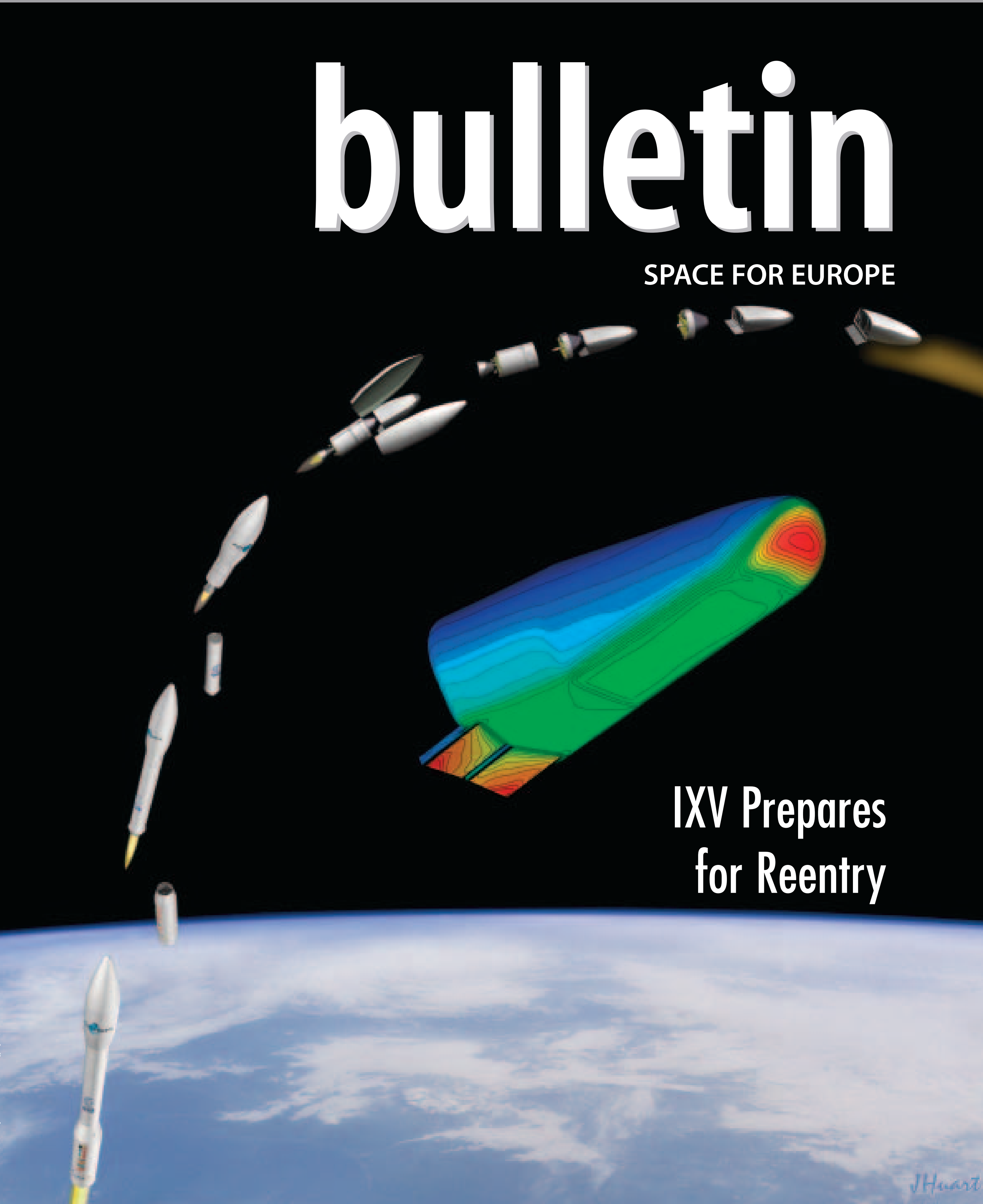
number 128 - november 2006

bulletin

SPACE FOR EUROPE



IXV Prepares for Reentry

European Space Agency
Agence spatiale européenne

european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European space organisations – the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Canada is a Cooperating State.

In the words of its Convention: the purpose of the Agency shall be to provide for and to promote for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems:

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by coordinating 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.

The Agency is directed by a Council composed of representatives of the Member States. The Director General is the chief executive of the Agency and its legal representative.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany.

ESRIN, Frascati, Italy.

Chairman of the Council: S. Wittig

Director General: J.-J. Dordain

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agence spatiale européenne

L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée – l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) – dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la Finlande, la France, la Grèce, l'Irlande, l'Italie, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaumi-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.

Selon les termes de la Convention: l'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

L'Agence est dirigée par un Conseil, composé de représentants des Etats membres. Le Directeur général est le fonctionnaire exécutif supérieur de l'Agence et la représente dans tous ses actes.

Le SIEGE de l'Agence est à Paris.

Les principaux Etablissements de l'Agence sont:

LE CENTRE EUROPEEN DE RECHERCHE ET DE TECHNOLOGIE SPATIALES (ESTEC), Noordwijk, Pays-Bas.

LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.

ESRIN, Frascati, Italy.

Président du Conseil: S. Wittig

Directeur général: J.-J. Dordain

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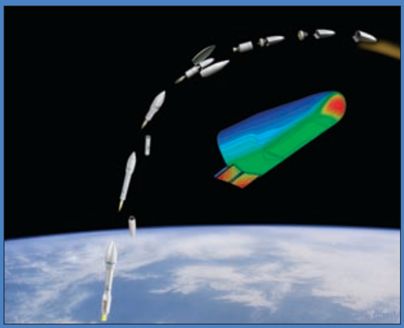
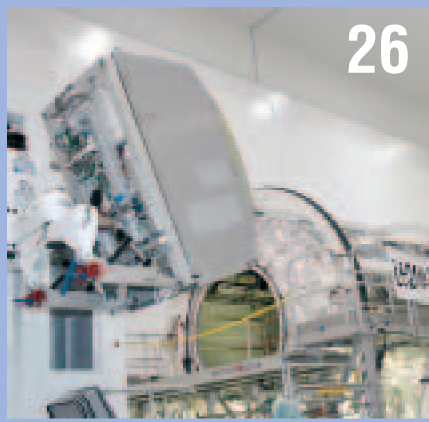


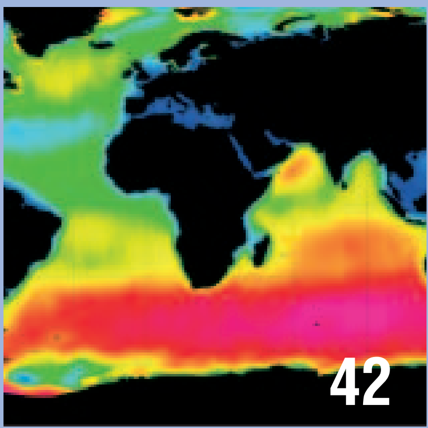
The Intermediate eXperimental Vehicle (IXV) is helping to build Europe's expertise in atmospheric reentry technology

Agenda 2011
Setting the Agenda for Europe's Space Agency

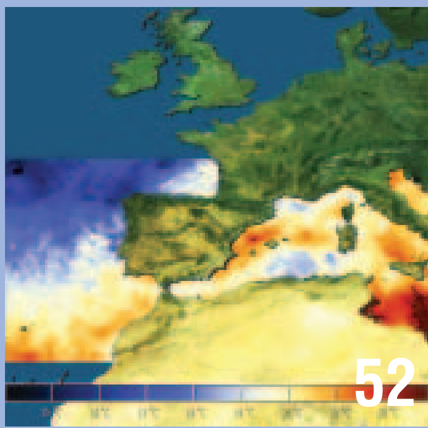
Unveiling the Universe
Two Missions Revealing the Cold Universe



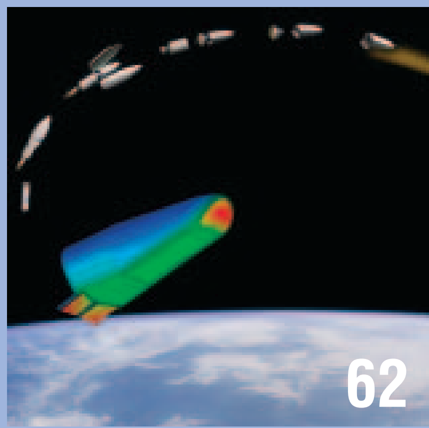
MELFI Ready for Science
ESA's Cryogenic Freezer Begins Work Aboard the International Space Station



Taking the Measure of Earth
Progress in Radar Altimetry



Healing the Earth
Supporting Environmental Conventions



IXV
The Intermediate eXperimental Vehicle

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Agenda 2011

A Document by the Director General and Directors

The Agency's *Agenda 2011*, released in October 2006, presents an evolving framework of action for achieving the wide-ranging objectives of Member States and for adapting ESA to a changing environment. *Agenda 2007*, presented in mid-2003, led to significant advances in less than 3 years, including a successful Ministerial Council at the end of 2005.

The plan of actions supporting *Agenda 2011* will be detailed and formalised in the *ESA Long-Term Plan 2007–2016*, updated by the Council annually. *Agenda 2011* is defined within the framework of the European Space Policy (ESP); indeed, it is an important input to that policy. In turn, its implementation will take into account the ESP as endorsed in mid-2007.

Overall Objectives and Priorities

The ESP will provide a European Union (EU) dimension to the space path followed for 30 years by ESA Member States. Conversely, this new policy will introduce a space dimension into the political ambitions of Europe as a global actor. The overall objectives of the next 5 years will serve these new dimensions and must therefore consolidate "*ESA as a global space agency, instrumental for Europe in serving the policies of its Member States and the EU, developing a competitive economy, and indispensable to the world in contributing to global policies and to the increase of knowledge*".

ESA is recognised as a globally-important agency in its core activities of science and exploration, human spaceflight and partnership in the International Space Station (ISS), and launchers. It has already developed important operational capabilities in meteorology and climate monitoring, acted as a catalyst for European space telecommunications and is jointly developing new applications (Galileo and Global Monitoring for Environment and Security/GMES) with the EU. The objective now is to develop beyond this, to make ESA a model for underpinning the use of space in the world today and specifically in the context of Europe's growing needs.

In order to reach this objective, three key priorities will drive ESA's actions:

Consolidation of steps taken at the 2005 Ministerial Council towards discoveries and competitiveness

The absolute priority in the coming years is to consolidate the capabilities and competitiveness of European industry. Without space manufacturers and service-providers, Europe cannot serve any of its ambitions. Significant investments in new and advanced technologies have to be made urgently.

Development and promotion of integrated applications (space & non-space) and integration of security in the ESP

New concepts, new capabilities and a new culture have to be developed in order to respond to a multitude of needs from users who are not yet familiar with space systems. The strong coordination and efficient exploitation of synergies have to be organised between national, intergovernmental and EU resources and capabilities, as well as between civil security and defence applications.

Evolution of ESA

The Agency's evolution must be accelerated in order to improve our global effectiveness, reinforce the motivations for Member States to invest in space, and prepare ESA for new members and a new relationship with the EU. The first step should be taken within 2 years, to adapt accordingly the industrial policy rules and procedures, decision-making, funding mechanisms and coordination between ESA and national programmes, resources and industrial policy. It is expected that, following such adaptation, there will be at least 22 Member States by 2011. A longer-term goal is for ESA to evolve towards the EU by 2014.

Programmes

Core activities to be proposed to the 2008 Ministerial Council include:

Space science: opening the door to new missions by introducing flexibility; astronomy missions in deep-space orbits; exploiting the synergies of Solar System missions with exploration (see below), and of fundamental physics missions with the ISS.

Earth science: focus on global change; one mission per year; increase cooperation with international partners and technology programmes; preparation of applications programmes.

Exploration: begin development of ExoMars follow-on mission; choose scenario to make Europe an indispensable partner: Moon orbit infrastructure (telecommunications, navigation), participation in human transportation (in conjunction with the launcher programme), synergy with space science missions; stimulate international cooperation taking into account the lessons learned from the ISS partnership.

Human spaceflight: based around the ISS, optimising the benefit for Member States through efficient use of research activities and applications.

Agenda 2011

	2006	2007	2008	2009	2010	2011
			CMIN 08	**EU Budget Revision**		**CMIN 11**
Programmes and Budgets	Implementation of CMIN 05 programmes Preparatory activities for integrated applications	Preparation of programme proposals for CMIN 08 Decision on GMES phase 2 of segment 1 European Space Policy	Major decisions on: – Level of Resources – Exploration – Technology – GMES segment 2 – Launchers – ISS Exploitation – Preparatory Prog on integrated applications	Complementary decisions on: – GMES – GNSS Implementation of CMIN 08 programmes	Preparation of programme proposals for CMIN 11	Major decisions on: – Level of Resources – Launchers – Telecom and Navigation
Evolution of ESA	Review and assessment of ESA Evolution Propose new Council meetings set-up	Action plan for ESA evolution Improved coordination with National Programmes	Update of Convention: – Decision making – Funding mechanisms Review of industrial policy	New Member States Implementation of updated Convention	New Financial Management System	
ESA internal operations	Agenda 2011 High Level Space Advisory Committee (HISAC)	New competences for integrated applications Enhanced Corporate Control	New Human Resources Policy Reinforced "One ESA"	Adaptation of organisation		Agenda 2015

CMIN: Ministerial Council; GNSS: Global Navigation Satellite System; other abbreviations as in text

The next step is to enable new services by exploiting several systems, space and non-space, acting in concert as a 'system of systems'. The potential is immense in many important areas, such as civil security, air traffic management and maritime surveillance. This will make space an indispensable tool for European policies. The challenge is to change from the single system (often satellite-centred) to a user-centred approach exploiting a network of capabilities.

For example, there are significant synergies to be exploited between civil security and defence. Disaster relief and crisis management missions include civil and military elements (transport, medical treatment, food supply, temporary accommodation), requiring close coordination and coherent information. Common communications equipment providing secure links is a clear demand.

For such applications, ESA will take the role of promoter of the space element of the overall system, which will be the responsibility of a dedicated operator. ESA is beginning pilot projects to help the proposal for an Integrated Applications Preparatory Programme in 2008, promoting space systems and demonstrating their role in a wider system. Examples include civil protection, disaster management, flight safety, human security, health, early-warning systems, maritime surveillance and education in developing countries.

Life and physical sciences: focus on basic and applied research in life and physical sciences using the ISS, sounding rockets and other opportunities; support future exploration initiatives.

Launchers: consolidate Ariane-5 and start exploiting Soyuz and Vega; Ariane-5 and Vega to evolve with family modularity; prepare technologies for next-generation launchers; international cooperation based on mutual dependence, with guaranteed access to space.

Current applications programmes will continue with emphasis on:

Galileo: once the system is deployed, the challenge will be to make the transition to a full operational system, with a commercial operator and services, followed by preparations for a second-generation system. Operational exploitation is planned to start in 2011.

GMES: as services require data from space and other sources, GMES is the typical case for the integrated applications approach. GMES services will gradually become operational as space assets are integrated into the coordinated data stream. The first services will be pre-operational in 2008, while full operational capacity will emerge from 2012 as dedicated GMES missions are launched.

Meteorology: the Meteosat Third Generation will be available in 2015, followed by MetOp's successor in 2019.

Telecommunications: the Small GEO and AlphaSat geostationary platforms will be developed to satisfy the small- and large-size satellite market demands, respectively, in partnership with industry and telecom operators.

Integrated Applications

The submissions for the 2008 Ministerial Council will emphasise new integrated applications pro-grammes, based on a multi-disciplinary approach, paving the way for security-related programmes. Operational space systems such as navigation and communications are part of our daily lives. They integrate space and ground elements, but are based on mainly a single type of system.

The full Agenda 2011 is planned for publication in the coming months. Agenda 2007 is available as ESA BR-213 (cost 10 Euro) from ESA Publications or at http://www.esa.int/esapub/br/br213/br213.pdf

Unveiling the Universe

Two Missions to Unlock the Secrets of the Cold Cosmos

Two pioneering missions: Herschel (left) and Planck (inset)

Gerald Crone, Anders Elfving & Thomas Passvogel
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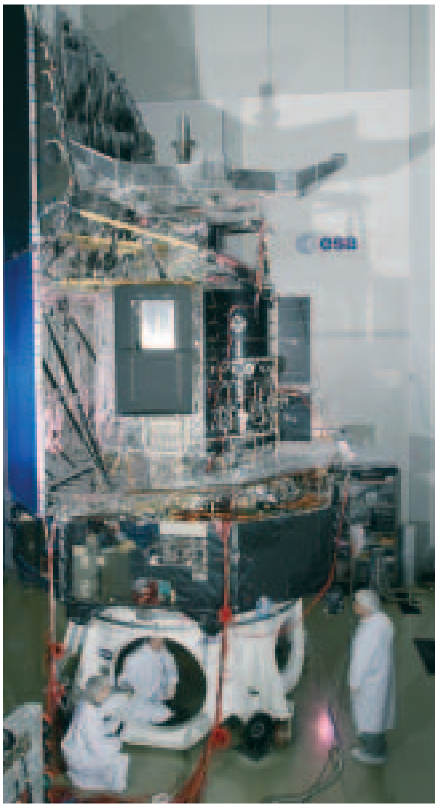
In 2008, an Ariane-5 will lift off from French Guiana carrying ESA's two pioneering Herschel and Planck deep space observatories to explore previously unknown regions of the Universe. Their target is the 'bright' part of the far-infrared spectrum that has tantalised scientists for decades. Until now, the technology has not existed to make precise observations of a distant domain that touches the very beginning of time.

Introduction

Herschel, detecting light emitted in the sub-millimetre and far-infrared range of the spectrum that is blocked from reaching Earth by our atmosphere, will reveal phenomena previously obscured from view, such as the very earliest galaxies and stars.

The Planck telescope, observing in a different part of the far-infrared spectrum with the highest precision ever, will investigate cosmic background radiation – the remnants of the radiation that filled the Universe immediately after the Big Bang some 14 billion years ago.

Extreme sensitivity is needed to measure the faint heat signatures of this



The Herschel spacecraft is 7.5 m high and 4x4 m across, with a launch mass of 3.3 t. The Payload Module consists of the telescope (a mirror mass-dummy is seen here at ESTEC) and an optical bench carrying the parts of the instruments that need to be cooled. A sunshield protects the telescope and cryostat from solar heating and prevents stray light from Earth entering the telescope; it also carries solar cells to generate the spacecraft's power

'cold' part of the cosmos, so the detectors on both Herschel and Planck have to operate at very low and stable temperatures. The spacecraft therefore cool their detectors close to absolute zero, ranging from 20K (–253ºC) to only a few tenths of a degree above the –273ºC of absolute zero.

The 3-axis stabilised Herschel fits the traditional notion of an observatory by pointing at specific targets on request or according to a flexible schedule agreed by scientists.

Herschel achieves its low cryostat temperatures by employing a 'thermos bottle' technique, boiling off helium at a controlled rate to keep the telescope receivers cool. The spin-stabilised Planck, on the other hand, uses passive cooling complemented by a series of three active refrigerators.

To provide the necessary cold and stable environment, the observatories will be positioned at the second Lagrange point (commonly known as L2), Herschel for its nominal mission lifetime of some 3.5 years and Planck for up to about 2 years. L2 is a virtual point in space, some 1.5 million km beyond the Earth as viewed from the Sun, where their gravitational forces of are balanced. Spacecraft can orbit this point, just like circling a planet, with a period of about 6 months.

The thermally benign L2 environment offers stable radio links to Earth and unbroken observing time, making it a preferred location in the coming years for international observatories of this kind.

Herschel and Planck Science

Herschel will look deep into the far-infrared and sub-millimetre range that bridges the gap between what can be observed from ground or airborne facilities and earlier space missions, such as ESA's Infrared Space Observatory (ISO) of 1995–1998.

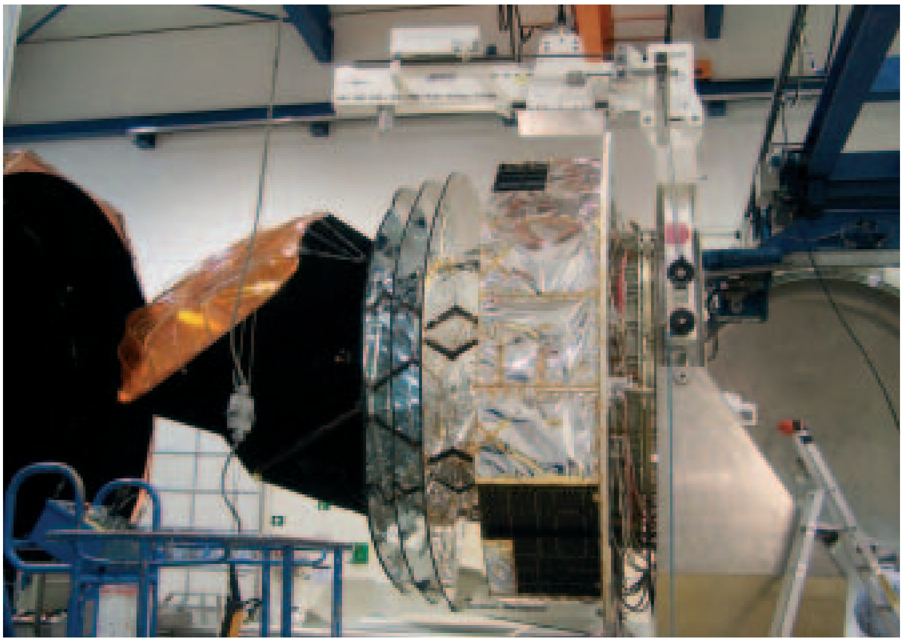
Radiation in this part of the spectrum not only passes through interstellar gas and dust but it is also emitted by the very same gas and dust. That means 'cold' objects, invisible to other types of telescopes, can be viewed.

Herschel's targets include clouds of gas and dust where new stars are being born, discs that may form planets, and the atmospheres of comets packed with complex organic molecules.

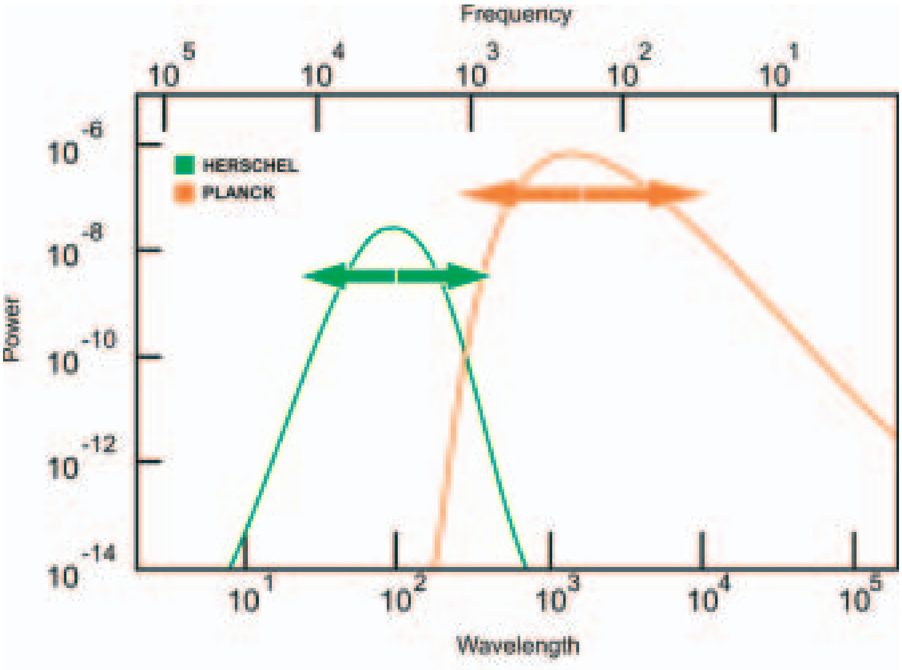
Two-thirds of Herschel's observation time will be available to the world scientific community, with the remainder reserved for the spacecraft's science and instrument teams.

Herschel's far-infrared and sub-millimetre wavelengths are considerably longer than the rainbow of colours familiar to the human eye. This is a critically important portion of the spectrum to scientists because it is here where a large part of the Universe radiates its energy.

Much of the Universe consists of gas and dust that is far too cold to radiate in visible light or at shorter wavelengths such as X-rays. However, even at temperatures well below the most frigid spot on Earth, they do shine in the far-infrared and sub-millimetre. Stars and other cosmic objects that are hot enough



Planck is 4.2 m high and has a maximum diameter of 4.2 m, with a launch mass of 1.8 t



The infrared sky background showing the frequency ranges targeted by Herschel and Planck

to radiate in visible light are often hidden behind vast dust clouds that absorb the energy and reradiate it at Herschel's wavelengths.

There is a lot to see at these wavelengths, and much of it has been virtually unexplored. Previous space-based infrared telescopes have had neither the sensitivity of Herschel's large mirror nor the ability of Herschel's three instruments to do such a comprehensive job of sensing this important part of the spectrum.

Planck, on the other hand, will continuously map the whole sky at a wide range of frequencies, enabling the separation of the galactic and extra-galactic foreground radiation from the primordial background. Its ultimate goal is to produce a map of the tiny irregularities known to exist in the Cosmic Microwave Background (CMB) field.

Work in this area began with NASA's Cosmic Background Explorer (COBE) and Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft, both of which detected temperature fluctuations in the CMB radiation, leading to strong support of what is known as the 'inflationary' Big Bang model to explain the origin and evolution of the Universe.

In spite of the importance of the COBE and WMAP measurements, however, many fundamental cosmological questions remain open. Planck's main objective takes it beyond its predecessors: measuring the CMB fluctuations with far greater precision. This will allow scientists to address fundamental questions, such as the initial conditions for evolution in the Universe's structure, the origin of structure in the Universe, the nature and amount of dark matter and the nature of dark energy (see box). Planck will also set constraints on theories involving high-energy particle physics that cannot be reached by experiments on Earth.

The mission's main observational result will be an all-sky map of the temperature fluctuations in the CMB. To achieve this, Planck will survey the sky at nine frequencies that bracket the 'peak' of the CMB infrared spectrum. These maps will include not only the CMB itself but also all the foreground emissions, whether galactic or extragalactic in origin. All nine maps will be combined by careful processing to create a single map of the CMB variations (see box).

A Common Heritage

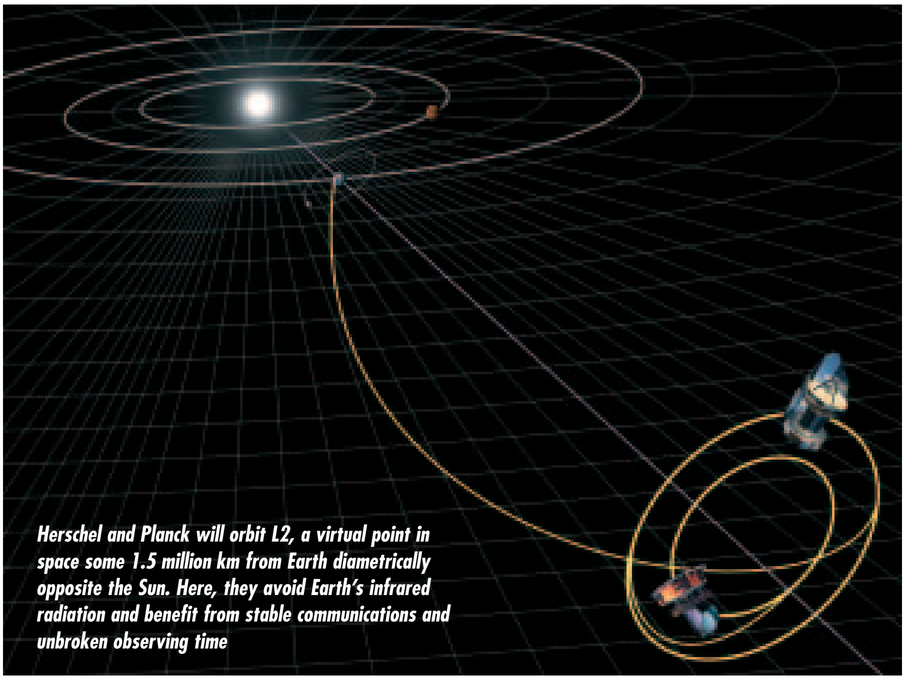
The Herschel and Planck spacecraft are broadly similar in that they have clear separations between the Service Module (housing all the electronics for spacecraft and instrument command and control) and the Payload Module, which carries the sensitive detectors and cryogenic telescopes.

Although the Payload Modules are quite different, the Service Modules feature many common aspects, with almost identical electrical and avionic systems.

'**Dark matter**' is a term coined to describe matter that does not emit or reflect enough electromagnetic radiation (such as light or X-rays) to be detected directly, but whose presence may be inferred from its gravitational effects on visible matter. Observed phenomena hinting at dark matter include the rotational speeds of galaxies, the orbital velocities of galaxies in clusters, and the temperature distribution of hot gas in galaxies and clusters of galaxies. It has been suggested that such objects, and the Universe as a whole, contain far more matter than is directly observable, indicating that the remainder is dark. Its composition is unknown but may include elementary particles.

The hypothetical '**dark energy**' permeates all of space and has a strong negative pressure. According to the Theory of Relativity, the effect of such a negative pressure is similar to a force acting in opposition to gravity at large scales. Invoking this effect is currently the most popular method for explaining recent observations that the Universe appears to be expanding at an accelerating rate, as well as accounting for a significant portion of the energy in the Universe.

Discovered in 1965, the **Cosmic Microwave Background** was produced in the Universe's infancy and now fills it entirely. Most cosmologists consider it to be one of the fundamental pieces of evidence for the Big Bang model of the Universe.



Herschel and Planck will orbit L2, a virtual point in space some 1.5 million km from Earth diametrically opposite the Sun. Here, they avoid Earth's infrared radiation and benefit from stable communications and unbroken observing time

The main functional difference between the two spacecraft is in attitude measurement and control. Herschel uses reaction wheels for 3-axis stabilisation, while Planck carries small thrusters for accurately reorienting its spin axis.

Even so, the observatories have a significant number of identical units, such as the star trackers which use the same hardware but different software to accommodate for the varying requirements of each mission.

The propulsion systems of both Service Modules also employ identical components. Planck has three propellant tanks for adjusting its injection into L2 after release by Ariane-5 and to feed the main push into the tighter orbit around L2, while two tanks are sufficient for Herschel's injection corrections. Ariane-5 will release the two into a direct transfer orbit that means they would naturally circle L2 without further propulsion.

Though the same thrusters are used, they are laid out differently to cater for the specific directional requirements and unique attitude restrictions of the two spacecraft.

The structure of each Service Module is essentially the same, although the majority of the equipment panels differ in their detailed designs in order to satisfy the specific thermal-mechanical requirements of the instruments.

Mission control

ESA's single ground station for controlling both missions is in New Norcia, Australia. The L2 orbital parameters mean that contact with each spacecraft occurs for just a few hours every night (daytime in Europe).

As a result, Herschel and Planck are both designed for minimal ground intervention during normal operations, functioning independently of ground control by following an onboard timeline programme that contains all the commands necessary to carry out the regular operations of the day.

During the daily periods of contact, lasting about 3 hours, science data recorded during the previous day are downloaded and the commands for the next autonomous period uploaded.

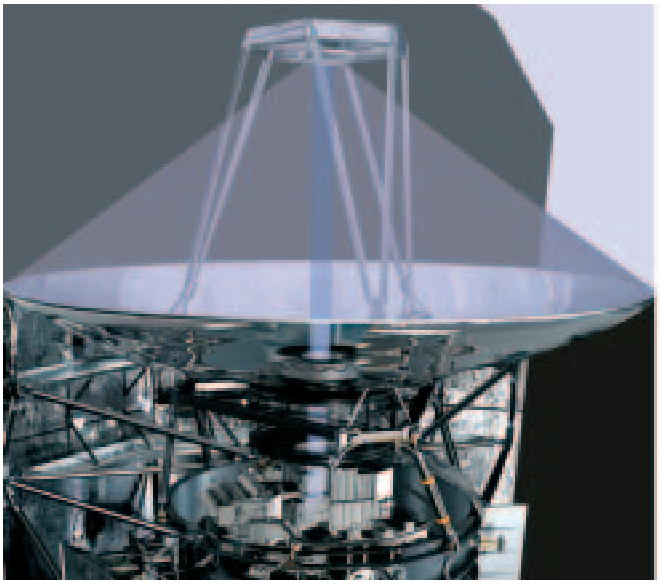
Each spacecraft is also programmed to continue nominal science operations in the event of a single onboard equipment failure, when a spare unit would automatically switch on to take over.

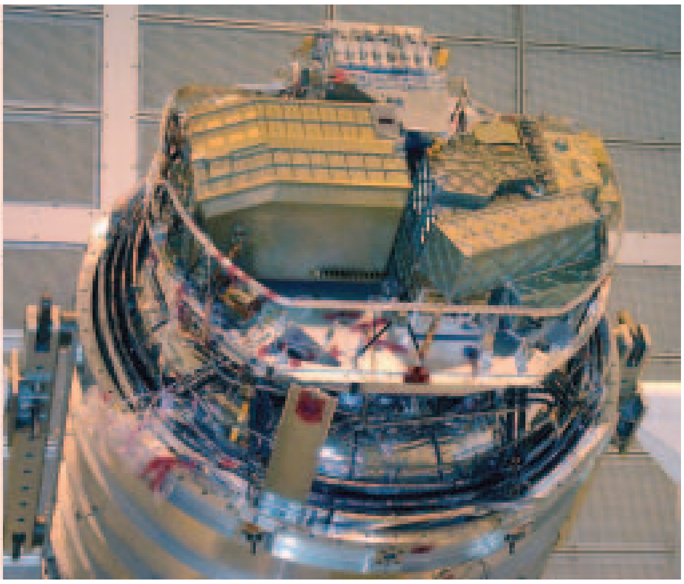
However, failures of more complex functions (perhaps within the computers) or combinations of failures leading to unspecified situations will not have autonomous recovery. If that happens, the effects are contained as far as possible and the spacecraft reconfigured automatically into its safe mode until ground controllers can restore operations.

The Herschel Payload

The Herschel telescope is a Cassegrain

By space standards, Herschel's 3.5 m-diameter mirror is a giant, the largest ever sent into space and a technological challenge. In comparison, the Hubble Space Telescope has a 2.4 m-diameter main mirror





The Focal Plane Units of PACS, SPIRE and HIFI are mounted above Herschel's cryostat at the telescope's focus

design with a primary mirror diameter of 3.5 m (the largest ever built for space) to focus light on three supercooled instruments.

In order to have the sensitivity to detect far-infrared and sub-millimetre radiation, parts of the instruments have to be cooled almost to absolute zero. The shared optical bench that carries all of the instruments is contained within the cryostat to maintain the low temperature. Some 2300 litres of liquid helium (at 1.7 K) will be used during the mission for primary cooling. To achieve the very lowest temperatures, individual detectors are equipped with additional, specialised cooling systems.

The elaborate cooling system maximises the overall cooling power, providing just the right amount at different temperature stages to satisfy local needs. Around 180 gm of helium is used per day, allowing the 3.5-year mission lifetime.

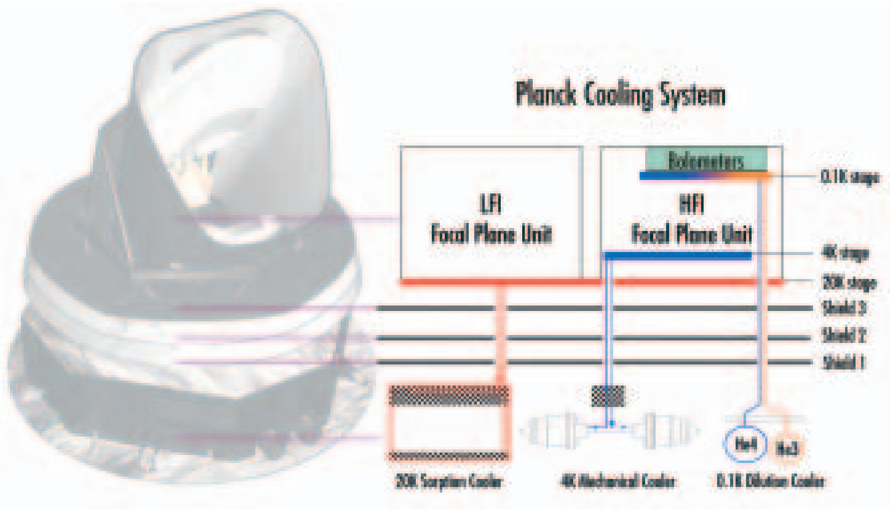
The whole cryostat assembly is protected from direct sunlight by a fixed shade, which also doubles as a solar panel to generate the 1500 W required to operate the entire satellite. The shield also significantly reduces any stray light and heat from the Earth and Moon in the orbit around L2.

International teams have developed Herschel's three scientific instruments. Both direct-detection instruments, the Photodetector Array Camera and Spectrometer (PACS) and the Spectral and Photometric Imaging Receiver (SPIRE), incorporate cameras. The third instrument, the Heterodyne Instrument for the Far-Infrared (HIFI), is a complementary very high-resolution spectrometer.

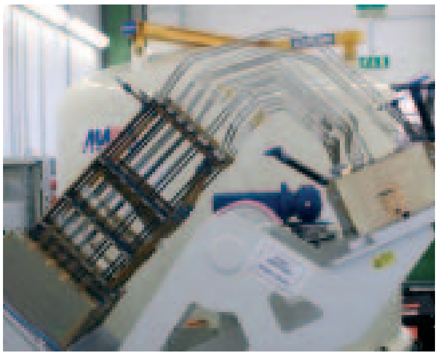
The size of Herschel's mirror meant that it could not be built in a single piece but instead had to be constructed from 12 separate petals, thus becoming the first segmented space mirror as well as the largest to date, weighing 240 kg with an average thickness of about 20 cm and a front face thickness of 2–3 mm.

Although the main technical challenges were in the instruments' focal-plane units (such as the optics, detectors and mechanisms), low-noise readout electronics and coolers, similar issues had to be faced within the spacecraft itself.

The Focal Plane Unit of Herschel's HIFI being prepared for cryogenic vibration testing at 20K



Planck's cryocooling chain



Planck's LFI, an array of radiometers, under calibration testing

Herschel's cryostat design was inherited from ESA's successful ISO mission, but it was still a major challenge to design capable instruments with very low heat demands on the cryogenic cooling system in order to reach the mission's desired lifetime.

The lightweight carbon-fibre sunshield was difficult to build and, owing to the high operating temperature (140–170ºC) of the solar cells, its triple-junction gallium arsenide cells had to be further qualified beyond their standard usage of 80–100ºC.

Other technical issues that had to be overcome during manufacture included the mass-optimised carbon-fibre face sheets, which had to be re-manufactured several times to find the best compromise between flatness, strength and mass.

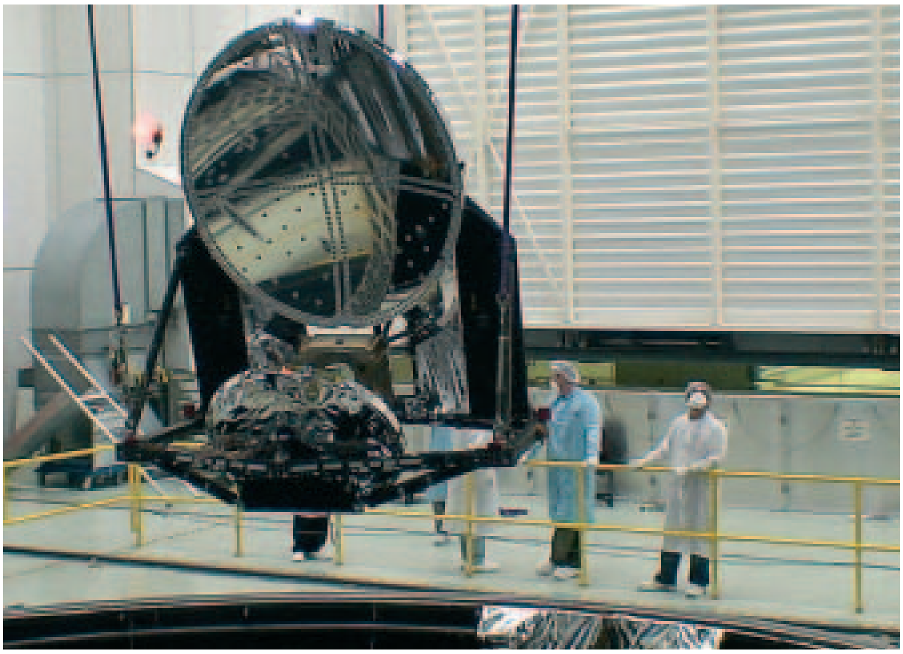
The design requirements on the primary mirror were also demanding. It has to be light enough to be placed into a distant orbit 1.5 million km from Earth but have an extremely smooth surface, polished to make it so uniform that its bumps are smaller than a few thousandths of a millimetre. Equally important, it has to be strong enough to withstand harsh conditions. At launch it will be shaken with a force several times that of Earth gravity before going through drastic temperature changes, from about 20ºC at launch to an average of –200ºC in space.

The mirror segments are built from silicon carbide, a stable material with the combined advantages of metal and glass. It is light and easily polishable, resists stress and fatigue, and withstands low and high temperatures without any notable changes of mechanical and thermal properties.

The Planck Payload

The overall design of Planck's Payload Module emerged from a design process that had to satisfy competing needs: shielding the sensitive radiometers from the heat of the satellite and microwave radiation from the Sun, Earth and Moon, while generating an all-sky map by slowly spinning once every minute around an axis pointing directly away from the Sun.

Planck's highly sensitive detectors have to work at temperatures very close to absolute zero, or else their own heat emissions would spoil the measurements. The satellite therefore has a sophisticated system of coolers.



Planck's off-axis aplanatic telescope combines a clear optical path with compactness. The eccentricity and tilt of the secondary mirror and the off-axis angle allow a large focal plane detector array, while minimising the polarisation introduced by the telescope. The telescope is seen here being prepared for thermal-vacuum testing at ESTEC

The telescope's line-of-sight is inclined at 85º to the spin axis so that the instruments scan a ring of the celestial sphere once per spacecraft revolution, and the whole sky in half a year. In order to view the celestial poles, the spin axis can be moved up to 10º away from the anti-Sun direction.

The Payload Module is dominated by three conical radiators that thermally insulate the two reflectors, the detector focal plane and the surrounding black baffle from the Service Module.

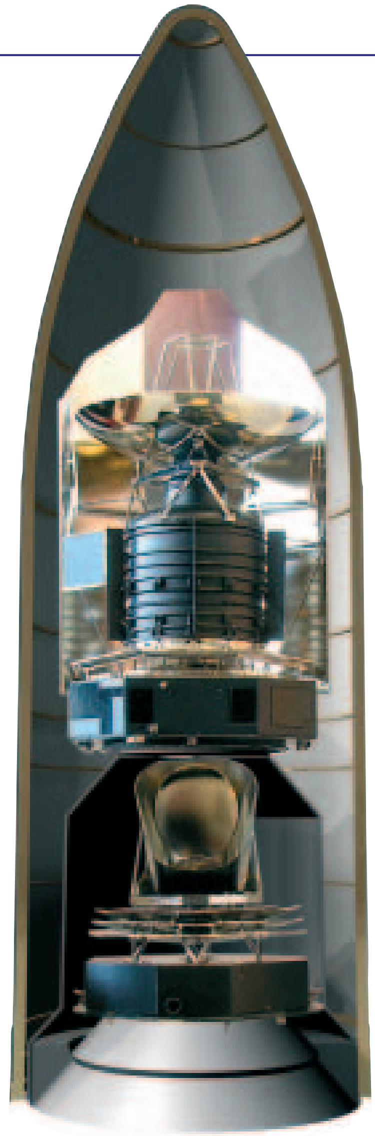
The black baffle is a powerful radiator for passively precooling the active three-stage cooling chain to around 60K. Further cooling of the detectors is performed via a cascade: 20K by a continuous hydrogen sorption cooler, 4K by a mechanical cooler and 100mK by mixing normal helium with a rare helium isotope.

Planck's two scientific instruments are the Low Frequency Instrument (LFI), an array of radio receivers using high electron mobility transistor mixers, and the High Frequency Instrument (HFI), an array of highly sensitive microwave detectors known as bolometers. They share the off-axis aplanatic telescope, which has a primary mirror measuring 2.0x1.5 m.

Verifying the cryogenic performance of Planck under realistic conditions was a true challenge. A dedicated test centre demonstrated the performance of the passive radiators at about 60K by cooling the facility's inner surfaces to below 20K with liquid helium.

Equally challenging was the verification of the alignment and radio-frequency performance at the operational 60K. Measurement at the Planck frequencies and in cryogenic conditions is not possible on Earth, so verification has to be done by combining analyses and test results.

Planck's detectors will convert the strengths of the microwave signals into units of temperature. The average temperature of the CMB is well known at –270.3ºC but there are variations of roughly one part in 100 000 around the sky.



Herschel (top) and Planck will be launched jointly by the most powerful version of Ariane-5 into a direct transfer orbit to L2

Planck will be able to find and map regions where the temperature varies from the average by a few parts in a million. These tiny differences in the CMB are like the marks in a fossil, revealing details about the organism they come from – in this case, the physical processes at the beginning of the Universe.

Planck's baseline mission calls for two complete scans of the sky during an initial 15 months of observations.

Status

Planck's flight instruments are now being integrated into the satellite at Alcatel Alenia Space in Cannes (F). Herschel's instruments will closely follow: they will be integrated into the satellite in early 2007 at Astrium in Friedrichshafen (D). These parallel programmes are approaching their final integration and test period before the launch in 2008.

Conclusion

Engineers from numerous European space companies have worked together on the design, construction and testing of ESA's Herschel and Planck observatories, overcoming many challenges that have pushed technology to new limits.

Credit must also go to the hundreds of scientists from specialist institutions across Europe and the United States for designing and developing the suite of highly sensitive instruments that will operate to the tightest of tolerances at temperatures close to absolute zero.

Infrared astronomy itself is still a young and exciting science, but astronomers studying this part of the spectrum have already unveiled tens of thousands of new galaxies and made surprising discoveries.

Yet scientists know there is still much more to find and processes such as the growth of structure in the early Universe and consequent birth of galaxies and other objects can best be studied with (far-) infrared telescopes situated in deep space, well away from the restrictions imposed by the Earth and its atmosphere.

ESA's Herschel and Planck observatories will help to provide answers to some of the most vexing questions now being asked in modern science: how did the Universe begin, how did it evolve to what we see today, and how will it evolve in the future? They will be throwing new light on an old story.

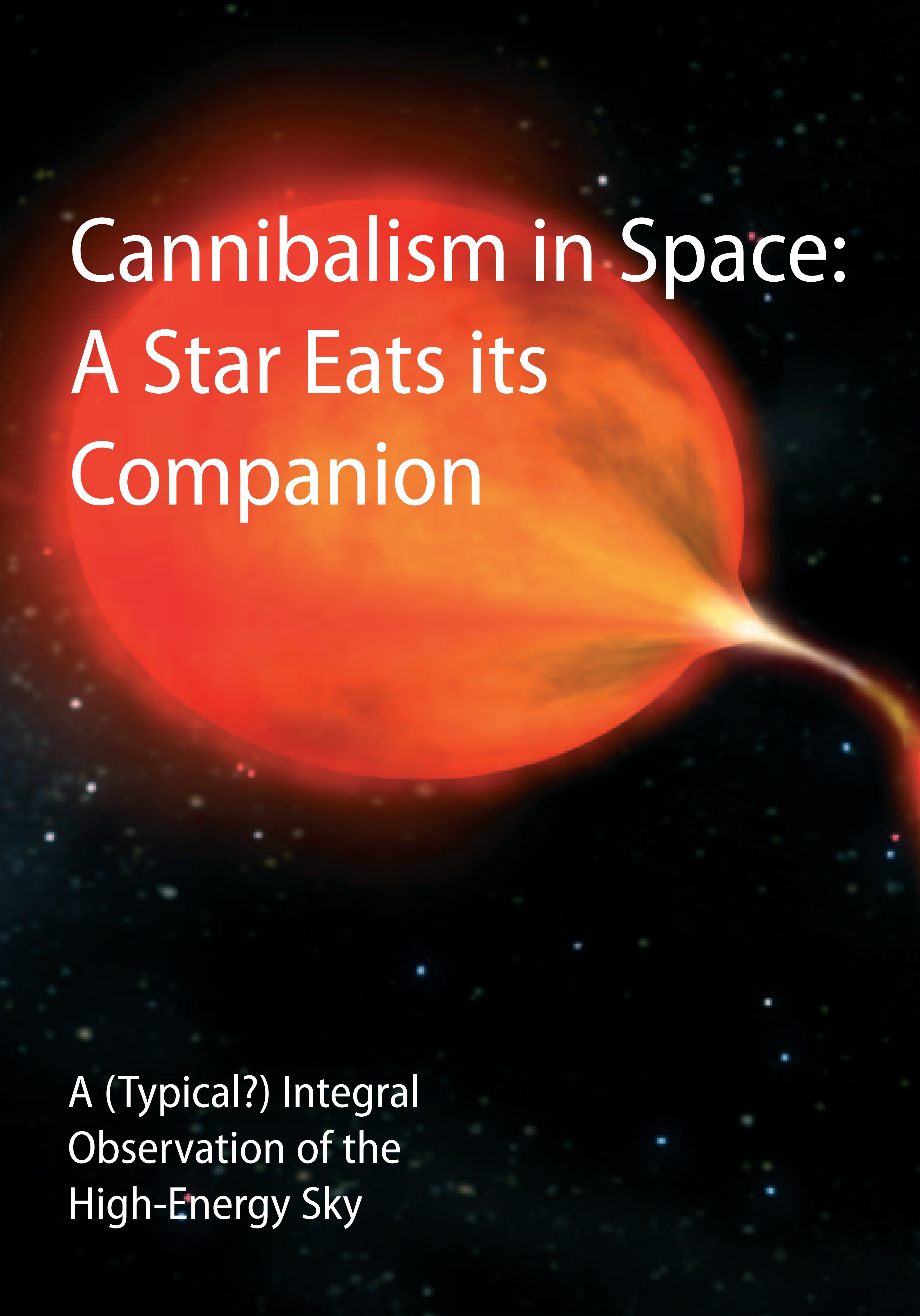
Acknowledgement

The authors express their thanks to Clive Simpson (*www.simcomm-europe.com*) for his contribution in writing the article.

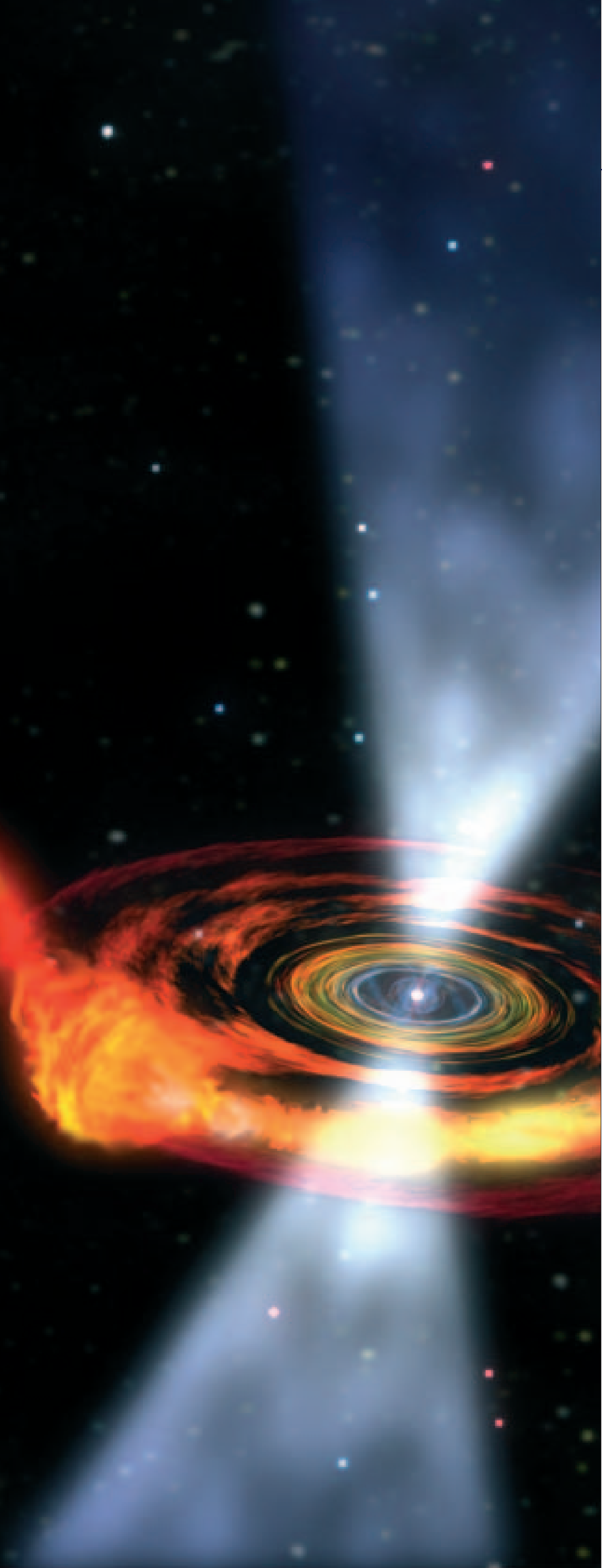
esa

Detailed information on Herschel and Planck can be found at www.esa.int/science
Scientific information is available at sci.esa.int/herschel & sci.esa.int/planck

Cannibalism in Space: A Star Eats its Companion



A (Typical?) Integral Observation of the High-Energy Sky



Christoph Winkler
Astrophysics and Fundamental Physics Missions Division, Research and Scientific Support Department, Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

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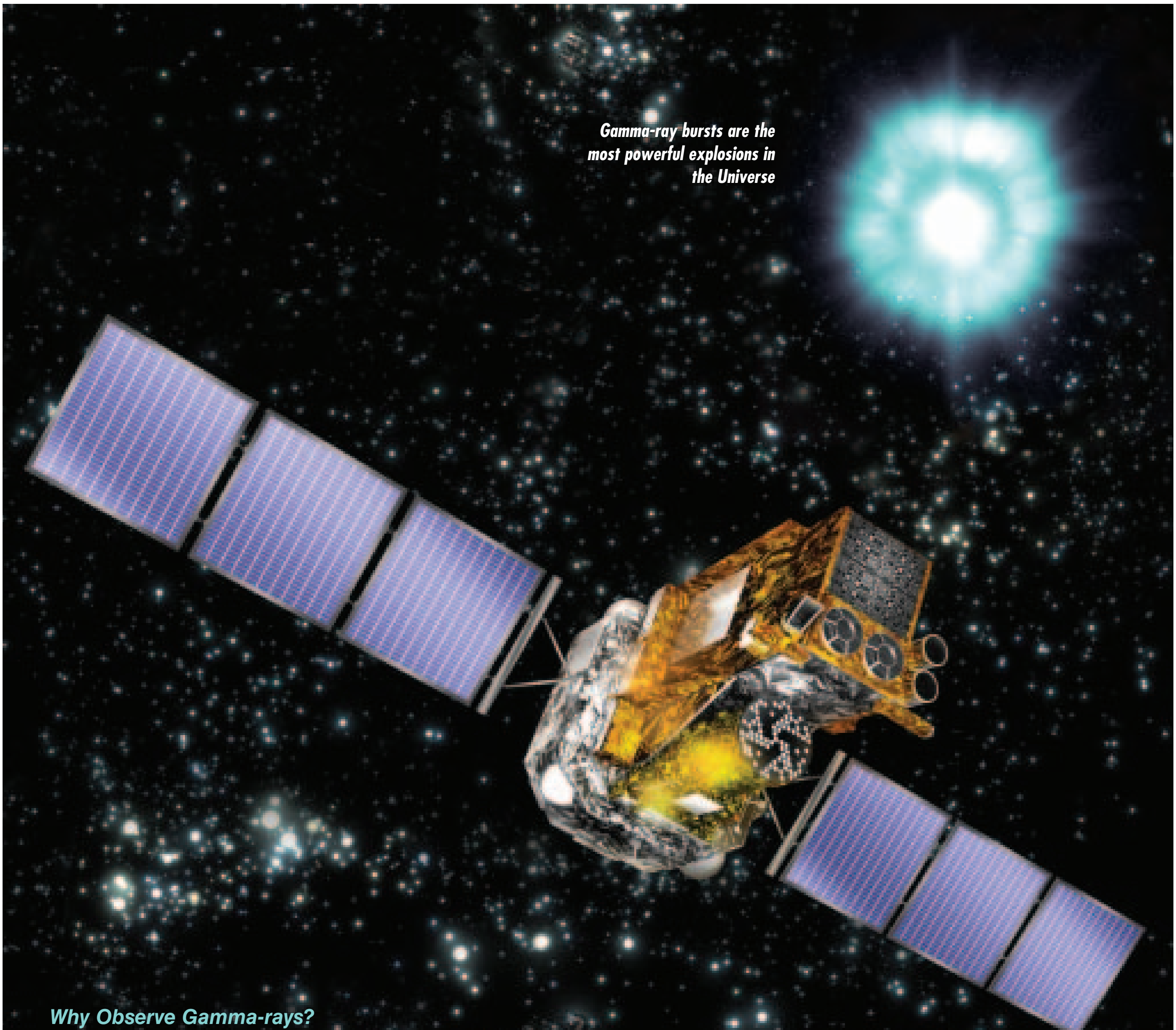
Michael Schmidt
Mission Operations Department, Directorate of Technical and Operational Support, ESOC, Darmstadt, Germany

The work of ESA's Integral high-energy observatory usually follows a long-term plan that is established every year by selecting only the very best of the numerous observing proposals from the scientific community. However, nature does not always follow the same plan, so Integral and the people who keep it running have to react to unforeseen and sudden 'Targets of Opportunity'. The case here is neutron star IGR J00291+5934, an incredibly dense object with a mass similar to that of our Sun's compressed into a rapidly spinning sphere only a few kilometres across. Not only that, but it is busy swallowing its stellar companion.

Introduction

The Integral mission

The scientific research with ESA's Integral (INTErnational Gamma-Ray Astrophysics Laboratory), launched on 17 October 2002, focuses on celestial objects that radiate in the energy band between 10 000 and 10 million electron volts (eV). On average, these gamma-rays are 10 000 to 10 million times more energetic than the photons reaching our eyes from the Sun and stars. They are generated by the most energetic and



Gamma-ray bursts are the most powerful explosions in the Universe

Why Observe Gamma-rays?

Light, or electromagnetic radiation, comes in many forms. There are radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays and gamma rays, all of which form the 'electromagnetic spectrum'. Oddly enough, visible light – to which human eyes are sensitive – is the smallest band of all. To our eyes, what we see seems like the entire Universe, but there is *much* more out there.

Different types of objects in the Universe emit different types of radiation. Our Sun is a rather obvious source of visible light. But it also glows in radio waves, infrared, ultraviolet and X-rays. Some objects emit only radio waves or X-rays. This is why it is important to study the Universe with various kinds of space observatories.

Integral is concentrating on the gamma-rays. These are produced by spectacular events such as stars exploding, matter falling into black holes and celestial objects colliding. By collecting gamma-rays, astronomers can see these violent events and judge how they shape the Universe.

For example, some chemical elements are created during explosions in which individual stars blow themselves to pieces. The new chemicals leave gamma-ray fingerprints in the fireball for astronomers to find. By studying these, Integral is piecing together how these chemicals are created.

Integral is also studying the mysterious blasts known as gamma-ray bursts. These explode at random in distant realms and are probably caused by the collision of neutron stars or perhaps the explosion of large stars.

violent events in the Universe. Integral detects these high-energy photons using two main gamma-ray instruments: the SPI spectrometer provides precise spectral information, and the IBIS camera images the objects with high accuracy. They are supplemented by two monitoring instruments covering the soft X-ray range below 10 000 eV (JEM-X) and the optical wavelength band (OMC). For a detailed description of Integral, its instruments, performance and ground segment, see the set of articles in *Bulletin* 111, August 2002.

The celestial objects of interest to the scientists using Integral include black holes in our Galaxy and local galaxies, neutron stars, X-ray binary stars, pulsars, remnants of supernova explosions and gamma-ray bursts. Studying the gamma-ray emission lines from the radioactive decay of excited heavy atomic nuclei or from the annihilation of electrons with their positron anti-matter equivalents is also important.

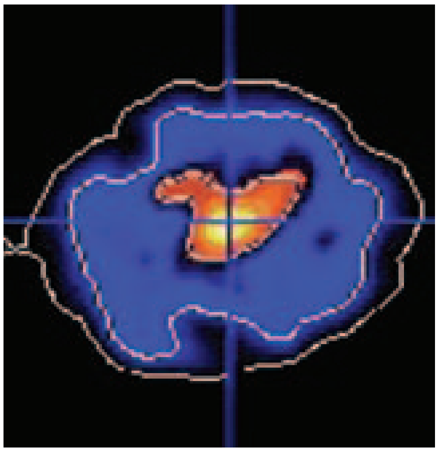
The observing programme

Integral is operated like a ground-based observatory, with the vast majority of its time used by astronomers at large. Proposals by the scientific community for Integral observations are solicited by ESA once a year and assessed by the Time Allocation Committee. Then, scientists at the Integral Science Operations Centre (ISOC) in ESA's European Space Astronomy Centre (ESAC, E) create a long-term observing plan. This is an optimised sequence of observations (targets, pointings and exposure durations), taking into account all the scheduling constraints, such as spacecraft pointing avoidance zones and observations that have to be performed at particular times. The Mission Operations Centre (MOC) in ESA's European Space Operations Centre (ESOC, Darmstadt, D) translates this plan into a sequence of spacecraft commands for uplinking to Integral from one of the ground stations, in Redu (B) or Goldstone (USA).

When a target has been observed, the data are downlinked in real-time to the ground stations and then forwarded to the Integral Science Data Centre in Versoix (CH), where they are processed and archived before being dispatched to the proposers for scientific analysis. Usually, therefore, the observing programme follows a sequence planned for the entire year, until a new set of proposals is solicited and selected.

At this point, readers may conclude that operating Integral is a routine matter, with very little to be done on the ground after the observing programme has been established and sent to the spacecraft.

However, this is far from the truth.



Integral views electron-positron annihilation at the centre of our Galaxy (J. Knödleseder et al., Astron. Astrophys., vol 441, p513, 2005)

The variable high-energy sky

A key characteristic of the high-energy sky is that a large majority of the gamma-ray sources vary with time. Some previously regarded as steady display sudden outbursts on every intensity scale. Others have regular outbursts. Sky areas supposed to be empty suddenly reveal new sources; these often turn out to be previously undetected persistent but weak sources that suddenly burst into life for an arbitrary period. Some sources may vary with a quite regular pattern, known from observations before Integral was launched.

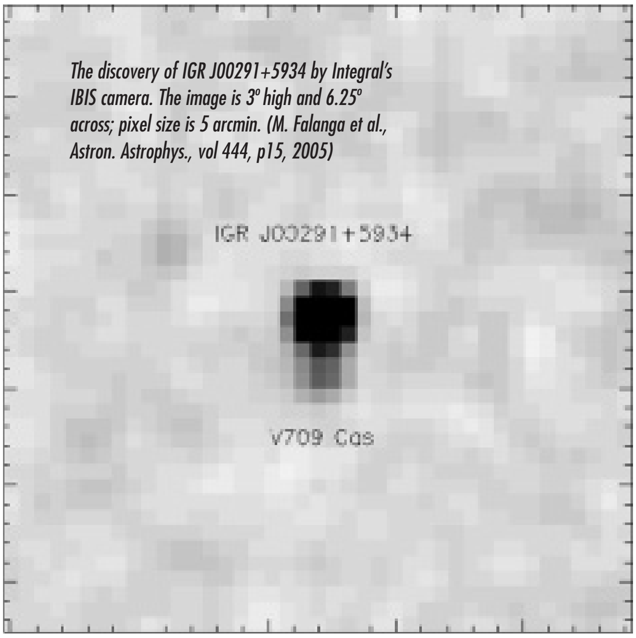
The reason for all this variability lies in the nature of these sources. Many are in binary stellar systems, and material from the companion star is accreted onto the compact object. This accretion process, which releases large amounts of energy, can appear to be highly variable for a range of reasons: the radiation may be temporarily blocked from view by the companion, nuclear explosions on the surface of the compact object, reconnections of intense twisted magnetic fields, or the continuous fast rotation of the dense object (a 'pulsar').

In other words, the high-energy sky looks like a Christmas tree, with candles flickering at every time scale imaginable. Many of these outbursts are relatively bright and provide plenty of photons (which are rather scarce in gamma-ray astronomy). This means that the data can be easily analysed and exciting new scientific results are obtained almost every time. This is what makes these observations so exciting.

Most of these events are unpredictable by their very nature, so they are commonly called 'Targets of Opportunities' (ToOs). Any mission exploring this energy regime should be prepared to react rapidly to such dramatic events. The Integral observing programme, stored in a database, already contains a number of accepted ToO observation proposals that can be activated if the unique event described in the proposal really happens. In that respect, we are not totally unprepared.

The entire ground network needs to be prepared because an alert could be received from either the external science community or ISDC at any time – 7 days a week, 24 hours a day. In the case of Integral, the call could come from the astronomers at ISDC monitoring the data as they are received, pointing out that something strange is going on in the sky right now – an opportunity not to be missed!

Such an alert was received by the Integral team on 5 December 2004, when Maurizio Falanga from the Commissariat à l'Energie Atomique (CEA), Saclay (F) requested that the spacecraft be repointed towards a powerful new source as soon as possible.



The discovery of IGR J00291+5934 by Integral's IBIS camera. The image is 3° high and 6.25° across; pixel size is 5 arcmin. (M. Falanga et al., Astron. Astrophys., vol 444, p15, 2005)

Changing Plans

It was a quiet Sunday in December. Erik Kuulkers, the ISOC duty scientist was enjoying the weekend and a nice Sunday lunch at home. Suddenly, at 13:37, the peace was interrupted by a familiar beep: a text on his mobile phone. Most of the time this means work ahead. A quick check confirmed that a request to trigger a ToO observation of IGR J00291+5934 had indeed just been received by the Integral helpdesk computers. Abandoning his plans for a calm pre-Christmas Sunday, Erik went off to work.

Checks and balances

Upon arrival at the ISOC, the first task was clear: verify that the request was justified. In many cases, there is already an accepted observation proposal with specific criteria to activate it. Of course, the astronomers know the criteria that they or the Time Allocation Committee have set. But in the excitement to get their chance, astronomers frequently try to trigger an observation without checking these criteria, reacting prematurely. But not in this case – the criteria were indeed met and the location of the source did not violate any spacecraft pointing constraints. The next question was the requested reaction time: this turned out to be rather short, within a day, if possible. This meant that the planning for the current 3-day orbit around the Earth would have to be changed, always a delicate task for the MOC, who have to merge the old and new planning seamlessly. Finally, the long-term planning for the current and upcoming orbits was reviewed to see which observations could be shifted to later in order to accommodate the imminent ToO, if accepted. The current main target was supernova remnant Cas A, a very long observation that had not been easy to fit into the overall available time.

With all the facts collected, Erik called the Integral Project Scientist, Christoph Winkler, who has the last word on the planning of scientific observations. So now his Sunday afternoon was also interrupted. The two scientists discussed the case and Christoph evaluated the impact of accepting the ToO, both scientifically and operationally. Finally, the decision was clear: the requested observation should be done as soon as possible.

Reshuffling the programme

By now it was nearly 16:00. Quickly, Erik informed the lucky observer that his observation would be scheduled and called colleagues at MOC in Darmstadt, whose weekend routine was also to be upset as the observing programme was about to be reshuffled. First, a suitable slot within the ongoing observation programme had to be found, keeping in mind both the pressure to start this ToO as soon as possible and the requirement to give Darmstadt enough time for the necessary checks and verifications on their side. And there was an additional complication: a short calibration observation that could not be moved around freely.

Evaluating all the constraints, Erik settled for a plan in which the first

Erik Kuulkers, Operations Scientist on duty at ISOC, studies the target visibility map for the ToO observation

The Integral control room at ESOC. From left to right: Orlane Bergogne (Spacecraft Operations Engineer, SOE), checking the instrument configuration; Michael Schmidt (Spacecraft Operations Manager, SOM) supervising the replanning activities; Salma Fahmy (Mission Planner) performing the replanning; Paolo Lippi (Analyst) checking the consistency of the database; Atef Soliman (SPACON) loading the new timeline; Federico di Marco (Attitude & Orbit Control System Operations Engineer) checking the slew sequence

observations of the ToO would begin on Monday afternoon, less than 24 hours from the time of planning, but late enough so that MOC's main activities could be performed on Monday morning.

Trying to create the changed planning files, Erik encountered another difficulty: a strange problem with inserting the necessary 'Reaction Wheel Bias' (more on this below). Cursing his luck at running up against such an issue on a Sunday, he tried several options but finally sent the planning files as they were to MOC to give his colleagues a chance to evaluate the new slews and pointing positions on the sky. By 18:15, all the files had been sent, the observer had been informed about the intended schedule of his first observations, the scientific community at large using Integral had been informed about the change in the observing programme, and the duty scientist could leave to enjoy what was left of his weekend. The current observations did not cover all of the requested time, but the rest could be planned more calmly, after the results from the first observation had been evaluated. (The remaining observations were scheduled for Wednesday night as part of the next orbit.)

Getting Integral Ready

Monday started as any other day during Integral's routine operations phase. The Spacecraft Controllers (SPACONs) performed the shift hand-over, the Spacecraft Operations Manager (SOM) arrived and talked to the SPACON on shift to get the latest news, and the rest of the Flight Control Team of Analysts and Spacecraft Operations Engineers (SOEs) arrived one after the other. During the status checks, the need for replanning the ongoing orbit was identified because there was fresh input from ISOC over the weekend. Since there was no accompanying alert for an immediate process and since the automatic processing of the planning file did not reveal any urgency, the replanning was postponed to later on Monday morning.

The activities at MOC started again when SOM Michael Schmidt contacted Mission Planner Salma Fahmy with a call along the corridor: "*We've got a Target of Opportunity that requires some replanning*". After the usual round of comments ("*Oh, not another ToO!*"), MOC contacted ISOC to discuss the proposed replanning.

In the planning process, ISOC provides a set of data files, including the Preferred Observation Sequence (POS), which defines the required science operations and provides the information that MOC needs to generate the spacecraft commands. The problems with this ToO was that the operations of the affected revolution were already taking place. The official lead time for the replanning was 8 hours, including a small margin.

The feedback from ISOC was: "*We have the approval by the Project Scientist that the ToO is so important that we should override the planned observations and we have sent a revised POS.*"

"*Well*", MOC told ISOC, "*we hope that a RWB [Reaction Wheel Bias to offload the wheels] has been introduced before the first slew*."

It was at this point that the Flight Dynamics (FD) team got involved. The Mission Planner informed the on-call FD staff, and warned him that a replanned POS (RPOS) had arrived and had to be processed. Some parts of the processing are automated, but there is still a considerable amount of manual effort. Therefore, everyone met in the control room.

The RPOS file is imported manually, as opposed to the fully automatic import for the routine POS files. The FD and the Flight Control Team checked the file by eye, in particular to verify that all the RPOS rules were met. "*Uh-oh!*" There was no RWB before the first slew. "*Well, the time of divergence is in about 4 hours and luckily there was an RWB planned in about 2 hours. If we can get the RPOS processed by then, there should be no problem.*"

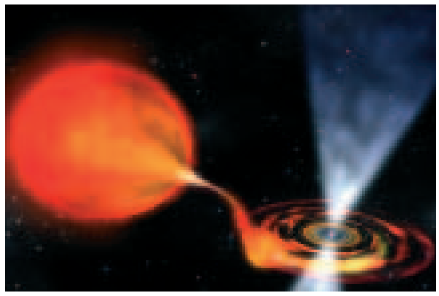
A quick call was made to ISOC to let them know and check that this approach was acceptable; the rest of the processing got underway. All aspects of the POS were checked, some visually such as the instrument mode parameters and telemetry bandwidth allocation, and some by the FD software, such as attitude constraints.

About an hour later, the RPOS had been processed, the Enhanced POS (EPOS) and the corresponding timeline had been generated, and it was time to make the switch to the new timeline. It was important to find a gap in the timeline when there was no commanding in order to stop the Autostack on the control system, abort the old timeline and load the new one. (Of course, before applying the new timeline the paperwork had to be completed. All the planning products were cross-checked and signed by the various people responsible.) With about 4000 commands in one timeline, the loading took a few minutes. In addition, the running FD software tasks had to be stopped and new ones scheduled for the new timeline. So a window of at least 10 minutes was needed. Owing to the observational pattern of a slew every 30 minutes followed by a period of stable pointing with no commanding, finding a slot was not a problem. It was decided to upload the new timeline after the next slew.

The Mission Planner, SPACON and FD observed the end of the slew and waited for the FD job to run to update the parameters for the next slew. "*Ding-dong*!" This was the notification by the control system that the update had arrived. "*Action!*"

The SPACON aborted the timeline, FD rescheduled the jobs, the new timeline was loaded, the updated Task Parameter File was applied to the new timeline, all associated documents were updated – and the job was done.

Everyone resumed their routine work as Integral's instruments observed the new target. The data were routed within a few seconds to the Science Data Centre, where a preliminary check of the results was made.



A neutron star pulsar consumes material from its close stellar companion

The ToO Observations of IGR J00291+5934

This 'new' source was serendipitously discovered by Integral within its wide field-of-view during a routine short observation around the constellation Cassiopeia, in the outer reaches of the Milky Way, when it suddenly flared on 2 December 2004. It was designated as IGR J00291+5934, where IGR denotes an 'Integral Gamma-Ray' source, and the numbers give the coordinates on the sky. On this day, the source proved to be bright enough to warrant a dedicated, longer Integral observation for in-depth investigation. Normally these sources stay bright for a few days, but some transient sources unexpectedly fade in less than a day without warning. So it is always exciting to await the outcome of the observation and analysis of the data. In this case, the observations were highly successful and the results were rapidly published in the leading scientific journal *Astronomy and Astrophysics* (see also the ESA news release at *http://www.esa.int/esaSC/SEMWSAA5QCE_index_2.html*).

What did we learn from these observations?

Neutron stars and pulsars

Pulsars are rotating neutron stars, which are created during stellar explosions. They are the remnants of stars of 8–10 times the Sun's mass that ended their lives in supernova explosions. These remnants still contain about the mass of our Sun but concentrated in a 10–20 km diameter! The extreme pressure forces electrons to combine with protons to form neutrons; the entire star is essentially one big atomic nucleus consisting of neutrons. Often, they are also rapidly spinning pulsars. Discovered by radio astronomers about 50 years ago, pulsars beam electromagnetic radiation from their polar regions, like a lighthouse sweeping its beam across the Earth at regular intervals. The extreme regularity of the pulse intervals makes them the most precise clocks in the Universe – much better than even atomic clocks on Earth.

The fastest accreting millisecond-pulsar

On 3 December 2004, using Integral's data of the discovery made the day before, and 2 days before the Integral alert was submitted, scientists observed the object with NASA's Rossi X-ray Timing Explorer (RXTE), a satellite specialised in high-precision X-ray timing measurements. These revealed that it was a pulsar, or more precisely an 'X-ray millisecond pulsar'. IGR J00291+5934 emits around 600 pulses a second, one of the fastest known. This corresponds to a rotational period of this solar-mass object of only 1.67 millisec (37 500 rpm!). This is much faster than most other pulsars in binary systems, which rotate every few seconds. (For comparison, the Sun takes about 25 days.) Only a few isolated (radio) pulsars are known to spin even faster. So, IGR J00291+5934 could be the 'missing link' between the relatively slow accreting pulsars in binary systems and the very fast isolated pulsars, having finally lost their companions in their old age.

Photons from polar regions

Many neutron stars have strong magnetic fields, which were frozen in during the collapse of their progenitors. This can create incredibly strong magnetic fields for a small, city-sized neutron star. Charged particles in the accreting flow are channelled along these magnetic field lines onto the polar regions of the neutron star (like solar particles in Earth's field generating our polar aurorae) where they finally hit the surface close to the poles, creating hot spots. Integral directly observed the photons from these spots, finding they account for most of the emission at energies above 30 000 eV. The key observation behind this result was the fact that Integral measured gamma-ray pulsed emission from IGR J00291+5934 up to energies of 150 000 eV exactly in phase with the 1.6 millisec X-ray pulsations recorded by RXTE. This proves that the observed high-energy emission must be connected with the polar regions emitting the lighthouse-beam radiation. Before this, such high-energy photons had never been seen in the pulsed emission from these objects.

Cannibals at work

Using the timing information on IGR J00291+5934, it was found that the companion star is perhaps as small as 40 Jupiter masses. The two stars orbit one another in only 2.5 hours. The binary system is very small: the stars are so close that they would fit into the radius of the Sun. The observations support the theory that the two stars are close enough for accretion: material is flowing from the companion into a disc around the neutron star before falling to its surface. If this process continues, the companion will be completely consumed by the much smaller star. This conclusion can be drawn once a change in the spin period is observed. Neutron stars – spinning rapidly at birth – gradually slow down after a few hundred thousand years. Neutron stars in binary systems, however, can do the opposite, accelerated by the angular momentum of the in-falling material from the companion. For the first time, this speeding up was observed directly in high-energy data. This is direct evidence for the star spinning faster and faster, as it cannibalises its companion. Over about 100 000 years, the spin will speed up by 0.6%, from 1.67 millisec to 1.66 millisec.

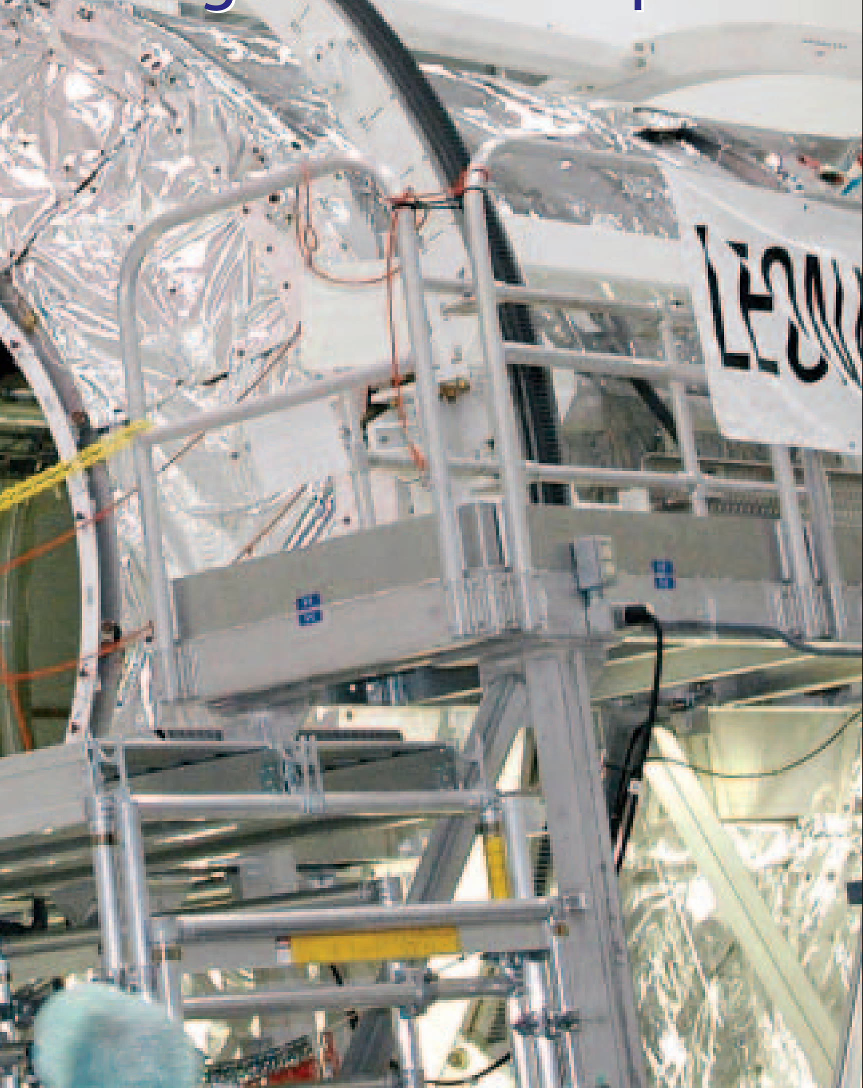
Conclusions

The observations of this ToO show that nature always has surprises and new questions to offer. Space observatories such as Integral, with their dedicated operational staff, are ideally suited to providing the right tools to find the answers. Over its first 3.5 years of operations, Integral has observed 29 Targets of Opportunity for a total of almost 8 million seconds.

Detailed information on Integral and its mission can be found at http://www.esa.int/SPECIALS/Integral/ and http://integral.esac.esa.int/

MELFI
Ready for Science

MELFI is loaded into its carrier module ready for launch aboard the Space Shuttle on 4 July 2006



ESA's –80ºC Freezer Begins Work in Space

Maria N. De Parolis & Giorgio Crippa
System Support Office, ESA Directorate of Human Spaceflight, Microgravity and Exploration, ESTEC, The Netherlands

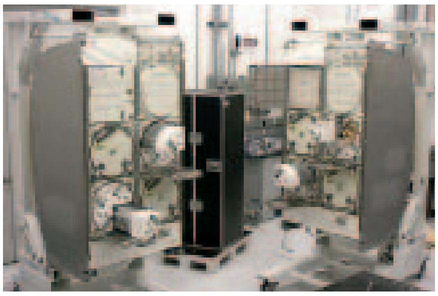
Jean Chegancas & Frederic Olivier
EADS-Astrium, Toulouse, France

Jerome Guichard
L'Air Liquide, DTA, Sassenage, France

After a 4-year wait, ESA's 'MELFI' freezer rack is now installed and working in the International Space Station (ISS). It provides researchers with a unique cold-storage facility important, for example, for biology and human physiology investigations. Originally designed for frequent return trips, a major shift in Station requirements meant that a major effort had to be made before launch aboard Shuttle mission STS-121 in July to prepare it for permanent residence in space. The first science samples have been successfully frozen, before the first European samples were added in September.

Introduction

The 'Minus Eighty-degree Laboratory Freezer for ISS' (MELFI) allows the fast-freezing and storage of life sciences and biological samples aboard the International Space Station. Developed by ESA on behalf of NASA and the Japan Aerospace and Exploration Agency (JAXA) under various bilateral barter agreements, the Agency has delivered three flight units to NASA and one to JAXA. A flight-standard Engineering Model, a Training Model



FU1 (left) and FU2 at the Florida launch site

with simulation capabilities and a Laboratory Ground Model are installed at NASA's Johnson Space Center (JSC) in Houston and have been used extensively by the ground and space crews to prepare for utilisation. In addition, ESA is providing spares and sustaining engineering to maintain all MELFI hardware for up to 10 years of operations.

The prime contractor is EADS-Astrium in Toulouse (F), with main subcontractors:

- L'Air Liquide (F), for the core cooling system;
- Linde (D), for the cold-volume chain;
- Kayser-Threde (D), for the electrical system and some rack components;
- ETEL (CH), for the motor and motor-drive electronics;
- DAMEC (DK), for the utilisation concept and hardware.

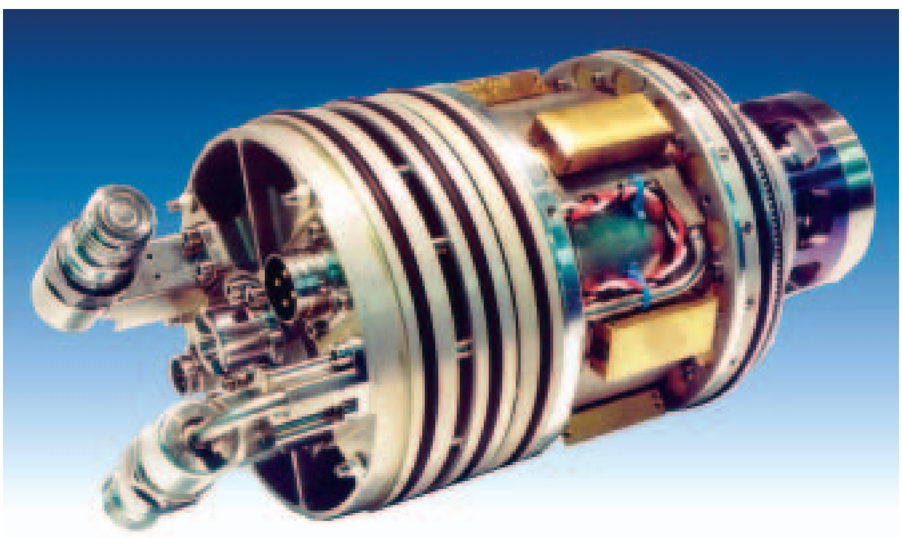
Brief Description

The samples are stored in four identical Dewar enclosures. Each Dewar can be set to cool to below three different temperatures: –80ºC, –26ºC and +4ºC. The centralised cooling system is based on a reverse Brayton cycle using very pure nitrogen as the working fluid. The basic machine was developed under ESA's Technology Research Programme (TRP), and then modified to satisfy MELFI's specific and stringent requirements. The Brayton expander and compressor wheels are mounted on the same shaft, running at up to 96 000 rpm. At that speed, the system produces 90 W of cooling power at –97ºC.

The cooling distribution to the Dewars is via vacuum-insulated nitrogen lines running from the machine. A distribution valve on each Dewar stabilises the temperature within the required range by modulating the cold nitrogen flow. The valves can also isolate each Dewar independently, shutting down one or more enclosures when the storage capacity is not needed.

Within the Dewars, trays and boxes accommodate basic samples shapes. Users can design their own accommodation hardware, based on defined interface requirements and their cooling needs. MELFI is a 'contact freezer' to allow selection of the cooling speed. For

A single Brayton machine provides cooling for MELFI



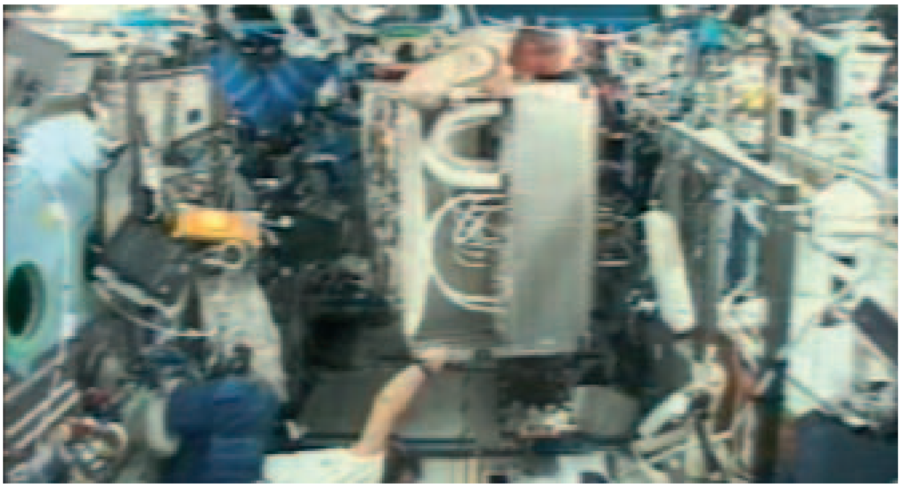
MELFI begins its journey to the ISS

fast cooling, the samples must be held against the Dewar trays and have a large, conductive surface. Conversely, samples requiring slow cooling need small, isolating interface surfaces.

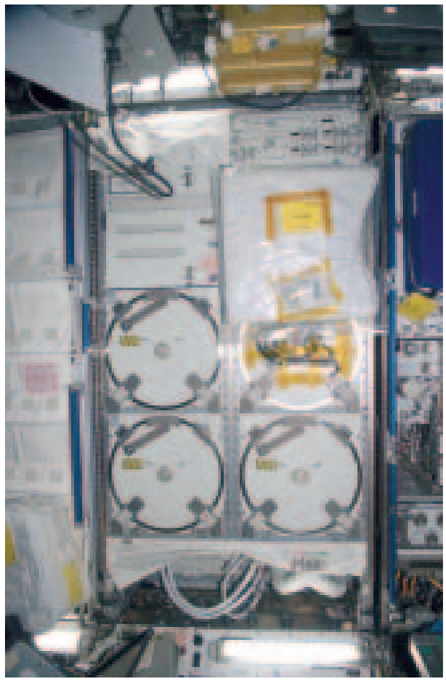
MELFI's cooling system provides a quite remarkable performance. It can cool about 300 litres in 2 days to less than –90ºC using only 900 W and hold it there with less than 800 W. It also meets the Station's stringent noise requirements (less than 40 dB). For comparison, similar systems on Earth use about double the power with noise levels around 60 dB (100 times higher), and could never handle 15 Shuttle launches!

The first MELFI flight unit (FU-1) was ready in October 2002 for a planned flight on Shuttle in March 2003. However, the *Columbia* disaster in February 2003 halted all launches for several years. FU-1 had to be deintegrated from its Multi-Purpose Logistics Module (MPLM) host and maintained for the next 3 years. This work included simple routine maintenance, such as briefly running the system and changing the operating fluids, and a more extensive effort to increase the time it can spend in orbit.

In fact, the change in the Station logistics scenario meant that MELFI's



MELFI is carefully manoeuvred into position in Destiny



...and ready for use

baseline utilisation had to be modified. The original plan was to cycle the three MELFI units between orbit and Earth, with ground maintenance shorter than 2 years between missions. The plan now is to launch only two MELFIs before the Shuttle retires in 2010 – and keep them in space.

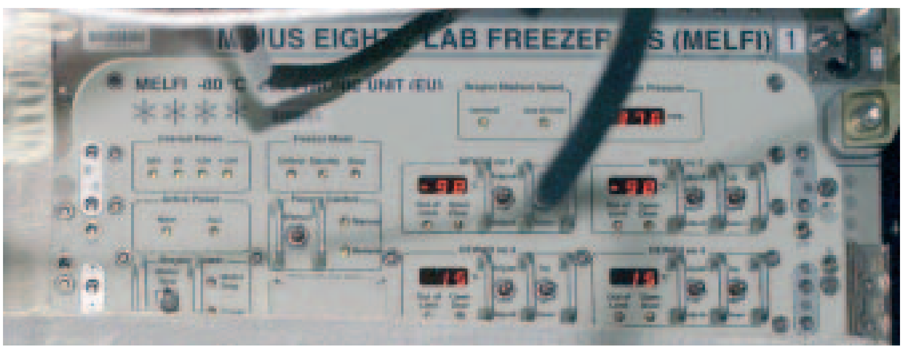
At NASA's request, ESA assessed this proposal. The study showed that MELFI's very robust design will allow it to remain in space, with additional maintenance using dedicated tools and spares provided by European industry. The consequences for the Station's work schedule have still to be discussed and agreed between the two agencies.

This has also changed how the samples are delivered to Earth. The original scenario used MELFI as a transportation freezer, up/ downloading frozen materials and processed samples every 3–12 months. But given the far fewer Shuttle flights now and the retirement in 2010, a new route for cooled samples needs to be found. At the moment, the only possibilities are the Shuttle's small middeck freezers (such as Merlin), or thermal bags lined with phase-change materials (PCMs). Of course, the middeck freezer path will be lost with Shuttle's retirement. And the thermal bags can hold the required temperature for only a few hours.

This problem of returning hardware and, in particular, experiments results from the Station is probably the most critical for using the ISS to its full potential.

ESA has studied retrievable capsules and freezers that could fit in them. This includes both active freezers and passive, long-term storage containers. However, the lack of funding and support from the stakeholders has so far prevented their procurement.

The control panel shows the two active Dewars at –98°C; the others remain at the ambient +15°C



Into Orbit

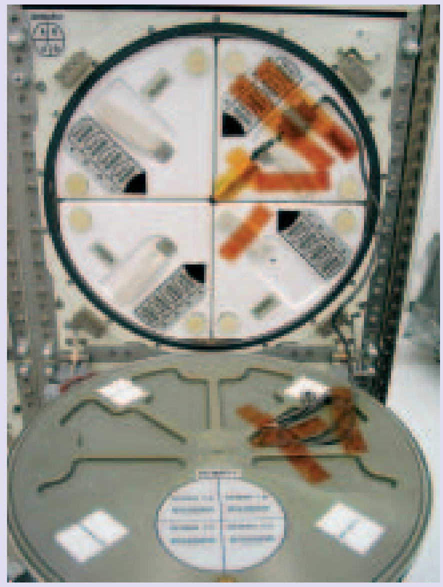
STS-121 delivered tonnes of equipment and supplies to the ISS following docking on 6 July, including MELFI FU-1. After attaching MPLM to the Station using Shuttle's robotic arm, the transfer of racks and supplies could begin. MELFI's move was particularly interesting because it is one of the largest and heaviest payload racks aboard the Station. Commander Pavel Vinogradov and Flight Engineers Jeff Williams and Thomas Reiter had to move the bulky item with great care through the ISS to its final position in the Destiny laboratory. There was always the risk of damage to the rack itself and to the many items stored en route.

Once all the connectors were locked, the rack was powered up on 19 July and commissioning began. First, there was a general check-out of all the subsystems, and then the 'MELFI On-Orbit Cooling Experiment' (MOOCE) began to test performance.

Starting up the cooling machine was particularly important. It was qualified on the ground for up to 15 launches and retrievals, but its behaviour after a real

Jeff Williams removes the frozen 5 ml MOOCE sample

MOOCE sample frozen in the ground model



MOOCE hardware installed on Dewar-2

launch and in weightlessness was somewhat uncertain. A very careful procedure was thus followed, commanded remotely by ground operators.

Much to their relief, all went smoothly and the various speed steps were all taken flawlessly up to the maximum 96 000 rpm. This was followed by individual activation of all the Dewar valves. The full functionality of the cold system had now been demonstrated. In particular, Dewar-2 reached –97°C in about 12 hours.

MOOCE

MOOCE has now measured MELFI's cooling characteristics in orbit. The main reason behind it is the need expressed by some scientists to cool samples very quickly from ambient temperature in order to avoid damage to tissue or cell structures.

The experiment hardware was defined by the ESA Project staff and designed and manufactured at ESTEC, within the Thermal Control Section of the Directorate of Technical & Quality Management. The hardware was qualified at ESTEC and extensively tested at NASA's Kennedy Space Center launch site to verify its behaviour with the Station's data-acquisition systems. Cooling-speed reference tests were performed on the ground for later comparison with on-orbit runs.

The Station crew began configuring the MOOCE hardware on 20 July. A slight problem arose when the computer was switched on and the procedure initiated, but a complete blank screen appeared. Since the complete data stream, including video, was available on Earth, the ground team could see what was happening and could help the crew very efficiently in troubleshooting. This allowed the problem to be solved in less than half an hour; the experiment was started by inserting the first sample.

There were no other mishaps and all the planned runs were completed in about a week. All the data were downloaded for evaluation and correlation with the ground data and analytical models.

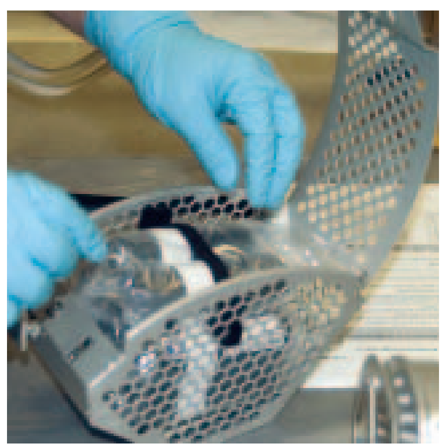
Complete analysis requires at least 3 months, but some preliminary conclusions can be drawn at the time of writing (September 2006). As expected, there are differences in the cooling times. The on-orbit curves show a slower rate, owing to the lack of natural convection, but there are also differences between the various runs. Those differences are most probably due to the way in which the samples were inserted into the freezer, and to the design of the packaging.

ESA will provide NASA and the user community with the '1 *g*-to-0 *g* tool" correlated with the on-orbit data. Users will be able to design different sample packaging, test them in the MELFI Engineering Model and predict the on-orbit performance.

First Samples

Given the positive results from the commissioning phase, NASA decided to activate another Dewar at the lowest temperature to prepare for the first insertion of science samples. 'Passive

ICEPAC inserted in a MELFI storage box





Jeff Williams inserts the POEMS sample container into Dewar-2: the first operational user of MELFI

Observatories for Experimental Microbial Systems' (POEMS), a US experiment devoted to microbial research, had the honour of being the first real sample cooled in Dewar-2, while a number of PCM packages were accommodated in Dewar-1.

These PCM packs (ICEPAC©) are essential for downloading processed samples to Earth. They were developed by NASA for the various temperature levels and require a long time for cooling, owing to their very high thermal inertia.

The thermal bags are filled with the ICEPACs just before insertion into the Shuttle middeck lockers before reentry. A large number of ICEPACs have to be used in order to stay safely within the allowed temperature range for up to 2 days. The bags are removed immediately upon opening of the Shuttle hatch as 'early retrieval' payloads. Logistics were developed by NASA, with some Ground Support Equipment provided by ESA, to ensure the specimens are delivered to the scientists in the best possible conditions.

The first European experiments to profit from MELFI were the SAMPLE, IMMUNO and CARD physiology experiments in September 2006. In the meantime, another ESA facility launched on STS-121, the European Modular Cultivation System (EMCS), completed commissioning in August and began operations in September with the TROPI plant experiment. TROPI then became a guest of MELFI in the autumn and will profit from the return route, together with IMMUNO and CARD, on STS-116 in December 2006.

MELFI FU-2 will be launched in 2008 and installed in Japan's Kibo module.

Conclusion

MELFI was a very challenging development for European industry. The advanced technology of the Brayton machine and its cold box required a great deal of resourcefulness. Highly dedicated engineers in the companies and ESA spent months on designing, manufacturing and verifying all the elements of the cold chain and developing the sophisticated control software to command them. The results, however, show that it was all definitely well worth the effort. Once again, European industry has shown its capability for being highly innovative and producing world-class payloads for science.

In order to get the full benefit from MELFI, it is important to capitalise on the technologies and to provide the Station and the science community with more transportation freezers and passive containers to be used after the Shuttle's retirement and for the Exploration programmes to come. Indeed, life sciences research is of paramount importance for ensuring human health and performance on these exploration missions.

MELFI may be operating in orbit for a very long time. With a robust logistics system for up/downloading samples, it will help scientists to get the best samples they need for making advances in life sciences for space and ground applications.

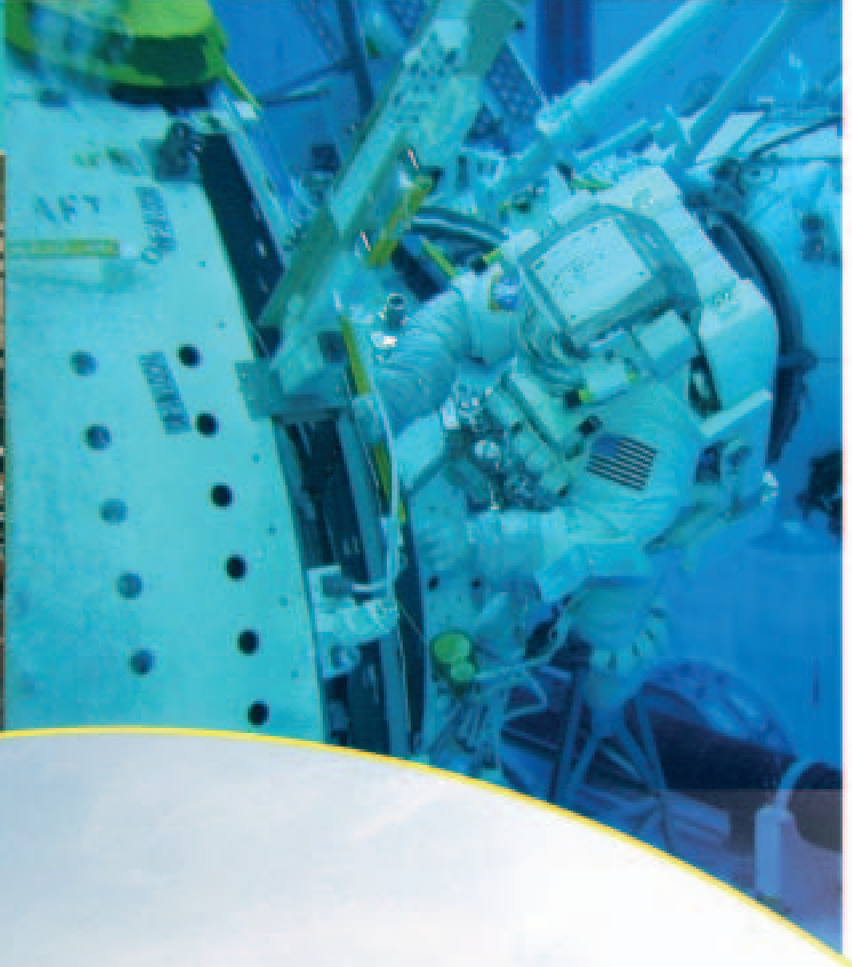
Acknowledgements

Thanks must be made to all the individuals who have contributed to the success of the MELFI. The authors wish to thank the development companies (EADS-Astrium, L'Air Liquide, Kayser-Threde, LINDE, ETEL, CRYSA, DAMEC) and their staff, NASA Project staff and ESA D/HME, D/TEC and D/RES staff for their invaluable support over many years.

More information about MELFI and its use on-orbit will be posted at http://spaceflight.esa.int/users after the MOOCE data are fully evaluated

Preparing for Space

EVA Training at the European Astronaut Centre



Hans Bolender, Hervé Stevenin,
Loredana Bessone & Antonio Torres
Astronaut Training Division, European Astronaut Centre, Directorate of Human Spaceflight, Microgravity and Exploration, Cologne, Germany

The European Astronaut Centre has developed an Extra Vehicular Activity (EVA) training course for ESA astronauts to bridge the gap between their scuba diving certification and the spacesuit qualification provided by NASA. ESA astronauts André Kuipers and Frank De Winne have already completed this 'EVA Pre-Familiarisation Training Programme' before their training at NASA. In June 2006, an international crew of experienced EVA astronauts approved the course as good preparation for suited EVA training; they recommended that portions of it be used to help maintain EVA proficiency for astronauts.

Introduction

During Extra Vehicular Activities (EVAs – spacewalks), astronauts venture from their protective spacecraft in autonomous spacesuits to work on, for example, the International Space Station (ISS) or the Hubble Space Telescope.

EVAs are among the most challenging tasks of an astronaut's career. They are complex and demanding, placing the astronauts in a singular, highly stressful environment, requiring a high level of situational awareness and coordination while working at peak performance.

Careful and intensive preparation of the astronaut is key to safe, smooth and successful EVAs. Water is the best environment for EVA training on Earth, substituting neutral buoyancy for microgravity. Preparation is therefore centred on special facilities such as the Neutral Buoyancy Laboratory (NBL) at NASA's Johnson Space Center (JSC, Houston), the Hydrolab at the Gagarin Cosmonaut Training Centre (GCTC, Moscow) and now also at the Neutral Buoyancy Facility (NBF) of ESA's European Astronaut Centre (EAC, Cologne).

During their Basic Training, all astronauts undergo a scuba diving course as a prerequisite to EVA training. For NASA and ISS partner astronauts undergoing Shuttle Mission Specialist training, this is followed by a general EVA skills programme at JSC that also helps to identify the most suitable EVA crewmembers.

Unfortunately, it is becoming increasingly difficult for ESA astronauts to undergo this NASA training. With the last Shuttle launch in 2010, the agreement for ESA Shuttle Mission Specialist training will come to an end. Moreover, the intense period of Station assembly flights means that NASA's NBL is significantly overbooked for operational testing and mission-related EVA training. And work for future exploration missions will only add to the burden.

So EVA skills training will not be fully available to international astronauts. Yet assignment to an EVA depends on evaluating astronauts' skills early in their training, and it is important for assigning Station crews and tasks.

EAC therefore took the initiative to develop the 'EVA Pre-Familiarisation Training Programme' to bridge the gap between scuba training and NASA's EVA skills training. It better prepares ESA astronauts in their initial qualification for using the Shuttle/ISS spacesuit (the Extravehicular Mobility Unit, or EMU), and to provide cognitive, psychomotor and behavioural skills ahead of the NASA training.

ESA Astronaut Claude Nicollier takes a photograph during a break from servicing the Hubble Space Telescope

"Together with NASA astronaut Mike Foale, I was privileged to perform EVA-2 during the Hubble Space Telescope Servicing Mission 3A in December 1999. As an ESA astronaut assigned to JSC for 20 years by then, my situation was not common: EVA training and discussions had almost become part of daily life as one of the major disciplines that had to be mastered for assembly of the ISS, in addition to a couple of anticipated Hubble visits.

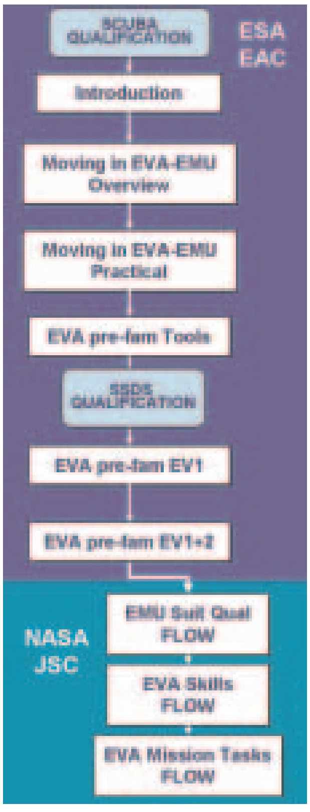
"In the future, European crewmembers will be less exposed to JSC's EVA culture than we were. Training in the Neutral Buoyancy Laboratory will not always be as extensive as it was, so preparation and preconditioning of astronauts from partner nations beyond the US and Russia are going to be a must for effective transition to the demands of training in the NBL.

"The preparation training provided at EAC's Neutral Buoyancy Facility will nicely fill that gap. Although without a spacesuit, it exposes the trainees to enough of the EVA challenges to be excellent preparation for NBL runs. Translation techniques, tether protocols, working under limited visibility and properly communicating with other crewmembers or the capcom/instructor can be exercised. It will give our astronauts a flying start in subsequent phases of EVA training, whether using the US Extravehicular Mobility Unit or the Russian Orlan spacesuit."

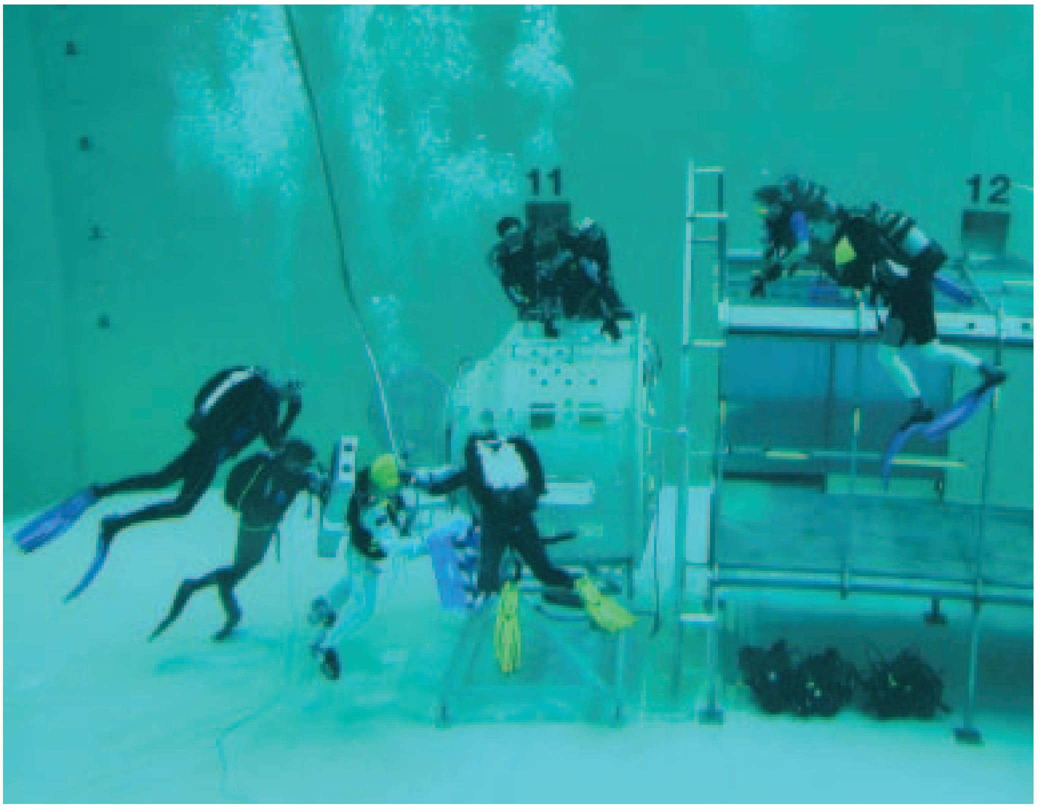
Claude Nicollier

EVA Pre-Familiarisation Training

A successful EVA requires psychomotor, cognitive and behavioural skills. Psychomotor skills range from the ability to move in the suit, move along the Station using handrails (translation) and pass obstacles, to operating equipment and tools. Cognitive skills are as important, and range from navigating around the Station despite the very limited field of view, to applying tethering and operational rules. Behavioural skills include situation and spatial awareness, decision-making and problem-solving, workload management and efficiency, teamwork and communication.



The training flow of ESA's EVA Pre-Familiarisation course at EAC



An ESA astronaut (white suit) performing the EV1 dive in EAC's tank. He is equipped with SSDS and a mockup of the life-support backpack

The objectives of the course are for the trainees to become able to:

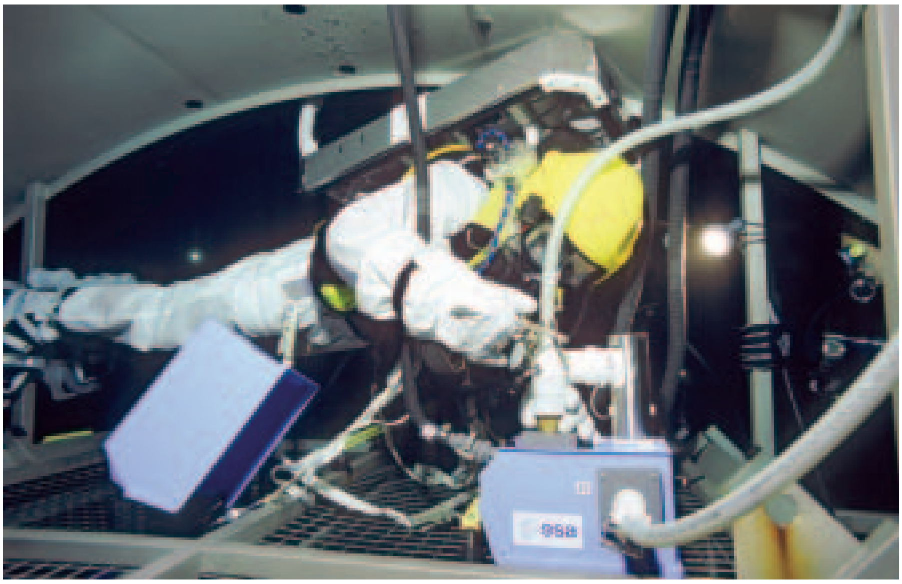
- explain and demonstrate the correct use of a set of tools and equipment, including the transportation and installation of Orbital Replaceable Units (ORUs) and the manipulation of connectors;
- perform translation, rotation, passing of obstacles in a typical EVA translation path, while wearing EVA-like equipment, using safety tethers or waist tether protocol (Russian-like);
- perform a worksite assessment, secure oneself at the worksite and perform, alone or with a partner, a defined task including ORU exchange;
- handle tether operations, as in exiting from an airlock;
- plan a typical EVA as a 'buddy' team, and carry it out in cooperation with a crewmember inside the craft.

The course is spread over 1–2 weeks, consisting of a series of classroom courses, briefings and in-water exercises, scripted to challenge the trainees to think and perform as if they were conducting actual EVAs.

The main elements of the programme are:

- a description of the EVA course leading up to the EMU Suit Qualification in the NBL, to give an overview of the programme and general expectations during the training exercises to follow;
- an overview of the EMU suit, describing its biomechanics and constraints in water and space;
- a briefing on 'moving in space', providing recommendations on the best strategies for moving in the suit without fighting it, for moving along and around the Station structure while allowing for suit limitations and the Station constraints (obstacles, keep-out zones);
- a practical session of underwater exercises to apply the movement strategies. This training is in the NBF tank led by an instructor to demonstrate various methods of performing translations in different body postures, changing attitude and adjusting body orientations around confining structures;
- a briefing and hands-on training on deck describing the EVA tool operations and interfaces to specific wet equipment that will be used in the underwater exercises;
- the Surface Supplied Diving System (SSDS) qualification, required for voice communications between the trainee and the instructor in the Control Room (for details see the 'NBF Characteristics' box);
- a second session underwater, the 'EV1 Run', to highlight the fundamental skills of a typical EVA. It is performed fully equipped for SSDS and wearing a low-fidelity mini-work station strapped to the chest to carry EVA tools, a backpack representing the EMU's Primary Life Support System,

a representative helmet, a pair of unpressurised EMU gloves and boots suitable for foot restraints. There is a very limited set of tethers, along with dummy tethers deliberately to increase the likelihood of tethers snagging during translation. The trainee has to perform an end-to-end EVA including airlock egress/ ingress, ORU payload transportation to/from a worksite, translation using waist tethers (Russian protocol) and operation of ISS connectors. The trainee must always comply with the EVA rules: items and body must be tethered at all times, touch handrails only for translation, use only D-rings or handrails for attaching safety tethers, and avoid keep-out zones. Disturbances are introduced during the scripted run to exercise situational awareness, communication skills and decision-making;



An ESA astronaut works with ISS connectors while standing in a portable foot restraint

– the third and final 'EV1+2 Run' underwater consists of a two-member EVA designed to emphasise teamwork and team situational awareness, crew communication and workload management, in an even more realistic and challenging scenario. The trainees are paired and encouraged to develop their own timeline and to define the sharing of their EVA tools. The equipment is the same as for the EV1 Run, except that the US safety tether protocol is used and the life-support backpack cannot be used owing to space limitations in the airlock. More tethers are also worn. The rules of engagement include all those of the EV1 Run plus additional constraints for an ORU change-out requiring specific tools from a toolbox at a second work site. The Test Conductor/instructor, who also plays the onboard crew role, inserts unexpected equipment failures and unplanned activities, adjusting the script's intensity to the crewmembers' performance.

These last two activities are controlled by a Test Director, responsible for leading the EVA operations and supervised by the Test Conductor. Both are in the Control Room, with a Medical Doctor and a Safety Officer, responsible for the well-being of the crew and the safety of the operations, and an Audio/Video Operator to ensure the distribution and recording of all required signals. The Dive Supervisor directs and monitors on-deck the pre- and post-dive activities of the Trainees, Safety, Utility and Camera Divers, SSDS operator and deck support personnel.

A study guide and DVD package with the course material, videos of the EVA runs at EAC and additional reference documentation and EVA skill demonstration videos, as well as computer-based training material, is given to the trainees upon course completion.

During the past 2 years the Neutral Buoyancy Facility and its operations have been constantly upgraded and adapted for the programme. Around 20 certified staff are available for NBF and EVA operations, many with cross-certification for multiple operational functions. Operations documents, processes, checklists and dive plans have been developed to support smooth and safe diving operations. Safety processes have been defined and conducted to evaluate and (re-)certify the NBF and EVA infrastructure and equipment.

A Test Readiness Review process has been developed to ensure safety and readiness of the test operations, facility, equipment and personnel. It is called on for each diving campaign, for new or modified equipment and for changes in procedures, rules or operations.

An end-to-end test of the emergency rescue chain was run in June 2006, including external support from medical operations, onsite security, the water rescue team of the fire brigade, and rescue helicopter teams.

Training Runs for ESA Astronauts

Two ESA astronauts with no EMU experience were scheduled to start their EVA training in Houston in late 2005, as part of their ISS crewmember training programme: Frank De Winne and André Kuipers. Both had done scuba training at EAC, and André had already undergone Russian Orlan suit training in the Hydrolab at the Gagarin Cosmonaut Training Centre.

To help them, development of the training programme was accelerated in early 2005, and tested by experienced spacewalkers Claude Nicollier and Gerhard Thiele.

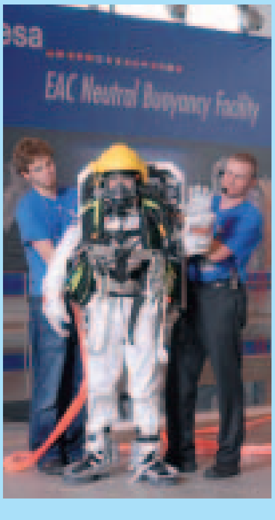
Neutral Buoyancy Facility Characteristics

NBF Hall, Rooms and Equipment
- 48 m long, 24 m wide and 14.4 m high
- NBF control room, scuba equipment room, EVA equipment room, electrical and mechanical repair shop, scuba filling station, technical rooms for pool maintenance, water filtration/purification, control and heating, showers/dressing rooms and sauna
- Remote air compressor with storage tank assembly including high-pressure feedline connection to multiple filling station in NBF hall
- Overhead girder crane with 5 t capacity

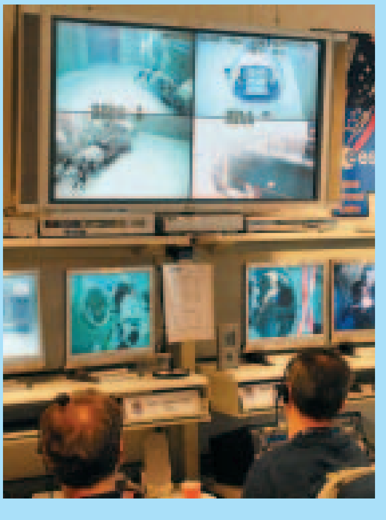
Water Tank
- 22 m long, 17 m wide and 10 m deep, volume 3747 m^3, temperature range 27–29°C
- Submersible platform 5x3.5 m for 0–9.5 m depths, 250 kg loading capacity at 0 m
- Continuous monitoring of water quality (e.g. pH value, chlorine, temperature)

Mockups
- Modified Columbus wet mockup with ISS handrails and EVA workstations
- Russian airlock mockup
- deployable solar panel mockup

Scuba and SSDS Diving Equipment
- 20 complete sets of scuba equipment (tanks, regulators, suits etc)
- 3 SSDS sets composed of:
  - full-face mask with microphone and earphones for 2-way communications between SSDS divers and on-deck personnel;
  - buoyancy jacket including inflator, with 6 litre/300 bar reserve air tank, pressure gauge and dive computer;
  - 60 m umbilical hose connected to deck air supply and for communication cables.
- SSDS cart on-deck hosting umbilicals, air tanks, pressure-monitoring devices and video and audio monitoring



EVA Tools
- ISS handrails mounted on airlock and Columbus mockups
- Portable Foot Restraints (PFRs) mounted on EVA worksites on Columbus mockup
- EMU-like boots for use with PFR
- EMU Primary Life Support System backpack, helmet and gloves (unpressurised)
- Mini Work Stations
- limited sets of EVA and dummy tethers
- EVA connectors (electrical and fluid)
- ORU box and EVA tool box



NBF Control Room
- Video: 8 channels, including switching matrix for observation and multiple recording of underwater and deck operations
- Additional monitor with switching matrix for deck personnel in NBF hall
- Audio: 2 audio loops for bi-directional communications between deck personnel and between deck personnel and divers (including private loops with SSDS divers)
- Underwater loudspeakers for unidirectional communication with all divers
- Wireless headsets for deck personnel

Frank and André completed the course in three slots. The first two, in June and September 2005, covered everything up to the EV1 Run so that they could gain their EMU Suit Qualification at JSC. Feedback from them and their NASA instructors confirmed that the ESA programme had significantly contributed to their performances during the first training run in Houston. They also provided valuable suggestions for improvement.

The training concluded in March 2006 before Frank and André resumed their EVA training at JSC, and focused on the EV1+2 Run. Both asked to perform it again some time as a refresher, because it appeared to be useful for proficiency training.

Frank and André's EVA Pre-Familiarisation Training was fully coordinated with NASA's chief EVA instructor. Following this success, the NASA EVA office decided to have international and experienced EVA crewmembers perform an official review to validate the training.

Cooperation with NASA

This programme was developed through very fruitful cooperation, first proposed in 2002, between EAC and the EVA training experts at JSC.

As a first step, NASA-NBL and ESA-NBF in 2004 jointly agreed on a *Diving Certification Protocol for ISS Crew Members and Training Specialists* to harmonise the requirements for scuba diving proficiency training and certification. The logical next step was to extend the cooperation to the NASA EVA Office to identify jointly how EAC could improve the preparation of European astronauts for future EVA training at the NBL. This led to the signature of a *Framework of Cooperation between the NASA EVA Office, NASA Neutral Buoyancy Laboratory (NBL), NASA EVA Operations and the ESA Neutral Buoyancy Facility (NBF) for the preparation of European Astronauts to EVA Pre-Familiarisation*.

As a result of this agreement, NASA provided 40 hours of EVA training to ESA instructors Loredana Bessone and Hervé Stevenin, including a 4-hour EMU Suit Qualification at NBL. It was the first time that non-astronaut Europeans had received such training at JSC. In cooperation with the NASA instructors, objectives were identified, requirements defined and the new course developed, tested and in place at EAC in less than a year.

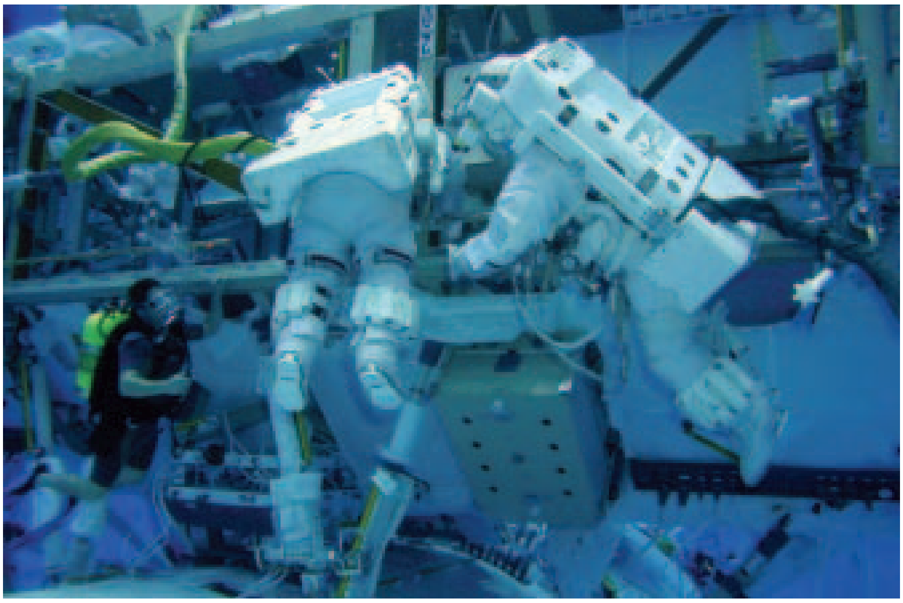
In December 2005 an *ESA-NASA EVA Pre-Familiarisation Workshop* took place at EAC over a week to demonstrate the ESA course to NASA EVA experts, including the supporting NBF operations and EAC's safety set-up. NASA feedback and recommendations were integrated and ESA and NASA jointly developed the EV1+2 Run.

Frank De Winne in the SSDS mask at EAC

"This training really helped me in preparing for the first EVA runs I had to do at JSC. During my first runs in the NBL, I was really amazed to see how much I had learned from these first simulations. This EVA precursor training is, for me, the first step in acquiring European expertise in operational training, beyond the normal system training that is already performed at EAC."

Frank De Winne

ESA instructors Loredana Bessone and Hervé Stevenin work in JSC's Neutral Buoyancy Laboratory to gain their NASA Suit Qualification



Claude Nicollier undertakes the pre-familiarisation training at EAC

ESA-NASA-JAXA Crew Review

The success of the workshop raised the interest of the NASA Crew Office, who decided to perform an official Crew Review, to assess the suitability of ESA's course for inexperienced EVA crewmembers, and the suitability of the EV1+2 run for maintaining the proficiency of experienced EVA crew during long periods of non-EVA training.

The following astronauts took part as trainees to evaluate the course:

- Scott Parazynski, NASA (former Chief of the NASA Astronaut Office EVA Branch, has logged 20 hours of EVA);
- Koichi Wakata, Japan Aerospace Exploration Agency (JAXA; two spacewalks);
- Paolo Nespoli, ESA (working for the NASA Astronaut Office EVA Branch).

The participants in the ESA-NASA-JAXA Crew Review, June 2006

They were supported by a NASA delegation that included representatives from the EVA office, the NBL and NASA Safety. Stephen Doering, Head of the NASA EVA Office, also attended the training at EAC. The first week consisted of a thorough safety inspection, and the preparation and execution at EAC of a joint NASA-ESA Test Readiness Review to ensure that both parties had a common agreement on the safety and operational readiness of the programme before the the crew arrived.

This event was followed by an intense week of training for the three astronauts, who went through the complete course. They provided outstanding feedback, including detailed recommendations to improve the quality even further. As a close-out of this Crew Review, all of them delivered reports to a NASA *EVA Crew Consensus Memorandum for Validation of the European Astronaut Centre EVA Pre-Familiarisation Training Program* issued by Dave Wolf, Head of the EVA Branch in the NASA Crew Office.

ESA Astronaut Paolo Nespoli (left) and NASA Astronaut Scott Parazynski prepare for a dive

Conclusion

The ESA EVA Pre-Familiarisation Training Programme has proved to benefit ESA astronauts who have not yet been through EVA training at JSC or GCTC ("*EAC personnel are to be commended for their innovation and hard work preparing this excellent course*" said Dave Wolf). It will also be of great value to the new ESA astronaut candidates, who will begin Basic Training at EAC within the next 2–3 years.

The programme not only prepares ESA astronauts for assignment to ISS EVA crews. As reported in the Crew Consensus Memorandum, "*it has also considerable potential to aid current ESA astronauts in general proficiency maintenance of EVA operations and situational awareness while not assigned to training at JSC or GCTC*".

The memorandum also states "*other*

Thomas Reiter during his ISS spacewalk on 3 August 2006

International Partner astronauts not in full time training at JSC or GCTC might find this program beneficial prior to commencing suited EVA training". This innovative ESA programme is an open door to extend current EVA cooperation to the other ISS partners.

Besides crew training, the NBF infrastructure (including the EVA expertise available at EAC) can also test space hardware underwater. The first underwater test of Eurobot is scheduled before the end of 2006.

Last but not least, this programme has provided ESA with valuable expertise in developing and performing spacewalk training. Combined with the EVA experience acquired by the ESA astronauts through their space missions, it is helping to build operational knowledge at EAC for Europe on the challenges of EVAs, which can only be beneficial for future human spaceflight exploration.

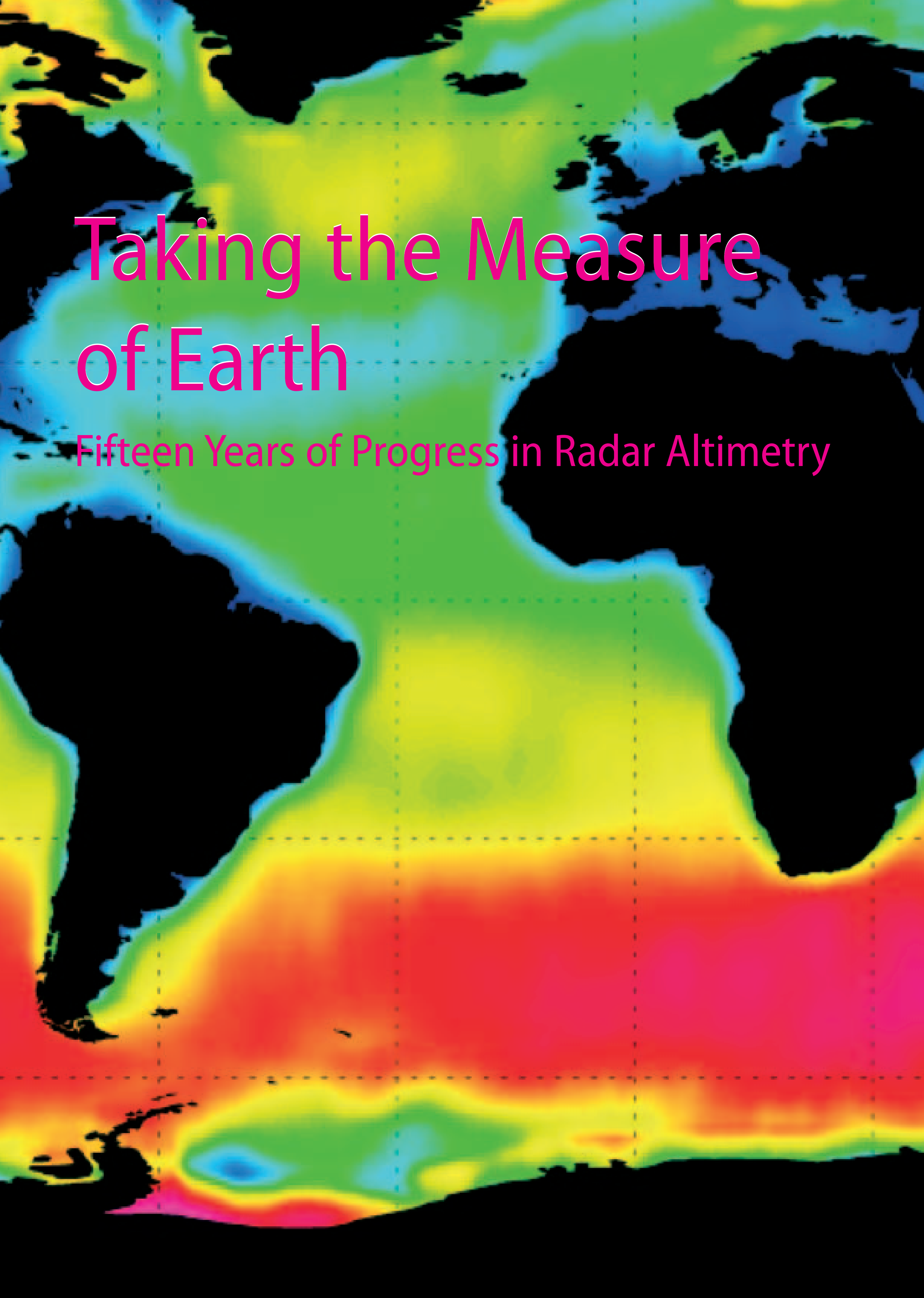
Acknowledgements

Numerous individuals and organisations made this course possible through their expertise, support and dedication. Our gratitude goes to all of them, but since it is impossible to name them all, the authors thank the organisations they represent: NASA-NBL, NASA EVA Office and EVA Operations, NASA JAXA and ESA Astronaut Offices, NASA and EAC Safety. The diving team from SDT&S, DLR Technische Dienste, DLR Institut für Luft- und Raumfahrtmedizin and EAC Medical Support Office, Berufsfeuerwehr Koeln and Taucherrettungsgruppe der Berufsfeuerwehr Koeln, ADAC Luftrettung 'Christoph-Rheinland', Polizeifliegerstaffel West. A special mention goes to the divers and EAC team members involved in the NBF/EVA operations.

Further information on the European Astronaut Centre and its activities can be found at www.esa.int/eac

Taking the Measure of Earth

Fifteen Years of Progress in Radar Altimetry



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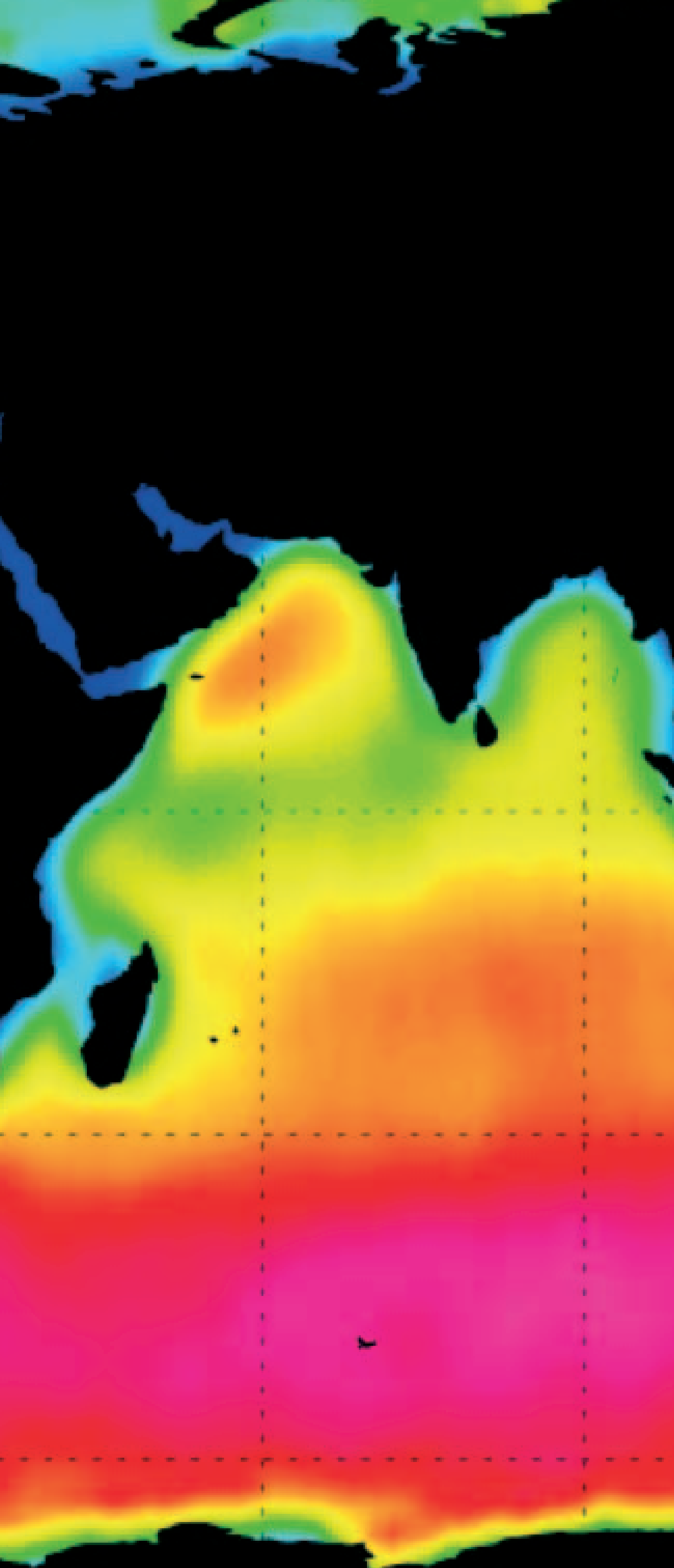
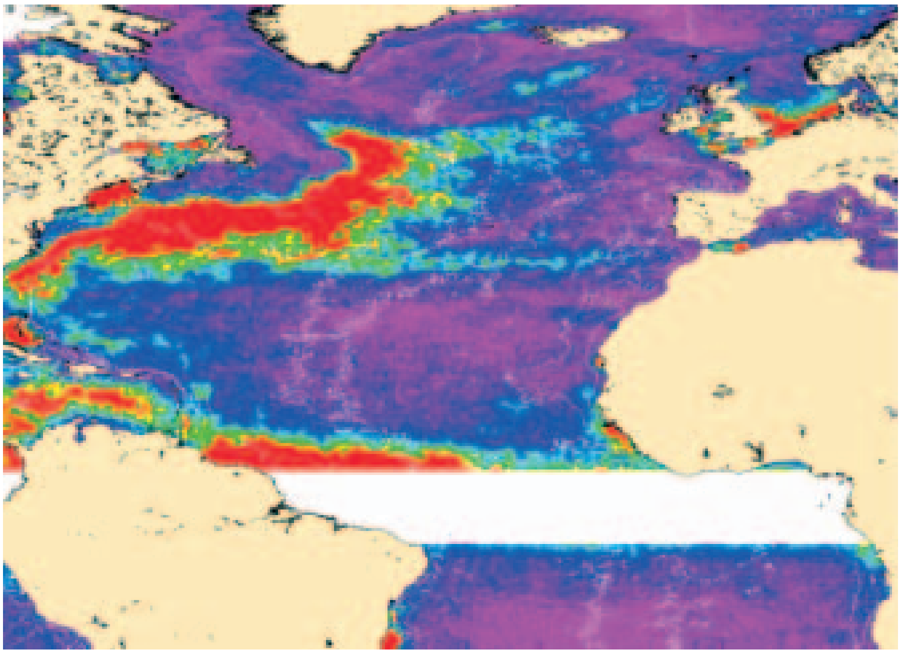


Wave heights measured by ERS-2 during the northern summer. Red/pink shows rougher seas during the southern winter

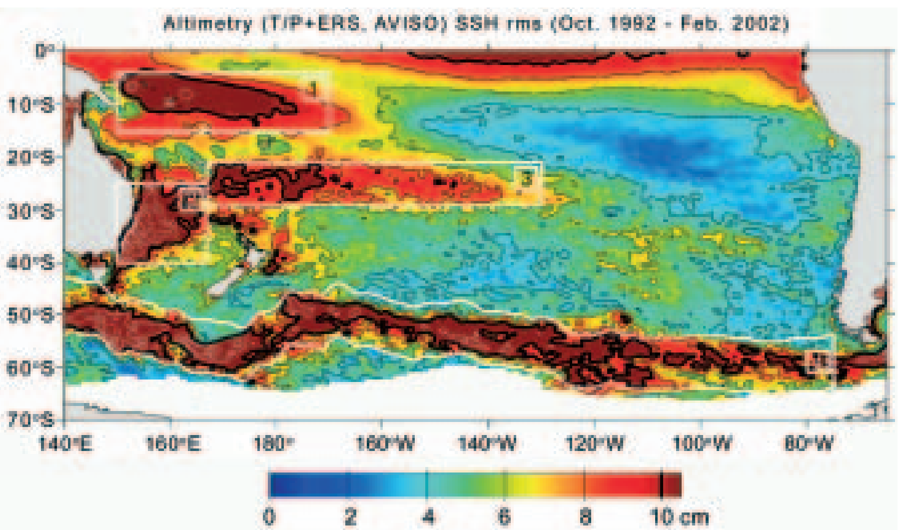
Radar altimetry is about to enter a new era. It is becoming an indispensable tool for oceanography as a new generation of radar altimeters providing higher resolution and precision is poised to begin service. Remarkable progress has been made since the launch of the pioneering ERS-1 in 1991.

Introduction

The ERS-1 European Remote Sensing satellite, launched in 1991, was ESA's first Earth-observation research satellite. Its comprehensive payload included an imaging synthetic-aperture radar, a radar altimeter and other powerful instruments to measure the sea-surface temperatures and wind characteristics. ERS-2 followed in 1995 and, remarkably, is still operating. At the time, the ERS twins were the most sophisticated Earth-observation satellites ever developed and launched by Europe. They have collected a wealth of valuable data on Earth's land surfaces, oceans and polar caps, and have been called upon to monitor natural disasters such as severe flooding or earthquakes in remote parts of the world.



The kinetic energy of eddies in the North Atlantic calculated from sea-level data along the Topex-Poseidon and ERS groundtracks. Red highlights the greatest energy. (Le Traon & Dibarboure)



The variability of sea-surface height from Topex-Poseidon and ERS data in the southern Pacific Ocean. Box 1 highlights the variability of the South Equatorial Counter Current. Box 3 shows the variability of the South Tropical Counter Current. (Qiu &Chen)

By 1992, the unique results from ERS and the CNES/NASA Topex-Poseidon had provided a strong foundation for the future of satellite altimetry and the missions then in development, such as Jason (CNES and NASA/Jet Propulsion Laboratory), Envisat and Geosat Follow-On (US Navy). Countries with different cultures, especially Europe and the USA, learned to work towards common goals, and the different geodesy, geophysics and oceanography scientific communities had to learn to work closely together. Cryosphere researchers benefited by adapting the technology and data-processing progress made by oceanographers, to monitor the ice caps and sea-ice.

Over several decades, new technologies with improved accuracy were developed. The accuracy of global geodetic measurements has increased from a few hundred metres at the beginning of the satellite era to a few centimetres now. Though a highly complex problem, it recently became possible to exploit radar altimetry to monitor inland water levels; the accuracy over these difficult terrains is improving rapidly.

After many years of development and data exploitation, radar altimetry is becoming operational in oceanographic applications. A new generation of high-resolution and high-precision instruments is entering service using techniques such as ‘delay-Doppler’ and interferometry. We now know much more about our Earth, ocean dynamics and the cryosphere than we would without altimetry, and we have laid the foundations for fully operational 3-D oceanography.

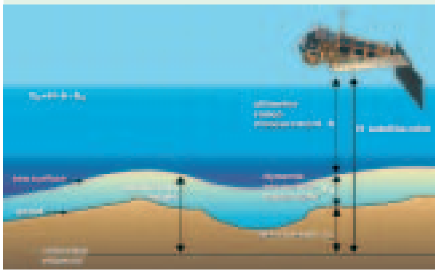
Understanding the Ocean

Radar altimetry has made an important contribution to oceanography by investigating the high-frequency variability in sea-surface height from global to basin scales, and its impact on the oceans’ general circulation. It highlights the importance of eddies in shaping and controlling the flows of major current systems such as the Antarctic circumpolar current and western boundary currents (Gulf Stream and Kuroshio), and the influence of eddies on the vertical mixing in the ocean. The results from 15 years of altimeter data on eddy variability in the oceans are outstanding and are certainly a major accomplishment. Altimetry has proved unique in dramatically improving our tide models, in observing internal tides and understanding the genesis of climatic events such as El Niño and the North Atlantic or North Pacific Oscillations. Now it is the interaction between phenomena such as planetary waves, eddies, tides and mean flow, and their impact on coastal regions, that must be investigated. These new studies will benefit greatly from the higher resolution sampling provided by the upcoming altimeter missions.

The Principle of Radar Altimetry

Radar altimetry measures the distance between a satellite and the surface below using radar echoes bounced back from the surface, whether ocean, ice cap, sea-ice, desert, lake or river. The characteristics of the echoes contain further information on the roughness of the surface, wave heights or wind speeds over the ocean.

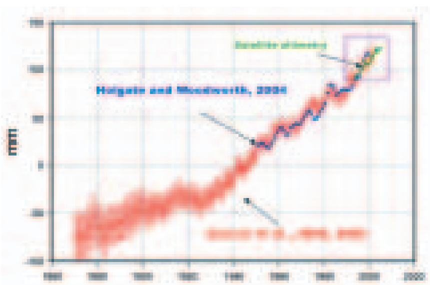
Altimetry measurements become scientifically more useful when the satellite's position is accurately known. Many satellites, including Envisat and CryoSat, carry the DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) radio receiver for precise orbit determination. DORIS calculates the orbit to an accuracy of a few centimetres by measuring the Doppler shift on signals broadcast from a network of more than 50 beacons spread around the world.



Sea levels

Altimeter observations from satellites show that the global mean sea level has risen over the past decade at a rate of about 3 mm each year, well above the rate of 1.8 mm per year over the previous 100 years. This is despite large geographical variations, including broad areas of falling sea level. Consistent increases in both sea level and sea-surface temperatures have been found in most parts of the Atlantic Ocean over the past 15 years.

The rise in sea level during the 20th century appears to be accelerating. Satellite measurements for the last 15 years are shown in green. (Cazenave et al.)



In the Indian and, particularly, Pacific oceans, the trends in both sea level and temperature are still dominated by the large changes associated with the large El Niño Southern Oscillation of 1997–1998. Fresh water brought by rain, snow, melting sea-ice, ice sheets and glaciers complicate our understanding of the rise in sea levels. It can be expected that the next decade of altimetry will provide fundamental new insights into these important features.

Tsunamis

The Sumatran tsunami of December 2004 was the first to be observed by altimeters in space, which has allowed scientists to improve our understanding of how tsunamis propagate. This is invaluable for helping to avoid disasters, in addition to being of great interest for science. One of the main components of building propagation models is the underwater equivalent to altimetry: bathymetry. This is the measurement of the depth contours of the soil, rock or sand at the bottom of a body of water such as an ocean or a lake. Deriving sea-floor topography from radar altimetry is improving the accuracy of these models because the nature of the floor influences how tsunamis move and build.

Marine meteorology

Radar altimeters are indispensable for observing the sea state in a variety of applications. Wave climatology, a well-established altimeter application, is continuously enriched by new data as they become available; the longer the record, the more consistent and reliable the results. Correlation of wave-height variations with climatological phenomena such as the North Atlantic Oscillation has been observed – and has opened a whole new area of science. Wave modelling, a traditional application, has greatly improved recently thanks to the assimilation of altimeter data in near-realtime, and is now generating accurate sea-state predictions, to the enormous benefit of the shipping industry. In addition, sea-surface topography measured by radar altimeters is also used in near-realtime jointly with sea-surface temperature and models to investigate how the upper-ocean thermal structure is involved in strengthening hurricanes.

Understanding the Cryosphere

Glaciologists had to wait until the advent of ERS-1 to see a polar altimeter flying over sea-ice and the ice sheets. The instrument proved to be a very powerful tool for glaciology, with three major scientific objectives: ice-sheet modelling and dynamics, ice-sheet mass balance and sea-ice thickness. There are also numerous secondary uses.

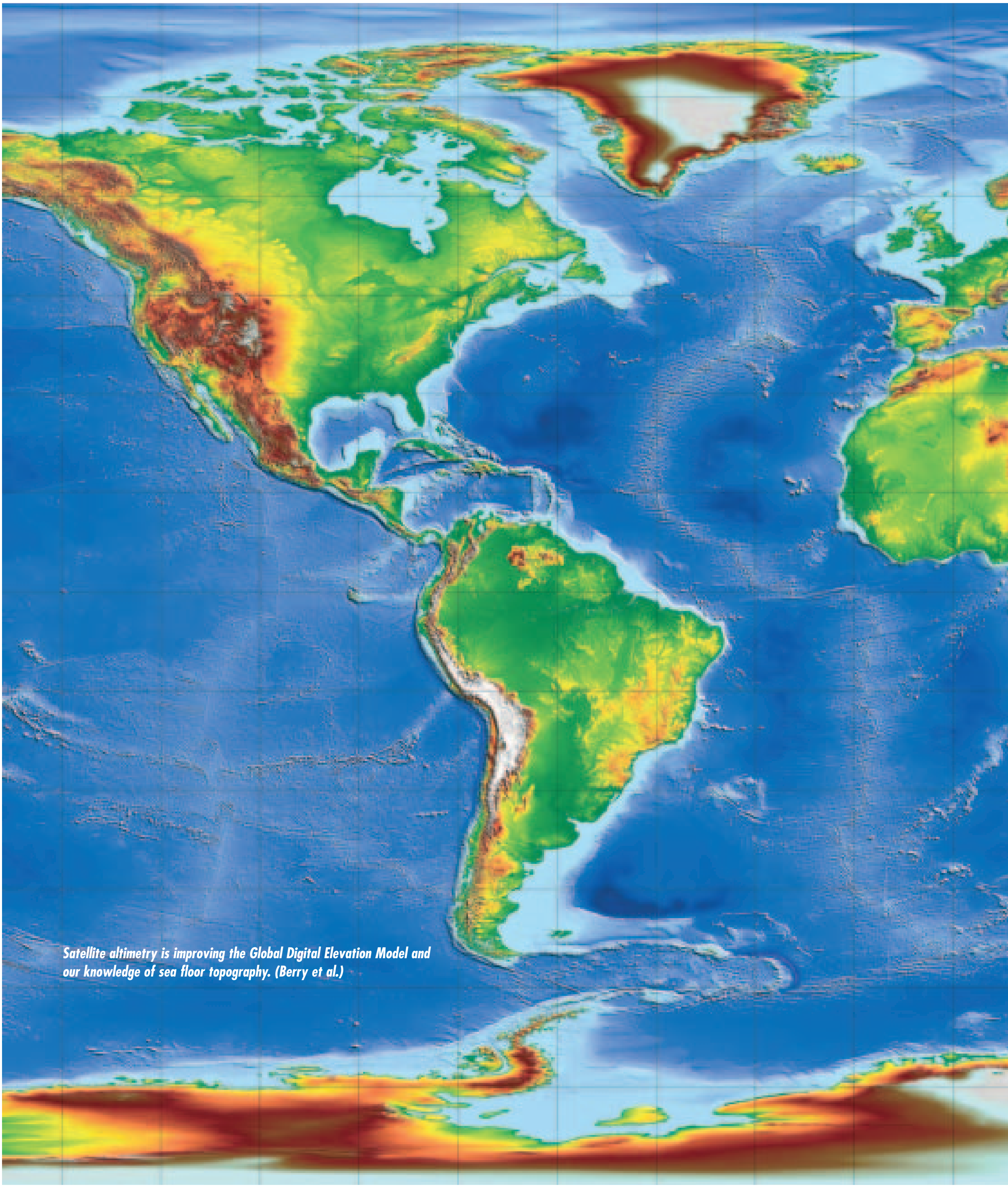
Ice sheets

The mass changes in ice sheets has been studied from space, ranging from the largest sheets in Antarctica and Greenland, to smaller ones such as the Austfonna (in Svalbard, the world's third largest icecap and the largest glacier in Europe). Overall, the Greenland and Antarctica sheets are found to be almost in equilibrium, losing as much ice as they gain, but local data suggest a loss that could accelerate in the near future.

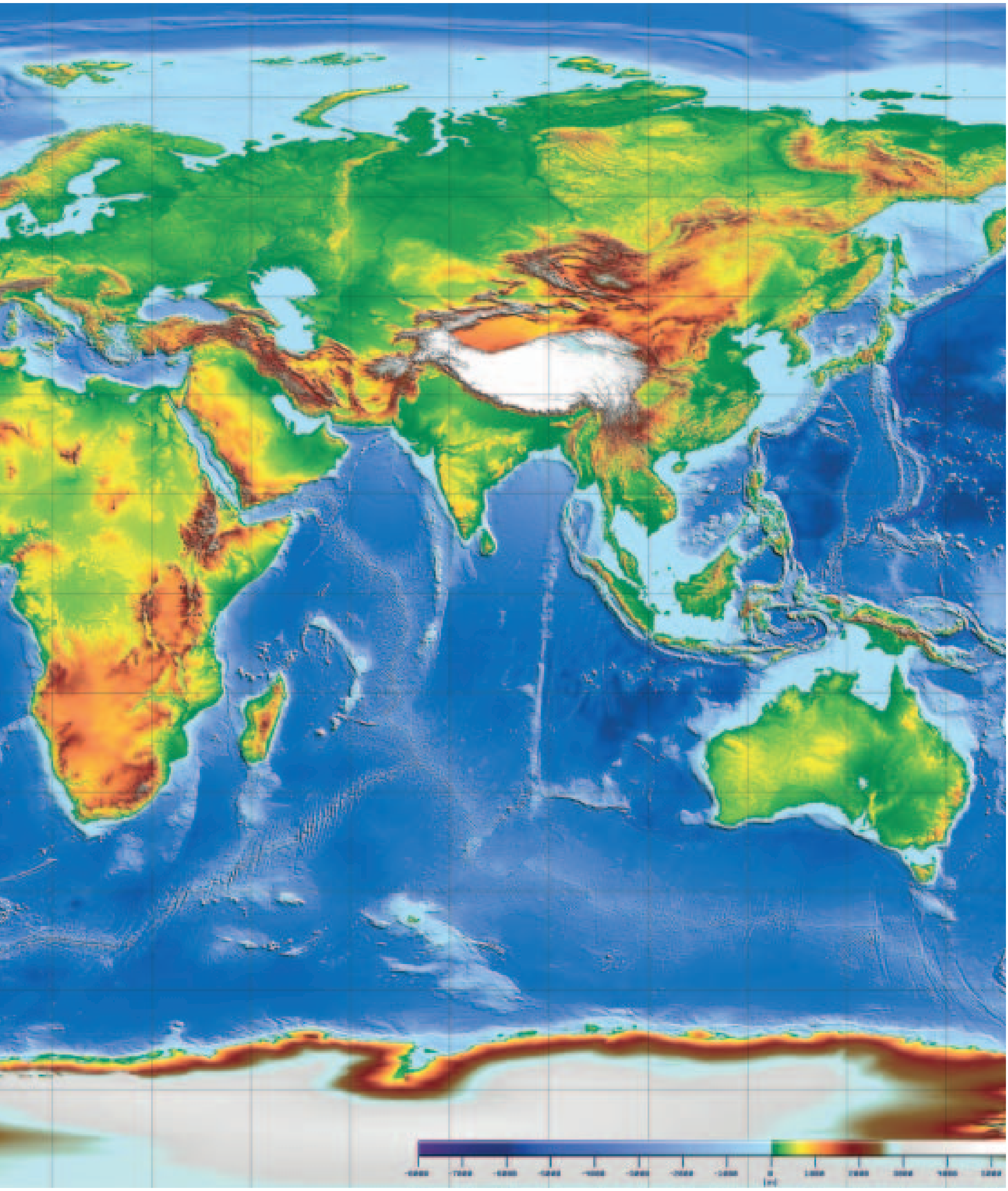
Radar altimeters are not only able to map the global trend but can also catch local imbalances. However, discrepancies between some studies may be explained by the behaviour of radar waves interacting with packed snow. This is why Envisat's dual-frequency altimeter is helping to improve our knowledge of how radar waves penetrate the snow.

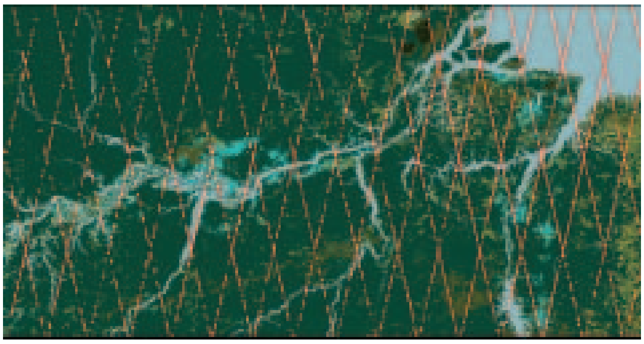
Altimetry over Land and Inland Water

The potential of satellite radar altimeter data for applications over land and inland water is now well known, as data from Topex-Poseidon, Jason, ERS-1, ERS-2 and Envisat have extensively shown. Initially developed to make precise measurements of sea surfaces, radar altimeters rapidly proved able to provide information over the continents. Their development to monitor continental water surfaces provides a powerful tool for studying regional hydrological systems.

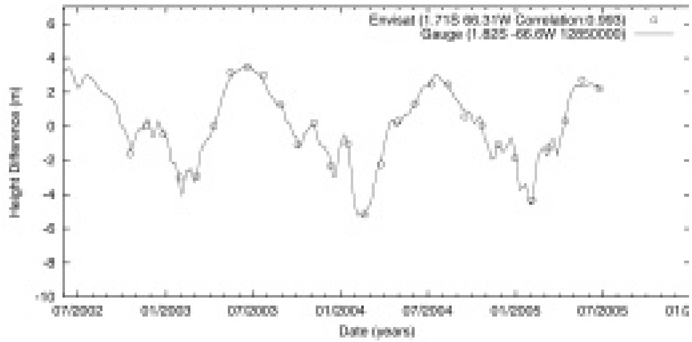


Satellite altimetry is improving the Global Digital Elevation Model and our knowledge of sea floor topography. (Berry et al.)





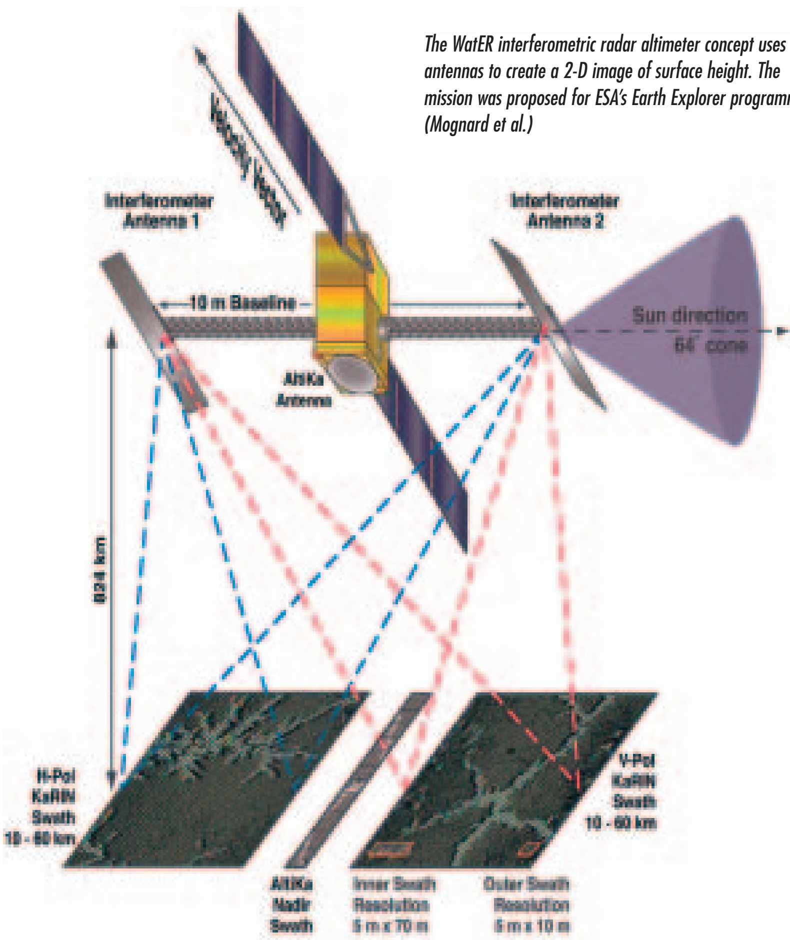
The ground track of Envisat's radar altimeter over the Amazon basin, using a 35-day repeat cycle. The height readings over the rivers were used to produce the accompanying graph of river levels since 2002 (Berry et al.)



Envisat altimeter measurements (circles) of the river levels in the Amazon Basin compare well with in situ readings from gauges (line). (Berry et al.)

Although monitoring inland waters is rapidly developing, the potential of multi-mission altimetry is only now being realised. One such mission is WatER, proposed both to ESA in 2005 as a response to the second call for Earth Explorer core missions and to NASA as a possible partnership mission with ESA. There are different scientific and technical challenges to be overcome in such missions. One is the need to map river basins in two dimensions, inferring the slopes as well as the levels of rivers.

While WatER would need several years to be developed, if selected, scientists are meanwhile focusing on exploiting today's missions (ERS-2, Envisat, Jason-1, Geosat Follow-On) and on the future CryoSat, Jason-2 and Sentinel-3 missions for studying inland waters.



The WatER interferometric radar altimeter concept uses two antennas to create a 2-D image of surface height. The mission was proposed for ESA's Earth Explorer programme (Mognard et al.)

Gravity and Marine Geoid Modelling

Geodesy

After years of slow progress, two missions – CHAMP (2000) and GRACE (2002) – are providing exciting results in global geodesy, and GOCE (2007) will soon join them. Geodesy primarily concerns positioning and the gravity field and geometrical aspects of their variations, and it can include the study of Earth's magnetic field. Gravity anomalies reflect mass variations inside the Earth, offering a rare window on the interior. The geoid is the shape of an ideal global ocean at rest, and it is used as the reference surface for mapping all topographic features, whether they are on land, ice or ocean. The geoid's shape depends solely on Earth's gravity field, so its accuracy benefits from improved gravity mapping. Measuring sea-level changes, ocean circulation and ice movements, for example, need an accurate geoid as a starting point. Heat and mass transport by oceans are important elements of climate change, but they are still poorly known and await measurement of ocean surface circulation.

The new EIGEN04 gravity model derived from these missions and terrestrial gravity data eliminates much of the 'meridional striping' seen in gravity models. Subtraction of this new model from an altimeter-derived sea surface reveals the dynamic ocean topography, at a resolution nearly sufficient to resolve the western boundary currents.

These models are an improvement over the EGM96 combined model and thus will provide an improved reference for higher-resolution marine gravity models derived from altimetry. The new global-scale geoid models also serve as a global vertical reference system. Scientists are preparing for the GOCE mission, which will provide improved spatial resolution (about 100 km), sufficient to resolve western boundary currents such as the Gulf Stream fully.

Marine gravity

Although no new non-repeating orbit radar altimeter data have been available since the ERS-1 geodetic phase in 1994–1995, reprocessing the raw altimeter waveforms has produced a near-40% improvement in the accuracy of the gravity field. Comparisons with shipborne gravity measurements over the deep ocean show the accuracy is now 3–5 mGal and the shortest half-wavelength resolved is approaching the altimeter track spacing of 8 km from ERS-1.

The Cryosat launch failure was a major setback for the marine gravity and geophysics communities because that mission would have provided a new global altimeter dataset with dense track spacing and, more importantly, it would have demonstrated the technology for the next generation of marine gravity measurements by altimetry. Scientists are delighted that ESA is rebuilding the satellite.

The laser altimeter aboard NASA's ICESat has provided new gravity information in those parts of the Arctic Ocean where permanent sea-ice closely conforms to the shape of the geoid. Further improvements in the accuracy and resolution of marine gravity would provide important contributions in both scientific and practical studies such as locating 50 000 uncharted seamounts in the deep oceans and exploring the offshore sedimentary basins for oil. Other applications include mapping the details of plate tectonics, planning shipboard surveys in remote areas and improved inertial navigation of aircraft and ships.

Bathymetry

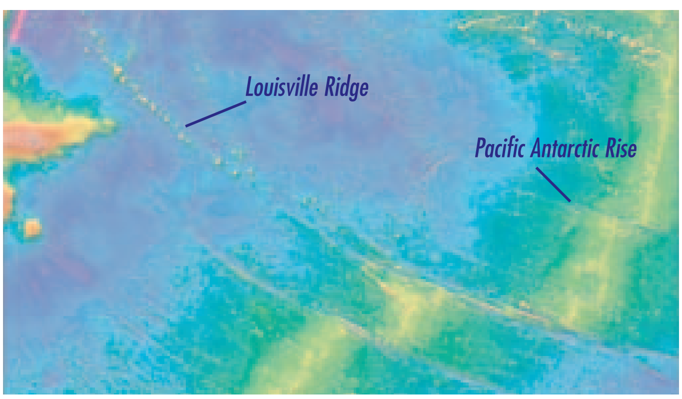
Ocean bathymetry is currently best measured by sonars aboard ships, but only a small fraction of the global ocean basins have been surveyed; it is estimated that it will take 125 ship-years to survey all of the deep oceans. The need for improved global bathymetry is critical because it forms the basic data for many fields, including tsunami propagation, hydrodynamic tide models/tidal friction, ocean circulation, seafloor tectonics, identification of volcanic chains, defining the 2500 m isobath for the law of the sea, and fisheries management.

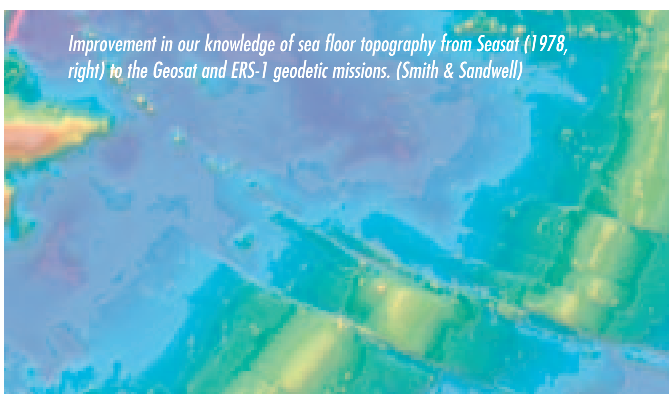
For example, the Pacific-Antarctic Rise and Louisville Ridge were unknown features 30 years ago. The Pacific-Antarctic Rise, covering an area about equal to North America, is a broad part of the ocean floor lifted up between two major tectonic plates. The Louisville Ridge lies to the west of this, and is a chain of large underwater volcanoes discovered in 1972 using depth soundings collected along random ship crossings of the South Pacific. Six years later, the full extent of this chain was revealed by a radar altimeter aboard NASA's Seasat. Recent data collected by Geosat and ERS-1 show the Pacific-Antarctic Rise and the Louisville Ridge in unprecedented detail.

Progress in Ocean Integrated Systems

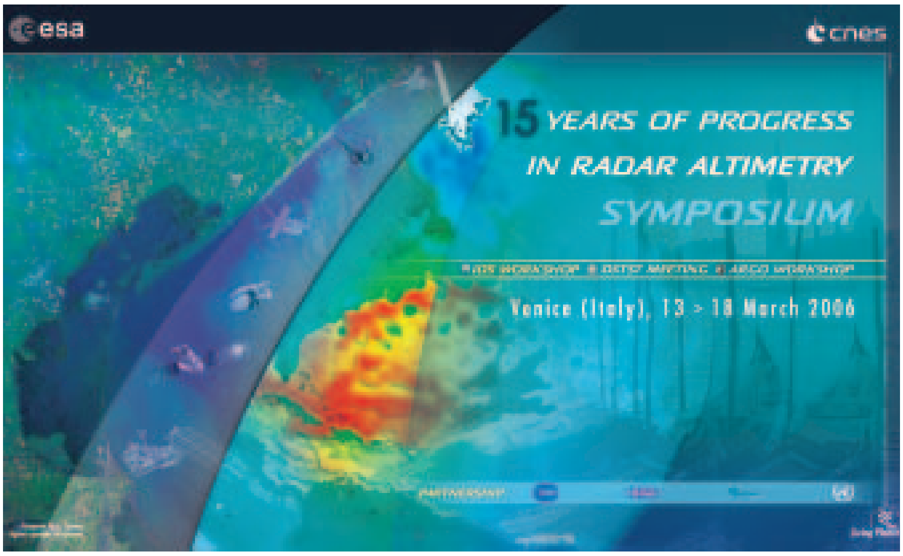
In 15 years there has been a wide range of activities: synergies between remote sensing and *in situ* data, development of operational oceanography systems, model validation and studies of the impact of the integrated approach on research and applications. The international Global Ocean Data Assimilation Experiment (GODAE) is a practical demonstration of near-realtime global ocean data assimilation that supports operational oceanography, seasonal-to-decadal climate forecasts and oceanographic research.

The main integrated systems developed as part of GODAE cover high-resolution (eddy-resolving) systems that focus on the forecasting of ocean mesoscale conditions, and lower resolution systems for climate applications. Such applications require a precise and dynamically consistent description of the ocean state. Use of advanced data assimilation techniques allows diagnostic studies such as heat balance. A major





Improvement in our knowledge of sea floor topography from Seasat (1978, right) to the Geosat and ERS-1 geodetic missions. (Smith & Sandwell)



issue for effective data assimilation is to estimate the model 'error covariance' and there has been a significant advance in accounting better for these errors.

A major contributing project to GODAE is Argo, an array of more than 2000 free-floating floats that provide temperatures and salinity measurements at various depths across the oceans. Argo results are scientifically valuable in their own right but can be combined with altimetry data for enhancing environmental and climate knowledge. Studies on the impact of altimetry and Argo on seasonal forecasts show they can significantly improve data-assimilation systems. Thanks to these studies, Argo and altimetry are now used in the operational seasonal forecasting systems of the European Centre for Medium range Weather Forecasting.

Physics and biology can be coupled through the joint analysis of altimetry, sea-surface temperature, ocean colour and model data. There are now studies into the different mechanisms that could explain the observation of planetary waves in altimeter, sea-surface temperature and ocean colour data. Horizontal advection is an important mechanism but vertical and biological effects cannot be ruled out. Other studies have shown the importance of ocean physics on the development of phytoplankton blooms in the wake of islands.

The main conclusion is that major advances over the past 5 years have helped to develop an 'integrated' approach to describe and forecast ocean conditions. Integrated descriptions of the ocean state are now available and are used to characterise and understand ocean climate variations better. This is crucial for the long-term sustainability of the global ocean observing system. The use of Argo and altimetry data is essential for developing an improved understanding of variations in the ocean climate. The strong synergies between Argo and altimetry will become more or more obvious as Argo is expanded.

A New Challenge: Coastal Monitoring

Altimetry may contribute in many ways to the study of coastal phenomena, especially tides, currents and sea state, that directly affect, for example, offshore oil exploration, fishing, marine aquaculture and coastal planning and development. Altimetry can supply direct measurements of sea level and sea state, and vital information about 'forcing' from areas just outside the coastal domain. These include the influence of offshore ocean circulation and the inflow of fresh water from land masses, closely tied to river and lake levels and to ice extent, all of which can be observed by altimetry satellites. However, coastal monitoring has very demanding requirements. The phenomena are often small-scale, rapidly changing and highly turbulent events calling for combined satellite and *in situ* data (such as from tide gauges and buoys) to ensure adequate resolution and coverage, as close as possible to the shore-line. Future altimetry systems will also have to meet these requirements, either by employing constellations of satellites or by developing new wide-swath radar concepts.

The Future of Altimetry

The European Commission-funded GAMBLE (Global Altimeter Measurements By Leading Europeans) project brought together European experts in 2002–2003 to consider future developments in satellite altimetry. The aim was to provide recommendations for research and future altimeter missions to support and build on current work in operational oceanography and to maintain ocean-monitoring programmes.

GAMBLE recommended in 2003 that coverage by a single satellite is not sufficient to meet both operational and scientific user needs. Rather, a constellation of at least three nadir-viewing altimeters is needed to provide the sampling required for many practical purposes. GAMBLE stressed the demonstration of new technology such as wide-swath altimeters and larger constellations of altimeters aboard microsatellites. The latter could prove to be very effective in the timely deliverance of sea-state information and in warning of natural hazards.

An important topic for the future of altimetry is the ongoing transition towards operational services. In Europe, a leading initiative is the Global Monitoring for Environment and Security (GMES) programme to develop a coordinated operational environmental information service, partly based on today's space infrastructures. The MERSEA ocean science component of GMES involves 50 European partners aiming to develop and sustain an integrated, operational system to provide analysis and forecasting over the global ocean and European seas.

For the GMES core marine services, the operational Sentinel-3 mission will deliver key information on sea-surface topography, sea-surface temperature and water quality, for example. The operational phase of Sentinel-3 is planned for around 2011–2015.

For the near future, the main operational mission will be Jason-2, developed by NASA and CNES to be operated by the US National Oceanic & Atmospheric Administration (NOAA) and Eumetsat. It extends the Topex-Poseidon and Jason-1 series and enhances the current altimetry services for climate monitoring and operational oceanography. In the longer term, Eumetsat is offering its capability as a leading European operational organisation to run some proposed future missions, such as GMES Sentinel-3 and, possibly, the Jason-2 follow-on.

Scientific developments have seen a recent tendency towards Ka-band altimetry. In particular, CNES is now proposing its AltiKa mission for a launch around mid-2009, aiming at filling the possible service gap after Envisat and complementing Jason-2 for the resolution of ocean mesoscale variability. It will increase accuracy and sampling capabilities in coastal regions and improve continental ice-sheet monitoring, though with the possible reduction of observing capability under exceptional rain and cloud conditions.

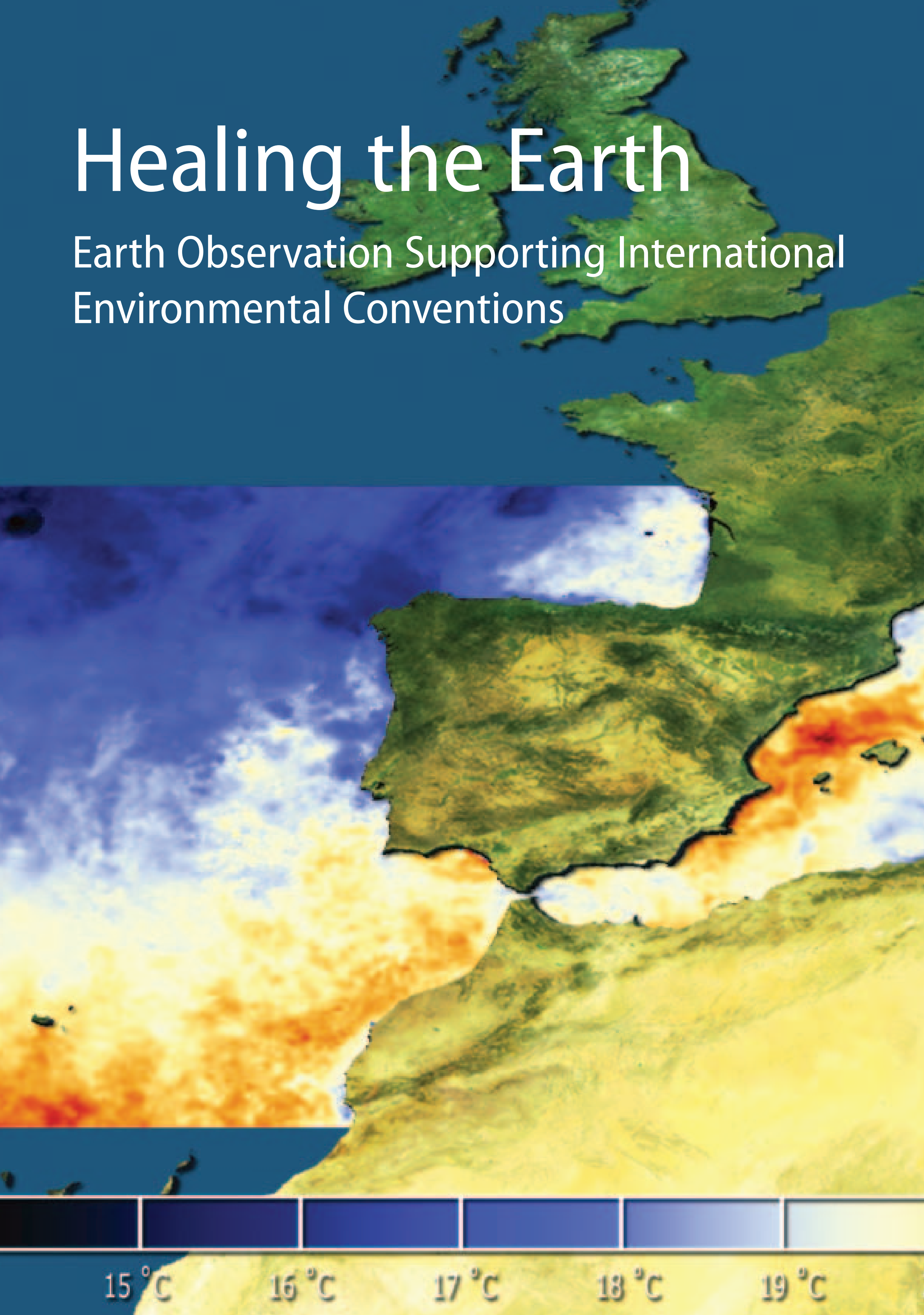
Considerable scientific progress is expected from wide-swath interferometric altimetry, not only by resolving smaller-scale ocean variability, but also by providing a truly 2-D sampling of hydrological systems. In August 2005, a consortium with over 150 participants from the wider hydrological community submitted the WatER mission proposal to ESA's Earth Explorer programme. To be flown after 2010, WatER would contribute to a fundamental understanding of the global water cycle by providing global measurements of terrestrial surface water storage changes and discharge. The main instrument is the KaRin wide-swath Ka-band interferometric altimeter, which could map rivers, lakes and wetlands at a spatial scale over 100 m with a height accuracy of 5–10 cm.

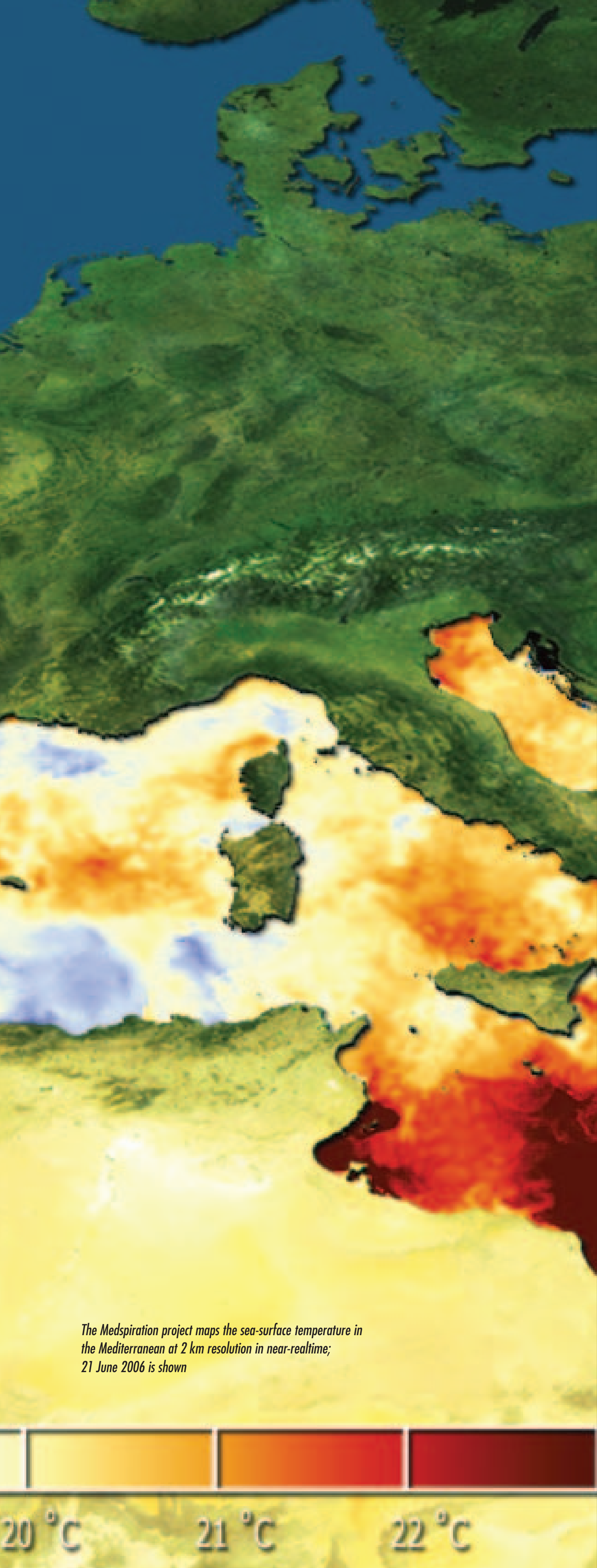
Finally, higher resolution is needed not only for progress in mapping ocean mesoscale and coastal variability and hydrological systems, but also to make the next advances in geodetic and bathymetric signals using space altimetry. Studies have shown that these advances could be realised in a highly cost-effective manner with a high-resolution radar altimeter (as carried by CryoSat) aboard a microsatellite.

Acknowledgements
This article is based on a report of the Symposium '15 Years of Progress in Radar Altimetry' held on 13–18 March 2006 in Venice (I). All abstracts, oral presentations and posters can be viewed at *http://earth.esa.int/venice06*. The papers are available in the proceedings SP-614 from ESA Publications Division at *http://www.esa.int*

Healing the Earth

Earth Observation Supporting International Environmental Conventions





The Medspiration project maps the sea-surface temperature in the Mediterranean at 2 km resolution in near-realtime; 21 June 2006 is shown

Olivier Arino, Diego Fernandez-Prieto & Espen Volden
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ESA is building long-term relationships with several user communities that can benefit from the Agency's Earth observation programmes. Since 2000, ESA has been working in close collaboration on three international environmental conventions. Here we see how its Earth observation activities are benefiting these conventions.

Introduction

Dramatic environmental problems affecting our planet have mobilised governments, scientists, private companies and environmental organisations over the whole world. As a result, several multilateral environmental agreements (MEAs) have been signed that aim at reducing environmental degradation.

An example is the United Nations Conference on Environment and Development (UNCED), also known as the 'Earth Summit', held in Rio de Janeiro, Brasil, in 1992. It resulted in the definition of the 'Agenda 21' plan of action and the subsequent signature of different multilateral agreements such as the UN Convention to Combat

Desertification (UNCCD), the UN Convention on Biodiversity (UNCBD) and the UN Framework Convention on Climate Change (UNFCCC).

The road started in 1992 continued in the World Summit on Sustainable Development in Johannesburg, South Africa in 2002. There, many governments reinforced their commitment to sustainable development at the local, regional, national and international levels, and recognised MEAs as useful for achieving that objective.

Implementing these Conventions requires the collection, analysis and understanding of a huge amount of environmental information, from local to global scales. This information provides a better understanding of the scientific background of the problems faced, helps decision-making and enables environmental plans to be put in place. It also allows the Convention Secretariats and related bodies to improve their assessment of the performance of the Conventions and apply enforcement procedures if necessary.

Earth observation (EO) technology can significantly contribute by:

- improving the scientific knowledge of the environmental problems;
- improving the execution of National Action Plans;
- improving MEA performance;
- broadening the political process;
- contributing to the creation of common databases and reporting procedures among different conventions (see the table for a summary).

However, today's limited use of EO technology in implementing MEAs contrasts with its large potential. To explore the potential, and promote the use of, EO technology in supporting environmental conventions, ESA launched the 'Treaty Enforcement Services using Earth Observation' (TESEO) initiative in 2001. These studies have been followed by larger implementation projects, such as the Kyoto Inventory, GlobWetlands and DesertWatch, addressing key needs expressed by different users within the convention communities. This article focuses on the UNFCCC, the Ramsar Convention on Wetlands and the UNCCD.

Potential contributions of Earth Observation in implementing multilateral environmental agreements

	Ramsar Convention	UNCCD	UNFCCC
Improving scientific knowledge	• Understanding wetlands, e.g. water cycles, vegetation status • Understanding global wetlands distribution • Understanding interrelations between wetland areas, the surroundings and whole catchment areas	• Understanding expansion and retraction of deserts • Understanding causes and consequences of land degradation • Understanding water cycle at global scale • Understanding the causes and effects of drought	• Understanding the carbon (by providing global model input parameters such as global leaf area and vegetation indices, statistics on global fires) • Understanding the causes and effects of global warming and climate change
Improving execution of resolutions, declarations and obligations	• Improving inventories, e.g. by mapping land cover, land use and base information • Assessing environmental character, e.g. by estimating and mapping hydrological and vegetation parameters • Monitoring (continuous mapping of changes in vegetation status, land cover or water table)	• Improving reliability and capability of early warning systems of drought by providing timely information over large regions on agriculture and land cover, temperature, albedo, etc. • Improving land degradation assessment and monitoring by providing timely and continuous information on land cover and use and its dynamics by estimating vegetation status over large areas on a regular basis	• Improving forest and land cover inventory capabilities at national scales • Improving identification and estimation of de- and reforestation phenomena • Improving estimation capabilities of over-ground biomass, greenhouse-gas emissions, carbon stocks in 1990 (baseline year) by allowing mapping of forest areas and types
Improving MEA performance and reporting mechanisms	• Improving derivation of geo-information and environmental parameters required in the Ramsar site sheets, e.g. base maps, location of wetlands, land cover and land use, hydrology, wetland types • Producing comparable maps and environmental indicators of Ramsar sites in one country, and among different parties • Creation of a database of geo-information and a Ramsar information system including comparable information for all Ramsar sites	• Estimating indicators to measure Convention performance based on measurable environmental phenomena, e.g. increases in forest area of improvements in vegetation status • Allowing joint reporting to the Convention Secretariat (e.g. common report of Annex IV countries) providing comparable information from different countries • Improving derivation of geo-information, environmental indicators and statistics so countries report quantitatively rather than qualitatively on progress towards their objectives	• Improving reliability and comparability of reporting information • Allowing verification by independent bodies of the information reported by parties • Improving capabilities of independent bodies to auditing Clean Development Mechanism projects (e.g. verification of forest extent and state over time)
Broadening the political process	• Illustrating problems affecting wetlands worldwide and increasing awareness	• Illustrating problems of desertification at global, regional, national and sub-national levels to increase awareness • Illustrating problems related to drought at global, regional and national levels to increase awareness • Deriving geo-information and statistics to quantify the problems and induce political support	• Illustrating effects of global warming at different scales (especially global) to increase awareness • Deriving statistics and geo-information at global level to prove to policy-makers the urgent need for action and induce political support
Common reporting	Deriving common environmental information, such as base maps, land cover maps, land cover maps, change-detection maps, environmental indices, global statistics, for different conventions)		

UN Framework Convention on Climate Change

Climate change is a global issue that must be addressed with global models – and global data are needed as input to these models. Earth observation satellites are uniquely able to provide such global datasets continuously. They also provide data at national and local scales, which can help the implementation of conventions and protocols, and help the members in their reporting duties. In addition to providing adequate satellite data, ESA has begun a number of activities to demonstrate how 0satellite data can support the UNFCCC objectives.

Global observations from satellite

The importance of systematic global observation for understanding climate change has always been recognised by the UNFCCC. Improvements in technology have made it possible to measure systematically, globally and homogeneously many of the variables essential for understanding and monitoring the climate system. ESA has initiated several global-scale projects that transform satellite data into meaningful parameters to provide insight into climate change.

Important variables that satellites can measure over land are daily global 'albedo' (the fraction of sunlight reflected back from Earth), vegetation levels, fires and burnt areas, snow cover, elevation of ice-sheet surfaces, glacial evolution and land cover. Some of these factors are required as inputs for carbon cycle models, and others give an immediate view of the impact of climate change.

Vegetation cover, fire location, timing and areas affected, as well as additional information on the vegetation growth cycle, are being estimated globally within ESA's GlobCarbon project. They are used as input to carbon-assimilation models. Worldwide fire locations have been analysed for 10 years on a monthly basis: data are freely accessible in the *World Fire Atlas*. at *http://dup.esrin.esa.it/ionia/wfa/*. This atlas has been used by more than 70 scientific teams, most of them in atmospheric modelling. A global land cover map at 300 m resolution is being developed within the GlobCover project using Envisat data from 2005 (see the title spread of this article).

The large volume of data acquired from 20 years of satellite observations of sea-surface temperature (SST) has given scientists a uniquely detailed view of the changing physical characteristics of the surface of the oceans, sampled at a rate impossible with only ship-based observations. The Medspiration project combines data measured independently by several different satellite systems into a set of products that represent the best measure of SST, presented in a form that can be assimilated into ocean forecasting models.


Diário de Notícias

1,6 milhões pagam taxa reduzida de Segurança Social

Portugal's Diário de Noticias *highlights the warming of the Mediterranean Sea between 2 July and 2 August 2006, with the headline 'Mediterranean water at 30°C full of jellyfish'*

Ocean algae absorb thousands of tonnes of carbon, forming one of its most important and long-lasting removal routes. By precisely measuring ocean colour, we can accurately gauge the concentrations of phytoplankton globally. Coupling ocean colour with atmospheric aerosol and trace gas measurements will also yield new insights into the chemical links between ocean and atmosphere. A long time-series of global ocean-colour information will be provided by the GlobColour project.

The polar regions are especially sensitive to changes in climate, and models consistently predict future warming to be much more significant there. Many variables can be observed from satellite, in particular by exploiting radar's ability to see through clouds. The GlobIce project is providing information based on satellite data for the polar regions.

Greenhouse gases and aerosols are the primary agents in forcing climate change; continuous observations spatially and temporally homogeneous are therefore required. Since 2003, the TEMIS consortium has been providing measurements of ozone and greenhouse gases, including carbon dioxide (currently a research field) and methane, by exploiting satellite data. GlobAerosol aims to provide a daily global aerosol product over land and water from several satellites.

Land use and forestry

Mankind's land use and forestry have a significant effect on the net emissions of carbon. Measuring these activities is a main function of the Kyoto Protocol, which obliges the Annex 1 countries (who agreed to cut their 1990-level

A dedicated Kyoto Protocol land-use map of Switzerland was completed in the Kyoto Inventory Project and is being refined in the GSE Forest project

greenhouse-gas emissions by an average of 5.2% by 2008–2012) to report on them during the first commitment period of 2008–2012 and to establish the baseline for 1990. ESA began working with the UNFCCC Secretariat in 2001 to produce the required maps and statistics, based on satellite images combined with ground measurements and other data.

So far, more than a 100 million hectares have been mapped, and the same amount will be added by ESA's Global Monitoring for Environment and Security Services Element Forest Monitoring (GSE-FM) service by 2008. All of Switzerland and The Netherlands was mapped for the baseline year of 1990 and two other years, in addition to large parts of Italy, Germany, Spain, France, Greece, Denmark and Poland. The changes in land use and forestry between these years were also mapped.

Standards and best-practices have been established, and all the maps were verified using aerial photos, forest inventory data and other field measurements, and their utility assessed by the ministry or agency in charge of the Kyoto Protocol reporting of each country.

ESA is also working with non-Annex 1 countries (those not obliged to cut greenhouse gases) on their national communications under the UNFCCC. Forest projects under the Kyoto Protocol's Clean Development Mechanism can also be supported by satellite images by, for example, identifying sites, establishing baseline scenarios and verifying plantation evolution. ESA is working in Uganda and Paraguay to demonstrate the usefulness of such services.

Currently, avoiding emissions from deforestation and forest degradation in developing countries is a priority for the UNFCCC. ESA, through GSE-FM, has started to address this. Satellite images can be used both in establishing a historical deforestation baseline and in continuously monitoring deforestation and degradation. Pilot cases to assist in policy formulation for this issue are being developed. This is an example of EO influencing the policy-making process.

Ramsar Convention on Wetlands

The objective of the Ramsar Convention on Wetlands, signed in 1971 (in Ramsar, Iran), is 'the conservation and wise use of wetlands by national action and international cooperation as a means to achieving sustainable development throughout the world'. The wise-use concept is understood to be 'the sustainable utilisation for the benefit of humankind in a way compatible with the maintenance of the natural properties of the ecosystem'. This complex and challenging task requires all national and international agencies involved to:

- better understand wetland areas, their internal processes and their significance in the global environment;
- manage wetland areas efficiently so that they may yield the greatest continuous benefit to present and future generations;
- inform the general public and policy makers of the importance of wetlands and promote their conservation and protection worldwide.

Existing and future EO technology plays an important part in providing reliable and cost-effective synoptic information to monitor and assess these critical ecosystems worldwide.

How can EO support Ramsar?
Parties implementing the Ramsar Convention and taking advantage of EO technology range from international

agencies and scientists to wetland managers and local communities. However, the type of information required varies significantly.

The table shows the different geo-information products that can be derived from EO data for the Ramsar community. The community has been categorised according to the scope of the organisation: global, regional, national or local. User requirements are split into two groups: global and local.

For global needs, the nature of EO data makes it a unique tool for providing global information to users on a regular basis. For local needs, EO provides an efficient source of continuous and synoptic information not only for wetland sites, but also for entire basins supplying the wetlands. This provides a novel capability to EO users, for instance, to extend inventory information and monitor activities through catchment areas of wetlands to identify and monitor threats upstream that could potentially damage the wetland site.

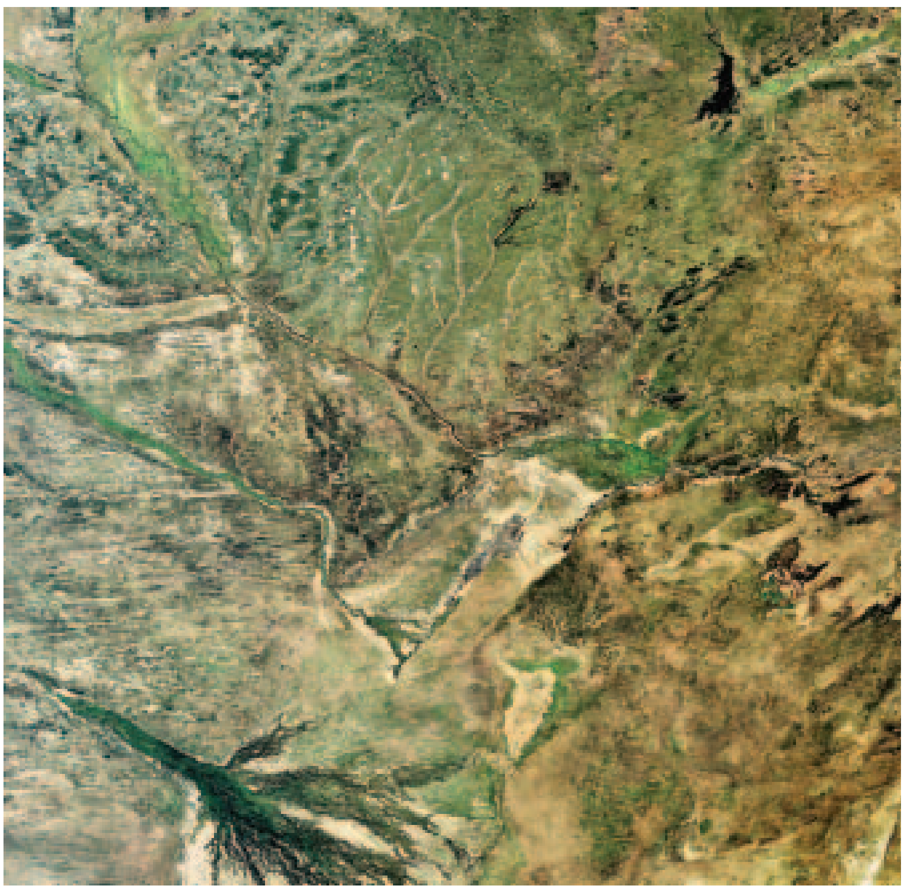
In some cases, managing large wetlands and the corresponding catchment areas involves the inventorying, assessment and monitoring of a huge geographic area, such as the Okavango Delta. In these cases, and even though in the table it is mentioned as local information, this actually requires collecting and analysing information at national and even regional scales, which often can only be done by using EO technology.

The GlobWetland project

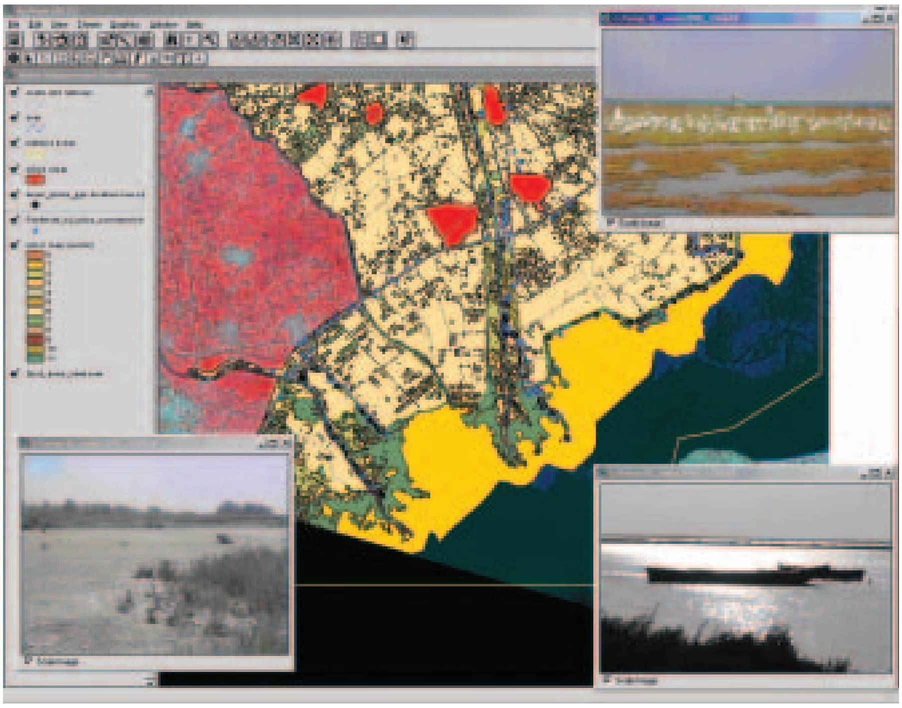
As a large-scale demonstration of these capabilities, ESA launched the GlobWetland project in 2003. It is developing and demonstrating an EO-

Earth Observation potential contributions to the Ramsar Convention

Scope	End-user	User requirements where EO can contribute
Global	Ramsar Bureau, UN agencies, international non-governmental organisations (NGOs) and international research organisations, scientific community	Global extent of wetlands and their temporal variations (seasonal, multi-year) as an input for global environment models (carbon, methane production, etc.); global monitoring of wetlands with respect to global environmental changes; global inventory of wetlands.
Regional	Regional policy makers (e.g. European Community), regional developing agencies (e.g. African Development Bank), regional environmental agencies (e.g. European Enviroment Agency)	Inventories and maps of: • wetland boundaries, e.g. size and variation; • land cover/use of wetland site and catchment area; • digital elevation model of site and catchment area; • water regime, e.g. periodicity, extent of flooding; • water chemistry, e.g. colour, transparency; • biota (vegetation zones and structure); • location of potential threats to the wetland (at site and in catchment area); • additional information, e.g. infrastructures Assessment activities such as: estimation of biological (e.g. vegetation condition) physical (e.g. water table) and chemical (e.g. chlorophyll) parameters that characterise the ecological condition of a wetland. Monitoring activities such as: identifying and monitoring changes in biological, physical and chemical condition of wetland site, threats in the wetland site and the corresponding catchment area, which may affect the wetland condition (e.g. alien species, overgrazing, urban expansion, agricultural activities, industrial pollutants). Rapid reaction to catastrophic events, such as floods and pollution emergencies. Implementation of management (e.g. rehabilitation) plans, such as: • basic information for inventories and as a basis for planning and decision-making (e.g. base maps); • change analysis to monitor the efficiency of the taken actions and impact assessment.
National	National focal points, related national ministeries, implementing agencies national NGOs	
Local	Scientific community, local authorities, local wetland managers, local basin authorities, local NGOs, land owners, local communities, farming and fishing associations	



The 'jewel of the Kalahari': Botswana's Okavango Delta is highlighted in the lower left corner of this Envisat MERIS image, acquired on 2 July 2006. The world's largest inland delta is a labyrinth of lagoons, swamps, channels and islands and a home to a vast array of wildlife. The Okavango River flows inland and irrigates 15 000 square km of the Kalahari Desert. Such wetlands are the most biologically diverse ecosystems on Earth, more productive even than tropical rainforests



An example of the GlobWetland Information System for Axios, Greece

based information service to help wetland managers and national authorities respond to the requirements of the Ramsar Convention. The project involves 50 wetlands in 21 countries, and relies on the direct collaboration of several regional, national and local conservation authorities and wetland managers.

A set of EO-derived products was defined based on the requirements of individual wetland managers and national focal points of the convention (mainly environment ministries). Core products include: land-use and land-cover maps; long- and short-term change-detection maps; and water-cycle regime maps. Site-specific products include leading-edge EO applications such as the analysis of biophysical parameters within water bodies, coastal erosion, subsidence, peatland burned areas and digital elevation models.

The main products, focusing on wetland land cover and water-table dynamics, are based on semi-automated processing techniques that make use of multiple types of EO data, user-supplied data and field information. Space sources include synthetic-aperture radar (SAR) and optical data at various resolutions from Envisat Advanced SAR and MERIS, Radarsat, Spot, Landsat, Ikonos, Quickbird, CHRIS/Proba and ASTER. Observations were tailored to the individual sites, ensuring maximum coverage of wetland vegetation and capture of the changes in water extent using SAR data.

The impact of these EO products on the daily work of wetland managers and conservation authorities has been significant. It is not possible to isolate the management of wetlands from the land use and water management regime within their catchment areas. All freshwater wetlands depend upon a net positive water balance determined by the relative contributions of rainfall, evapotranspiration, abstraction, groundwater exchange and surface flows. These in turn (even rainfall) are strongly influenced by the land use and land cover in and around the wetland which, along with water management objectives, form part of the information base of management plans necessary for the conservation and wise use of wetlands.

Geo-information is vital to wetland management. The Convention advises that it should be organised at different scales. Level-1 is for information on a broad scale, such as a river basin. Resolution becomes progressively higher through a wetland region (Level-2), wetland complex (Level-3) and wetland habitat (Level-4). This approach is taken in GlobWetlands to maximise the efficient use of geo-information and reserve the most expensive imagery for relatively small areas where detailed assessment is required.

Wetland managers and ecologists use many information sources to determine ecological change and to target their interventions, through negotiation of land use and water allocations within stakeholder-based catchment planning. Combining the strategic use of EO-derived geo-information with ground data, for example, local land ownership, water-gauging information or species counts is now considered to be an essential partnership for sustaining these vital reservoirs of life and opportunity.

UN Convention to Combat Desertification

The international community has, with the UNCCD, launched an innovative initiative to reverse and prevent the mismanagement of the world's drylands. Where past 'Plans of Action to Combat Desertification' ignored the complex interplay of socio-economic influences behind dryland over-exploitation, the UNCCD confronts them directly. The convention suggests a new 'holistic' and participatory approach aiming for sustainable development of drylands. In this respect, the convention has some unique features compared to other environmental treaties. By stating that desertification is primarily a problem of sustainable development, it draws attention to the interface between sustainable natural resource management and economic development issues, notably in poor countries with scarce and/or overexploited natural resources.

The UNCCD is not an ideal legal instrument to combat desertification. Desertification remains a poorly understood concept – notably the complexity of the phenomena and the interaction between poverty and land degradation. It involves a very complex set of interactions and issues, with few easily identifiable causes or tidy solutions. Moreover, estimates of the areas involved range from a third of the world to close to half; and people affected from 1-in-6 to 1-in-3.

A better use of EO data is, therefore, becoming more critical to understanding desertification processes and man-made effects on natural ecosystems, and can ultimately contribute to improving policies. Areas of UNCCD implementation that could directly benefit from use of spaceborne EO technology are:

- the collection and analysis of short-term and long-term data and information to identify causal factors, both natural and human, contributing to land degradation, desertification and/or drought;
- increased knowledge of the processes leading to land degradation, desertification and drought, and better understanding of the interaction between climate and desertification and assessment of the effects of drought on desertification;
- the systematic observation of the environment to assess qualitative and quantitative trends in natural resources, evaluating the causes and consequences of desertification, notably ecological degradation, and monitoring the effects of these to improve the value of combating strategies;
- the establishment and/or strengthening of early warning systems to evaluate the impacts of natural climate variability on regional drought and desertification, and generate seasonal-to-interannual climate predictions to improve the efficiency of drought-mitigation programmes on affected populations.

The DesertWatch project
Following the TESEO project and the consultation with national delegations during the 2003 Conference of the Parties in Havana, Cuba, ESA launched DesertWatch in 2004. This project aims to develop a tailored, standardised, commonly accepted and operational information system based on EO technology. It will support national and regional authorities of Annex IV countries (the North-Mediterranean Region) in reporting to the UNCCD and assessing and monitoring desertification and its trends over time. It will help:

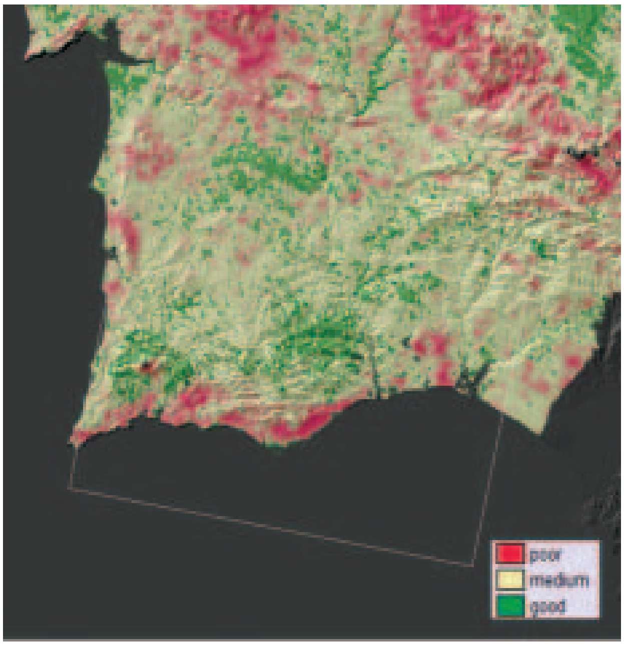
- to create standard and comparable national geo-information products on the status and trends in desertification;
- to create a common framework for reporting to the UNCCD for Annex IV countries;
- to create a common basic infrastructure as a base for further developments where EO plays a key role;
- the development of a common methodological approach for all Annex IV countries to assess and monitor desertification problems and identify trends and potential scenarios.

To this end, the National Committees to Combat Desertification of Italy, Portugal and Turkey have helped in the preparation of the project, defining the main information needs and validating the results. Their participation is critical to ensure the full integration of the final system into the daily working practices of national and regional administrations. The project follows a ‘develop-operate-transfer’ approach to support the full transition from a research phase to an operational phase, where selected national and regional technical centres continue operations, thereby ensuring sustainability.

Based on preliminary user needs, DesertWatch information is being organised in autonomous layers that can be integrated and combined in suitable models to derive different thematic products on three scales: pan-European, national and sub-national.

The products include some land use indices, derived from Landsat and MERIS data, aimed at identifying key drivers, pressures and impacts on land degradation processes, such as deforestation, forest fragmentation, forest fires, irrigation, urbanisation and land abandonment. With additional socio-economic data and other information, these indicators form the basis for deriving information on the risk and status of desertification.

A second component of the system includes a number of biophysical indexes measuring the density of



Example of a land degradation index from MERIS data covering southern Portugal

vegetation and the soil/rock abundance ratio. The former and its trends over time are key towards a better understanding of the vegetation status and its stress with respect to rainfall and climate variations. The second can be considered as a substitute for erosion indices; it is an accurate indication of the proportion of developed soils and parent material, which provides the basis for determining the degree of soil erosion.

A Land Degradation Index derived from meteorological and Envisat MERIS data has been developed to highlight the degree of soil degradation. The index is relative to the soil type and the local conditions: an arid soil can be considered as 'good' even with only a few rainfall episodes because of the vegetation growth for that type of soil and local conditions.

The temporal component is a key factor to understanding desertification processes today in the Mediterranean area. The project is investigating the variations of the last 20 years through a trend analysis using EO archives. The above indicators will be generated at three different dates showing the evolution of the main pressures and impacts related to land degradation since 1984.

Finally, the system will provide users with a tool to explore different future scenarios in land use and cover, and impacts on land degradation due to different environmental policies and management practices. The project must include modelling components for poten-tial land-use evolution forecasts based on previous land-use maps, socio-economic data and a number of user-defined rules.

Conclusion

Earth observation technology offers many ways to improve the implementation of multilateral environmental agreements, such as the continuous provision of global data, historical data archives, observations of several environmental parameters at global, national and local scales, and the provision of synoptic and comparable information without infringing on national sovereignties.

In spite of these benefits, EO support of MEAs is still limited and, in many cases, restricted to research and demonstration projects. This is because of several factors in the environmental and EO sectors. The gap between these two worlds has hampered the integration of this technology into the common operational practices of environmentalists and governments in many fields. However, more integration of related technologies, such as geo-information systems and information technology, as well as wider awareness within the environmental community and the technological developments in the space sector, offer a promising future.

The next generation of EO satellites will provide novel and advanced capabilities to monitor the world's environment on a regular basis. The success of new technologies depends on the parties involved in the space sector (space agencies, value-added companies and research institutions) developing user-driven, cost-effective operational applications.

ESA's Earth observation programmes will continue in this direction, supporting governments, scientists and all those pursuing the goals and targets of environmental conventions. ESA is continuously consulting the international user community via themed workshops and participation in the Conference of the Parties of the different conventions. Also, new activities addressing the information needs of other major conventions, such as the UN Convention on Biological Diversity, are ready to be launched. They will open the door to the development of new and more efficient EO-based information services, reinforcing the international community with new tools to deal with the key environmental problems that confront our planet.

Acknowledgements

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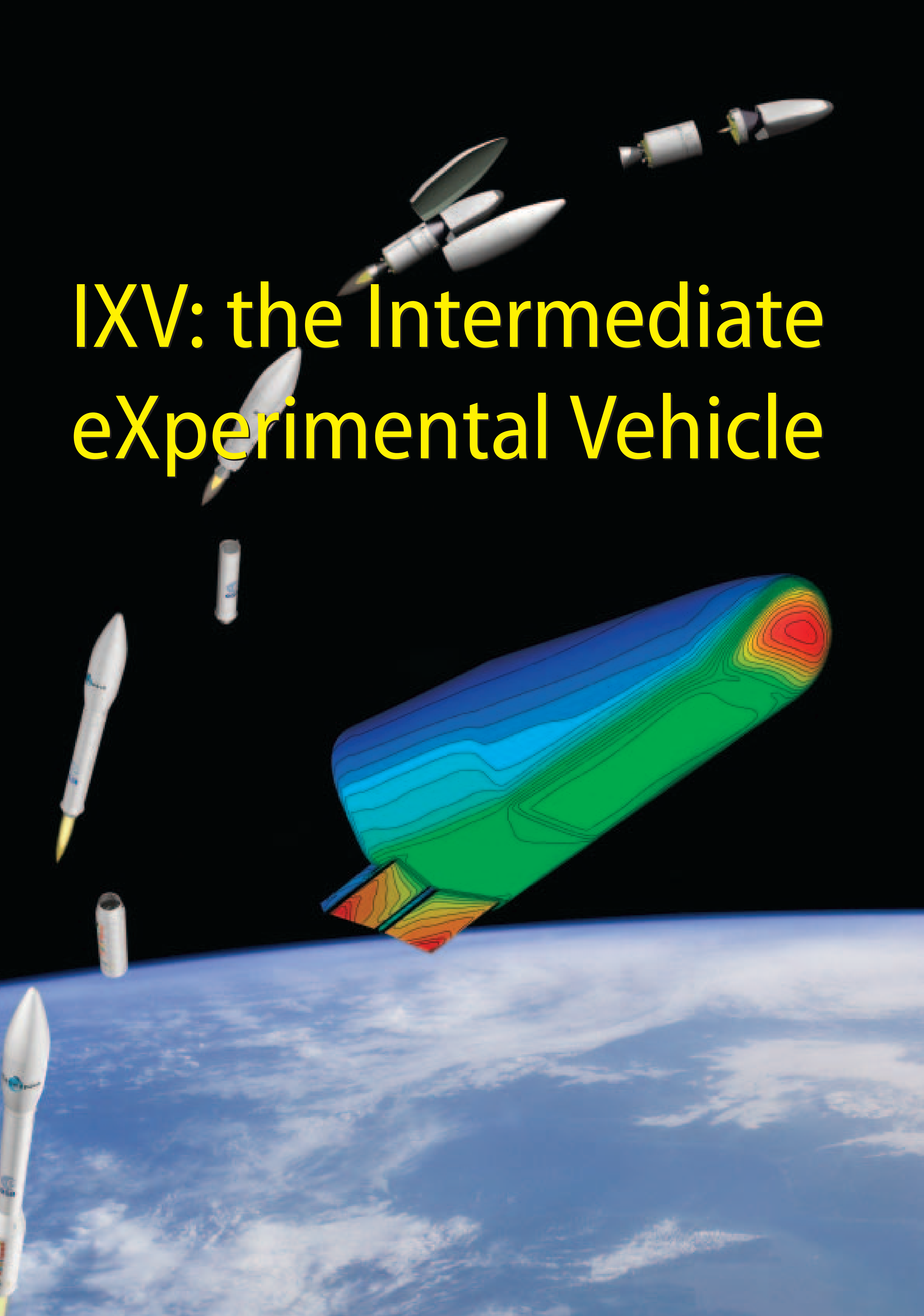
Useful Links

www.esa.int/due *www.esa.int/gmes*
www.unfccc.int *www.unccd.int*
www.ramsar.org *www.temis.nl*
www.medspiration.org *www.globaerosol.info*
www.globcolour.info *www.globwetland.org*
World Fire Atlas http://dup.esrin.esa.it/ionia/wfa/

IXV: the Intermediate eXperimental Vehicle



Europe Among the World Players in Atmospheric Reentry

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With the objective of placing Europe among the world's space players in the strategic area of atmospheric reentry in future international transportation, exploration and scientific projects, several studies on experimental vehicle concepts and improvements of critical reentry technologies have paved the way for the flight of an experimental craft. The Intermedidate eXperimental Vehicle is building on previous achievements at the system (such as the Atmospheric Reentry Demonstrator) and technology levels, and providing a unique means of establishing Europe's autonomous position in this international field.

Introduction

Returning to Earth from orbit is still a challenge, as the loss of Space Shuttle *Columbia* tragically underlined. Braking from 7.7 km/s through the atmosphere to a safe and precise landing calls for a wide range of demanding technologies to be mastered. The number of experimental reentry vehicles studied in recent years by ESA, France, Germany and Italy underlines Europe's need for flight experience with reentry systems and technologies in order to consolidate its position among the world's space players in this strategic field. Europe must be able to play a more ambitious role in international cooperation in space transportation, exploration and scientific projects. ESA's Future Launchers Preparatory Programme (FLPP) was conceived by its Member States to provide a framework for, among other technology challenges, the development of the Intermediate eXperimental Vehicle (IXV) by 2010.

Project Definition and Status

ESA and its industrial prime contractor Next Generation Launcher Prime SpA (I), a joint venture between Astrium (F, D) and Finmeccanica (I), assisted by ASI, CNES, DLR and ESTEC, initiated the IXV project at the beginning of 2005 by defining the mission objectives and maturing the design.

The objectives include the complete and deep identification of what experiments Europe needs in reentry technology, with an optimised plan of flight experiments that trades cost against technology maturity needs.

A thorough comparison has been performed for all the existing ESA and national concepts against shared criteria, focusing on: experiment requirements (technology and systems), programme requirements (technology readiness, development schedule and cost) and risk mitigation (design feasibility, maturity, robustness and growth potential).

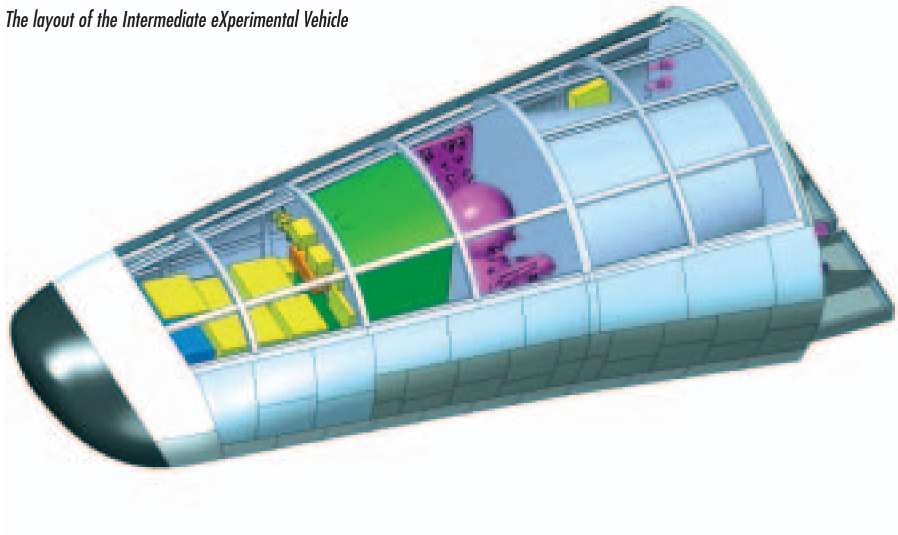
The result of the trade-off has led to the selection of the slender lifting body configuration. The baseline design builds upon the extensive national (CNES/Pre-X) and ESA (AREV: Atmospheric Reentry Experimental Vehicle) efforts.

The contractors are now working on Phase-B1 (preliminary design definition), targeting a system requirements review by mid-2007.

The Reference Mission

The IXV baseline mission is driven by using Vega as the launcher, with critical safety issues that call for Vega's stages to fall over uninhabited areas and the experimental vehicle to fly over sparsely populated regions.

The layout of the Intermediate eXperimental Vehicle



The reference mission plans a launch from Kourou (French Guiana) into an orbit with a 70º inclination, followed by a landing in the North European Aerospace Test Range at Kiruna (S). The scenario is being refined (see below), and backup schemes leading to a sea landing are also being considered.

IXV will be delivered into an orbit of 180 x 307.2 km, where Vega's upper stage will fire above the Pacific Ocean off the coast of Chile to trigger reentry.

IXV will begin formal reentry 120 km above the Atlantic Ocean, at a speed of 7700 m/s and an angle of 1.19º below the horizontal. The reentry trajectory lasting around 20 minutes will be controlled by a combination of moving aerodynamic surfaces and thrusters from hypersonic speeds at 120 km altitude down to Mach 2.0, while travelling a surface distance of 7500 km. All the while, it will gather large quantities of data to verify the performance of several critical reentry technologies.

IXV will then be slowed from Mach 2 by a set of parachutes deployed by drogue 'chutes, before airbags inflate to soften the landing.

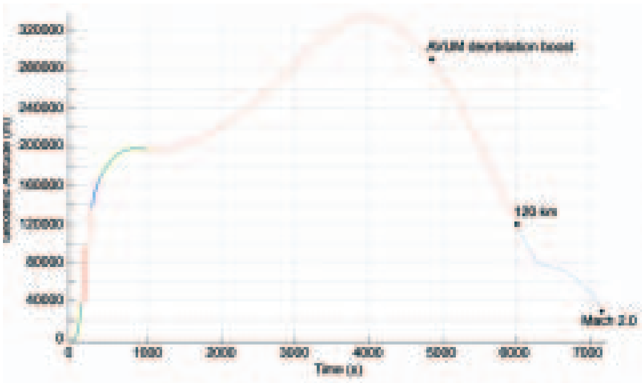
Even though the end-to-end trajectory lies principally over low-population territories, a failure during reentry has risks that need to be thoroughly identified, assessed and mitigated at an early stage in the project.

A study is therefore under way by industry as a first step in Phase-B1 to assess how the safety requirements affect the mission, with a comparison of all the feasible mission scenarios. The landing scenario and area will soon be selected by ESA with technical assistance from ASI, CNES, DLR, ESTEC and recommendations from industry.

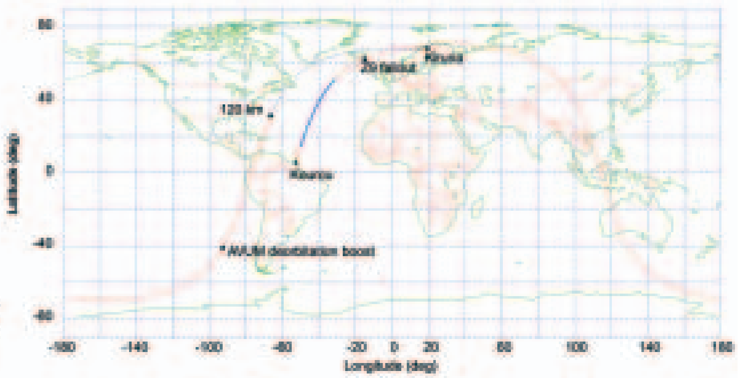
Reentry System and Technology

From experience with ambitious experimental vehicles around the world, such as NASA's series of X-vehicles, there is general consensus within Europe's space community that a step-by-step flight programme is the best approach. It limits the risks, allows stepped costs and ensures that progressively more sophisticated developments benefit from the results of relatively low-cost missions.

Since 2002, ESA has focused on an optimised long-term scheme of flight experiments. Further consolidation with industry in 2005 confirmed the Intermediate eXperimental Vehicle as the core of this effort. IXV integrates key technologies at the system level, including thermal protection and active aerodynamic control surfaces. This is a significant advance on Europe's previous flying testbeds, although the shape is not necessarily representative of



The IXV trajectory from launch to Mach 2



The current reference trajectory from Kourou to Kiruna

future operational vehicles (this explains the *Intermediate* in the name).

IXV is a lifting reentry body, with its shape resulting from the set of design requirements, including the need to maximise the internal volume for carrying experiments. The goal is to get the most out of the vehicle while guaranteeing the mass (limited by Vega's capacity) and centre-of-gravity location.

The primary objectives of the IXV project can be grouped into three categories: reentry system demonstration, technology experimentation and technology validation.

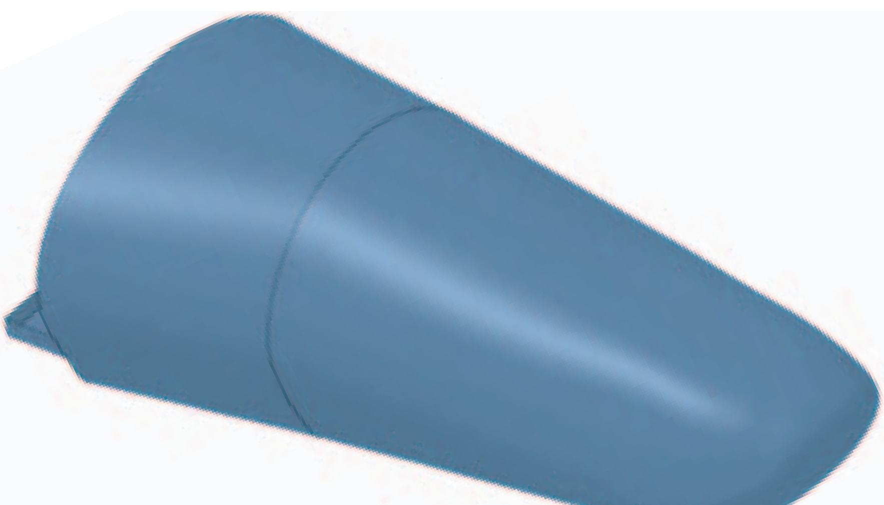
The first focuses on gaining experience in lifting and aerodynamically controlled reentry, which would be a significant advance on earlier ballistic and quasi-ballistic efforts, such as the Atmospheric Reentry Demonstrator capsule flown by ESA in 1998. Europe needs to go through the entire design loop for such a complex system, specify the entire system development phases in detail, address the manufacturing and assembly issues of critical reentry technologies, the integration of these key technologies at the system level (during the design, assembly, testing and operations), perform overall system integration and verification for a vehicle fully loaded with advanced and innovative instrumentation, and conduct the flight while ensuring the highest safety for the ground below.

The reentry technology experiments centre on verifying the performance of system-integrated advanced thermal protection and hot structures under realistic flight conditions. These include advanced ceramic and metallic assemblies, insulation, attachments, junctions and seals, as well as advanced guidance navigation and control techniques.

This verification of performance in flight builds on previous efforts and ground verification, and aims at maturing the technologies for operational space applications.

Reentry technology validation focuses on gathering representative reentry performance data in order to investigate aerothermodynamic phenomena and validate system design tools, evaluating the behaviour of air around a lifting body for atmospheric entry in the hypersonic regime (above Mach 5). The most interesting phenomena stem from the behaviour of the airflow around the vehicle, when the air molecules break apart to dissipate the high energies involved in reentry and the perfect-gas laws are no longer valid. This complex situation affects the interaction between shockwave and boundary-layer flows, the interaction between shockwaves, the transition from laminar-to-turbulent boundary-layer flows, the transitional boundary-layer separation, the heating of thermal protection materials by turbulent boundary-layer flows, the overheating owing to external cavities, the behaviour of materials' catalytic properties, the materials' oxidation, the reduction in efficiency of the control surfaces through boundary-layer flow separation, and the efficiency of the reaction control system.

The experiment objectives are being translated into the vehicle design via an



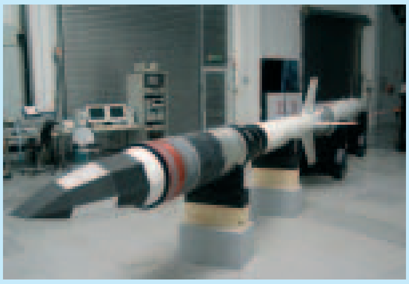
The aerodynamic shape of IXV

The IXV is Europe's next logical technology step after the successful flight of ESA's Atmospheric Reentry Demonstrator, and the important complementary national efforts in Germany on the Phoenix-1, a winged vehicle released by helicopter for autonomous runway landings, and on the Shefex-1, a sharply pointed body launched by a 2-stage rocket for testing advanced materials, and in Italy on the USV-1, a slender winged laboratory released from a balloon for transonic-to-supersonic flights.

ESA's Atmospheric Reentry Demonstrator

Phoenix-1 (EADS-ST)

Shefex-1: 'Sharp Edge Flight Experiment' (DLR)



USV-1: 'Unmanned Space Vehicle' (CIRA)

extensive flight-measurement plan that accommodates:

- important layer measurements for IXV's guidance, navigation and control system and for ground controllers to monitor the mission's progress;
- Vehicle Model Identification (VMI) measurements for post-flight reconstruction of IXV's dynamic behaviour and environment;
- IXV's mandatory core experiments on the reentry enabling technologies;
- complementary passenger experiments that are not directly necessary for mission success but will increase the technological return.

The current IXV baseline design is the result of extensive analyses, including mission and trajectories, aeroshape design optimisation, computational fluid dynamics for aerodynamics and aerothermodynamics, flying-quality assessment for longitudinal/lateral stability, trimmability and controllability of the vehicle. Additional analysis and significant testing, including thermal, mechanical and wind and plasma tunnels, are planned for the upcoming project phases to help select the final system and subsystem designs.

Complementary Passenger Experiments

In order to maximise the mission's technological return, ESA organised scientific and industrial workshops in 2005. The impressive response highlighted the wide interest in using the flight for complementary research to benefit future launchers, exploration and science. More than 50 passenger experiment proposals have been received by ESA from European industry, research centres and universities. They address innovative techniques and instrumentation for investigating aerothermodynamic phenomena, innovative materials and concepts for thermal protection and hot structures, and additional methods for guidance, navigation, control and structural health monitoring.

The proposed instrumentation includes thermocouples, heat-flux and pressure sensors, combined heat-flux, temperature and pressure sensors and/or probes, flush air data system, antennas, reflectometers, catalytic sensors, slip flow and skin friction sensors, advanced pyrometric temperature and heat-flux sensors, a miniaturised spectrometer/pressure system, an infrared thermography system, a combined Rayleigh lidar and electron beam fluorescence system, and high-resolution temperature-mapping systems.

The innovative materials and concepts proposals include actively cooled systems, ceramic nanostructures, metallic matrix composites, ultra-high-temperature ceramics, self-healing oxidation protection, high-performance insulation, secondary protection layer systems, intermetallics, aged ceramics, borosilicon carbonitride (SiBNC) polymer ceramic fibre technology, and smart thermal protection.

Suggested techniques for guidance, navigation and control include realtime GPS and/or Galileo signal tracking for accurate navigation and attitude determination during reentry, realtime trajectory control and new autonomous and highly adaptive guidance software. Proposals for structural health monitoring look at the vibro-acoustic environment and structural damping.

ESA and NGL Prime SpA are making a detailed evaluation of the compatibility between each passenger experiment and the IXV system to assess the technical and programme impacts, including feasibility, reliability, risk and cost. They are important issues because these passenger experiments would be integrated into a system baseline that is already significantly loaded with its own functional and VMI measurements and core experiments.

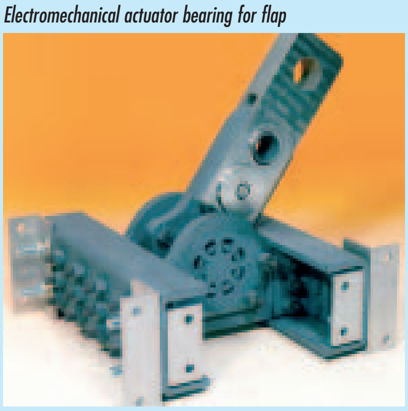
Project Schedule

The IXV project schedule runs across the different overlapping FLPP periods, with the ESA Councils at Ministerial Level as milestones for funding contribution and subscription. The

Europe has been developing advanced thermal protection systems and hot structures for space transportation systems for almost 20 years through a series of ESA and national programmes, such as Hermes, Manned Space Transportation Programme (MSTP), Future European Space Transportation Programme (FESTIP), Technology Research Programme (TRP), General Support Technology Programme (GSTP), ARD, Ausgewaehlte Systeme und Technologien fuer zukuenftige Raumtransport-Anwendungen (ASTRA), X-38/Crew Return Vehicle and FLPP-1/2.

Several thermal protection and hot-structure assemblies and components have been designed, developed, manufactured and qualified for flight. The final verification of their flight performance by IXV will provide Europe with advanced and competitive flight-proven hardware ready for future launchers, exploration and science applications.

Electromechanical actuator bearing for flap



Nosecap assembly (DLR)

Segments of a leading edge

project phasing allows the industrial work to continue smoothly.

Today's budget of about €55 million covers the completion of Phase-B, Phase-C and early phase-D, to the second quarter of 2009.

The IXV project cost-at-completion requires additional funding for completing Phase-D/E/F, including procurement of the Vega launch and post-flight evaluation of the performance. The additional funding is expected either at the next Ministerial Council, in mid-2008, and/or through additional contributions from cooperation with national and/or international agencies.

Industrial Organisation

The project is organised with well-defined levels of industrial responsibilities, reflecting the progressive restructuring of European industry for the development and exploitation of next-generation launchers. It merges the best industrial competences and ensures a single optimised overall system structure.

Under the responsibility of NGL Prime, the system activities focus on project management, planning, costing, control and system engineering. These include technology requirements, technical specifications, subsystem procurement, environments and internal/external interfaces, product assurance and safety.

NGL Prime contracts system support and subsystem design and production to level-1 companies, including Astrium (F, D) and Alcatel Alenia Space (I), and level-2 subcontracts to European industry and research organisations from ESA Member States participating in IXV. The subsystem efforts centre on structures, thermal protection and control, descent and recovery, guidance, navigation and control, power, data handling, telemetry, software, mechanisms, flap control, reaction control, ground and flight segments and flight test instrumentation.

Today's industrial team is growing to include all the required industrial and research organisations within Phase-B. This will allow a solid commitment on the schedule and cost-at-completion by the time of the Preliminary Design Review at the latest. It will also allow the industrial activities to ramp up smoothly after Phase-B.

ESA Member State Participation

IXV is supported by 11 Member States: Austria, Belgium, France, Germany, Ireland, Italy, Portugal, Spain, Sweden, Switzerland and The Netherlands. Although Europe lacks experience in developing such a complex lifting-body reentry system, the broad participation of Member States provides a large and efficient industrial organisation with all the competences to make the project a success.

National and International Cooperation

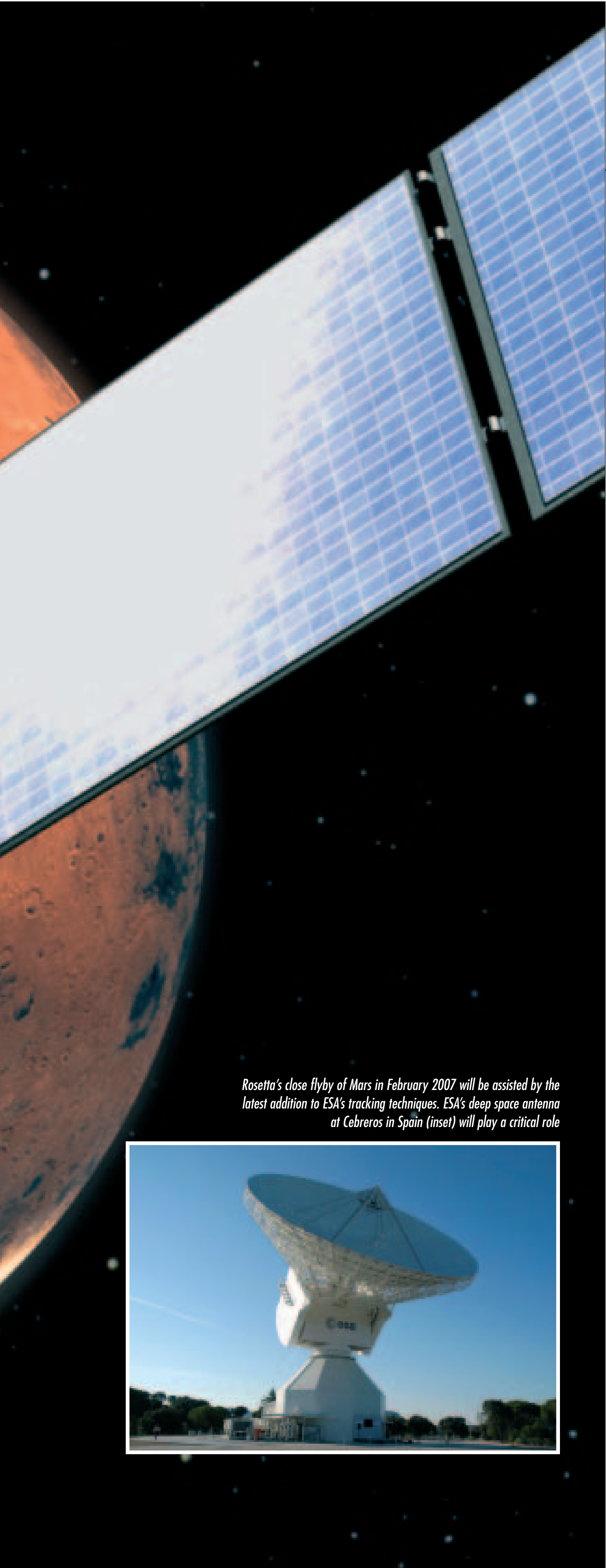
The nominal project planning and execution is done within ESA's FLPP, which is funding IXV activities up to early 2009. Although the rest of the funding is expected to be agreed upon at the next ESA Council at Ministerial Level in 2008, it is important to increase coordination and harmonisation with national programmes in order to avoid wasteful duplication and help to secure budget resources for the following IXV phases as soon as possible.

ESA is fostering cooperation with national agencies in Europe to streamline all the national activities on reentry systems and technologies towards the common IXV objectives. The Agency is evaluating the benefits and constraints stemming from project financing by multiple budgetary sources (including ESA and national), while maintaining its own coherent approach to ensure common industry policy principles for participating Member States.

ESA is also exploring cooperation opportunities with international agencies, such as in Russia, to benefit from the existing expertise in reentry systems in order to reduce experiment risks and costs, while maintaining the key objectives of Europe's technology experiments. esa

Delta-DOR

A New Technique for ESA's Deep Space Navigation



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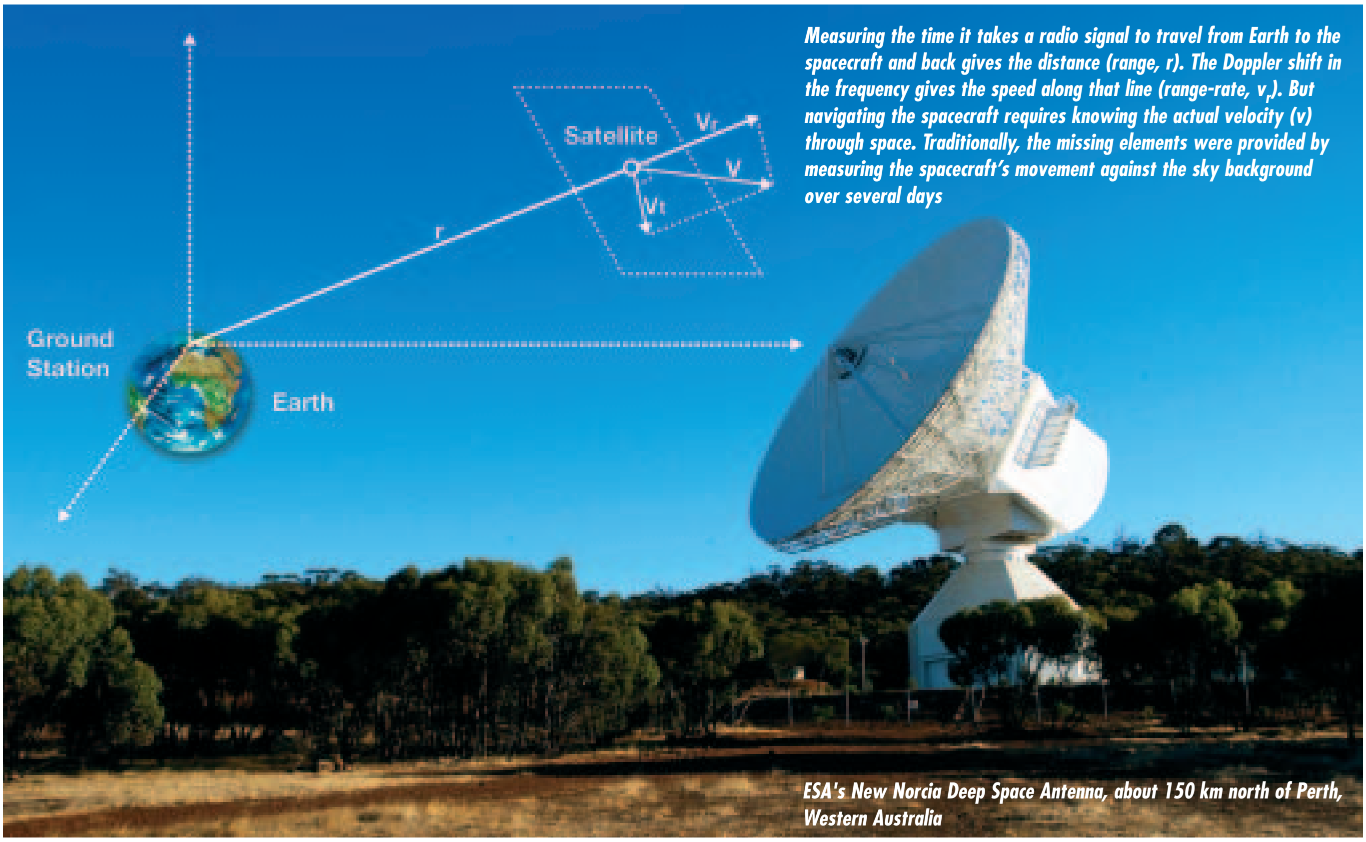
Rosetta's close flyby of Mars in February 2007 will be assisted by the latest addition to ESA's tracking techniques. ESA's deep space antenna at Cebreros in Spain (inset) will play a critical role

When ESA's second deep space antenna became available in late 2005 Cebreros in Spain, the Agency could begin using a powerful new navigation technique particularly important for interplanetary craft: delta-DOR. Delta-DOR contributed to the successful orbit insertion of Venus Express around the planet in April 2006, and it is expected to be a fundamental tool for navigating all of ESA's current and future interplanetary missions.

Introduction

Routine navigation of a spacecraft around the Solar System relies on two tracking methods: ranging and two-way Doppler. Precisely measuring the time it takes radio signals to travel to and from a spacecraft gives the distance from the ground station ('two-way range'), while measuring the signal's Doppler shift provides the craft's velocity along that line-of-sight ('range-rate'). The other two position coordinates, against the sky background, are obtained only indirectly from the motion of the ground station as the Earth rotates. This imposes a daily sinewave oscillation



Measuring the time it takes a radio signal to travel from Earth to the spacecraft and back gives the distance (range, r). The Doppler shift in the frequency gives the speed along that line (range-rate, v_r). But navigating the spacecraft requires knowing the actual velocity (v) through space. Traditionally, the missing elements were provided by measuring the spacecraft's movement against the sky background over several days

ESA's New Norcia Deep Space Antenna, about 150 km north of Perth, Western Australia

on the range and range-rate data related to the position of the spacecraft. These position components, though, can only be deduced to much lower accuracy. Also, when the spacecraft is close to the celestial equator, the calculations struggle and the north-south position is very poorly determined. The craft's velocity components in the plane-of-sky are not measured and can only be found from how the position changes from day to day. This means that tracking over several days is necessary and calls for very high-fidelity modelling of the spacecraft's motion.

The tracking system at ESA's 35 m-diameter deep space antennas (DSAs), at New Norcia in Western Australia and Cebreros near Madrid provides very accurate measurements. Typically, the random errors on range are about 1 m and on the two-way range-rate less than 0.1 mm/s. Nevertheless, the limitations described above mean the accuracy of resulting orbit determination may not be good enough for navigation during critical stages of a mission. This is especially the case on approaching a planet before landing, performing a swingby or insertion into orbit. However, ESA can now augment the conventional tracking by measurements known as 'Delta Differential One-way Range' (delta-DOR).

NASA's Deep Space Network (DSN) has provided delta-DOR data since 1980 and has aided the navigation of ESA missions since 1986.

In 1992, the navigational accuracy of Ulysses on its approach to Jupiter was improved by the addition of delta-DOR measurements. In the second half of 2003, 56 delta-DOR measurements from the Goldstone (California, USA)-Madrid baseline and 49 from the Goldstone-Canberra (Australia) baseline were processed at ESOC for Mars Express. For the release of Beagle-2 and insertion into Mars orbit, this provided a 7-fold reduction in the navigation uncertainty compared with the standard method.

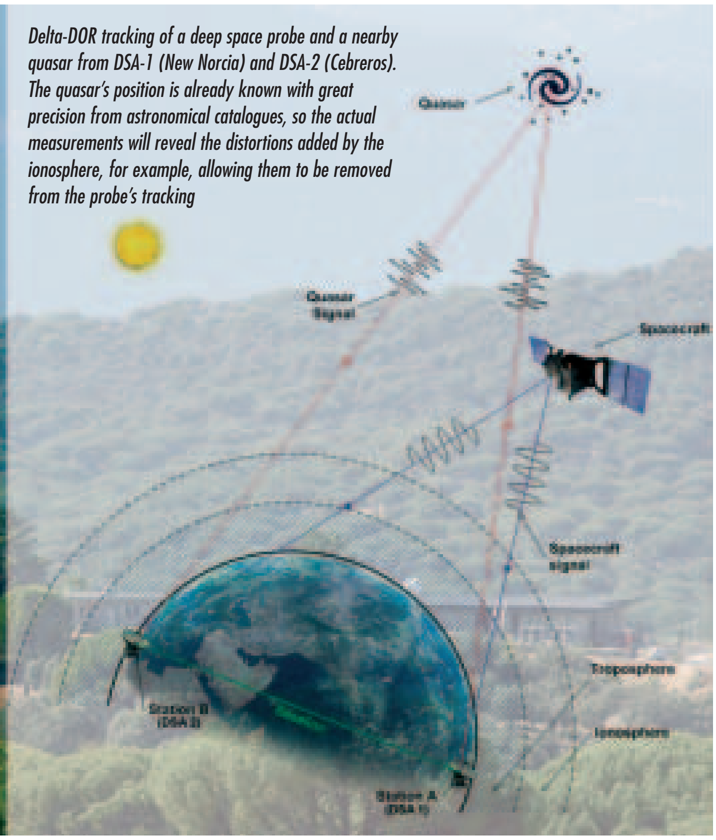
The ESA Delta-DOR Concept

The delta-DOR technique for navigating interplanetary spacecraft is based on a simple but effective concept. It uses two widely separated antennas to simultaneously track a transmitting probe in order to measure the time difference ('delay time') between signals arriving at the two stations. The technique of measuring this delay is named Differential One-way Range (DOR).

Theoretically, the delay depends only on the positions of the two antennas and the spacecraft. However, in reality, the delay is affected by several sources of error: for example, the radio waves travelling through the troposphere, ionosphere and solar plasma, and clock instabilities at the ground station.

Delta-DOR corrects these errors by 'tracking' a quasar in a direction close to the spacecraft for calibration. The chosen quasar's direction is already known extremely accurately by astronomical measurements, typically to better than 50 *billionths* of a degree (a nanoradian).

ESA's second Deep Space Antenna, at Cebreros, Spain



Delta-DOR tracking of a deep space probe and a nearby quasar from DSA-1 (New Norcia) and DSA-2 (Cebreros). The quasar's position is already known with great precision from astronomical catalogues, so the actual measurements will reveal the distortions added by the ionosphere, for example, allowing them to be removed from the probe's tracking

The quasar is usually within 10º of the spacecraft so that their signal paths through Earth's atmosphere are similar.

In principle, the delay time of the quasar is subtracted from that of the spacecraft's to provide the delta-DOR measurement (the Greek symbol 'delta' is commonly used to denote 'difference'). The delay is converted to distance by multiplying by the speed of light.

A complication is that the quasar and spacecraft cannot be measured simultaneously. In practice, three scans are made: spacecraft-quasar-spacecraft or quasar-spacecraft-quasar, and then interpolation between the first and third converts them to the same time as the second measurement, from which the delta-DOR data point is calculated.

As two angles are required to define a direction, full exploitation of delta-DOR calls for measurements from two different baseline orientations, the closer to 90º the better. The error in the delta-DOR measurement translates into an angular error that diminishes with longer baselines. Maximising the baseline is limited by the need for the spacecraft and quasar to be mutually visible from both antennas for long enough.

During each scan, signals are sampled and recorded in the stations. The recorded data are transferred to ESOC, where they are processed to extract the delay.

A spacecraft signal is normally a sequence of frequency-spaced tones (either dedicated DOR tones produced by the transponder or harmonics of the telemetry subcarrier), each tone with its full power contained in a few Hertz of bandwidth. In contrast, quasar signals look like noise buried in the antenna's overall noise. For this reason, two different algorithms (based on the signal's characteristics) are necessary when extracting the delay in the signal arrival times at the two stations.

Also, the accuracy improves if the tones are further apart in frequency. So a wide bandwidth is important.

With the Cebreros DSA-2 antenna coming into operation in September 2005, ESA had the potential for making delta-DOR measurements for the first time. With DSA-1 at New Norcia in Western Australia, the baseline is 11 650 km. However, even with this basic infrastructure, the system had to be upgraded for delta-DOR: modifying the receivers at each station, a new architecture for the communication links from the stations to ESOC, the development of a 'correlator' to extract the delays from the raw data recorded at each station, and a flight dynamics system able to use the measurements.

The system upgrade was completed in less than 10 months, driven by the need to have an operating and tested delta-DOR capability before the Venus Express launch in November 2005. The improved system could then help to navigate the craft between the planets and into the critical orbit insertion.

The Venus Express orbit had to calculated to very high accuracy, so an uncertainty of only 1 nanosecond (a billionth of a second) was imposed on the delta-DOR time-delay measurements. This corresponds to an angular accuracy of roughly a millionth of a degree – better than 4 km on the probe's position at a distance of 150 million km.

With only two stations available, ESA can provide delta-DOR tracking with just one baseline, and can track the spacecraft only in the portion of space visible between New Norcia and Cebreros.

The ideal case for delta-DOR purposes would be to have another deep space antenna at American longitudes, preferably in the southern hemisphere. This would provide a baseline almost perpendicular to the current one, completely resolving the angular position of the spacecraft.

With such a baseline, ESA could be independent of outside help for delta-DOR tracking.

Setting up the System

Creation of the delta-DOR system was done step by step. Several elements of the existing infrastructure had to be modified and some created *ex novo* to meet the highly demanding requirements on a very tight schedule.

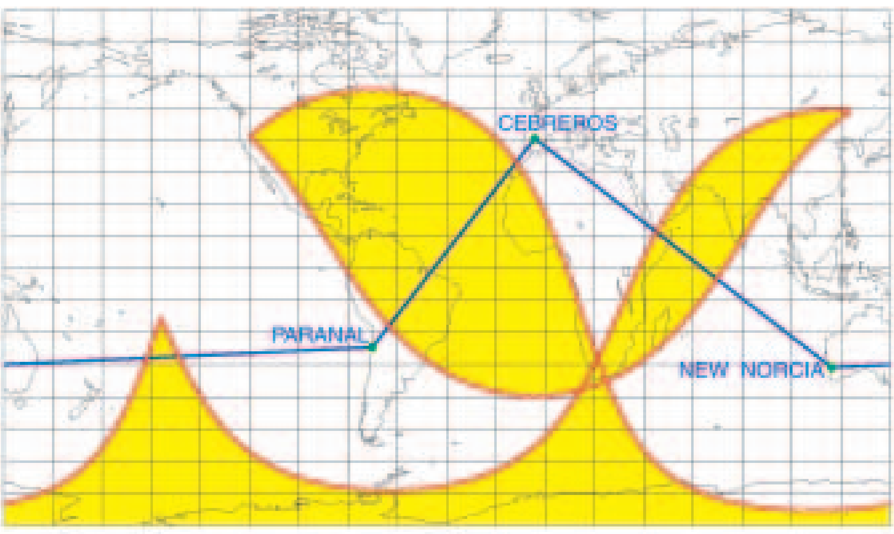
Receiver modifications

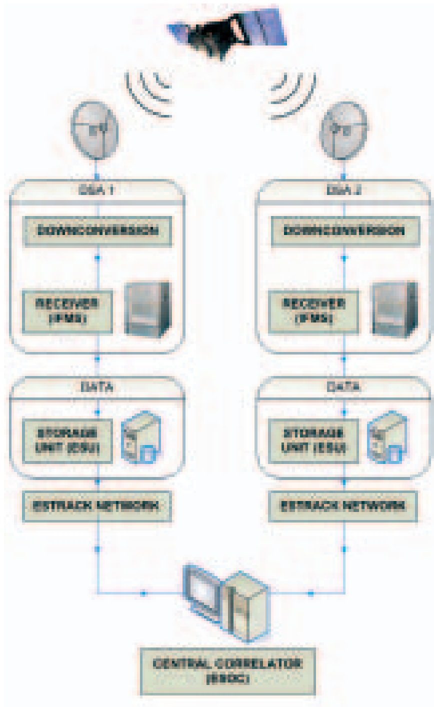
The existing Intermediate Frequency Modem System (IFMS) receiver had to be modified for simultaneous reception of multiple signals and to synchronise the raw data, essential for achieving the required accuracy.

The IFMS is a multi-mission receiver developed by British Aerospace under ESA contract for a large variety of routine tracking purposes – telecommand transmission, telemetry reception, data decoding, ranging and Doppler measurements. In order to support delta-DOR measurements, the IFMS was upgraded to receive up to eight channels in different portions of the downlink spectrum with a relative time-tag synchronisation among the channels of better than 1 nsec. Remote installation of the software (another characteristic feature of this receiver) then allowed a fast upgrade of the receiving system in both antennas. For redundancy, two of the three receivers in each station were upgraded.

Two External Storage Units (ESUs), each an off-the-shelf server, were added to each station to offload the storage burden from the receiver. They also permit fast formatting and long-term storage of the data.

Areas of mutual visibility (greater than 10° above the horizon) between DSA-1 (New Norcia), DSA-2 (Cebreros) and a hypothetical station in Paranal (Chile), highlighting the advantage of having a third antenna





The system updated for delta-DOR: the improved receiver, the storage units at each station, the modified wide-area network and the development and installation of a software correlator at ESOC

Data transfer

Once the data have been stored on the ESUs, they are transferred to the correlator at ESOC for processing. The quantity is substantial (up to 11 Gbyte) – mainly from the quasar observations. Furthermore, they must reach ESOC within 12 hours in order to be used for navigation within 24 hours of the observations. To cope with these restrictions and to keep the costs down (so no dedicated data links), existing resources had to be used. Both stations are connected to ESOC via a triangular network, where each side has a 2 Mbit/s capacity. For the delta-DOR data transfer, the capacity is used on a best-effort basis, on both the direct line (single hop) and the indirect line (dual hop). The busy lines, especially for New Norcia, required special data retrieval and stacking algorithms. (See also 'New Communication Solutions for ESA Ground Stations' in *ESA Bulletin* 125.

A high throughput was achieved: an average of up to 1.2 Gbyte/hour from

New Norcia and up to 1.4 Gbyte/hour from Cebreros, or up to 95% of the available bandwidth.

The correlator
The data are finally collected and processed in a ‘correlator’ explicitly designed for delta-DOR processing. The challenge in this case consisted of containing the costs (thus building a *software* correlator instead of the more complex and expensive hardware correlator normally used) and the very tight schedule. Defining the software requirements and identifying the interfaces with all the other elements was a demanding task, requiring the analysis of similar processors developed by NASA’s Jet Propulsion Laboratory and radioastronomy systems. The Department of Aerospace and Astronautical Engineering of the University of Rome ‘La Sapienza’ developed this software correlator. The host machine is an off-the-shelf server with enough computational power to process the data to meet the 24-hour constraint.

Flight dynamics support
An important role during all phases is played by the ESOC Flight Dynamics team, who support the planning, execution and evaluation of delta-DOR observations by:

– identifying suitable quasars near to the direction of the spacecraft, and providing visibility information;
– providing accurate orbit predictions to the correlator, including derived quantities like expected one-way range and range-rate values for both the spacecraft and quasar for both stations;
– processing the reduced DOR data within complex software to generate the delta-DOR residual (the difference between the actual measurement and its value predicted from mathematical models) and, together with the processing of the conventional data, to determine the spacecraft orbital parameters.


Two IFMS receivers were upgraded at each ground station

Delta-DOR Operations
The two ground stations are usually remotely operated from the Ground Facilities Control Centre in ESOC. Orbit predictions required to point the antennas to the object are delivered to the stations on a routine basis. The unique delta-DOR feature is the production by the Flight Dynamics team of predictions for quasars. The operations of all ground elements supporting delta-DOR (ground stations, correlator, Flight Dynamics, communications, ESOC facilities) are scheduled according to Flight Dynamics requirements, which mesh with station usage by other missions, and in coordination with a delta-DOR observations planning team. The data recorded at the ground stations are retrieved offline via the correlator workstation during or just after the observation itself.

Based on the raw data, and on the prediction files provided by Flight Dynamics, the correlator extracts the delay between the signal arrival times at the two stations required for the orbit determination software. These are delivered to the Flight Dynamics team to calculate the spacecraft’s orbit.

The Validation Campaign with Mars Express
Testing of ESA’s delta-DOR system began in late 2005 using Rosetta and Venus Express. Around the same time, DOR measurements were made of pairs of quasars (one of each pair representing the spacecraft) so that the correlation of the quasar signal could be validated. In January and March 2006, test DOR data were obtained from Mars Express.

Of all these tests, those with Mars Express were the most important. While in orbit around Mars, its trajectory is determined using only Doppler data, with a resulting error in its position relative to the planet of usually less than 200 m. Our knowledge of the position of Mars itself has about the same accuracy. Mars Express could thus be used to evaluate the real accuracy of the delta-DOR measurements.

The Mars tests revealed a correlator problem that caused the delta-DOR measurements to be wrong on the order of 5 nsec. After this was corrected, processing of the six sets of DOR data showed that all but one of the delta-DOR measurements were accurate to better than 0.5 nsec (the goal was 1 nsec). The other gave 0.7 nsec; this was caused by using a quasar 15º from the spacecraft (the standard is within 10º).

The Operational Venus Express Campaign
Following these encouraging results, and although the project was still in its validation phase, it was decided to make delta-DOR measurements of Venus

Express and use them operationally. Fifteen data points derived from sessions on five occasions in March and early April 2006 augmented a total of 45 NASA measurements obtained at the same time, mainly from the Goldstone-Canberra baseline.

Pre-launch analysis had shown that, under normal circumstances, the navigation accuracy needed for insertion into orbit around Venus could be achieved with range and Doppler data only. Delta-DOR increased confidence, because it could confirm the basic correctness of these conventional orbit solutions.

Also, delta-DOR covered the contingency case of the spacecraft switching to its basic safe mode during the last few days before arrival at Venus. In that case, thrusters would fire autonomously and perturb the orbit with a velocity increment of unknown magnitude and direction and imprecisely-known timing. Delta-DOR would reveal the orbit much faster than conventional data.

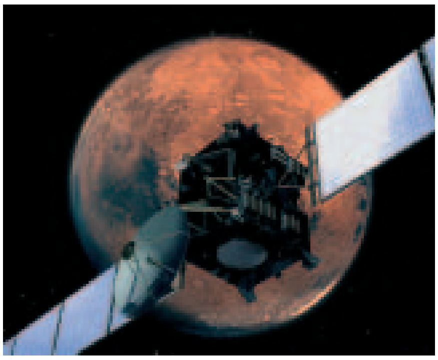
Analysis showed that the quality of these ESA measurements was only slightly inferior to those obtained using NASA's 34 m antennas. The most accurate were obtained with NASA's 70 m dishes. Although the delta-DOR data substantially reduced the navigation uncertainties, the improvement was not as marked as that for Mars Express. This was mainly due to a combination of unfavourable geometry and problems achieving consistent modelling of small accelerations from solar radiation pressure and possible outgassing from the spacecraft.

Despite this, the single most important navigation parameter, the minimum altitude above Venus at arrival, was only 3 km higher than the predicted 386 km. Even with all the information available after the event, it is not possible to distinguish entirely between small navigation errors and the small difference between the actual and expected performance of the orbit insertion.

The Future

On 25 February 2007, Rosetta will swing by Mars at a planned altitude of 250 km. Errors in the swingby are fuel-expensive to correct afterwards, so it is planned to make both NASA DSN and ESA delta-DOR measurements, mostly in January and February.

In early 2007, Rosetta will appear in Earth's southern sky, at the limit of simultaneous visibility from Goldstone and Madrid for NASA. It is expected that very few, if any, DOR measurements can be made from this baseline. This means that, in order to exploit delta-DOR capabilities to obtain complete direction information (that is, use two baselines), one must be of NASA stations and the other of ESA stations – a truly complementary arrangement between two space agencies.



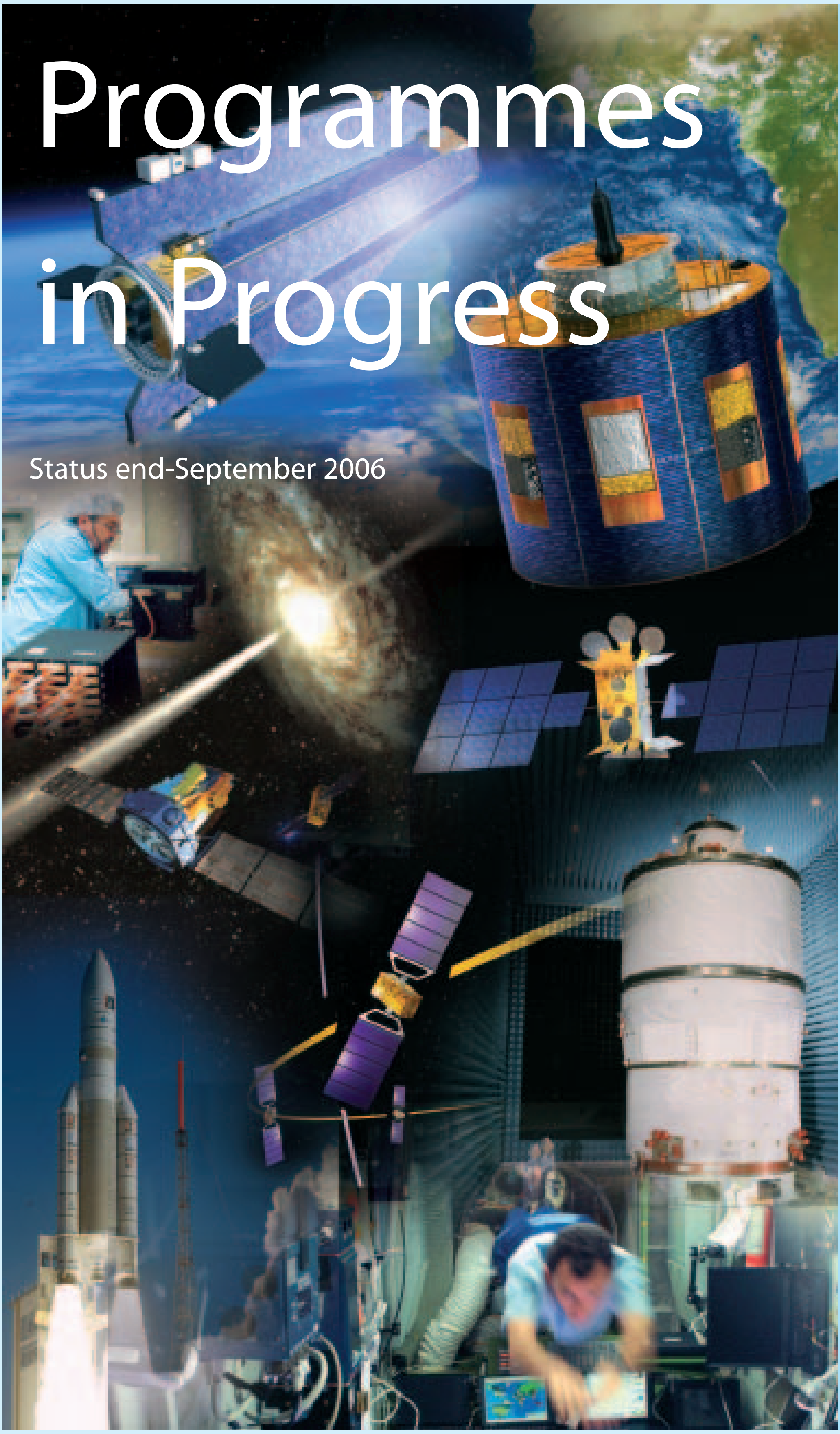
ESA's delta-DOR measurements will be important for combining with NASA's information during the Rosetta flyby of Mars in February 2007

Future interplanetary ESA missions will also benefit from this technique. It is expected that it will help BepiColombo to make significant fuel savings in its correction manoeuvres. In preparation, a SMART-1 tracking campaign validated the capability of the system to record and process dedicated DOR tones transmitted by the spacecraft.

Finally, collaboration with NASA and Japan will be improved by the development of data translators to exchange data and results. This will greatly extend the number of baselines available for delta-DOR observations, benefiting everyone involved in the navigation of deep space probes. e

Programmes in Progress

Status end-September 2006



	PROJECT
SCIENTIFIC PROGRAMME	SPACE TELESCOPE
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	SOHO
	HUYGENS
	XMM-NEWTON
	CLUSTER
	INTEGRAL
	MARS EXPRESS
	SMART-1
	DOUBLE STAR
	ROSETTA
	VENUS EXPRESS
	HERSCHEL/PLANCK
	LISA PATHFINDER
	GAIA
	JWST
	BEPICOLOMBO
EARTH OBSERVATION PROGRAMME	METEOSAT-5/6/7
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	CRYOSAT
	GOCE
	SMOS
	ADM-AEOLUS
	SWARM
	EARTHCARE
COMMS./NAV. PROGRAMME	ARTEMIS
	ALPHABUS
	SMALL GEO SAT.
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	GALILEOSAT
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	PROBA-2
	SLOSHSAT
HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME	COLUMBUS
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	ISS SUPPORT & UTIL.
	EMIR/ELIPS
	MFC
	ASTRONAUT FLT.
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	EXOMARS
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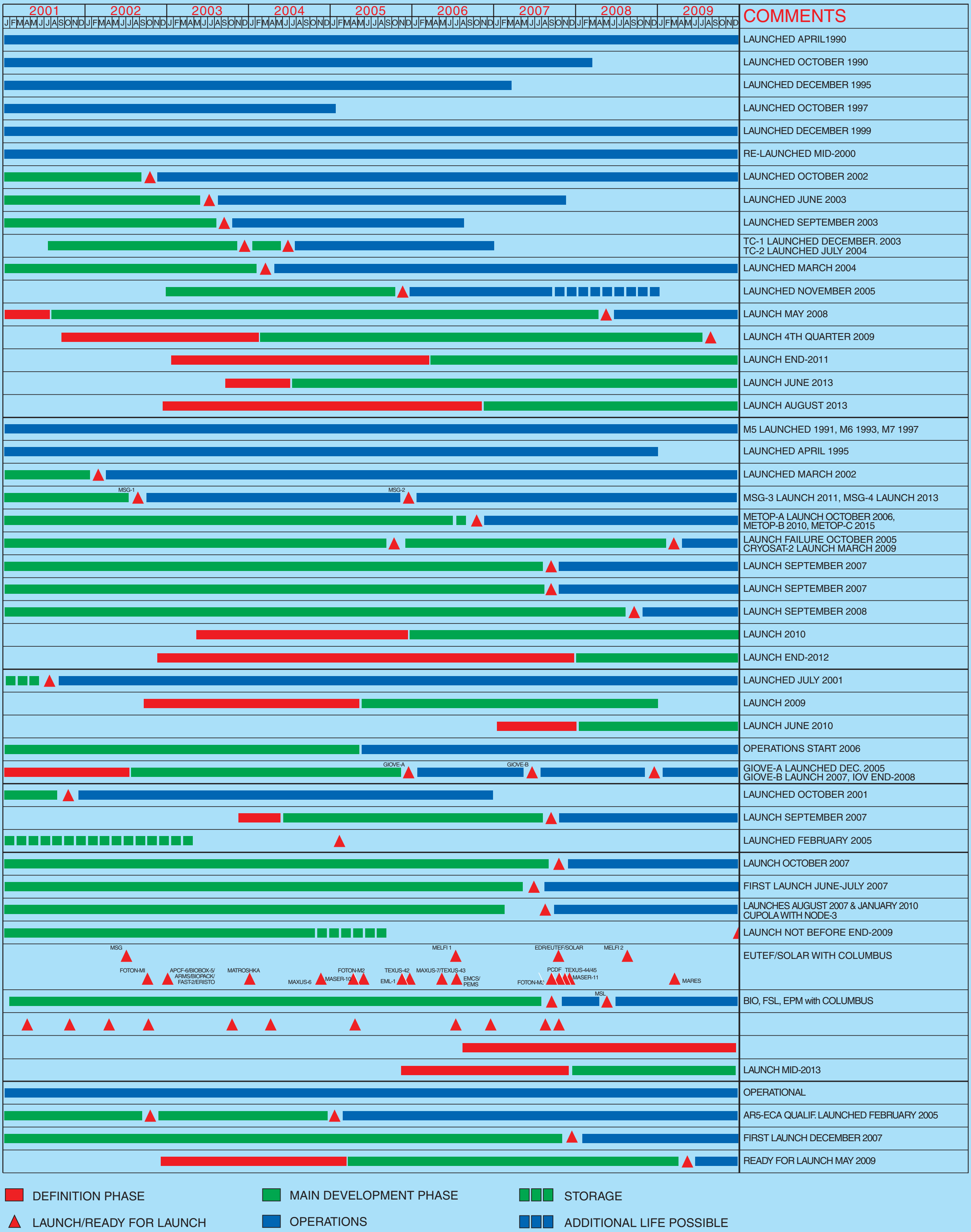
	ARIANE-5 PLUS
	VEGA
	SOYUZ AT CSG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MSG-3 LAUNCH 2011, MSG-4 LAUNCH 2013
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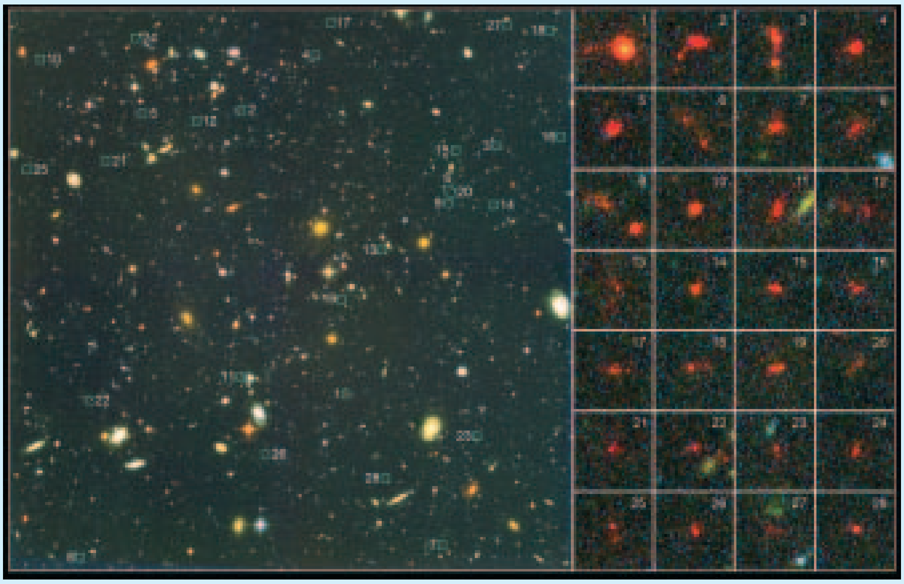
LAUNCHED OCTOBER 2001
LAUNCH SEPTEMBER 2007
LAUNCHED FEBRUARY 2005
LAUNCH OCTOBER 2007
FIRST LAUNCH JUNE-JULY 2007
LAUNCHES AUGUST 2007 & JANUARY 2010
CUPOLA WITH NODE-3
LAUNCH NOT BEFORE END-2009
MSG
MELFI 1
EDR/EUTEF/SOLAR
MELFI 2
FOTON-M1
APCF-6/BIOBOX-5/
ARMS/BIOPACK/
FAST-2/ERISTO
MATROSHKA
MAXUS-6
FOTON-M2
TEXUS-42
MAXUS-7/TEXUS-43
EML-1
EMCS/
PEMS
PCDF
TEXUS-44/45
MASER-11
MARES
EUTEF/SOLAR WITH COLUMBUS
MSL
BIO, FSL, EPM with COLUMBUS
LAUNCH MID-2013
OPERATIONAL
AR5-ECA QUALIF. LAUNCHED FEBRUARY 2005
FIRST LAUNCH DECEMBER 2007
READY FOR LAUNCH MAY 2009
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
STORAGE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE

HST

A team of US and European astronomers analysing two of the deepest views of the cosmos made with the Hubble Space Telescope has uncovered a gold mine of more than 500 galaxies that existed less than a billion years after the Big Bang. This sample is the most comprehensive compilation of galaxies in the early Universe, researchers said. The discovery is scientifically invaluable for understanding the origin of galaxies, considering that just a decade ago early galaxy formation was largely uncharted territory. Astronomers then had not seen even one galaxy from when the Universe was a billion years old, so finding 500 in a Hubble survey is a significant leap forward for cosmologists.



This Hubble image shows 28 of the more than 500 young galaxies uncovered in the analysis of two Hubble surveys. (NASA; ESA; R. Bouwens & G. Illingworth, University of California, Santa Cruz, USA)

Ulysses

On 6 October, Ulysses completed its 16th successful year in orbit. The spacecraft continues its climb to high southern latitudes with all subsystems and science instruments in good health. Science operations are currently being conducted according to a revised payload power-sharing plan. Largely as a result of the gradually improving thermal situation as Ulysses gets closer to the Sun, several instruments not in the core payload category have been able to acquire data for short periods (typically a month). These include the gamma-ray burst experiment and the solar wind electron sensor. Ground segment performance has been excellent, leading to an overall data return for the period of 98.6%. By the middle of November, the spacecraft will have reached 70ºS solar latitude, marking the start of the third South Polar Pass.

One of the fathers of the Ulysses mission (and one of its longest-serving Principal Investigators), Johannes Geiss, recently celebrated his 80th birthday. Geiss is a world-leader in the measurement and interpretation of the composition of matter that reveals the history, present state and future of astronomical objects. A symposium devoted to these topics was held in September to honour him and celebrate his birthday. At that meeting, George Gloeckler, his Co-PI on the Ulysses Solar Wind Ion Composition instrument (SWICS), noted that Johannes Geiss was the first to measure the composition of the noble gases in the solar wind when, in the late 1960s, he flew his brilliant foil experiments on five Apollo missions to collect solar wind ions on the Moon. In recent years, Geiss, together with his colleagues on the SWICS team, has determined the isotopic and elemental composition of the solar wind under all solar wind conditions and at all helio-latitudes.

Geiss' quest to measure and understand the composition of matter is not limited to the solar wind, however. He has also played a key role in the *in situ* measurement of molecular ions in comets and the interpretation of these data, and in the study of the composition of plasmas in the magnetospheres of Earth and Jupiter. On behalf of the Ulysses team, we wish Johannes Geiss 'many happy returns' and many more scientific discoveries.

ISO

The 5-year ISO Active Archive Phase is due for completion in December 2006. This is the last phase of ISO, aiming at ensuring the best use of the legacy provided by the first true infrared observatory in space, in close collaboration with active National Data Centres. Major releases of the ISO Data Archive included:

- the introduction of products derived from systematic manual processing of data, including queryable catalogues and atlases (Highly Processed Data Products). ISO will have about a third of its content populated with Highly Processed Data Products;
- the adoption of an innovative way to document quality information for each observation;
- the characterisation by object type;
- full integration into the Virtual Observatory.

ISO results continue to appear in the refereed literature and are clearly used to prepare proposals with other astronomical facilities. The *ISO Science Legacy* book was published, reviewing the most significant results from papers published until 2005. Over 1380 refereed papers based on ISO data have been published to date. Documentation about the mission, its instruments and data products has been published in the 5-volume *ISO Handbook*. This is accompanied by a legacy of around 200 documents organised in the

ISO Explanatory Library on the ISO web site. Support continued to be provided directly to users in their exploitation of the ISO data throughout the period.

SOHO

SOHO-18 'Beyond the Spherical Sun: A New Era in Helio- and Asteroseismology' was held jointly with the annual meeting of the Global Oscillation Network Group (GONG) 7–11 August at the University of Sheffield, UK. Nearly 130 participants discussed over 150 papers, which will be published as ESA SP-624. A French-Spanish team reported the detection of g modes in the Sun using 10 years of GOLF data. Their results also suggest a solar core rotating significantly faster than the rest of the radiative zone. If confirmed, this could open a new era in the study of the dynamical properties of the central solar interior.

On 9 August a Polish amateur astronomer discovered the 1000th SOHO comet in the Kreutz group of Sun-grazing comets. The 1185th comet discovered in data from SOHO's LASCO and SWAN instruments in total, the faint object is officially designated C/2006 P7 (SOHO) by the Minor Planet Centre of the IAU. Before the launch of SOHO, only some 30 members of the Kreutz group were known. All 1000 Kreutz comets are believed to be fragments of a single comet observed in about 371 BC by Aristotle and Ephorus, and the fragments themselves continue to fragment, making more Sun-grazing comets.

Cassini-Huygens

The Cassini Orbiter mission continues smoothly. Regular observations are published on JPL's web page (*http://saturn.jpl.nasa.gov*). Each Titan flyby brings new surprises as the radar probes new territory. Lakes have been spotted near the north pole but it is not yet known whether they are dry or filled with liquid. Upcoming observations of the same territory under a different geometry may help to answer this question.

The analysis and interpretation of Huygens data continue. The excellent scientific return of Huygens is well illustrated by the movies recently released by the DISR team (available at *http://saturn.esa.int*). These give a good account of the work done so far by all the teams to understand and interpret the performance of the probe during the descent and the returned science data. A recent detailed interpretation of the Huygens observations by Titan meteorologists suggests that methane was drizzling down on the day of the Huygens landing.

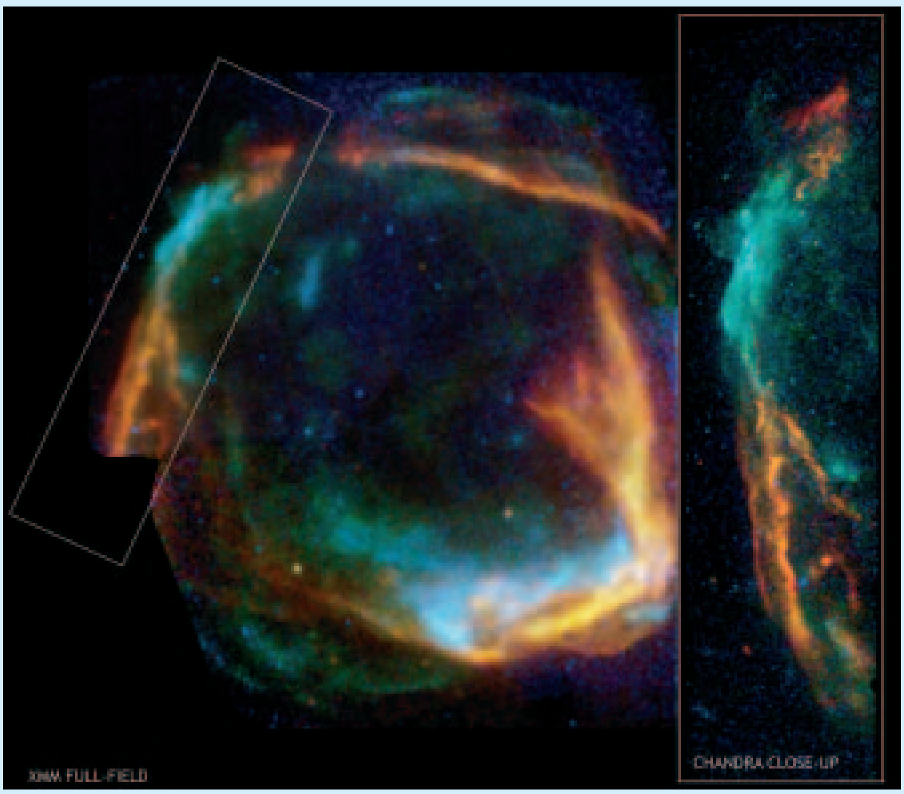
XMM-Newton

XMM-Newton operations are continuing smoothly, with the spacecraft, instruments and ground segment all performing nominally. The 6th Announcement of Observing (AO-6) opportunity for observations to be performed between May 2007 and May 2008 has opened. XMM-Newton scientific results have been reported in 1188 refereed papers, of which 181 are from 2006.

A preliminary version of the second XMM-Newton serendipitous source catalogue, 2XMMp, has been released. The catalogue has been constructed by the XMM-Newton Survey Science Centre (SSC) on behalf of ESA. It contains over 150 000 source detections, making it the largest catalogue of astronomical X-ray sources ever produced. The catalogue is derived from the available pointed observations that XMM-Newton has made so far, and covers less than 1% of the sky.

XMM-Newton has found evidence linking stellar remains to the oldest recorded supernova. The combined image from the Chandra and XMM-Newton X-ray observatories of a supernova remnant called RCW 86 shows the expanding ring of debris that was created after a massive star in the

XMM-Newton full field (left) and Chandra close-up (right) images of the oldest recorded supernova, RCW 86. Both images show low-energy X-rays in red, medium energies in green and high energies in blue. (ESA/XMM-Newton; NASA/CXC; Univ. Utrecht, J. Vink)



Milky Way collapsed and exploded. The new observations reveal that RCW 86 was created by a star that exploded about 2000 years ago. This age matches observations of a new bright star by Chinese (and possibly Roman) astronomers in 185 AD and may be the oldest known recording of a supernova.

Cluster

The four spacecraft and instruments are operating nominally and have successfully come through the long eclipse season, including spacecraft-1, which now has very weak batteries. To counteract this, ESOC defined a new mode of operation called ‘decoder only’, where the computer and all other subsystems are switched off. To warm up spacecraft-1 and recharge the batteries, the instruments were switched off for all the eclipses (15–23 September). The other three satellites recorded data as usual between eclipses.

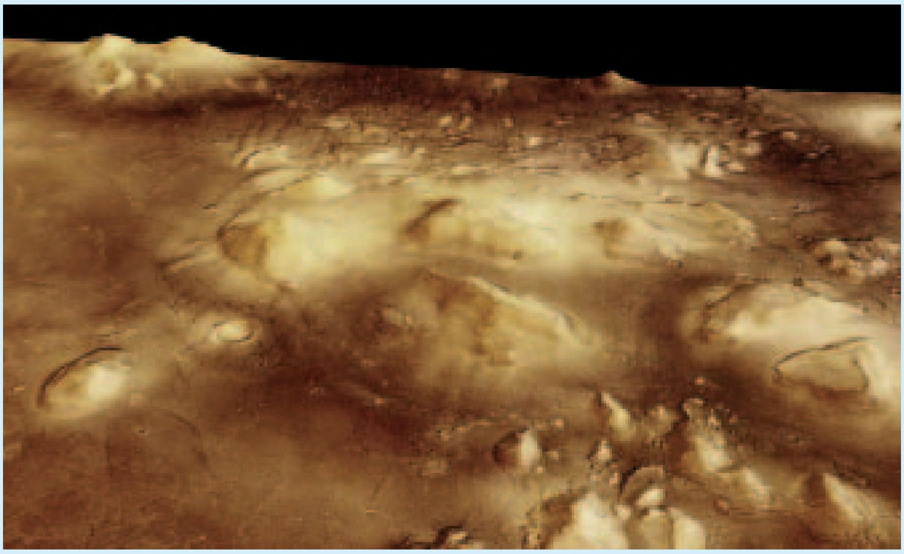
JSOC and ESOC operations continue nominally. The data return from June 2006 to the end of August 2006 was on average 99.8%. The Cluster Active Archive is also operating nominally. User access is growing every month and a total of 256 users were registered at the end of August (more than 80% increase over the last quarter).

An article on magnetic reconnection in the tail, where Cluster could detect a magnetic null for the first time, was accepted by a new journal: *Nature Physics*. The article was written by a team of Chinese scientists from Peking University together with European scientists. Magnetic nulls are expected in the centre of the reconnection when the two opposite fields cancel each other before reconnecting.

Integral

Integral operations continue smoothly, with the spacecraft, instruments and ground segment all performing nominally. Targets selected in response to the 4th Announcement for Observing proposals (AO-4) are being observed. AO-4 includes a pilot key programme observation of the galactic bulge region, which attracted a great deal of interest. The scientific community will be invited to propose specific key programmes in AO-5.

Integral scientific results have been reported in 203 refereed (of which 62 are from 2006) and 355 non-refereed publications. The 6th Integral workshop was held at the Space Research Institute (IKI) in Moscow with the theme ‘The Obscured Universe’. The workshop was attended by about 180 scientists from around the world. The topics discussed covered nearly all the major scientific areas being investigated using Integral, including the nature of the high-energy cosmic background, massive black holes, and nucleosynthesis and X-ray binaries in our own Galaxy.



A perspective view of the Cydonia region of Mars based on images from the High Resolution Stereo Camera aboard Mars Express. Resolution is 13.7 m/pixel; date 22 July 2006. See the ‘In Brief’ news section of this issue for further information. (ESA/DLR/FU Berlin, G. Neukum)

Mars Express

In early June, Mars Express celebrated 3 years in space. Most of the summer was spent preparing for, and entering, the power-challenging eclipse/aphelion season. The special Survival Mode was tested and successfully used to sail safely through the longest eclipses. With the craft being configured for the low-power/aphelion season, payload operations are suspended (except for radio science during solar conjunction) for some 10 weeks. However, thanks to excellent support from the full ground segment, it proved possible to make two sets of coordinated Mars Express-NASA Rover/CRISM spectrometer observations between the low-power/aphelion and the solar conjunction windows. Insufficient downlink capacity was available at the time, and the data will be downlinked after the end of the solar conjunction on 5 November.

The latest major Mars Express discovery was made by the SPICAM team when they found the highest clouds above any planetary surface. The results are a new piece in the puzzle of how the Martian atmosphere works. Until now, scientists had been aware only of the clouds that hug the Martian surface and lower reaches of the atmosphere. Thanks to SPICAM, a fleeting layer of clouds was discovered at an altitude of 80–100 km, most likely composed of carbon dioxide.

A spectacular set of images covering the Cydonia region, and including the famous ‘Face on Mars’ and its appearance following years of geological processing, were released, and can be found on *http://www.esa.int/marsexpress*

Double Star

The two spacecraft and their instruments are operating nominally. TC-2 has started the eclipse season and TC-1 follows in November.

The European Payload Operation System, which coordinates the operations for the seven European instruments, is running smoothly. Data are acquired using the VILSPA 2 ground station for 3.8 h/day over an average of two passes per day. The availability of the ground station between January and July 2006 was above 99%.

A study on pulsed magnetic reconnection was published in *Annales Geophysicae* using Double Star and Cluster data. It was shown that newly reconnected flux tubes ('flux transfer events') are observed in the equatorial plane by Double Star and at higher latitude by Cluster. This showed that the reconnection site was at least extended over 2 h in local time. Furthermore, Double Star could detect these events during one of its longest observations (about 8 h).

Rosetta

At the end of its first period of solar conjunction, lasting March–May 2006, Rosetta was configured in Passive Cruise Mode during June and July. In this mode, the craft's activity level is reduced and ground contact is limited to once per week. Nevertheless, at the beginning of July it was possible to perform, via time-tagged commands autonomously executed onboard, measurements of the plasma environment with the RPC instruments while Rosetta was crossing the tail of Comet Honda. In August, preparation for the Mars swingby of 25 February 2007 began, with more frequent tracking from ESA's New Norcia and NASA's Deep Space Network ground stations. The fourth periodic payload checkout took place at the end of August, when the scientific instruments were activated in sequence and checked out over a period of 5 days outside of ground contact, and the resulting housekeeping and science telemetry data downlinked to the ground station at the end of the test. Preliminary analysis indicates that all instruments and the Philae lander are in good health.

On 29 September the second large Deep Space Manoeuvre was executed to target the trajectory for the Mars swingby. The manoeuvre was extremely accurate (0.1%) and placed Rosetta on its final course towards the Red Planet.

Intense analysis, testing and validation activities are under way at the Control Centre in preparation of the next critical mission phases: Mars and Earth swingbys in February and November 2007, respectively, and the first asteroid (Steins) flyby in September 2008. The payload is usually inactive in this cruise period, with the exception of periodic test activities and occasional scientific opportunities. However, payload operations are planned for December, when there will be many test and calibration activities, including major onboard software updates.

Venus Express

After the successful insertion into Venus orbit on 11 April, the spacecraft and its subsystems and the payload passed their in-orbit commissioning with flying colours. The spacecraft is functioning well and all payload elements, with the exception of the Planetary Fourier Spectrometer, show nominal performance. During Venus Orbit Insertion, VIRTIS provided spectacular views of the south pole's cloud structure. On 4 June commissioning concluded and the nominal science mission started. Management of the mission was transferred from the Scientific Projects Department to the Research and Scientific Support Department.

During the initial science phase the instruments already demonstrated that the objectives of the mission can be fulfilled: preliminary temperature and composition profiles of the atmosphere were derived. The feasibility of bi-static radar observations was demonstrated and the VMC imaging system provided the first sequences of the observations of the cloud movements in the atmosphere. Most spectacular so far have been the observations by VIRTIS at the different wavelengths in the 1–5 µm range. It clearly showed that we can penetrate to different levels deep in the atmosphere and even can relate the observations to distinct surface features.

Venus Express is operated from the VEX Mission Operations team at ESOC with daily 8 h tracking passes via ESA's deep space antenna in Cerbreros (E). Payload operations are coordinated by the VEX Science Operations Centre at ESTEC.

SMART-1

The operational mission ended on 3 September, at 05:42:22 UT, when the New Norcia ground station in Australia lost radio contact with the spacecraft. SMART-1 ended its journey in the Lake of Excellence, at 34.4ºS/46.2ºW. The ~2 km/s impact took place on the nearside of the Moon, in a dark area just near the terminator at a grazing angle of 5–10º. The time and location was planned to favour observations of the event from ground-based telescopes. This was achieved by a series of orbit manoeuvres during the summer, using ingenious combinations of wheel offloading and thruster firings to reach an optimum orbit. The last manoeuvre was performed on 1 September. A final adjustment had to be made as a reanalysis of available lunar data performed at the University of Nottingham (UK) suggested that, in the absence of any further manoeuvres, impact would very likely occur one orbit earlier if SMART-1 clipped the rim of Clausius crater.

The impact concluded a highly successful mission that, in addition to testing innovative space technology, conducted a thorough scientific exploration of the Moon for about a year and a half, gathering data on the morphology and mineralogical composition of the surface in visible, IR and X-ray wavelengths.

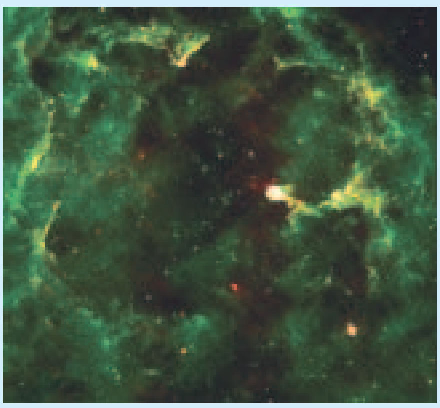
Professional and amateur observers from South Africa, the Canary Islands, South America, the continental USA, Hawaii and many other locations participated in the campaign. The most impressive observation was the IR impact flash seen by the Canada-France-Hawaii telescope. The Joint Institute for Very-long Baseline Interferometry (JIVE) in Europe coordinated a successful joint campaign covering five radio telescopes.

In addition to its mission proper, SMART-1 tested and calibrated parts of the ground segment for the Chinese and Indian space agencies in preparation for their Chang'e-1 and Chandrayaan lunar missions.

Akari (Astro-F)

Akari, Japan's IR astronomical satellite with ESA participation, continues its sky survey and its mapping of our cosmos. New exciting images recently recorded by Akari depict scenes from the birth and death of stars. In the IR camera image of the reflection nebula IC1396 at 9 µm and 18 µm (see photo), it is possible to discern new generations of stars being born in the outer shells of gas and dust ejected by violent massive star formation at the centre of the nebula. Akari's superior quality and high-resolution imaging allowed the clear detection of a shell-like dust cloud surrounding the old star U Hydrae at a distance of about 0.3 light years from the central star, implying that a short and violent mass ejection took place from the star about 10 000 years ago. This image was taken with the far-IR surveyor instrument at 90 µm. Akari is due to complete its first scan of the entire sky in October.

Akari reveals stars being born in nebula IC1396 (JAXA)



ESA's contributions to the mission are working well: regular and efficient ground station coverage from Kiruna (S) and pointing reconstruction software, developed at ESAC, which is already in routine use. The ESAC team is in close contact with the Open Time users in Europe, to maximise the overall scientific return of the pointed observations programme, despite increasing operational constraints.

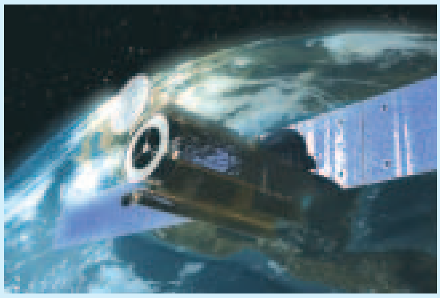
Hinode (Solar-B)

Solar-B was launched on 22 September at 21:36 UT from JAXA's Uchinoura Space Centre and renamed Hinode ('sunrise'). It is a Japan-led mission with US and UK instrument participation and ESA and Norwegian ground support. It is studying the mechanisms that power the solar atmosphere and looking for the causes of violent solar eruptions. The Sun-pointing platform carries three major instrument packages:

- Solar Optical Telescope (SOT), a high-resolution (0.2 arcsec) visual imaging system with a vector magnetograph and spectrograph;
- X-ray Telescope (XRT), for coronal imaging in a wide temperature range from 1 million K to over 30 million K;
- EUV Imaging Spectrograph (EIS), to measure temperatures and flows in the solar corona.

The satellite is in good health. It was injected into an orbit well within the nominal range and then adjusted into its final Sun-synchronous polar orbit. Following spacecraft commissioning, the three scientific instruments will be turned on by the end of October. First observations are planned for November.

Like its predecessor Yohkoh, Hinode started out as a Japan/US/UK mission. In order to enhance the scientific outcome of the mission, ESA joined the Hinode team in 2005 in the form of a coordinated endeavour with Norway. In partnership with the Norwegian Space Centre in Oslo, ESA is providing ground station coverage through the Svalbard Satellite Station. This is the only station in the world that can receive data for each of Hinode's 15 daily orbits. As a result, the data rate of Hinode and hence the scientific return of the mission will be significantly increased, and scientists from ESA's member states will have access to the data. These will be accessible via the European Hinode Data Centre, which is being built at the Institute of Theoretical Astrophysics at the University of Oslo.

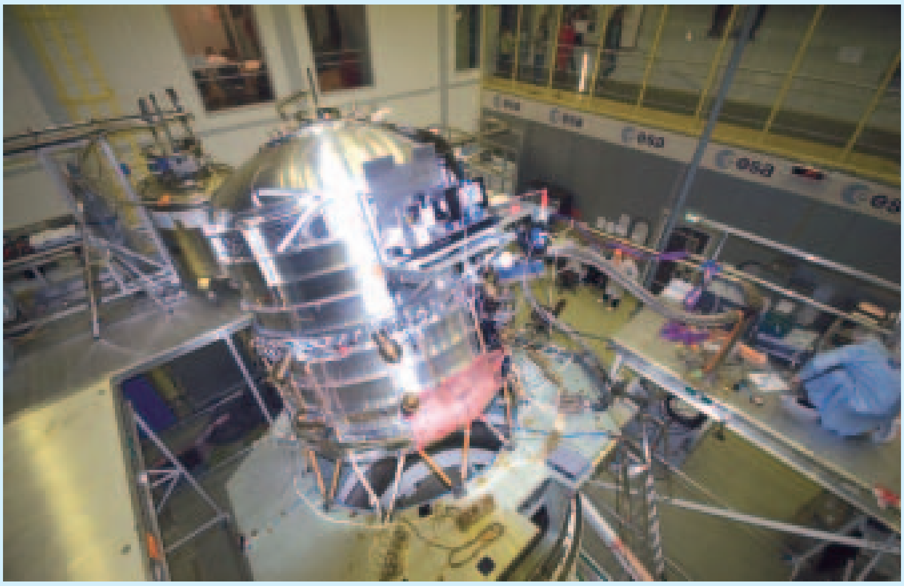


Hinode is operating successfully (JAXA)

Herschel/Planck

The satellite development in industry is progressing well, with the completion of the flight hardware. The improvements to the insulation system of Herschel's cryostat to recover the full lifetime performance have been completed, and the cryostat is back in ESTEC for another round of cryogenic testing. These tests include cryostat lifetime verification and verification of the cryostat internal straylight. The Flight Model (FM) of the Herschel Service Module (SVM) is now fully assembled and in the final stages of its electrical and functional testing. During the summer, the SVM successfully supported the first System Validation Test (SVT), when the spacecraft was controlled by the mission control centre, at ESOC.

The Planck spacecraft FM was returned to Alcatel (Cannes, F) for final electrical testing



The Herschel cryostat in the ESTEC cleanroom during preparation for its straylight test

and integration of the instruments and telescope. The electrical and functional verification testing is now concentrating on the Planck SVM, and is overall progressing nominally. The telescope FM completed its cryogenic testing with the videogrammetry measurement of the displacements.

On the Herschel telescope, a Tiger Team reviewed the results of the cryo-optical testing and confirmed readiness for integration with the spacecraft.

All Herschel and Planck instruments are in the final stages of their acceptance testing and instrument FM calibration. Planck's instrument testing was completed and the instruments are being deliveried for integration. Herschel's instruments are close to the start of their final calibration phase.

LISA Pathfinder

The SMART-2/LISA Pathfinder Implementation Phase contract is progressing well. The main system activity during the reporting period was the consolidation of the spacecraft design and the redefinition of the LISA Technology Package (LTP) Central Assembly accommodation inside the spacecraft. This activity was required in order to guarantee the LTP structural integrity during launch, while ensuring the delicate thermoelastic performance during the orbital measurement phases.

All the subsystem and equipment has now been selected and the contracts kicked off with one only exception: the thermal hardware is due to be procured in 2007. An important contract, awarded before the summer, was the parallel development of the two European micropropulsion technologies (needle indium thrusters and slit caesium thrusters). This additional technology development phase was deemed necessary after a previous competitive Invitation to Tender revealed that no technologies were ready for use in LISA Pathfinder. The suitable technology will be selected in the second half of 2007.

The LISA Pathfinder Engineering Model proof-mass undergoing magnetic susceptibility testing at the International Bureau of Weights and Measures (BIPM) in Paris

For the LTP, all the subsystem PDRs have been held and some CDRs have taken place. Good progress is being made despite the many technical challenges. The most critical subsystems are still the inertial sensor vacuum enclosure, the electrostatic suspension front-end electronics and the caging mechanism. Progress has been made on all of these. Breadboard tests confirmed the difficulty in meeting the extremely demanding performance requirements of these subsystems.

In the meantime, tests continue on the LTP various Engineering Models, both to confirm the basic concept of the electrostatic suspension of the inertial sensor in the pendulum facility at the University of Trento and to measure the magnetic susceptibility of the test mass. The test mass is made from a special alloy (73% gold, 27% platinum by mass) designed to minimise this fundamental property, to make the test mass insensitive to the spacecraft magnetic field and its gradient.

The Ground Segment, consisting of the Mission Operation Centre and the Science and Technology Operation Centre, has been defined and will undergo its PDR in October.

The launch is expected to take place at the end of 2009.

Microscope

The system- and satellite-level PDR was held on 13 February 2006 and closed on 13 April 2006 by the CNES Steering Committee. The approval to proceed with Phase-C/D was not given owing to delays in the development of critical technologies: the field-emission electric propulsion (FEEP) and T-SAGE inertial sensor. Since the Microscope FEEP development at ESA is closely linked to that on LISA Pathfinder, CNES decided to postpone the Phase-C/D until the end of the development/qualification phase of the LISA Pathfinder FEEP, planned for September 2007.

In the period March–June 2006, CNES studied alternative propulsion solutions to the slit FEEP. Two backup solutions were analysed: the needle FEEP being studied within the LISA Pathfinder parallel FEEP Phase-1 and the micronewton proportional cold-gas thruster (based on the technology development for Gaia). CNES presented the results of the analysis to their Board on 28 June, which recommended focusing on the nominal slit FEEP solution and monitoring with ESA support the development of the backup solutions.

Phase-B for the T-SAGE accelerometer development at ONERA was closed in May, though a delta-Phase-B is required in order to implement the recommendations of the PDR to solve the outstanding issues before starting Phase-C.

Gaia

In early July, Gaia passed the System Requirements Review, the first major milestone in the life cycle of a project. The board members declared that it had met all the objectives; this was very important because it forms the basis for the start of the detailed design activities.

The competitive selection of subcontractors continues according to the rules of the Agency. At the time of writing, more than a third of the nearly 80 procurements have been successfully completed. The progress of this activity is critical for the overall schedule stability of Gaia. The major risks, such as flight CCD production, mirror polishing and the detailed design work on the payload module, are all well in hand and progressing satisfactorily. No impact on the overall schedule for a launch at the end of 2011 has been identified.

In agreement with the Gaia Science Team, a number of dedicated working groups have been implemented to deal respectively with the specifics of the overall science data flow and the radiation characterisation of the CCDs.

The Gaia Science Team met at regular intervals to be briefed about the progress of the project, to provide advice as required and to discuss scientific matters.

JWST

NASA has reached a Technology Readiness Level (TRL) 6 for five out of ten JWST critical technologies: the Sunshield membrane; the Primary Mirror Segment Assembly; the Sidecar ASIC; and the Near-IR and Mid-IR Focal Plane Assemblies. The last three elements are part of the NIRSpec and MIRI instruments. Following recent problems in vibro-acoustic tests, the NASA-provided NIRSpec Micro Shutter Array will be the last item to reach TRL-6, in December 2006.

NASA-provided software platforms and EGSE were delivered to the MIRI and NIRSpec instrument developers. European personnel also received the training to operate this equipment.

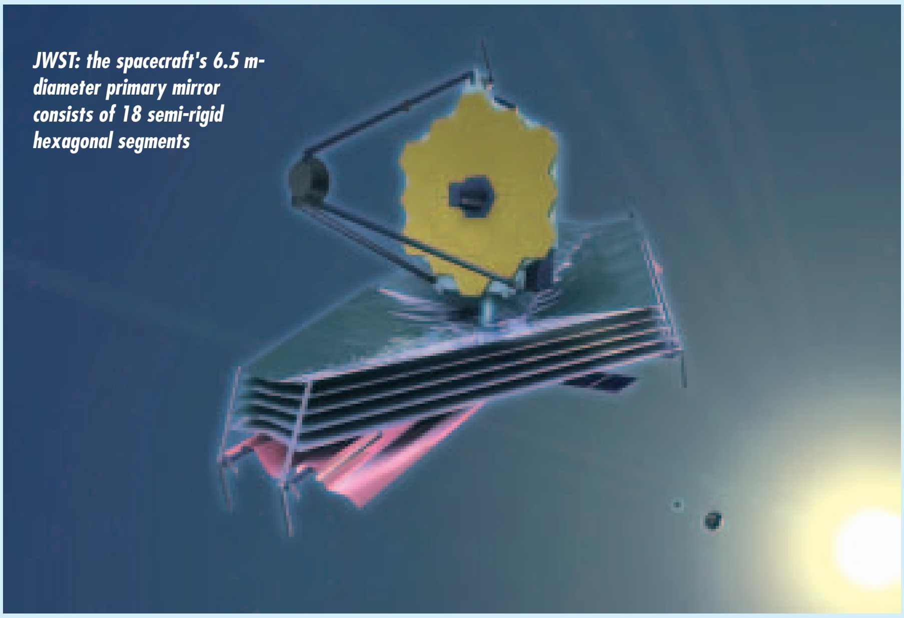
The build-up of the NIRSpec industrial consortium is reaching completion, with the last two procurements being finalised. The NIRSpec subsystems CDR campaign is starting.

Problems were encountered during the environmental and operational lifetime testing of the NASA-provided Micro Shutter Array flight-like devices. During the random vibration test, shutters remained stuck in the closed position and wire bonds and flex mounts broke. However, stiction problems remain the biggest concern.

The MIRI subsystem CDR campaign was concluded before the summer break. The action plan to close all open issues is consistent with the preparation of the MIRI optical system CDR, scheduled to kick-off in December.

Parts and subassemblies for the instrument Verification Model are being manufactured and tested. The MIRI Contamination Control Cover was delivered after successful vibration and cryogenic testing.

Finalisation of the ‘Definition Phase of the JWST Launch Services’ contract is under way. This definition phase will cover activities from now until 3 years before launch, and is meant to assist NASA and the JWST Prime Contractor during the development of the mission.



JWST: the spacecraft's 6.5 m-diameter primary mirror consists of 18 semi-rigid hexagonal segments

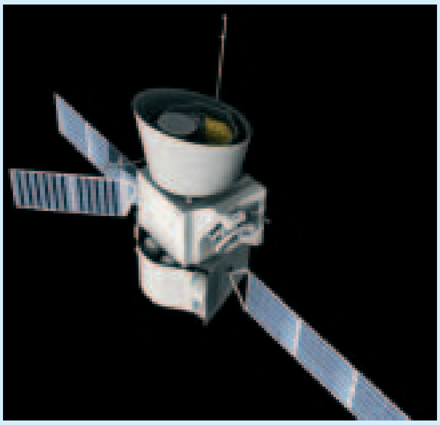
BepiColombo

The BepiColombo mission scenario foresees a Soyuz-Fregat launch in August 2013 and arrival at Mercury in August 2019 for a nominal 1-year scientific mission.

Proposals from Alcatel Alenia Space and Astrium were received on 17 May 2006 in response to the Invitation to Tender for the Implementation Phase. The Tender Evaluation Board, supported by a large team of specialists, performed a detailed evaluation of the proposals and recommended selection of the Astrium proposal. Both contenders were informed of this result on 6 July. Subsequent negotiations took place to integrate Alcatel Alenia Space within the core team. The contract proposal will be submitted to the Industrial Policy Committee at the end of January 2007. The cost-at-completion will be submitted to the Scientific Programme Committee (SPC) for approval in February 2007.

The third Science Working Team meeting was held in Padova (I) 26–28 September. The instrument design and prototyping is proceeding according to plan, but the immediate allocation of funds is of concern to some Principal Investigators. The project places particular emphasis on model philosophy, verification and procurement schedule for the present work with the Experimenter teams until detailed interface and accommodation work can be started with the Prime Contractor. The financial commitment from the Lead Funding Agencies to support the payload on the Mercury Planetary Orbiter is being obtained in accordance with the Science Management Plan. The proposed text of the Multi-Lateral Agreement between ESA and the Lead Funding Agencies has been informally discussed between all parties and is now being distributed for final approval. Likewise, a bilateral agreement between ESA and Roskosmos was drafted for the Mercury Gamma-ray and Neutron Spectrometer.

The joint Memorandum of Understanding with JAXA for the Mercury Magnetospheric Orbiter is awaiting JAXA approval, after which it will be submitted to the SPC.



The BepiColombo composite: the Mercury Transfer Module attached to the MPO and MMO spacecraft

The technology demonstration work for gridded ion thrusters is continuing on the Astrium RIT thruster and the QinetiQ T6 engine; almost 5000 h of thrust time has been achieved.

LISA

The Mission Formulation activity with Astrium GmbH is in its Phase-2 and is proceeding well. Following consolidation of the mission baseline architecture design, some trade-offs of alternative configurations were performed. These deal with alternative payload concepts, including off-axis telescope, in-field-of-view pointing and single proof-mass configuration.

The possibility of stable maintenance of the triangular constellation, thus removing the breathing angle, was analysed. The conclusion is that this option cannot be considered any further for two main reasons: the required thrust authority would be far above the FEEP capabilities, and the noise induced by this active/permanent thrust would severely degrade the measurement sensitivity of the LISA system.

Technology Development Activities Invitations to Tender will be released shortly to cover optical mechanisms, optical bench and telescope characterisation.

NASA is currently initiating an NRC review to decide on the prioritisation of the Beyond Einstein programme elements (LISA, Con-X and the JDEM probes). The target date for the final decision is October 2007. The LISA project is well under way in updating the documents that are expected to be required. In parallel, NASA is supporting the mission formulation activity. Regular Quarterly Progress Meetings and Technical Interchange Meetings are held to exchange information and results and jointly to consolidate the mission design.

GOCE

Substantial progress has been made with the gradiometer instrument over the past few months. Three Accelerometer Sensor Head (ASH) Flight Models (FMs) have been assembled and tested at ONERA. Five ASHs have therefore been completed to date; a sixth is being assembled and is expected to enter acceptance testing before the end of October. Alcatel Alenia Space has integrated the three Front-End Electronic Unit FMs, the Thermal Control Electronic Unit Proto-Flight Model (PFM) and the Gradiometer Accelerometer Interface Electronic Unit PFM and nearly completed the final functional testing. Moreover, the upgrade of the Structural Thermal Model of the Gradiometer Core, which will be used during the satellite FM test campaign, has also been completed.

On the platform side, there was a severe setback on 19 July when an anomaly in the Electrical Ground Support Equipment (EGSE) triggered a chain of events that ultimately led to an over-voltage on the platform PFM, causing the failure of one power converter of the Command and Data Monitoring Unit (CDMU) PFM and stress on many electronic components of the Power Conditioning and Distribution Unit (PCDU) PFM. Both units were demounted and returned to their manufacturers for further investigation and recovery. The EGSE unit was also returned for correction. As a consequence, the functional testing of the platform PFM had to be stopped, while the closed-loop functional testing of the Drag Free Attitude Control

System on the platform Engineering Model Test Bench continue. In order to minimise impact on the overall schedule, it was decided to use the time to recover the CDMU and PCDU PFMs to pack and ship the platform PFM and associated EGSE to the satellite prime contractor. Platform PFM transportation took place during the last week of September. It was agreed that industry will continue to work double shifts until completion of the assembly, integration and test programme.

Final acceptance testing of the first of two identical Ion Thruster Assemblies (ITA FM1) was successfully completed in September. ITA FM2 testing then began and will be followed by the integration of ITA FM1 and FM2 on a panel where the xenon gas feed system and the two Ion Propulsion Control Units have already been integrated. Functional tests are expected to take place throughout October and November, before final delivery of the full Ion Propulsion Assembly PFM in December.

The Factory Acceptance Test of Version 1 of the ground segment's Calibration and Monitoring Facility & Reference Planning Facility was completed in July. The pre-acceptance review of Version 2 of the Level 1 to Level 2 High Level Processing Facility of the European GOCE Gravity Consortium was held in July. Development of the Flight Operations Segment and the Payload Data Segment continue according to plan, and entry into the Ground Segment Overall Validation phase is expected soon.

CryoSat-2

The Contract for the Phase-C/D/E1 development of the CryoSat-2 satellite was signed with Astrium GmbH on 26 July 2006. Almost all of the subcontractor contracts have also been negotiated and kicked off. Manufacturing is in progress and many items of the flight structure, including composite panels and machined elements, are ready for integration.

Most equipment has seen some design evolution (owing to obsolescence of electronic parts, for example) while in a few cases limited redesign has been necessary to absorb the impact of the redundant SIRAL and to eliminate minor weaknesses found during the original CryoSat development. In three cases the manufacturer is developing a new equipment design to replace obsolescent equipment used in the original CryoSat. Consequently a series of delta-CDRs at equipment level have been held, leading up to the system-level delta-CDR starting in November 2006. The major lower-level delta-CDR for SIRAL was completed in July.

A 3-month delay in the star tracker delivery was announced, which appears to be a knock-on effect from damage incurred during testing of a star tracker in another programme. Since the same design is used in several ESA programmes, the possibility of optimising the production sequence and schedule to reduce the delay for CryoSat, without introducing delay to the other programmes, is being investigated.

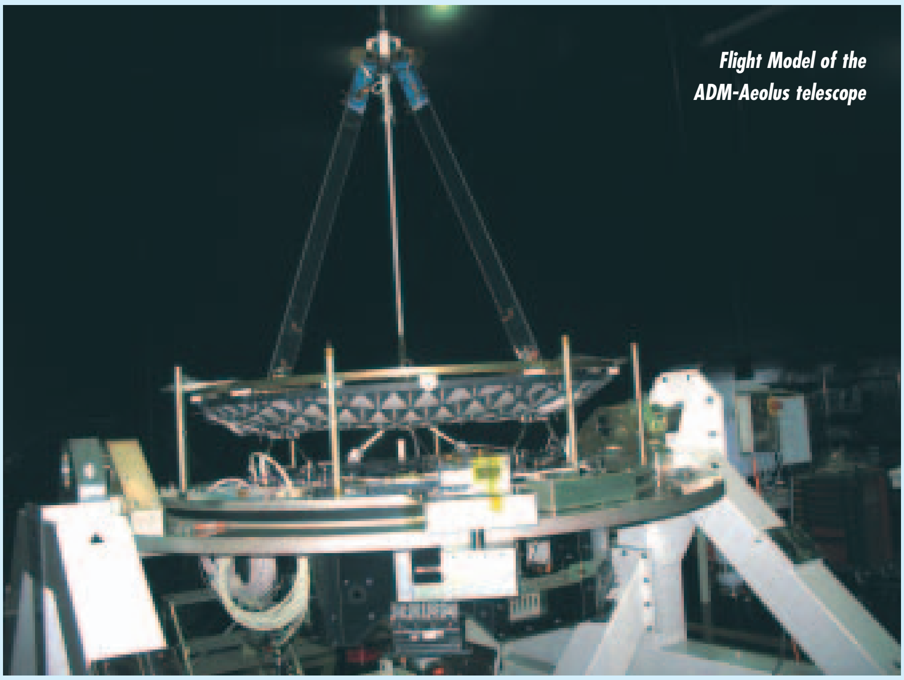
The process of approving all electronic parts has been almost completed during this reporting period.

Close-out work on the various components of the Payload Data Ground Segment has finished and the facilities hibernated. No further activities will be undertaken until 2007. The launch is scheduled for March 2009.

SMOS

Delivery of subsystem units for the payload protoflight model continues. All LICEF receivers have been delivered, and are being used to populate the arm segments of the structural model to undergo the 'on farm' antenna pattern characterisation at the Technical University of Denmark. All three arm measurements have been completed; still to be measured is the central hub structure with one adjacent segment of each arm. Once all the antenna characterisation is completed, the LICEF receivers will be transferred to the FM arm segments that are under integration with electrical, radio-frequency and optical harness, thermal control hardware, and other subsystems such as the noise sources of the calibration subsystem.

Platform integration of the recurrent Proteus platform has progressed significantly at the Alcatel Alenia Space facilities (Cannes, F). It is interrupted owing to the resumption of the Calypso launch campaign. Rockot launcher



Flight Model of the ADM-Aeolus telescope interfaces were reviewed in the Preliminary Mission Analysis Meeting involving ESA, CNES, Alcatel, Eurockot and Khrunichev.

For the overall SMOS ground segment, the PDR has been completed. While the elements of the flight operations ground segment, both on the CNES and the ESA side, were found to be in an adequate development state, the payload data ground segment, including the data processors for level-1 and -2 data products, were judged to be schedule-critical. Backup solutions were suggested by the Board for investigation and eventual implementation by the project.

The building refurbishment and preparations for the X-band receive antenna are progressing nominally for installing the ESA-part of the ground segment at ESAC (E).

ADM-Aeolus

The FM platform with tanks, pipework and harness installed was shipped to Astrium Friedrichshafen (D) for integration of the flight electronics units. Tests on the flight software using the onboard computer and the first platform electronics units are showing satisfactory results. The silicon carbide FM telescope integration is complete and its performance is excellent. All electronic units of the flight instrument except the laser have been bench-tested together; their performance is excellent.

There have been further thermo-mechanical problems with the laser. As a result, the thermal-vacuum test of the Qualification Model will now start in November.

A workshop for potential users was held at ESTEC at the end of September. All users expected a significant impact from the satellite on Numerical Weather Prediction. There will be many other benefits in climatology. There was widespread support for follow-on missions to avoid a data gap before the first post-MetOp satellite. This included some suggestions for cooperation with the US, where there is at present no comparable mission.

Launch of the satellite remains scheduled for September 2008.

Swarm

Phase-B of the satellite activities with EADS Astrium GmbH is progressing. The Satellite System Requirement Review is completed. Feasibility and preliminary mission analysis studies have been initiated with Arianespace, Kosmotras and Eurockot.

Procurement activities for the satellite units and instruments are well advanced, with subcontractor bids for critical elements of the programme already in the negotiation phase and close to kick-off. Other offers are in preparation.

Phase-B of the Electrical Field Instrument is progressing. Breadboard activities of the critical elements are near completion.

The Absolute Scalar magnetometer Phase-B is underway with LETI, Grenoble (F), under the leadership of CNES. The breadboard activities of the instrument are near completion. The manufacturing of the Engineering Model has started. The PDR is planned for mid-December.

MetOp

The planned launch date for MetOp-A of 17 July could not be kept. After three consecutive launch attempts, all halted by the Soyuz ground control system through a variety of relatively minor operational problems, the launcher's maximum period allowable in a fuelled condition was exceeded and it had to be returned to the manufacturer (TskB in Samara) for refurbishment. The satellite was returned to the integration facilities for storage.

Starsem and its industrial partners analysed the causes of the launch interrupts and identified technical solutions that allowed the launch campaign to restart on 30 August consistent with a launch on 7 October.

Launch of MetOp-A from Baikonur Cosmodrome on 19 October aboard a Soyuz-2/Fregat

Reactivation of the campaign meant that some essential and time-consuming activities had to be repeated. These were mainly solar array preparation, instrument cleaning and, finally, a satellite functional test.

MetOp was remated with its Fregat upper stage and reencapsulated to form the 'Upper Composite'. Unfortunately, during the transfer of the Upper Composite from the integration facilities to the transport train, a handling error caused a mechanical shock. This necessitated an investigation to check the integrity of the flight hardware, including mechanical analysis of the loads induced on the spacecraft and a detailed visual inspection that required MetOp's return to the cleanroom and removal from the fairing. The inspection revealed no damage to the satellite, and complementary analyses from the launcher authorities (TsKB, NPO-L and EADS-Casa)) and the spacecraft industry (Astrium) demonstrated that the allowable specifications for MetOp loads were not exceeded.

These additional activities meant that the launch date had to be delayed, to 17 October. Final preparations, formal rehearsals and simulations for both the launch and early orbit phase, satellite in-orbit verification and routine operations phases of the MetOp mission were completed. Both ESOC and Eumetsat Ground Systems are ready for the satellite launch. The 17 October launch attempt was halted by another Soyuz ground control system problem and the 18 October attempt was thwarted by high-altitude winds, but MetOp successfully reached orbit on 19 October.

MSG

Meteosat-8/MSG-1
A reset of the Central Data Management Unit (CDMU) resulted in the satellite entering safe mode on 23 September 2006. Although the exact cause is not yet known, it is likely to be a single event upset, as similar situations have been observed on the Spacebus 3000 CDMUs. After nominal reconfiguration, the satellite became the operational satellite again on 10 October 2006. Satellite condition is nominal and the instrument performance remains of excellent quality.

Meteosat-9/MSG-2
After successful commissioning, MSG-2 became the hot standby for Meteosat-8. With Meteosat-8 entering safe mode on 23 September, MSG-2 automatically became the operational satellite for the data delivery until the switch back to Meteosat-8 on 10 October. The satellite (now renamed Meteosat-9) shows flawless nominal operations.

MSG-3
MSG-3's flight PROM has been integrated and tested. It is planned to put MSG-3 in long-term storage by the end of the year, awaiting launch in early 2011.

MSG-4
Preparation activities for MSG-4's thermal-vacuum test and optical-vacuum tests have been completed. MSG-4 is now waiting for its test slot at Alcatel Alenia Space in Cannes (F); the thermal-vacuum test is expected to start by mid-November.

Human Spaceflight, Microgravity & Exploration

Highlights
Space Shuttle *Discovery* (STS-121) was launched to the ISS on 4 July with ESA astronaut Thomas Reiter aboard. He became the third member of the Expedition-13 ISS crew and is carrying out the long-duration Astrolab mission. Also launched, and commissioned in the US Lab Destiny, were ESA's European Modular Cultivation System, the –80ºC Freezer (MELFI) and the Percutaneous Electrical Muscle Stimulator.

Thomas Reiter working in the Destiny laboratory, 10 September

On 9 September Space Shuttle *Atlantis* (STS-115) was launched to the ISS, marking the return to major assembly work on the Station with the installation of the P3/P4 truss – the first configuration change for the ISS since November 2002.

The Space Station Control Board has made progress on the scheduling of the remaining Shuttle flights to the ISS, with the Columbus launch on flight 1E on 17 October 2007.

Space Infrastructure Development
The Columbus ground processing Phase-1 at the Kennedy Space Center was completed, including the integrated leak test which demonstrated that the ESA module is the least susceptible Station module in this respect. Columbus is now in storage at the KSC until April 2007.

A European commercial carrier, the Astrium-built ICC-Lite, has been baselined as the payload bay structure to support the SOLAR observatory and EuTEF facility payloads on the Columbus launch, saving several hundred kg of structural mass compared to its US counterpart.

Qualification and acceptance of the Columbus Control Centre is now almost complete, following the completion of the review (Q&AR) with the Board on 21 July.

The ATV *Jules Verne* spacecraft hardware and software is stable; acoustic and leak tests were completed and preparation is under way for the final major environmental test, the thermal-vacuum test. The second of three functional qualification test campaigns has started on the Flight Simulation Facility (FSF) at Les Mureaux (F), and a number of functional qualification tests were performed, and some major bilateral interface tests were also completed. However, some problems during functional qualification testing, which is on the critical path for the programme, are still being encountered on test platforms, usually caused by equipment front ends, and qualification testing will now continue through into early 2007, resulting in a launch date not earlier than mid-June 2007.

Qualification and acceptance of the ATV Control Centre is almost complete and the corresponding Q&AR review has started. Operations qualification for the *Jules Verne* mission is well under way, with many parts of the pre-qualification programme completed. The operations product verification review has taken place and the Board meeting in October gave the go-ahead for the start of the simulations and training programme.

The implementation review of the ISS operations services contract was completed and plans were agreed with industry for the work up to end-2007. This includes the Columbus and *Jules Verne* launches as well as the final transition from development to operations programme.

Node-3 functional testing was completed and mechanical activities, in preparation for acceptance and shipment early next year, are under way. However, NASA has indicated that it would like to transfer more activities from KSC to Europe; negotiations on these activities are under way, for which NASA will fund the European prime contractor of Alcatel Alenia Space in Turin (I).

Roskosmos has announced to the SSCB that it is planning on a long delay, to end-2009, for the launch of its Multipurpose Laboratory Module (MLM). This will entail a corresponding delay for the European Robotic Arm (ERA). Plans are already in place to store the flight unit, freeze all activities in Russia and go into team-keeping mode with Dutch Space.

Christer Fuglesang preparing for his EVA during Shuttle mission STS-116 in December 2006

Utilisation Planning, Payload Developments and Preparatory Missions

The SURE proposals review (32 proposals, four of which are industrial projects) is under way and the peer review of the 49 bedrest study proposals (15 science disciplines) is in preparation.

Precursor missions: Maser-11 Phase-A/B studies are almost completed and Phase-C/D will follow directly. The Phase-C/D Texus-44/45 Request for Quotation is starting in 2006, with a launch planned for end-2007, and Foton-M3 payload development activities are progressing well for a launch in September 2007.

Columbus payloads: European Drawer Rack (EDR)/Protein Crystallisation Diagnostics Facility (PCDF) integration has been concluded and Phase-C/D experiment development for Increment-16 is under way. The deployment of the first experiments for the Fluid Science Laboratory (FSL) and Biolab, as well as the Flywheel Exercise Device, is envisaged for flight 1E, together with the upload on 1E of various consumables for human physiology experiments.

Destiny payloads: on-orbit recertification of the Microgravity Science Glovebox (MSG) is almost complete, the Material Science Laboratory (MSL) flight model pre-ship review has started, and development of ANITA, which will be deployed on ATV-1 and accommodated in an Express rack on Destiny, is approaching completion.

Following launch on STS-121 (ULF-1.1) and commissioning, MELFI and EMCS are supporting the scientific programme. The Portable Glovebox has been used for the BIO-2 experiments that were performed during the Soyuz-13S visiting flight. During that flight, A. Ansari, acting as a short-term medical test subject, performed several human physiology experiments. The experiment programme executed by Russian cosmonaut P. Vinogradov (Increment-13) was successfully concluded.

ISS Education

Preparation of the education programme the Christer Fuglesang STS-116 mission (December 2006) is under way, and filming of the experiment has been approved by Principal Investigator.

The ARISS (Amateur Radio on the ISS) radio contact with the ISS and Thomas Reiter was organised in Patras, Greece on 29 July, with the participation of the Greek Minister of Education. The UTBI experiment (University of Valencia) was launched on Soyuz-13S.

Development and testing of the CASPER experiment (University of Dublin) is proceeding, with the launch targeted for Progress-23P.

Astronaut Activities

As part of his mission aboard the ISS, Thomas Reiter performed an EVA of more than 6 hours with NASA astronaut Jeff Williams. They completed all the preparation activities for the next ISS truss assembly (installing the motor controller on the radiator joint), deploying the new camera to monitor the condition of the Shuttle's carbon-carbon structures, installing two materials experiments (MISSE-3 and -4) and performing additional tasks.

Most Astrolab experiments have been already initiated by Thomas Reiter and will be performed repeatedly. More experiments and consumables were uploaded on Soyuz-13S and more will follow on Progress-23P.

Although the plans have not yet been formalised, ESA astronauts Leopold Eyharts and Frank De Winne have started to train as prime and backup for a mini-increment of 2–3 months after the launch of Columbus. They will be followed by a Canadian during stage 1J/A (with André Kuipers as backup) and then a JAXA astronaut during stage 1J.

Hans Schlegel was selected as a crewmember aboard Columbus/Shuttle flight 1E, in addition to Christer Fuglesang (12A.1, December 2006) and Paolo Nespoli (10A, Node-2 flight in August 2007).

The first ESA ATV training was provided to the Expedition-15 crew in September when the Russian prime and backup crewmembers received 'ATV Part 1 Training' at the European Astronaut Centre (EAC). Some 20 weeks of ISS crew training will be implemented at EAC for Columbus, ATV and payloads during the next 12 months.

Exploration

For ExoMars, now in Phase-B1 under Alcatel Alenia Space-Italy as prime contractor, the selection process of the second-level contractors has progressed with the issue in early August of the Invitations to Tender for the Descent Module Entry, Descent and Landing System (EDLS), Descent Module Support Structure and Rover Egress System (SES) and the Carrier/Orbiter. The Request for Quotation for the Rover Vehicle was released. All proposals have been received and are being evaluated.

Industrial activities began in early September with Galileo Avionica for the Drill and the Sample Preparation and Distribution system (SPDS) design and breadboard, and with Aerosekur for the airbag design and breadboard. The Planetary Protection support contract kicked-off at end-August with SEA/Open University.

Work has progressed on both the baseline mission, based on a Soyuz launcher and relying on a NASA telecommunications orbiter, and an enhanced option requiring an Ariane-5 launch. The latter option would allow an independent European mission with its own telecommunications orbiter and would provide the opportunity for continuing Mars Express-type science. A close examination was made of the overall project schedule, which resulted in a critical assessment of the 2011 launch target, which was considered to be very tight. The 2013 launch would provide a robust schedule with several months' contingency.

On the payload side, a series of instrument interface meetings between ESA, the prime contractor and each Pasteur instrument teams allowed good progress in the design and definition of the instrument interfaces. An assessment of the Pasteur payload mass allocation began in early July and continued into August to check whether some of the payload instrument requests could be accommodated.

The Geophysics and Environment Package (GEP) status review activities began with a first meeting in early July and continued through August and September. Further investigations are ongoing.

A preliminary meeting took place with Roskosmos to discuss potential cooperation in ExoMars. Of particular interest is the procurement of Radioisotope Heater Units (RHUs) of the type developed for the Russian Mars-96 mission. A follow-up technical meeting with BIAPOS, the company that developed and manufactured these devices, took place in early September with encouraging results. A meeting is foreseen in the near future to address the possibility of broader ESA/Roskosmos cooperation on the rover, airbags, parachute design and development.

Under the Exploration Core programme, the overall objectives and strategy for 2006–2009 were drawn up in line with the programme proposal resulting from the Berlin Ministerial Council in December 2005.

For the general exploration technologies and preparation for lunar exploration, several activities are under preparation. Habitation and life-support activities are being proposed for approval, dealing with further development of Melissa, development of the ALISSE advanced life-support system evaluator, further development of the ARES air-revitalisation system and further definition of exploration habitation requirements, for near-term implementation.

System-level studies are being proposed for *in situ* resource utilisation, better definition of ISS use for exploration and lunar mission analysis specifically addressing Lagrange orbits.

The Mars Sample Return Phase-A2 contract kicked off at end-August. Two precursor mission definition studies (autonomous rendezvous and soft/precision landing) will be performed after a first system design refinement loop.
Four tenders for approved planetary protection/RHU units/radiation-related activities of the Core programme were issued; proposals were received and are under evaluation.

Crew Space Transportation System

The Programme Declaration for the CSTS preparatory programme and a side document recording statements by participating States and ESA's Director General in connection with subscriptions were finalised on 29 September.

ESA and Roskosmos are discussing an exchange of letters that will establish the formal basis for conducting the preparatory programme as a cooperative undertaking. A fully-fledged agreement in accordance with the requirements of both agencies will be worked out and signed at a later stage. In parallel, the two parties will discuss and put in place the necessary measures to launch programme activities at both Agency and industrial level.

The ESA procurement process for industrial activities is being launched so that a contract can be awarded to industry as soon as possible.

Vega

The qualification test campaign for the launcher's upper composite started at the beginning of August in the ESTEC Test Centre. In September, it passed its vibration tests mounted on a shaker while some 400 accelerometers and 40 strain gauges measured the movements and deformation of the structure. Acoustic tests are scheduled for mid-October.

The Vega upper composite is prepared for testing in the Large European Acoustic Facility at ESTEC

The qualification test of the Zefiro-23 forward skirt was successful on 22 September. The test plan at the component level to characterise the skirt mechanical characteristics is under way.

The Zefiro-9 performance recovery plan was concluded. A slight modification of the propellant formulation and an increase in the expansion ratio were proposed. The modifications were reviewed in the Zefiro-9 CDR that began in September.

The composite structure for the P80 Demonstration Model firing test arrived in French Guiana during July, and the propellant casting was successful in August. Integration of the nozzle, igniters and sensors is proceeding according to schedule. The first firing test is planned for end-November.

Soyuz at CSG

The earthworks at the Soyuz Launch Site

The construction site has changed considerably in the past few months. Temporary facilities such as offices, changing rooms and catering facilities, were erected around the site. The stone crusher was erected and put to work, allowing the rock debris from the flame chute excavation to be used elsewhere. The foundations of the Launch Operation Centre and for the air-conditioning facility were laid. Hoisting equipment is being installed around the building construction sites.

The excavation of the flame chute is proceeding at a good pace, although problems have been encountered. It was discovered that the rock layer where the pillars of the launch table would have rested is not uniform. Instead, the construction company is building a concrete pillar, 8 m in diameter and 8 m deep, to reach the rock ceiling. The impact on the planning is being analysed and measures will be taken to regain the time needed for this unforeseen activity.

The CDR for the Launch System is scheduled for late October. The next industrial CDR for the Russian deliveries will be held in three steps, one for each major industrialist involved. The first began in late September, with the other two before the end of the year.

FLPP

An Authorisation To Proceed (ATP) was awarded to industry in July for the Vinci Expander Demonstrator first contract, funded by FLPP-2. The NGL ELV and Building Blocks system concept studies began after national agencies agreed on the Launcher System Workshop conclusions. The first set of industrial activities for the Intermediate eXperimental Vehicle (IXV) was completed. The second set began, while IXV activities to be funded by FLPP-2 are upcoming, with the Statement of Work being finalised.

For the consolidated FLPP contract with NGL, all technical and contractual clarifications were received and contract signature is planned in October. Pending finalisation of negotiations, industrial activities were launched by ATP.

In Brief

SMART-1: Crash Scene Investigation

Early on 3 September, observers around the world saw a small flash illuminate the surface of the Moon. They had witnessed the final moments of ESA's tiny SMART-1 spacecraft as it impacted the lunar soil.

SMART-1 scientists and engineers at the European Space Operations Centre (ESOC), in Darmstadt (D), confirmed the impact at 05:42:22 UT, when the New Norcia ground station in Australia suddenly lost radio contact. SMART-1 ended its remarkable journey in the Lake of Excellence, at 34.4ºS/46.2ºW.

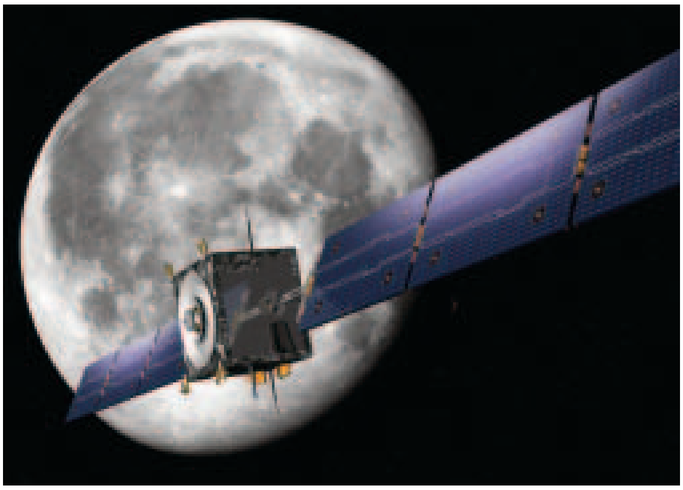
The 2 km/s impact occurred in a dark area near the terminator (the day-night line) at a grazing angle of 5–10º. The time and location were planned via a series of corrections during the summer – the last on 1 September – to favour observations by telescopes on Earth.

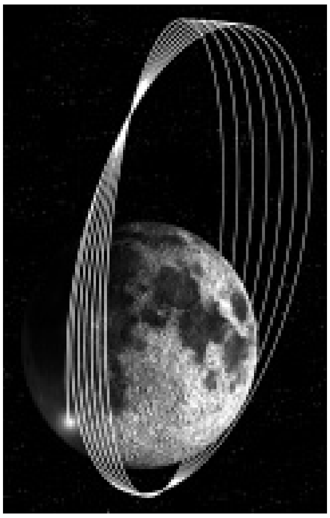
The impact concluded a spectacularly successful mission that, in addition to testing innovative space technology, had been exploring the Moon for 16 months, gathering data on the structure and mineral composition of the surface in visible, infrared and X-ray.

Professional and amateur observers from South Africa, the Canary Islands, South America, the continental USA, Hawaii and many other locations were watching, hoping to spot the faint flash for information about the impact dynamics and the lunar surface excavated by the spacecraft.

The final days of SMART-1 saw intense activity as controllers shepherded it towards its destiny. Based on estimates that included local topography, impact was due during orbit 2890, at 05:41 UT somewhere at mid-southern latitudes on the near-side. Then, with only a few days to go, the data suggested that, in the absence of any further manoeuvres, impact would very likely occur one orbit earlier, at 00:38 UT during orbit 2889, if SMART-1 clipped the 1600 m-high rim of Clausius crater.

During the night of 1–2 September, ESOC controllers planned to use the thrusters to



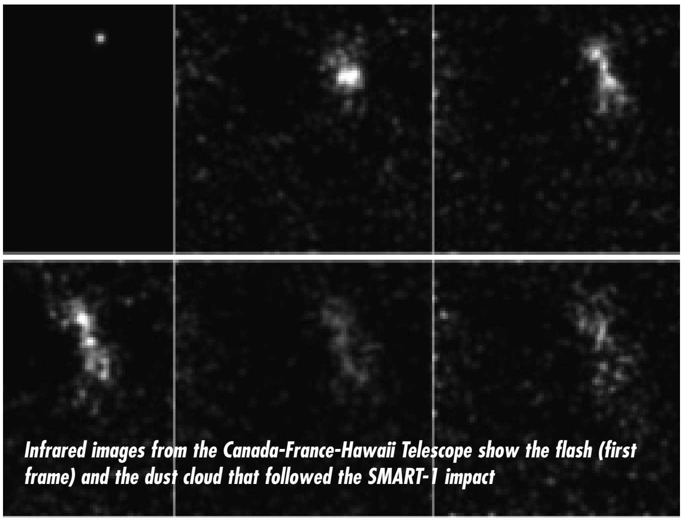


boost the perilune of the penultimate orbit, while maintaining the intended impact time and location. Suddenly, to add to the tension, SMART-1 unexpectedly placed itself into 'safe mode', at 13:09 UT on 1 September with the manoeuvres pending. Most spacecraft functions and payload operations were suspended.

After a tense 6 hours, Spacecraft Operations Manager Octavio Camino happily reported full recovery at 17:15 UT. The manoeuvres were successful, boosting perilune by 592 m and shifting impact to 05:42 UT.

The impact took place on orbit 2890. SMART-1 sent its last signals at 05:42:21:759 UT, and the Mount Pleasant Observatory radio telescope of the University of Tasmania in Hobart, lost the signal at 05:42:22.394 UT. These times are remarkable agreement with the final predictions and the coordinates derived from the position of the infrared impact flash observed by the Canada-France-Hawaii Telescope (CFHT) on Hawaii.

"*From the various observations and models, we are trying to*



Infrared images from the Canada-France-Hawaii Telescope show the flash (first frame) and the dust cloud that followed the SMART-1 impact

reconstruct the 'movie' of what happened to the spacecraft and the Moon's surface. For this lunar 'Crash Scene Investigation', we need all possible Earth witnesses and observational facts," said Bernard Foing, SMART-1 Project Scientist.

Extensive data processing is now under way to define the site's topography. From a preliminary analysis of the stereo data and earlier maps built with SMART-1 data, it should have hit the Moon on the ascending slope of a mountain about 1.5 km high, above the Lake of Excellence plain.

In the CFHT infrared movie, a cloud of ejected material and debris was seen moving about 80 km in 130 sec by Christian Veillet, Principal Investigator for the observations at CFHT. To determine which part of the flash came from heated lunar rock or from the probe's remaining propellant, it was important to obtain measurements in several optical and infrared wavelengths, in addition to the CFHT observations at 2.12 micron.

"*Our decision to extend the scientific mission by a further year (it was initially planned to last only 6 months) allowed scientists to use a number of innovative observing methods at the Moon. This was tough work for the mission planners, but the lunar data archive we are now building is truly impressive*," said Gerhard Schwehm, SMART-1 Mission Manager.

"*For ESA's Science Programme, SMART-1 represents a great success and a very good return on investment, both from the technological and the scientific point of view. Future scientific missions will greatly benefit from the technological and operational experience gained thanks to this small spacecraft, while the scientific data gathered by SMART-1 are already helping to update our current picture of the Moon*," said David Southwood, Director of Scientific Programmes.

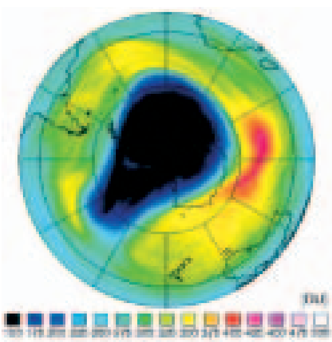
"*The legacy left by the huge wealth of SMART-1 data, to be analysed in the months and years to come, is a precious contribution to lunar science at a time when the exploration of the Moon is once again catching the world's interest*," said Bernard Foing.

Envisat Finds Record Ozone Hole

Measurements from ESA's Envisat satellite have revealed a record loss of ozone over Antarctica: the 40 million tonnes by 2 October 2006 exceeded the previous record of about 39 Mt in 2000. The size of this year's ozone hole is 28 million km^2, nearly as large as the record hole of 2000; its depth rivals 1998's record low.

"*Such significant ozone loss requires very low temperatures in the stratosphere combined with sunlight. This year's extreme loss can be explained by the temperatures above Antarctica reaching the lowest recorded since 1979*," said ESA atmospheric engineer Claus Zehner. The ozone layer, found about 25 km above us, shields life on Earth from the Sun's harmful ultraviolet rays. Over the last decade, the ozone has thinned by about 0.3% per year globally, increasing the risk of skin cancer, cataracts and harm to marine life. The reduction is caused by pollutants such as man-made chlorofluorocarbons, which have still not vanished despite being banned under the Montreal Protocol of 1987. A single molecule of chlorine can break down thousands of molecules of ozone.

The ozone hole of 27 September as measured by Envisat's SCIAMACHY instrument (KNMI/TEMIS)



The ozone hole, first recognised in 1985, typically persists until November or December, when the weakening polar vortex winds allow in ozone-rich air. ESA is backing the Tropospheric Emission Monitoring Internet Service (TEMIS) to provide operational ozone and UV radiation monitoring based on Envisat SCIAMACHY and ERS-2 GOME-1 data. The ozone data from these instruments, spanning 11 years, will be extended by the MetOp satellite series and its next-generation GOME-2 for years to come.

"*Long-term measurements of ozone levels are of key importance for being able to monitor the ozone's predicted recovery, which is currently estimated to take place by around 2060*," Zehner said.

Space Colloquium

During 19–22 September, the Western European Union (WEU) Assembly and the European Interparliamentary Space Conference joined forces to hold a colloquium on 'Space, Defence and European Security' in Kourou, French Guiana, in association with ESA, CNES and Arianespace.

The event brought together more than 100 Members of Parliament from European nations along with Members of the European Parliament and senior executives from ESA, CNES, Arianespace and the space industry. The main aim of the discussions was to examine the space sector in its application to security and defence and assess industrial

Greece photographed by ESA astronaut Thomas Reiter from the International Space Station during his radio contact with 'Space Camp' students on 29 July. This year's ESA Space Camp was held in Patras, Greece

capabilities in the light of the challenges facing Europe. The participants noted the gulf between the strategic ambitions that Europe has for its space dimension and the level of funds it was prepared to commit to it.

The President of the Interparliamentary European Security and Defence Assembly (WEU Assembly), Jean-Pierre Masseret, emphasised the importance of Europe being able to draw on the full gamut of space-based facilities: Earth observation, telecommunications, intelligence, navigation and ballistic missile early warning systems, noting further that this comprehensive range of capabilities played a crucial part in preventing, managing and exiting crises, and would guarantee genuinely autonomous powers of decision and action in security and defence matters for Europe.

The President of the European Interparliamentary Space Conference, François Roelants du Vivier, welcomed the colloquium being held in Kourou, in his view "*not a moment too soon*". If Europe wanted to catch up with its main competitors in space, it needed to take the financial decisions that were necessary, and quickly. The vital necessity of the security and defence dimension being discussed at the colloquium was something that parliamentarians must seriously take on board in order to convince governments to invest massively in space – an area that has been far too long neglected.

The Director General of ESA, Jean-Jacques Dordain, felt that messages were being received from the conference that would constitute important inputs into the preparation, by the European Commission and ESA, of the European Space Policy, to be unveiled at the Fourth Meeting of the Space Council, in May 2007. Members of national parliaments and the European Parliament had affirmed the strategic importance of space for Europe. In defining and implementing a European Space Policy, Europeans should build on present successes. There was a need to take feedback from users, consolidate technological and industrial capacities, maintain flexibility, strengthen coordination between the parties involved and manage the evolution of space governance by stages. This was a challenge for everyone and one to which, with the commitment of all concerned, and in particular of the member states, Europe was quite equal.

For the President of CNES, Yannick D'Escatha, space had become thoroughly interdisciplinary, and was thus a key element of major European policies. He emphasised the special 'dual' contribution of space in virtually every field – military and civil – connected with people's security and was adamant that Europe must take advantage of this dual-use aspect, in view of the difference in levels of investment in Europe and the USA (1:6).

On the subject of access to space, the Chief Executive Officer of Arianespace, Jean-Yves Le Gall, pointed to the ever-stronger position of European launchers. Ariane-5's reliability and regular launches had enabled Europe to orbit the greatest number of commercial satellites in 2005 and 2006. This had given Europe a ready, reliable, guaranteed competitive access to space for sovereign missions by European governments.

In this respect, the European launcher programme was a model of the success of European integration in the service of security and defence, as the launches of 26 military satellites already illustrates. Finally, the full range of launchers in use at Europe's Spaceport in Kourou from 2008 – Vega, Soyuz and Ariane-5 – would mean that Europe could independently put a payload of any given weight into any chosen orbit. esa

Vega Nozzle

A ceremony at Snecma Propulsion Solide in Bordeaux (F) on 14 September marked the formal delivery of the first nozzle for the P80 first stage motor of ESA's Vega small launcher.

The delivery is a milestone for the Vega programme. Several years of intensive development have achieved a major step forward in reducing costs. Not only a major event for Vega, it also bodes well for future updates to the Ariane-5 boosters.

Now in Kourou, the nozzle is being integrated with the P80 motor for the first firing test, planned for end-November. Vega's maiden flight is planned for late 2007.

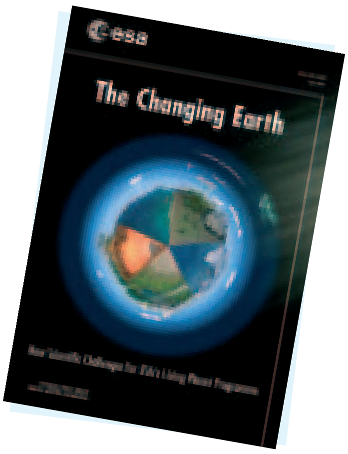
New Goals for Earth Science

ESA announced in September a new science strategy for the future direction of its Living Planet Programme, addressing the continuing need to further our understanding of the Earth System and the impact that human activity is having.

The Changing Earth: New Scientific Challenges for ESA's Living Planet Programme focuses on the most fundamental challenge facing humanity at the beginning of the 21st century: global change. A better knowledge of the Earth System and the impact of increasing human activity is of crucial importance in providing the basis for managing a sustainable environment.

The new strategy aims to assess the most important Earth-science questions to be addressed in the years to come. It outlines the observational challenges that these raise, and the contribution that the Agency can make. Underpinning the strategy is a set of ambitious objectives, including:

– launch a steady flow of missions addressing key issues in Earth science;
– provide an infrastructure to allow satellite data to be quickly and efficiently exploited for research and applications;
– provide a unique contribution to global Earth observation capabilities, complementing satellites operated by other agencies and *in situ* observing systems;
– provide an efficient and cost-effective process for science priorities to be rapidly translated into space missions, adequately resourced with associated ground support;
– support the development of innovative approaches to instrumentation.



The Changing Earth *(SP-1304; €20, 83pp) can be ordered using the form at the back of this issue*

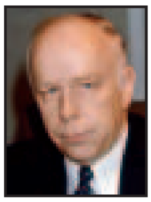
MetOp-A in Orbit!

MetOp-A, the first of three meteorological satellites developed jointly by ESA and Eumetsat, was successfully launched from Baikonur Cosmodrome, Kazakhstan at 16:28:13 UT on 19 October aboard a Russian Soyuz-2/Fregat rocket. Some 69 minutes later, the Fregat upper stage released the 4093 kg MetOp over the Kerguelen archipelago in the South Indian Ocean into a circular orbit at an altitude of 837 km.

With a slightly retrograde 98.7º inclination, this orbit enables MetOp-A to circle the globe from pole to pole while always crossing the equator at the same local time – 9:30 am. This Sun-synchronous orbit allows revisits to almost each point of the Earth's surface under similar illumination conditions almost on a daily basis. MetOp will provide a closer view of the atmosphere from low orbit, delivering data that will improve global weather prediction and enhance our understanding of climate change.

Following release, the satellite came under the control of ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany, and automatically deployed its solar array. It then underwent the first checkouts of its systems and deployed its antennas. Handover to Eumetsat was on 22 October for full satellite commissioning and routine operations. *Bulletin* 127 (August 2006) includes detailed articles on MetOp.

Leader Passes



It is with regret that ESA notes the death of Michel Bignier, on 12 October. A leading figure in the space world and Director General of CNES 1972–1976, he was Director of ESA's Spacelab programme 1976–1980, and then Director of Space Transport Systems until 1986. "*He has been one of the main players in the long struggle to adopt a balanced European Space Programme,*" said ESA Director General Jean-Jacques Dordain, echoing the deep regret of all those at ESA who had the opportunity to know Bignier and appreciate his work and commitment to a true European space policy.

Asteroid Honour

The Minor Planet Center at the Smithsonian Astrophysical Observatory (Harvard, USA), under the auspices of the International Astronomical Union, has designated minor planet number 10969 as 'Perryman', named for Michael Perryman of ESA's Science directorate. Previously project scientist of the Hipparcos and Gaia missions, and professor at Leiden University, Michael Perryman was cited for his leadership in the development of space astronomy. The minor planet was discovered in May 1971 by C.J. van Houten and I. van Houten-Groeneveld on Palomar Schmidt telescope plates taken by T. Gehrels.

These spectacular images of the Cydonia region of the Red Planet were captured by the High Resolution Stereo Camera of Mars Express. Obtained on 22 July and released in September, they include the famous 'face' on Mars in unprecedented detail (inset and arrowed).

Cydonia sits in the transition zone between the planet's southern highlands and the northern plains, a region characterised by wide, debris-filled valleys and isolated remnant mounds of various shapes and sizes. One of these massifs became famous as the 'Face on Mars' in an image taken in 1976 by NASA's Viking-1 orbiter. It was an illusion caused by the angle of the Sun and the shadows giving the impression of eyes, nose and mouth. Other formations seen here in the top left quadrant resembled 'pyramids'. While the features are not artificial, they are nevertheless of great interest to planetary geologists. Image resolution is about 13.7 m per pixel. *(ESA/DLR/FU Berlin; G. Neukum)*


10 km
N

New Zealand's dramatic landscape is captured by Envisat's MERIS imaging spectrometer on 10 September at a resolution of 300 m. Two of the volcanoes on the North Island are visible as snow-capped circular features. Mount Ruapehu, the North Island's tallest peak at 2797 m, is at top centre, while Mount Taranaki is at top left. Mt. Ruapehu last erupted in 1995 and 1996; Mt. Taranaki is classed as dormant but it is still considered a risk. Their impressive landscapes have attracted attention from film directors: Mt. Ruapehu was transformed into the fiery Mount Doom in 'Lord of the Rings', while Mt. Taranaki served as the setting for 'The Last Samurai'. As almost all volcanoes occur near tectonic plate boundaries, it is no surprise that volcanism has greatly affected New Zealand's landscape. Volcanoes have claimed more lives in the country than any other form of natural disaster. South Island is at bottom left.

The current configuration of the International Space Station, after a second pair of 73 m-long solar wings (in shadow) was attached in September by Shuttle mission STS-115. The new wings will double the Station's power when they are brought online during the next Shuttle flight, STS-116, planned for launch in December. Part of the job will be done by ESA astronaut Christer Fuglesang during his two spacewalks on that mission. STS-116 will also return ESA astronaut Thomas Reiter, who has been working aboard the Station since 6 July, to Earth. Next year will be a busy time for ESA and its astronauts at the Station: Paolo Nespoli will accompany Node-2 aboard STS-120 in August, Hans Schlegel is scheduled to fly with the Columbus module on STS-122 in October, and the Agency's Automated Transfer Vehicle (ATV) will begin its delivery service some time during May–July following launch by Ariane-5 from Kourou.

A new Hubble image of the 'Antennae' galaxies is the sharpest yet of this merging pair of spiral galaxies. As they smash together, thousand of millions of stars are born, mostly in groups and clusters. The galaxies started to fuse about 500 million years ago, making them the nearest and youngest example of a pair of colliding galaxies. Nearly half of the faint objects are young clusters containing tens of thousands of stars. The orange blobs to the left and right of centre are the two cores of the original galaxies, and consist mainly of old stars criss-crossed by filaments of dust. The two galaxies are dotted with brilliant blue star-forming regions surrounded by pink hydrogen gas. Only about 10% of the new super star clusters will live to see their ten millionth birthday – most will disperse into individual stars but about 100 of the largest will survive to become globular clusters as we see in our Galaxy today. (*NASA/ESA/B. Whitmore, STScI*)

The fourth Ariane-5 success of the year. On 13 October, flight V173 from Kourou, French Guiana, delivered two commercial telecommunications satellites safely into geostationary transfer orbit. DirectTV-9S will broadcast TV services to the USA, while Optus-D1 will provide communications and TV services over Australia and New Zealand. The mission also carried Japan's LDREX-2 to demonstrate the deployment of a lightweight antenna planned for the ETS-8 engineering test satellite. The fifth and final Ariane-5 launch of the year is planned for December. As with the others in 2006, it will use the 'ECA' version to carry two main passengers: the AMC-18 TV-distribution satellite for SES Americom, and WildBlue-1 to handle Ka-band Internet traffic. Ariane-5 ECA, with its large cryogenic upper stage, is the most powerful of the world's commercial launchers. (*ESA-CNES-Arianespace/Photo Optique Video CSG*)

Publications

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B. Warmbein & A. Wilson (Eds.)
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The Changing Earth – New Scientific Challenges for ESA's Living Planet Programme (July 2006)
ESA Earth Observation Mission Science Division
(Ed. B. Battrick)
ESA SP-1304 // 83 pp
Price: 20 Euro

ESA Special Publications

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K. Fletcher (Ed.)
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D. Danesy (Ed.)
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Proceedings of the Second Working Meeting on MERIS and AATSR Calibration and Geophysical Validation (MAVT-2006), 20–24 March 2006, ESRIN, Frascati, Italy (July 2006)
D. Danesy (Ed.)
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