payload Training Session at the European Astronaut Centre (EAC) in August. However, following the Shuttle Return to Flight (LF-1), and the subsequent delay to further Shuttle flights, including the Astrolab mission, both have now been entered into the Expedition 13 crew training flow.

All eight American and Russian Expedition 13 crew members received the first week of ATV increment training at EAC from 22-26 August. With this event, ESA became the third International Partner to enter into operations implementation for the ISS.

P. Nespoli successfully passed the seat liner fit-check for Soyuz-TMA spacecraft. esa

In Brief

ESA Council Meeting at Ministerial Level Charts Europe's Future Direction in Space

On 5 and 6 December in Berlin, the objectives and priorities for Europe in space for the coming years were discussed at a Meeting of the ESA Council at Ministerial Level, chaired by Minister Brinkhorst of The Netherlands.

The Ministers in charge of space activities in the Agency's 17 Member States and Canada met to deliberate on a plan for discovery and competitiveness for Europe in space, and to decide on the relevant future programmes. They came together to take decisions that will provide Europe and its citizens with a competitive space sector able to lead the search for new discoveries, guarantee access to strategic data and new services, and consolidate Europe's share of the worldwide commercial market.

With that aim firmly in mind, during their two-day meeting they endorsed the continuation of a set of ongoing programmes and agreed to undertake major new initiatives designed to give Europe a clear vision and tangible means to strengthen its space exploration and exploitation activities.

The Ministers appreciated the efforts already made to heighten European citizens' awareness of space activities and their benefits, thanks in particular to the success of recent ESA scientific missions such as Huygens and Mars Express. These missions, together with a series of successful Ariane-5 launches, have confirmed once again that by combining its skills and efforts Europe is able to succeed in the most challenging of enterprises and achieve a level of excellence for discovery and innovation in the global arena.

The Ministers also noted the increase in the scale and quality of the Agency's relations with its international partners. They recognised that the global scenario in the space sector is evolving rapidly, in particular with increasing numbers of players

photo esa/s. corvaja

photo esa/s. corvaja

mastering major space technologies and offering competitive conditions for civil and dual-use applications.

The Ministers reaffirmed the strategic importance of Europe continuously improving its scientific, technological and industrial capabilities in the space field, to enable it to better respond to the expectations of its citizens concerning the environment, quality of life and security. They noted that European industry has encountered considerable difficulties in recent years, resulting from a significant downturn in the commercial market, as well as competition from industries operating on the basis of lower production costs. They also took note of the measures taken by industry to improve its position, through difficult reorganisational and consolidation processes, which have led to a reduction in the volume and distribution of European capabilities.

A major political step was achieved with the approval of an overall European launcher policy ensuring coherence between the launcher and satellite fields.

The Ministers recognised that it is crucial to continuously foster European cooperation on space activities by further developing an overall European Space Policy encompassing ESA, the European Union, plus national and industrial programmes, and to allocate the available resources and capabilities to common European initiatives, so as to achieve the critical mass needed to face the worldwide competition.

Decisions Taken on Programmes and Activities

On the programmatic side, the Ministers took decisions concerning the Agency's mandatory activities (scientific and basic) and optional programmes (Earth observation, telecommunications, satellite navigation, human spaceflight, microgravity, exploration, launchers). Those decisions confirm the ESA countries' commitment to boosting progress in space science and to being at the leading edge of discovery, thus supporting the development of competitive services and future applications for the people of Europe.

The specific decisions taken concern:

– The Agency's Mandatory Activities: the Level of Resources for 2006-2010 (Scientific Programme and basic activities)

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....a successful conclusion

photo esa/s. corvaja

....and the closing Press Conference

A detailed report on the Berlin Ministerial Meeting, and the six Resolutions that were passed, will appear in ESA Bulletin No. 125

– Continuation of Ongoing Programmes, with subscriptions for:
  - the Earth Observation Envelope Programme
  - the International Space Station Exploitation Programme Period-2 and the European ELIPS Programme Period-2
  - launcher evolution
  - Advanced Research in Telecommunications Systems (ARTES), focusing on technologies, applications and mission demonstrations.

– New Programmes, with subscriptions for:
  - the Global Monitoring for Environment and Security (GMES) space component, which is a key European contribution to the Global Earth Observation System of Systems (GEOSS) initiative
  - the European Space Exploration Programme 'Aurora', comprising its first Exploration mission ExoMars and a Core Programme to prepare for future exploration missions
  - the preparation of future launchers
  - the General Support Technology Programme (GSTP), for the preparation of new dedicated technology programmes, focusing on the development of technologies with a view to non-dependence and security, and aimed at preparing and demonstrating new concepts such as formation-flying satellites in order to carry out missions of strategic and economic value to space science, Earth observation and new – in particular security-related – areas.

Third Space Council Focuses on Environment and Security

The third meeting of the Space Council – a joint and meeting of the ESA Council at Ministerial Level and the European Union Competitiveness Council (Internal Market/ Industry/ Research) – took place in Brussels on 28 November. The Space Council was established to coordinate and facilitate cooperative activities between the European Community and ESA through their Framework Agreement, which was adopted in 2003 and entered into force in May 2004. The first meeting of the Space Council took place in Brussels on 25 November 2004, the second in Luxembourg on 7 June 2005.

At this third meeting, chaired jointly by Lord Sainsbury of Turville, UK Minister for Science and current Chair of the EU Competitiveness Council, and German Secretary of State Georg Wilhelm Adamowitsch, representing the German Minister for Economy and Technology Michael Glos, then Chair of the ESA Council at Ministerial Level, the Ministers stressed the strategic importance of the initiative for Global Monitoring for Environment and Security (GMES).

GMES is an EU-led initiative, the space component of which will be developed by ESA. The objective is to provide Europe with timely and reliable information on environmental and security issues on a sustainable basis, in support of public policy-makers' needs. Its implementation will see the early deployment of three fast-track services for emergency response, land monitoring, and marine services, which are due to enter into operation by 2008. Other services will follow based on a deployment plan covering the years 2009-2013.

At their Brussels meeting, the Ministers emphasised the importance of maintaining an autonomous European Earth-observation capacity to support political decision-making, and the significance of the international dimension of GMES and its status as the main European contribution to the worldwide Global Earth Observation System of Systems (GEOSS).

To ensure the continuity of data needed to establish the GMES operational services and to avoid duplication, the Ministers requested that the best use be made of existing and planned satellite and in-situ systems at European and national level. To this end, they invited national Agencies and European organisations (such as Eumetsat), which already have or are in the process of building up assets and capacities that could be valuable for GMES, to make those capacities available for the initiative under appropriate conditions.

After the meeting, Lord Sainsbury remarked that: *"Environmental monitoring is more important than ever before. GMES has the potential to bring together existing and new technology - helping us to better understand and protect our planet. Today, Europe's space Ministers took a significant step towards achieving this."*

The German State Secretary, Georg Wilhelm Adamowitsch, said: *"With the Global Monitoring for Environment and Security Initiative (GMES), the second EU flagship programme, after the satellite navigation system Galileo, Europe is building up a strategic global monitoring capacity. This will allow Europe to decide, on the basis of independent information, on issues such as the environment, sustainable development, natural resources and the security of its citizens. Germany will contribute to GMES not only via the EU and ESA, but also through national satellite missions and data-processing structures."*

European Commission Vice-President Günter Verheugen, in charge of enterprise, industry, competitiveness and space matters, added: *"I am very happy that at this meeting of the Space Council the directions the Commission proposed for the global monitoring system GMES were endorsed. GMES is the result of excellent cooperation between the Commission and ESA. This demonstrates our capacity to build an effective European Space Policy".*

ESA's Member States were due to subscribe to the Agency's contribution to the programme covering the development of the GMES space component at the ESA Council Meeting at Ministerial Level in Berlin on 5/6 December (see page 82 for latest news), while the Commission intends to allocate a major portion of its Seventh Framework Programme funding earmarked for space to GMES.

esa

Hunting dark matter in the Alps

Fifty-one students from ESA's Member States attended the 29th annual Alpbach Summer School on the theme "Dark Energy and Dark Matter", held from 19 to 28 July.

Scientists think that dark matter and energy represent about 95% of our Universe. Confronted with this astonishing figure, research laboratories and space agencies are busy studying the means to make progress in this field.

The 2005 Alpbach Summer School was devoted to this topic. Lectures provided students with the scientific results and theories, the science goals of planned missions and other technical details. Workshops were organised with teams working to identify a specific astrophysical problem linked with dark matter and energy and develop technical concepts to address it. In this way, participants could find practical applications for the knowledge gained from the lectures and develop organisational and team skills as well as creativity. They had to learn to work as a group, to use the best capabilities of each member, and to propose an exciting mission, in order to learn more about the "dark" side of the Universe.

Participants were divided into four teams. By the end of the workshop, the teams had addressed the instrumentation, showing that it could meet the scientific requirements, but also the spacecraft's construction, its subsystems, its orbit and its launch, together with a cost estimate. The results of these mission studies were presented to an expert review panel during the final day.

Teamwork is an integral part of the workshop

The four missions defined and developed by the students concentrated on:

- B-mode polarisation measurement of the cosmic microwave background and the Sunyaev Zeldovich Effect as a probe of matter distribution via clusters of galaxies.
- IR-optical observations of weak lensing and cosmic shear and the mass function of galaxy clusters using X-rays and IR-optical data.
- High-precision measurements of the w parameter using large X-ray, optical and IR telescopes.
- High-redshift gamma-ray-burst afterglows as a probe of the Lyman-α forest and hence the matter distribution over redshift.

An international jury chaired by Catherine Turon, Professor at the Observatoire Paris-Meudon and Chair of ESA's Astronomy Working Group, assessed the work of the teams.

The Alpbach Summer School is organised by the Austrian Aeronautics and Space Agency in cooperation with ESA and the national space authorities of its Member States, with the support of the International Space Science Institute (ISSI).

Participants of the 29th Alpbach Summer School

By 'GIOVE'

Dutch Minister Karla Peijs and the freshly christened GIOVE satellite

The first two Galileo satellites are going to be called GIOVE - standing for 'Galileo In-Orbit Validation Element'. The satellites are currently being prepared to take the first step of the In-Orbit Validation phase, leading to the full deployment of Galileo, the European satellite navigation system. The name GIOVE was announced by Karla Peijs, the Dutch Minister of Transport, Public Works and Water Management, on Wednesday 9 November, at ESA's ESTEC centre in Noordwijk (The Netherlands).

GIOVE A is currently undergoing final preparations in the ESTEC test facilities prior to being sent to the Baikonur cosmodrome in Kazakhstan, from where it will be launched by a Soyuz rocket at the end of December 2005. The second satellite, GIOVE B, is currently undergoing final integration testing in the Alenia Spazio facilities in Rome (Italy) and will be launched later in 2006, also from Baikonur.

Naming the satellites GIOVE pays fitting tribute to the achievements of Galileo Galilei (1564-1642) not only in the field of astronomy, but also navigation. On 7 January 1610, as one of the first to turn his telescope skywards, the famous scientist discovered the first four satellites of the planet Jupiter - "Giove" in Italian. These were later named Io, Europa, Ganymede and Callisto. Galileo realised that the formation of these four satellites, whose eclipses are frequent and visible, provided a clock whose face could be seen from every point on the Earth.

Tables describing the motion of the first four Jovian satellites to be discovered were used to determine longitude at sea and on land. Galileo's method of determining longitude by observing the eclipses of Jovian satellites heralded a revolution in navigation, geodesy and cartography in the 17th and 18th Centuries.

Almost 400 years on, another revolution in navigation is on its way, with the advent of Europe's Galileo positioning infrastructure. GIOVE satellites A and B mark the start of in-orbit validation of this new system. They will be followed by four other satellites, to be launched in 2008.

This first step in the Galileo programme, known as the Galileo System Test Bed (GSTB), involves the launch of two satellites for in-orbit testing of critical technologies such as atomic clocks and novel navigation signals specifically developed for the programme. It will also secure the frequencies allocated to Galileo by the International Telecommunications Union (ITU).

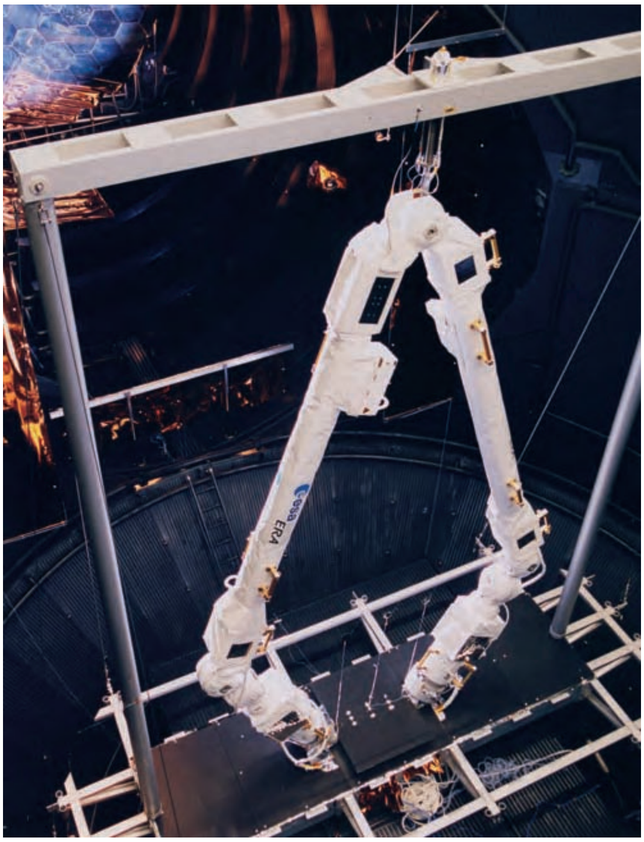
GIOVE A is being developed by Surrey Satellite Technology Ltd. (UK). It is designed to fulfil the following main objectives: secure frequency filings, validate key technologies such as rubidium clocks, characterise the orbital environment and deliver signal broadcasting using two transmission channels in parallel.

GIOVE B, which is designed to fulfil similar objectives, is being developed by Galileo Industries, a European consortium comprising Alcatel Space Industries (F), Alenia Spazio (I), Astrium GmbH (D), Astrium Ltd. (UK) and Galileo Sistemas y Servicios (E). This satellite also provides complementary features such as a passive hydrogen-maser clock and simultaneous three-channel transmission.

European Robotic Arm to be launched on Proton

On 27 October, ESA's Director of Human Spaceflight, Microgravity and Exploration, Mr Daniel Sacotte, signed a contract for the launch preparations and first operations of the European Robotic Arm (ERA) on the International Space Station (ISS). The contract, worth 20 million Euro, was signed with Dutch Space, the Industrial Prime Contractor leading an industrial consortium of European companies.

Mr Daniel Sacotte (left), ESA's Director of Human Spaceflight, Microgravity and Exploration, and Mr Ben Spee, Director of Dutch Space, sign the ERA contract



The European Robotic Arm in ESTEC's Large Space Simulator

Originally ERA was scheduled for launch on a Space Shuttle, together with the Russian Science and Power Platform, which was intended to become its home base for operations on the station. Last year Russia introduced the Multipurpose Laboratory Module (MLM) as a new module to be added to the ISS and proposed that ERA could also be installed, launched and operated on the MLM. Since the MLM is designed for launch on a Russian Proton rocket, ERA will no longer be carried into space on a US Space Shuttle, but aboard Proton. This requires some technical, operational and contractual re-arrangements between the parties involved.

Under the contract now signed, the consortium led by Dutch Space will requalify the ERA flight and ground segment for a launch on Proton, and will deliver the ERA hardware to Russia. The consortium will also implement ERA training for the Russian cosmonaut instructors and will support the training of the Russian cosmonauts in ERA operations. It will also support ground processing and launch preparations in Russia. This will take place at various locations: at the Khrunichev premises, where the Proton launcher is built; at Energia, which together with Khrunichev builds the Multipurpose Laboratory Module; at the Gagarin Cosmonaut Training Centre in Star City; and at the launch site in Baikonur.

Under the new contract, in-orbit validation of the robotic arm is the final activity to be performed by the consortium. This involves participation in, and analysis of, the first operation of ERA after launch when the arm's performance will be validated under real space and operational conditions.

The European Robotic Arm is over 11 metres long and weighs 630 kg. It is capable of moving payloads weighing up to 8000 kg and is able to position them with an accuracy of 5 mm. It will be launched from Baikonur to the ISS on a Russian Proton rocket in November 2007.

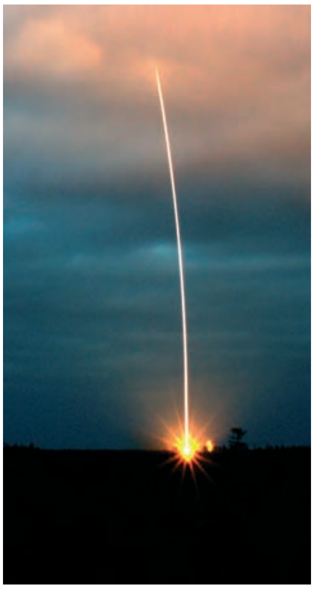
With its seven joints and an impressive concentration of tools and electronics, the arm can move hand-over-hand between fixed base points around the Russian ISS segments and will be used for a wide variety of tasks.

ERA can be used to install, remove and deploy solar arrays and radiators and, via the new Russian equipment airlock, can transfer small payloads from inside to outside the ISS and vice versa. This will reduce the time needed for extravehicular activities (EVAs) to the absolute minimum, and save the crew from having to perform preparatory tasks like carrying payloads out of or into the ISS. Another important task for ERA will be to transport astronauts from the airlock to the positions where they have to perform their work, which again saves time and effort. ERA is equipped with four cameras and lighting units, which provide for thorough inspection of the ISS.

The European Robotic Arm can be operated from inside the ISS. However, an astronaut outside the Station can also drive the arm while performing an EVA.

ERA will be operated in the harsh environment of space for at least 10 years.

CryoSat Mission lost due to launch failure



On 8 October Yuri Bakhvalov, First Deputy Director General of the Khrunichev Space Centre officially confirmed on behalf of the Russian State Commission that the launch of CryoSat ended in a failure due to an anomaly in the launch sequence.

Preliminary analysis of the telemetry data indicates that the first stage performed nominally. The second stage performed nominally until main engine cut-off was to occur. Due to a missing command from the onboard flight control system the main engine continued to operate until depletion of the remaining fuel. As a consequence, the separation of the second stage from the upper stage did not occur. Thus, the combined stack of the two stages and the CryoSat satellite fell into the sea in the nominal drop zone north of Greenland with no consequences for populated areas.

An investigating commission has been established by the Russian State authorities to further analyse the reasons for the failure, and the results are expected within the next weeks. This commission will work in close cooperation with a failure investigation board consisting of Eurockot, ESA and Khrunichev representatives.

CryoSat never made it to space

PROBA going strong for four years

PROBA 1, ESA's Project for On-Board Autonomy and one of the most advanced small satellites ever flown in space, completed four successful years in orbit on 22 October 2005. All of its functions and equipment are performing nominally.

PROBA 1 has supported earth-observation campaigns with its main instruments CHRIS (Compact High Resolution Spectrometer) and the HRC (High Resolution Camera). Data on radiation and in-orbit debris environments are also routinely provided by its SREM and DEBIE instruments. A further extension of 1 year for the operations of PROBA 1 from the ESA Operations Centre in Redu (B) is envisaged.

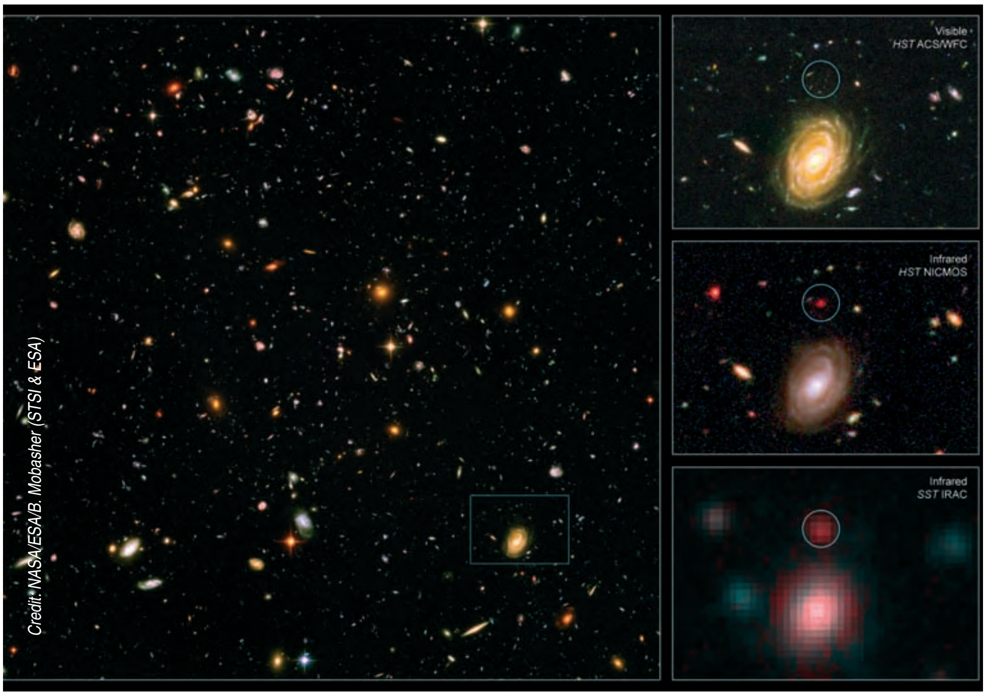
PROBA performs autonomous guidance, navigation, control, onboard scheduling and payload resources. Management measuring just 60x60x80 cm^3 and weighing only 94 kg, PROBA aims to use and demonstrate a variety of automatic functions, both onboard the spacecraft and in the mission's ground segment.

Two other ESA missions celebrated their anniversaries in October: the scientific solar observatory SOHO looks back on 10 highly successful years and the Ulysses mission celebrated its 15th anniversary in space.

Recent CHRIS image of Liverpool in the UK

'Big baby' galaxy found in newborn Universe

The NASA/ESA Hubble Space Telescope and NASA's Spitzer Space Telescope have teamed up to 'weigh' the stars in distant galaxies. One of these galaxies is not only one of the most distant ever seen, but it appears to be unusually massive and mature for its place in the young Universe.



The NASA/ESA Hubble Ultra-Deep Field image with the 'big baby' galaxy HUDF-JD2 at lower right. The three insets on the right show the galaxy, marked with a circle, at different wavelengths from Hubble and Spitzer observations

This has surprised astronomers because the earliest galaxies in the Universe are commonly thought to have been much smaller agglomerations of stars that gradually merged together later to build the large majestic galaxies like our Milky Way. *"This galaxy appears to have 'bulked up' amazingly quickly, within a few hundred million years after the Big Bang,"* said Bahram Mobasher of the European Space Agency and the Space Telescope Science Institute, a member of the team that discovered the galaxy. *"It made about eight times more mass in terms of stars than are found in our own Milky Way today, and then, just as suddenly, it stopped forming new stars. It appears to have grown old prematurely."*

The galaxy, HUDF-JD2, was pinpointed among approximately 10 000 others in a small patch of sky called the Hubble Ultra-Deep Field (HUDF). Thanks to the Hubble Space Telescope, this area is captured in the deepest images of the Universe ever made by mankind at optical and near-infrared wavelengths.

The galaxy was detected using Hubble's Near-Infrared Camera and Multi-Object Spectrometer (NICMOS), but at near-infrared wavelengths it is very faint and red. It is also within the deepest survey from the Spitzer Space Telescope, the Great Observatories Origins Deep Survey (or GOODS). The galaxy is believed to be about as far away as the most distant galaxies and quasars now known. The light reaching us today began its journey when the Universe was only about 800 million years old.

Scientists studying the HUDF found this galaxy in Hubble's infrared images and expected it to be a very young 'baby' galaxy, similar to others known at comparable distances. Instead, they found a 'teenager', much bigger than other galaxies known from this early cosmic era, and already very mature.

Hubble's Advanced Camera for Surveys (ACS) does not see the galaxy at all, despite the fact that the HUDF is the deepest image ever taken in optical light. This indicates that the galaxy's blue light has been absorbed by travelling for millions of light-years through intervening hydrogen gas. However, the big surprise was how much brighter the galaxy is in images from Spitzer's Infrared Array Camera (IRAC), which easily detects it at wavelengths as much as 15 times longer than those seen by Hubble.

Spitzer's IRAC is sensitive to the light from older, redder stars, which should make up most of the mass in a galaxy, and the brightness of the galaxy suggests that it is very massive indeed. Previous observations have revealed evidence for mature stars in more ordinary, less massive galaxies at similar distances. Other joint Spitzer and Hubble analyses identify more galaxies nearly as massive as the Milky Way, seen when the Universe was less than one thousand million years old.

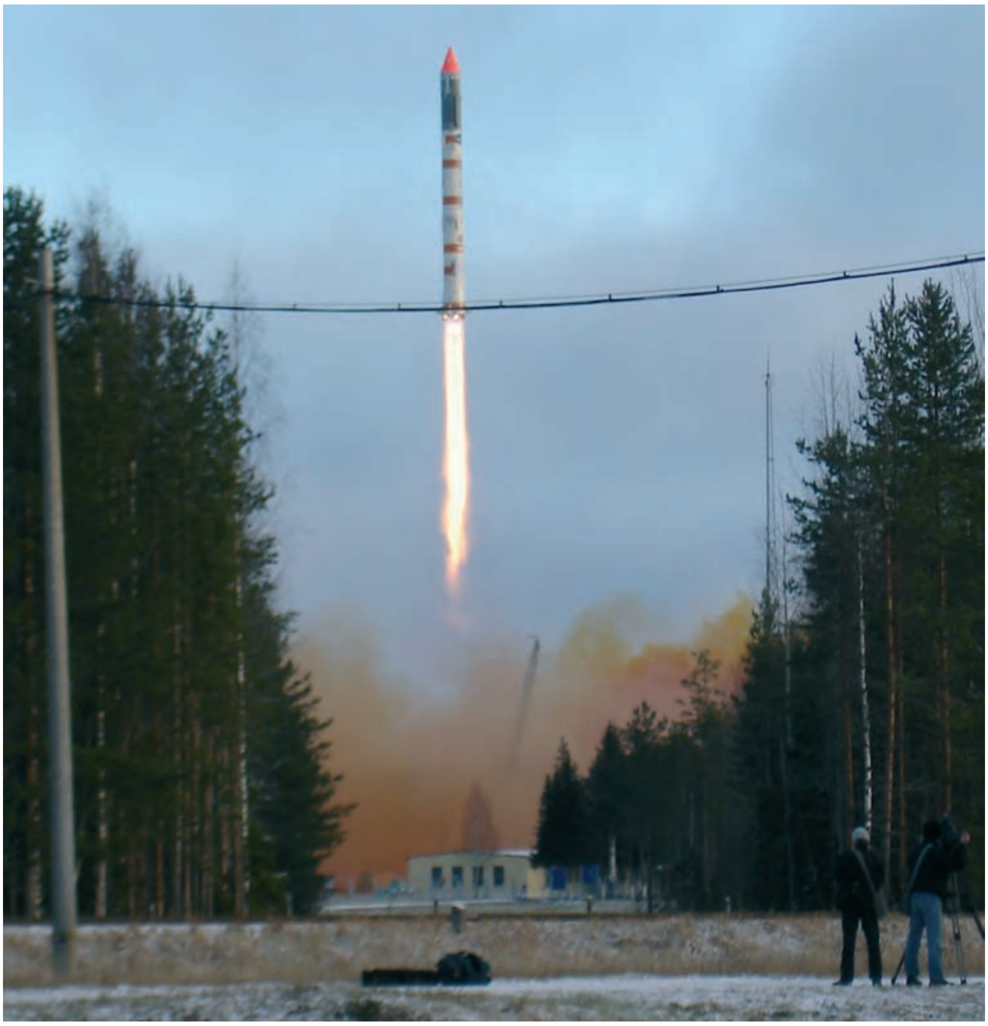
The new observations by Mobasher and his colleagues dramatically extend this notion of surprisingly mature 'baby galaxies' to an object which is perhaps ten times more massive, and seems to have formed its stars even earlier in the history of the Universe. esa

SSETI launched but lost

SSETI Express, a low-Earth-orbit spacecraft designed and built by European university students under the supervision of ESA's Education Department, was successfully launched on 27 October from the Plesetsk Cosmodrome on a Russian Kosmos 3M launcher and sent its first signals to the ground control centre at the University of Aalborg (DK). It successfully deployed two of its three cube sats before going into safe mode because of a failure in the electrical power system onboard the spacecraft that prevents the batteries from charging, resulting in shutdown of the satellite.

Currently, the student teams continue to investigate the situation and assess the chances of recovery.

"Even if we don't recover contact with SSETI Express, it was still a very worthwhile mission for everyone. We will take many lessons learned on to our next educational satellite project, SSETI ESEO", said Roger Elaerts, Head of ESA's Education Department.



The first European student satellite blasting off into low-Earth orbit from Plesetsk

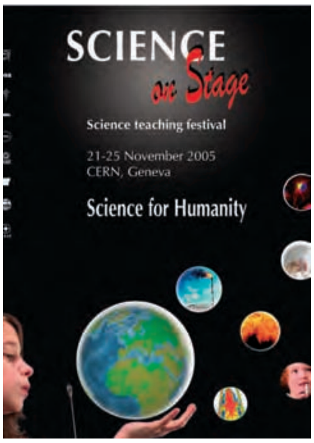
SSETI Express (SSETI being the acronym for Student Space Exploration and Technology Initiative) is a small spacecraft, similar in size and shape to a washing machine, weighing about 62 kg and with a 24 kg payload. Onboard the student-built spacecraft were three pico-satellites. In addition to acting as a test bed for many designs, including a cold-gas attitude-control system, SSETI Express was also designed to take pictures of the Earth and to function as a radio transponder.

More than a hundred students from 14 countries and 23 universities worked together via the Internet to jointly design, build and test the satellite. The Student Space Exploration and Technology Initiative, launched by ESA's Education Department in 2000 to get European students involved in real space missions, gives students practical hands-on experience and encourages them to take up careers in space technology and science.

"Naturally, the SSETI teams are disappointed that we lost contact, but the mission has still been a success from both an educational and a technical standpoint", said Project Manager Neil Melville. *"The main goal of the mission was to educate students by having them involved hands-on in all the different aspects of a space mission, and now we really have experienced everything"*.

The CubeSats Xi-V and UWE-1 are alive and well; the status of NCube-2 has yet to be confirmed. Stable two-way communications between the ground station and SSETI Express was established and both the Aalborg University as well as many radio amateurs all over the world downloaded a significant amount of house-keeping data.

Science teachers take centre stage



Science on Stage shows are always hands-on.....

Would you know how to turn a bucket into a seismograph, how to make a model of a DNA double helix from cans and bottles – all to scale – or simulate a human eye with the help of a shampoo bottle? More than 500 science teachers from 29 countries across Europe left with hundreds of new ideas for their classroom after a week of experiments, shows and workshops at Science on Stage at CERN, the European Organization for Nuclear Research in Geneva, Switzerland. They are probably trying them out in class at this very moment.

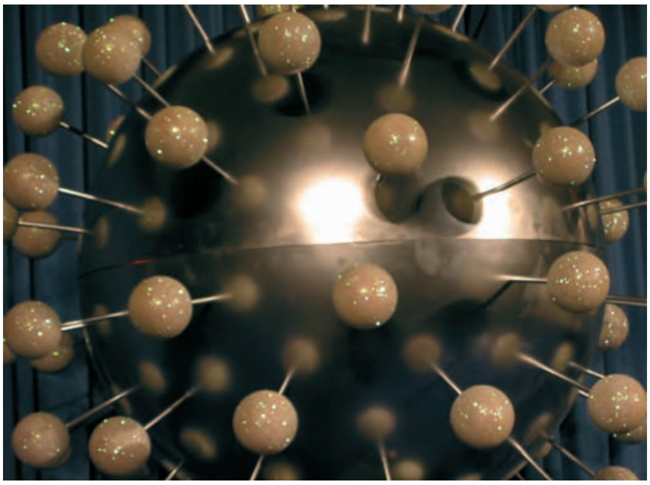
Science on Stage is the follow-up project to Physics on Stage, a science teaching festival organised by the seven research organisations of the EIROforum and supported by the European Commission. While the first three events concentrated on making physics teaching more attractive, the festival now also covers biology, chemistry and mathematics. Its formula hasn't changed however. The heart and soul of the 5-day festival is the "science teaching fair", a big marketplace where every country has a booth and teachers could spend all day showing their experiments and projects and getting inspired by their colleagues. They also meet in workshops to discuss trends in teaching science, learn more about current research topics or exchange ideas for school projects, and every day there are performances and presentations that approach science from a theatrical or artistic point of view.

British delegate David Featonby shows magic tricks based on physics.

"Stacks of maths", a Spanish maths show, proves that $(a+b)^2$ is indeed $a^2 +2ab +b^2$

Two Austrian delegates demonstrate the physics of cooking

"This is wonderful," said Melanie Sondershaus, a teacher from Germany who came to Geneva to present her interdisciplinary project on Einstein. *"Five days are not enough to see everything!" "It's a great opportunity to meet other teachers and get inspired,"* agreed a Romanian colleague. For the first time, Science on Stage had themed days ranging from Space and Astronomy Day, Einstein Day and Life Sciences Day to Sustainability and Technology and Science Day. Many countries



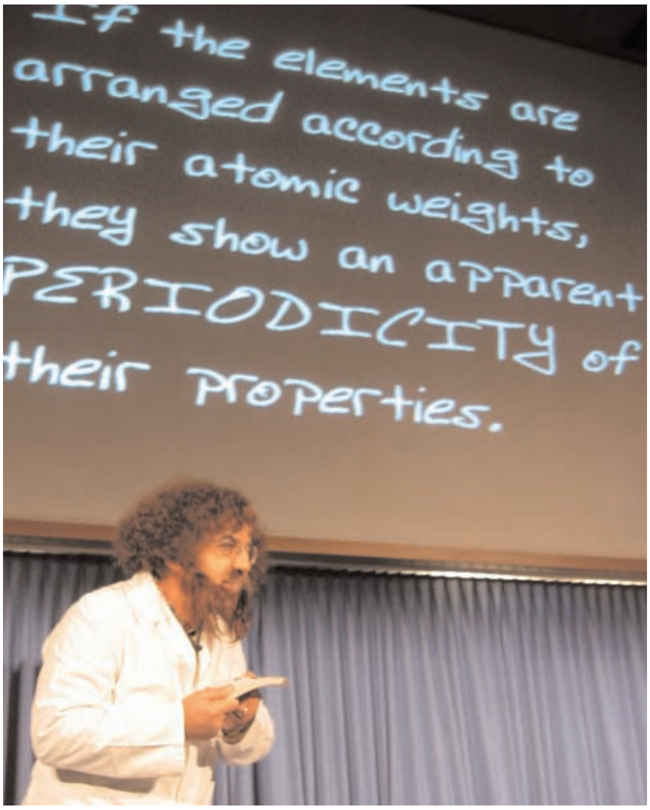
A model of a virus

A student on the Hungarian stand demonstrates their model of the nervous system

organised their booths accordingly, and at the end of each day science journalist Myc Riggulsford got the most inspiring projects up on a demonstration stage to wrap up the day's theme in an hour-long show.

An international jury selected the most inspiring projects for the European Science Teaching Awards: Seven teachers won visits to organisations or book vouchers, each donated by one of the seven EIROforum oganisations; the four winners of Euro prizes – money that will go into developing the project further and making it more widely known – went to Tobias Kirschbaum and Ulrich Janzen from Germany, who received 1000 Euros for his reconstruction of an ancient Chinese Seismograph, and to Jerzy Jarosz and Aneta Szczygielska from Poland, who got 2000 Euros to develop their model of the human cardio-vascular system. The project " Physics is cool!" - The Box of Experiments, presented by Wim Peeters from Belgium, won 3000 Euros. The overall winner with a prize of 4000 Euros was French teacher Catherine Garcia-Maisonnier with "Building a Weather Balloon at School".

The next Science on Stage will take place in Grenoble in April 2007.



The Italian performance "Elements: a Magic Chemical Show".

Nanna Kristensen from Denmark won a prize for her project "Jewellery is Chemistry".

Key ESA/EC agreement on Earth Observation data signed

An agreement on space-based information services and access to, and provision of, Earth Observation data was signed on 26 October by ESA and the Joint Research Centre of the European Commission. The signature took place at ESRIN, the ESA Earth Observation Centre in Frascati, Italy.

Volker Liebig, Director of ESA's Earth Observation Programme, signed the agreement on the 'Specific arrangement concerning the development of space-based information services and the access to and provision of Earth Observation data' on behalf of the ESA Director General, Jean-Jacques Dordain, while Freddy Dezeure, Director of Programme and Resource Management of the EC Joint Research Centre (JRC), signed on behalf of the Commission.

"This document defines the respective tasks and responsibilities of ESA and the JRC for a strong coordinated approach to the use of Earth Observation data in support of the information services of the EU. This will strengthen cooperation with the EU and secure the GMES (the joint EC-ESA initiative for Global Monitoring for Environment and Security) as a major information management and policy support tool for Europe," said Volker Liebig.

There are four fields in which ESA and the JRC undertake to work together in close cooperation:

- coordinating the use of Earth Observation satellite missions, in which they have a common interest
- developing services aimed at meeting the specific needs of end users (in particular in EU services)
- optimising access to support information for EC actions
- coordinating and providing technical support with regard to Earth Observation activities within the European initiative INSPIRE (INfrastructure for SPatial InfoRmation in the European Union), whose objective is to harmonise the methods employed by Member States to collect data on the geographical characteristics of their own territories.

This agreement gives JRC, a key partner in implementing the European GMES initiative, access to a wider and more continuous data set from a large variety of Earth Observation satellites. As a provider of technical support to the services of the EC, JRC is ideally placed to foster pre-operational and operational services, in support of the EU policies and services being developed through GMES. ESA is playing the role of lead agency in the development of space systems, particularly in support of the GMES initiative.

The document signed at ESRIN puts into effect many of the actions envisaged in the 'Framework Agreement between the European Union and the European Space Agency' in the field of Earth Observation. This agreement, signed on 25 November 2003, laid the foundations for significant strengthening of the European space sector, by promoting the implementation of a global space policy to secure independent and cost-effective space capabilities for Europe, to be developed in line with EU policies on sustainable development, economic growth and employment.

Volker Liebig, Director of ESA's Earth Observation Programme and Freddy Dezeure, Director of Programme and Resource Management at the EC Joint Research Centre (JRC)

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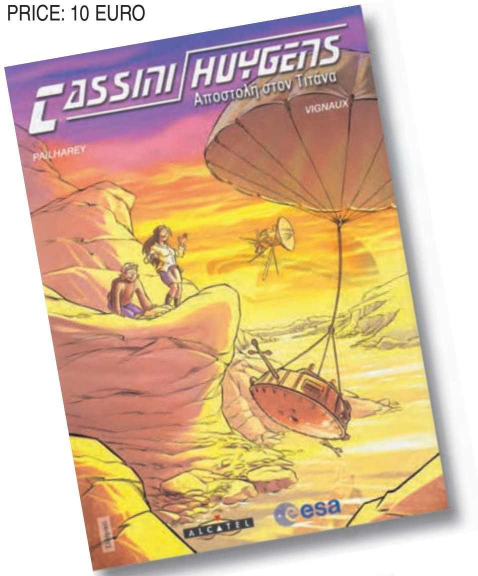

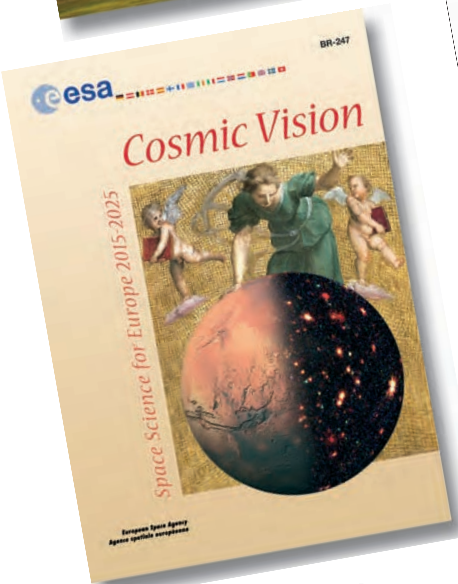

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