esa

number 132 - november 2007

bulletin

SPACE FOR EUROPE

Node-2 Aloft
Columbus Next

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.

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(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.

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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.

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(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;
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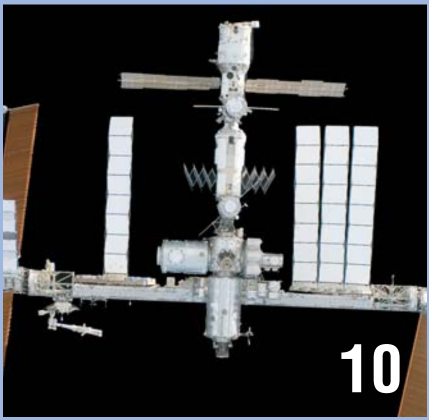
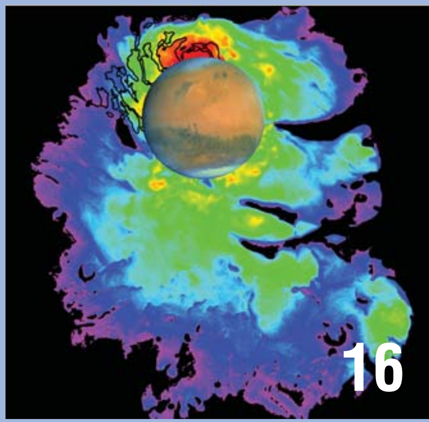
Space Shuttle *Discovery* delivers the European-built Node-2 to the International Space Station in October, paving the way for the arrival of the Columbus laboratory module in December. *Inset (from top):* ESA astronaut Paolo Nespoli suits up on Node-2's launch day; Node-2 is attached to the Station; ESA astronauts Hans Schlegel (left) and Léopold Eyharts prepare for the Columbus launch; Columbus begins its journey to the launch pad. *(NASA)*



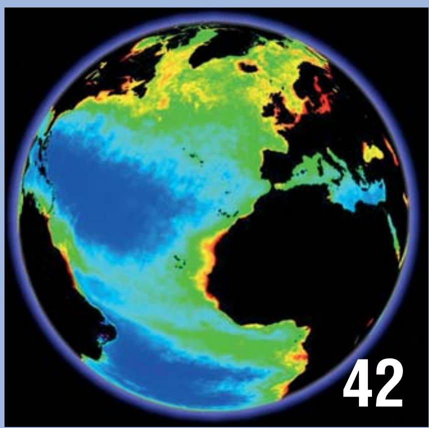
Node-2 in Place!
Europe's First Module Permanently Attached to the ISS



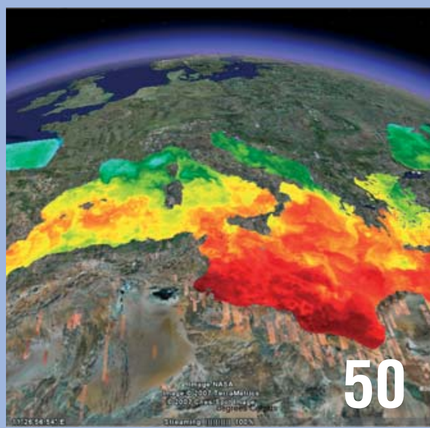
Revealing the Red Planet
Mars Express Provides an Unprecedented View

Pinpointing the Milky Way
The Formidable Challenge of Processing Gaia's Data

ESA Optical Ground Station
Ten Years Since First Light



Globcolour
Precursor to Ocean Colour Services



Medspiration
Precursor to Sea-Surface Services

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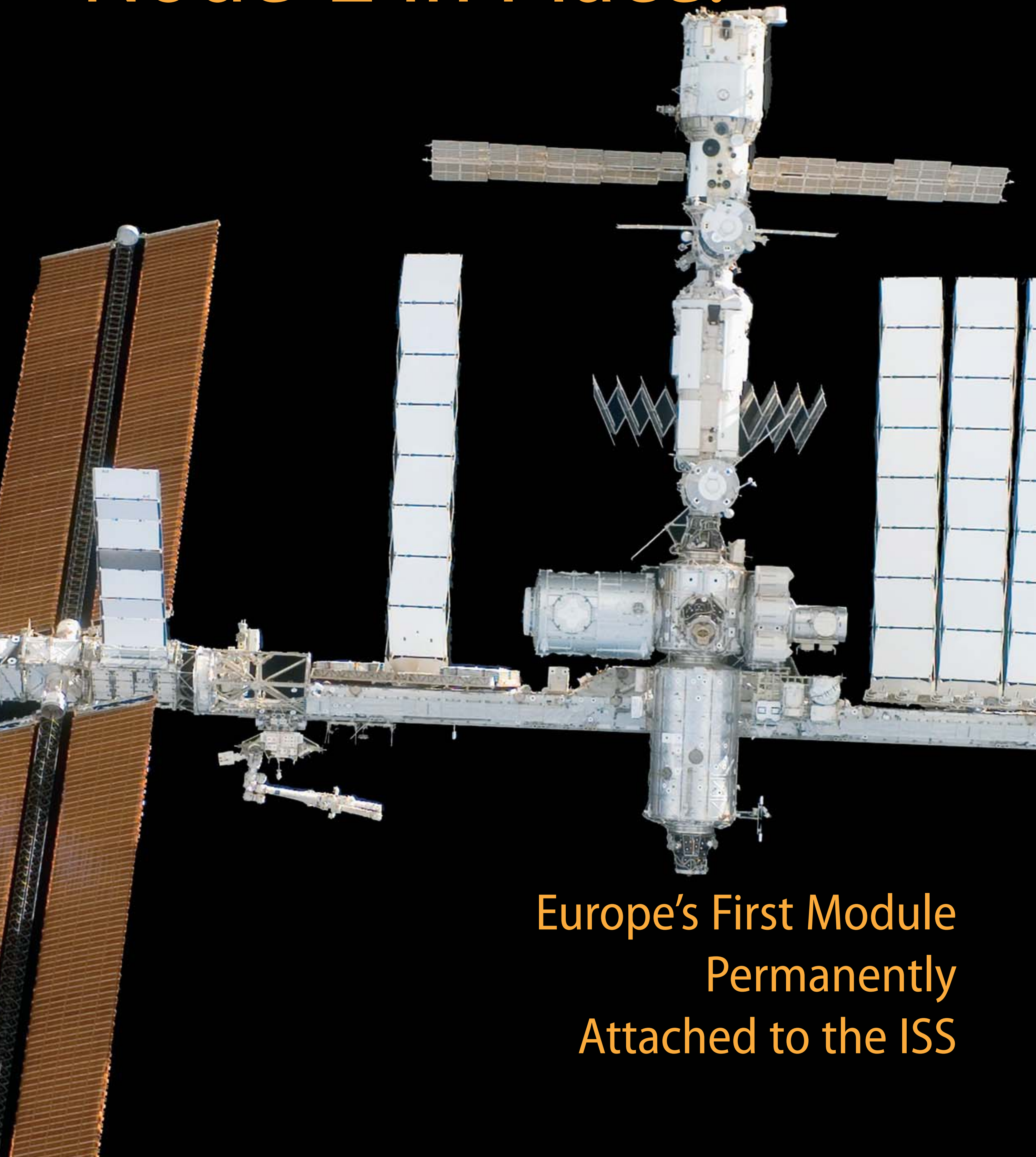
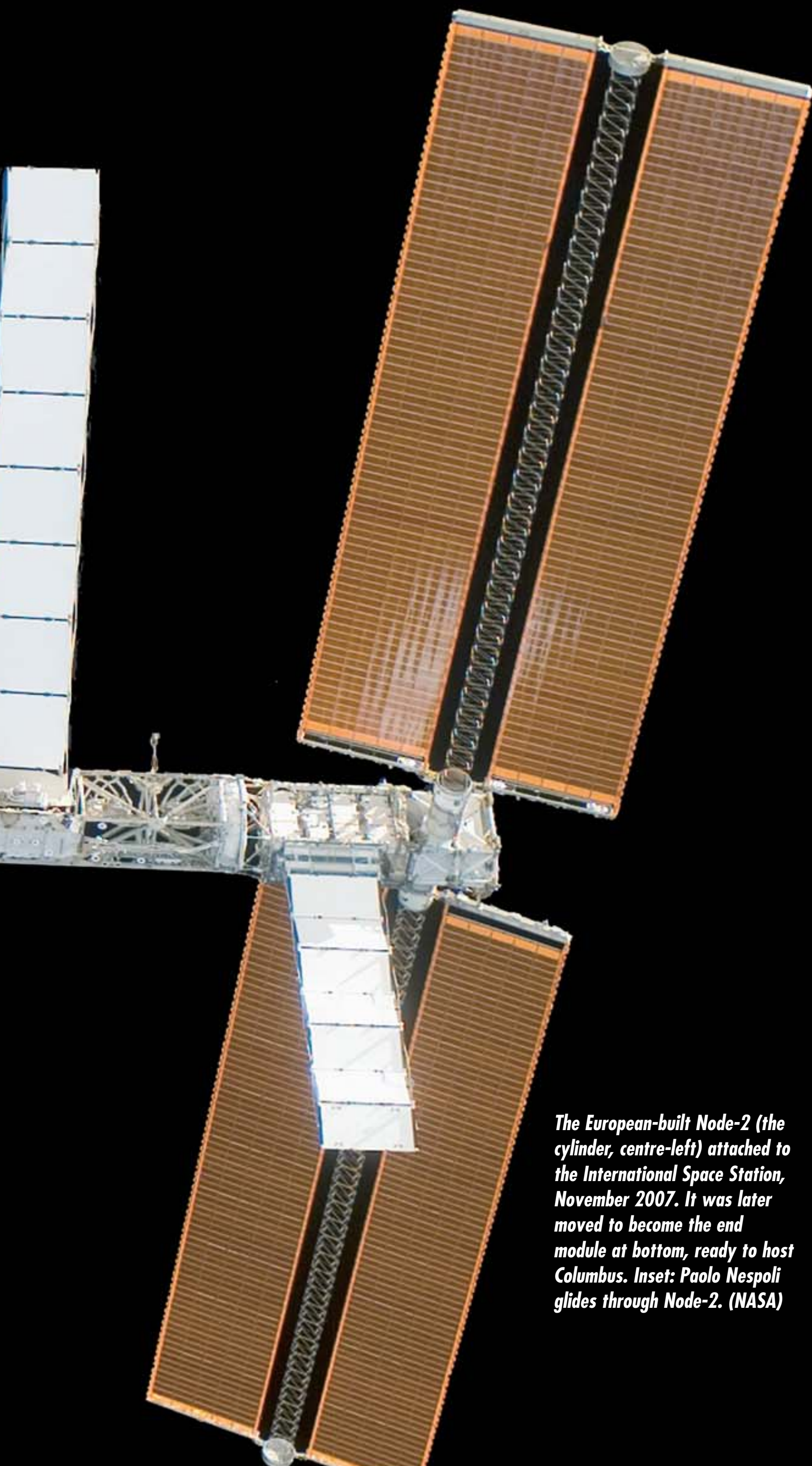
Node-2 in Place!



Europe's First Module Permanently Attached to the ISS



The European-built Node-2 (the cylinder, centre-left) attached to the International Space Station, November 2007. It was later moved to become the end module at bottom, ready to host Columbus. Inset: Paolo Nespoli glides through Node-2. (NASA)

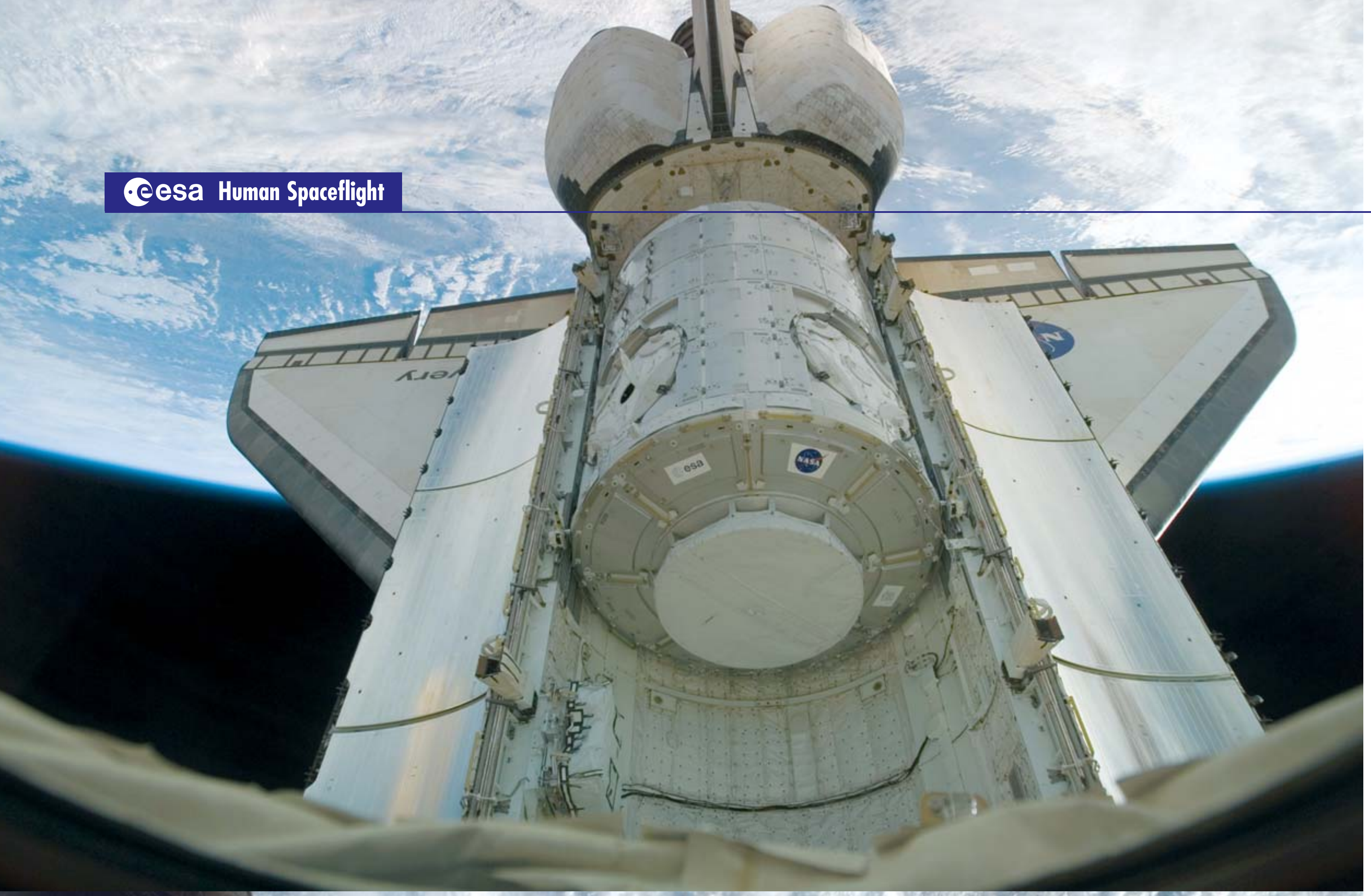
Philippe Deloo
Head of Cupola/Nodes Project Office,
Directorate of Human Spaceflight, Microgravity & Exploration, ESTEC, Noordwijk,
The Netherlands

Node-2 is now safely attached to the International Space Station (ISS), opening the way for expanding the outpost's research capabilities. This interconnecting node is crucial for the Station to host Europe's Columbus and Japan's Kibo modules. These laboratories will offer the long-awaited facilities for performing full-scale research and experiments aboard the ISS.

Introduction

European involvement in Node-2 began in 1997 with the signature of the Columbus launch barter arrangement: ESA committed to provide goods and services to NASA to offset the cost of a Shuttle launch for Columbus, the European laboratory module. The goods and services promised by ESA included Node-2 and Node-3. (NASA's own Node-1 was launched in 1998 as the Station's second element.)

Strictly speaking, Node-2 is not the first European-built module attached to the Station, but it is the first that will stay for the rest of the Station's life. Two Italian Multi Purpose Logistic Modules (MPLMs) have already flown several



Above: Node-2 arrives in the Shuttle's cargo bay (NASA)
Below: the Station's robotic arm hoists Node-2 to its temporary attachment point, 26 October (NASA)

times to the Station, delivering and returning cargo aboard the Shuttle. They are docked to the Station for around a week before being returned to Earth.

To take advantage of the organisation and procedures developed for the MPLM programme, full management responsibility for the two Nodes was delegated by ESA to ASI, the Italian space agency. In June 1997, ASI and Alenia Spazio of Turin (now Thales Alenia Space) signed the contract for their design, development, manufacture, integration, test and launch processing.

NASA's participation in the programme and in the oversight of Alenia's activities was very strong throughout the programme. The Marshall Space Flight Center in Huntsville, Alabama, and the Johnson Space Center in Houston, Texas, were the main NASA centres following the development. This extensive NASA involvement was justified by the amount of NASA equipment to be integrated into the modules and the fact that the American agency is the final owner.

Following the successful design review in 2001, the start of Node-2's integration and verification phase was authorised.

In May 2003, Node-2 was declared ready for shipment from Turin. Loaded into a 'Beluga' Airbus, it was shipped to the Kennedy Space Center (KSC) in Florida and its ownership transferred to NASA after an acceptance review. From then on, Node-2 was under NASA responsibility for the rest of its preparation for flight.

In 2004, following an agreement with NASA and ASI, ESA took over from ASI the management of the Nodes programme. This entailed direct responsibility for supporting Node-2 ground operations at KSC and for Node-3's integration and verification.

Although NASA was now leading the Node-2 activities, the level of European support remained high and indispensable, as the knowledge of the element and the design authority remained with ESA's contractor Alenia Spazio. Also, the contractor was asked several times to make modifications to Node-2 at KSC. These arose from changes to the baseline design to adapt it to new requirements of the ISS programme. European support to the Node-2 ground operations ended this September with the Flight Readiness Review.

Node-2 is now also known as 'Harmony', the name selected by NASA following a contest among more than 2000 American schoolchildren.

A Strategic Element

Node-2 is a strategic element for the Station's growth. It is particularly important for Europe because it is essential for attaching the Columbus laboratory to the Station. It has six docking ports: two at the ends and four around the cylinder. Node-2 is now attached to the forward end of the US Destiny laboratory and will host up to five other elements: Columbus to starboard, Kibo to port, a NASA Pressurized Mating Adaptor (PMA) on the front as the main docking location for visiting Space Shuttles, and a PMA below for MPLM or Japan's visiting HTV unmanned cargo ferry. There is no element yet assigned to the top port, following cancellation by NASA of the Centrifuge Accommodation Module. This position will be used for storing Japan's Experiment Logistic Module until Kibo arrives.

In addition to holding these elements, Node-2 will also provide them with vital resources: power, heating, cooling and data and video exchange with the ground and the rest of the Station. Node-2 is outfitted like a small power substation, handling the links between the Station's solar arrays and radiators and the users in the attached modules. The Node carries four avionics racks for power conversion and distribution, command and data handling, and

From the top: ISS Commander Peggy Whitson and Paolo Nespoli prepare to open Node-2's hatch for the first time, 27 October; entering Node-2; the ISS and Shuttle crews pose in Node-2; Paolo Nespoli with a Node-2 model (NASA)

The Next European-built Elements

Node-2 is the first of a large family of European elements that will fly to the ISS in the near future. Columbus will follow next, aboard the next Shuttle flight, scheduled for launch on 6 December. Columbus has been at KSC since May 2006 and completed its last verifications tests this summer.

In February 2008, it will be the turn of the first Automated Transfer Vehicle (ATV), 'Jules Vernes'. The ATVs are launched by Europe's Ariane-5 and are designed to rendezvous and dock with the Station automatically.

There will also be a number of MPLM missions carrying supplies and returning results. Finally, the combined Node-3 and Cupola, will be launched in early 2010 to complete the Station's assembly. The Cupola was also built by AleniaSpazio under ESA contract following an agreement with NASA. It was delivered to NASA in 2005 and is stored at KSC. Node-3 is also in storage, but in Turin, following the completion of its integration and verification last summer.

The family might continue to grow in the coming months. NASA, ESA and ASI are discussing the possibility of modifying an MPLM so that it can stay permanently attached to the Station as a storage volume, an increasingly critical need for the outpost.

With completion of the Station's assembly, we can look forward to at least 10 years of exploiting this huge global investment, the largest cooperative space venture to date.

audio/video switching. Six heat exchangers transfer the heat transported via water loops from the attached elements to ammonia loops flowing to the large radiators on the Station's truss.

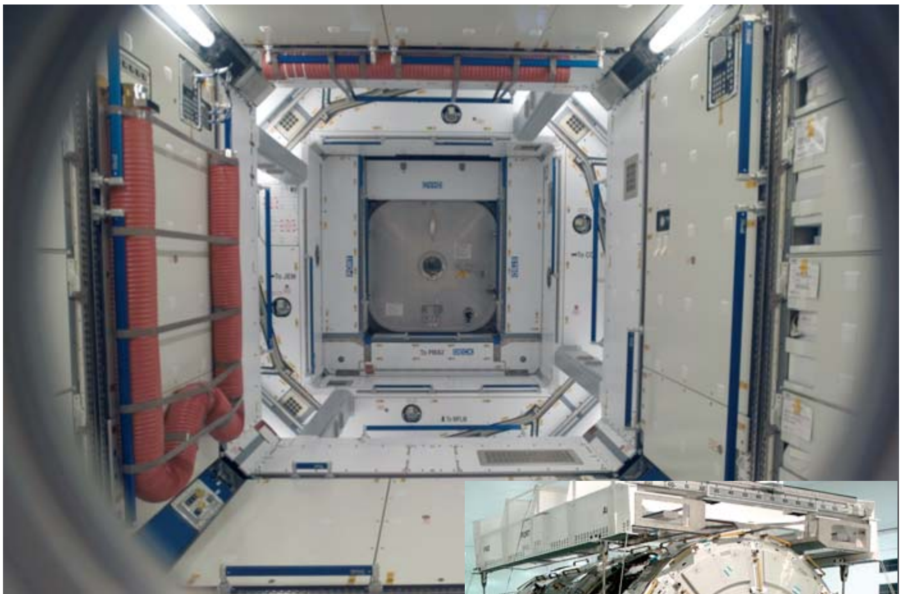
The Installation of Node-2

Node-2 was delivered to the ISS by Shuttle mission STS-120, also designated ISS Assembly Flight 10A. That complex mission was highly successful but the installation was far from finalised. Node-2 was sitting at a temporary position and was later moved during November to the front face of Destiny, to await the arrival of Columbus in December.

This protracted choreography is dictated by the fact that Node-2's final position was already occupied by PMA-2 for docking Shuttles. So with STS-120 docked to PMA-2, Node-2 was lifted out of the Shuttle's cargo bay and attached to Node-1's port side. With the Shuttle gone, the ISS crew could shuffle PMA-2 and Node-2 around, using the Station's robot arm. All of this effort involves several spacewalks.

STS-120 included other important assembly tasks, such as the relocation of the P6 truss segment to its final position at the extreme port end of the ISS main truss and the deployment of the related solar arrays, the full deployment of the thermal radiators on the back of the S1 truss, the delivery of essential supplies and equipment, and the exchange of one member of the Station's permanent crew.

The very capable crew consisted of commander Pamela Melroy, pilot George Zamka and Mission Specialists Scott Parazynski, Stephanie Wilson, Douglas Wheelock and Paolo Nespoli, an ESA astronaut from Italy. The ISS crewmembers were Flight Engineer Dan Tani for the ascent and Flight Engineer Clayton Anderson for the return. While Parazynski, Wheelock and Tani were assigned to EVA tasks, Paolo Nespoli coordinated the operations between the spacewalkers, the Shuttle and ISS robot-arm operators and the ground controllers, helped to prepare for the spacewalks by assembling tools and setting up the EVA suits, and assisted with the airlock operations before and after the spacewalks.



Above: Node-2's interior before the hatch is opened for the first time in orbit. Right: preparing Node-2 for launch (NASA)

Nespoli also played a prominent role during the robot-arm operations in the early and final days of the mission that checked the Shuttle's thermal protection for any launch damage. Nespoli was the arm's prime operator for inspecting the spaceplane's nose and wing leading.

Node-2's big day came on Flight Day 4 with astronauts in the cargo bay standing by as the Station's own robot arm lifted the module out and attached it to Node-1. The whole process took about 3 hours. While on the arm, it drew current to power the heaters to stay warm in the extremely cold conditions found in some Station's attitudes.

It was not until Flight Day 5 that astronauts could open the hatch and enter the Node, after the basic life support functions had been activated. The first event right after crossing the threshold was a press conference with ESA and ASI. Station Commander Peggy Whitson and Paolo Nespoli marked this important milestone for Europe.

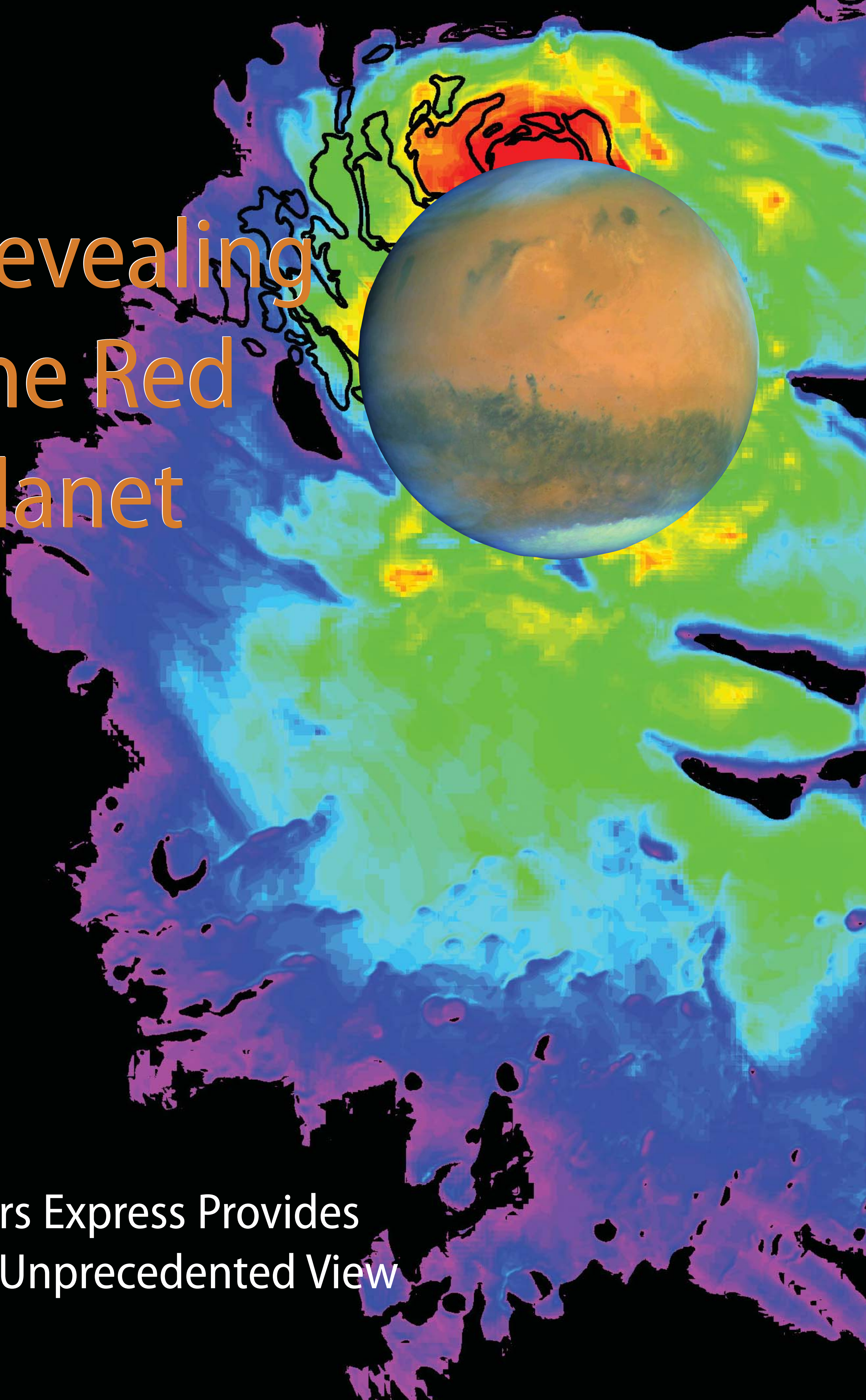
For the remainder of STS-120, Node-2 activities consisted of outfitting and preparation for the relocation to the front of Destiny, after the Shuttle's departure. Nespoli took part in this effort and helped to transfer important equipment to the Station for Columbus.

In the month after STS-120, and before the arrival of STS-122 with Columbus, PMA-2 was moved on 12 November using the Station's arm from Destiny to Node-2's end port. Then, the combination was attached to Destiny's forward port, its final location, on 14 November.

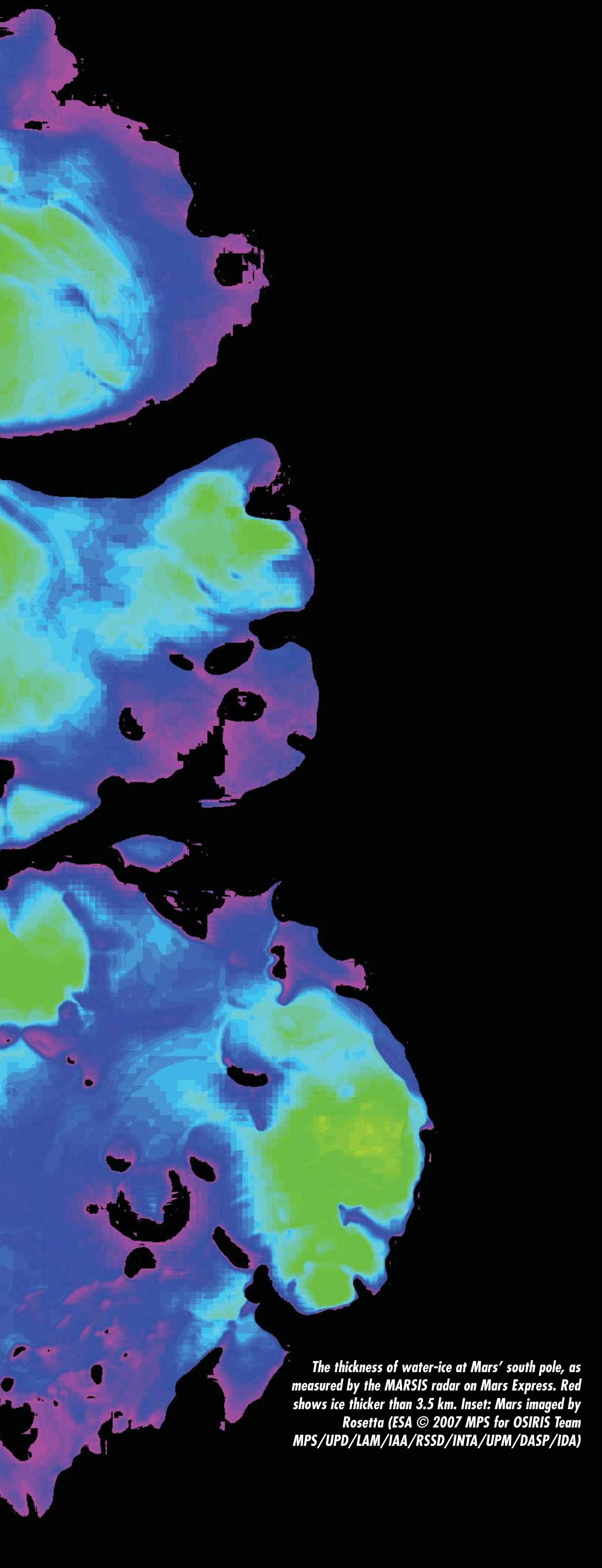
The final connection of all the utilities was done by Peggy Whitson and Dan Tani during two EVAs, followed by the full activation and checkout. Their successful completion will clear the way for the installation on Node-2 of Columbus in December and Japan's logistics and science modules early next year. esa

Detailed information on Paolo Nespoli's mission and Node-2 can be found at www.esa.int/esperia

Revealing the Red Planet



Mars Express Provides an Unprecedented View



The thickness of water-ice at Mars' south pole, as measured by the MARSIS radar on Mars Express. Red shows ice thicker than 3.5 km. Inset: Mars imaged by Rosetta (ESA © 2007 MPS for OSIRIS Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA)

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& Olivier Witasse
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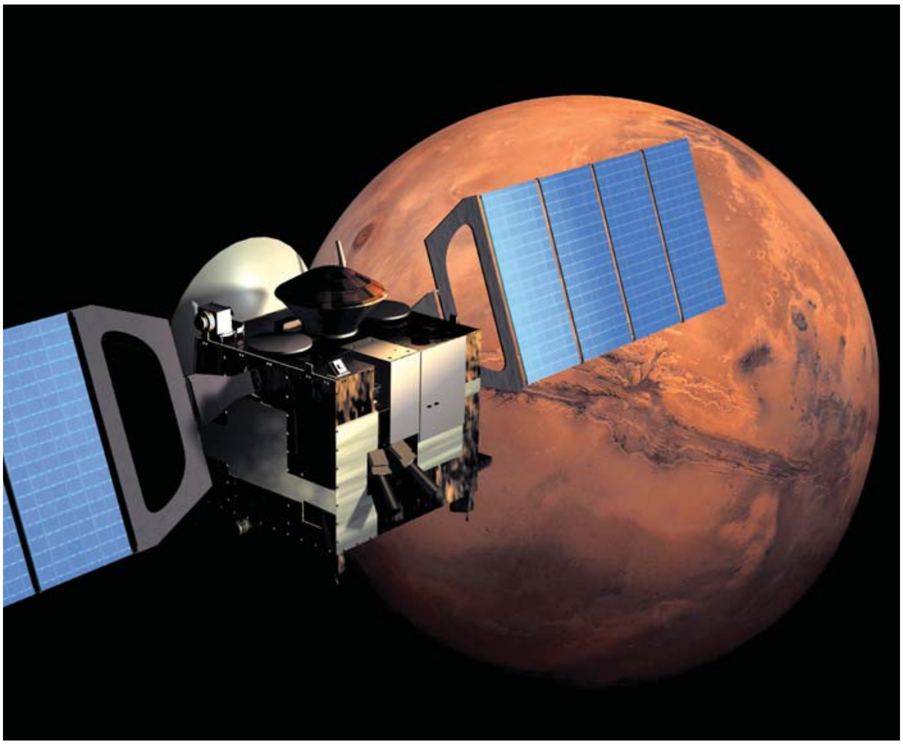
Mars Express arrived at its destination in December 2003 to probe every facet of the Red Planet, from the interior to the ionosphere, in unprecedented detail. In addition to these global studies, the mission's unifying theme is the search for water in its various forms everywhere on the planet. The mission has been extended into 2009, and could last even longer.

Introduction

Mars Express has now been orbiting the planet for almost 4 years. Its High-Resolution Stereo Colour Imager (HRSC) has shown breathtaking views of the very different hemispheres, highlighting the very young glacial and volcanic features, from hundreds of thousands to a few million years old, respectively. The OMEGA infrared mineralogical mapping spectrometer has provided unprecedented maps of water-ice and carbon dioxide-ice in the polar regions. It has shown that mineral changes in the planet's early history reflect abundant liquid water, while the nature of minerals formed later suggest a colder, drier planet with only periods of surface water.



The Planetary Fourier Spectrometer (PFS) has confirmed the presence of methane for the first time, pointing to volcanic activity and/or life. The SPICAM ultraviolet and infrared atmospheric spectrometer has provided the first complete vertical profile of the atmosphere's carbon dioxide density and temperature. It discovered 'nightglow' over the atmosphere's nightside, auroras over mid-latitude regions linked to the magnetic fields from the ancient surface, and very high carbon dioxide clouds.

The ASPERA energetic neutral atoms analyser has found that the solar wind is slowly stripping off the high atmosphere down to 270 km, and measured the current rate of loss. The MaRS radio science experiment has studied surface roughness by pointing the craft's high-gain antenna at the planet and recording the echoes. The interior has been probed by studying the gravity anomalies affecting the orbit. A transient ionospheric layer due to meteors burning up in the atmosphere was found.

Finally, the MARSIS radar recorded strong echoes from the surface and a little below, peeling away the very fine structure of the polar caps. Radar probing of the ionosphere has found a variety of echoes in areas of remnant magnetism.

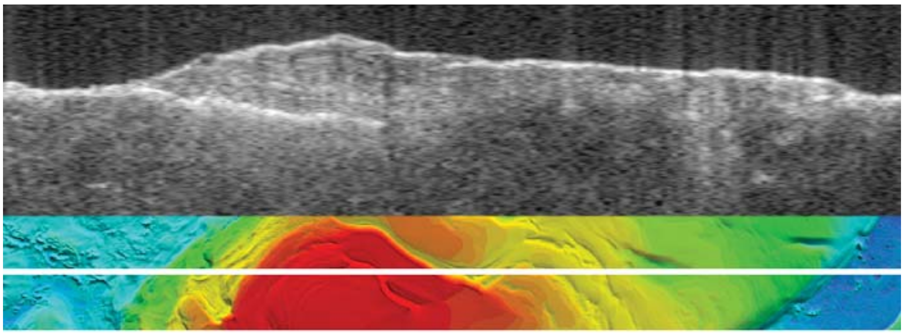
Interior and subsurface

One of the objectives of MaRS is to study the variations in the planet's gravity field. Gravity is measured by observing the accelerations of a test mass, which is in this case is the Mars Express craft itself. For example, the mass excess of a volcano attracts the craft, while the mass deficit of a crater allows it to drift away from Mars. Time variations of the gravity field also disturb the craft's orbit, though in a more complex way. The speed and position to within a few tens of metres of Mars Express are measured by Earth antennas through the round-trip time and the Doppler frequency shift of the radio signal between the Earth and the orbiter. Flying over specific targets is useful for revealing the crust's density. Scientists have focused on the volcanic Tharsis region, revealing a higher density than average.

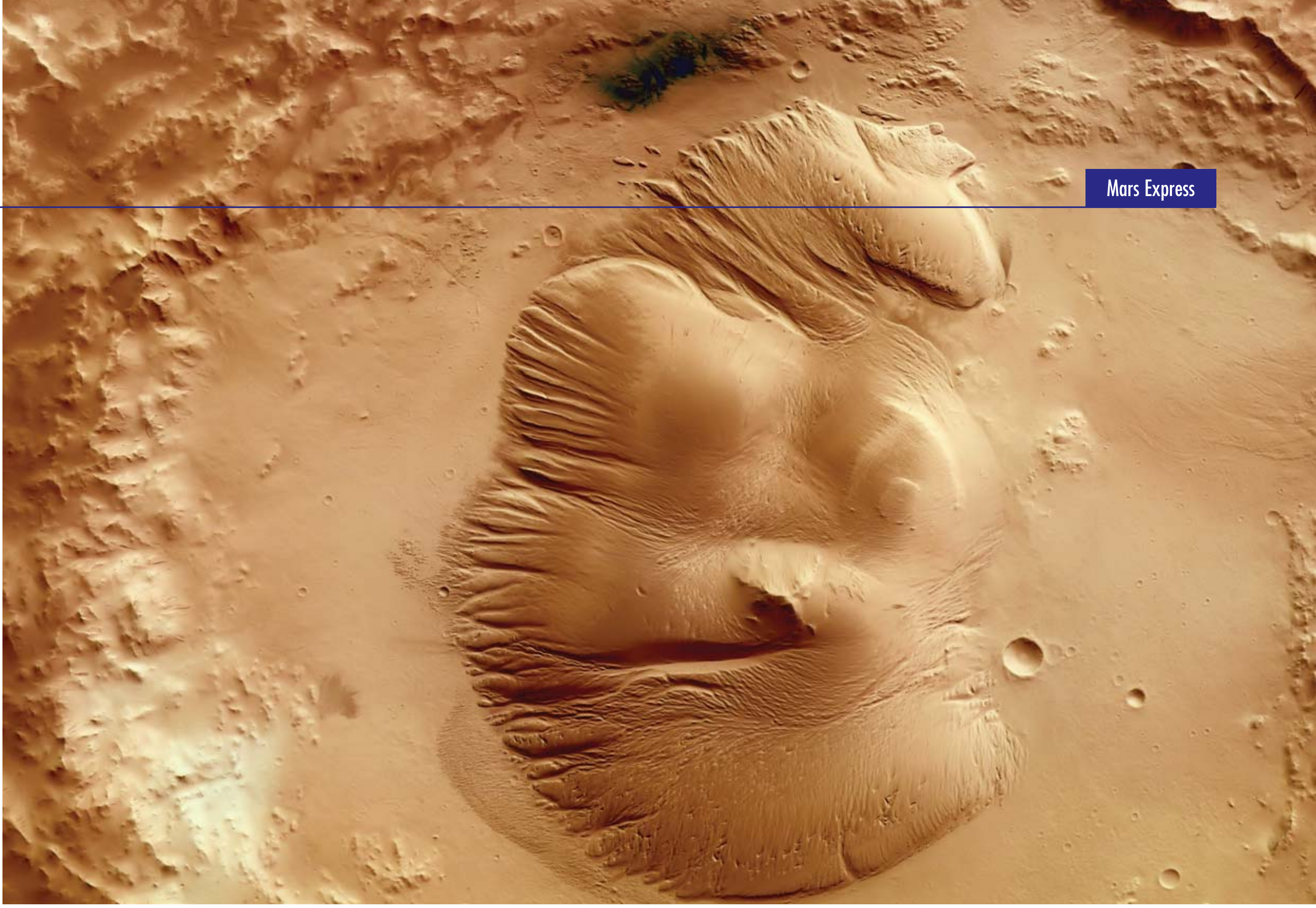
The trajectory is also disturbed by the moons Phobos and Deimos, refining our estimates of their masses.

Real imaging of the planet's interior was impossible before Mars Express. Altimetry and radio science data from past NASA missions, as well as Mars Express, provided indirect information about the internal structure, but the first direct probing of the subsurface has been done by MARSIS. This multi-frequency synthetic aperture radar can also 'sound' the ionosphere, the shifting layer of charged particles high in the atmosphere. It can detect material discontinuities in the subsurface to show the distribution of water (solid and liquid) in the upper crust.

Thanks to MARSIS, the layered deposits at both poles have been penetrated and investigated down to their base, several kilometres deep. As a result, we can now say the North Pole layers are dominated by water-ice, with variable amounts of dust. The southern



Sweeping the MARSIS radar (represented by the white line) in the lower map across the edge of the layered deposits at the north pole reveals the internal profile (upper image)



The central area of the 100 km-diameter Nicholson Crater is characterised by a peculiar bulge, which remains to be explained. The image was captured by HRSC during orbit 1104 on 27 November 2004. North is to the right. (ESA/DLR/FU Berlin; G. Neukum)

cap is more asymmetric, with a maximum ice thickness of 3.7 km. Its interior appears to be almost completely water-ice, with little dust.

The total amount of water in the southern ice cap is equivalent to a global ocean 11 m deep. It is truly an extremely large water reservoir. It also appears the 'lithosphere' under the southern cap is not distorted by the heavy ice.

Surface Geology and Mineralogy

Mars was first completely photographed by NASA's two Viking orbiters in the 1970s, providing topographic and geological mapping for almost three decades. Since then, only high-resolution but relatively small images have been captured – until Mars Express. HRSC has provided the first large-footprint high-resolution stereo colour images of Mars. It has shed new light on the timing and extent of geological activity from the very early stages more than 4000 million years ago up to the very recent past. Local changes are still going on.

A key finding is the recent activity of some of the large volcanoes. Tharsis is the largest volcanic province, where Mons Olympus, the Solar System's largest volcanic edifice, is located. The area is young, in some places only 5 million years. In general, the most recent activity in both the Tharsis and Elysium volcanic provinces was around 100–200 million years ago, which is still geologically very young by Martian standards.

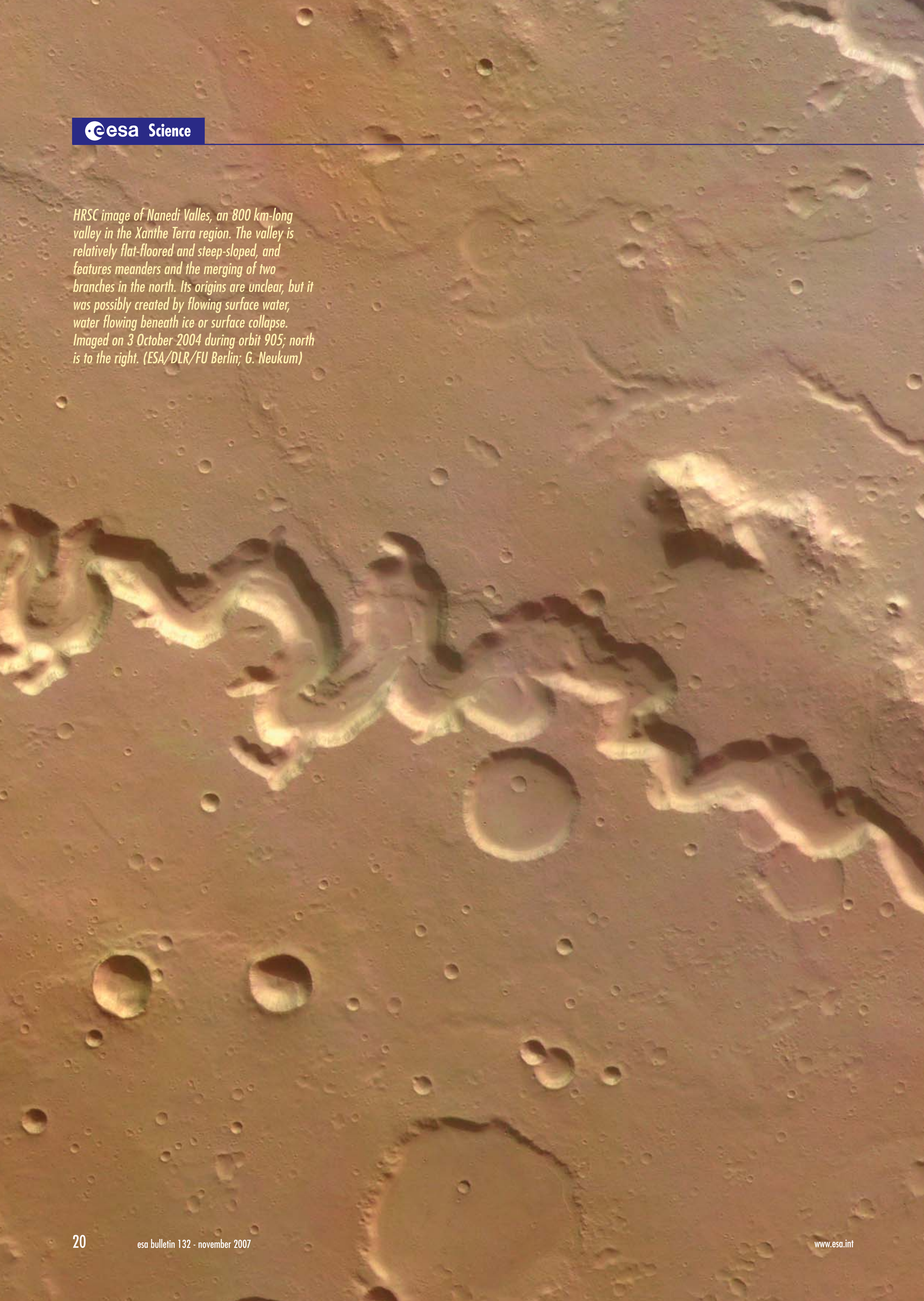
Ice activity also appears to be recent, and is possibly still active in some areas. Ice-related landforms are extremely widespread, over a very large range of latitudes, longitudes and altitudes. Of particular interest is the discovery of possible glaciers in tropical and equatorial areas, active perhaps only a few million years ago.

Apart from the scientific importance of such recent ice-rich deposits and their implications for climate change on Mars, they might still contain ice, possibly accessible for future Mars robotic or human exploration. Among the peculiar landforms discovered by HRSC is a possible recently frozen body of water in Elysium, close to the equator. It is is very young – only about 5 million years old.

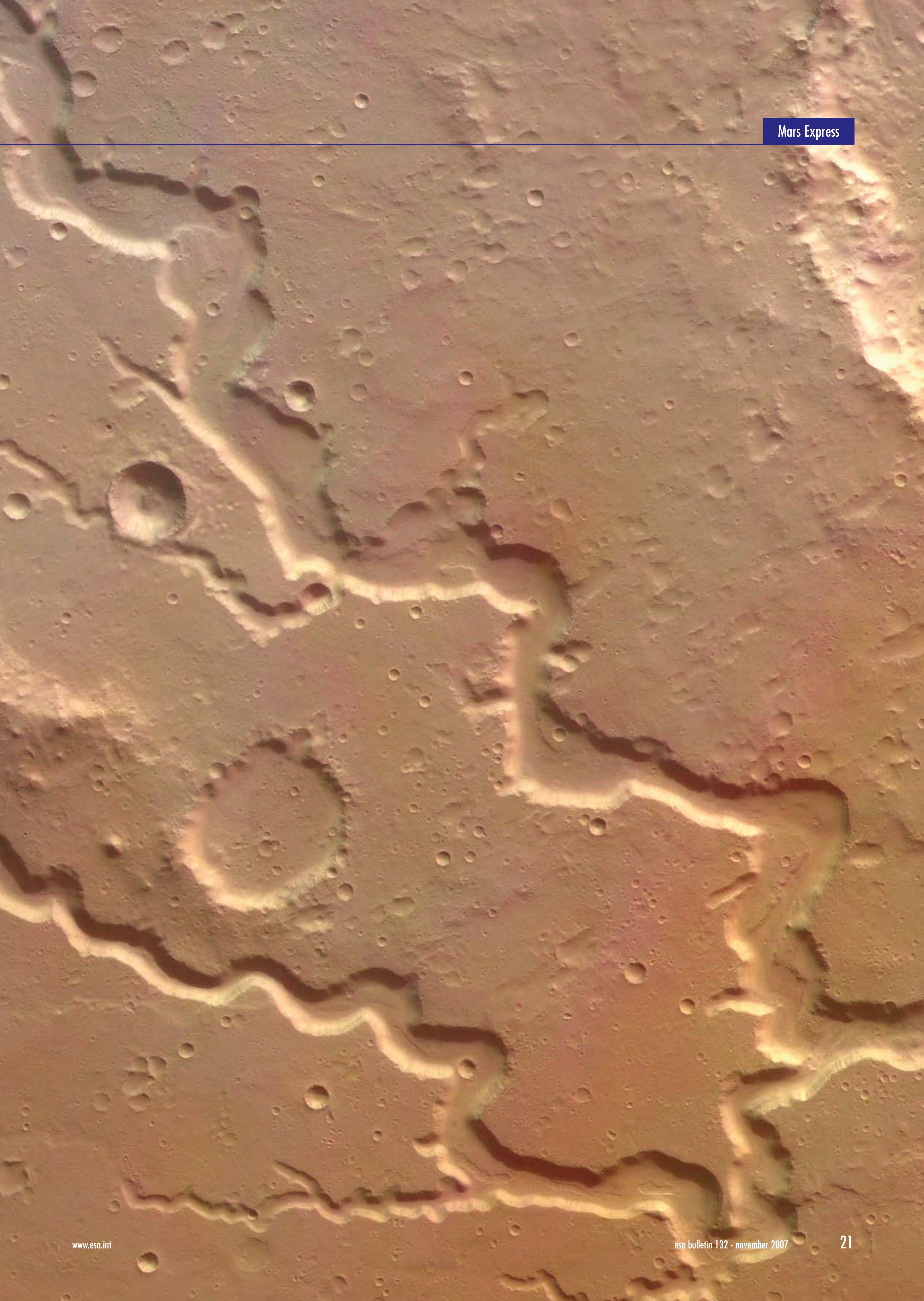
High-resolution, wide-swath images from HRSC have allowed scientists to determine surface ages in unprecedented detailed over large areas. The principle is simple: older surfaces have more impact craters.

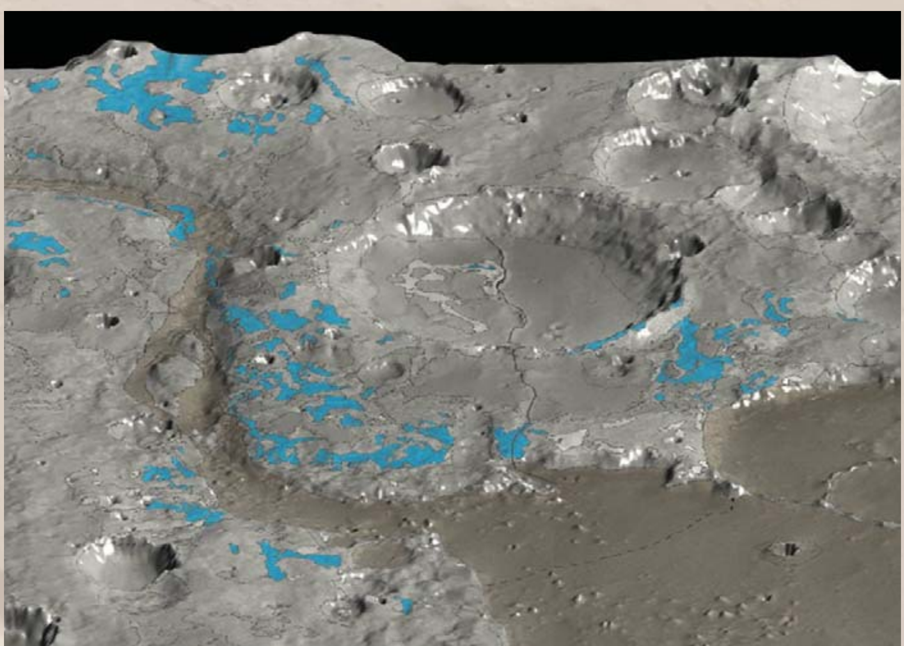
The high resolution over large areas, together with consistent illumination and matching colour and stereo information, has made possible the geological study and mapping of small to regional areas with much greater detail than in the past. This allows the geological characterisation of most geological provinces, both of volcanic and sedimentary origin on Mars. In particular, sedimentary basins benefit from HRSC imagery, mostly for correlating sediments over large areas and providing a very good background for very highly detailed observations.

Similarly, high-resolution colour



HRSC image of Nanedi Valles, an 800 km-long valley in the Xanthe Terra region. The valley is relatively flat-floored and steep-sloped, and features meanders and the merging of two branches in the north. Its origins are unclear, but it was possibly created by flowing surface water, water flowing beneath ice or surface collapse. Imaged on 3 October 2004 during orbit 905; north is to the right. (ESA/DLR/FU Berlin; G. Neukum)





OMEGA has revealed the sites (blue) of hydrated minerals in Marwth Vallis, proving the presence of copious amounts of water in the past

images are the basis for a new generation of maps. The Viking images have resolutions of several tens to few hundred metres; HRSC is raising the level by an order of magnitude, adding stereo and colour information. This will fill more than 10 000 map sheets at 1:200 000 scale.

No other planned mission will provide comparable wide-swath, high-resolution and global coverage. HRSC is a valuable resurce for future generations of planetary scientists.

Among the many firsts from the mission is the high-resolution hyper-spectral imaging of Mars. OMEGA is a visible/near-IR hyperspectral camera, capable of identifying and mapping atmospheric and surface constituents, including ices and minerals, by their spectral fingerprints.

It has observed the polar caps in detail. The seasonal frost is mostly carbon dioxide-ice, while the bulk of the layered material is mainly water-ice mixed with dust. There is evidence of hydrated sulphates (gypsum) around the northern cap. The southern cap's 'cryptic region', a rather dark area during the southern spring, is shown to be dust dominating the carbon dioxide-ice.

Most of the composition of the surface rocks was poorly known, but OMEGA has provided the answers. The features and variability of minerals in the crust have been characterised and global maps of pyroxenes (a class of silicate rocks) obtained. Clearly hydrated minerals have been found and mapped. Two main classes of hydrated minerals have been discovered by OMEGA: phyllosilicates and sulphates, each with distinct spatial and temporal settings. Phyllosilicates, mainly formed from the aqueous alteration of volcanic rocks, were discovered in the most ancient outcrops on Mars. Hydrated sulphates were discovered in areas mainly in association with thick layered deposits in Valles Marineris, the largest canyon on Mars (about 6000 km long and down to 7 km). All of these occurrences are clearly distinct – most importantly in time – from the ancient phyllosilicates: they are remarkably younger.

All of these discoveries have provided new and more reliable limits on the timing and extent of aqueous alteration on Mars, which has profound implications for reconstructing its evolution and looking for possible traces of past life.

Another important contribution by OMEGA is in complementing the 'ground truth' from NASA's rovers. investigating the surface composition.

OMEGA has given new insights into surface composition across all terrains. All other current and planned imaging spectrometers are basing their targets and detailed observations on OMEGA's results. Most very high-resolution imaging spectrometers often cover only very limited areas in one go, providing very detailed but largely discontinuous coverage; not so OMEGA.

A value of the multidisciplinary Mars Express is using the instruments in synergy. HRSC and OMEGA provide highly complementary information. This is certainly important for studying the poles: the morphology and colour details from HRSC, the composition from OMEGA and the 3-D slice through more than 3.5 km of ice by MARSIS. The structure and history of the poles' layered deposits are now known in much greater detail, shedding new light on their composition, volume and dynamics.

Atmosphere

New results on the atmosphere have been provided by SPICAM, MaRS, PFS and OMEGA.

For the first time, SPICAM has mapped the ozone. Ozone-rich areas are found at high latitudes in the northern late winter-early spring period, the southern autumn and at the end of the northern summer. Water vapour is measured at the same time (another first), essential for understanding their relationship.

Observing starlight after it has passed through the atmosphere day or night allows vertical profiles of the density and temperature of carbon dioxide to be obtained for the first time from an orbiter. As carbon dioxide accounts for most of the atmospheric, it is important in planning for future entry probes. Ozone's variation with altitude is also measured.

SPICAM reports the highest clouds ever observed on Mars: carbon dioxide-ice clouds have been seen at about 100 km in the southern winter subtropical latitudes, giving new information on cloud formation processes and on the atmosphere's dynamics.

Certainly the most intriguing achievement by PFS is its detection of methane. It found a global average of 10±5 parts per billion (ppb) during the first year of observations, with a maximum of 30 ppb, indicating variation with location. The methane concentrations on Earth and Titan are much higher: respectively, 2 parts per million and 5%.

This discovery has led to an intense debate on where this methane is coming from: life (highly hypothetical), volcanic activity (but the large volcanoes look quiet) or some hydrothermal source? Whatever the source, the presence of methane has been confirmed by terrestrial telescopes.

PFS is also measuring the air temperature from the surface up to about 50 km. Above 60ºN, it is cold enough for carbon dioxide-ice to condense; the edge of the seasonal cap is seen around 62ºN. There is also a clear connection between the surface topography and the temperature of the atmosphere above it.

Other achievements by PFS include: identifying minor atmospheric gases such as hydrogen fluoride and hydrogen bromide; detecting water-ice clouds; measuring atmospheric dust content; and studying the effect of dust storms on the atmosphere.

Pressure, temperature and density of the atmosphere are routinely provided by MaRS, from the surface up to 50 km height, for a wide range of latitudes.

This broad collection of data is useful for comparison with atmospheric models being developed.

OMEGA is also providing information on the atmosphere. A recent study shows that water is transported from one pole to the other as vapour, which then condenses and freezes on the surface. This is a new insight into the water cycle of Mars.

Upper Atmosphere

New results on the upper atmosphere have come from SPICAM, MARSIS, MaRS and ASPERA.

SPICAM has detected two new ultraviolet emissions. The first comes from nitric oxide on the nightside, which is an important result because these molecules are formed from the recombination of N and O atoms produced on the dayside and transported by atmospheric circulation. The second emission is from nitrogen molecules, predicted long ago but never seen.

SPICAM has also discovered a new kind of aurora. It is probably caused by electrons, diverted by the crustal magnetic field anomalies in the southern hemisphere, colliding with atmospheric molecules.

Apart from studying the subsurface, the MARSIS radar is also probing the ionosphere. The active sounding mode gives the electron density as a function of altitude. Very interesting shapes in the areas of the crustal magnetic field have been discovered.

In the subsurface sounding mode, the waves reach the surface and the echo is analysed. The signal is altered by the double pass through the ionosphere, which gives the total electron content for the first time in a planetary atmosphere beyond Earth.

In this subsurface mode, the radar signal can be completely absorbed if there are enough free electrons around 80 km altitude, which tells us about the state of the ionosphere and its variability. The external factor responsible for this variability is in particular the penetration of energetic solar particles, and possibly solar flares and meteor showers.

The radio science team routinely derives electron density profiles in the 80–500 km altitude range. How the ionosphere behaves is known from previous NASA missions: a peak in the electron density appears at around 140 km owing to the ionisation of the atmosphere by the solar radiation. The location of the ionopause (the upper boundary of the ionosphere), still a matter of debate, was detected in some profiles at about 350 km. The major result of this experiment is the clear detection of a lower layer, peaking at about 80–90 km. This layer is formed by metallic ions from meteors, reactions between magnesium and iron, and molecular oxygen ions, and the ionisation of metals by photons.

ASPERA has revealed many new interesting findings on the solar wind interaction with Mars. The measurements have shown that the interaction with the atmosphere is seen all the way down to the lowest point of the craft's orbit, about 250 km high, above the dayside. This is quite deep in the ionosphere and the atmosphere. A consequence is that, over 3500 million years, some 0.2–4 millibar of carbon dioxide has been lost. This is not much, showing this is not an efficient way for the atmosphere to escape.

With its novel technique for measuring energetic neutral atoms (ENAs), ASPERA is exploring a new dimension in the solar wind interaction with planets that have no intrinsic magnetic field. Mars is 'shining' in ENAs. Part of this is caused by reflections of inflowing hydrogen ENAs from the solar wind, but a large fraction is emitted when hot plasma, from the solar and planetary winds, interacts with the upper atmosphere.

Concluding Remarks

Mars Express has completely revamped our understanding of the planet's geological evolution, in conjunction with the ground truth provided by NASA's rovers. A great wealth of data has been gathered, allow us to build a comprehensive and multidisciplinary view of Mars, including the surface geology and mineralogy, the subsurface structure, the state of the interior, the climate's evolution, the atmospheric dynamics, composition and escape, the aeronomy and the ionospheric structure.

Major advances are being made, such as discovering water-ice below the surface, mapping the various types of ice in the polar regions, the history of water on the surface of Mars, the abundance of methane in the atmosphere, mid-

HRSC view of Dao Valles and Niger Valles, a system of outflow channels up to 40 km wide on the southern flank of the Hadriaca Patera volcano. The north-eastern ends of the two valleys are almost 200 m deeper than the south-western portions. Imaged during orbit 528 in June 2004, centred at 93°E/32°S. (ESA/DLR/FU Berlin; G. Neukum) latitude auroras above crustal magnetic fields, and much younger timescales for volcanism and glacial processes.

New techniques used by state-of-the-art instruments have provided the first subsurface radar sounding of another planet, complete atmospheric density and temperature profiles up to 100 km altitude, stellar occultations, total electron content in the ionosphere and surface coverage at high-resolution both in stereo and colour. The latter will become global provided that the mission is sufficiently extended. These superb images have provided ESA with a significant tool for public outreach, and will also undoubtedly be the legacy of the mission for future generations of scientists.

So far, the various Mars Express instrument teams have published about 235 refereed publications in scientific journals worldwide. The scientific data from the nominal mission is now available in the mission archive for further study by the general public and scientists alike. Together with the Principal Investigators and their large teams of co-investigators, the tremendous success of this mission is due to the various ESA teams throughout almost all ESA establishments and a number of contractor locations.

The nominal mission lifetime of one Martian year (January 2004 to November 2005) for the orbiter has already been extended twice, up to May 2009). The extensions give priority to fulfilling the remaining goals of the nominal mission (including gravity measurements and seasonal coverage), to catch up with the delayed MARSIS observations, to complete global coverage of high-resolution imaging and spectroscopy, and subsurface sounding with the radar, to observe atmospheric and variable phenomena, and to revisit areas of discoveries.

The scope of cooperation has been enlarged, in particular with NASA's Mars rovers and Mars Reconnaissance Orbiter, and with Venus Express as it is carrying the same instruments to another planet, providing a unique opportunity for comparing our nearest neighbours.

Finally, Mars Express is providing valuable data for preparing the first mission of ESA's Aurora Exploration Programme: ExoMars includes a rover for biological, geophysical and climatological investigations. Mars Express is helping to identify potential landing sites by establishing a surface/subsurface geological database. It is also helping to refine the existing atmospheric database, in order to assess potential risks. Other future ESA exploration missions to Mars, such as the planned Mars-NEXT mission of the Aurora programme, will benefit from Mars Express.

Detailed information on Mars Express and its mission can be found at http://sci.esa.int/marsexpress

Pinpointing the Milky Way

The Formidable Challenge of Processing Gaia's Data

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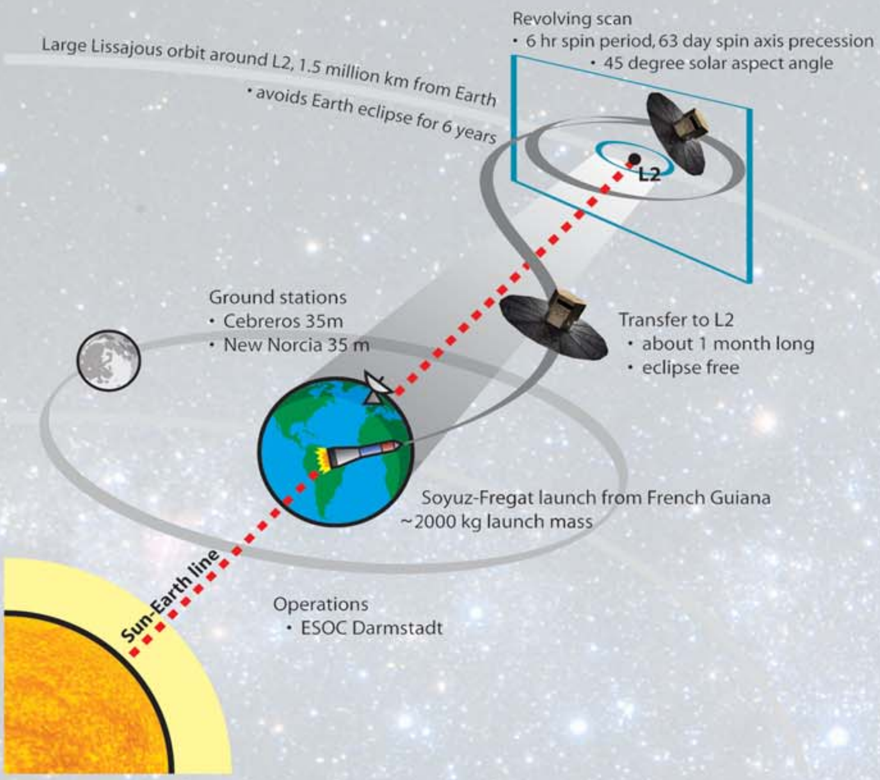
In the course of Gaia's 5-year astronomical survey, the equivalent of around 20 000 DVDs of raw information on our Galaxy will be harvested and transmitted to Earth. Sophisticated processing is needed to distill this flood of complex data into the final Gaia Catalogue of about 1000 million celestial objects. A group of more than 300 European scientists and software developers is rising to the challenge: the Data Processing and Analysis Consortium is already preparing for Gaia's launch in 2011.

Introduction

Gaia is a pioneering astronomy mission set to revolutionise our view of the Galaxy, the Milky Way, with a precise and detailed survey of the 1000 million brightest celestial objects. With high-accuracy 'astrometry', Gaia will pin-point the position of each star and track its movement across the sky. Measuring its light spectrum will reveal how fast the star is approaching or receding (its 'radial velocity'). Gaia will also gather 'photometric' data, measuring the brightness of a star in a few dozen colours. This array of data will reveal a



Gaia's launch and operations. (ESA/Astrium)

moving 3-D Milky Way map of unprecedented scope and precision, as well as providing profiles of the physical properties of each star, including temperature and elemental composition.

By surveying all celestial bodies down to the very faint magnitude of +20, Gaia will cover a representative fraction of the Milky Way's population, providing scientists with the material to tackle unanswered questions about our home galaxy, potentially revealing its history, current state and future.

This catch-all survey will naturally include many objects besides stars. Gaia will spot several thousand brown dwarfs (failed stars, too small to ignite) and extrasolar planets, and map out our immediate neighbourhood in great detail, detecting hundreds of thousands of minor Solar System bodies.

Beyond the Milky Way, Gaia will observe bright objects like supernovae and quasars, as well as many distant galaxies.

As a complete sky survey without preprogrammed targets, the discovery potential of Gaia is profound. Who knows what it might find?

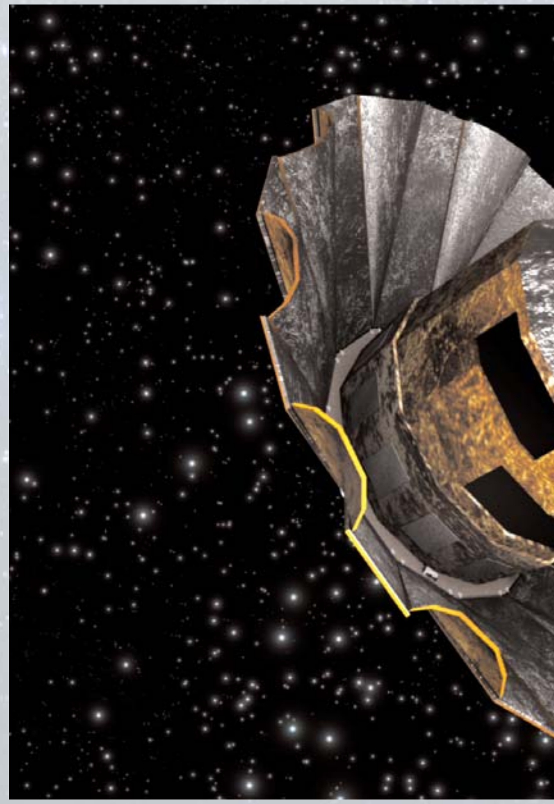
Through sophisticated processing and analysis, the raw data will be translated into the mission's final product: the Gaia Catalogue, an extensive galactic census, rich in scientific content. The unprecedented accuracy and unbiased nature of this full-sky survey will prove valuable, even revolutionary, to a huge range of scientific disciplines besides galaxy studies. Gaia's wealth of data will inform and invigorate scientific areas as diverse as the life cycles of stars, the distribution of 'dark matter' and Einstein's theory of general relativity.

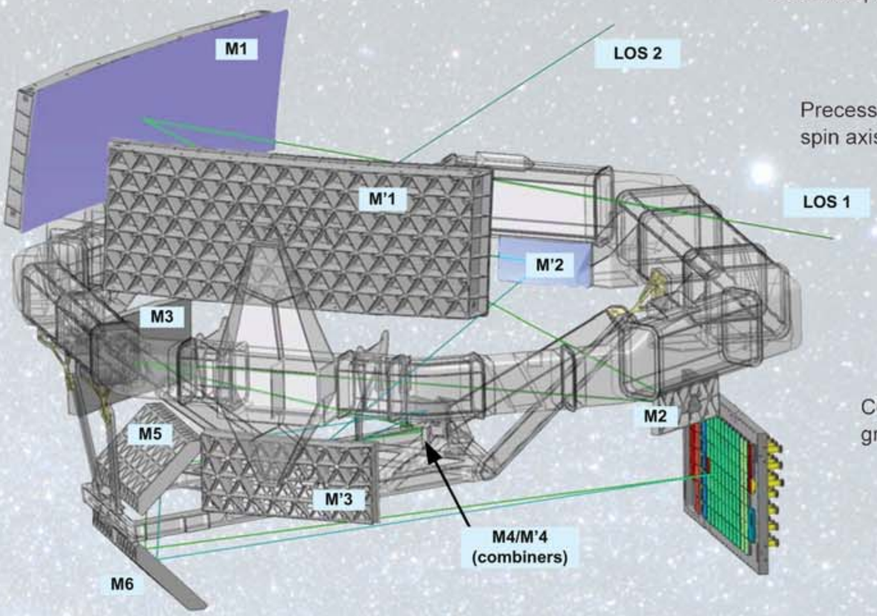
Selected as an ESA Cornerstone mission in 2000, Gaia is now moving from its design phase into development; launch is set for late 2011.

Gaia continues a European tradition in pioneering astrometry, building on the expertise generated by the very first space-based astrometry mission, Hipparcos. Flying between 1989 and 1993, Hipparcos mapped 99% of stars down to magnitude +11 with unprecedented accuracy. Its astrometric achievement is still unchallenged. Gaia will outdo its predecessor by orders of magnitude in terms of accuracy, sensitivity and quantity. While Hipparcos followed a programme of pre-selected objects to observe, Gaia's survey is complete and unbiased.

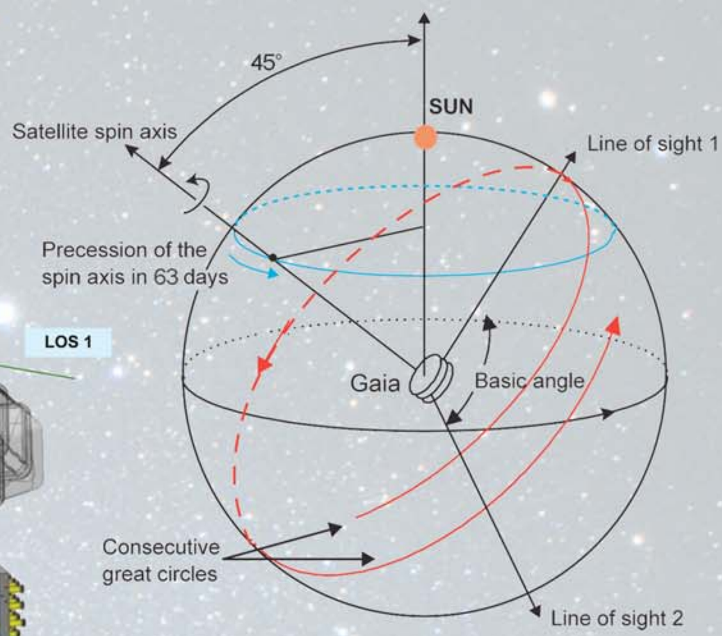
Advanced astrometric instruments and processing will enable Gaia to discern the positions of stars and their minute movements with incredible accuracy: around 25 microarcseconds (about 0.00000001°) for stars of magnitude +15 – roughly the ability to discern a single human hair from a distance of 500 km. A magnitude +15 star is already extremely faint, around 4000 times dimmer than the faintest stars visible to the human eye. Gaia's census will be complete for all celestial bodies down to magnitude +20 (about 400 000 times dimmer than the faintest naked-eye stars), which equates to around 1000 million objects.

Following launch, Gaia will travel 1.5 million kilometres from Earth, away from the Sun, to circle the second





The complex arrangement of Gaia's mirrors. LOS is the line-of-sight, the viewing directions of the telescopes. (EADS Astrium)



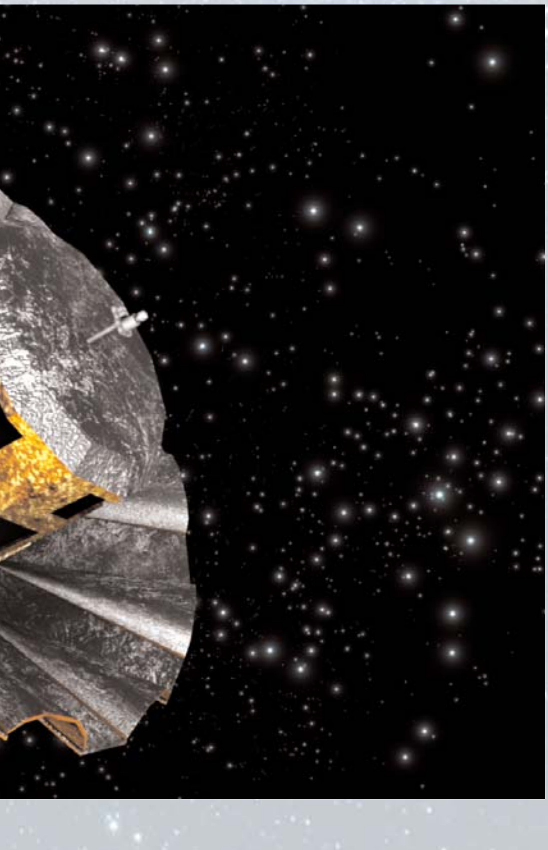
The 'scanning law' that allows Gaia to view the entire sky in a series of overlapping great circles

Lagrangian point of the Sun-Earth system. Known as L2, this is a point in space where the combined gravitational pulls of the Earth and Sun balance out, allowing a spacecraft to hold position. Shaded from the light of the Sun, Moon and Earth by a large shield, the satellite will revolve slowly, with one full revolution every 6 h, thereby scanning great circles across the sky.

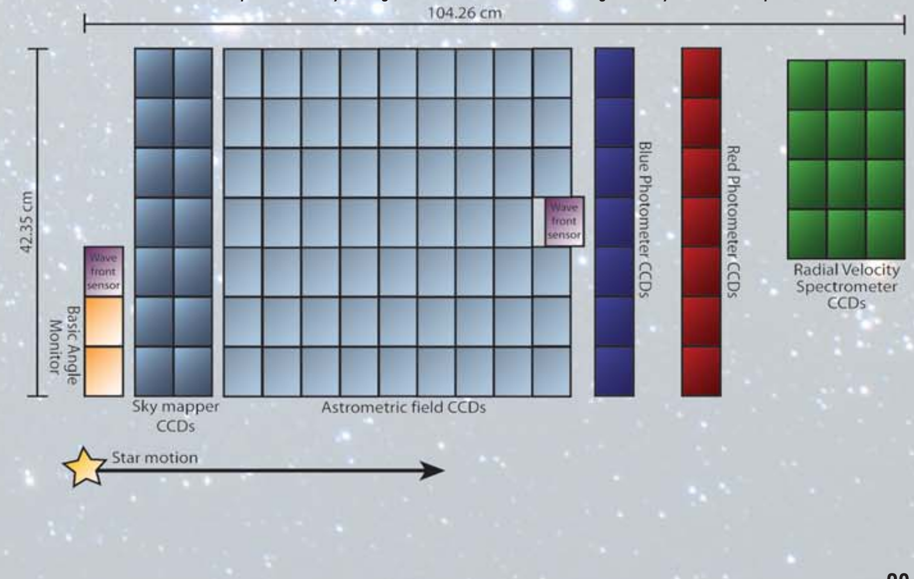
Inside the satellite, Gaia's instruments are mounted on a hexagonal optical bench. Two telescopes sharing a focal plane look out through apertures in the payload housing. The two viewing directions are separated by a fixed basic angle. Light from a celestial object enters through an aperture, and strikes the large primary mirror opposite (either M1 or M'1).

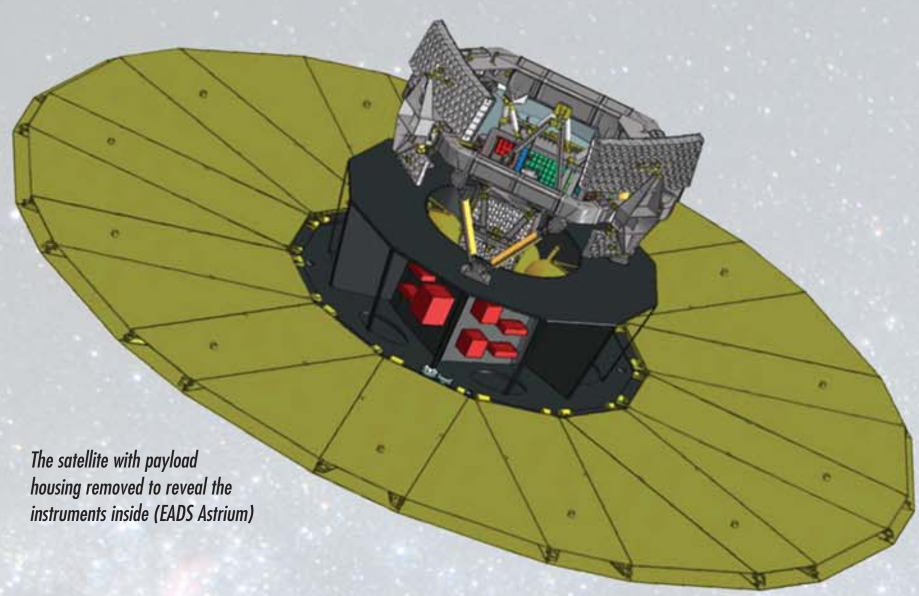
The light is bounced by a series of mirrors along a total focal length of 35 m, with the two paths meeting at the M4/M'4 beam combiner before finally reaching the shared focal plane. Having two different lines of sight allows Gaia to measure the relative separations of the thousands of stars simultaneously

Gaia deploys its sunshield. (ESA/C. Carreau)



The focal plane assembly: a large mosaic of 106 CCDs amounting to nearly 1000 million pixels. (EADS Astrium)





The satellite with payload housing removed to reveal the instruments inside (EADS Astrium)

present in the combined fields of view. These wide-angle measurements build up a rigid network of relative star positions, contributing to Gaia's exceptional accuracy. The 'folded-up' focal length of 35 m is required to attain Gaia's high resolution.

At the focal plane is a large mosaic of sophisticated, custom-built charge coupled devices (CCDs), light detectors of essentially the same kind as found in a digital camera. Containing 106 CCDs, the focal plane assembly comprises a total of nearly 1000 million pixels (a 'gigapixel'), compared to the few million of a typical digital camera.

As Gaia slowly rotates, the image of a celestial object crosses the focal plane. The path it takes is recorded as astrometric data. Red and blue photometry prisms between the beam combiner and the focal plane enable Gaia to measure the brightness of an object in a number of 'colours', or bands of wavelength.

A radial velocity spectrometer grating, also located between the beam combiner and focal plane, will perform spectrometry: measuring an object's spectrum of light, in this case specifically to observe how spectral lines are shifted, from which the object's radial velocity can be inferred.

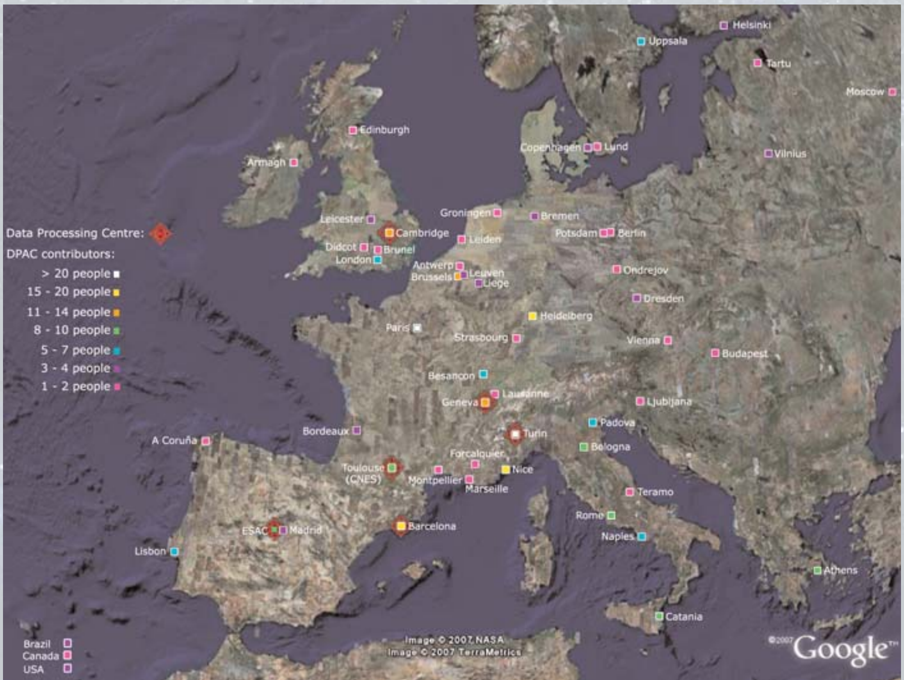
This arrangement means that the focal plane used for astrometry also serves the photometric and spectroscopic instruments, with certain CCDs assigned specifically to photometry and spectroscopy. The instruments steadily scan the sky as Gaia spins and gradually 'precesses' (the spin axis itself moves in a circle every 63 days). In this way, the whole sky is eventually covered, with each part being observed around 70 times in the course of Gaia's lifetime.

The Gaia Data Challenge

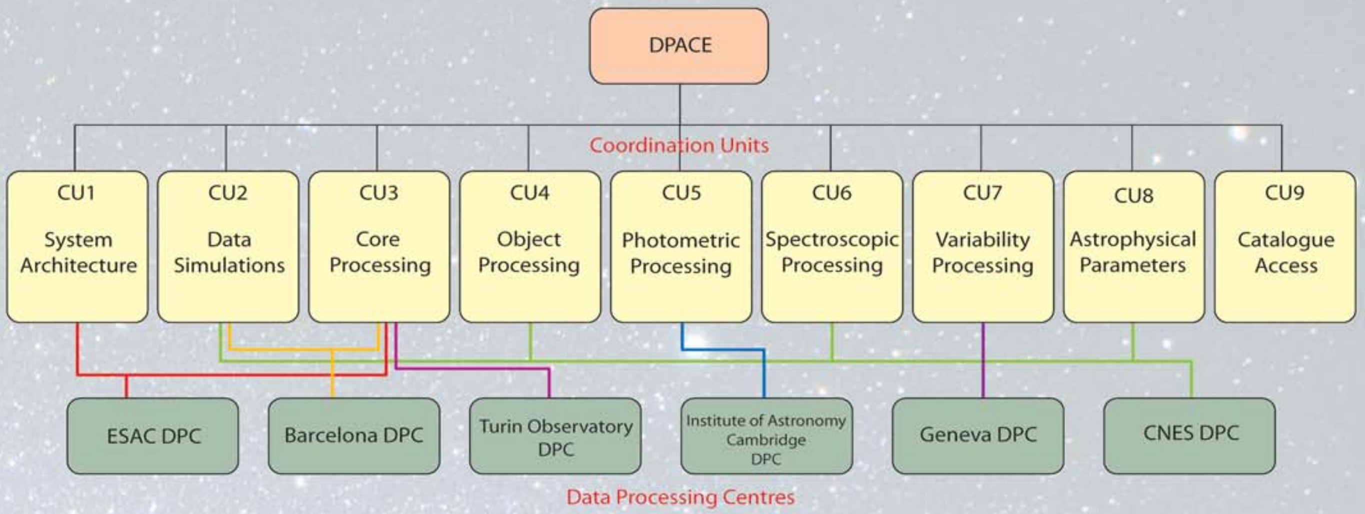
By its very nature, Gaia will acquire an enormous quantity of complex, extremely precise data, representing the observations of 1000 million diverse objects dozens of times each by a 'double vision' instrument that is spinning and precessing. These data will be transmitted daily to a ground station, either Cebreros in Spain, or New Norcia in Australia. Both have dishes 35 m in diameter to catch the faint radio whisper from space. Downlink speeds and station visibility constraints will result in a daily raw telemetry volume of roughly 50 Gbytes. By the end of Gaia's operational life, around 100 terabytes (10^{14} bytes) will have been channelled to Earth: the equivalent of more than 20 000 DVDs, and some 1000 times the raw volume from Hipparcos.

In its original format, Gaia's data is unintelligible. Not only because it is squeezed into packets by numerical coding but also because of the way Gaia scans the sky, picking up fragments of information at each transit of the 1000 million objects.

It is the combination of data complexity and sheer volume that presents such a demanding task: extensive, sophisticated treatment is required to yield meaningful results, by piecing together the fragments and translating them into



DPAC membership is distributed across more than 15 countries



The DPAC organigram shows the relation of the Coordination Units, the Data Processing Centres and the DPAC executive committee (DPACE)

real positions, motions and other physical information.

In terms of dedicated computing power alone, Gaia's requirements are considerable. The centre of an image moving across the focal plane needs to be determined to within 1% of a pixel size. With several thousand million images registering over the course of the 5-year lifetime, if each one took a mere millisecond to process, it would still require about 30 years to deal with the entire set one image at a time. With the aim of releasing a final Gaia Catalogue only a few years after the satellite has finished collecting data, the need for distributed or parallel processing is clear.

The data treatment, as well as the instruments themselves, ensures that Gaia performs as accurately as intended. The orientation of the spacecraft must be known to microarcsecond accuracy about all three principal axes. Not only must Gaia be extremely physically stable, but the data processing must also work to this highly precise scale.

Microarcsecond-astrometry raises a further unique challenge: at this level, ordinarily negligible 'relativistic' effects come into play. According to general relativity, the path of light is bent by the gravitational attraction of a massive body such as the Sun. This bending appears to shift a star from its true position. At Gaia's level of accuracy, this is constantly significant, distorting the apparent positions of celestial bodies across the entire sky. Highly precise relativistic corrections must therefore be calculated and introduced into the data processing.

It is clear that the Gaia data challenge is an enormous task in terms of expertise, effort and dedicated computing power. In late 2006, ESA's Announcement of Opportunity for Gaia's data processing was released, calling for a proposal to build and operate a single processing pipeline leading to the intermediate and final mission products. The announcement expected the system to be developed as a collaboration between ESA's Gaia Science Operations Centre and a broad scientific community supported by national funding agencies.

In response, a large pan-European team of expert scientists and software developers submitted their proposal for a comprehensive system capable of handling the full size and complexity of the Gaia data. In May 2007, ESA's Science Programme Committee approved the proposal put forward by the Data Processing and Analysis Consortium (DPAC). At this point, DPAC became officially responsible for Gaia data processing and analysis.

DPAC

DPAC is a collaboration drawing its membership from all over Europe, including a diverse community of more than 300 scientists and software engineers, spread throughout more than 15 countries, and six large Data Processing Centres. The consortium brings together skills and expertise from across the continent; its international nature and cooperative spirit reflects that of ESA itself.

The consortium is divided into specialist units known as Coordination Units (CUs). These are the building blocks of DPAC, with each unit assigned a unique set of processing tasks. They are supported by the Data Processing Centres (DPCs), the centres with the actual computer hardware. While the CUs are structured for developing the software, each is closely associated with at least one DPC, where their 'algorithms' are actually used.

Besides the technical challenge faced by DPAC, the sociological challenge of coordinating the efforts of 300 people undertaking an unprecedented feat in data processing for astronomy is not to be underestimated. Effective communication, organisation and maintaining motivation for the large consortium as essential.

The Gaia Data Flow

Gaia's processing is broken down into components to facilitate distributed development, identifying the major parts of the system that may operate relatively independently. This approach is also driven by the fact that the system is to be developed in many countries by a number of teams, each with different levels and fields of expertise.

Over the 5-year mission, Gaia will yield a total uncompressed data volume of around 100 Tbytes. The satellite will have contact with the ground station once a day for an average 11 h, during which an uncompressed volume of roughly 50 Gbytes will be downlinked at a rate of a few Mbits per second.

Within an hour, the Mission Control System at the Mission Operations Centre in Germany will receive Gaia's housekeeping telemetry that reveals the health of the craft and its payload. Meanwhile, on the Science Operations Centre (SOC) side in Spain, the science telemetry is received for preliminary processing in the Initial Data Treatment. This is the first step in unravelling the complex scientific data; this preliminary processing decodes and decompresses the telemetry, initially matches observations to known objects, and works out a 'rough' (sub-arcsecond) satellite attitude.

The SOC also carries out 'First Look' processing – this is Gaia's regular health check. While the Mission Control System does basic system monitoring, the First Look indicates any anomalies in the science output that can be corrected on board. The Flight Control Team resolves any anomalies through commands to the satellite.

DPAC focuses on processing the data into science products rather than the presentation of the final catalogue. Production of the actual catalogue will be covered by a future Announcement of Opportunity. The ninth Coordination Unit, 'Catalogue Access' is a place-holder, to be activated at a later date.

Scientific Processing

After the complex raw data from Gaia's instruments have been untangled, the intermediate data requires scientific processing as the next step towards the final data product. Basic meaningful scientific data will be extracted via 'iterative processing', with the output of one cycle forming the input of the next, gradually moving closer to the result. Unlike the near-realtime processing outlined above, each iteration will take around 6 months or more. This will continue after the satellite has finished

An artist's impression of our Galaxy (R. Hurt/JPL-Caltech/NASA)

its job, with each CU sending its output to the overarching Main Database.

The Main Database is the hub of all the data in the system. It is planned that this database will be 'versioned' every 6 months or so, with the final Gaia Catalogue being derived from by about 2020.

Since the science processing is iterative, each new version of the database will be derived from the preceding version. On detecting something of immediate interest to the broader scientific community, DPCs may issue occasional 'science alerts' in the course of the processing. These will be sent to the SOC for immediate dissemination.

One of the most intensive tasks is the 'astrometric core solution', which is key to unlocking the data potential of Gaia. This produces the calibration data and attitude solution needed for all the other treatments, as well as the accurate positions and motions of about 100 million well-behaved primary objects. After this is performed and the products stored in the central database, the more specialised tasks can begin: photometric and spectroscopic processing, and the treatment of all the difficult objects, such as multiple stars.

Further specialised analyses deal with the types of variable stars and retrieving stellar astrophysical information such as temperature and chemical composition.

The Astrometric Core Solution

The vital astrometric core solution is obtained via the Astrometric Global Iterative Solution (AGIS). This is the foundation of DPAC's scheme for reconstructing results from raw data, a procedure that iteratively adjusts unknown parameters to converge gradually on an optimal solution. Variants of the Global Iterative Solution will be used in the photometric and spectroscopic processing.

AGIS will be applied to around 10% of the objects – that means 100 million objects, and hundreds of millions of unknowns. AGIS begins by calculating astrometric parameters (positions and motions) for the predictable, well-behaved primary objects by firstly assuming that attitude and calibration parameters are known. Assuming then that the astrometric and calibration parameters are known, the attitude is estimated. Then, with the assumption that astrometric and attitude parameters are known, calibration parameters can be estimated.

The whole sequence will be repeated several times in the course of the processing, perhaps once every 6 months during the initial accumulation of observations. Iteration is necessary as many times as it takes to converge upon a solution that fits the data.

Conclusion

DPAC has a pivotal role in fulfilling Gaia's potential. Excellent progress has already been made and further challenging work still lies ahead. In the course of the processing, intermediate data releases with valuable scientific content are expected. When the Gaia Catalogue is finally published in around 2020, DPAC's work will be complete, and Gaia's processed data will be made freely available for investigation by the world's entire scientific community. esa

Key terms

Astrometry: the precise measurement of the positions and motions of celestial bodies.

Photometry: the measurement of the brightness of a celestial body over wide bands of wavelength.

Spectrometry: the measurement of the spectrum of light emitted by a celestial body.

Radial velocity: the speed at which a celestial body approaches or recedes from the observer.

Magnitude: used here to mean 'apparent magnitude', this is the brightness of an object as seen by the observer. The scale is negative and logarithmic: the higher the number, the dimmer the object appears. The Sun has an apparent magnitude of –26.7; the next brightest star in the sky, Sirius, is –1.4. The dimmest stars our eyes can see are around +6.

Dark matter: hypothetical matter of uncertain composition that potentially accounts for the majority of mass in the observable Universe. Its presence is inferred from gravitational effects on visible matter; neither emitting nor reflecting light, it cannot be observed directly.

Quasar: an extremely bright, active core of a very distant young galaxy.

Supernova: an exceptionally bright explosion at the death of a massive star.

Further information on Gaia and its mission can be found at http://www.esa.int/science/gaia


The ESA Optical
Ground Station
Ten Years Since First Light

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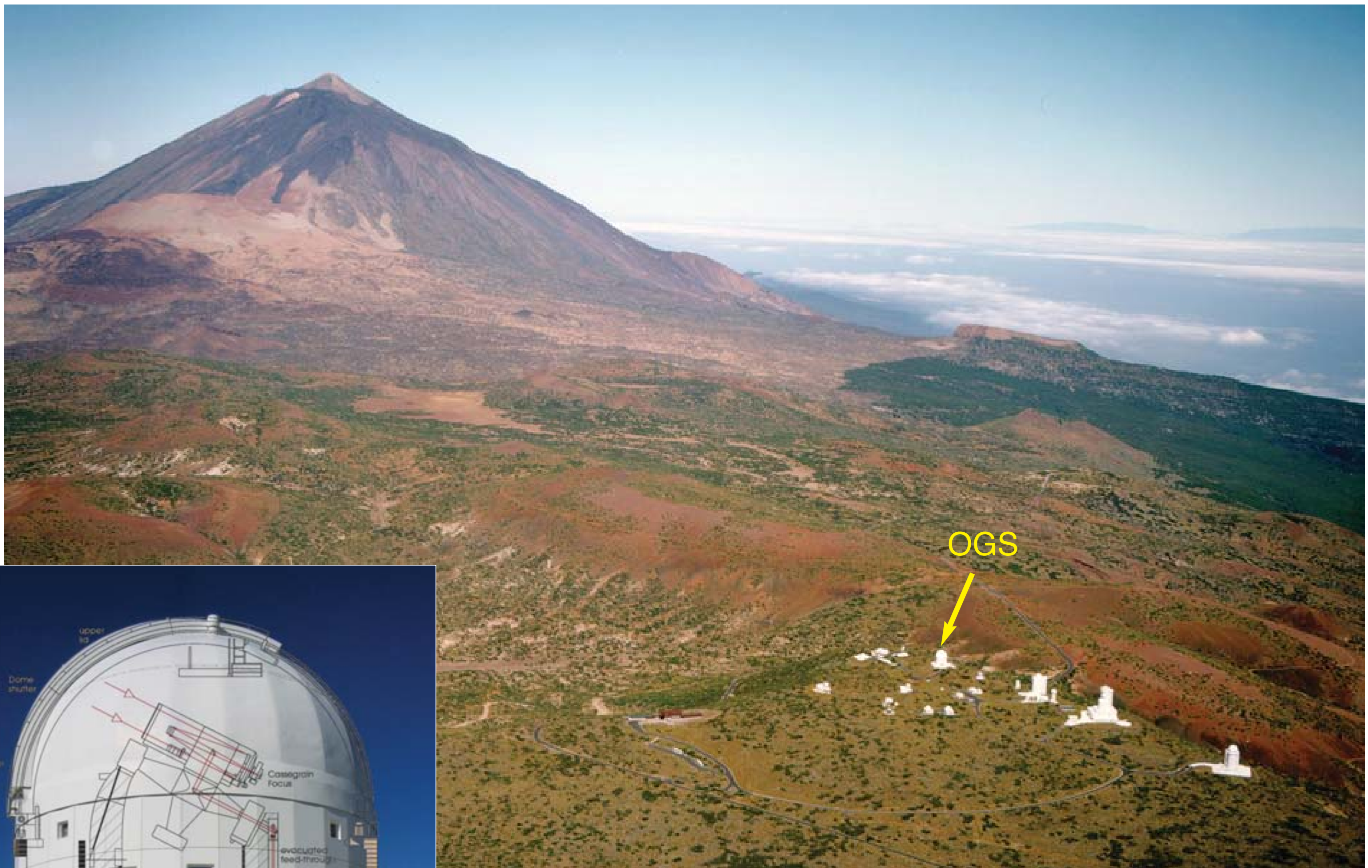
ESA's Optical Ground Station, created to test the laser-communications terminal on the Artemis geostationary satellite, has been operating for 10 years. Using a 1 m-diameter telescope, it simulates a low-orbit laser-communications terminal, allowing the performance of its partner on Artemis to be verified. The Station has seen extensive service over a wide range of applications, becoming a general-purpose facility for a multitude of ESA, national and international endeavours.

Introduction

ESA's Optical Ground Station (OGS), on the premises of the Instituto Astrofísica de Canarias (IAC) at the Observatorio del Teide, Tenerife (E), was developed to test the 'Semiconductor laser Intersatellite Link Experiment' (SILEX) carried by the Agency's Artemis satellite in geostationary orbit. SILEX is an optical system that receives data from France's Spot-4 Earth-observation satellite in low orbit via a 50 Mbit/s laser link to Artemis. The data are then relayed to the ground via a Ka-band radio link. This means that Spot-4 can download its images



The Observatorio del Teide site at Izaña, Tenerife with the ESA Optical Ground Station. (IAC)

The 1 m Zeiss telescope, with its 'English' equatorial mount

even when it is beyond the limited range of ground stations.

When ESA took the ambitious initiative in the mid-1980s to embark on SILEX, it soon became evident that it would be highly desirable to verify the complicated acquisition sequence between the two laser terminals as they tried to establish a link between two moving satellites. The very tight beam of a laser communications link demands near-perfect pointing, acquisition and tracking.

The solution was to build the OGS to simulate one end of the link. A number of other useful performance characteristics could also be measured, like laser wavelength, polarisation, acquisition and communication timing, which are not readily available from onboard telemetry.

The decision to build the OGS was taken in 1993. A Memorandum of Understanding was established with IAC, and agreed at the December 1993 ESA Council. Construction was completed in 1996, and since the final acceptance of the telescope and its control system in 1997, the OGS has continuously supported the deployment and pre-operational use of SILEX. ESA became the world-leaders in civil optical space communications.

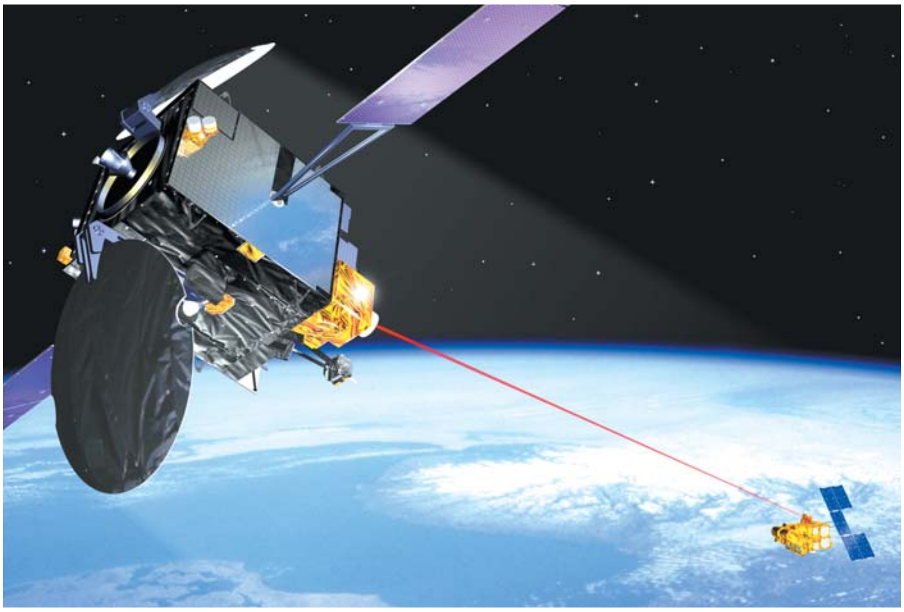
Building the OGS

The idea of establishing a general-purpose optical ground station facility, with a large telescope, was already alive in the late 1980s among optical engineers in the Technical Directorate, and preliminary design concepts were elaborated. The main stumbling block, however, was the high cost. But then 'history' gave a helping hand. After the fall of the Berlin Wall, ESTEC engineers visited companies in the former East Germany in search of industrial capabilities for ESA activities and came across a 1 m telescope at Carl Zeiss Jena. The telescope was set to be scrapped because it could no longer be sold to its original customer in Russia following German unification. The German DLR space agency procured the telescope, dome and control electronics on behalf of ESA as part of their policy to support industry in the 'Neue Bundesländer'.

The search then began for a suitable location for the station. The dominant criterion was to find a high-altitude site in the south of an ESA Member State. The observatories on the Canary Islands were the first choice. The Observatorio del Teide on Tenerife was chosen, because of its excellent seeing conditions at 2400 m altitude, its proximity to the Earth's equator (minimising the atmospheric path to a geostationary satellite hovering over the Equator), and the excellent infrastructure provided by the IAC.

The IAC allowed an ESA building on its site and provided access to its infrastructure in exchange for 25% of the observation time. Construction began in 1994. On 30 June 1996, the OGS was inaugurated by His Majesty, King Juan Carlos of Spain. Final acceptance testing of the telescope and control system was successful in 1997, when 'first light' was declared.

However, the real test as a checkout station for SILEX had to wait a couple of years owing to launch delays of Artemis. The satellite was orbited on 12 July 2001 but underperformance of the Ariane-5 third stage left it in a far too-low transfer orbit. Within 10 days, Artemis fired its apogee motor to reach a circular parking orbit at 31 000 km altitude. The final climb into the target 36 000 km geostationary orbit had to be done with the ion thrusters, a process taking an entire year and preventing payload testing.



Spot-4 (right) beams its data to the SILEX terminal aboard Artemis along the laser link

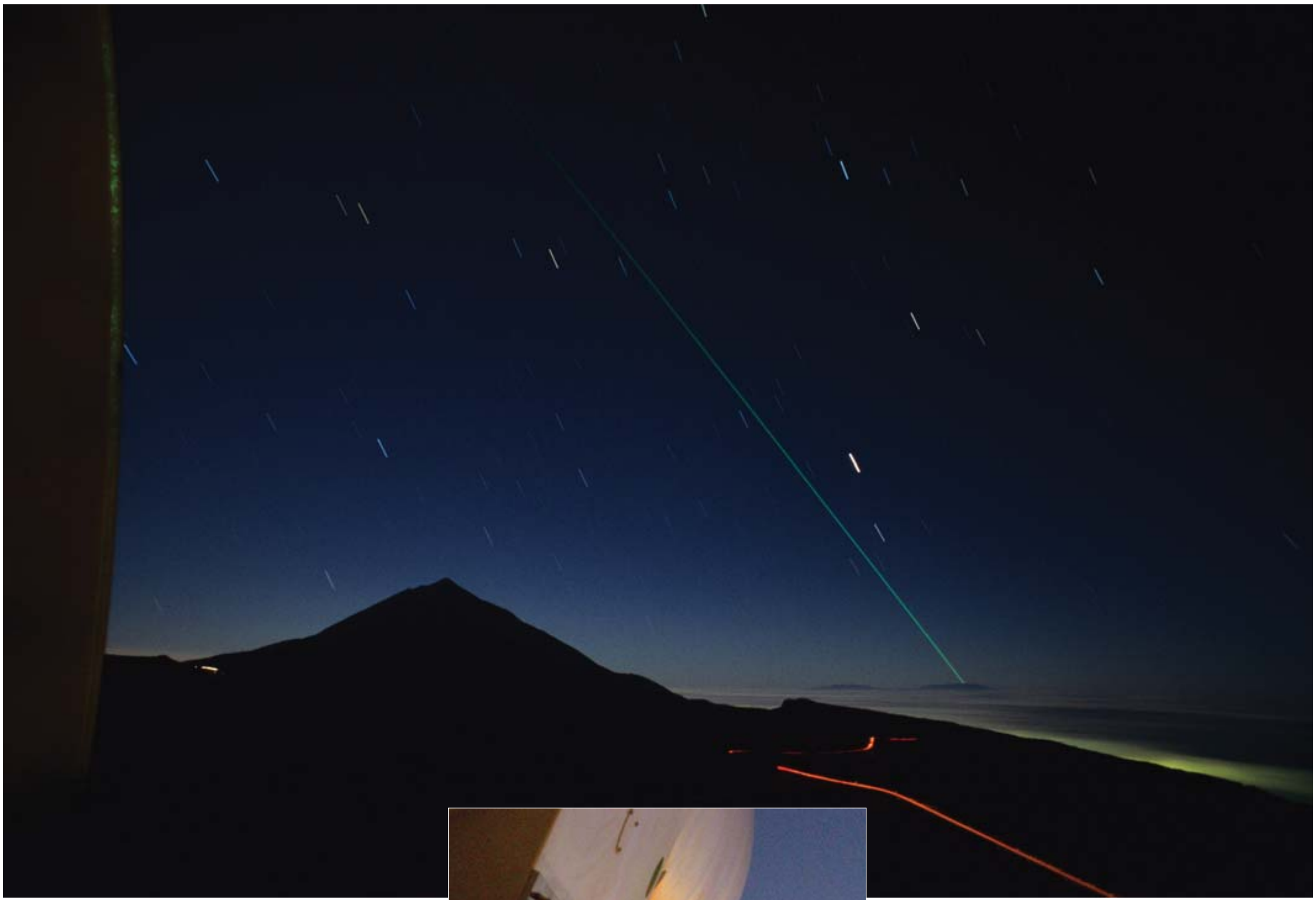
Queen Sophia and King Juan Carlos are greeted by René Collette (left), then ESA Director of Telecommunications, at the OGS inauguration

In order to check the health of SILEX as early as possible, it was decided to make the first tests with Artemis in its parking orbit. On 15 November 2001, the Artemis beacon signal was acquired in the OGS for the first time and, a few moments later, full optical communications with the satellite were established. This was a milestone in the long and successful history of optical space communications in Europe, because it marked the first demonstration of such a link in space. Five days later, the inter-satellite link between Spot-4 and Artemis was successful. The optical data relay service has been used since February 2003 on a daily basis.

More than a hundred laser communication sessions have been performed from the OGS with Artemis, mainly to characterise the beam propagation and how atmospheric turbulence affects communications. It also monitors the terminal performance at regular intervals.

National Space Laser Communications

The OGS often supports national optical space communications. In September 2003, a team of engineers from Japan's JAXA space agency tested the



The laser link experiment between La Palma and Tenerife

Green laser at dawn for a TerraSAR-X link test

engineering model of the 'LUCE' (Laser Utilizing Communications Equipment) terminal. This SILEX-compatible laser terminal was developed by JAXA under a cooperation agreement with ESA and launched into low Earth orbit in August 2005 on the Japanese OICETS satellite. The inter-satellite laser link experiments with Artemis were successful.

Similarly, the OGS helped to prepare the French LOLA (Liaison Optique Laser Aéroportée) aircraft-to-Artemis optical link experiment by providing measurement data to optimise the link.

Most important, however, is the fact that the OGS is now playing a key role in the development and verification of second-generation laser terminals. While SILEX was a vital development step for Europe, flight-testing a pre-operational optical link in space and stimulating the development of many new equipment technologies, it has limitations. Direct-detection, semi-conductor laser diode technology, as used by SILEX, LUCE and LOLA, is appropriate only for moderate data-rate systems, because the laser power and detector sensitivity are limited.

'Coherent' systems based, for example, on 'Nd:YAG' laser radiation, are highly promising for high data-rate systems, because of their high laser power and receiver sensitivity. The OGS plays a vital role in verifying these new concepts.

For instance, extensive use of the OGS was made during the development and early in-orbit testing of the coherent Nd:YAG laser communication terminals (LCT) developed by TESAT (the former ANT and Bosch Telecom) under DLR-German national funding. The first two were launched recently: the first on 24 April 2007 on the US Department of Defense NFIRE (Near Field Infra-Red Experiment) satellite, and the second on 15 June 2007 on TerraSAR-X, a German Earth-observation satellite using X-band synthetic aperture radar. The first TerraSAR-X tests were performed from the OGS in August 2007, when the required pointing, acquisition and tracking were demonstrated with the help of a Maksutov wide-field camera. The same is about to be done with NFIRE's terminal, before the actual inter-satellite link at 5.6 Gbit/s is attempted at the end of 2007.

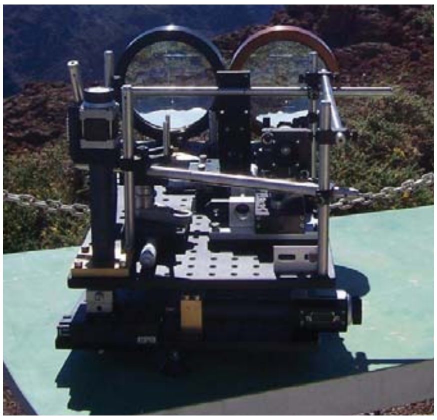
The OGS is being prepared for the commissioning and testing of the coherent laser terminals on TanDEM-X (a partner satellite to TerraSAR-X) and ESA's Alphasat next-generation telecommunication satellite, due for launches in 2009 and 2011, respectively. These terminals, specifically designed for data-relay between low Earth orbit and geostationary satellites, are being developed in a joint effort between Oerlikon Space AG (CH) and TESAT (D).

Inter-Island Link Experiments

A particular advantage of the OGS being on Tenerife is the proximity of the other Canary Islands, allowing laser-link experiments to be performed. Indeed, Tenerife with Gran Canaria and La Palma 70 km and 150 km distant, respectively, forms an excellent testbed for long-distance atmospheric transmission experiments. La Palma in particular, with its Roque de Los Muchachos observatory 2300 m above sea level, is a perfect counterpart for experiments with the OGS. Knowing this, the telescope and dome were designed to work as low as 4º below the horizontal. Even before the advent of the OGS, ESA was using this site for early laser-communications experiments and to obtain atmospheric turbulence data for designing the OGS.

The inter-island scenario was used by DLR in November 2005 to test the performance of its coherent laser terminals described above. The data transmitter operating at 5.6 Gbit/s sent its beam from La Palma across 150 km to the OGS. There, the telescope's 1 m aperture was reduced to 60 mm to simulate the real receiver. Although the experiment struggled with that year's severe weather conditions, important link measurements were made for the later space-to-ground commissioning of the terminals.

Another typical example was the testing, in 2002, of the engineering model of the AMIE camera eventually flown on SMART-1. AMIE was placed on La Palma, receiving the laser beam



Quantum entanglement transmitter on La Palma

from the OGS. In this way, it was possible to characterise the far-field pattern of the four OGS beams, to prepare for the expected signal strength seen by SMART-1 on its flight to the Moon. The actual tests between the OGS and AMIE were done in 2004 while the satellite was spiralling out towards the Moon with the help of its ion propulsion engine. The OGS was able to see SMART-1 up to 150 000 km away, and to direct the laser beam towards AMIE. The OGS-AMIE optical link was an important precursor experiment for deep-space optical links, which promise higher data rates than possible using radio frequencies.

In this vein, a particular inter-island experiment was planned for this October using the demonstration system developed by Oerlikon Space for linking the L2 Lagrange point and the OGS – a distance of 1.5 million km. L2 is an attractive location for future science missions. To scale it down to the 150 km separation from La Palma, the aperture was reduced from 10 cm to 10 micron. Error-correction coding compensated for the atmospheric turbulence to achieve the required 10 Mbit/s.

A series of intriguing experiments was recently carried out by a team of European scientists to demonstrate that the weird quantum effect known as 'entanglement' still operates over the distance to La Palma. Theory predicts that when two photons or other particles are entangled, the fate of one determines the fate of the other, no matter how far apart they are. Albert Einstein called it 'spooky' that one particle 'knows' the state of the other. However, it remained to be shown that entanglement is not lost over long distances. On their journey, the photons could interact with atoms and molecules in the air. Would this destroy the entanglement? If so, entanglement would be useless as a means of quantum encryption via satellite, because all the signals have to pass through the atmosphere.

A quantum optical terminal was placed on La Palma, generating entangled photon pairs and sending one photon towards Tenerife, while keeping

The Optical Ground Station, with Mount Teide behind

the other for comparison. The experiments showed that photons did indeed remain entangled over about 150 km through the atmosphere, a world record. It also confirmed that the entangled signal will survive the journey from Earth into space, and vice versa, making the satellite distribution of global quantum keys feasible.

A Versatile Tool

The OGS has been used in a wide range of applications, including space-debris tracking, lidar atmospheric measurements and astronomical observations.

From very early on in its design, close cooperation was maintained with the Mission Analysis Section of ESA's European Space Operations Centre (ESOC) to observe space debris. While space debris in low Earth orbit is best observed with radar, the more distant geostationary and geostationary transfer orbits are better served optically. To search for space debris effectively, a special wide-field, 16 million-pixel CCD camera array cooled by liquid nitrogen was developed for the OGS. Regular surveys have created an extensive debris catalogue, making ESA a world-leader in the subject.

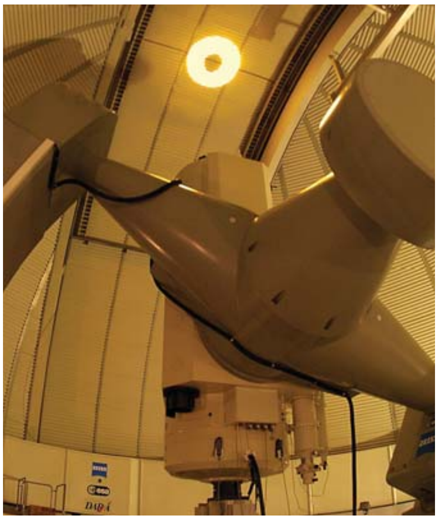
The Science Directorate is also a frequent user of the OGS. A spectrograph was installed with a 4 million-pixel, cooled CCD camera in conjunction with interference filters and 'grisms' (grating/prism) for comet observations. Similarly, S-Cam, a photon-counting imaging spectro-photometer based on superconducting tunnel junctions, is looking for planets beyond the Solar System.

Observations are also planned in conjunction with the planet-hunting COROT mission, using the space debris camera and special Johnson/Bessel filters for exoplanet detection.

The OGS regularly participates in international campaigns and special events, such as the impact of NASA's Deep Impact probe with Tempel-1 in July 2005.

The IAC is also entitled to use the OGS on a regular basis. More than 50 papers have been published since 2000 in astronomical journals based on work performed by IAC scientists with the OGS. Since 2002, the IAC has been analysing the behaviour of our atmosphere's mesospheric layer, about 90 km up. A tuned laser excites the layer of sodium atoms in the mesosphere, creating an artificial star; the results are fundamental for characterising the sky above El Teide Observatory.

The OGS spectrograph



The sodium-wavelength beam for studying the mesosphere, 90 km up

Status, Operations and Future

With the gradually decreasing importance of the OGS for SILEX, the responsibility for day-to-day management has been handed over from the Artemis project to the Optics Section of the Technical and Quality Management Directorate. In 2005, the Industrial Policy Committee approved a procurement proposal for a service contract with IAC for continued maintenance and operations for 2006–2010. Maintenance is obviously needed as a certain amount of wear and tear is becoming noticeable. The OGS telescope control system, which is based on the old DOS operating system, will have to be replaced soon, as will the dome control electronics. The primary mirror is tarnishing and will soon need recoating.

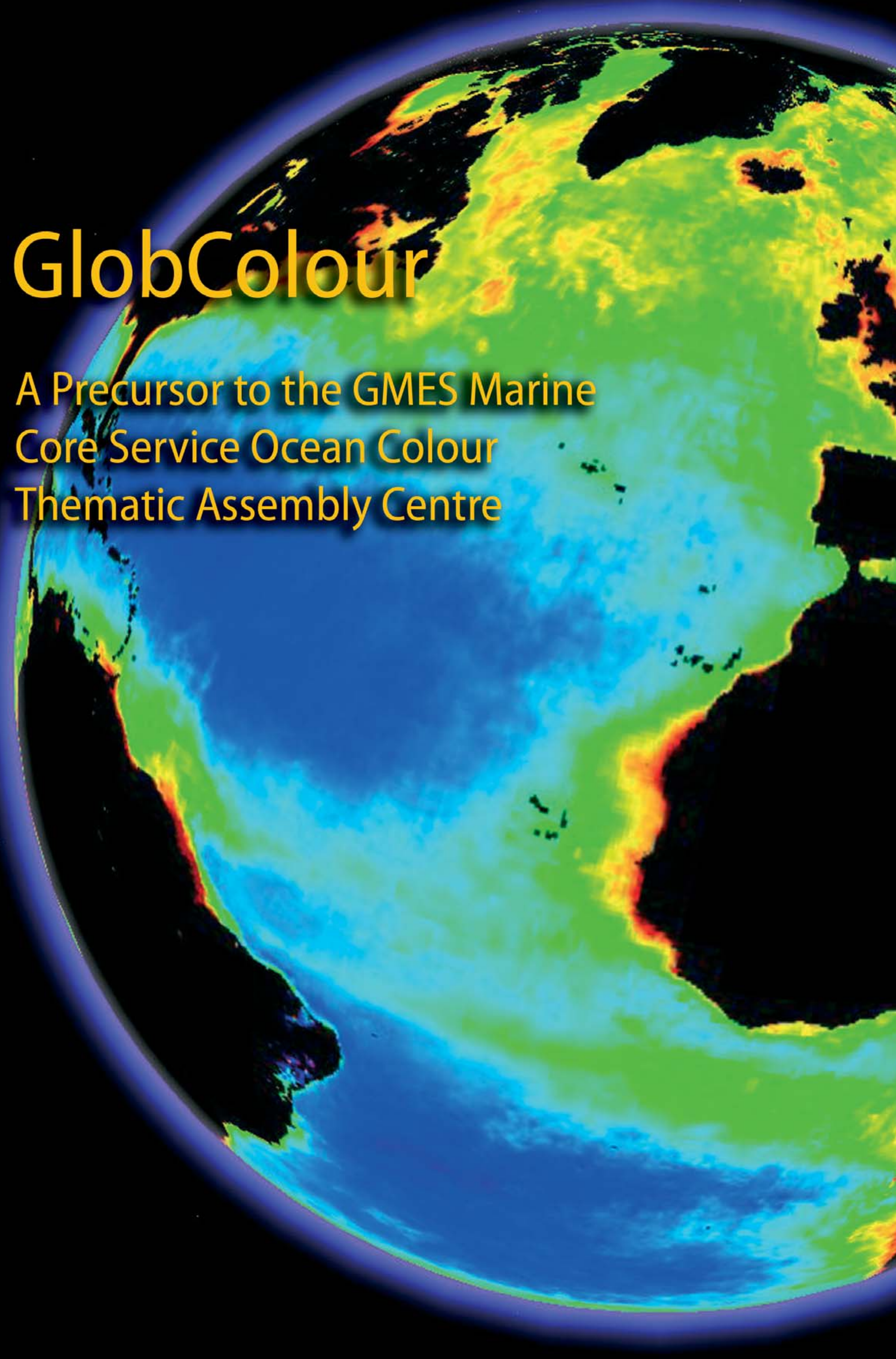
Using the OGS is handled in a very flexible way. Every semester, a call for observation requests is issued. In case of conflicting requests, a compromise is sought with all users. Two exceptions are made, however. As the OGS was built as a checkout facility for laser communications payloads in space, these experiments are given priority. Secondly, space-debris observations need dark (moonless) nights, so they are blocked to other users.

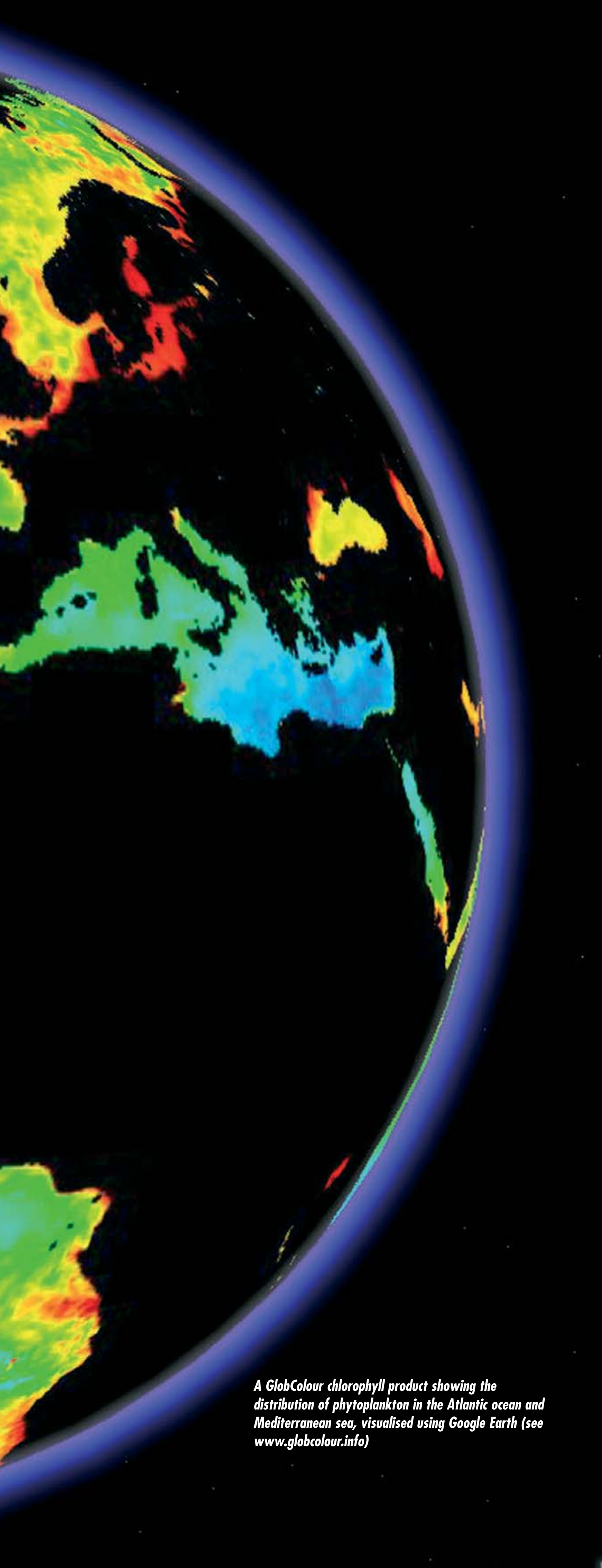
Unlike other observatories, applicants for OGS time neither need to submit an observation proposal nor have to pass a peer review: observation time is allocated on a first-come-first-served basis. IAC personnel are available for daily operations of the facility and assistance to external users under the terms of the service contract, which also has simple provisions for recharging costs to external users.

After 10 years of operation, the ESA Optical Ground Station continues to be in high demand by many users. This is not surprising because allocation of observing time is straightforward and the installation of experimental equipment simple. Optical space communications will remain the focus in the future, particularly in the light of the various space laser communications programmes under way, and ESA's increasing emphasis on developing equipment for deep-space optical data links. Because of this, important improvements are envisaged, such as the addition of adaptive optics and guide-star laser equipment.

GlobColour

A Precursor to the GMES Marine Core Service Ocean Colour Thematic Assembly Centre





A GlobColour chlorophyll product showing the distribution of phytoplankton in the Atlantic ocean and Mediterranean sea, visualised using Google Earth (see www.globcolour.info)

Simon Pinnock
Science, Applications and Future Technologies Department, Directorate of Earth Observation Programmes, ESRIN, Frascati, Italy

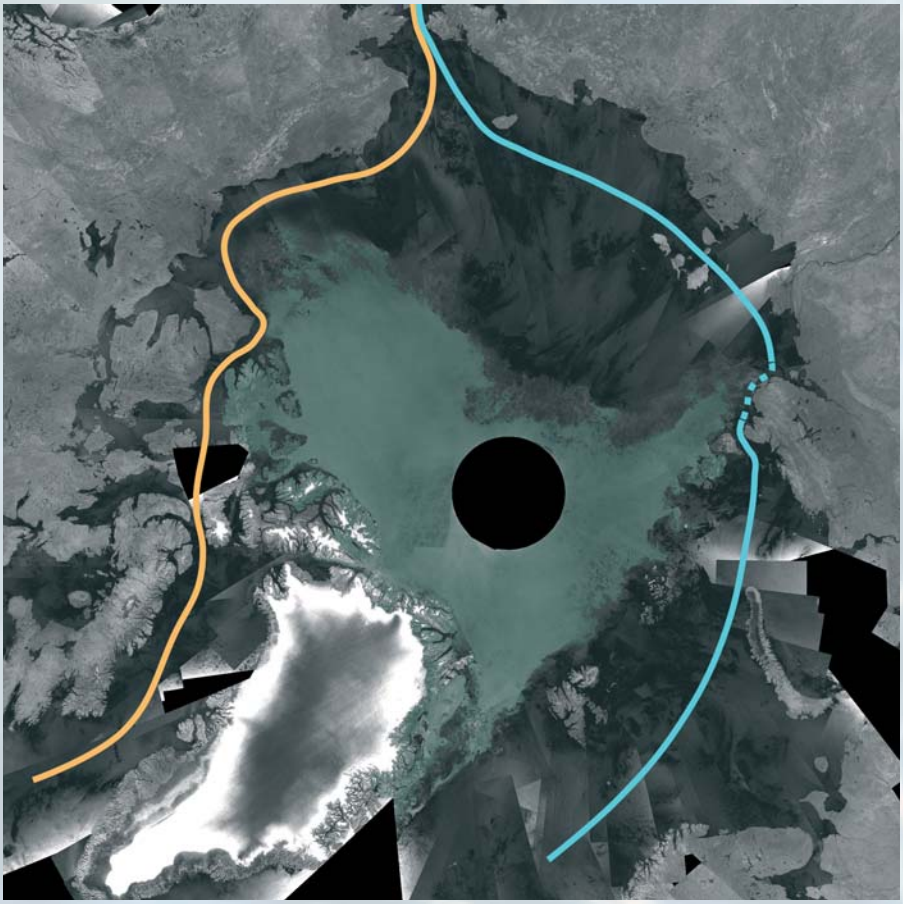
Odile Fanton d'Andon,
ACRI-ST, Sophia Antipolis, France

Samantha Lavender
University of Plymouth / ARGANS Limited, Plymouth, United Kingdom

ESA's GlobColour project is providing valuable information on marine biological activity, essential for assessing the amount of carbon dioxide being absorbed from the atmosphere by the oceans, and for projecting the severity of future global warming. By merging data from three satellite sensors, GlobColour offers the most complete 'ocean colour' data covering the last 10 years. A near-real time ocean colour service is being developed to demonstrate the capability of supporting operational decision-making. Together with the Medspiration project on sea-surface temperature, GlobColour is laying the groundwork for the operational exploitation of Envisat and Sentinel-3 that will be sustained under the European Commission's 'GMES Marine Core Service'.

Introduction

The 25 000 million tonnes of carbon dioxide pumped annually into Earth's atmosphere by human activity is contributing to a global warming that is likely to make our planet less habitable. If left unchecked, the consequences could be disastrous for humanity.



A result of global warming? Shipping shortcuts between the Atlantic and Pacific are opening through the Arctic. This Envisat radar mosaic of the Arctic Ocean for early September 2007 clearly shows the most direct route of the Northwest Passage open (orange line) and the Northeast Passage only partially blocked (blue line). The dark grey represents the ice-free areas, while sea-ice and land show up as light grey

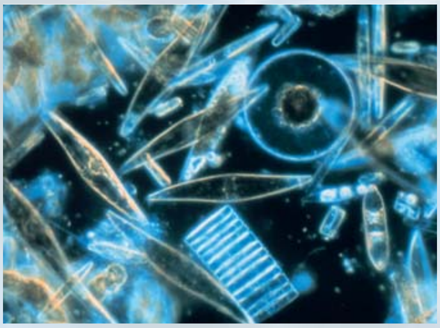
Warming seas and melting glaciers are raising the mean sea level by 2–3mm each year, increasing the risk of severe flooding in low-lying coastal cities, such as London and Amsterdam, and of the huge river delta populations of Asia and Africa. Mountain glaciers that used to be reliable summertime water sources for much of the world's agriculture are gradually disappearing, making conflicts over scarce water resources ever more likely. Changes in ocean circulation may well be disrupting fisheries and be behind some of our recent unseasonable weather. Tropical cyclones like Hurricane Katrina, which wrecked New Orleans in 2005, and Hurricane Dean in the Caribbean this year, are becoming more intense. Together with heat waves, which have killed tens of thousands in Europe in recent summers, these phenomena are linked to increases in sea-surface temperature. The fourth and latest assessment of the Intergovernmental Panel on Climate Change shows that many of the effects of global warming are already happening or are reasonably predicted to begin soon.

Optimists remind us of the benefits of global warming. Longer growing seasons in temperate regions will lead to more productive agriculture. Melting sea ice will open up global transportation shortcuts via new Arctic sea routes and allow exploitation of previously inaccessible oil reserves. But such benefits need to be weighed against the negative impacts. Whatever the outcome of that contentious debate, nobody can reasonably argue against careful management of the changes we are bringing upon the 'Earth system'. And management, if it is to be effective, starts with quantitative, accurate and unequivocal information on the state of our planet.

ESAs GlobColour project will contribute by providing scientists with a valuable new multi-satellite dataset on ocean biological activity. The colour of oceanic sea water depends largely on the number of microscopic (commonly green) phytoplankton it contains. Clear blue surface waters in the middle of ocean basins are poor in nutrients and contain relatively few phytoplankton, while regions of upwelling near continental shelves bring nutrient-rich waters from the deep ocean to the surface, enabling phytoplankton to bloom and colouring the water green. Things get rather more complicated in the coastal zones, where the seawater is also coloured by organic runoff from the land and suspended sediments, but the principle remains the same. Tiny phytoplankton are the first link in a food chain that humans also depend on for food.

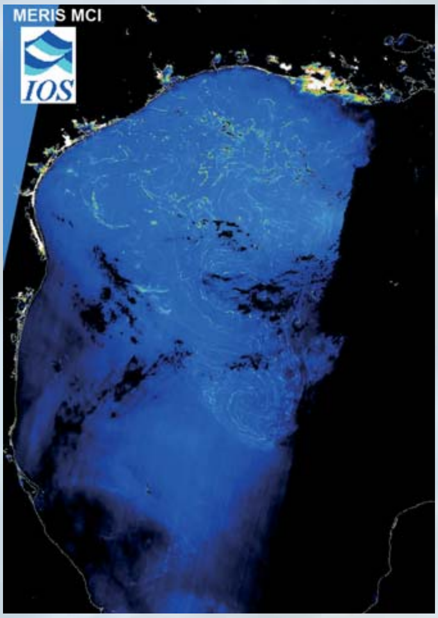
As well as being fundamental for our food supply, the ocean's biological activity is worth keeping an eye on for other good reasons. It could help to mitigate climate change by absorbing carbon from the atmosphere, and turning some of it into organic detritus, which eventually sinks to become locked in sediments on the deep sea floor. This is the 'ocean biological pump'. By absorbing some of the carbon we emit into the atmosphere each year, it helps to reduce the amount of warming.

Marine phytoplankton seen through a microscope. (N. Sullivan, US National Oceanic & Atmospheric Administration/Department of Commerce)



As the concentration of carbon dioxide in the atmosphere increases, some of it also dissolves chemically in the oceans, making seawater more acidic. Together, these two processes are estimated to be about equivalent to the terrestrial carbon sink. One problem, however, is that this gradually increasing acidification of the oceans could eventually reduce the ability of coral and some types of plankton to build their skeletons and shells, slowing biological activity, and reducing the amount of carbon absorbed by the oceans. Monitoring the evolution of the biological pump as atmospheric carbon dioxide increases is therefore essential for accurate projections of future climate change.

This kind of frailty means that information on ocean biology can also be a useful indicator of climate change. It can help scientists to check the predictions of their highly complex models, and to give early warning of things they didn't expect.



Sargassum in the Gulf of Mexico. First seen from space with the help of MERIS by Jim Gower and Stephanie King of the Canadian Institute of Ocean Sciences, and Chuamin Hu of the University of South Florida

History

The science of measuring ocean colour from space began in 1978 with the launch of NASA's Coastal Zone Color Scanner (CZCS). This highly successful proof-of-concept mission exceeded its one-year design lifetime by almost a factor of eight. More importantly, it helped to realise the potential for measuring chlorophyll concentration in the oceans by providing scientists with the necessary data to develop effective retrieval algorithms.

Spurred on by this success, several agencies began planning new global ocean colour missions. The DLR German space agency developed the Modular Optoelectronic Scanner that flew on India's IRS-P3 satellite 1996–2004, and on Russia's Mir space station. The Orbital Sciences Corporation in the USA developed GeoEye's SeaWiFS mission with the primary goal of providing commercial services to the fisheries industry. Thanks to both NASA's Earth Science Programme and ESA's Earthnet, these commercial data were also made widely available to the science community, which has made SeaWiFS the workhorse scientific ocean colour instrument for the last ten years. Japan's JAXA launched the Ocean Colour and Temperature Scanner on ADEOS-1, and the ocean colour-capable Global Land Imager on ADEOS-2. Both were accompanied by the POLDER instrument from France's space agency CNES. Unfortunately, they were all lost less than a year after launch through failures in the solar panels of both ADEOS satellites.

In 2004, CNES flew a third POLDER-type instrument on the Parasol mission. Although intended to monitor global dimming owing to anthropogenic aerosol emissions, Parasol has recently started to provide ocean colour data. In the meantime, NASA followed the success of CZCS with two sophisticated and multi-purpose Moderate Resolution Imaging Spectrometer (MODIS) instruments. While the first MODIS, launched on the Terra satellite in 1999, has suffered from unstable calibration making ocean colour retrievals difficult, the second, launched on Aqua in 2002, provides high-quality observations.

Since 1999, several other missions which do not provide global data have been launched by China, Japan, Taiwan, India, Korea and Argentina.

ESA's first ocean colour instrument, the Medium Resolution Imaging Spectrometer (MERIS), was launched on Envisat in 2002. MERIS provides high-quality ocean colour data at both global (1 km) and coastal (300 m) resolutions, and has improved retrieval capabilities for coastal waters. Specialised narrow spectral bands allow not only the possibility to monitor phytoplankton in the oceans, but also to monitor biological activity in the much more complex coastal zones. MERIS' enhanced capabilities are opening up new possibilities for monitoring the marine environment, such as the recent detection in the Gulf of Mexico of vast thick beds of floating 'sargassum' seaweed, the first time this phenomenon has been observed by satellite.

User Needs

In 1996, the International Ocean-Colour Coordinating Group (IOCCG) was established to facilitate coordination between the science community and space agencies. Specialised scientific working groups of recognised world experts were set up to build consensus, such as providing recommendations on satellite sensor specifications and documenting scientific best practice.

In their second report, in 1999, IOCCG analysed user needs for global ocean colour monitoring. As well as the need to quantify the global ocean carbon flux, these requirements included monitoring fisheries and coastal zones, and providing ocean forecasters with essential information on the way light and heat are absorbed by the upper layers of the ocean. IOCCG combined these user needs to derive specific requirements for satellite missions, which showed that global coverage is needed at least every 3 days. The report considered the complementarity between different satellite missions, and pointed out that, owing to interference from Sun glint and cloud cover, no single instrument would be capable of meeting this requirement. The report also noted, however, that by combining observations from multiple sensors, a significant increase in coverage would be achieved. For instance, SeaWiFS, with the widest swath (2800 km) can provide only 60% global coverage in 8 days. But by combining data from the three currently flying sensors, it is possible to achieve the same coverage in only 4 days.

As well as improving spatial coverage, merging data from different satellite missions can provide improved temporal coverage. Thanks to the natural variability in the Earth system, the only way to detect the subtle signals of climate change is to average many measurements over a long time period. This is rather like your car's fuel gauge, which has to average measurements made over several minutes in order to read the true depth of petrol in a tank that is being sloshed about as you drive along. This leads to a strong need for multi-decadal ocean colour time series for global change monitoring. The only way to produce such a dataset is to string together the multi-annual time series from different sensors into a consistently calibrated data set spanning a time period much longer than the lifetime of any single satellite.

Combining data from several satellites brings several extra benefits. As different satellites usually fly over the same area at different times, combining the data leads to a better sampling of the daily variability. As well as getting a result with a smaller random error simply because of the larger amount of data, since all sensors are built differently, the intercalibration step required before the data can be merged tends to reduce instrumental biases. Merging also highlights suspicious regions where retrievals differ more than expected, which can be missed when data are compared with the very few 'ground-truth' measurements available. Erroneous temporal trends in the time series from individual sensors can also be more easily corrected.

For these reasons, and the fact that they are based on all the available information, scientific analyses built on a merged dataset have the highest possible credibility. This is an important criterion when governments need to use these analyses to make decisions with potentially huge social and economic implications.

The GlobColour Project

ESA's Data User Element (DUE) is building the user community for Earth observation data by running projects to develop and demonstrate user-driven applications. In so doing, it helps to transfer research techniques into viable applications, and puts Earth observation to work for the benefit of Europe's citizens. Since 1996, almost 90 projects have been kicked-off involving more than 180 formally committed user organisations and 150 European and Canadian companies. Several projects have pioneered applications that are being developed into operational services by the European Commission under the Global Monitoring for Environment and Security (GMES) initiative.

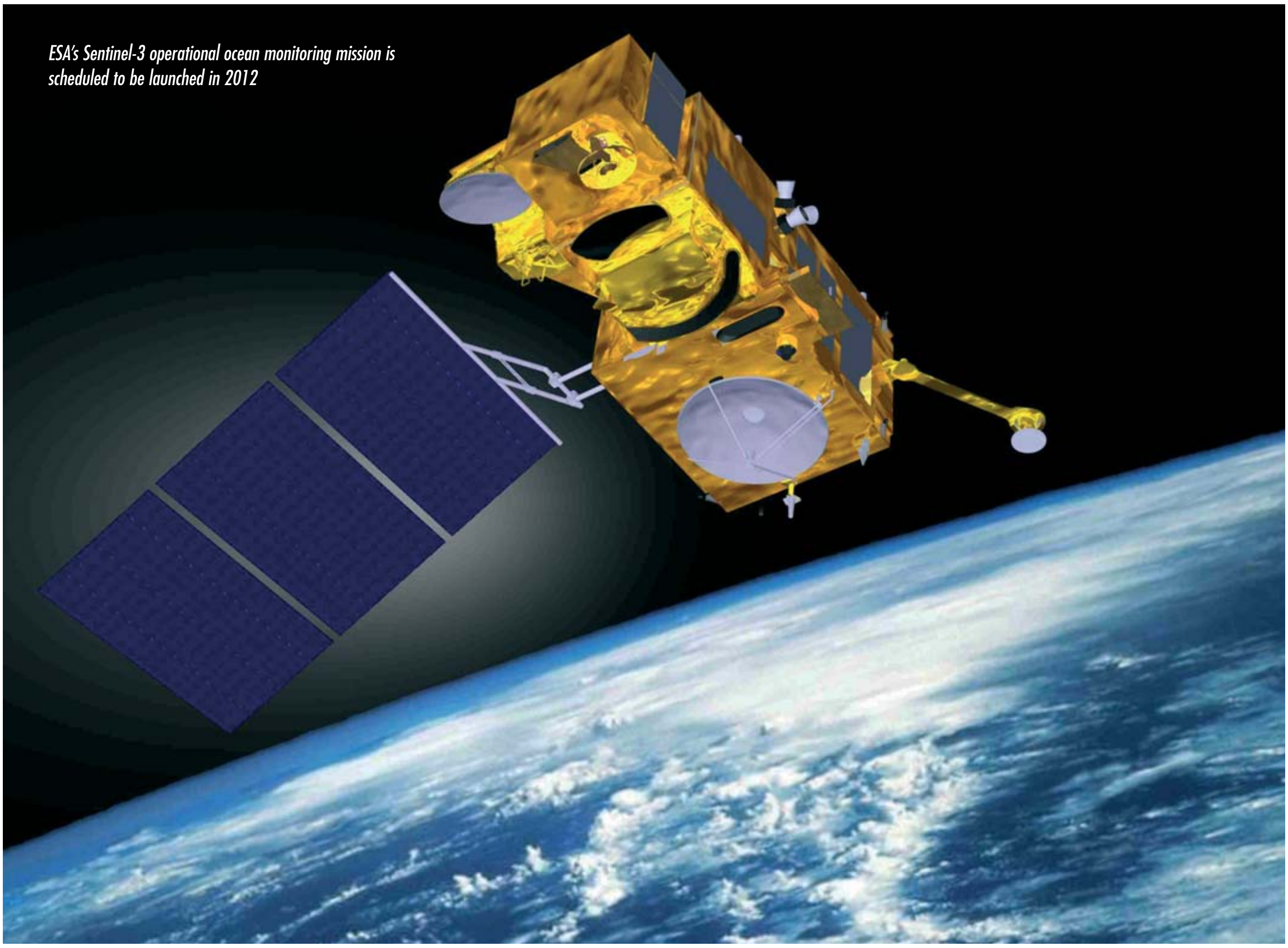
The DUE also supports scientific programmes and international environmental conventions, such as the United Nations conventions on climate change, desertification and biodiversity, by providing large-scale satellite-derived information for global change research and monitoring.

In 2005, the IOCCG convened a working group to examine the state-of-the-art in ocean colour data merging. It showed that the research techniques had matured sufficiently and the time was now ripe for putting them to work. This effectively threw down the gauntlet for attempts to be made to merge large quantities of global satellite data to provide the consistent high-quality long time series that the user communities are asking for. ESA took up the challenge by initiating the GlobColour project, and NASA started the Ocean Color Time-Series, which builds on their earlier Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies programme. Comparisons between these merged datasets will help to refine the techniques. GlobColour is the only one that so far includes MERIS.

In setting up GlobColour, three user organisations were invited to help. Their roles are to specify the detailed user requirements, act as a channel to the broader end user community, and to provide feedback and assessment of the results. The International Ocean Carbon Coordination Project based at UNESCO in Paris provides direct access to the carbon cycle modelling community's requirements and to the modellers themselves who will use the final products. The UK Meteorological Office's National Centre for Ocean Forecasting provides an understanding of the requirements of operational users. The IOCCG brought its knowledge of the global user needs and valuable advice on best practice within the ocean colour science community.

The 3-year project began in November 2005 under the joint leadership of ACRI (F) and the University of Plymouth (UK). The objective is to produce the best possible global daily ocean colour data set by merging data from the three most capable sensors: SeaWiFS, MODIS on Aqua, and Envisat's MERIS, and to process all available data from them to produce a consistently calibrated time series covering from 1997 to 2008.

The first year of work, 2006, was devoted to development and prototyping. Four months of merged global data were produced with each of three merging methods. Validation and intercomparison of this prototype dataset, and consideration of these results in terms of how best to meet the user requirements provided the basis on which the final merging methodology was selected. The results of this first year of work were presented at a user consultation workshop organised by the Laboratoire d'Océanographie de Villefranche in France, in December 2006. This was an opportunity for the wider global user community to hear about


ESA's Sentinel-3 operational ocean monitoring mission is scheduled to be launched in 2012

the results and to influence the direction of the project. It also provided the final stamp of approval on the merging methodology before large-scale processing began in 2007.

Almost the full 1997–2007 set of global daily merged ocean colour products has been processed. An intensive phase of validation was also undertaken to assess the quality of the dataset. As it is based on a much larger set of *in situ* data than could be used for the validation of the prototype data set, it provides significantly clearer results. Both the final products and the quality assessment will be presented at a second user consultation in Oslo, organised by the Norwegian Institute for Water Research (20–22 November 2007). The data will then be made freely available for use by the worldwide science community via the project's web portal: at *www.globcolour.info*

Of course, GlobColour will not stop there. In 2008, the project will continue merging ocean colour data, but with a new twist. Having demonstrated the means to provide the global change community with a long-term global dataset for ocean carbon cycle research, the project will attempt to reuse what it has developed to support operational oceanography. Like weather forecasters, operational oceanographers need near-real time observations to assimilate into predictive ocean models in order to forecast the future ocean state. Ocean colour can provide forecasters with the information they need to generate forecasts of, for example, water clarity for naval mine-clearing operations, and biological activity for fisheries and aquaculture industries. As always with computers: 'garbage in, garbage out', so the accuracy of these forecasts depends critically on the quality of the input data. Hence using GlobColour's 'best possible' multi-sensor ocean colour products should ensure the best possible ocean forecasts can be made.

The Future

Having reached its 5-year design life in March 2007, Envisat is still going strong, but even the most optimistic of ESA engineers knows the satellite is on borrowed time. It has to be deorbited when its fuel runs out about 5 years from now. SeaWiFS is already 10 years old and showing signs of age, and Aqua too will reach its design life in 2008. So what about the future?

Following the last 30 years of research

MERIS reduced-resolution image from 3 May 2007 showing a bloom of phytoplankton (primarily coccolithophores) along the edge of the continental shelf south west of Ireland and to the west of the English Channel, and suspended sediments in the Irish Sea, Bristol Channel and English Channel

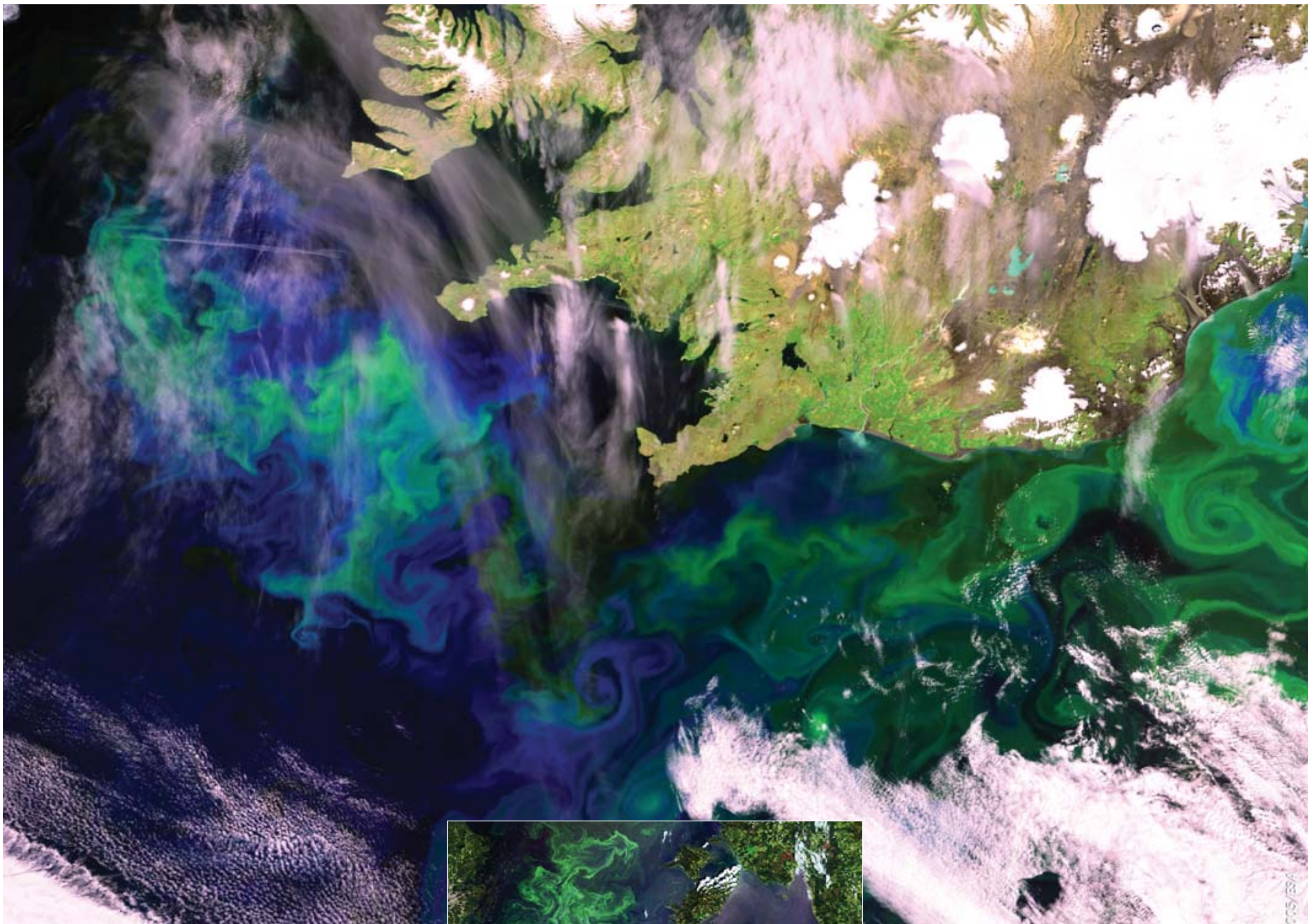
and development since the launch of CZCS, the age of sustained operational ocean colour monitoring will finally begin with the launch of ESA's Sentinel-3 and the joint NASA-NOAA NPOESS (National Polar-orbiting Operational Environmental Satellite System) satellites. The The Visible/Infrared Imager/Radiometer Suite (VIIRS) on NPOESS will provide basic capabilities to monitor global ocean chlorophyll, while Sentinel-3 will carry the Ocean and Land Colour Instrument (OLCI), partly based on MERIS. Thanks to this heritage, OLCI will have significantly enhanced capabilities to provide both more accurate chlorophyll retrieval, not only in the open ocean, but also, like MERIS, in coastal waters, by providing operational monitoring of other optically active marine components such as dissolved organic material and suspended sediments.

With operational satellite missions in place, ocean colour data merging also needs to continue on an operational basis. The initial 12-year GlobColour time series will need to extend well into the future to allow scientists to continue to monitor and more fully understand the sea's role in the carbon cycle. But whereas ESA programmes such as DUE can develop and demonstrate new Earth observation-based services, the implementation of long-term operational services has to be sustained by the user communities themselves. As a major user of environmental information, the European Commission is putting in place this long-term operational capacity through its GMES initiative. In 2008, the EC-funded Marine Core Service will start to provide a suite of operational services to support Europe's decision-makers. As one of these services, GlobColour's merged ocean colour dataset will continue to support the global change research community well into the future within the Ocean Colour Thematic Assembly Centre (OC TAC).

The main objective of OC TAC is to bridge the gap between space agencies providing ocean colour data and GMES marine applications. It will deliver core ocean colour products, annotated with quality control flags and reliable error estimates at pixel level at global to regional European scales, consolidating European efforts and maximising their impact. The aim is to integrate the best components of existing pre-operational systems developed in the last few years by national, ESA and European projects like GlobColour, MarCoast and Mersea into a common European system, filling gaps and creating a common external interface.

Having focused this article on the global oceans, we should not forget that MERIS and OLCI were also designed for monitoring the coastal zones. Coastal waters are rich in nutrients and support a much more active biology than the relatively barren surface waters of the open oceans. They could account for a significant fraction of the carbon absorbed by the sea, but assessment of the fluxes of carbon between coastal waters and the atmosphere is still a topic of research. Apart from helping to monitor and understand the carbon cycle, MERIS and OLCI coastal capabilities open up whole new domains where ocean colour information can be put to good use.

Coastal waters are vitally important as sources of wealth, but they are also where mankind's impact on the marine environment is greatest. Warmer seas and increasing levels of nutrients from agricultural runoff can give rise to more frequent algal blooms, which in turn can suffocate marine life by mopping up all the available oxygen. Some blooms give off neurotoxins that damage fish stocks, can make seafood and shellfish unsafe to eat, and can even be directly harmful to swimmers. The total socio-economic impact of such harmful algal blooms in Spain, Italy and Greece alone is estimated at €329 million each year. Predictive models are under development with the aim of forecasting algal blooms, to allow action to be taken to



MERIS image over Iceland, 21 June 2004. Phytoplankton play an important role in the Earth-system: they could help to reduce the amount of carbon dioxide in the atmosphere, and are a useful indicator of changes in ocean productivity

minimise the risks to commercial operations and human health. But the accuracy of these forecasts will depend critically on the availability of high-quality satellite-based observations.

Governments are already obliged by the European Water Framework directive to monitor harmful discharges from rivers into their immediate coastal environments. In the future European Maritime Policy these obligations are likely to be enlarged to include areas further offshore where, to be cost-effective, monitoring will have to rely on a combination of *in situ* sampling and Earth observation. The increased temporal sampling resulting from data merging will be invaluable when put to work in monitoring these rapidly changing coastal zones.

Ocean colour data are important for predicting harmful algal blooms. Envisat/MERIS recorded this Baltic scene in July 2005

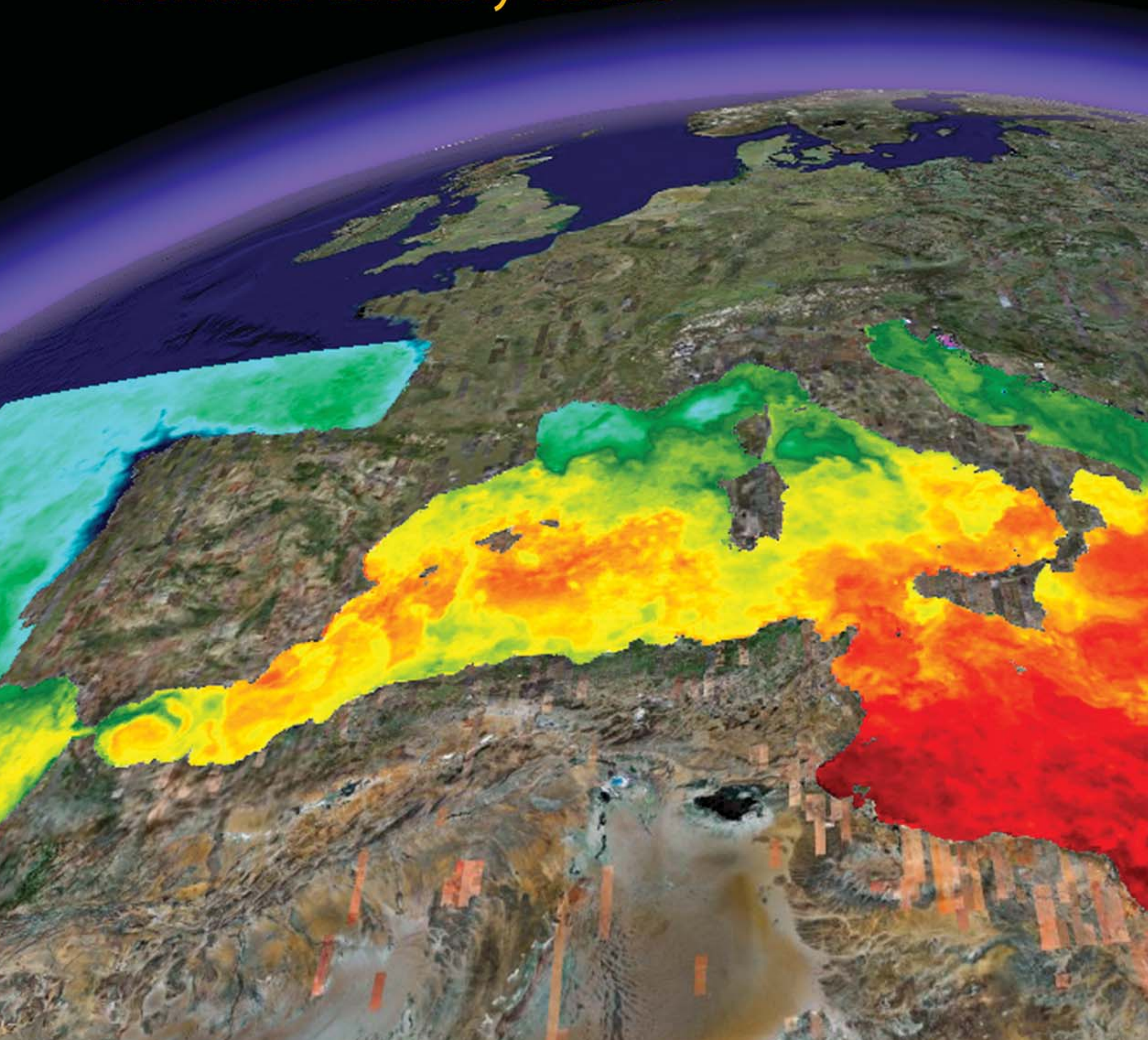
Through GlobColour, ESA is currently providing scientists with the best possible ocean colour data set for carbon cycle research, allowing politicians to make informed decisions on climate change mitigation and adaptation policies. Just as importantly, it is also laying the groundwork for valuable information services that will be needed to support Europe's Maritime Policy and the well-being of her citizens well into the future.

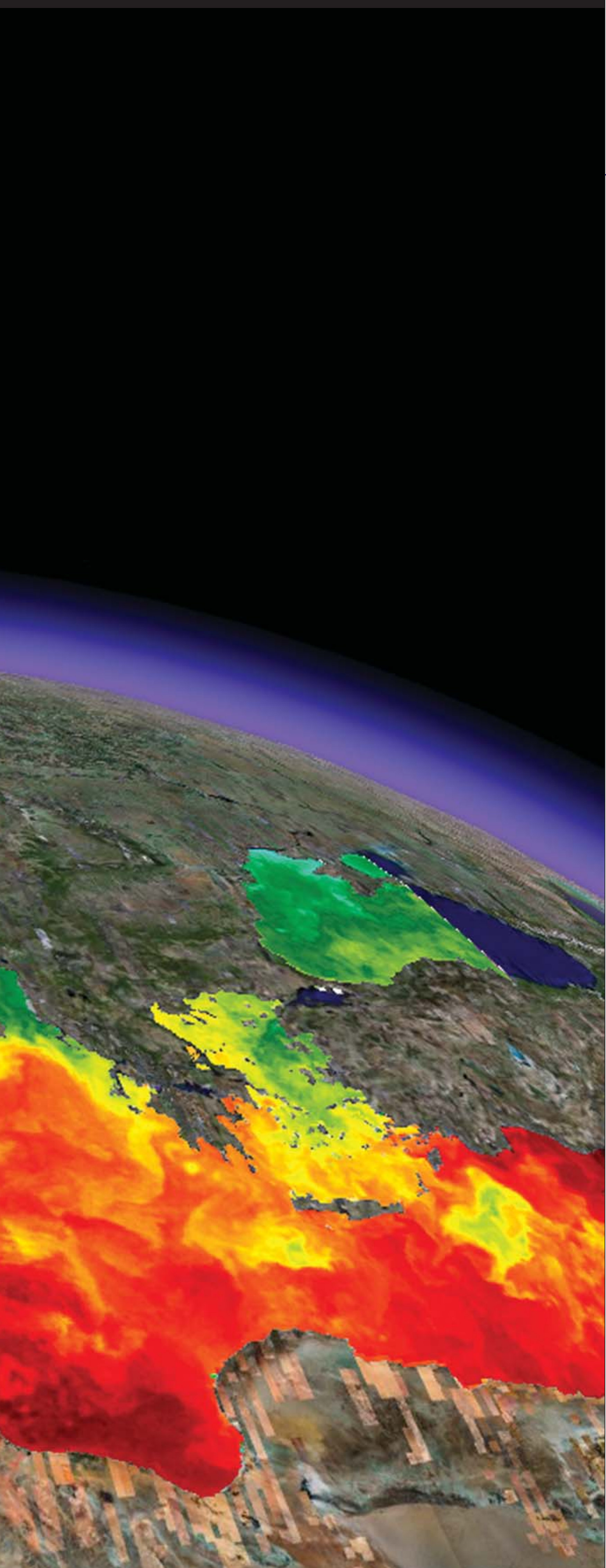
Acknowledgements

The authors would like to acknowledge the hard work and dedication of the GlobColour project team (ACRI, University of Plymouth, Laboratoire d'Océanographie de Villefranche, Norwegian Institute for Water Research, University of California Santa Barbara, Brockmann Consult, Deutsche Zentrum für Luft- und Raumfahrt, ARGANS Ltd), the enthusiastic participation of the champion users (IOCCG, IOCCP and the UK Met Office), as well as NASA and GeoEye for access to MODIS and SeaWiFS.

Medspiration

A Precursor to the GMES Marine Core Service Sea-Surface Thematic Assembly Centre





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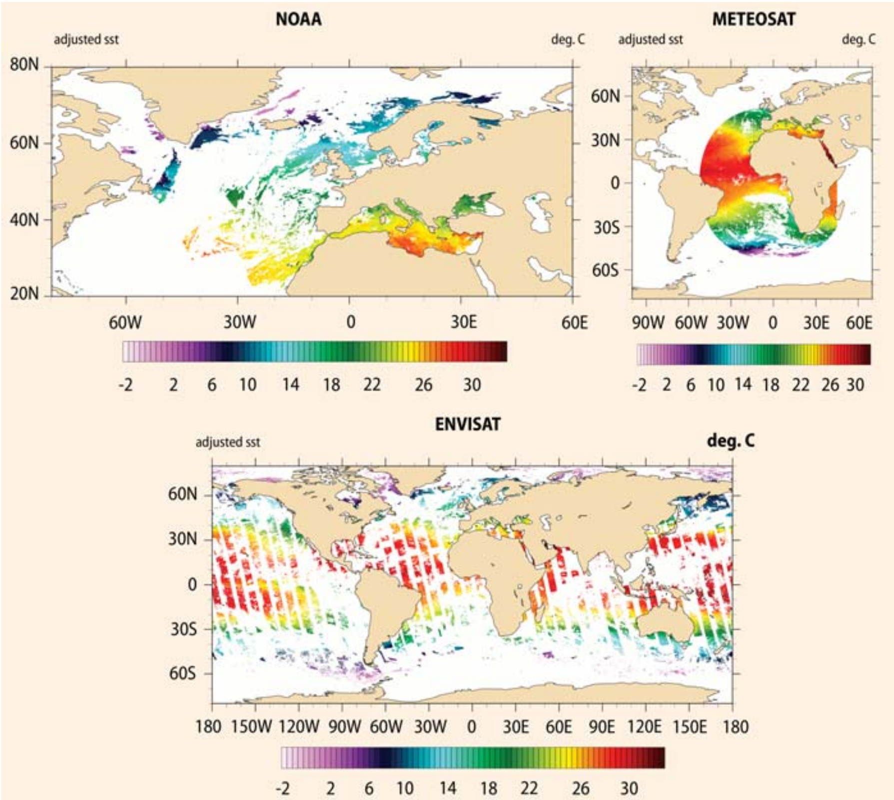
The Global Monitoring for the Environment and Security (GMES) initiative lead by the European Commission and ESA recently opened the call to set up the 'Marine Core Service' for oceanography users. Two of the six planned 'Thematic Assembly Centres' will build on ESA's Medspiration and GlobColour projects, which covered, respectively, sea-surface temperature and ocean colour. Both are described in companion articles in this issue. The services will make full use of instruments aboard ESA's Envisat. Their successors on the Sentinel-3 satellite series will ensure operational space oceanography services for the two decades starting in 2012.

Introduction

Accurate knowledge of sea-surface temperatures (SSTs) and how they changes with time is essential for many applications: monitoring climate variability, seasonal forecasting, operational weather and ocean forecasting, military operations, validating ocean and atmosphere models, ecosystem assessment, tourism and fisheries research. In particular, SSTs are required to feed the numerical models used by operational



Observations from several space sensors are combined to obtain Medspiration products: NOAA AVHRR17 & AVHRR18 (2 km resolution, two passes/day, top left); Meteosat/SEVIRI (10 km resolution, 3-hourly snapshots, top right) and Envisat/AATSR (1 km resolution, 14-15 orbits/day, bottom)

weather and ocean forecasting centres in near-real time. The minimum specifications for SST observations were defined by the Global Ocean Data Assimilation Experiment (GODAE): global coverage each day, 10 km resolution and an accuracy of 0.3ºC, updated every 6 hours. In 2002, recognising that none of the existing satellite measurements could meet these requirements, the GODAE High-Resolution SST Pilot Project (GHRSST-PP; see *http://www.ghrsst-pp.org*) was started. As the European contribution and to develop demonstration services in collaboration with European users, ESA began the Medspiration project in January 2004.

The Measurement Challenge

Different *in situ* and satellite sensors provide different results because the thermal structure of the top few centimetres of the sea is complex. For instance, infrared sensors operating in the 3.7–12 micron band are seeing the the 'conductive diffusion-dominated sublayer' at a depth of 0.01–0.02 mm, whereas microwave radiometers operating at 6–11 GHz sense the temperature at a depth of about 1.2 mm. Beneath the ocean surface, *in situ* buoys record temperatures at depths ranging from 20 cm to hundreds of metres.

Comparison between all these measurements is complicated by their different spreads in time and space, daily and seasonal changes in ocean thermal structure and the different local conditions such as winds, surface heating by the Sun and the time of day.

Many operational centres require estimates of the accuracy of each satellite observation so that they can make full use of the data. As the accuracy of satellite SST observations has increased to the point where they are equal to, if not better than, the operational *in situ* observing systems, ancillary information is required to understand how complementary observations differ. GHRSST-PP established through international consensus a data product that includes ancillary information necessary to interpret the SST data derived from satellite instruments. This 'L2P product' includes wind speed, solar irradiance at the surface, atmospheric aerosol optical depth, sea-ice cover and deviation from reference climatology for each satellite pixel. In addition, uncertainty estimates are computed, in order to deliver information to the users for them to develop their own quality control when merging complementary datasets. Medspiration spearheaded the development of the GHRST-PP L2P specification that is now used by centres around the world.

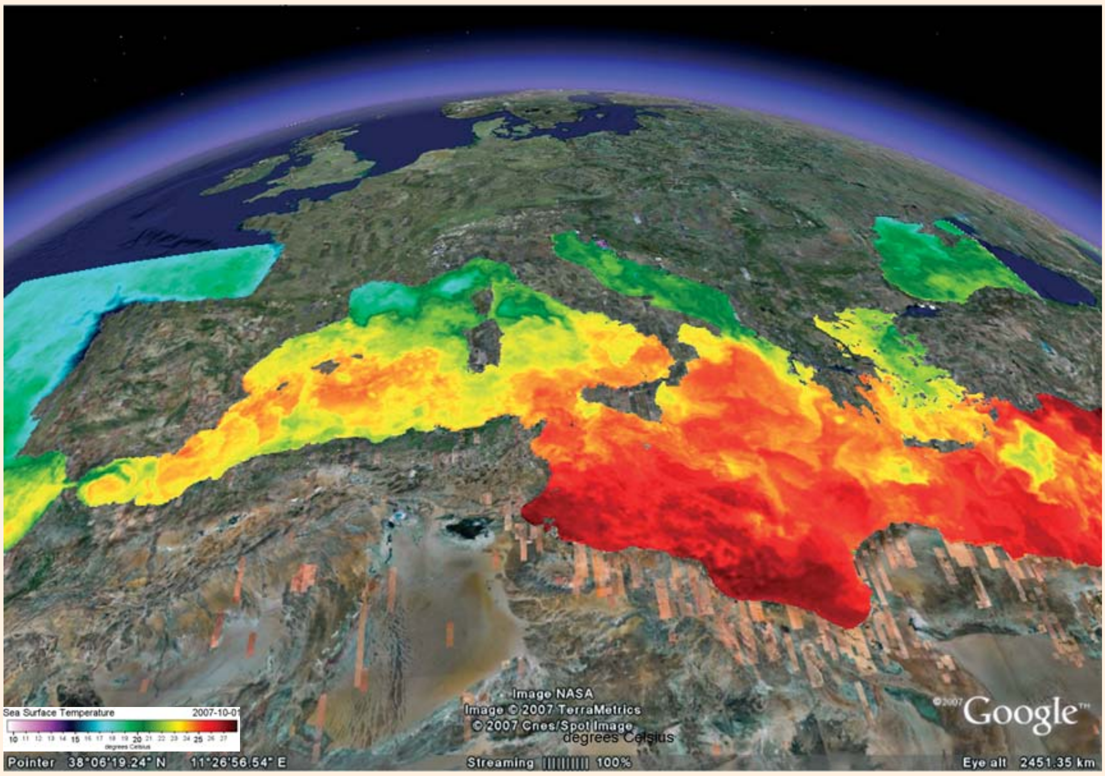
The Medspiration Project

Medspiration developed and operates a new processing system to generate near-real time L2P SST products for the Europe and Atlantic areas. These use information from Envisat's Advanced Along-Track Scanning Radiometer (AATSR), NOAA's Advanced Very High Resolution Radiometer (AVHRR), Meteosat's Spinning Enhanced Visible & InfraRed Imager (SEVIRI), Aqua's Advanced Microwave Scanning Radiometer (AMSRE) and the Tropical Rainfall Measuring Mission's TRMM Microwave Imager (TMI), following the GHRSST-PP specifications.

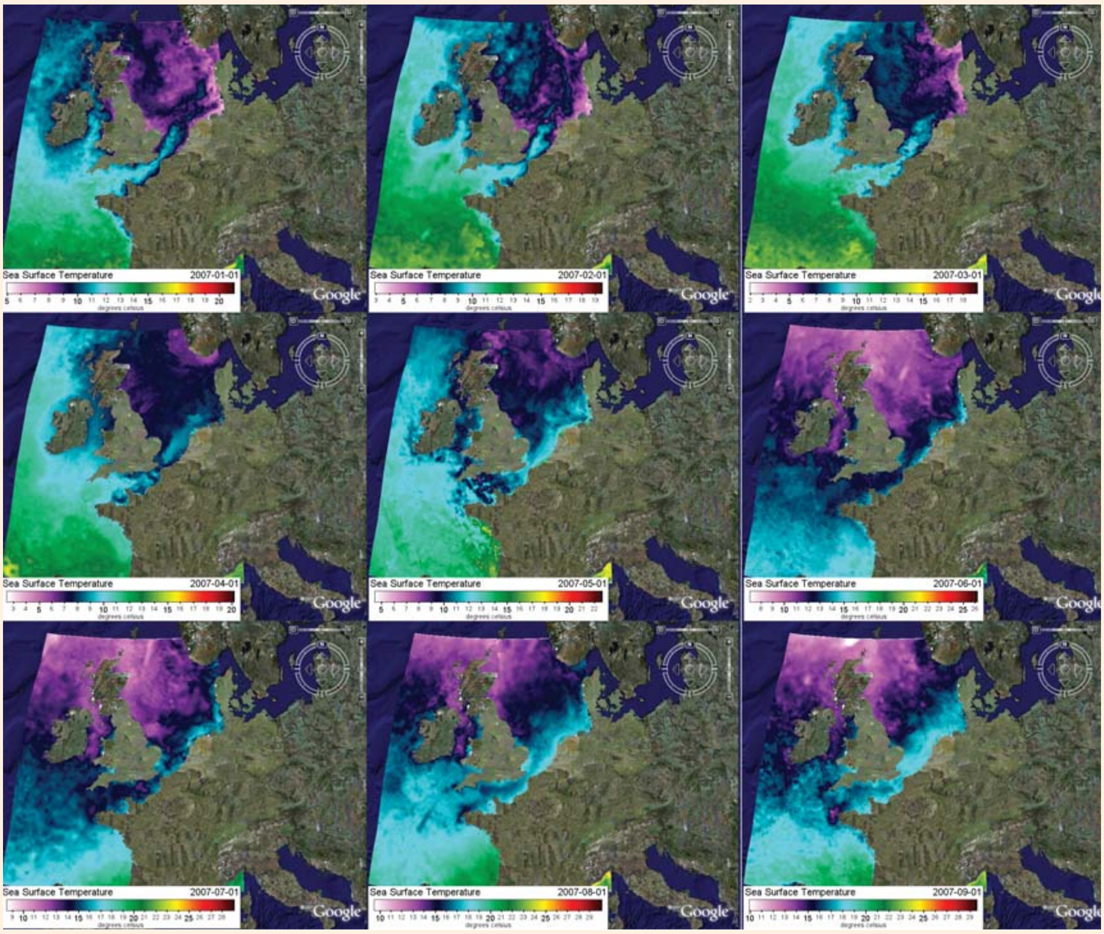
The Medspiration consortium is led by the National Oceanography Centre, Southampton (NOCS, UK), partnered with the Institut Francais de Recherce et d'Exploitation de la Mer (IFREMER, F), Météo-France, Collecte Localisation Satellites (F), Avel Mor (F), Consiglio Nazionale delle Richerche (I), Meteorogisk institutt (N) and Vega (UK).

Providing SST products since June 2005 in a uniform format has made it much easier for major users to work with data from several complementary sources and to blend them into single products.

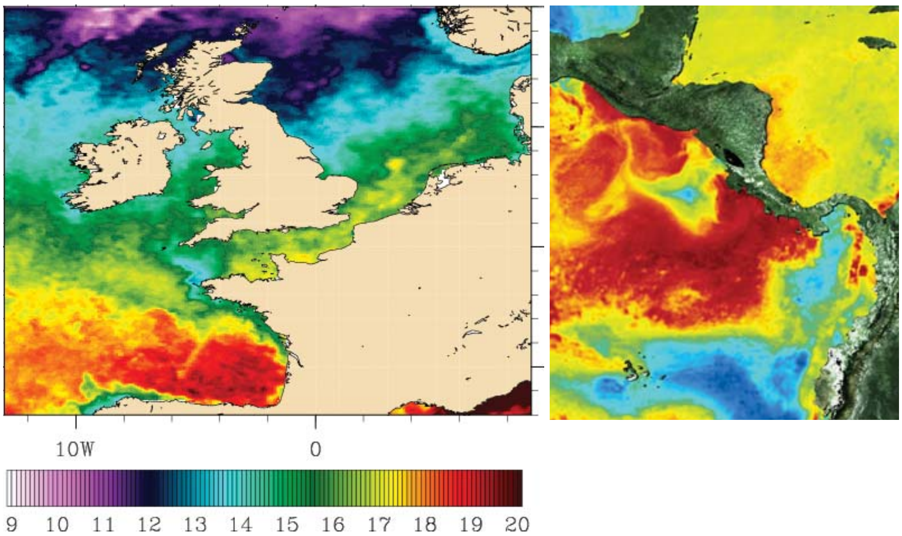
Uncertainty estimates for each SST observation is a key user requirement



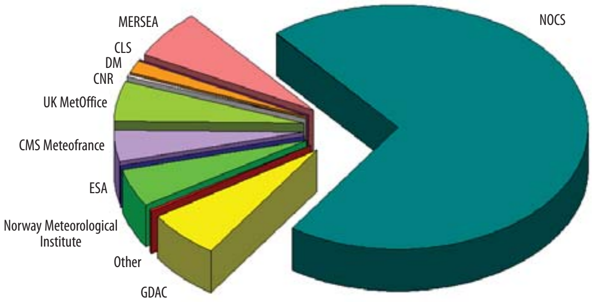
Sea-surface temperatures computed over the Mediterranean on 10 September 2007, visualised using Google Earth. Daily maps, ready for 3-D visualisation are available at http://www.medspiration.org/data_access/kml/



Time series of sea-surface temperatures (°C) computed over Europe on the first day of the January to September 2007. Daily plots of SST over selected areas are available on http://www.medspiration.org/



Sea-surface temperatures (ºC) computed over north-western Europe (left) and the Galapagos (right). Daily plots of SST over selected areas are available at http://www.medspiration.org/



Left: more than 170 GB of data are disseminated monthly to Medspiration users worldwide (shown is August 2007). Right: newspapers in Germany, Spain and Portugal have been using the information provided by the project

for these products. They allow users to select the accuracy level suitable for their application and to make optimum use of the SST observations. However, estimating the uncertainties in a particular satellite observation is a challenging task. The vast amount of observations, the highly variable characteristics of the atmosphere and the stability of the satellite instruments themselves over time are all important factors to consider.

A 'Level4 blended product' is also produced at ultra-high resolution on a 2x2 km grid for the Mediterranean Sea, Atlantic shelves and Galapagos region in the tropical Eastern Pacific Ocean. This provides the 'foundation SST' (the temperature at the highest point in the water column each day that is not affected by diurnal warming or the 'thermal skin effect' (the top 1 mm or so of oceans is cooler) as derived from all the available L2P outputs and *in situ* data, weighted and interpolated according to the characteristics and quality of each input value. The product also contains an estimate of the skin temperature and its daily variation.

In the first quarter of 2007, an average of more than 1700 L2P products were generated every month by Medspiration, with more than 460 Gb disseminated to a wide range of users, including the UK Met Office, Mercator and Meteofrance.

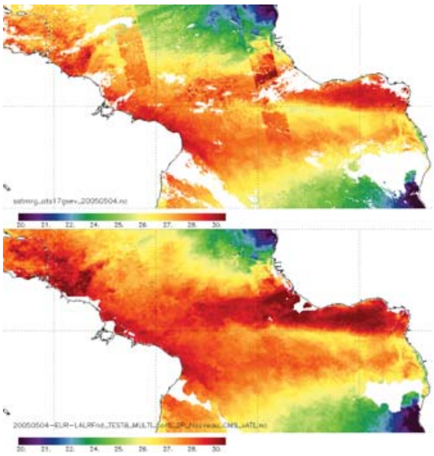
The ATSR Contribution

One of Medspiration's tasks is to convert the highly accurate Envisat/AATSR SST data into the GHRSST format and provide a near-real time demonstration service for operational users. While limited in daily global coverage because of its narrow 512 km swath, AATSR is now considered as an internationally recognised reference SST dataset thanks to Medspiration. AATSR SSTs are combined with other sources to generate daily global maps for a wide variety of ocean science applications that will ultimately lead to better weather forecasting, improved seasonal weather prediction, and stable climatologies for monitoring global change.

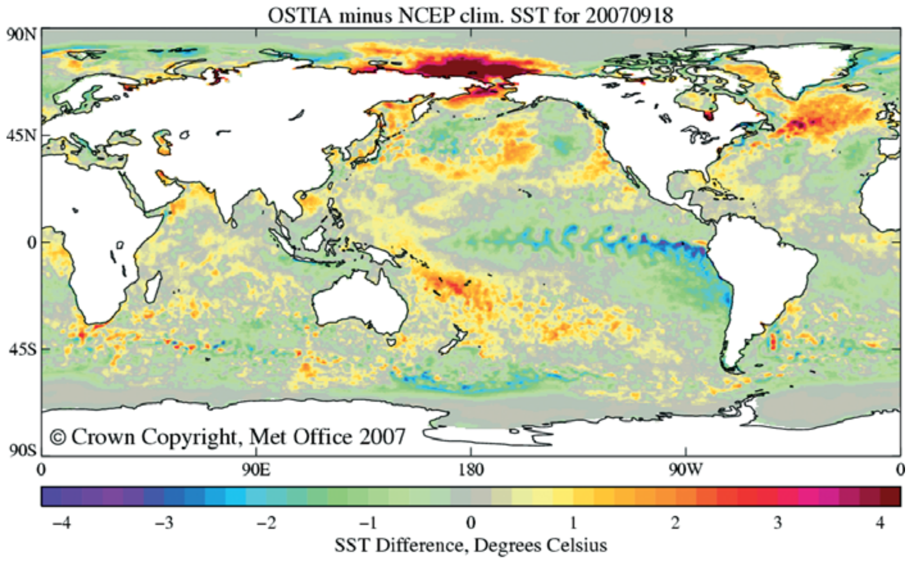
Infrared sensors at present offer the finest spectral resolution for derivation of SST. However, the SST calibration approach used over 20 years for NOAA AVHRR data is compromised by dependence on *in situ* buoy measurements that cannot eliminate the uncertainties from the unmeasured changing near-surface thermal structure of the water. AATSR's ability to look in two directions at once (as will Sentinel-3's Sea and Land Surface Temperature Radiometer) avoids this, providing a robust method for removing atmospheric effects. This allows the apparent cooling effect of Saharan dust in other IR sensors to be removed. Routine comparisons between SEVIRI and AATSR data have helped to develop a new retrieval algorithm that reduces the negative effect of Saharan dust on SEVIRI SST products.

Medspiration demonstrated that, even if AATSR coverage is less extensive than other polar-orbiting sensors for SST, its high absolute accuracy can be used as a benchmark against which bias adjustments can be made to other SST products, before being applied operationally.

By simply collating different sources of data without applying this bias correction, discontinuities appear along the boundaries between the sources. Such sharp edges are bound to corrupt the final analysis. When the bias



Exploitation of multiple assets allows bias correction and error removal. Top: Results of an SST analysis using SEVIRI, AVHRR and AATSR, when no bias correction is applied. Bottom: bias correction using AATSR as a reference standard is applied over a 5-day window



The difference between OSTIA SST and reference climatology (1985–2001) for 18 September 2007. The large SST anomaly in the Arctic Ocean is obvious: it is up to 8.5ºC warmer. Other features include the current La Nina condition in the eastern tropical Pacific Ocean, differences in the North American Great Lakes and upwelling off the north-west African coast. OSTIA data are available at http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html

adjustment to AATSR is applied, the sharp edges disappear and the temperature is raised significantly in those regions where the data were too cold. This is a far more satisfactory outcome than simply smoothing away the sharp edges. Research is continuing to optimise the choice of the time window and the averaging length scale when calculating the bias.

In Australia, the Bureau of Meteorology's BlueLink project uses AATSR instead of buoy SST data to tune the parameters in empirical algorithms for local atmospheric correction of AVHRR data. The outcome is regional maps of SST that are already bias-corrected to AATSR and which should enjoy the same improved stability as AATSR.

All the datasets produced by Medspiration are used at the Met Office in the Operational SST and Sea Ice Analysis (OSTIA; (*http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html*). OSTIA produces global SST fields at a grid resolution of 6.5 km on a daily basis taking input from SEVIRI, AATSR, AVHRR, AMSRE and TMI. In the near future, AVHRR data from the MetOp satellite will be brought on-line. In this system, Envisat AATSR SST is used as a reference dataset to which all other satellite SST datasets are adjusted. Owing to the exceptional stability and accuracy of the AATSR SSTs, there is significant impact on the analysis in areas where no *in situ* observations are available, as in the Southern Ocean. This approach proved particularly important for determining the spatial structure of the AMSRE biases in the Southern and Arctic Oceans.

OSTIA is used to track temperatures in the Arctic area, showing them to have been exceptionally high in the summer of 2007. The unprecedented retreat of sea ice in the Arctic region since June 2007 and the large open water area in the Chuckchi and Beaufort Seas have resulted in unprecedented SST values in this region: more than 10ºC above the 1985–2001 computed values.

Higher SSTs are a consequence of thermal stratification in the surface ocean enhanced by predominant high-atmospheric pressure (typically low winds and clear skies) and more buoyant freshwater from melting ice and rivers. Warm southerly winds from the Gulf of Alaska increased the ice melt and freshwater input, while also pushing the sea ice polewards.

Sentinel-3 and the Marine Core Service

Medspiration has been instrumental in providing advanced integrated SST data products in a mature service that allows operational systems to develop new products, such as OSTIA, with confidence. At the outset, a primary goal for both GHRSST-PP and Medspiration was to establish a mechanism to sustain the systems, products and services developed by them. As the user community has developed in Europe, a need for a European GHRSST-PP Global Data Assembly Centre (GDAC) and SST services has emerged based on the rapidly developing operational ocean forecasting capability of several centres. The GMES initiative has recognised the importance of ocean forecasting in Europe and called for a federated Marine Core Service (MCS) with a sustained core operation delivering fundamental analyses and forecasts of the ocean state to a wide variety of users, ranging from operational forecasting centres to local government, businesses and individual citizens.

As part of the MCS system, an SST Thematic Assembly Centre (SST-TAC) has been defined that will deliver and operate a European core service providing comprehensive SST products derived from satellite and *in situ* observations. It offers economies of scale by integration and consolidation of SST activities within Europe. The European-GDAC will work in partnership with a US GDAC to specify, monitor and deliver accurate error uncertainties for individual satellite data streams and to integrate these data in the most appropriate manner using the next generation of analysis systems. Operational solutions will ensure the timely availability of complete and accurate SST products by proper integration of Medspiration (L2P production, L4 analysis, uncertainties) capabilities, and comprehensive interaction with operational forecast systems and users.

The evolution of Medspiration and GHRSST-PP within the MCS SST-TAC system includes a significant shift in the way that European SST data-providers generate and serve SST data to the applications community. L2P datasets will, ideally, be generated by each agency at source (similar to the US and Japanese GHRSST-PP systems): ESA will continue to generate and deliver operatioal near-real time L2P data from Envisat's AATSR, and plan to follow on with Sentinel-3 from 2012 for the next 20 years; Eumetsat will continue to generate and provide L2P for Meteosat's SEVERI and MetOp's AVHRR. In this way, there is a mature shift from the demonstration spearheaded by Medspiration in Europe into an integrated and sustained operational system making optimal use of all available assets and governance systems to benefit user communities with the best SST datasets for their applications.

GHRSST-PP developed a data standardisation strategy to maximise existing data sources, facilitating their exploitation for SST and use of their peculiar characteristics. The approach has been shown to be scientifically sound and technically feasible. Through Medspiration, a much wider range of users is benefiting from AATSR data in the GHRSST-L2P format. AATSR, thanks to its excellent accuracy, is becoming a SST reference standard for operational ocean and weather forecasting agencies. The heritage of the ATSR-class of sensors will be secured by the GMES Sentinel-3 mission, providing global SST to within 0.3ºC and 1 km.

New Opportunities for ESA's Redu Ground Station

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ESA's Redu ground station in 2005.
Inset: Redu when it opened in 1968

ESA's Redu ground station in Belgium has been operated since 1 July 2007 by Redu Space Services (RSS), a company made up of SES Astra and Verhaert Space. The change is significant: RSS is not only operating the station, it is also explicitly tasked to bring in new business. A very healthy future beckons for Redu as the ESA Centre of Excellence for telecommunications, navigation, in-orbit testing services and in-orbit technology demonstration.

Introduction

Since 1968, ESA's Redu ground station, on the edge of woodland in the depths of the Ardennes countryside in Belgium, has tracked a wide range of satellites. Over the years and the succession of ESA missions, the team of engineers and technicians has seen the number of antennas grow and the activities encompass telecommunications, technology demonstrations and navigation satellites.

On 1 July 2007 a new phase began in Redu's history: a contract was awarded to Redu Space Services S.A. to operate the station. In addition to continuing the present maintenance and operation activities, the contract includes commercial efforts to optimise the use of resources and to ensure a stable future for the station and its staff.

The contract introduces a new approach to operating a facility, increasing the managerial and technical responsibilities of the contractor for third-parties activities, leaving ESA to concentrate on its core business. Instead of the previous approach of providing manpower, the contractor now provides individual services under the Agency's supervision. This approach is already typical in the business world, and it should yield increased flexibility and efficiency for both ESA and RSS.

Redu's History and Activities

Europe was taking shape in the 1960s, a process that began reaching into space as it set about developing and deploying satellites for science and technology missions. This involved building up a worldwide network of stations for monitoring and controlling the satellites and receiving data from them. The Redu site in the Luxembourg district of Belgium is in a natural basin of 19 hectares, well away from the radio interference of inhabited areas. As a mark of its first steps into space, the 'stop' sign at the entrance to the station requested vehicles to turn off their engines whenever a satellite was transmitting!

Today, the site includes 2500 m^2 of operations and administration buildings, a redundant power supply, fibre-optic connectivity, security, services, fire

detection/prevention, a canteen and utilities. A 15 m-diameter S-band dish and a 13.5 m Ka-band dish are the largest on the site. Seven 4–9 m S-, L-, Ku- and Ka-band antennas are used for testing satellite transponders, while eight others are used for tracking, telemetry & control and as backups for telecommunications satellites. These assets are maintained and operated by technicians supported by a Radio Frequency Laboratory and test and operational facilities.

Since 1 January 1968, when the station was declared operational, Redu has supported three basic elements: demonstration missions, telecommunication programmes and commercial activities. They included Europe's first scientific satellites (the ESRO, HEOS and GEOS series), first weather satellites (Meteosat-1 and -2) and first telecommunications satellite (Orbital Test Satellite, OTS).

The success of OTS, in 1978 led directly to the development of the European Communication Satellites (ECS) and the creation of Eutelsat. Eutelsat became an intergovernmental entity to operate Europe's first regional satellite system on behalf of, at the time of privatisation in July 2001, the participating states. Under a 10-year agreement, ESA provided the first-generation satellites for Eutelsat, which became the owner of each one after the in-orbit testing performed by Redu. The ESA station also housed the control centre. The last ECS satellite was handed over in 1988 and operated until 1 December 2002, when the final command was sent from Redu to shut it down.

During this period, Redu also took control of Marecs-B2, providing the payload operations control centre for Olympus and supported telecommunications satellites for other entities.

Telecommunications and Navigation

Communications satellites are complex assemblies of hardware and electronics. Before reaching their final position in geostationary orbit, they have to endure very harsh treatment on the rockets that propel them into space. So checking that their performance has not suffered is important once they have arrived in orbit.

However, precisely measuring the characteristics of a piece of communication equipment floating in space 36 000 km away is not easy. The techniques have little in common with those used in test chambers – they require ground stations designed for that

purpose and built with care. Since the mid-1970s, ESA has developed the tools and knowhow at Redu to test its own telecommunications satellites in orbit and offer the service to other organisations and private companies. This expertise is widely recognised in Europe. Redu's In-Orbit Test (IOT) facilities are also used to check that the performance of ground stations for major telecommunications operators meet requirements.

The Galileo project has found in Redu the expertise and facilities for IOT of its navigation satellites. Redu has already been involved in the in-orbit testing of the GIOVE-A experimental navigation satellite, and will host ESA's IOT facilities for GIOVE-B.

Redu's telecommunications background is being fully exploited for Artemis, ESA's Advanced Relay and Technology Mission Satellite, launched in 2001 to demonstrate new techniques, principally for data relay and mobile services. Redu is in charge of the Artemis Payload Mission Control Facility and of the 'PASTEL' unit for the optical link between Artemis and the Spot-4 satellite. ESA has been involved in industry activities such as the airborne laser optical link experiment with Artemis in December 2006.

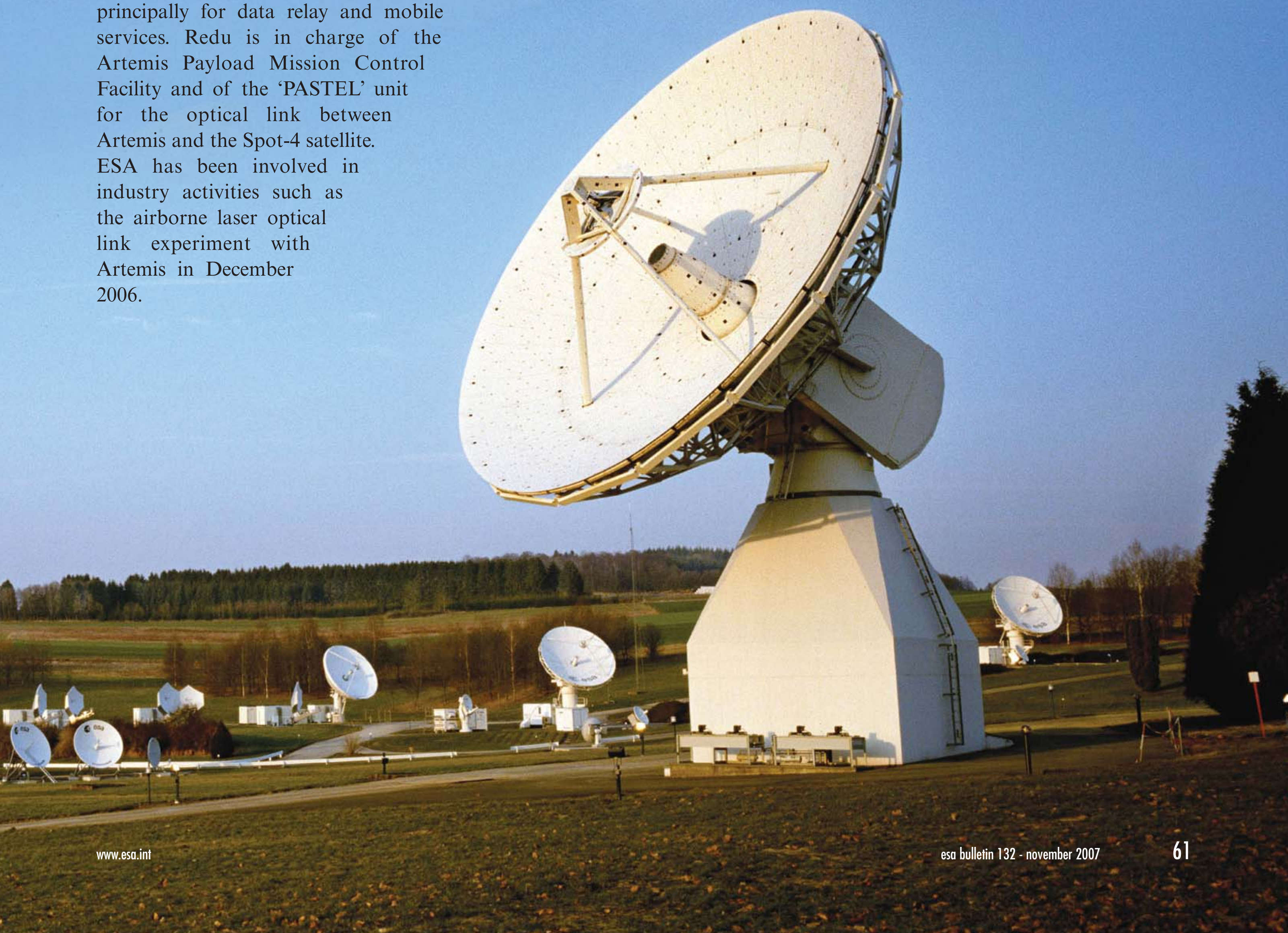
Proba and In-Orbit Demonstrations

Redu's 15 m S-band antenna was added in the 1990s for commanding and tracking scientific missions. It is extensively used for ESA's Integral gamma-ray observatory, launched in 2002.

The expertise acquired from controlling the ECS satellites made Redu the ideal site for routine operations of ESA's small, low-cost Proba satellites. Proba-1 validated new spacecraft autonomy and 3-axis control and data system technology. Its main payload is the novel CHRIS imaging spectrometer, provided from an announcement of opportunity to scientists. Launched on 22 October 2001, its mission was initially planned to last 2 years but its 5th birthday and its success in providing Earth observation data to the scientific community were celebrated at Redu in 2006. Operations continue. The Proba-2 technology and solar mission will follow in 2008, with the Proba-3 first demonstration of formation-flying in 2011. Others will follow, with Redu as their natural centre for in-orbit demonstrations.

Commercial Activities and Evolution

From its opening in 1968, Redu was part of ESA's ESTRACK Network, linked to the ESOC Mission Control Centre in Germany and under the responsibility of the Director of Operations. Today's activities and the link with commercial entities led to the overall responsibility



for the station being transferred on 1 January 2007 to the Director of Telecommunications and Navigation.

As a result of a number of ESA internal reviews, which analysed Redu's programmatic situation, the state of investments, its cost structure and the projected range of activities into the mid-future, the decision was taken to aim for increased commercial use at the same time as satisfying ESA's needs. Several major European operators and service companies answered the Call for Opportunity.

Finally, the contract was awarded to Redu Space Services S.A., a joint venture between SES Astra TechCom Belgium S.A. and Verhaert Space N.V, the Belgian company that provides the Proba platforms. The contract allows RSS to offer new commercial services from Redu, thereby increasing usage of the ESA facilities and optimising the resources in place for the common benefit of ESA and the operator. Redu remains an ESA station, under clear conditions for both parties. This contract is a real opportunity to increase usage by many commercial customers under a no-discrimination basis, thereby increasing the economic value of the station for the region.

ESA is looking for strong cooperation with RSS to create synergies and to ensure a good future for the station and its staff. Redu now has a good opportunity to expand, to develop and promote applications serving society. The station's future no longer depends entirely on ESA programmes, but can also be built on new commercial ventures.

Conclusions

Approaching its 40th birthday, Redu is facing the new challenge of responding to the evolution of the telecommunications and navigation markets from public to private companies. The new contract also marked the end, on 1 July 2007, of an almost-25 year contractual engagement with Vitrociset, who had been in charge of maintenance and operation during that time. ESA is thankful to Vitrociset and recognises not only a long and professional involvement in the ground station but also its cooperation in ensuring the quick and full takeover of the station personnel by RSS.

Soyuz at the European Spaceport

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In the spring of 2009, a Russian Soyuz rocket will ascend from the European Spaceport, the Centre Spatial Guyanais (CSG) in French Guiana, for the first time. Soyuz will complement Europe's launcher family of Ariane-5 and Vega. The 'Soyuz at the CSG Programme' is a key element in the strategic partnership between ESA and the Russian space agency. The programme encompasses building the new launch facility at CSG, adapting the vehicle to withstand the tropical conditions in French Guiana, and participating in the development of an improved third stage.

Introduction

ESA and Roskosmos, the Russian space agency, have a long-term partnership for the development and operation of launch vehicles. The 'Soyuz at the CSG Programme' is a key element, with important benefits for both Western Europe and Russia. Their industries have joined forces to face the fierce competition in the world's launch services market.

The Earth's rotational speed at the CSG, located 5ºN of the equator, increases the Soyuz payload capacity to

The Soyuz launch site

geostationary transfer orbit (GTO) by almost half in comparison to the Baikonur Cosmodrome in Kazakhstan.

As a medium-size vehicle, Soyuz will perfectly complement Europe's operational Ariane-5 heavy-lift launcher and the upcoming small Vega. From CSG, Soyuz will carry major European research and applications missions, including the Galileo constellation of navigation satellites.

While targeting primarily satellite missions, Soyuz offers the growth potential for manned flights from CSG, should that political decision be taken in the future.

Programme Scope and Partners

The 'Soyuz at the CSG Programme' began in 2004 to exploit launches to a variety of orbits, including GTO, Sun-Synchronous Orbit and Medium Earth Orbit. The programme has three main elements:

- the construction of a new launch site in the community of Sinnamary, French Guiana.
- the adaptation of Soyuz to handle the different flight and range safety requirements, the climate and the interfaces with the existing ground segment at CSG.
- European participation in developing the Soyuz 2-1b version, featuring a third stage offering improved performance.

The overall cost of the programme is €344 million (2002 terms). €223 million is being funded by seven ESA Member States (Austria, Belgium, France, Germany, Italy, Spain, Switzerland) and the European Union, through its 6th Framework Programme and the Trans-European Network. Arianespace, the Soyuz operator at CSG, is providing the remaining €121 million through a loan from the European Investment Bank.

During the development phase, from 2004 to spring 2009, the roles of the major partners are:

- ESA is responsible for the overall management of the programme;
- Roskosmos is in charge of activities within the Russian Federation;
- the Launcher Directorate of CNES is ESA's main contractor as System Architect, in charge of development, and responsible for both European and Russian activities;
- CNES is also responsible for range and flight safety at CSG by delegation of the French government;
- Arianespace is in charge of the Russian activities and will be the commercial operator.

The key Russian companies are:

- TsSKB-Progress, the Soyuz designer and manufacturer, in Samara.
- NPO Lavotchkin, in Moscow, the designer and manufacturer of the Fregat upper stage.
- KBOM, in Moscow, responsible for all Russian ground equipment in the launch zone.

Soyuz ST Launcher

Soyuz is the most reliable workhorse in Russia's launcher fleet. In its different versions, it has flown almost 1800 successful missions, from the world's first satellite in October 1957 and the first manned flight in 1961, to manned and unmanned ferry missions for the International Space Station.

The Soyuz-ST version for CSG is based on the Soyuz-2 developed by TsSKB-Progress within the Russian Federal Space Programme. Soyuz-ST has three main stages using kerosene and liquid oxygen as propellants.

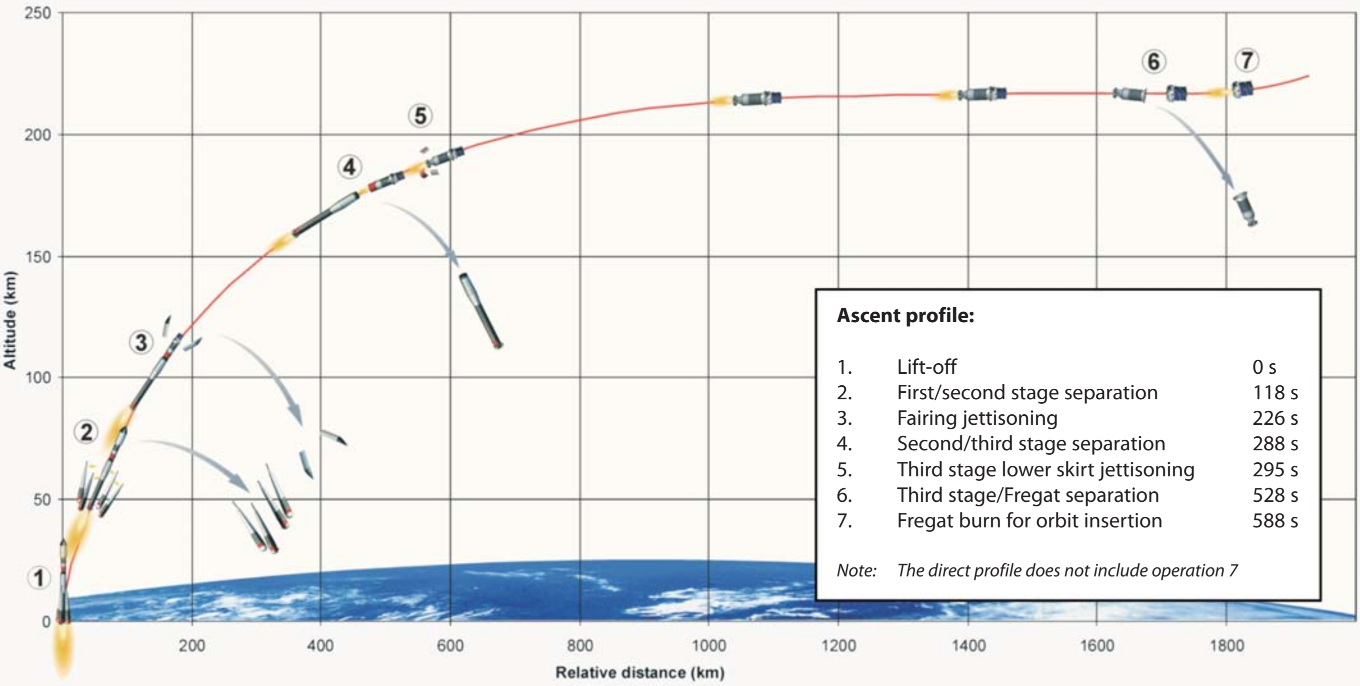
The first stage comprises four strap-on boosters, referred to as Block B, V, G and D. Each has a length of 19 m, a diameter of 2.68 m, a gross mass of 44.2 t and a dry mass of 3.8 t, powered by an RD-107A engine with four chambers and nozzles. The thrust per engine at lift-off is 838 kN.

The Block A second, core, stage also ignites for launch. Its length is 28 m, diameter 2.95 m, gross mass 101.9 t and dry mass 6.9 t. Its RD-108A engine with four chambers and nozzles delivers 792 kN at lift-off.

The Block I third stage has a length of 6.7 m, a diameter of 2.66 m, a gross mass of 25.2 t and a dry mass of 2.4 t. The RD-0110 engine provides 298 kN.

The 'upper composite' on top of Block I consists of the Fregat storable-propellant reignitable upper stage, which also provides 3-axis stabilisation and spin-up to the payload, the payload fairing (11.4 m long and 4.11 m diameter) and the payload itself.

There are two versions of Soyuz-2. The Soyuz 2-1a features an advanced digital command and telemetry system, and upgraded injector heads in the first and second stage engines. Its maiden flight came on 8 November 2004 from the Plesetsk Cosmodrome in northern



Above: the ascent profile of Soyuz for a typical GTO mission has seven main steps

Below: the mobile gantry and launch table

Russia. It carried ESA's MetOp satellite from Baikonur on 19 October 2006, and the Meridian satellite from Plesetsk on 24 December 2006.

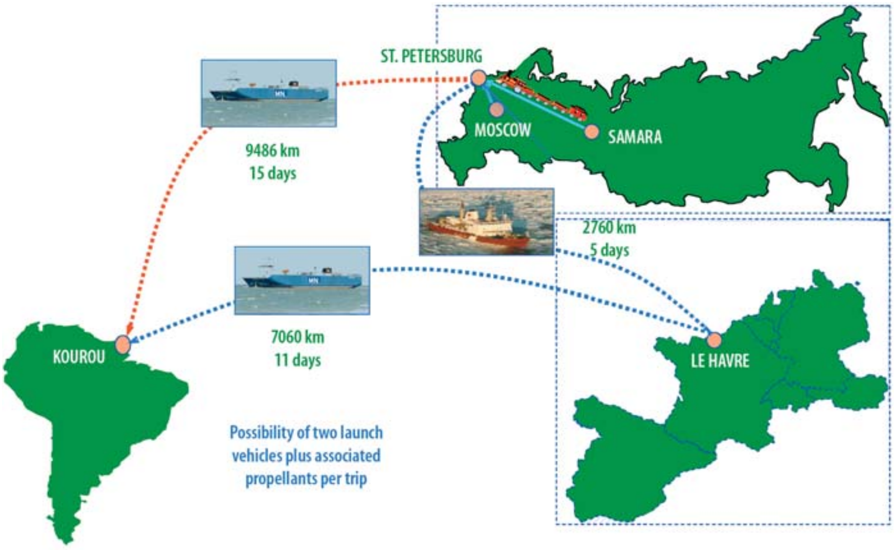
The newer Soyuz 2-1b uses the more powerful RD-0124 third stage engine. Its first flight, on 27 December 2006 from Baikonur, carried the CNES COROT astronomy mission.

Soyuz-STa (with the RD-0110 stage-3 engine) will be able to deliver 2730 kg into GTO, and 4450 kg in Sun-synchronous orbit (660 km altitude, 98.1° inclination). The more powerful Soyuz-STb (RD-0124 stage-3 engine) will be able to handle 3060 kg and 4900 kg, respectively.

Specific adaptations were required for Soyuz-ST to fly from French Guiana. It must cope with the tropical climate (especially the high humidity) and the salty sea-air, as well as meeting new flight and range safety rules. The boosters are equipped with valves to ensure they sink in the Atlantic. The launcher also features new S-band telemetry systems. The automatic emergency flight termination system has been been extended to allow manual command from the ground. The existing 'AVD' onboard system detects critical anomalies and automatically commands a rapid engine shutdown by closing the main engine valves. CSG safety rules demand that emergency engine shutdown can also be ordered by ground controllers.

The command is routed via the 'European Safety Kit', developed in Europe from the Ariane-5 original. It receives the ground order and channels

Construction of the launch pad



How all the elements reach CSG

it into the Soyuz-ST command system. In addition, its radar transponders are used for tracking the vehicle, to ensure that the correct course is being followed.

The Soyuz Launch Site

The Soyuz-ST launch area is situated on the north-western part of CSG, about 27 km from the town of Kourou and 18 km from the community of Sinnamary.

The site has 17 building complexes within an area of 120 ha. Teams of up to 350 European workers dug out around a million cubic metres and began constructing the main buildings in early 2005. They will be ready by the end of this year, before the arrival of the Russian teams and equipment early next year.

The main buildings comprise:

– the pad itself, a multi-floor launch table sitting on a 200 000 m^3 flame trench, protected by four lightning towers and equipped with powerful water pumps to remove any rain water before lift-off.
– the launcher integration building (MIK, after the Russian acronym), in the preparation zone, allowing the horizontal integration, preparation and test of the three stages;
– the launch control centre, a 420 m^2 three-storey all-concrete building for launch monitoring and command, protects the teams against explosions and falling debris during countdown and launch;
– storage for air, nitrogen and helium;
– power generation and air-conditioning;
– the kerosene storage area;
– the liquid oxygen storage area;
– storage for hydrogen peroxide, which powers the turbo-pumps of the Soyuz first- and second-stage engines.

The mobile servicing tower is specifically designed for Soyuz at CSG. It is a major improvement over the Baikonur and Plesetsk facilities, as it protects Soyuz from the climatic conditions in French Guiana and allows the vertical integration of the upper composite. The gantry retreats from the Soyuz shortly before launch powered by its own four electric motors.

Operations

Soyuz is built, integrated and tested at TsSKB-Progress in Samara, Russia, while the Fregat upper stage is produced at NPO Lavotchkin in Moscow. Both are transported by rail in protective containers to St Petersburg's harbour, where they are transferred to a roll-on/roll-off vessel for shipping to Kourou's Pariacabo harbour.

At Kourou, the containers are taken by lorry to the launch site. The 3-stage vehicle is integrated horizontally and tested in the MIK and then rolled out horizontally to the pad by rail, where it is raised to the vertical. The mobile gantry is then moved around it for protection from the climatic conditions and to begin the final launch preparations.

In parallel, Fregat is prepared in the MIK building for the journey by road to the S3B building in CSG's existing Payload Preparation Complex, where it is filled with propellants (unsymmetrical dimethyl hydrazine, UDMH; and nitrogen tetroxide, NTO) and then mated vertically to the satellite and fairing. Four days before launch, this upper composite travels to the launch zone, where it is lifted to the gantry's upper platform by a special crane and mated with the vehicle. During all of these operations, the payload is kept under controlled environmental conditions.

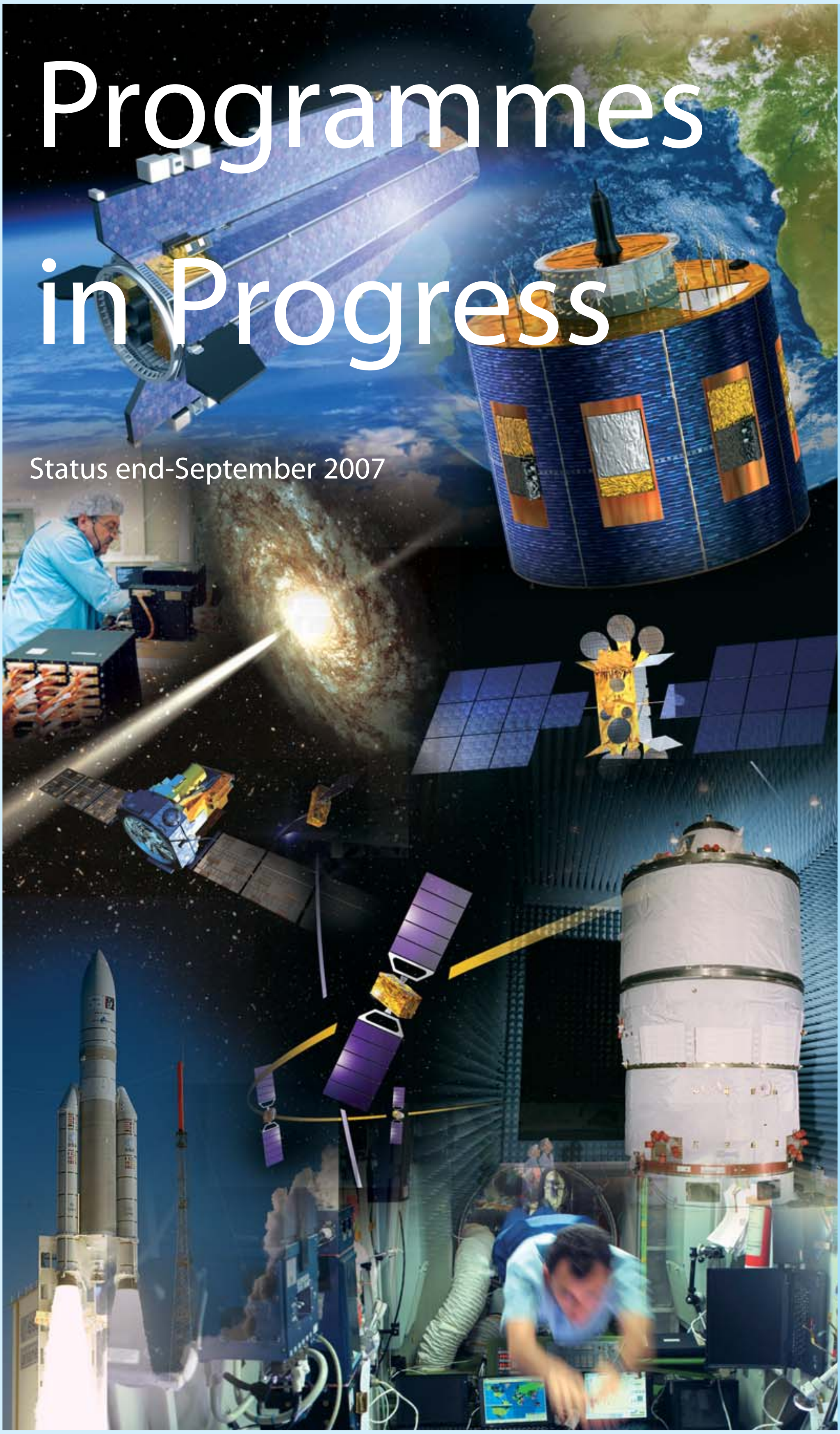
A few hours before launch, Soyuz is filled with propellants while the mobile gantry is still in place. About an hour before launch, the gantry moves to its rear position around 80 m away for safety. During lift-off, the gantry's large gates remain open to reduce acoustic reflections back to the Soyuz and to limit pressure loads on the gantry structure.

Summary

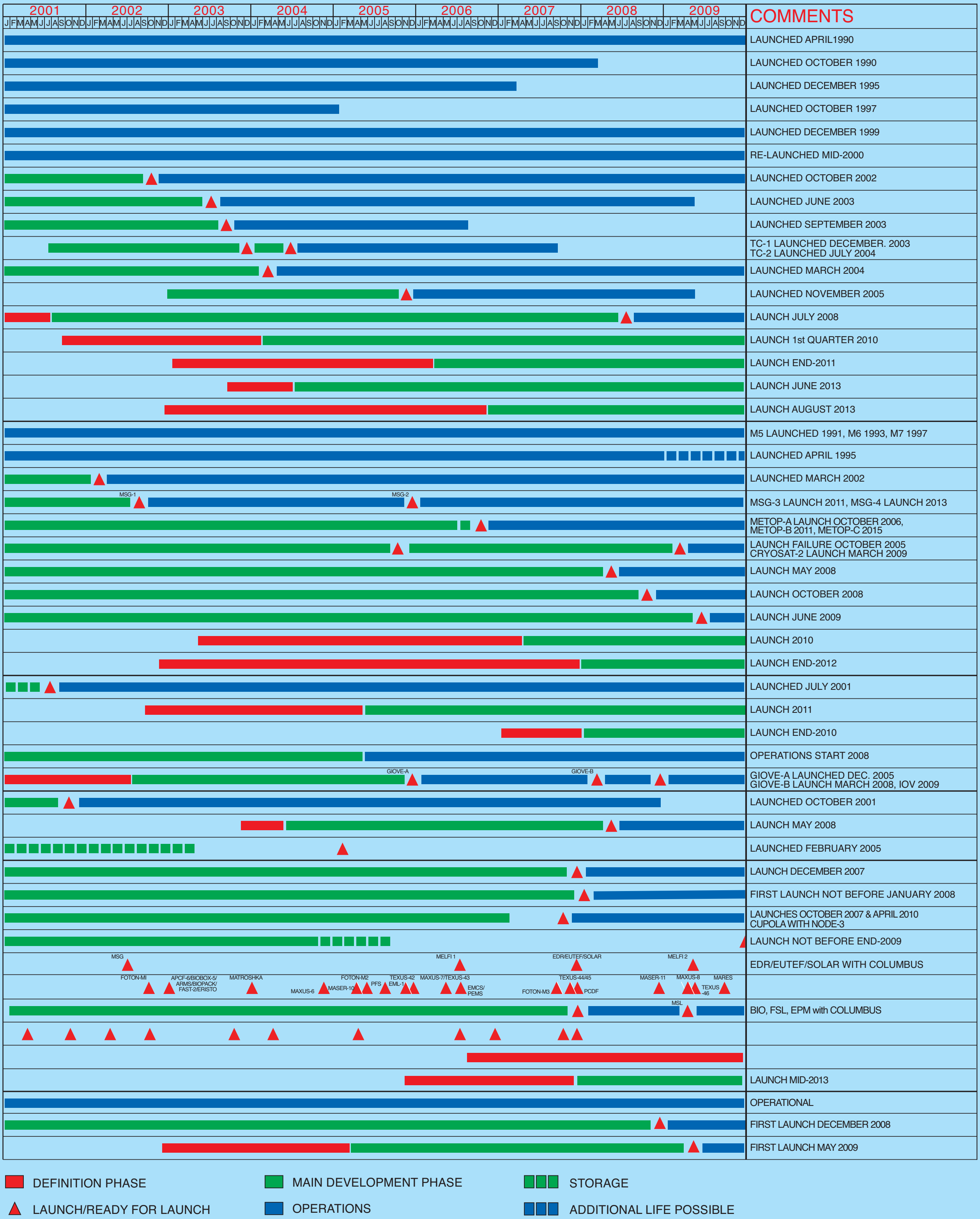
The 'Soyuz at the CSG Programme' is well under way to ensure the first launch of the Soyuz-ST from the European Spaceport in spring 2009. The European facilities and buildings will be completed on schedule by the end of 2007 before the arrival of the mobile gantry and the first Russian teams and equipment. The period from early 2008 to spring 2009 will see the arrival, assembly and testing of all the Russian equipment and the technical and operational qualification of the facilities. The first launch campaign under the responsibility of Arianespace, the future operator, is expected to take place in March 2009 before a gradual build-up to two to four flights per year.

Programmes in Progress

Status end-September 2007



	PROJECT
SCIENTIFIC PROGRAMME	SPACE TELESCOPE
	ULYSSES
	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
	ERS-2
	ENVISAT
	MSG
	METOP
	CRYOSAT
	GOCE
	SMOS
	ADM-AEOLUS
	SWARM
	EARTHCARE
COMMS./NAV. PROGRAMME	ARTEMIS
	ALPHABUS
	SMALL GEO SAT.
	GNSS-1/EGNOS
	GALILEOSAT
TECHNOL. PROG.	PROBA-1
	PROBA-2
	SLOSHSAT
HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME	COLUMBUS
	ATV
	NODE-2 & -3 & CUPOLA
	ERA
	ISS BARTER & UTIL. PREP.
	EMIR/ELIPS
	MFC
	ASTRONAUT FLT.
	AURORA CORE
	EXOMARS
LAUNCHER PROG.	ARIANE-5
	VEGA
	SOYUZ AT CSG


2001 2002 2003 2004 2005 2006 2007 2008 2009
COMMENTS
LAUNCHED APRIL1990
LAUNCHED OCTOBER 1990
LAUNCHED DECEMBER 1995
LAUNCHED OCTOBER 1997
LAUNCHED DECEMBER 1999
RE-LAUNCHED MID-2000
LAUNCHED OCTOBER 2002
LAUNCHED JUNE 2003
LAUNCHED SEPTEMBER 2003
TC-1 LAUNCHED DECEMBER. 2003
TC-2 LAUNCHED JULY 2004
LAUNCHED MARCH 2004
LAUNCHED NOVEMBER 2005
LAUNCH JULY 2008
LAUNCH 1st QUARTER 2010
LAUNCH END-2011
LAUNCH JUNE 2013
LAUNCH AUGUST 2013
M5 LAUNCHED 1991, M6 1993, M7 1997
LAUNCHED APRIL 1995
LAUNCHED MARCH 2002
MSG-1
MSG-2
MSG-3 LAUNCH 2011, MSG-4 LAUNCH 2013
METOP-A LAUNCH OCTOBER 2006,
METOP-B 2011, METOP-C 2015
LAUNCH FAILURE OCTOBER 2005
CRYOSAT-2 LAUNCH MARCH 2009
LAUNCH MAY 2008
LAUNCH OCTOBER 2008
LAUNCH JUNE 2009
LAUNCH 2010
LAUNCH END-2012
LAUNCHED JULY 2001
LAUNCH 2011
LAUNCH END-2010
OPERATIONS START 2008
GIOVE-A
GIOVE-B
GIOVE-A LAUNCHED DEC. 2005
GIOVE-B LAUNCH MARCH 2008, IOV 2009
LAUNCHED OCTOBER 2001
LAUNCH MAY 2008
LAUNCHED FEBRUARY 2005
LAUNCH DECEMBER 2007
FIRST LAUNCH NOT BEFORE JANUARY 2008
LAUNCHES OCTOBER 2007 & APRIL 2010
CUPOLA WITH NODE-3
LAUNCH NOT BEFORE END-2009
MSG
MELFI 1
EDR/EUTEF/SOLAR
MELFI 2
EDR/EUTEF/SOLAR WITH COLUMBUS
FOTON-M1
APCF-6/BIOBOX-5/
ARMS/BIOPACK/
FAST-2/ERISTO
MATROSHKA
MAXUS-6
MASER-10
FOTON-M2
PFS
TEXUS-42
EML-1
MAXUS-7/TEXUS-43
EMCS/
PEMS
FOTON-M3
TEXUS-44/45
PCDF
MASER-11
MAXUS-8
TEXUS
-46
MARES
MSL
BIO, FSL, EPM with COLUMBUS
LAUNCH MID-2013
OPERATIONAL
FIRST LAUNCH DECEMBER 2008
FIRST LAUNCH MAY 2009
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
STORAGE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE

HST

HST is operating normally after recovery from the safing event on 31 August. It entered the 'Zero Gyro Sun Point' safe mode following the failure of gyro-2, which had accumulated more than 57 000 h of run time – well above average. Gyro-6 was successfully turned on, and scientific operations resumed. The observing efficiency remains high, at about 54%.

Activities continue in preparation for Servicing Mission 4 (SM4), planned for August 2008. The astronauts will also attempt to repair the Space Telescope Imaging Spectrograph, which failed in August 2004, and the Advanced Camera for Survey (ACS), which failed in early 2007. The ACS repair passed its Critical Design Review (CDR) in early October 2007.

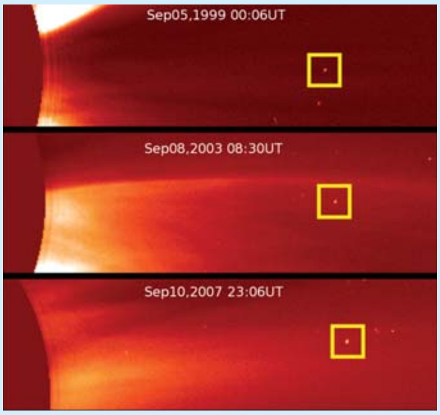
A Workshop is being planned in Bologna (I) on 29–31 January 2008 to raise awareness of the expanded scientific capabilities of HST after SM4. The goals of the workshop are: to inform the general astronomical community of the exciting scientific opportunities of the refurbished HST for UV to near-IR imaging and spectroscopy; to provide insight into (and detailed information on) the new HST imaging and spectroscopic capabilities and characteristics as well as general information about the mission; to provide more detailed information about initial calibration observations, the Cosmic Origins Spectrograph (COS) Guaranteed Time observing programmes and plans for Early Release Observations and Early Release Science with both COS and Wide-Field Camera-3; to provide future guest observers with details of observation planning, data reduction and data products and archiving. The workshop is being sponsored by INAF, in collaboration with ESA and NASA (STScI and ST-ECF). Additional information on this Workshop can be found at *http://www.iasfbo.inaf.it/bawhst/*

Ulysses

A recent analysis of an unusual energetic particle event in September 2004, observed both at Ulysses (then 5.4 AU from the Sun) and at 1 AU, provided new insights into the role played by complex solar wind structures in shaping the time-intensity profiles of such events. This has implications for the commonly-used models of particle propagation that are based on diffusion and convection. A 'roadmap' of solar wind/magnetic field data acquired during the recent perihelion passage was compiled by the Project Scientists to assist the other Principal Investigator teams in interpreting their observations. The latest science results from the current pole-to-pole transit were discussed at the 58th Ulysses Science Working Team meeting, held at the University of New Hampshire (USA) on 9–10 October.

SOHO

With more than 1350 comet discoveries already to its credit, SOHO for the first time found a rare periodic comet. Only around 190 of the thousands of comets seen by astronomers are classified as periodic. The credit for discovery and recovery of the comet goes to Terry Lovejoy (Australia, 1999), Kazimieras Cernis (Lithuania, 2003) and Bo Zhou (China, 2007).



Comet P/2007 R5 (SOHO): for the first time, SOHO's LASCO instruments has found a periodic comet, which flies by the Sun at regular intervals. While many SOHO comets are believed to be periodic, this is the first one that has been conclusively proved and officially declared as such. (ESA/NASA/SOHO)

Two very successful SOHO workshops were held over the summer: SOHO-19 on 'Seismology of Magnetic Activity' at Monash University, Melbourne (AUS); and SOHO-20 on 'Transient Events on the Sun and in the Heliosphere' in Ghent (B). The papers will be published in special issues of *Solar Physics* and *Annales Geophysicae*, respectively.

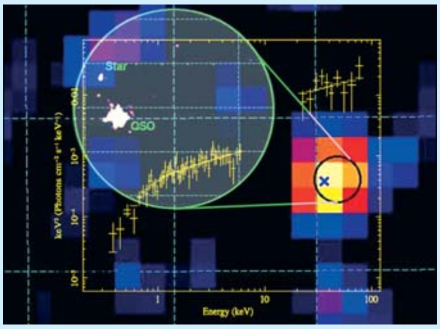
A SOHO/EIT image was prominently featured on the cover of the 13 August issue of *Newsweek* magazine.

Cassini-Huygens

Repeated observations of Titan's surface at northern latitudes by the Cassini radar led to the interpretation that the position of Titan's pole is changing and the moon's spin is varying owing to the variation of the momentum exchange between its atmosphere and surface. These results give further evidence of an ocean layer of liquid water/ammonia under the icy crust of Titan that decouples the crust from Titan's core. It affects the precise knowledge of the coordinates of the Huygens landing site in an as-yet unknown way.

A mosaic of Titan high northern latitude radar images was released in mid-October. In recent months, Cassini has been moving progressively over Titan's southern hemisphere. During the Titan flyby of 2 October 2007, Cassini's radar imaged the surface at southern latitudes. The next few radar passes should bring the craft closer to the south pole. These future observations are expected to reveal whether lakes or seas of liquid hydrocarbons are as prevalent there as they are at the north pole.

Spectacular observations of Saturn's moon Iapetus were obtained during a low-altitude flyby in early September. High-resolution images of the boundary between the dark and the wide areas were obtained. The observations are expected to provide clues as to the origin of the dark material on the surface of Iapetus.



The detection of GR J22517+2218 by Integral/IBIS. (L. Bassani, IASF-Bologna, INAF)

XMM-Newton

About 130 scientists participated in the 'XMM-Newton: the Next Decade' workshop, which helped to identify important future topics to be addressed by XMM-Newton. The proceedings will be published as a regular issue of *Astronomical Notes/Astronomische Nachrichten*.

The second XMM-Newton Serendipitous EPIC Source Catalogue, 2XMM, was released on 24 August. Constructed by the XMM-Newton Survey Science Centre on behalf of ESA, it contains 247 000 X-ray source detections, which relate to 192 000 unique X-ray sources, making it the largest catalogue of astronomical X-ray sources ever produced. The net sky area coverage is about 360 square degrees. This catalogue and associated products are supported by a new version of the XMM-Newton Science Archive.

Cluster

The Cluster mission continues to show new facets of the Earth's magnetic environment and its interaction with the solar wind. J. Rae published an article in *Journal of Geophysical Research* showing that ultra low-frequency waves are shaking the whole magnetosphere after a geomagnetic storm. A subsequent article, in *Geophysical Research Letters*, by Q. Zong showed that these waves can accelerate particles to very high energies.

Double Star

A recent study using Cluster and Double Star TC-2 data showed that the source of the aurora could be much closer to Earth than previously expected. This study showed that magnetic reconnection and its competing process, the current disruption, could happen at the same place, about 80 000 km from Earth.

Integral

GR J22517+2218 was just another unidentified object discovered with the Integral imager, IBIS. However, this time the quest for an identification turned out to be particularly rewarding. Follow-up observations with NASA's Swift Observatory identified its optical counterpart in MG3 J225155+2217, a quasar with a redshift of 3.668, the farthest object so far detected by Integral.

The image shows the detection of this new source by IBIS in the 20–100 keV band. The zoom refers to a Swift observation covering the entire Integral uncertainty region. The brightest object detected in the 2–10 keV band is indeed the high-redshift quasar. Superimposed on the image is the combined Integral/Swift spectrum over the 0.4–100 keV band (or 2–500 keV in the source rest frame).

Mars Express

The recent dust storms had strong adverse effects on the quality of the HRSC and OMEGA science data. This has a very significant science impact as these dust storms took place during conditions that were otherwise highly favourable for HRSC and OMEGA.

Mars Express Data Workshops are foreseen at ESAC (E) in 2008 to address atmospheric, ionospheric and radar data (ASPERA, PFS, SPICAM, MaRS and MARSIS). Preparations for 'The European Mars Science and Exploration Conference – Mars Express & ExoMars' (12–16 November 2007 at ESTEC) are well underway. A total of 271 accepted abstracts has been received, resulting in 125 oral presentations and 146 posters.

The latest major Mars Express papers concern OMEGA results, and are available in a special issue of the *Journal of Geophysical Research* (**112**, E8, 2007).

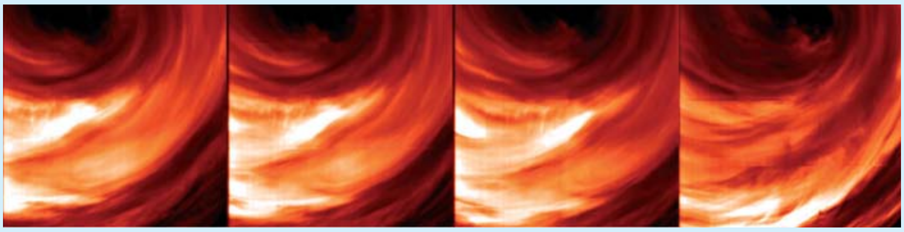
Rosetta

In preparation for the flyby of asteroid 2867 Steins in September 2008, a 3-day scientific workshop was held in Athens (GR), 23–25 October 2007. The workshop provided the opportunity for the PI teams and other representatives of the Rosetta Science Working Team to get together with other scientists of the asteroid community for the detailed scientific preparation from which the science operations requirements will be derived.

As the Rosetta target Comet 67P/Churyumov-Gerasimenko will again approach the inner Solar System in 2008/09, a workshop was arranged on 7 October 2007 to coordinate the efforts of observing the comet with ground-based telescopes during its approach. The 35 participants discussed the observational plans of various groups from Europe and the US, and collaborations were initiated. The workshop was held in conjunction with the DPS Annual Meeting to ensure that interested comet scientists from all over the world could attend and contribute.

Venus Express

Spectacular images and movies of the dynamics of the south polar vortex were produced and several very different regions with distinctly different dynamic characteristics were found, mainly by the VIRTIS and VMC instruments. The structure of the atmosphere with respect to



Venus Express views of the southern polar region, from the polar vortex (at the top) to the mid-latitude region of the lower atmosphere. The images were taken at 1.74 µm from about 60 000 km. The first three were taken at short intervals and allow detailed determination of the windfield by tracking of features. The fourth show the same region a day later, highlighting the variability in the region

temperature and density is being characterised by SPICAV and VERA (radio science), which complement each other well in terms of altitude. Maps of surface temperature, based on measurements by VIRTIS in the 1 µm spectral window, are being compared with synthetic maps based on Magellan altimetric maps and a constant lapse rate, and a programme for search of hotspots (volcanic activity etc.) started. Many minor species are being characterised at different levels of the atmosphere. SPICAV identified a new absorption line not known or in any catalogue; after a long investigation, this turned out to be an isotope of carbon dioxide, namely $C^{16}O^{18}O$. This has implications on the degree of greenhouse effect on Venus, and to some extent also on Earth.

At the time of Venus maximum elongation from the Sun, during May-June 2007, a dedicated space- and ground-based observational campaign was held, during which 16 teams of scientists around the world made coordinated studies of Venus. At the same time (5 June), the Messenger spacecraft made a swingby of Venus and took coordinated measurements with most of its instruments. A special workshop on these results will be held in ESTEC in December 2007.

Akari (Astro-F)

Akari exhausted its cryogen on 26 August 2007, reaching the pre-launch expectation of 550 days. More than 90% of the sky was covered twice by the all-sky survey. European astronomers obtained 400 pointings, i.e. exactly 10%, as in the cooperation agreement. As planned, testing of the near-IR IRC camera is underway, in view of its planned operation at non-cryogenic temperatures, in Phase-3. As requested by JAXA, support from the ESA Kiruna station continues until the planned end date of 31 October. ESAC continued to contribute to the testing of the instruments' processing pipelines, and released updated Instrument Data User Manuals, in June and September 2007. A hands-on data reduction workshop was held at ESAC 18–19 September, when seven experts from Japan helped European scientists in reducing their data with Akari processing toolkits. The mass processing with the pointing reconstruction software started at ESAC on the basis of datasets consistently pre-processed at ISAS.

Hinode (Solar-B)

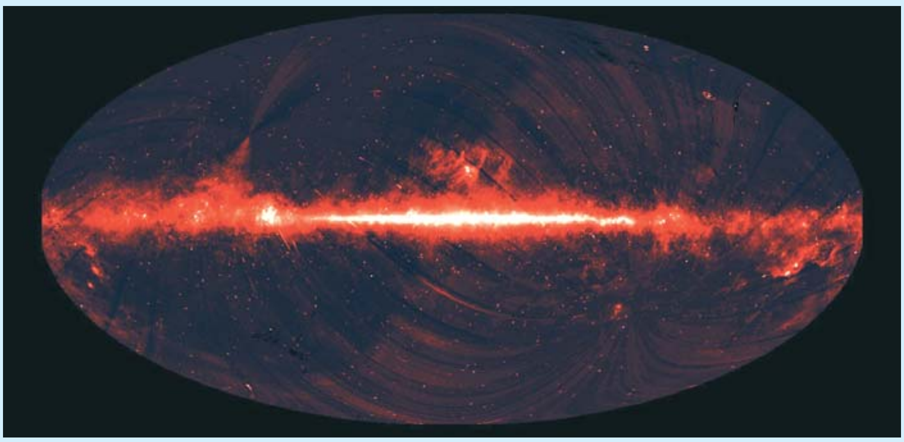
Hinode has already made several fundamental discoveries (e.g. direct observations of Alfven waves in the Sun's chromosphere; detection of ubiquitous horizontal magnetic fields in the photosphere; observations of kG fluxtubes a the Sun's poles). These and other results will be published in a special issue of *Science* magazine, to which 16 articles have been submitted. In addition, there will be a special issue in *PASJ* comprising some 40 early results papers from Hinode.

On the occasion of the 1st Hinode Science Meeting, at Trinity College Dublin (IRL) 20–24 August, ESA released the news item 'Hinode helps unravel long-standing solar mysteries' (*http://www.esa.int/esaCP/SEMKOOWZK5F_index_0.html*)

CoRot

The first long planetary observation ended on 15 October, followed by a repointing of CoRoT towards the galactic anti-centre. CoRot is essentially photon noise-limited over the whole magnitude range, from +11.5 to +16. The rate of appearance of new hot pixels is now stabilised. At this rate, at the end of the nominal 2.5-year mission, 11% of pixels will suffer from charges in excess of 300 e^-, 2.2% from charges >1000 e^- and 0.015% from charges >10 000 e^-. It is estimated that this should result in the loss of less than 3% of asteroseismology data, well within the <5% specifications.

Akari's view of the entire sky in IR at 9 µm. The bright stripe from left to right is the disc of our own Galaxy. Several bright regions corresponding to strong IR radiation appear along or next to the Galactic Plane; these are sites of newly born stars



Three further new planets were confirmed, ten planetary candidates are being followed up and six new stellar binaries were identified. About a dozen refereed articles are in preparation; until these are accepted, all results on exoplanets are embargoed. Asteroseismological results are also excellent and papers are being prepared. A press conference is planned at the Paris Observatory (F) for end-October, following the completion of the first long look. CNES is also organising a CoRot conference to be held in Paris in November 2008.

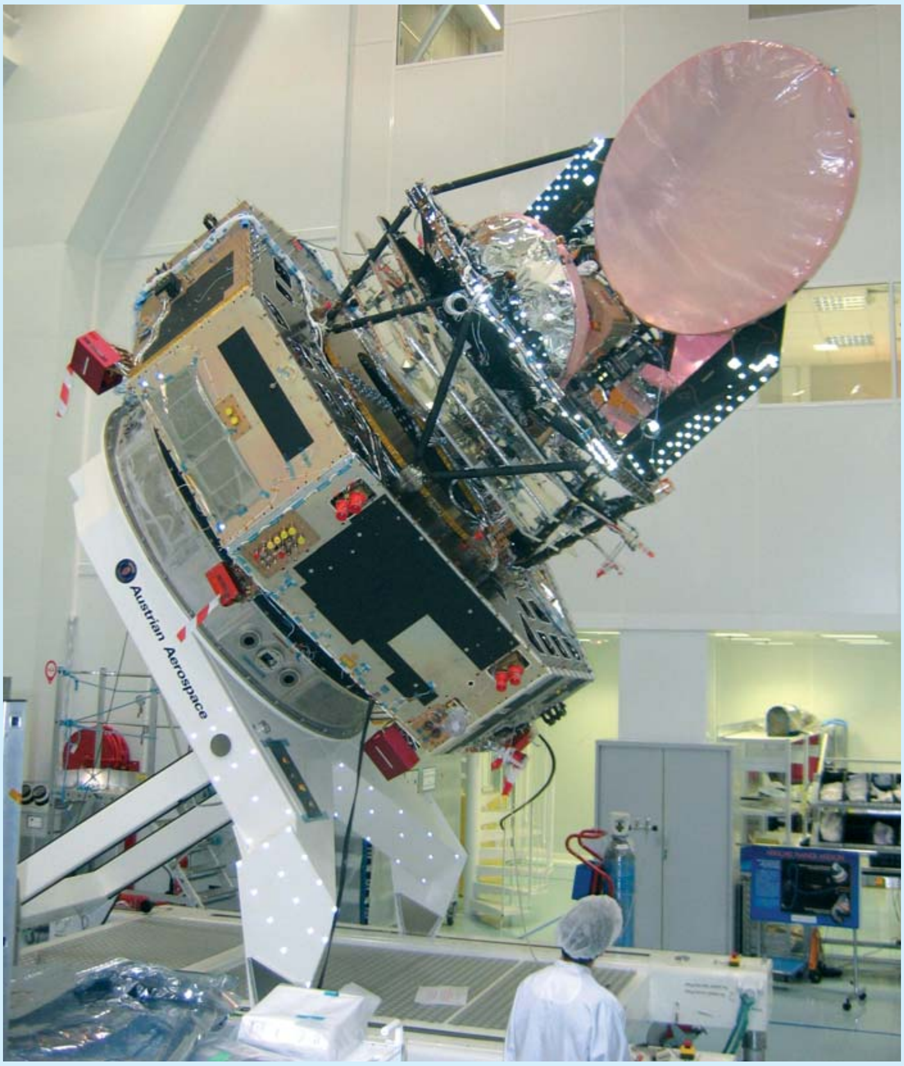
Herschel/Planck

Good progress has been made on both spacecraft with the completion of the final integration steps and the preparation of the first satellite functional and performance tests.

Another Herschel major milestone was achieved: the cryostat was mated to the service module. The instruments completed their final calibration and test campaign, so now all three instruments have been delivered. The three focal plane units were integrated onto the optical bench in the cryostat. Electrical connection and check-out with the electronic units mounted on the service module is ongoing. The preparation and debugging activities for the spacecraft functional test are under way in parallel.

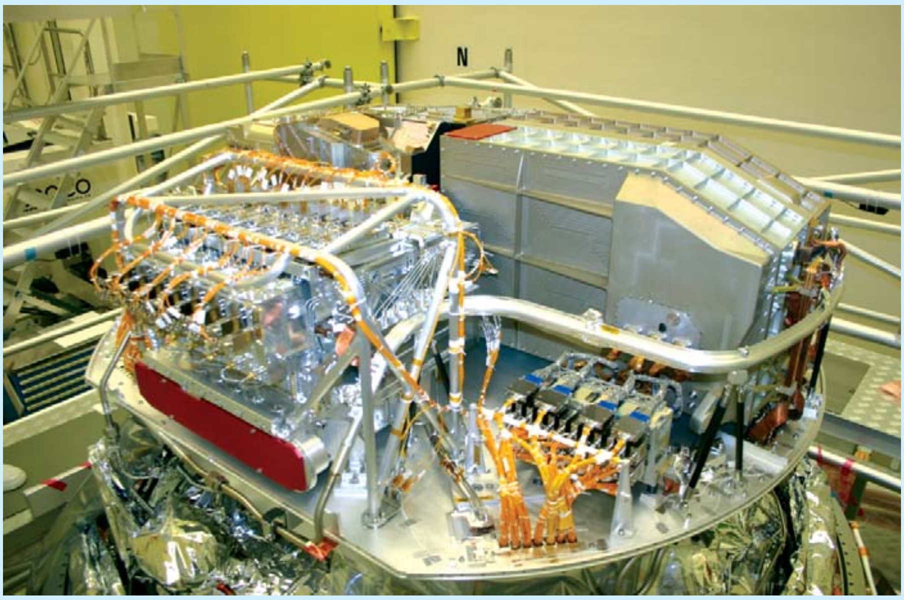
The activities on the Planck spacecraft continue in line with the flight model plan. The step-by-step electrical integration and functional testing of the two instruments continues as planned, in parallel with the preparation and debugging activities for the functional tests. The qualification model of the telescope was used for the end-to-end verification using a novel measurement method at the operational frequencies with a representative instrument. With this method now validated, the same verification of the telescope will be carried out on the flight model spacecraft.

The progress on the ground segment elements is well in line with the spacecraft achievements.



The Planck satellite

Herschel's instruments mounted on the optical bench



LISA Pathfinder

The challenging SMART-2/LISA development is proceeding largely according to schedule. The main activity in the reporting period was the consolidation of the spacecraft design, in preparation for the spacecraft CDR. In parallel, most of the subsystem had their own CDRs. The flight models of a few units have already been delivered, including the primary structure of the science module, the digital Sun sensors and the separation mechanism device, while other units have been manufactured and tested (gyro package, low- and medium-gain antennas and batteries) and are ready for shipment. The propulsion module is being manufactured. The static test on the science module FM structure has started and will be followed by the separation and shock test and by the propulsion module static test.

The hardware design review to confirm the start of the real-time test bench (electrical tests of various Engineering Model units connected together on a bench) is under way.

The two European micropropulsion technologies (needle indium thrusters and slit caesium thrusters) continue their challenging development to prove their readiness. Despite many hiccups, good progress was made in both. The first controlled priming was achieved with the slit-technology thruster and progress is being made in the needle emitter production. The technology better suited to LISA Pathfinder will be selected in the spring of 2008.

For the LISA Technology Package (LTP), most of the subsystem CDRs have taken place and the system CDR documentation, delivered by the LTP Architect, is under review at ESTEC. Many of the electrical units have been built and delivered to Astrium GmbH for the Real-Time Test Bench. Progress has been made on all critical subsystems, including the inertial sensor vacuum enclosure, the electrostatic suspension front-end electronics and the caging mechanism. In particular, the caging mechanism will undergo a second breadboard test before the end of the year to confirm the design of the delicate interface between the gold-platinum Test Mass and the mechanism 'fingers' holding it during launch.

The launch is expected to take place in the first half of 2010.

Microscope

Phase-C/D of the accelerometer development has started. The Engineering Model of the Sensor Unit was assembled and is undergoing electrical tests. ONERA will soon begin further tests aimed at proving that the test mass will not stick when released from the caging mechanism, that its surface integrity will be preserved and that no significant amount of deposit will be produced.

To assess the potential use of cold gas as for micropropulsion, a detailed analysis was performed by CNES and all potential perturbations (outside the intrinsic noise) were found to be within the limits imposed by the drag-free specifications. However, this analysis should be confirmed before end-2007 by characterisation of the cold-gas propulsion in the nanobalance test facility recently commissioned at Thales Alenia Space, Turin (I). Taking account of the tests still to be performed on both cold-gas and FEEP technologies, the final selection of which technology to use has been delayed to April 2008.

Gaia

The spacecraft PDR was held before the summer and completed with the Board meeting at the end of June. The review process identified a number of critical issues that required specific attention by the Prime Contractor. Nearly all of these issues were resolved over the summer break. The few remaining open items will be closed before the end of the year.

Radiation testing continued during the summer and provided further evidence that understanding the performance of the ASTRO CCD irradiated with almost twice the mission dose has progressed well, further confirming the selected strategy (in-orbit characterisation/calibration and charge injection).

Meetings were held with the Gaia Data Processing and Analysis Consortium (DPAC) and agreements were reached on all points regarding management and interfaces between the ESA project and DPAC. The relevant documents have been agreed and form the basis for the formal Multilateral Agreement between ESA's Executive and the Member States involved in the funding of DPAC.

The last meeting of the Gaia Science Team in its old composition was held in September. Ways on how to preserve the accumulated experience of these members were discussed and a way forward agreed. The first meeting with the new members will be held later this year.

JWST

The Director of the NASA Goddard Space Flight Center (GSFC) visited the MIRI integration facilities at Rutherford Appleton Laboratory (UK), where the Verification Model was ready to start the testing campaign.

The Integrate Science Instrument Module structure scale model (2:1) completed testing, confirming that the cryogenic deformations are within specifications. The preparation for the Mission PDR is under way; the review date is confirmed for April 2008.

Following the successful completion of NIRSpec's FORE mirror polishing and the subsequent alignment in the Three-Mirror Anastigmat configuration, 'first light' was seen with the qualification model of the silicon carbide FORE optics assembly. The measured wavefront error is within specification. This is a major milestone in NIRSpec's development.

The start of the instrument-level CDR was confirmed for April 2008, allowing sufficient time to close out the subsystem CDRs. First deliveries of the Data Analysis Electrical Ground Support Euqipment and the Mechanical Ground Support Equipment passed their Delivery Review Boards.

NASA has successfully manufactured 10 flight-quality Micro shutter subarrays. Four sub-arrays are required for the flight model. The quality of the array has improved significantly and the associated programme risk was retired at JWST mission level.

MIRI's Verification Model is integrated and has undergone warm alignment and gravity release test successfully. The preparation for the first cryogenic test campaign is under way.

A bottom-up qualification review campaign is being performed. Those for the Cleanliness Control Cover mechanism and the Cryogenic Harness were already successful.

Flight detector chips have already been down-selected for the MIRI imager. The selection of for the spectrometer is, however, pending the upgrade of the screening facility. The anomalies on the Focal Plane Electronics for the Verification Model were resolved by the Jet Propulsion Laboratory (US) and all the acceptance tests were run successfully.

BepiColombo

Following closure of the spacecraft System Requirements Review, the equipment procurement started and competitive Invitations to Tender for the first 16 items were issued. The first offers were received by the Prime Contractor's Core Team and the Agency, and are under evaluation. In parallel, the system design is being consolidated.

The work on key technologies continues in anticipation of the selection of contractors for, in particular, multi-layer insulation, radiator, blocking diodes, solar array, high-temperature rotary joint and high-gain antenna. Micrometeoroid hypervelocity impact tests were conducted on two candidate electric propulsion grids, showing that the damage remains local.

The Science Working Team conducted its meeting in Berlin with participation by the international scientific community involved in the European and Japanese payload. The meeting concentrated on scientific subjects and working groups were formed to work on Mercury's interior and geodesy, surface and atmosphere and magnetosphere. Routine progress meetings and delta Instrument Requirements Reviews are being conducted during September to November.

Work at Japan's JAXA space agency on the Mercury Magnetospheric Orbiter design is progressing nominally. The PDR for the scientific instruments and spacecraft equipment has begun.

LISA

The Mission Formulation activity performed by Astrium (D) is proceeding in its Phase-3, which includes trade-off of the In-Field of View (IFOV) architecture with different positions of the test masses. The latest activity concentrated on the IFoV two-active-test-mass configuration. The main challenge consisted in achieving an architecture that uses a telescope that can be easily procured whilst retaining a compact and lightweight design.

A novel approach was devised with a crossed-telescope configuration. Its advantage is the containment of the diameter, which is beneficial for the spacecraft size and ultimately on the overall mass. The drawback is the need for a highly stable mechanism to steer the light beam within the telescope field of view, as opposed to steering the whole telescope, as in the baseline configuration.

The cooperation with NASA proceeds very well on all fronts. The review for the prioritisation of the NASA 'Beyond Einstein' programme initiated by NASA headquarters and performed by the National Research Council (BEPAC) was completed and the draft report published on 5 September. Whilst not being recommended as the first mission to be implemented within 'Beyond Einstein' (mainly for programmatic reasons tied to the need to wait for the results of LISA Pathfinder), scientifically LISA received the highest rating from the review committee. To quote from the report: "*On purely scientific grounds LISA is the mission that is most promising and least scientifically risky. Even with pessimistic assumptions about event rates, it should provide unambiguous and clean tests of the theory of general relativity in the strong field dynamical regime and be able to make detailed maps of space time near black holes. Thus, the committee gave LISA its highest scientific ranking.*"

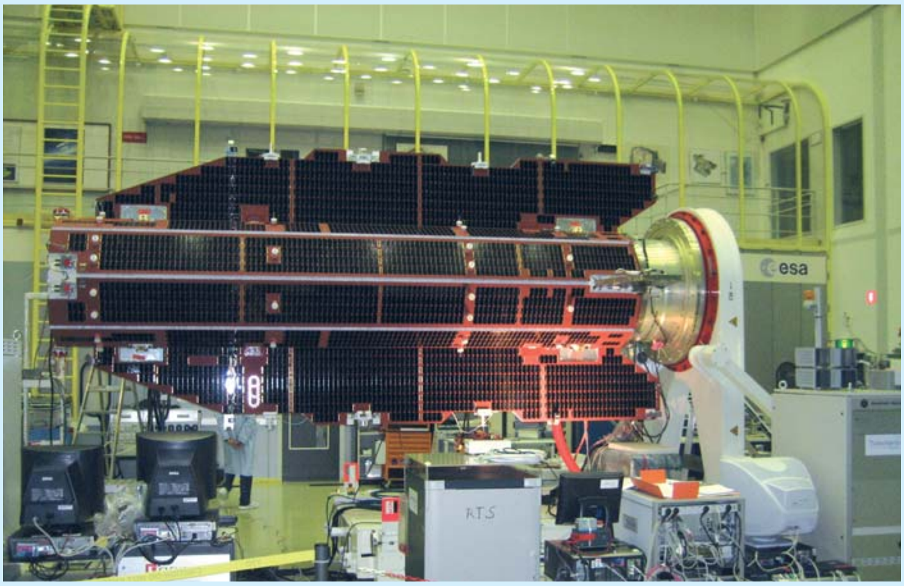
This corroborates the standing of LISA as a candidate for the first large mission (L1) of ESA's Cosmic Vision Programme.

GOCE

The Gradiometer Core Proto-Flight Model passed its acceptance testing, confirming the good health of the six Accelerometer Sensor Heads (ASHs). In addition, the acceptance testing of a seventh ASH, the spare model, was completed.

Following the completion of its acceptance test campaign in Quinetiq (UK), the Ion Propulsion Assembly (IPA) was transported to Thales Alenia Space in Turin for integration on the satellite. With this, the satellite reached the complete configuration in mid-July. Subsequently, testing activities continued in double shifts, 6 days a week until the middle of August. The satellite was then shipped to ESTEC, where it arrived on 23 August, ready to start the environmental test campaign. This was a very important milestone for the GOCE programme.

The satellite Qualification Review was completed on 20 July. The first part of the GOCE Ground Segment Overall Validation test was completed, proving that the ground segment elements are correctly working together in closed loop. The second part will



GOCE in the ESTEC Test Centre

be run in autumn after an update of the Payload Data Segment processors.

CryoSat-2

The thrusters for the reaction control and propulsion system were delivered and integrated into the satellite. The plate carrying the remaining reaction control items, including latch valves, pressure regulators and pressure transducers, is under final testing and expected to be delivered soon for integration, thus completing the reaction control and propulsion system.

In Albuquerque (USA), the advanced solar cells, and the associated electrical hardware, are being installed on the solar array substrate panels. Despite the early delivery of some equipment, the electrical integration has not yet started owing to a small delay in the delivery of the power control and distribution unit. Nevertheless, the test procedures that will be needed for this activity (and subsequent testing) are in an advanced state, due both to the heritage from CryoSat-1 and to the use of the 'virtual satellite' (known as the Real-time Test-Bed) developed for CryoSat-1 and upgraded for CryoSat-2. This system is also used for testing onboard software updates.

A feature of the satellite is a novel gyro based on MEMS (micro electro-mechanical structures) technology, which is under development and will be given a flight opportunity on CryoSat-2. The measurements from this passenger will not be used by the onboard software, but should provide useful data during the early stages of the mission.

Almost all of the contracts to upgrade the ground segment facilities, required to cope with some changes in the satellite compared to CryoSat-1, have been placed, in time for the start of extensive system testing during 2008.

SMOS

After delivery and formal hand-over to Thales Alenia Space (Cannes, F) of the SMOS payload at the end of June 2007, integration with the Proteus platform and satellite electrical verification was completed. The satellite is being readied for sine vibration testing.

An overall Ground Segment CDR was successful. Components of the Flight Operations Ground Segment were delivered and are being validated and configured for operations. Components of the Data Processing Ground Segment are still under development. Prototype Level-1 and -2 Data Processor modules are being finalised. Preparation for operations continues with an update of Payload Module flight procedures and joint operations preparation with CNES.

For the launcher, a Final Mission Analysis Review was completed in June 2007. Work is progressing nominally for the submission of the Safety Data Package Phase-2, in the definition of the telecommunications requirements for the launch campaign and the Launch and Early Orbit (LEOP) phase and in the preparation of the launch campaign logistics.

ADM-Aeolus

Successful operation of the first flight model of the transmitter laser master oscillator was demonstrated. However, detailed visual inspection of the mirror assemblies showed defects on some of the mirror surfaces. Since they were considered too risky for flight, a decision was taken to replace these mirrors. Life-time tests on representative samples of mirrors in the UV section showed a potentially marginal end-of-life damage threshold of the high-reflectivity coatings against laser-induced damage. A sufficient number of mirrors using a different, more robust, coating technology is available and was used to replace the marginal mirrors.

Measurements of the output beam characteristics after the refurbishment of the master oscillator showed an unexpected variation of the beam profile. Investigations on the root cause of this effect are under way.

The Mie Spectrometer (MSP) was repaired and retested. A small non-compliance in the optical characteristics of the unit could be accepted, because it was found to have only a negligible impact on the overall instrument performance. The MSP was integrated with the rest of the instrument and is undergoing final optical alignment.

The satellite platform was shipped from Astrium Friedrichshafen (D) to Astrium Stevenage (UK). The mechanical and electrical setup was completed and recommissioning of the satellite ground support equipment was performed. The integration of the propulsion hardware was completed with the installation of the spacecraft thrusters. The integrity of the propulsion system was proven in a 'box leak test'.

The ground campaign of the Aladin Airborne Demonstrator (A2D) was successfully completed in July 2007 at DLR's Lindenberg (D) test site. Because of constraints in the availability of the test-aircraft, the first Aeolus flight campaign will not start until November 2007.

The Announcement of Opportunity for the Aeolus calibration and validation activities was released on 1 October 2007; the deadline for the submission of proposals is 15 December 2007. All pertinent information is accessible through the web-based portal at *http://eopi.esa.int/AeolusCalVal*

Swarm

The major elements of the mission are in progress. The engineering models of the Accelerometer instruments are on the manufacturing path. The 'Teaser' precursor accelerometer instrument, due to fly on a Russian satellite, was tested by VZLU. A failure of the hold and release mechanisms occured during the vibration test. Remedy design actions are being studied for Swarm.

The procurement and design of the structure with Astrium remains a major concern for the project as it is on the critical path; the satellite structure is identified as a risk for the mass budget of the satellite.

During the progress meeting in mid-September, several major concerns were identified, in particular a significant increase of the mass of the satellite owing to the structure and the intrinsic specific impulse (ISP) of the gas selected for the mission. A test campaign by Marotta for Cryosat showed that the ISP of the freon is 10% less than expected, leading to a satellite mass increase of 15 kg. Although a result of the structure PDR was to reinforce the structural design in order to meet the performances, these correctives actions lead to a mass increase of 6 kg.

Mitigation solutions had to be implemented in order to maintain the compatibility of Swarm with at least two launchers. Therefore, the semi-major axis of the orbit of the two lower-altitude satellites was increased for the beginning of the mission. This measure allows the saving of the propellant necessary for orbit maintenance in the previous orbit scenario and is enough to resolve the mass issue. This point was discussed with the Mission Advisory Group members and it was agreed there is no impact on the mission.

The procurement activity is under way with the selection of subcontractors for the solar cells, harness, thrusters, S-band antenna, cold-gas propulsion feed assembly and magnetotorquers and the preparation of the specifications for the structure and level-1b processor.

A consolidation of the level-1b algorithms for the magnetic package and the EFI instrument is under way with industry. The level-2 algorithms were initiated, with the kick-off of four studies pertaining to processing architecture, ionospheric current, mantle conductivity and air density.

MetOp

As part of a cooperative effort between NOAA and Eumetsat, the Initial Joint Polar Satellite System (IJPS), MetOp is designed to work in conjunction with the NOAA satellite system, whereby MetOp occupies the 'morning' orbit and the NOAA satellite takes the 'afternoon' shift.

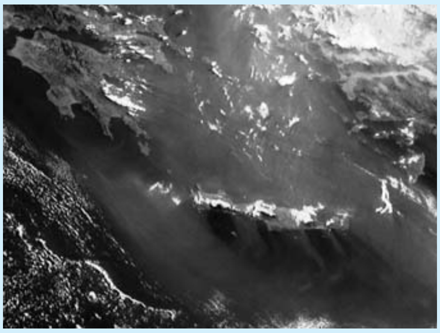
MetOp-A has completed its first year in orbit, thereby offering a data flow of unprecedented accuracy and resolution from its 11 instruments. It recently experienced an anomaly on HRPT-A, which is now under investigation. As the redundant HRPT-B will not be switched on until the root cause of the anomaly is found, the HRPT service to users is in the meantime provided by NOAA-17, which is the backup for the morning orbit in the IJPS. The MetOp-A instrument performance is excellent.

The service and payload modules of MetOp-B and MetOp-C are being kept in hard storage at the contractor's premises, waiting for the restart of assembly, integration and testing activities in 2009 for a planned MetOp-B launch in 2011.

MSG

Meteosat-8/MSG-1

On 22 May, Meteosat-8 was hit by an object that raised its orbit by about 130 m. Apart from the bent R1 thruster and some multi-layer insulation damage, no vital damage occurred. The unaffected redundant propulsion system thruster branch became



This Meteosat-8 image of 13 July 2007 shows how wind can modify the ocean surface reflectance in the HRV channel (broadband visible). Usually, ocean surfaces appear black in this channel because the reflectance is only a few percent. However, in areas with strong surface winds (rough sea, foam, white caps) the reflectance can increase significantly. The grey over the Aegean Sea and around Crete indicates strong wind; the black south of Crete indicates weak winds (calm sea) in the lee of the island's high mountain ranges; white areas are clouds. (Eumetsat)

Left: MSG-4 in optical cacuum test configuration at Thales Alenia Space, Cannes (F). This test demonstrates the performance of the SEVIRI infrared channels, with the detectors operating at temperatures of 85K to 95K

Right: the Soyuz-U launch from Baikonur at 11:00 UT on 14 September 2007 began the 12-day Foton-M3 mission

the nominal one. The thermal behaviour has somewhat changed, but is stable and manageable.

Since then, the satellite's passage through the more demanding eclipse season has confirmed that performance was unaffected by the hit. Performance continues to be excellent.

Meteosat-9/MSG-2
Meteosat-9 is now Eumetsat's nominal operational satellite at 0º longitude. Satellite and instrument performance are excellent.

MSG-3
It is planned to move MSG-3 from intermediate storage in the Thales Alenia Space cleanroom into long-term storage before the end of 2007. Launch is foreseen for early 2011.

MSG-4
After its pre-storage review, MSG-4 will also be prepared for long-term storage. Launch is planned for no earlier than 2013.

Human Spaceflight, Microgravity & Exploration

Highlights
The Foton-M3 spacecraft was launched from Baikonur Cosmodrome, Kazakhstan, on 14 September. In total, it carried 43 scientific and technological payloads supplied by ESA, Germany, Belgium, France, Italy and Canada, plus a number of Russian experiments. Foton-M3 spent 12 days in orbit, during which time the experiments were exposed to microgravity and, in some cases, to the harsh environment of open space, before landing safely on the steppes near the Russian-Kazakh border on 26 September.

The mission was an important opportunity for European researchers to conduct a wide variety of experiments under microgravity and partially space radiation conditions prior to the availability of ESA's Columbus module Columbus on the International Space Station.

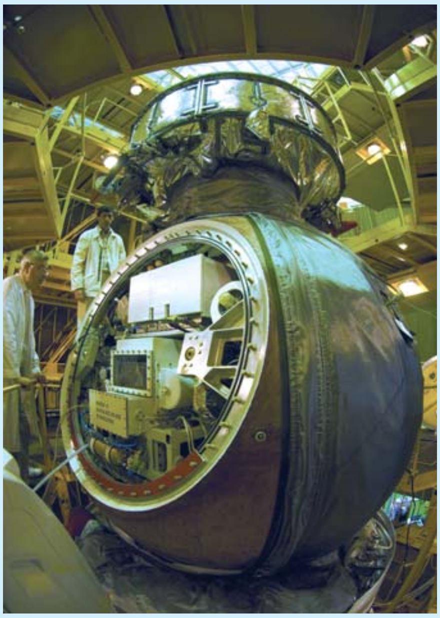
On 13 July, the culmination of more than 11 years of development and production, ATV-1, *Jules Verne*, was transported from ESTEC by lorry and barge to Rotterdam harbour. Once safely loaded aboard the *MN Toucan*, it began its transatlantic crossing to the European Space Port in Kourou, French Guiana. On 31 July the 400 t of spacecraft and equipment arrived at Pariacabo harbour and was trucked to Kourou to begin final integration. All functional qualification testing has been completed, as have the final interface verification tests, in preparation for the planned launch by Ariane-5 at the end of January 2008.

On 24 July, ESA and the Italian space agency (ASI) announced the name chosen for the mission of ESA astronaut Paolo Nespoli (I), a member of the Shuttle STS-120 crew for launch in October 2007. The mission was dubbed 'Esperia' from the Ancient Greek name for the Italian peninsula.

The 1st Lunar Architecture Requirements Review was held on 18 July with with almost 100 participants from industry, the science community, national agencies and various ESA Directorates. The first version of the European lunar reference architecture will be available by the end of 2007.

Preparations for the 'International Space Exploration Conference', which will take place in Berlin on 8–9 November are well underway. The programme is largely defined and invitations have been dispatched and more than 100 participants have already registered.

International Space Station
Space Shuttle *Endeavour* (STS-118) launched from Kennedy Space Center (KSC) on 8 August carrying a Spacehab Single Cargo Module, the third starboard truss segment (S5) and External Stowage Platform 3 (ESP3). Inside the Spacehab were ESA's ANITA and the Multigen-1 experiment. The mission saw four EVAs, the last of which was cut short due to the possible necessity to shut down Mission Control in Houston with the approach of Hurricane Dean. It was decided to bring STS-118 back a day early; *Endeavour* landed safely at KSC on 21 August. Damage to an Orbiter tile from External Tank foam loss, did not impair the



Preparation of the Foton-M3 spacecraft at the launch site

flightworthiness of the Orbiter, and minor changes to the Tank foam were made for the next mission.

At KSC, the Space Station Programme Control Board reviewed the Launch Package Assessment for flight 10A and approved the transfer of Node-2, ‘Harmony’, into the Orbiter’s payload bay. Node-2 was developed by Europe as part of the Columbus launch barter arrangement. Flight STS-120/10A, carrying Node-2 to the ISS together with ESA astronaut Paolo Nespoli, is scheduled for launch on 23 October, followed by Columbus on 6 December with ESA astronauts Hans Schlegel (D) and Léopold Eyharts (F).

On 13 September, ESA and NASA signed a bilateral Technical Understanding on ESA’s offset of ISS Common System Operations Costs obligation and transportation of ESA cargo. It also documents the related ESA rights on increment crew and utilisation crew time allocations, and is the basis for the development of a formal ESA/NASA Implementing Arrangement, covering ISS operations through to the end of 2015.

Space Infrastructure Development

The ‘Stage Verification’, which tests the final flight software of the vehicles with that of the ISS in the Software Development and Integration Laboratory at NASA’s Johnson Space Center was successfully completed for both Columbus and ATV *Jules Verne*.

The Columbus Flight Operations Review was completed, with no significant issues identified. Considerable progress was made on the development of operation interface procedures. The operation preparation programme will continue up to launch with particular emphasis on Joint Integrated Simulations. Final rework, adjustment and calibration of the Columbus experiment racks was completed at KSC, in readiness for the last system checkout of the Columbus module. The Final Acceptance Review of the integrated Columbus was concluded and the EuTEF and SOLAR external payload facilities are at the launch site being integrated onto their carrier.

Interface and End-to-End tests between the ATV-Control Centre and external entities were completed and, following a Delta-Qualification Acceptance Review board meeting in June, the remaining work is seen as routine close-out. The ATV operations qualification programme continues on track; the 11 planned Joint Integrated Simulations with MCC-Houston and MCC-Moscow began and continue with good success.

Utilisation

Having been transported in the Spacehab module aboard flight STS-118/13A.1, the Multigen-1 (sustainable plant growth in space) experiment was started in the European Modular Cultivation System (EMCS) aboard the ISS on 24 August. The experiment will continue for a nominal 75 days with the aim of growing several generations of plants in orbit to examine the possibility of sustainable plant growth for long-duration space exploration.

ANITA, the Analysing Interferometer for Ambient Air, is now deployed in the ISS ‘Destiny’ laboratory. The on-orbit commissioning and short-duration science part during the STS-118/13A.1 flight were successful. ANITA will continue an extended operational period as an ISS systems device.

ESA’s further Increment-15 research programme (Matroshka-2, Altcriss, Immuno, CardioCog-2) is being executed by the Russian cosmonaut aboard the ISS.

At KSC, all Columbus payload facilities are ready and will be launched together with the module on STS-122/1E. The first set of related experiment units will be activated in close conjunction with the overall module commissioning during the 1E Stage.

Astronauts

After 15 years as a member of the European Astronaut Corps, and having spent more than 350 days in orbit, Thomas Reiter will

The first ATV at Rotterdam, before crossing the Atlantic

Left: preparations for the Columbus launch took an important step on 16 October with the final closure of the module's hatch. Seen here are (from left) Bernardo Patti, ESA Columbus Project Manager; Gregor Woop, ESA Columbus Project Product Assurance & Safety; Alessio Festa, ESA Columbus Project Chief Mechanical Engineer; Giuliano Canovai, ESA Columbus Project Chief Avionics Engineer.

Right, facing page: Eurobot WET and astronaut J. Clervoy during underwater tests at EAC

leave the Corps to take up a position on the Board of Directors at DLR.

At the Multilateral Crew Operations Panel held in Tsukuba, Japan, it was decided to 'pre-assign' Frank De Winne as Flight Engineer-1 (Soyuz left seat) and André Kuipers as his backup for the ESA E2 flight, now advanced from Expedition-20 to -19a. This is the second Soyuz in Expedition-19, with a launch date of June/July 2009.

The agreements with DLR and CNES on cooperation for the functioning of the European Astronaut Centre were extended for a further 3 years, starting 1 January 2008.

Exploration

The ExoMars project passed important milestones in this period, including the transition to a bridging phase in anticipation of the start of Phase-B2 in 2008. Ongoing work in the Phase-B1 bridging activities has consolidated the design of the system and continued to push forward technology developments in critical areas such as the Rover drill and sample-preparation systems as well as Airbag technology. The Airbag Breadboard testing facilities were verified and several important tests were completed using the 'vented' airbags. In the Enhanced Baseline mission configuration, the Pasteur/Geophysics Environment Package (GEP) Payloads will accommodate the selection of the 16.5 kg Pasteur along with the 8.5 kg of instrumentation for the GEP.

Discussions on cooperation with NASA and Roskosmos continued in the period, with progress on the specific cooperation between ExoMars and the Russian Phobos-Grunt mission.

Good progress was made in the area of Planetary Protection, with an agreed text for an ESA/NASA Letter of Agreement allowing a good exchange of information on the subject.

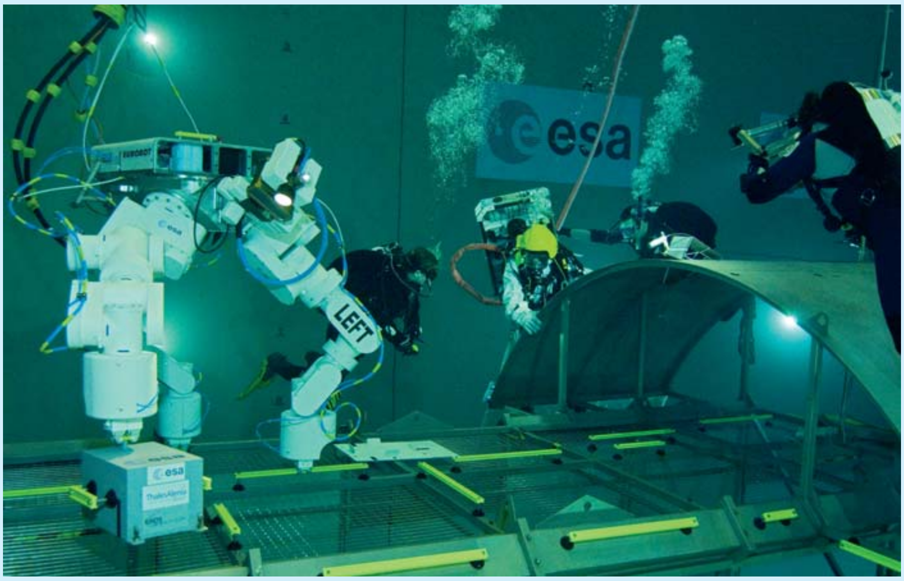
The next major milestone for the project is the November Programme Board, when the completion of the Implementation Review process is foreseen, clearing the way for a Phase-B2 start early in 2008.

Mars Sample Return (MSR) Phase-A2 work concluded the revision of MSR architecture, and system work proceeded on precursor mission concepts. System work has been used to guide and focus technology activities in critical fields, including soft-precision landing, autonomous rendezvous and bio-containment, with many activities approaching breadboard testing.

Concepts for the Next Exploration Science and Technology (NEXT) mission opportunity, in preparation for MSR, were studied and evaluated, with recommendations coming from the Exploration Science & Technology Advisory Group on 4 September, to proceed with two types of mission concepts at Phase-A level: Mars Orbiter with Network Science and Rendezvous demonstration; and Lunar Soft-Precision Lander with Mobility. These studies will be implemented through to the end of 2007 or early 2008.

Contacts with NASA were established to discuss possible cooperation schemes for an international MSR Mission. As part of the International Mars Exploration Working Group (IMEWG), a dedicated MSR working group was established under European leadership to coordinate the approach to MSR of the major space agencies and converge on a consolidated mission concept.

All ARES activities were kicked-off and a progress meeting was held in Friedrichshafen (D) 27–28 June that showed progress as



generally good and indicated that the recent increase in funding had boosted the motivation and output of the industrial team.

In cooperation with the EAC Training Team, the Eurobot Project and industry, the Eurobot Weightless Environment Test model underwent an underwater cooperation test campaign with ESA astronaut J. Clervoy at EAC's Neutral Buoyancy Facility, ending on 4 July.

For the Crew Space Transporation System (CSTS), European industrial activities were launched and exchanges with Russian industry were held before the summer break. At the beginning of September, Russian and European industry started the joint system engineering work, where progress is being made in collocation in Moscow.

An exchange of Letters covering coordination on CSTS between ESA and Japan's JAXA space agency was finalised and signed by JAXA's President and ESA's Director General at Le Bourget on 19 June.

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 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 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

Rosetta Swings By Earth

An important milestone was passed on 13 November when ESA's Rosetta comet mission swung by Earth. The craft is now heading back out into the Solar System with its new energy before coming back to Earth for another boost in 2009.

Rosetta came within 5295 km of Earth above 63°46'S/74°35'W (south-west of Chile) at 20:57 UT, whizzing past at 12.5 km/s.

Europe's comet chaser has now flown a little over 3000 million km of its 7100 million km journey to Comet 67/P Churyumov-Gerasimenko, aiming to reach the comet in 2014. This was the third planetary swingby for Rosetta and its second at Earth. Around closest approach, Rosetta took a good look at Earth's atmosphere and magnetosphere, imaged urban regions and looked for meteors from space. Shortly after, Rosetta turned to observe the Moon and, later on its outbound trajectory, the Earth-Moon system from a distance.

Rosetta will swing by Earth for the last time in November 2009. Before that, as it crosses the asteroid belt, it will grab the opportunity to study asteroid Steins in September 2008 esa.

Graham Land in Antartica imaged by Rosetta's navigation camera from 5500 km, soon after the craft's closest approach to Earth

Ariane-5 Reignition Prepares for ATV

Successful reignition of the upper stage engine during Ariane-5's October mission marked an important milestone in preparing for the first launch of ESA's Automated Transfer Vehicle (ATV) next year.

ATV, which carries supplies to the International Space Station, requires multiple firings of the 'Aestus' upper stage engine, but none had ever been carried out in space. Hundreds of reignition tests under various thermal conditions have been undertaken at the German space agency's Lampoldshausen (D) facility to qualify the engine for several reignitions.

In order to consolidate this ground qualification, a reignition experiment was performed during the Ariane-5 mission of 5 October after the two commercial telecommunications satellites had been safely dispatched into their transfer orbits. Aestus was reignited 54 min after the release of the second payload. The experiment validates the operational conditions (mainly temperatures and pressures) and procedures (propellant settling in tanks) for the ATV mission. esa

ERS-2 in Demand

The demand for data from ESA's veteran ERS-2 satellite is increasing as the 12-year-old mission's products and services play a vital role in the initial activities for the Global Monitoring for Environment and Security (GMES) programme. These activities include the MARItime Security Service (MARISS) project, which addresses illegal marine trafficking.

MARISS integrates near-real time satellite data with conventional vessel tracking to deliver an understanding of the maritime situation to coast guards, navies and border police forces in Europe.

Within the MARISS partnership, service providers require synthetic aperture radar imagery, such as that provided by ERS-2, within 15–20 minutes in order to detect vessels rapidly and extract their positions. These data are integrated with coastal surveillance systems such as coastal radar, the Automatic Identification System and the Vessel Monitoring System for tracking fishing vessels. With this information, service providers can locate all vessels not reporting their positions using the conventional identification systems and transmit the positions to the relevant authorities within 30–60 minutes of the satellite overpass. esa

TC-1 Demise

TC-1, one of the two satellites of the Double Star mission, was decommissioned on 14 October before its reentry into Earth's atmosphere. Along with its twin, TC-1 was the first satellite built and operated by the Chinese National Space Administration in cooperation with ESA.

Along with ESA's four Cluster satellites, TC-1 accomplished much during its 4-year life. It provided new insights into the the boundaries of Earth's magnetosphere and the fundamental processes that transport mass, momentum and energy into the magnetosphere.

GIOVE-B, the second Galileo demonstration satellite, is prepared for vibration testing in the ESTEC Test Centre. Launch is planned for March 2008 on a Soyuz rocket from Baikonur Cosmodrome in Kazakhstan

Ozone Hole Improvement

The ozone hole over Antarctica has shrunk by 30% since last year's record size. According to measurements made by ESA's Envisat satellite, this year's ozone loss peaked at 27.7 million tonnes, compared to the record ozone loss of 40 million tonnes in 2006.

Ozone loss is derived by measuring the area and the depth of the ozone hole. The area of this year's ozone hole – where the ozone measures less than 220 'Dobson Units' (DUs) – is 24.7 million sq km, roughly the size of North America; the minimum value of the ozone layer is around 120 DUs.

Scientists say this year's smaller hole – a thinning in the ozone layer over the South Pole – is due to natural variations in temperature and atmospheric dynamics and is not indicative of a long-term trend.

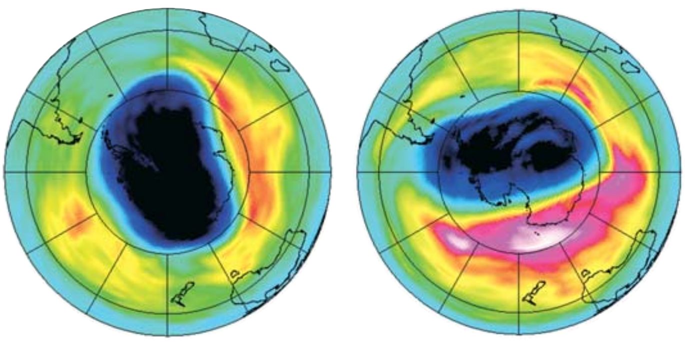
"*Although the hole is somewhat smaller than usual, we cannot conclude from this that the ozone layer is recovering already*," said Ronald van der A, a senior project scientist at Royal Dutch Meteorological Institute (KNMI). "*This year's ozone hole was less centred on the South Pole than in other years, which allowed it to mix with warmer air, reducing the growth of the hole because ozone is depleted at temperatures less than –78ºC.*"

During the southern winter, the atmospheric mass above the Antarctic continent is cut off from mid-latitude air by prevailing winds known as the polar vortex. This leads to very low temperatures, and in the cold and continuous darkness of the season, polar stratospheric clouds are formed that contain chlorine. As the polar spring arrives, the combination of returning sunlight and polar stratospheric clouds leads to the splitting of chlorine compounds into highly ozone-reactive radicals that break ozone down into individual oxygen molecules. A single molecule of chlorine has the potential to break down thousands of molecules of ozone.

The ozone hole, first recognised in 1985, typically persists until November or December, when the winds surrounding the South Pole (polar vortex) weaken, and ozone-poor air inside the vortex is mixed with ozone-rich air outside it.

KNMI uses data from Envisat's Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) instrument to generate daily global ozone analyses and 9-day ozone forecasts.

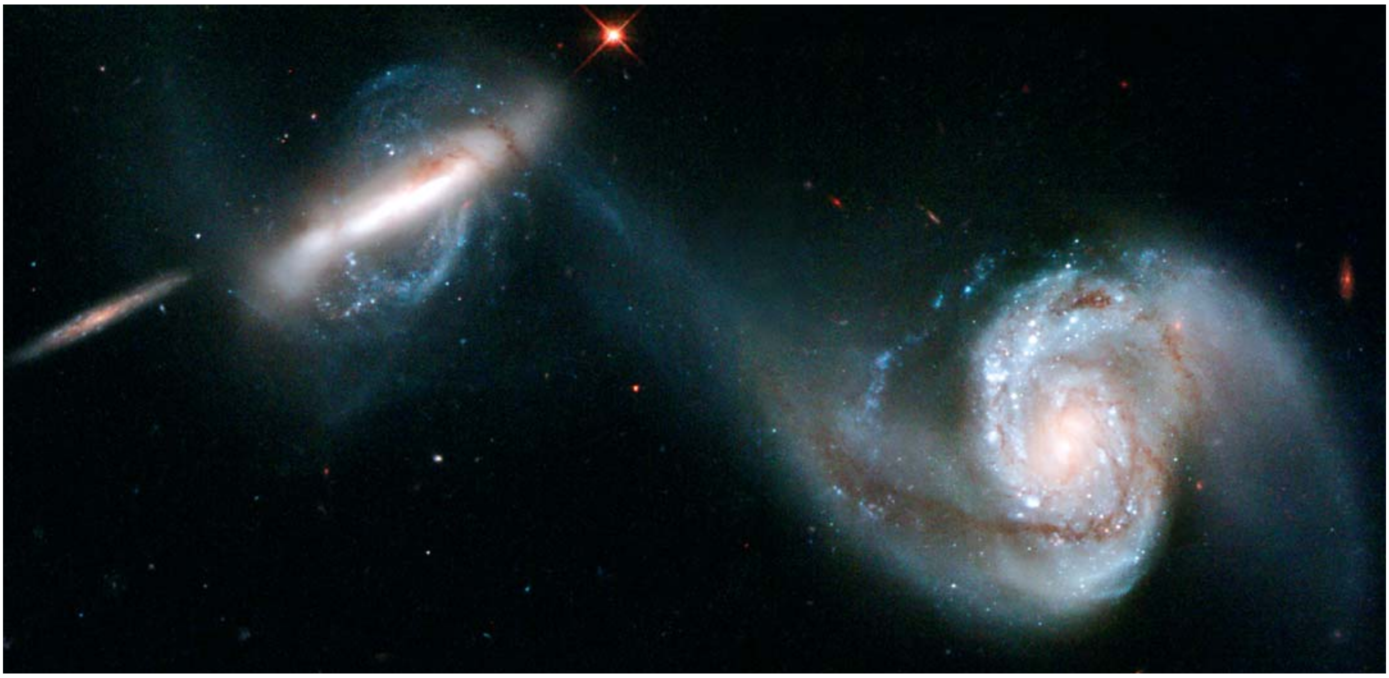
Envisat data show that the September 2007 ozone hole (right) over the Antarctic has improved since September 2006. (KNMI/ESA)



Cosmic Vision Next Step

The first steps of the next phase of European space science have been taken. At its meeting of 17–18 October in Paris, ESA's Space Science Advisory Committee (SSAC) selected the new candidates for possible future scientific missions in 2017–2018. All the candidate missions are now competing in an assessment cycle that ends in 2011. Before then, there will be an important selection in 2009. At the end of this process, two missions will be proposed to ESA's Science Programme Committee.

"*It has been an arduous process both inside ESA and in the*



'Arp 87' is a stunning pair of interacting galaxies. Stars, gas and dust flow from the large spiral galaxy, NGC 3808, forming an enveloping arm around its companion. The shapes of both galaxies are distorted by their gravitational interaction. The corkscrew shape of the tidal material suggests that some stars and gas drawn from the larger galaxy have been caught in the gravitational pull of the smaller one. The image was taken in February 2007 with the Hubble Space Telescope's Wide Field Planetary Camera 2. (NASA; ESA; The Hubble Heritage Team, STScI/AURA)

community to get these winning groups into what I suppose can be said to be the quarterfinals of one of the ultimate competitions in world space science," said ESA's Director of Science, David Southwood.

The selected missions fit well within the themes of ESA's Cosmic Vision 2015–2025 plan. The themes range from the conditions for life and planetary formation, to the origin and formation of the Solar System, the fundamental laws of our cosmos, and the origin, structure and evolution of the Universe.

From a list of 50 proposals submitted by the scientific community last summer, the candidates that have made it to the next phase of selection are described briefly below.

Laplace: Studying the Jovian System
The Jovian system, with Jupiter and its moons, is a small planetary system in its own right. Unique among the moons, Europa is believed to shelter an ocean between its geodynamically active icy crust and its silicate mantle. The proposed mission would answer questions on the habitability of Europa and the Jovian system. The mission would deploy three orbiting platforms for coordinated observations of Europa, the Jovian satellites, Jupiter's magnetosphere and its atmosphere and interior.

If approved, the mission would be implemented in collaboration with JAXA, the Japanese space agency, and NASA.

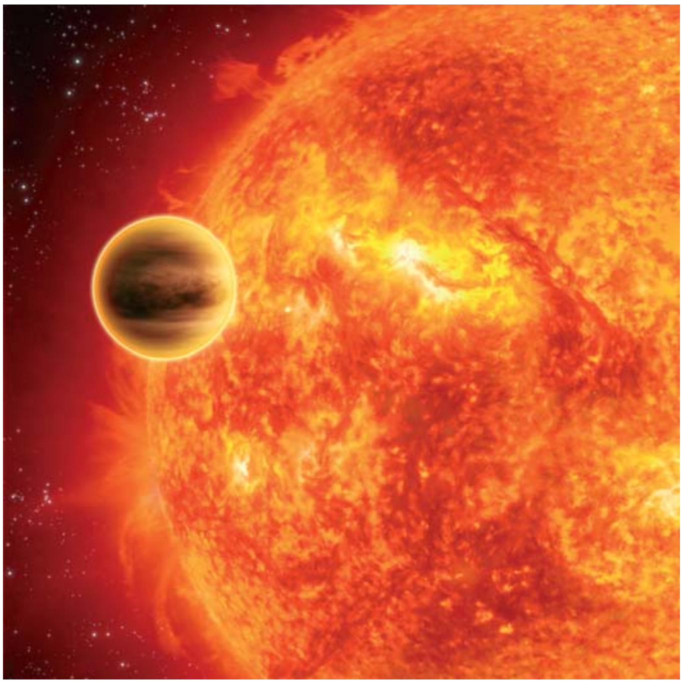
Tandem: A New Mission to Saturn, Titan and Enceladus
Tandem is proposed to explore Titan and Enceladus *in situ* and from orbit. Building on questions raised by Cassini, it would investigate the Titan and Enceladus systems, their origins, interiors, evolution and their astrobiological potential. An orbiter and a carrier would deliver a balloon and three probes onto Titan. If approved, Tandem would be in collaboration with NASA.

It is expected that a first selection between Laplace and Tandem will be made in consultation with foreign partners.

Cross-scale: Deeper Study of Near-Earth Space
Twelve satellites would make simultaneous measurements of the plasma at different scales at shocks, reconnection sites and turbulent regions in near-Earth space. It would address fundamental questions such as how shocks accelerate and heat particles or how magnetic reconnection phenomena generate or convert energy. It would be implemented in collaboration with JAXA.

Marco Polo: An Asteroid Sample-Return Mission
Marco Polo would characterise a near-Earth object at multiple scales and return a sample. It would study the origins and evolution of the Solar System, and the role of minor bodies in the process, origins and evolution of Earth and of life itself. It would consist of a mother satellite carrying a lander, sampling devices, reentry capsule and instruments. It would be implemented in collaboration with JAXA.

A Dark Energy Mission
Two proposals were received to study dark matter and dark energy – a hot topic in astronomy. While they propose different techniques ('Dune' would be a wide-field imager, while 'Space' would be a near-IR, all-sky surveyor), they address the same basic science goal. In



The proposed Plato mission would search for exoplanets

the follow-up study phase, a trade-off will lead to the definition next spring of a proposal for a European dark energy mission to go forward in the competition.

Plato: The New Planet-Finder
This photometry mission would detect and characterise transiting exoplanets as well as measuring the seismic oscillations of their parent stars. It would observe rocky exoplanets around brighter and better-characterised stars than its predecessors. Other ground- and space-based observations would derive the planets' masses and study their atmospheres.

Spica: The Next-Generation Infrared Observatory
Spica, a mid- and far-IR observatory with a large cryogenic telescope, would address planetary formation, the way the Solar System works and the origin of the Universe. It would perform wide-field, high-sensitivity photometric mapping at high spatial resolution, spectral analysis and coronography of planets and planetary discs. Spica is proposed in collaboration with JAXA.

XEUS: X-ray Evolving Universe Spectroscopy
XEUS is a next-generation X-ray observatory to study the fundamental laws and the origins of the Universe. With unprecedented sensitivity to the hot, million-degree Universe, XEUS would explore key areas of astrophysics: growth of supermassive black holes, cosmic feedback and galaxy evolution, evolution of large-scale structures, extreme gravity and matter under extreme conditions, the dynamical evolution of cosmic plasmas and cosmic chemistry. XEUS would orbit L2, the second Lagrange point, with two satellites (one carrying mirrors and the other detectors) flying in formation.

Various international partners have expressed interest in XEUS; discussions will start by the end of the year to ensure the earliest involvement in study work.

The candidate missions described here will also compete with the LISA gravitational wave observer, the other candidate for the 2018 launch slot.

MSG Services

ESA and Eumetsat agreed in November that the Agency will provide essential control services for the launches of the last two Meteosat Second Generation (MSG) satellites. ESA's European Space Operations Centre (ESOC), in Darmstadt (D) will provide control services during the critical Launch and Early Orbit Phase (LEOP), which involves moving the satellite from its initial position after separation from the launcher to its final position 36 000 km above Earth. The contract, valued at over €4 million, includes setting up the LEOP ground segment infrastructure at ESOC. The centre's flight control teams currently operate ten missions of 13 spacecraft, with ten more in active preparation.

MSG-3 and MSG-4 are scheduled for launches in January 2011 and January 2013, respectively. Joint ESOC and Eumetsat preparations will begin around 2 years before the planned launch dates.

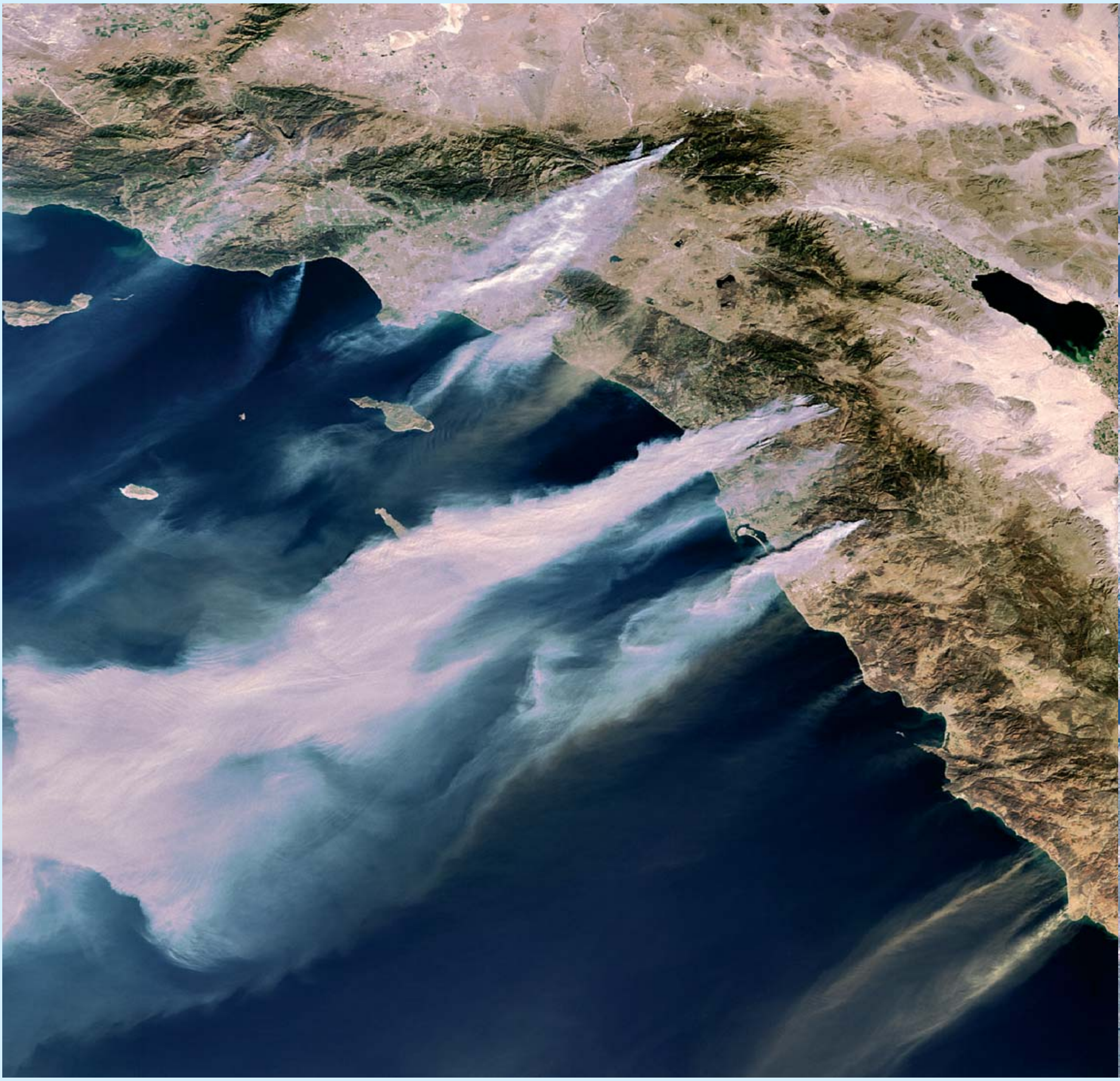
Lunar Support

The ESA ground station network has been mobilised to support China's Chang'e-1 Moon mission, launched on 24 October. Three ESTRACK stations were called on to track Chang'e-1 en route to the Moon and during the critical insertion into lunar orbit in early November.

The New Norcia deep-space station

Engineers at ESA's European Space Operations Centre (ESOC), in Darmstadt (D) were in voice contact with Chinese mission controllers at the Beijing Aerospace Command & Control Centre from 1 November. ESA's 15 m-diameter dishes at Maspalomas (E) and Kourou (French Guiana) were used first, and were then joined by 'DS1', the giant 35 m deep-space station at New Norcia, Australia. The three rotated tracking duties during Chang'e-1's cruise to the Moon, and were in contact during the critical orbit insertion manoeuvres of 5–7 November. At certain points, Chang'e-1 was not visible from China's own stations, making ESTRACK essential for mission success.

"*ESA's expertise in tracking Chang'e-1 sets the stage for future cooperation with China. The ESTRACK network is a resource that benefits not only the Agency but also all space science through such international cooperation*," said Erik Soerensen, Head of the System Requirements and Validation Section at ESOC.



This Envisat image of 22 October captures fierce easterly desert winds blowing smoke from wildfires in southern California, USA. Gale-force winds fed more than a dozen fires stretching from Santa Barbara to the Mexican border since breaking out the day before, killing more than a dozen people and forcing a million more from their homes in the biggest US evacuation since Hurricane Katrina two years ago. The firestorm ravaged at least 1825 sq km, destroying more than 1600 homes and wreaking over USD1 billion of damage. At bottom right, sand is being blown from Mexico's Baja California Peninsula over the Pacific Ocean to the west.

The scene was recorded by Envisat's MERIS (Medium Resolution Imaging Spectrometer) at a resolution of 300 m. MERIS images are available on ESA's MIRAVI website, accessible directly from ESA's homepage at *www.esa.int*

This Envisat/MERIS image from September highlights an ice-free Foxe Basin – a shallow extension of the Atlantic Ocean – in the Canadian territory of Nunavut. The Basin is ice-covered for most of the year. Located north of Hudson Bay between the Melville Peninsula (visible on the left) and the large Baffin Island (dominating the top and right), Foxe Basin connects with Hudson Bay (not visible but to the south) and Hudson Strait (located beneath Baffin Island) via the 320 km-long Foxe Channel. Baffin Island covers an area of some 507 451 sq km, making it the largest island in Canada and the fifth largest in the world. Stretching some 500 km at its widest point, the Basin is home to the last large landmasses discovered in North America. Prince Charles Island (the large round island in the centre), Air Force Island (to the east of Prince Charles) and Foley Island (off Prince Charles' northern tip) were all discovered in 1948 from aerial surveys.

Facing page: ESA's Columbus laboratory module is inserted into the cargo bay of Space Shuttle *Atlantis* ready for its December launch to the International Space Station, accompanied by ESA astronauts Hans Schlegel and Léopold Eyharts. *(NASA)*

Above: Europe's Meteosat meteorological satellite system marked the 30th anniversary of its first launch on 23 November. The development of Europe's first applications satellite was approved in 1972, creating the system that is now an integral and indispensable part of the world's network of weather satellites. Meteosat-1 was on-station over the prime meridian from 7 December 1977 and returned its first image (above) soon after; it delivered more than 40 000 until November 1979. The success led to the formation of Eumetsat (the European Organisation for the Exploitation of Meteorological Satellites). The seven highly successful first-generation satellites were succeeded by the second generation in 2004.

Publications

The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and Order Form inside the back cover

ESA Brochures

Agenda 2011 – A Document by the ESA Director General and the ESA Directors – October 2006 (September 2007)
D. Danesy (Ed.)
ESA BR-268 // 37 pp
Price: 10 Euro

SPACE Base Europe
How the International Space Station is Used to Improve Life on Earth and Continue our Exploration of the Solar System
G. Reibaldi & G. Caprara
ESA BR-270 // 236 pp
Price: 20 Euro

ESA Special Publications

ROME: Response of Organisms to the Martian Environment
C. Cockell & G. Horneck (Scientific Eds.),
J. Vago (Scientific Coordinator), C. Walker & K. Fletcher (Eds.)
ESA SP-1299 // 208 pp
Price: 40 Euro

The 6th Integral Workshop – The Obscured Universe, 2–8 July 2006, Space Research Institute (IKI), Moscow, Russian Federation (September 2007)
S. Grebenev, R. Sunyaev, C. Winkler, A. Parmar & L. Ouwehand (Eds.)
ESA SP-622 // 685 pp
Price: 60 Euro

Proceedings of the 6th International Symposium on Environmental Testing for Space Programmes, 12–14 June 2007, Noordwijk, The Netherlands (September 2007)
K. Fletcher (Ed.)
ESA SP-639 // CD
Price: 40 Euro

Proceedings of ESMATS – 12th European Space Mechanisms and Tribology Symposium, 19–21 September 2007, Liverpool, UK (August 2007)
A. Wilson (Ed.)
ESA SP-653 // CD
Price: 50 Euro

ISSI Scientific Report

The Physics of the Heliospheric Boundaries (November 2006)
V.V. Izmodenov, R. Kallenbach (Eds.) & B. Battrick (Publication Manager)
SR-005 // 413 pp
Price: 40 Euro

Planetary Systems and Planets in Systems (December 2006)
S. Udry, W. Benz, R. von Steiger (Eds.) & K. Fletcher (Publication Manager)
SR-006 // 312 pp
Price: 40 Euro

ESA Contractor Reports

Advanced High Rate Digital Modem – Phase 3 – Final Report (September 2006)
Space Engineering S.p.A.
ESA CR(P)-4590
Price: 25 Euro

Enabling Observation Techniques for Future Solid Earth Missions – Final Report (July 2004)
EADS Astrium, Germany
ESA CR(P)-4591 // CD
Price: 25 Euro

Characterisation and Modelling of Propagation Effects in 20-50 GHZ Band – Final Report (December 2006)
Politecnico di Milano, Italy
ESA CR(P)-4592 // CD
Price: 25 Euro

NOD – Near-Operational Demonstration of the Use of Satellite Systems for Fire Risk Management – Final Report (December 2005)
INSA, Spain
ESA CR(P)-4593 // CD
Price: 25 Euro

Bandwidth Efficient Burst Mode Demodulator (BMD-V2.0) – Final Report (July 2006)
Alcatel Alenia Space
ESA CR(P)-4594 // CD
Price: 25 Euro

ADM-Aeolus: Consolidation of Algorithms for Supplementary Geophysical Products – Cloud and Aerosol Backscatter and Extinction Profiling with the Spaceborne High-Spectral-Resolution Doppler Lidar – ALADIN – Final Report (February 2007)
Leibniz Institute for Tropospheric Research, Germany
ESA CR(P)-4595 // 118 pp
Price: 30 Euro

ALUSAT – ALways Up Satellite Terminals – Final Report (February 2007)
Integrasys
ESA CR(P)-4596 // CD
Price: 25 Euro

Satellite Networks Transport Architecture Project – Executive Summary (December 2005)
Skysoft, Portugal
ESA CR(P)-4597 // CD
Price 25 Euro

Assessment Test Programme for CW Pump Laser Diodes for Space Applications – Summary Report (November 2004)
Innolight
ESA CR(P)-4598 // CD
Price: 25 Euro

Assessment Test Programme for CW Pump Laser Diodes for Space Applications – Project PULAOS, Pump Laser for Solid State Laser Oscillators – Summary Report (January 2005)
Ferdinand-Braun-Institut, Germany
ESA CR(P)-4599 // CD
Price: 25 Euro

Validated Electromagnetic Modelling of Metal-Dielectric Photonic Bandgap (PBG) Structures – Final Report (November 2005)
TNO, The Netherlands
ESA CR(P)-4600 // CD
Price: 25 Euro

Wideband Low-Profile Antennas – Final Report (November 2005)
Univ. Catholique de Louvain, Belgium
ESA CR(P)-4601 // CD
Price: 25 Euro

Contract for Producing ESA Publications

ESA is outsourcing the production of its Scientific & Technical publications, such as the '4-digit SPs'. Typically around 20 publications per year are expected, principally on paper.

The invitation to tender is planned to be issued in January 2008. Expressions of interest from potential bidders can be sent until **31 December 2007** to Nandy Caneva of the General Procurement Service at:

Nandy.Caneva@esa.int

These potential bidders will then receive an email notifying them when the request for tenders is issued.

Please note that the contract is open only to companies from within ESA Member States