number 122 - may 2005

bulletin

SPACE FOR EUROPE

Ice Fields in FOCUS – The CryoSat Mission

European Space Agency
Agence spatiale européenne

european space agency

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(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
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Directeur général: J.-J. Dordain

Editorial/Circulation Office
ESA Publications Division
ESTEC, PO Box 299, Noordwijk
2200 AG The Netherlands
Tel.: (31) 71.5653400

Editors
Bruce Battrick
Barbara Warmbein

Design & Layout
Isabel Kenny

Advertising
Barbara Warmbein

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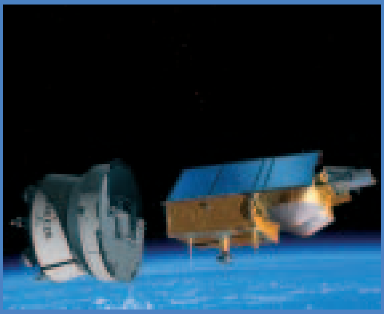
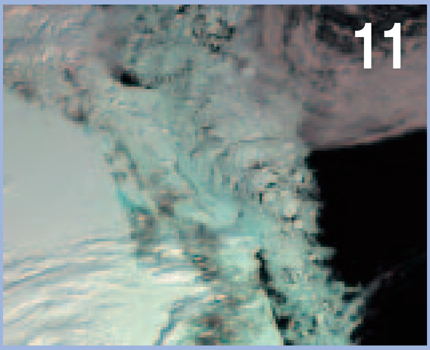
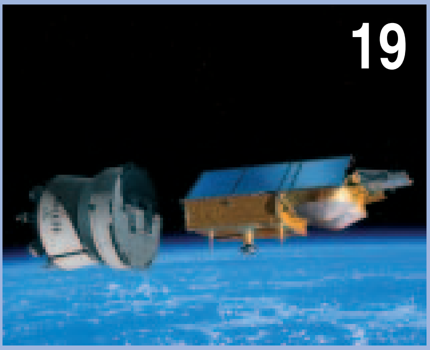


Cover: CryoSat at the moment of separation from the launch vehicle's upper stage
(Artist's impression by P. Carril)



CryoSat: A Mission to the Ice Fields of Earth



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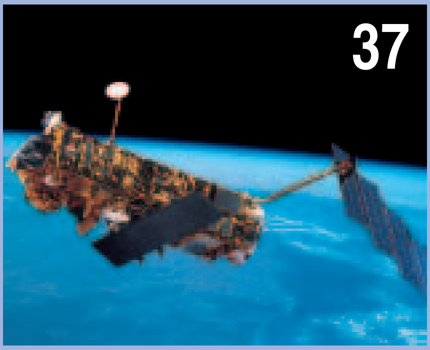

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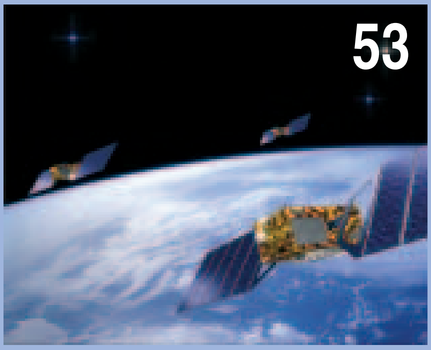

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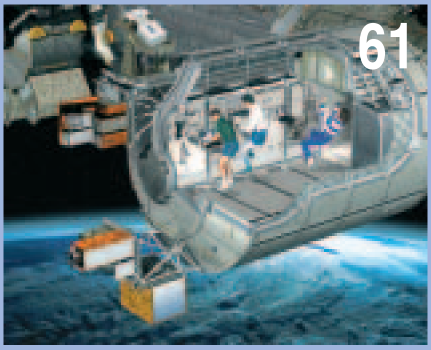

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Since 1991, when the Agency's first Earth-observation satellite ERS-1 was launched, ESA satellites have been providing scientists with crucial environmental data gathered from space. Climate change and the chemistry of our atmosphere, including ozone depletion and many other pressing questions, call for the availability of global satellite data sets if we are to gain a better understanding of the Earth as a global system. We still lack precise data sets showing the evolution of the sea ice and the land ice – a key parameter for the modelling and forecasting of our climate. This issue of the Bulletin carries a special feature on the soon to be launched Cryosat mission, whose data will fill this critical gap in our knowledge. The three articles provide an overview of this latest ESA Earth-observation mission, its scientific goals and the unique data products that it will provide.

Observation of the Earth has formed part of ESA's activities since the start of Meteosat meteorological-satellite operations in the late 1970s. Three ESA remote-sensing satellites – ERS-1, ERS-2 and Envisat – have also been launched and have provided a vast amount of data and novel scientific results. Currently, ESA is serving some 6000 users in the Earth-observation domain.

In 1999, ESA's Living Planet Programme was approved, its two main components being a line of satellite missions called Earth Explorers, and a Development and Exploitation element. The goal of the Earth Explorer missions is to provide the European scientific community with the tools that they need to better understand and monitor the Earth-system processes. The great complexity of the broad spectrum of processes to be addressed, the need for stability and flexibility, for a long-term undertaking, and for a fast response to rapidly evolving needs and possibilities, has led to two types of Earth Explorer mission being defined:

– the 'Core Missions', intended to address complex multidisciplinary issues, and

– the 'Opportunity Missions', intended to respond quickly to changing user requirements.

The realisation of these missions is supported by the Development and Exploitation component. Together, they constitute the ESA Earth Observation Envelope Programme (EOEP).

The forthcoming Core Missions are:

- GOCE (Gravity-field and steady state Ocean Circulation Explorer)
- ADM-AEOLUS (Atmospheric Dynamics Mission)
- EarthCare (Understanding the influence of cloud, radiative and aerosol processes in climate regulation)

while the Opportunity Missions selected are:

- CryoSat (Sea-ice and land-ice thickness trend)
- SMOS (Soil Moisture and Ocean Salinity)
- SWARM (Earth magnetic-field survey).

CryoSat is scheduled for launch this summer (2005) and will be the first of the Earth Explorer missions to go into operation. It is due to the urgency with which the variability of sea ice and land ice need to be investigated that CryoSat has been selected as the first Opportunity Mission of the ESA Living Planet Programme. It is considered to represent an important scientific milestone, paving the way towards a long-term environmental-monitoring programme for Earth observation known as 'GMES'. This Global Monitoring for Environment and Security programme (which will be described in the August issue of the ESA Bulletin) will provide Europe in the years to come with the tools and services necessary to monitor the life-sustaining environment of our home planet on an operational basis.

Volker Liebig
Director of ESA Earth Observation Programmes
ESRIN, Frascati, Italy

CryoSat: A Mission to the Ice Fields of Earth

The transport of Arctic sea ice east of the Greenland ice sheet captured in an Envisat MERIS image. Each year 2000 gigatons of sea ice is transported by the East Greenland current into the Greenland Sea, where, in melting, it moderates the salinity 'pumps' of the ocean conveyor

Prof. Duncan Wingham
CryoSat Lead Investigator
University College London (UCL), London, UK

The accurate prediction and observation of the ice masses at the poles, and particularly of their rates of change, is of interest to us all, not least because 5% of the Earth's population live just 1 metre above sea level. Native Arctic populations face profound changes to their way of life and even existence. Economic interests, associated with oil and gas and trans-Arctic shipping, will grow as the pack ice declines, as too may strategic concerns over the sovereignty of the Arctic Ocean. The loss of pack ice may also affect the circulation of the Atlantic, and with it the winter weather of Western Europe. CryoSat is ESA's first mission dedicated to the observation of the Earth's polar ice masses. Its goals are to determine if there is indeed a downward trend in the mass of Arctic sea ice, and whether we should regard Antarctica as under threat from global warming.

At the Melting Point

Viewed from space, the largest change in the appearance of the Earth over the next century will be the almost complete destruction of the Arctic polar cap. The ice covering the Arctic Ocean is a thin layer of frozen seawater, thickening each winter in the polar night, and thinning each summer in the Sun of the polar day. As atmospheric warming approaches the poles from lower latitudes, summer melting will expose the Arctic Ocean. Heat stored in the surface water will delay on the onset of freezing the following winter. Less ice will form and, year on year, the thickness and coverage of ice will decline until the Arctic Ocean takes on the blue of the ice-free oceans to the south.

The floating shelf edge of the West Antarctic ice sheet. In the Pine Island Bay, warm ocean currents have made their way beneath the fringing, floating shelves to melt the ice sheet at great depth at its point of floatation. This has triggered a flow from the inland ice accounting for one fifth of present sea-level rise (Photo courtesy of British Antarctic Survey)

A little further south lies the Greenland ice sheet, the one surviving relict of the great ice sheets that covered North America and Eurasia some twenty thousand years ago. Although a survivor, it is only just clinging on. Only its own height protects it from the winds that circulate around its base, which are far warmer than those during the period of its growth. Even so, half of the snow falling on its high plateau is lost through melting each summer. A small temperature rise of a few degrees is all that is needed for all of the year's snowfall to be lost each summer. Once that point is reached, the ice sheet faces inexorable and accelerating decline. The lower it falls, the warmer its surface becomes. In perhaps a thousand years, its three million gigatons of ice will have become seven metres of global ocean, completing what the arrival of the interglacial climate ten thousand years ago was not quite able to achieve unaided.

At Earth's southern pole lies the Antarctic ice sheet. Its defences to the threat of warming at lower latitudes are far more formidable than those of Greenland. Its pure white surface offers little storage for heat from the summer Sun, and in winter temperatures drop to minus sixty centigrade in the intense cold of the polar night. The zonal winds of the Southern Hemisphere, unimpeded by continents, insulate the Antarctic atmosphere from events further north, and a succession of ocean fronts maintain ever colder water as the ice sheet approaches. Even so, its ramparts may be breached. Warm water, whose source lies far to the north in the Atlantic, circulates around the Antarctic continent at depth, one thousand metres below the surface. In the western, Amundsen Sea sector of the continent, this water has broken the cordon of coastal fronts and gained access to the continental shelf. There, melting the ice-sheet base one kilometre beneath the surface, it has triggered an ice discharge that accounts for one fifth of the present rise in global sea level. Even the deep freeze of the Antarctic may not, it seems, be immune to our modest effort to change the Earth's surface temperature.

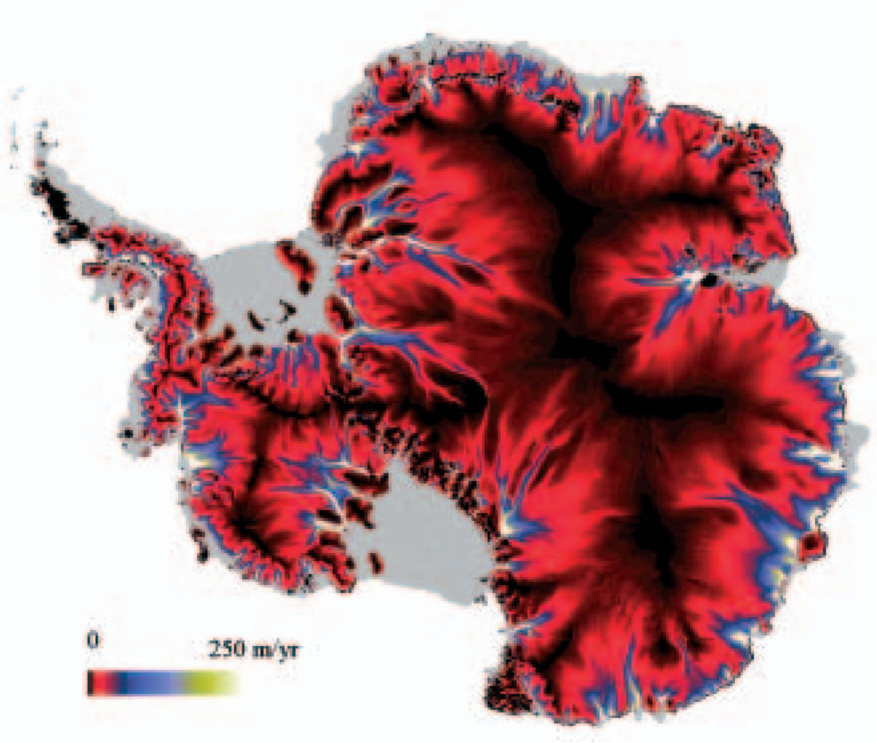
While the demands of thermal equilibrium make the bleak long-term future of Arctic ice a fairly sure one, the same cannot be said of the rate at which its decline will occur. The machinery of numerical climate models is less secure in

A hot-water drilling site in Antarctica. This photograph gives an impression of the difficulties facing scientific explorers at the poles, even in favourable circumstances (Photo courtesy of British Antarctic Survey) predicting the consequences of atmospheric warming than the fact of it. This is true of many predictions – the thermal expansion of the ocean is a good example. It is particularly true of the Earth's ice masses, for which models must capture the mass balance between snowfall, freezing and melting, and the dynamic balance between the forces of gravity, flow and the stress of the wind and ocean currents. Today, numerical models neither capture the observed year-to-year variation of Arctic sea ice, nor the decadal growth and decline of the Antarctic ice sheet. Observation of actual change retains the essential role of experiment in policing the theory of numerical simulation, nowhere more so than of the polar climate.

Has the Thaw Started?

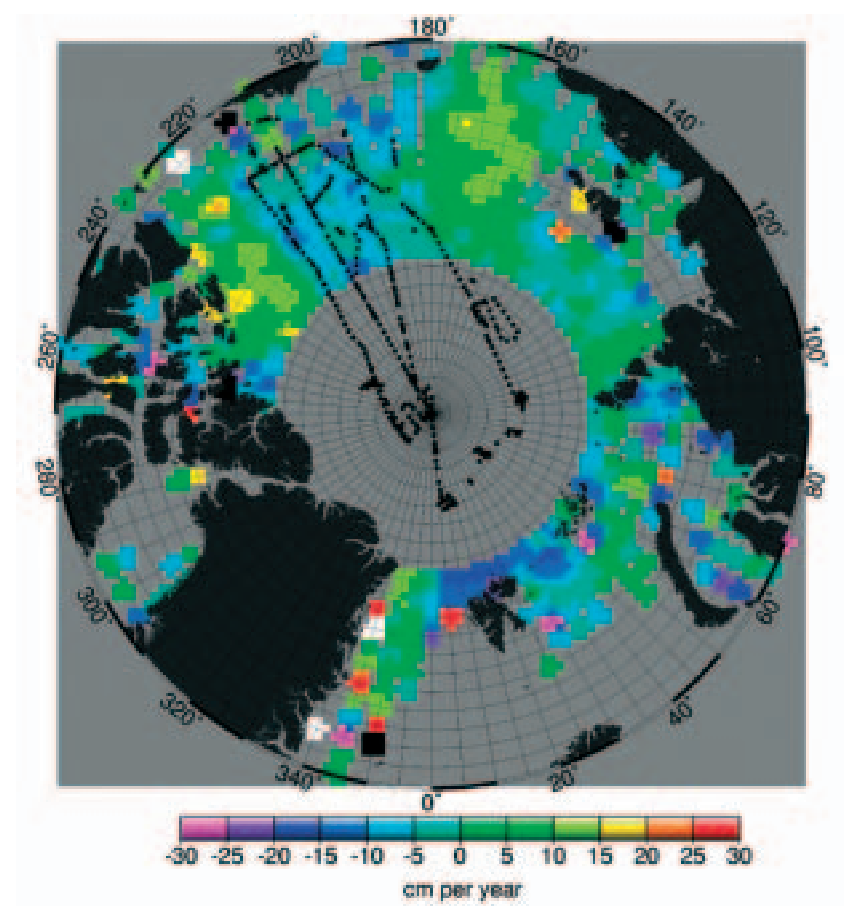
The first polar exploration dates from the early 20th century, and organised scientific exploration from the 1950s. Since then, some hundreds of scientists have returned each summer to survey the geology, physics, chemistry and biology of the poles. This is a considerable effort, underpinned by a logistics infrastructure that requires some 100 MEuro annually. It is, nonetheless, a thinly spread resource and the difficulties are impressive. The Arctic Ocean and Antarctic Ice Sheet are each the size of Western Europe. Sub-zero temperatures and violent storms are common at sea level. They are unpopulated, and dark for half the year. In both hemispheres, pack ice presents a difficult and sometimes dangerous obstacle to exploration. Given that the global scientific polar resource is roughly that of a single nation's effort in meteorology, one starts to appreciate why our knowledge of the poles towards the end of the 20th century was roughly that of Europe's knowledge of Africa towards the close of the 19th.

In consequence, understanding the poles has been an incremental process; each year's activity adding a small improvement to what went before. In addition, most measurements could only be interpreted by appealing to a 'mean' or 'climatology', that is, a time-invariant, state. This is not uncommon in the Earth sciences. When data is very sparse in space or time, the most conservative assumption in one of uniformity in the gaps. Where variability was encountered, in snowfall for example, the tendency was to average it away, to consign it to a very rapid variation that could be considered 'noise'. Working this way, there was by the 1980s a fairly good understanding of this 'mean' state: we knew the shape of the ice sheets and had a good idea of their depth; maps were available of the 'average' thickness of Arctic ice, and of the snowfall in both hemispheres. Numerical models, as is often the way, could match these mean states: the shape of the Antarctic and Greenland ice sheets could be reproduced with models that included simplified representations of ice flow and heat flux; and the distribution of Arctic sea ice was explainable by describing the ice as flowing like honey.



The ice streams of Antarctica. These frozen rivers of ice, up to 50 km wide and 3 km deep, extend deep into the Antarctic interior. They were the last great rivers of Earth to be accurately mapped, by this image derived from ERS-1 altimetry in 2000 (Copyright: Science, 2000)

By the mid-1980s, however, the pressing questions did not concern the mean state. They concerned the first derivative. How were the ice masses changing, and why? From the first, climate models predicted accelerated change in the Arctic as a result of a reduction in summer albedo. Was this observable? Antarctica may be too cold to be much affected by a slight warming, but it contained the equivalent of seventy metres of global sea-level rise: how much was in contributing to sea-level rise anyway? What was apparent was that these questions were unanswerable with the measurements available at that time. As late as 1992 a review concluded that, for all that we could be sure, Antarctica might account for all the observed rise in 20th century sea level, or none of it. It was not just trends that were unavailable. Even in 1998, when I came to specify the CryoSat mission, I could find no information concerning the natural variability of Arctic ice mass, and, if one doesn't know the natural variability, one can hardly distinguish our own, unnatural contribution to a climate fluctuation.



Arctic sea-ice thinning 1993 to 1999. For the first time, ERS altimetry provided a synoptic view of ice-thickness changes in the Arctic Ocean. The observations reveal areas of growth and decay, showing changes of up to 1 m over the six-year period (Courtesy of Seymour Laxon, University College London).

The Contribution of the ERS Satellites

What has started to alter this state of ignorance is a very twentieth century method of exploration: Earth-orbiting satellites, and, in particular, the European ERS satellites. Hyperbolic claims for Earth-orbiting satellites are often made, but it is in fact difficult to exaggerate the impact that these satellites have had in recent years. The ERS satellites carried active microwave radars to polar latitudes for the first time. Accurate radar altimetry at latitudes greater than 72 deg became available, and the last great rivers of Earth – the ice streams of Antarctica – were mapped throughout their length for the first time.

Another technical advance underpinned the ERS missions. The 1980s saw an order-of-magnitude improvement in the accuracy of low-Earth orbits. Better knowledge of Earth's gravity field and the arrival of microwave tracking systems made orbits accurate to 5 cm routine by the mid-1990s and, by sufficient averaging of data, changes as small as 1 cm per year became detectable. For the first time, a measurement system was in place to make accurate measurements of changes in Antarctic ice mass. In just four years of the ERS mission, the uncertainty in Antarctica's contribution to sea level had been halved. Moreover, a picture started to emerge, becoming more focussed year-on-year, of the regional changes in Antarctic ice.

What has made these Antarctic observations especially powerful has been another innovation of the ERS satellites: satellite radar interferometry. An ice sheet is a balance between ice accumulating through snowfall and ice lost through flow to its margins. Changes due to snowfall may be ephemeral; they may thicken an ice sheet one decade and thin it the next. Changes due to flow, however, particularly if they are spatially extensive, have a longer-term significance. The two may be distinguished if the pattern of thinning can be correlated with the pattern of flow. In the event, just as ERS altimetry was providing Antarctic thinning, ERS SAR interferometry was providing the detailed pattern of flow. We now know that a steady draw-down of a sector of West Antarctica is providing one fifth of the present rise in global sea level.

The other great innovation of the ERS was the discovery, by my colleague Seymour Laxon, that its radar altimeter echoes were sensitive, if closely examined, to the difference in height – some 20 cm – between sea-ice floes and the ocean surrounding them. Since we know the density of the ice and the sea water with some accuracy, this measurement, with some help from Archimedes, provides the thickness and mass of the ice floes. The discovery provided synoptic maps of ice thickness of large sectors of the Arctic Ocean and, with time, its temporal variability. It became possible to investigate with confidence how the total mass of ice varied from year-to-year, and how, year-on-year, the action of the ocean and the winds redistributed ice around the Arctic. For the first time, the natural variability of Arctic ice could be securely examined.

What makes the polar results of the ERS missions all the more surprising is that they were obtained opportunistically. The inclination of the ERS orbit was a consequence of the Sun-synchronous design of the SPOT platform; the altimeter was based on a design dating from the 1970s whose original purpose was to measure the ocean geoid. (Envisat, which extends the climate records of the ERS missions, has the same orbit and essentially the same altimeter design.) Viewed with polar spectacles, the orbit and radar altimeter have signal weaknesses. In both hemispheres, the orbit leaves

	Sea ice **10^5 km^2 at 50°**	**Ice Sheets** **10^4 km^2 at 70°**	**Ice Sheets** **13.7 x 10^6 km^2**
Residual uncertainty	5.3 cm/yr	11 cm/yr	0.7 cm/yr
Measurement requirement	1.6 cm/yr	3.3 cm/yr	0.21 cm/yr
Predicted accuracy	1.2 cm/yr	3.3 cm/yr	0.12 cm/yr

Table 1. CryoSat performance and measurement accuracy for its nominal three-year mission duration

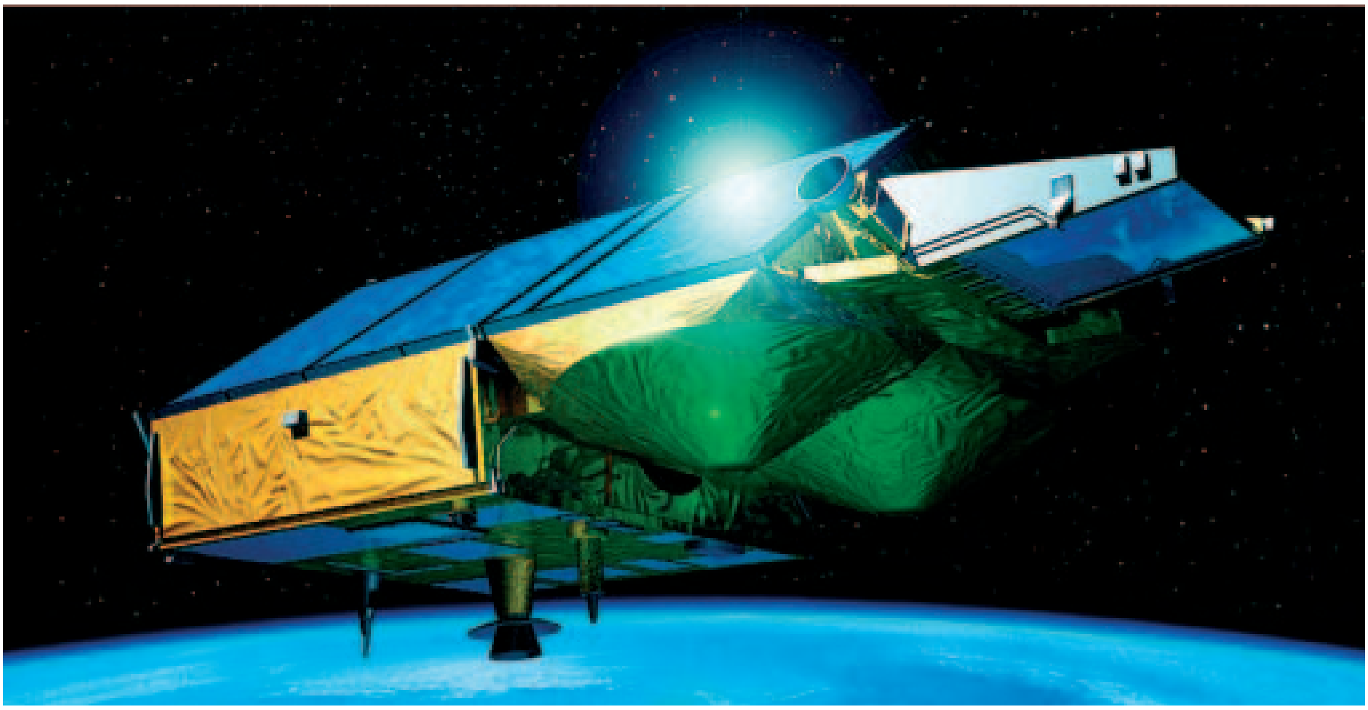
unsurveyed the 9 deg of latitude nearest the poles. The historical records of Arctic sea-ice thinning hint, at least, that the largest thinning falls in the missing sector. Moreover the region around North Pole marks the separation of Canadian- and Greenland-bound ice. To understanding the variability and the trend, the polar 'hole' needs filling. In the south, the 'hole' includes the southerly Ross Ice Shelf ice streams, which may, or may not be pursuing an on-going retreat from the last ice age.

The ERS and Envisat altimeters resolve only the largest of sea-ice floes; some 90% remain unsurveyed. The consequence of this is that the measurement density is low, and only by averaging over large space or time scales can usefully accurate measurements be made (typically, half of the observed Arctic). A great deal of the interaction of the ice with the wind and ocean is hidden from the measurements. The design also fails to deal with the marginal slopes of the ice sheets. This is more serious than it sounds: although comprising only 17% of the area, more than 35% of the snow falls in these marginal regions, and these are the regions most exposed to a warming atmosphere (in the Arctic) or ocean (in the Antarctic).

CryoSat – Starting with a Clean Sheet

CryoSat is ESA's first satellite that is dedicated to observing changes in the polar ice masses. It has two goals. Firstly, the mission seeks to build a detailed picture of the trends and natural variability in Arctic sea ice, and provide a dataset with which to examine the roles of the atmospheric and oceanic heat fluxes, and the winds and the ocean currents, in redistributing ice in the Arctic Ocean from year to year. Secondly, the mission seeks to completely observe the trend in thinning rate of the great ice sheets of Antarctica and Greenland.

How accurately must it do this? The performance of a satellite mission is simply the uncertainty that remains at the end of the mission. If one aims to measure a trend, one can never do this better than the limit allowed by natural variability. CryoSat has been designed to ensure that the residual uncertainty in ice trends is no more than 10% greater than the limit of natural variability; speaking more loosely, it has been designed so that the measurement error is a great deal smaller than the variations of the ice sheets



Artist's impression of CryoSat in orbit. The twin dishes of the interferometer are prominent in the foreground, with a star-tracker baffle apparent on the zenith face of the interferometer bench. The DORIS, X-band and S-band antennas are visible on the nadir panel, which is also the principal radiating face of the satellite. The triangular 'nose' is also a radiator. Body-mounted GaAs solar panels cover the zenith faces themselves. For the three years of the mission lifetime (a budgetary and not a scientific constraint), this leads to the mission requirements in Table 1.

Clearly, the scientific importance of CryoSat would be even greater if the mission were to be repeated. This said, the performances listed in Table 1 are sufficient to ensure that CryoSat, during its lifetime, will both allow us to determine whether the trends in sea-ice thickness reported from sparse historical submarine records reflect the onset of global warming or merely the ephemera of atmospheric variability, and reduce the uncertainty regarding the contribution of the Antarctic and Greenland ice sheets to sea level to that of other sources of ocean volume. In any case, CryoSat's performance is, more or less, as good as it may get: further improvements in measurement accuracy would have very little impact on the residual uncertainty.

This approach to specifying the mission requirements is very different from the past. Then, performance was an opportunist outcome. Here, we have started with a clean sheet. What new challenges result? As an oversimplified summary, the performances in Table 1 demand at the smaller spatial scales an improvement of three to ten times that of missions of the ERS and Envisat class. At the largest spatial scale, they also demand truly polar coverage. To meet these performances with an altimeter mission, one has at one's disposal, essentially, the accuracy of an individual measurement, the spatial sampling density, and the orbit inclination. In fact, the accuracy of an individual CryoSat measurement is similar to those of its predecessors; it is improving the sampling density that provides the order-of-magnitude improvement demanded by Table 1.

Sampling density is determined by the length of orbital track per unit area (or number of crossovers per unit area), the along-track sampling interval of the transmitted pulses (which cannot be greatly increased) and, crucially for an altimeter, the proportion of measurements successfully retrieved from the radar echoes. By selecting a retrograde orbit inclination of 92°, the orbit sampling at latitudes greater than 70° is greatly increased (by up to two orders of magnitude) over that of lower inclinations. Selecting a long repeat cycle (369 days) further improves on the orbit cross-over density of earlier missions (while maintaining a 30-day sub-cycle ensures monthly sampling of the moving sea ice). A 92° inclination does not quite provide complete coverage (some 5 x 10^5 km^2 of a total ice sheet area of 13.7 x 10^6 km^2 is lost), but pushing the inclination further polewards has a heavy penalty in terms of orbit sampling between latitudes of 70° and 80°.

As we have noted, for instruments of the ERS and Envisat class, the retrieval probability is less than 0.1 over sea ice, and close to 0 over the ice-sheet margins. The performances of Table 1 also demand a new class of instrument. The problem is essentially one of instrument resolution. Pulse-limited altimeters can resolve the freeboard of only the largest sea-ice floes, and the complex geometry of the ice margins makes their echoes too complicated to interpret. The CryoSat radar, 'SIRAL', meets this demand through two innovations. Firstly, the resolution is improved by a factor of 10 by the addition of synthetic-aperture processing in the along-track direction. By reducing the resolution to 1 km from 10 km, we expect to improve detection probability to some 70% of sea-ice floes. Secondly, by adding an additional antenna in the across-track direction, radar interferometry may be used to determine the direction of the echoes from the complex topography of the ice-sheet margins. We expect that this, together with the reduction in clutter provided by the synthetic processing, will raise the detection probability in the marginal regions to around 0.4. Taken together, the actual design of CryoSat's orbit and altimeter result in the predicted measurement accuracy given in the final row of Table 1, which meets, or is even slightly better than the required accuracy.

The Technical Challenge

Starting with a clean sheet is all very well, but one has to implement the consequences. Certainly there are significant technical demands compared with earlier radar-altimeter missions. The sampling demands of synthetic-aperture processing push the instrument into the high-bit-rate class – at 400 Gbit/day, the CryoSat data-rate is already 20% of that of the 13-sensor Envisat mission. The introduction of interferometry at 13.6 GHz places stringent demands on the mechanical stability of the interferometer baseline and on the phase stability of the radio-frequency (RF) and intermediate-frequency (IF) receivers, and on the internal calibration system. This is made more difficult by the range of solar illumination angles resulting from the orbit. The addition of interferometry also demands improvements in attitude knowledge: star-trackers must replace horizon sensors. There are other less-demanding but significant changes needed: upgrading of the radar power amplifier, for example.

Nonetheless, none of these demands were sufficient to question the practicality of the mission. The real practical challenge of CryoSat was its implementation within the target (1998) Opportunity Mission budget of 100 MEuro. That it has been possible at all is undoubtedly due to a number of historical factors. The first is the heritage of European industry. The Champ and Grace missions provided a high-inclination, non-Sun-synchronous, low-cost bus design that employed the Earth-facing panel as the principal radiator and used oversized, body-mounted solar panels to avoid deployables. The Topex/Poseidon and Jason missions also provided a heritage of high-performance radar-altimeter hardware that has, in the event, proved more than adequate to meet the new demands of interferometry. The second is the emergence (as an unexpected consequence of the Strategic Arms Limitation Talks) of inexpensive Russian launchers (in the case of CryoSat, based on the SS19 rockets). Thirdly, there has been the development of relatively inexpensive star-trackers based on CCD technology. Finally, the development of the Envisat ground stations at Kiruna and Svalbard, coupled with the arrival of inexpensive solid-state memory, will permit inexpensive operation using a single ground station.

In some respects too, the mission has been ruthlessly designed to cost. To maintain a single ground station approach, the use of the synthetic-aperture modes is limited (more or less) to the regions of sea ice and the margins of the ice sheet. Elsewhere, a conventional, low-bit-rate, pulse-limited mode is employed. The data acquisition, processing and distribution to users is carefully limited in its functionality. (This said, what spare capacity exists is now being employed to provide at least experimental use of the high-bit-rate modes over land and ice-free ocean surfaces, and a 'near-real-time' ocean wind and wave product is being implemented within the ground segment.) Perhaps more important is the recognition that a lower-cost mission demands an increase in risk; in particular, some elements of the radar will fly non-redundant.

There is one other factor that deserves comment. The low cost (and implicitly compressed schedule) of CryoSat has undoubtedly made higher-than-usual demands on the small Agency and industrial teams responsible for CryoSat. The level of this demand was perhaps not foreseen at the outset, but it has nonetheless been met across the board, and this too has been a major factor in meeting the constraints of a low-cost mission.

The Contribution of the CryoSat Mission

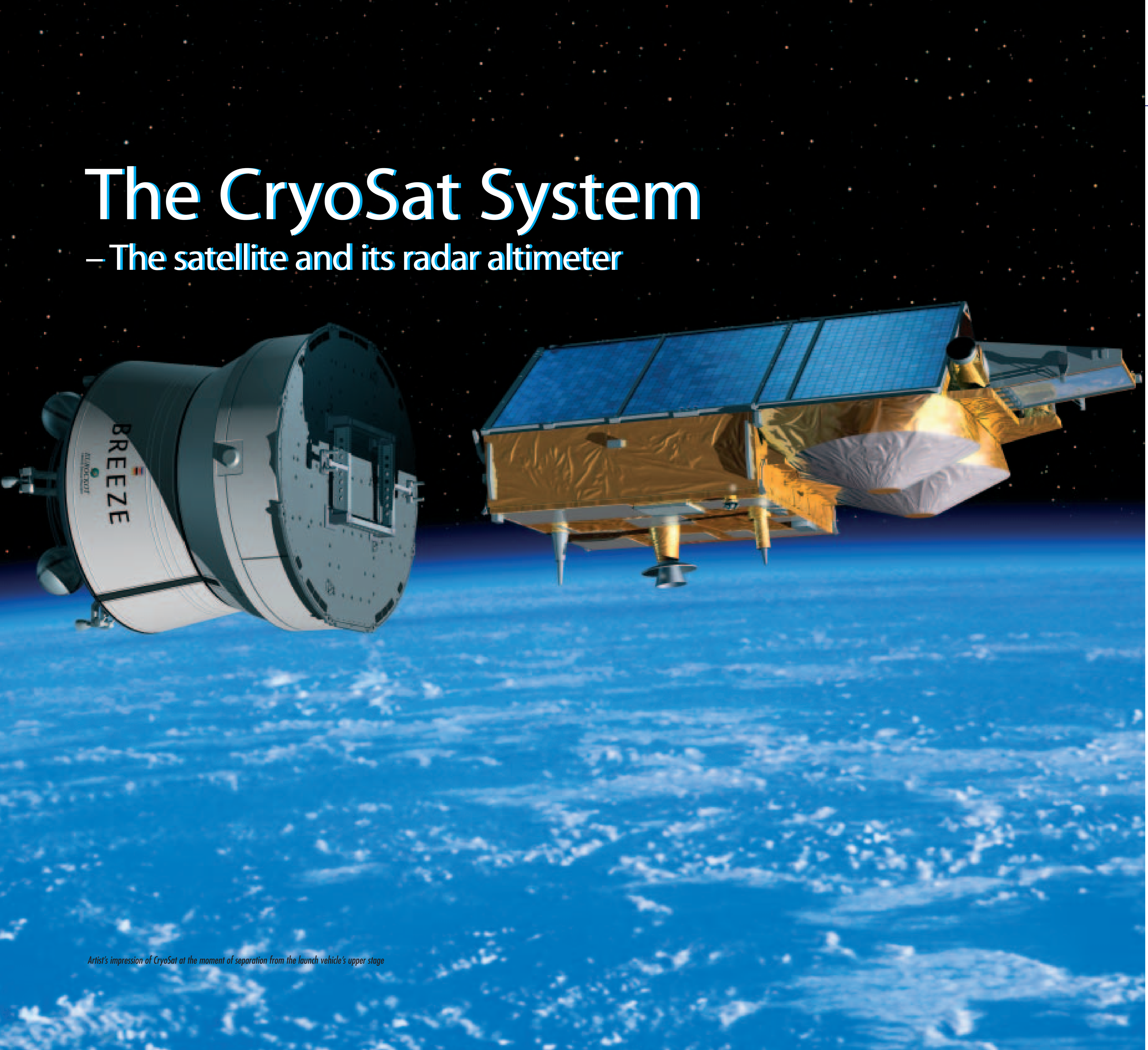
Without question, the most pressing question concerning the poles is whether our actions have already started an irretrievable process of climate change, and how fast this is happening. The measurements of CryoSat will not (any more than any other satellite) answer this question directly. For one thing, heat in the atmosphere and ocean is not separated into parcels, one of which is conveniently labelled 'anthropogenic contribution'. Ice mass, particularly sea-ice mass, is a sensitive measure of a warming atmosphere, but the problem of attribution remains. If one had a very good dynamic (that is, theoretical) description, it might perhaps be possible to identify the special character (the 'fingerprint') of an anthropogenically forced change, but it would be a brave act to claim that today for the polar ice bodies. The alternative is to have a good enough empirical record of the past situation that an anthropogenic change may be distinguished. It is in providing that empirical record of the natural variation that CryoSat will make its particular contribution.

CryoSat aims at measuring the ice mass budget. Like any fluid, this leaves open the momentum and energy budget. Here, however, the value of Cryosat measurements will be greatly increased by combining them with ice dynamics determined from SAR measurements, and in particular those of Envisat's global-monitoring mode. Taken together, the two data sets bear directly on two of the three conservation equations governing their flow. This is an approach that has already borne fruit in understanding Antarctic ice flow. For a very considerable time, the complexity of models of sea-ice flow has exceeded the capacity of measurements to criticise them. If scientists can grasp the nettle of combining these two data sets, new, more reliable predictions will result.

CryoSat is also a technical experiment. Its radar has not been flown before, and the mission has yet to prove that its payload may one day form the backbone of an operational system. In selecting a radar, Europe has taken a different path from the United States, which with Icesat attacked the resolution problem through laser altimetry. The selection of a particular technology is not an issue of principle, but of cost. In fact, there is reason to suppose that each technology has its advantages. The missions will overlap, however, and in observing the same ice will provide an opportunity to design an optimal 'operational' mission. It is worth reflecting that it has taken twenty years to perfect the ocean altimeter and to build modelling and assimilation tools with which to best use its observations. Seen against this background, there is every reason to expect that CryoSat will be a truly memorable mission.

The CryoSat System

– The satellite and its radar altimeter



Artist's impression of CryoSat at the moment of separation from the launch vehicle's upper stage

Guy Ratier, Richard Francis & Constantin Mavrocordatos
CryoSat Project, ESA Directorate of Earth Observation, ESTEC, Noordwijk, The Netherlands

Reinhold Zobl
Head of Earth Observation Programmes Department, ESA Directorate of Earth Observation, ESTEC, Noordwijk, The Netherlands

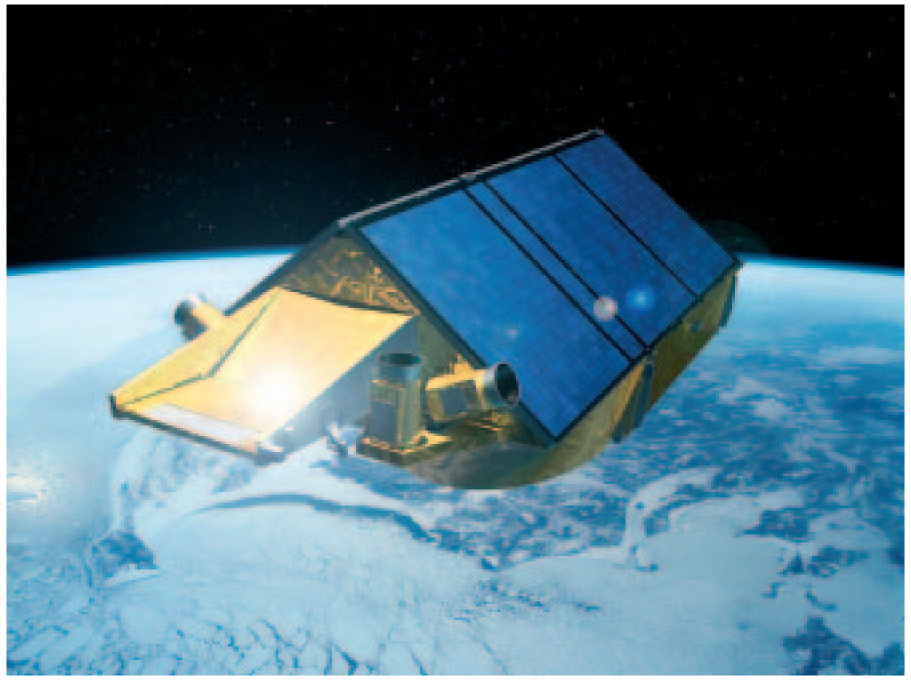
In the preceding article Prof. Duncan Wingham has outlined the genesis of CryoSat, its scientific objectives and its programmatic constraints. The mission objectives are characterised by the determination of small height-related changes over a three-year period. This imposes requirements on the type of measurements to be made, the physical stability of the system, control of the measurement configuration, and consistency in the data-processing system. The programmatic constraints, on the other hand, may be simply characterised as the need for a relatively short development cycle with a stringent cost ceiling.

CryoSat is a fully integrated system in which all of the elements have been developed together within the programme to ensure the control needed to satisfy the mission objectives. However, in the interests of readability, the system's description has been split over two articles: this one describing the elements that are to be launched into space, and the following one those parts that will remain on Earth.

Precision Measurements from Space

The CryoSat satellite is the part of the system that makes the measurements. The fundamental measure is the distance from the satellite to the Earth's surface below, and for this a radar altimeter is used. Given the enormous success of the ERS radar altimeters over icy surfaces, this was a natural choice.

CryoSat's radar altimeter is called SIRAL, a contraction of SAR (Synthetic Aperture Radar) and Interferometric Radar



Artist's impression of CryoSat in orbit, flying almost towards the viewer. The prominent features visible are the solar arrays, giving a roof-like appearance, and the three star trackers which are mounted on the rigid structure supporting the SIRAL antennas. The structure forming the 'nose' at the very front of the satellite is a thermal radiator for the heat generated by the SIRAL instrument

Altimeter, and this indicates where improvements have been made in the instrument concept. As well as a conventional mode, which offers continuity with earlier missions, SIRAL can also operate in so-called 'synthetic-aperture mode'. This increases the along-track resolution, enabling it to more readily distinguish the narrow 'leads' of open water between sea-ice floes. Over the rough terrain at the edges of the major ice sheets, this increased along-track resolution is further augmented by across-track interferometry using the second antenna and receive channel. The derived angle of arrival of the radar echoes allows more precise identification of the point from which the echo came.

SIRAL makes measurements of the range to the surface that are very precise: each has an uncertainty of just a few tens of centimetres. The averaging of many such measurements brings the system performance to the level needed to satisfy the mission objectives. However, the precise measurement of range alone is insufficient. The exact position of the satellite at the time of each measurement is needed to convert this simple measure of range into something scientifically meaningful, which is the height of the surface above some known reference. We may talk loosely of height above sea level, but in this demandingly precise application we refer to height above a 'reference ellipsoid' – an exactly defined, almost spherical surface that closely approximates to the shape of the Earth. To determine the satellite's position, and thus its height above this reference ellipsoid, measurements from some further payload items are needed.

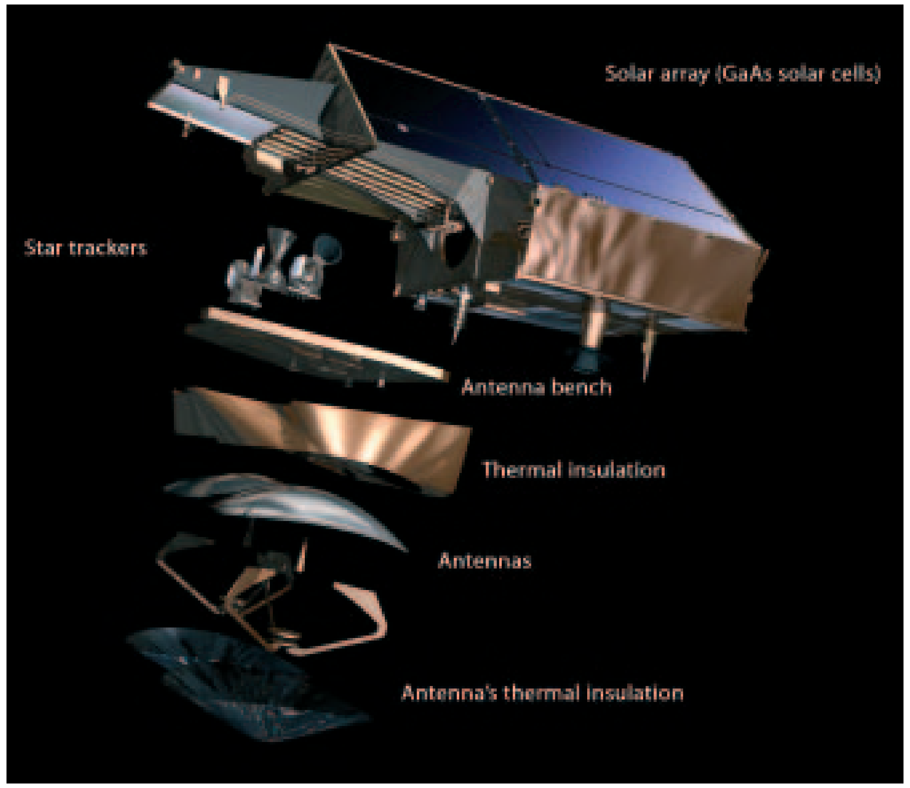
CryoSat includes a DORIS Receiver, a special radio receiver that picks up signals from a network of more than 50 transmitting stations evenly spread around the Earth. By measuring the Doppler shifts of these signals, the range-rate to each one can be determined. The accuracy of the orbit that may be computed from such a dataset obviously depends on several factors, not least the precision and accuracy of the Doppler-shift measurements. In this DORIS excels, and for over a decade the system has been the foremost means of making routine, high-precision orbit determinations. The DORIS receiver is augmented by a passive laser retro-reflector, which allows precise range measurements to be made by ground-based laser-ranging stations.

The final item in this collection of high-precision payload equipment is a set of star trackers, needed to complement the SIRAL interferometer measurement. SIRAL measures the angle of arrival of the echo in its own reference frame, i.e. with respect to the line joining the centres of the two antennas, the 'baseline'. Before that information can be used to identify the exact position on the Earth, we must know the orientation of that baseline, and in order to meet the mission objectives this measure must also be precise to within 30 arcseconds. This is the angle subtended by a football at a distance of 2 km.

The scientific mission objectives not only defined the type and accuracy of the measurements that had to be made (which led to the payload selection), but also their location and timing. As Prof. Wingham explains in the previous article, this 'where and when' is encapsulated in the definition of a specific orbit for CryoSat. The orbital inclination is 92° (and therefore retrograde), with a mean altitude of about 720 km, the exact altitude being defined by the required track-repeat characteristics. This orbit is not one of the class known as 'Sun-synchronous', for which the orbital plane maintains a fixed orientation with respect to the Sun, because, as we shall see later, this would have impacted on the satellite's design.

Designing the System

The full CryoSat system has several parts, and although will not describe here those that will remain on the ground, we will outline the overall architecture as this has an impact on the design of all of the elements. Programmatic constraints were dominant in this part of the system definition and led to the minimum configuration required to satisfy the mission objectives. The key feature is that a single ground station is used for CryoSat, both for command and control and for downlinking, processing and distribution of the science data. The ESA ground station at Kiruna in Sweden was selected. As well as enabling the sharing of resources with other on-going ESA missions, this choice resulted in manageable requirements in terms of handling the 3 to 4 consecutive orbits per day during which contact with the ground station is not possible.



Exploded view of the CryoSat spacecraft

The design of the CryoSat satellite was determined, as is always the case, by a number of key factors. From the mission-science objectives came the payload complement and its requirements, the orbit and the minimum lifetime. Programmatic constraints included the need to operate from a single ground station, launch on a 'small' and therefore low-cost launcher, extensive onboard autonomy, a low-cost design and a decision to forego the normal approach of building precursor, 'proof-of-concept' models of the satellite (structural model, engineering model, etc.).

While it is not the case that these driving factors led inevitably to the CryoSat design (indeed during the competitive feasibility-study phase, another entirely different concept was developed), it is true that the main features of CryoSat can be traced back to these drivers. A major role was also played by heritage from the CHAMP and GRACE satellites, which were designed against similar orbital and programmatic constraints.

So instead of a rather ponderous deduction of CryoSat's design from the mission's requirements and constraints, here we will take a 'reverse engineering' look at CryoSat to show how it responds to these drivers. We will start with the most obvious feature, its shape. So why does CryoSat look like dog kennel?

As mentioned earlier, the required orbit is not Sun-synchronous. Every day the orbital plane shifts to be almost 3 minutes earlier with respect to the Sun; in 8 months, therefore, it drifts through all local times. This means that the direction from which sunlight falls on the satellite is constantly changing. The operation of the SIRAL instrument demands that its antennas point towards the Earth's surface to within a few tenths of a degree, and furthermore that the two antennas are side-by-side as the satellite flies. This means that rotating the satellite to face the Sun is out of the question. Mechanisms on satellites are very costly and so the CryoSat geometry was arranged such that every orbit has enough sunlight on one or both of the solar panels to maintain a positive energy balance onboard.

This assumes, of course, that the solar panels have the intrinsic capability to generate enough power in the first place, if the Sun were shining directly on them. The requirement to fit CryoSat inside the fairing of a 'small' launcher put absolute constraints on the size of the panels, thus removing one of the key degrees of freedom in this equation. That only left one parameter to ensure sufficient power generation – the efficiency of the solar cells themselves. Thus CryoSat, as a low-cost mission, has ended up pioneering the use of new, high-efficiency solar cells in low Earth orbit. More about this later, but we can say right now that this choice was still cheaper than introducing fold-out solar panels.

The two SIRAL antennas are accommodated side-by-side near the front of the satellite. They are slightly elliptical in outline in order to fit within the launcher's fairing – which slightly complicates the scientific data processing, but has no impact on performance. We have already indicated that both the structural stability and knowledge of this assembly is vital to the mission performance, and the design has a number of special features to ensure this. In the calm environment of space, the principal enemy of stability is heat, which causes expansion. The first line of defence against that is to use materials that are least susceptible to it. We have mainly used Carbon-Fibre Reinforced Plastic (CFRP), which has a coefficient of thermal expansion close to zero. It is used for the antennas themselves and also for the substantial 'bench' on which they are mounted, and for the mounts for the star trackers fitted to this bench. We have also used invar, a low-expansion metal originally used for the pendulums of

Parameter	LRM	SAR	SARIn
Receive chain	left	left	left and right
Centre frequency		13.575 GHz	
Bandwidth		350 MHz	
Transmit power		25 W	
Noise figure		1.9 dB at duplexer output	
Antenna gain		42 dB	
Antenna 3 dB beamwidth (along-track)		1.0766°	
Antenna 3 dB beamwidth (across-track)		1.2016°	
Interferometer baseline	–	–	1.172 m
Samples per echo	128	128	512
Sample interval		0.47 m	
Range window	60 m	60 m	240 m
PRF	1970 Hz	17.8 kHz	17.8 KHz
Transmit pulse length		49 µs	
Useful echo length		44.8 µs	
Burst length	–	3.6 ms	3.6 ms
Pulses per burst	–	64	64
Burst repetition interval	–	11.7 ms	46.7 ms
Azimuth looks (46.7 ms)	91	240	60
Tracking pulse bandwidth	350 MHz	350 MHz	40 MHz
Samples per tracking echo	128		
Tracking sample interval	0.47 m	0.47 m	3.75 m
Size of tracking window	60 m	60 m	480 m
Averaged tracking pulses (46.7 ms)	92	32	24
Data rate	51 kbps	11.3 Mbps	2 x 11.3 Mbps
Power consumption	95.5 W	127.5 W	123.5 W
Mass		62 kg	

Key characteristics of the SIRAL

clocks.

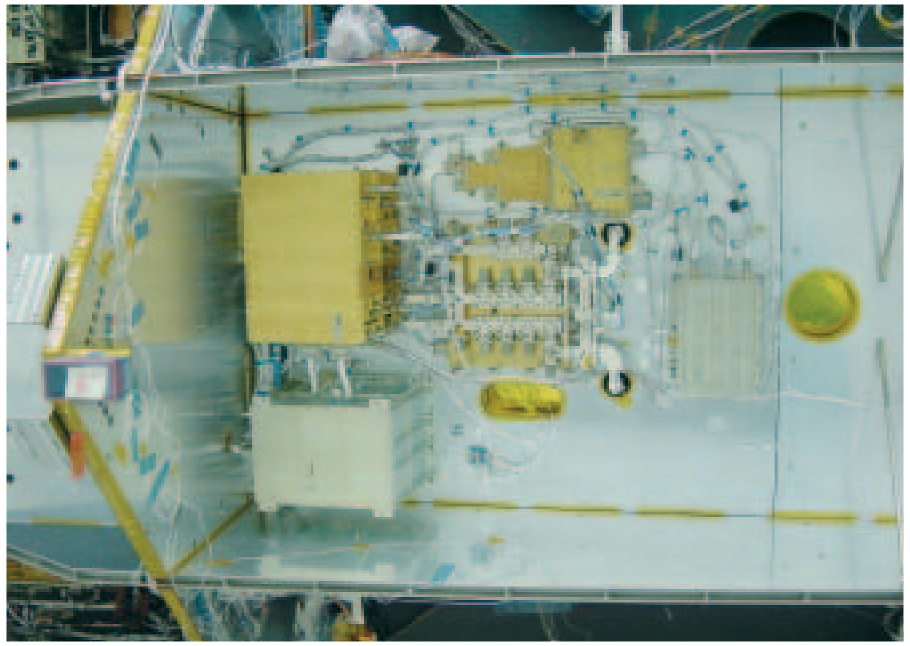
However, the majority of the satellite is made of aluminium, and so another vital part of the defence is isolation. The sensitive antenna bench is attached to the rest of the satellite by a three-point quasi-isostatic suspension, which minimises the transfer of thermal distortions and heat variations. The theme of isolation is carried further by the wrapping the bench and all its attachments with multi-layer insulation; even the antenna apertures are protected from the hot Sun by an exotic single-layer insulation coated with germanium.

The Payload: Re-use and innovation

Like all of CryoSat's equipment, the SIRAL radar altimeter is derived from existing equipment, in this case a conventional pulse-width-limited altimeter called Poseidon-2, which is currently flying on the US-French Jason mission. SIRAL is a single-frequency Ku-band radar, featuring some new design characteristics that enable it to provide data that can be more elaborately processed on the ground (a high pulse-repetition frequency and pulse-to-pulse phase coherence are needed for the along-track SAR processing). The across-track interferometry needs a second complete receiver chain, including the second antenna. These features make this instrument unique.

The electronics of the radar are divided into a number of separate units, principally for ease of manufacture and testing. One large unit houses all the digital electronics, and the remaining boxes contain radio-frequency circuitry and the transmitter's power supply. Several innovations were necessary compared to the Poseidon-2 equipment, most notably due to the need for significantly increased transmitter power, which led to the development of a complete new transmitter section, and in the provision of the second receive path.

A less obvious but far more pervasive change was the new need for phase stability, introduced by both the SAR and interferometric functions. Phase had never been an issue with previous altimeters, but for SIRAL it is critical. Consequently, the SIRAL development effort has seen much analysis, measurement, characterisation, optimisation and tuning, as well as the introduction of some special means of calibrating phase performance in flight.


The SIRAL electronic equipment mounted in the nose of the satellite

The antenna subsystem has not been immune to this. It was developed as a discrete item consisting of two Cassegrain antennas mounted side-by-side on the rigid antenna bench. The two antennas are identical, but one is used both to transmit and receive, whereas the other is used only to receive echoes. The Cassegrain design offers particular advantages for the SIRAL as the resulting waveguide lengths are much shorter than those required for the more common, front-fed design. The entire assembly went through a measurement campaign that challenged the capabilities of the test facility due to the exacting phase-measurement requirements.

We have already mentioned SIRAL's ability to operate in different modes. The *low-resolution mode* operates in the same way as a conventional pulse-width-limited altimeter and uses a single receive channel. The rate at which the radar pulses are transmitted is low, relatively speaking, at 1970 per second, and the echoes are transformed from the time domain to the spectral domain and averaged onboard. The data rate at which science data are generated in this mode is therefore low, at 51 kbps. This mode will be used over ice-sheet interiors, where the surface slopes are small. It will also be used over the ocean.

In the *SAR mode*, which also uses a single receive channel, the along-track horizontal resolution of the altimeter is improved during the on-ground processing by exploiting the Doppler properties of the echoes. The result is equivalent to decomposing the main antenna beam into a set of 64 narrower synthetic beams along-track. The footprints of the different sub-beams over a flat surface are adjacent rectangular areas ~250m wide along-track, and as large as the antenna footprint across-track (up to 15 km). Consequently, a larger number of independent measurements are available over a given area, and this property is used to enhance the accuracy of the measurements over sea ice. To ensure coherence between the echoes from successive pulses, the pulse repetition frequency is about 10 times higher than for the low-resolution mode. The instrument operates in bursts, with a group of 64 pulses transmitted together, followed by a pause during which the echoes arrive. The echoes are then stored onboard in the time domain, without any averaging. Therefore, the data rate is significantly higher, at 11.3 Mbps.

The *SAR-Interferometric mode* (SARIn) is used mainly over the ice-sheet margins, where the surface slopes are high. The combination of SAR and interferometry makes it possible to accurately determine the arrival direction of the echoes both along and across the satellite track, by comparing the phase of one receive channel with the other. In this mode, both receive channels are active and the corresponding echoes are stored in the time domain. The data rate is about twice as high as for the normal SAR mode. In order to cope with abrupt height variations, the range-tracking concept for this mode has to be particularly robust. In SIRAL, this is ensured by using narrow-band tracking pulses, transmitted between successive wideband measurement bursts.

CryoSat's DORIS receiver is part of an overall system that is able to provide orbit tracking measurements and time-transfer. The DORIS system consists of a network of more than 50 ground beacons, receivers on several satellites in orbit, and ground-segment facilities. It is part of the International DORIS Service (IDS), which also offers the possibility of precise location of user-beacons.

Each beacon in the ground network broadcasts two ultra-stable frequencies (at 2036.25 and 401.25 MHz). The use of two frequencies allows the ionospheric effects to be compensated for. Every 10 seconds, the onboard receiver measures the Doppler shift of these signals using an ultra-stable oscillator as a reference; this essentially enables the line-of-sight velocity to be determined. The set of radial velocities from the dense network of precisely located beacons forms a rich set of tracking data. The full set of DORIS Doppler measurements goes through a lengthy quality-control and checking process within the ground segment (at CNES, as explained in the following article) before a final, high-precision orbit determination is performed: this is the stable reference needed to extract the most subtle signals from the SIRAL measurements.

The DORIS system includes the

possibility of encoding information on the uplinked signals, and two privileged master beacons, at Toulouse and Kourou, provide such uplink services. Data uplinked from these stations (which is updated weekly and used by all DORIS instruments in orbit) include the coordinates of the stations, Earth-rotation parameters, etc. The uplinked data also include time signals that allow synchronisation of the DORIS internal time reference using the International Atomic Time (TAI) system.

These data are needed onboard because DORIS is able to make real-time orbit calculations from the data it collects, though with significantly less accuracy than the final precise orbit determination. However, this real-time orbit knowledge has expected errors of less than a metre and is used onboard by the central flight software to control the satellite's pointing (more on this later). Associated with position, DORIS also computes time, accurate to about 10 microseconds, which is also used onboard as the master clock.

A final onboard service offered by DORIS is the provision of the reference frequency to the SIRAL instrument, which does not have its own ultra-stable oscillator. The frequency of the DORIS oscillator is continuously monitored as part of the precise-orbit-determination service, and this measurement is taken into account in processing the SIRAL data.

CryoSat includes a set of three identical star trackers, which are the only means of determining the orientation of the SIRAL interferometric baseline. They are also the principal three-axis attitude measurement sensor in the nominal operating mode. They are lightweight, low-power-consuming, fully autonomous devices. They are accommodated such that the Sun and Moon can each blind only one head at any time; this makes the whole sensor system single-failure tolerant. The star-tracker algorithm is optimised to use rather faint stars, of around magnitude 5. Barely visible to the naked eye except at dark sites, they are far more numerous than the brighter stars and provide many more triangulation possibilities for the pattern-matching process in all directions of the sky.

The final element of the payload is the laser retro-reflector, a passive optical device for ground-based measurement of the satellite's orbit by laser-ranging stations. Such reflectors are used on all radar-altimeter satellites, and several other spacecraft also. The device on CryoSat is based on an existing design that has been flown on many Russian and other satellites.

What Makes it Tick?

All of the data generated by CryoSat's scientific payload have to be recorded onboard as the satellite is only in contact with its single ground station for brief periods. Typically there are 10 passes of 5 to 10 minutes duration each day, occurring on consecutive orbits. These contacts are followed by a gap of 3 or 4 'blind orbits'. To handle the large data volume, a 256 Gbit data recorder is installed. Following the modern trend, this is realised as solid-state memory with literally thousands of RAM chips. The unit is derived from similar equipment on ESA's Mars Express spacecraft and, of course, comprehensive memory-management and data-handling functions are built in. It can continue recording data as it replays its memory into the data link to the ground station.

This downlink is a potential bottleneck because the total contact time is relatively short. To overcome this, the downlink data rate is especially high; at 100 Mbps, it is more than 12 times as fast as the best ADSL Internet access available in The Netherlands. Again this approach is built on heritage, this time from ESA's MetOp mission, with the frequency and bandwidth reused from an allocation originally given to EnviSat.

CryoSat is an unusual satellite in that it has virtually no moving parts, the only exceptions being a couple of valves in the propulsion system. This has led to savings in cost as well as testing. One area where this lack of moving parts is particularly noticeable is in the attitude and orbit control subsystem, where gyroscopes and reaction wheels are usually commonplace.

Attitude control for CryoSat is innovative since it principally exploits two of the payload equipment items, another example of re-use. The star tracker provides real-time measurements of the satellite's orientation with respect to the stars, which together with the DORIS time and orbit information allows the onboard software to calculate the satellite's orientation with respect to the Earth.

Measurement is half of the problem: it is also necessary to produce torques that will turn the satellite as needed to keep it Earth-pointing within the required tolerance. CryoSat's main means of generating such torques is to use electromagnets interacting with the Earth's magnetic field. The devices themselves, called 'magnetotorquers', are simply multiple turns of wire wrapped around a ferrite core, powered by a controllable electric current from the main computer. Magnetotorquers cannot produce torque around the direction of the Earth's field itself, and this direction constantly changes with respect to the satellite. So a 'backstop' control in the form of a set of small cold-gas thrusters guards against excessive pointing errors. These are very small indeed, with a thrust of 10 mN – about the same as the weight of 1 cc of water. Simulation has shown that these will need to fire for a total of about 3 seconds per orbit. Although this is not long, it will, together with the gas used by the two 40 mN thrusters to maintain the orbit in the face of air-drag, eventually consume the 35 kg of pressurised nitrogen onboard.

The attitude-control system has other sensors too, which are used during the initial stabilisation after separation from the launcher, and in emergencies. These are a set of magnetometers and an ingenious sensor, the combined Earth-Sun sensor, which measures the temperature difference between a black and a mirrored surface on each face of the satellite. A clever piece of software then calculates the direction to both the Sun and the Earth.

Putting it Together

One of the key means by which the CryoSat programme has been able to compress schedule and cost has been through a bold early programmatic decision. The idea was that by embracing existing equipment designs and building-

CryoSat in a Nutshell

CryoSat Mission
To determine fluctuations in the mass of the Earth's major land and marine ice fields.

Mission Duration
Six months of commissioning followed by a three-year operational mission.

Mission Orbit

Type:	LEO, non-Sun-synchronous
Repeat cycle:	369 days (30 day sub-cycle)
Mean altitude:	717.212 km
Inclination:	92°
Nodal regression:	0.25° per day

Payload
SIRAL (SAR/Interferometric Radar Altimeter):

- Low-Resolution Mode provides conventional pulse-width-limited altimetry over central ice caps and oceans.
- SAR Mode improves along-track resolution (~250 m) over sea ice through a significantly increased pulse-repetition frequency and complex ground processing.
- SAR Interferometric Mode adds a second receive chain to measure the cross-track angle of arrival of the echo over topographic surfaces at the margins of ice caps.

Star Trackers (3) measure the interferometric baseline orientation, as well as driving satellite attitude control.

DORIS enables precise orbit determination, as well as providing in-orbit position to the AOCS.

Laser Retroreflector enables tracking by ground-based lasers.

Configuration
- Simplified rigid structure with no moving parts.
- All electronics mounted on nadir radiator.
- SIRAL electronics mounted close to antennas.
- SIRAL antennas on isostatically mounted plate with Star Trackers.

Dimensions
4.60 m x 2.34 m x 2.20 m

Mass
670 kg (including 36 kg of fuel).

Power
- 2x GaAs body-mounted solar arrays, with 800 W each at normal solar incidence.
- 60 Ah Li-ion battery.

Propulsion
- 2 x 40 mN cold-gas thrusters.
- Gaseous-nitrogen propellant (36 kg at 250 bar).

Spacecraft Attitude
- Three-axis-stabilised local-normal pointing, yaw-steering, with 6° nose-down attitude.
- Star trackers, magetometers, magetotorquers and 10 mN cold-gas thrusters.
- < 0.1° pointing error; < 0.001°/s stability.

Command and Control
Integrated data-handling and AOCS
computer; communication by 1553 bus and
serial links.

On-board Storage
- 1 Solid-State Recorder, capacity 256 Gbits.
- Data generated onboard: 320 Gbit/day.
- Full mission operation with a single ground station at Kiruna.

RF Links
- X-band data downlink: 100 Mbps at 8.100 GHz.
- S-band TTC link: 2 kbps uplink, 8 kbps downlink.

Launch Vehicle
Rockot (converted SS-19), launch from Plesetsk.

Flight Operations
- Mission control from ESOC *via* Kiruna ground station.
- Onboard measurements automatically planned according to a geographically defined mask.

Payload Data Processing
- Data-processing facility at Kiruna ground station.
- Local archiving of data with precision processing after one month following delivery of precision orbits from DORIS ground segment.
- Possibility of quick-look data.
- User Services coordinated via ESRIN with dissemination of data from Kiruna.

CryoSat in the EMC chamber at ESTEC in Noordwijk

in conservative margins, it would be possible to directly build a proto-flight satellite; no test articles would be built.

The savings inherent in such an approach were very persuasive, in terms of both time and equipment. However, it was obvious that the benefit of test models, particularly the 'engineering model', goes beyond merely testing the hardware; they allow unglamorous but essential work, such as test-procedure debugging, to be done away from the critical path. So for CryoSat we decided to build a 'virtual satellite' in software. This has been so useful for various aspects of testing that it has already been cloned several times, a rather difficult feat to perform with a hardware version!

Nevertheless, by mid-2004 the proto-flight CryoSat was ready for final testing. This is an inescapable ordeal and involves a long programme of 'torture' for the satellite. CryoSat had its mass properties (centre of gravity, moments of inertia, etc.) measured before it was attached to the launcher-separation system and shocked, as the explosive separation bolts fired. It was then clamped to a large table and severely shaken to simulate the effects of launch. Thereafter, it has been put into a sealed chamber and bombarded with all manner of electromagnetic signals to test its resistance to interference from the space environment, the launcher, and even from itself.

Next it will be exposed to vacuum, simulating the extremes of solar 'cooking' and the chill of deep eclipse. The final test will see CryoSat placed in an acoustic chamber in which large horns will generate a sound field so intense that it would instantly deafen any engineer present – this simulates the extreme sound pressures experienced inside a launcher's fairing during flight.

In between times, CryoSat is constantly being probed and measured, both as diagnostics and status checking, and to verify that the Mission Control Centre is able to flawlessly monitor and control it.

Getting it Up There

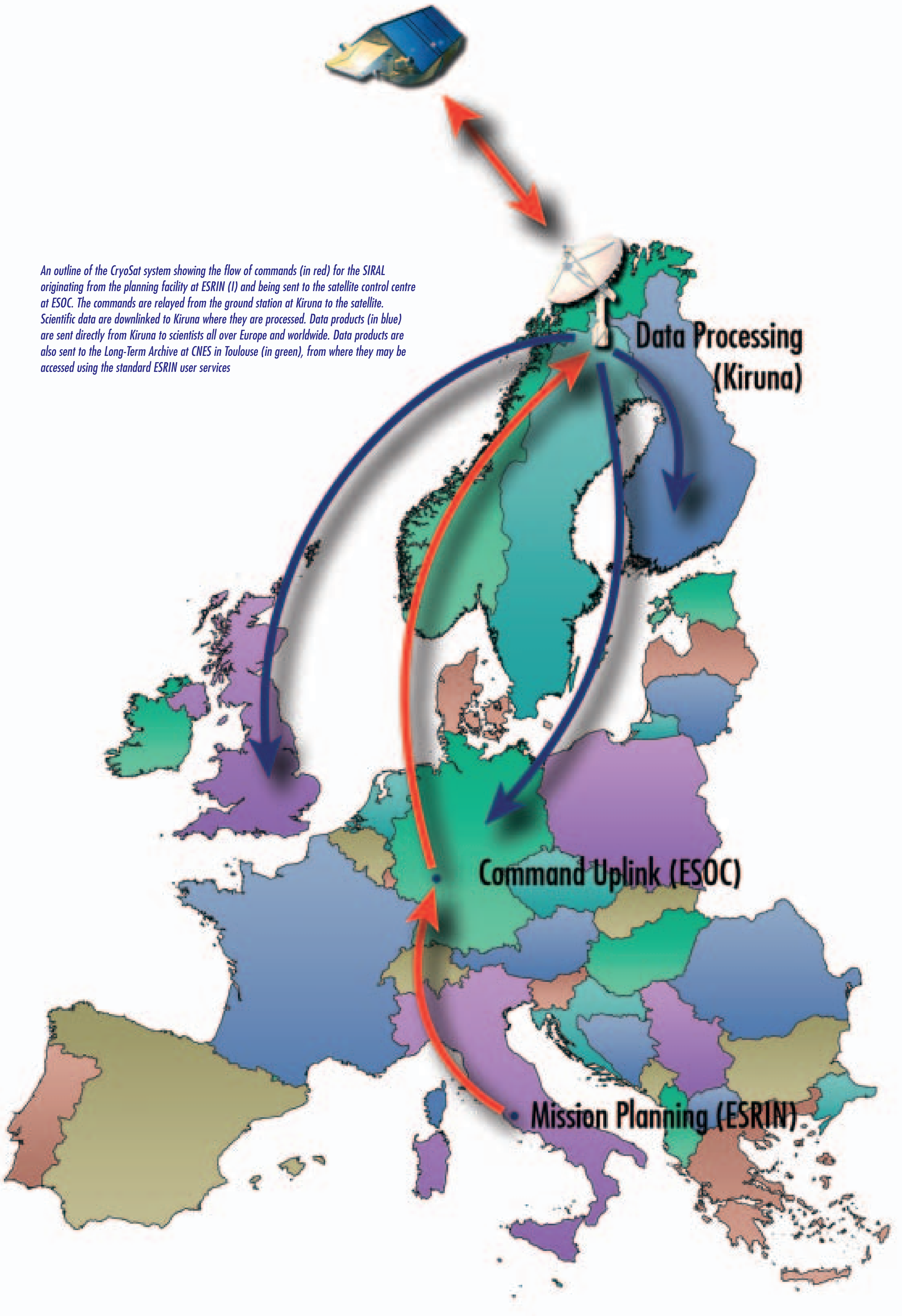
At the end of the test campaign, and after the Flight Acceptance Review, it will be time to ship the satellite to Russia for the launch. The launch vehicle, called 'Rockot', is a converted SS-19 inter-continental ballistic missile, with a versatile, re-startable upper stage known as Breeze-KM. The launch will take place from Plesetsk, some 800 km north of Moscow. This very large facility has been used for Russian launches for many years, although is relatively new for European customers.

The launch will be towards the north, and the upper stage will shut down while over the Arctic. Then the composite of CryoSat attached to the upper stage will coast through about half an orbit before the Breeze-KM fires again, over South Africa. This final orbit-injection burn will put the composite into the correct orbit, and again it will coast until reaching Europe.

The launch time has been selected such that the orbital plane is at right angles to the direction to the Sun, so that the composite flies around the line marking dawn and dusk. This means that CryoSat is in sunlight all the time and can receive power from the solar arrays. A series of small burns by Breeze-KM keep CryoSat close to its nominal Earth-pointing attitude.

All of these activities are performed blind, as the only communication with the launcher is from ground stations in Russia. The separation of CryoSat from the Breeze-KM after the final orbit-injection burn is therefore delayed until the composite comes within range both of the Russian stations and slightly thereafter the CryoSat ground station at Kiruna. Then, after almost a complete revolution, the final separation marking the start of CryoSat's autonomous life in orbit will occur somewhere over Romania.

CryoSat on the shaker at ESTEC for vibration testing



An outline of the CryoSat system showing the flow of commands (in red) for the SIRAL originating from the planning facility at ESRIN (I) and being sent to the satellite control centre at ESOC. The commands are relayed from the ground station at Kiruna to the satellite. Scientific data are downlinked to Kiruna where they are processed. Data products (in blue) are sent directly from Kiruna to scientists all over Europe and worldwide. Data products are also sent to the Long-Term Archive at CNES in Toulouse (in green), from where they may be accessed using the standard ESRIN user services

The CryoSat Data Products:

– Their generation, in-situ validation and applications

Richard Francis, Pierre Viau & Robert Cullen
CryoSat Project, ESA Directorate of Earth Observation Programmes, ESTEC, Noordwijk, The Netherlands

Malcolm Davidson
Mission Experts Division, ESA Directorate of Earth Observation Programmes, ESTEC, Noordwijk, The Netherlands

The preceding articles have described how the CryoSat mission came about, how it was designed, and how the satellite was put together. Little has yet been said about how we will plan the operations, or about the data that will flow to the scientific community. This last article therefore describes those parts of the overall system that will not be launched into space. They include the control and processing centres, as well as less material things like the operations concept and the approach to validation

CryoSat was conceived with clear ideas about the scientific potential of the measurements it would produce. Now, shortly before launch, we have accepted 80 proposals from scientific groups who want to exploit this potential, and this article concludes with some examples.

System Architecture

In the previous articles, the main reference to the ground segment was in terms of constraints on the satellite design, stemming from the decision to use a single ground station. However, there is much more to be said about the ground activities; indeed once the satellite is in orbit the ground facilities, operations and planning, and ultimately the resulting data products, are the only tangible part of the mission.

Conceptually the system architecture is simple, which is largely a consequence of the clear focus of the mission. This has meant that the operations planning can be agreed with the users well in advance, with little need for special planning to meet unexpected user requests.

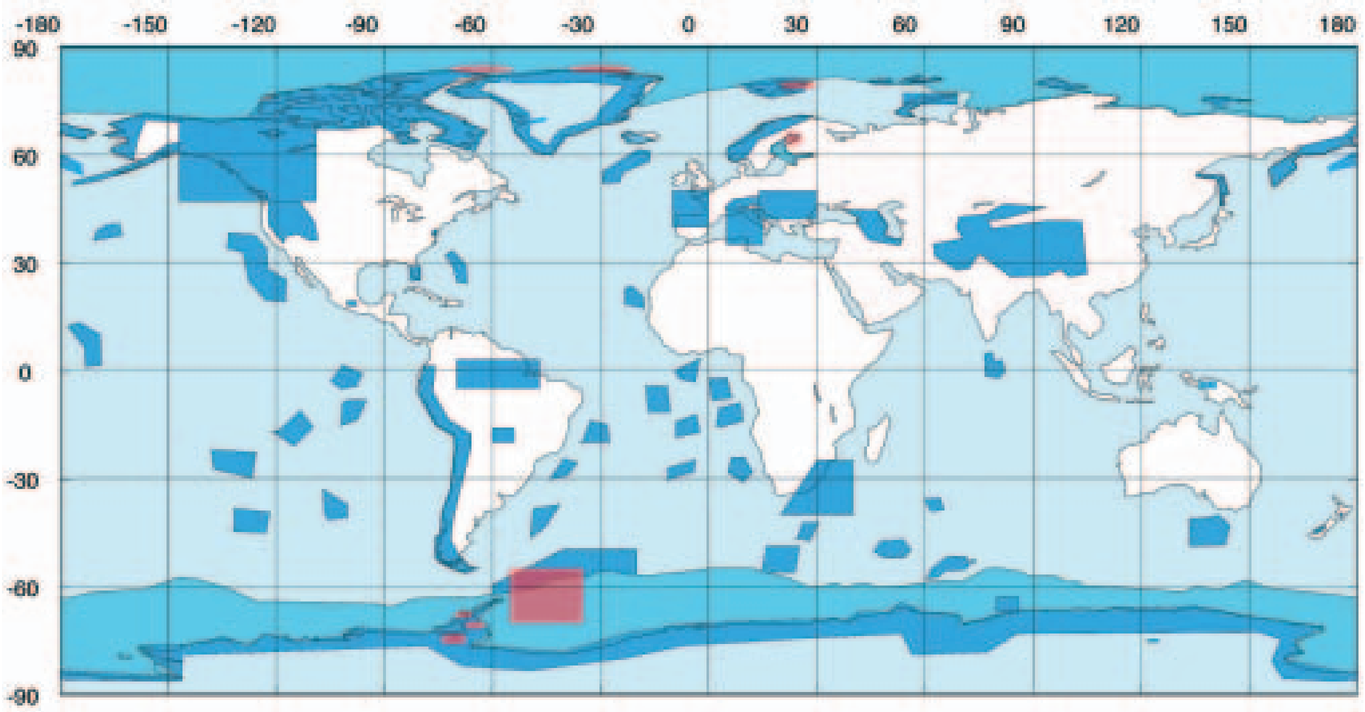
The main parts of the system are the planning facility at ESRIN (I), the Mission Control Centre at ESOC (D), and the ground station at Kiruna (S). As well as providing the link to the satellite, the Kiruna station hosts the data processing and archiving system. From here, the scientific data will be distributed directly to users.

There are other data flows in the system since CryoSat, like any altimeter mission, needs auxiliary data from a variety of sources. For example, the precise orbits are computed by an expert group at CNES in Toulouse (F). They need to get the data from the DORIS instrument as soon as it is available, and will take 30 days to compute and check the orbits to the highest accuracy (the 30-day delay is not important for the CryoSat mission). These data will be sent back to Kiruna and incorporated into the CryoSat data products.

The number of these internal interfaces can make the full system appear complex, but they are simple data transfers, which are extensively tested before launch. To the scientist using CryoSat data the system will appear extremely simple: it is an FTP server.

Planning the Operations

Unlike the previous ESA Earth-observation missions, the planning of CryoSat operations is very static, and this is quite appropriate for what is essentially



These are the geographic zones used for planning SIRAL operations. The pale-blue regions are where the conventional Low Rate Mode will be used, the intermediate-blue regions are for SAR and the darker-blue ones for SARIn. The red areas are identified calibration and validation areas

a survey mission. The key to this is that the exploitation of the three different measurement modes of the SIRAL instrument can be planned well in advance.

The original CryoSat concept proposed by Prof. Wingham already identified geographic zones where the various SIRAL modes would be used; for example, the mountainous edges of the ice caps and glaciated regions of the World were delineated on a map and marked for SARIn mode. These zones have become the definition of the baseline mission.

Following the two Announcements of Opportunity (AOs) that were issued, many scientists have defined further regions that they want to study using specific SIRAL modes. These have been added to the map defining the baseline mission, along with some specific regions that will be used for calibration and validation measurements. The resulting patchwork of zones forms the heart of the mission-planning system.

In fact, twelve such maps have now been defined, one for each calendar month, taking account of the seasonal variation in sea-ice cover in both hemispheres. The example shown here corresponds to September.

Now that we have distilled the users' data needs into these maps, the planning cycle can become quite automated. By planning we mean the generation of a time sequence of commands to the payload, each with an associated time when it must be executed – this is called the 'mission timeline'. It is prepared by overlaying the ground-tracks of the orbit, calculated in advance for the relevant period, over our map and determining the times at which the mode transition commands must be executed as CryoSat passes from each zone to the next. Needless to say, this is done by software, and extra functions for checking the flow in and out of the onboard data recorder are implemented too.

In keeping with the programmatic constraints, all of the nominal activities occur during normal office hours and so planning is done on a weekly basis, starting three weeks in advance. The sequence of activities will go like this:

- during week *n-2*, the operation timeline for week n will be generated at ESRIN and sent to ESOC
- during week *n-1*, ESOC will upload the timeline of commands to the satellite and store them onboard
- commands will be executed onboard during week *n*, but
- up to 4 working hours before their execution, last-minute commands (for special calibration targets) can be planned by ESOC and added to the onboard timeline.

What is notable about this cycle is that the information flows are unidirectional: commands to the satellite and data products to the user.

So What are the Data Products?

In the previous article, we have described the prodigious amounts of data generated by CryoSat, namely some 50 Gb per day. Modern desktop computers could perhaps swallow just a few days of this. At the ground station, this incoming 'stream' (perhaps 'torrent' would be more appropriate) of data is separated into files according to the payload instrument mode. These files are the so-called 'level 0' data products; they are archived at Kiruna, but not distributed.

The ESA Kiruna ground station, originally set up for ERS-1, had a second antenna added for Envisat. As well as supporting other ESA missions, it is the only ground station for the CryoSat mission and hosts the data-processing, local-archiving and distribution functions

The first step in making something meaningful from the data is to generate a product of the same size as the level 0, but now containing the coherent synthetic radar beams (achieved by applying a two-dimensional FFT to the bursts of radar echoes). This so-called 'full-bit-rate' product is also archived, but not generally distributed. The data volume and the complexity of applying the necessary calibration corrections makes this product attractive only to all a handful of very specialised radar laboratories.

A reduction in data volume, to about 4 Gb per day, occurs in the next step, whereby all of the synthetic radar beams illuminating a given strip of the Earth's surface are combined into one composite radar echo, a process we call 'multi-looking'. These echoes, which include phase information for the SARIn mode, have been calibrated and constitute the 'level 1b products – one product type per instrument mode. Several CryoSat users plan to exploit these radar-echo data using their own customised re-tracking software, and so the level 1b products are available to registered users.

The final step in the data processing at Kiruna takes the level 1b products and applies specific re-tracking of power and phase to generate a product that can be used directly by geo-scientists rather than radar scientists. This 'level 2' product contains measurements of the surface elevation along the ground-track, corrected for the atmospheric and geophysical effects which always have to be taken into account in altimetry. The product has a space reserved for sea-ice thickness, but this parameter will not be calculated at the start of the mission since we are not confident in all aspects of its computation until more in-situ measurements have been made, as we will describe later. Until that time the space will be used for the ice freeboard measurement.

This level 2 product is packaged as a single file per orbit and the data are substantially refined compared to the lower-level products: at 50 Mb, a full day's worth of data could be downloaded in 10 minutes over a slow 1 Mbps ADSL connection, and the entire mission could be stored on an iPod.

These level 2 data are only generated and distributed when the precise orbit becomes available from CNES, which takes 30 days. So to satisfy the existing meteo-ocean community who require a subset of altimeter data in near real time, which is to say within 3 h of the measurement, there is a further dedicated product. This so-called 'FDMAR' product (named for commonality with a similar Envisat product) is processed in the same way as the regular level 2 product, but uses the real-time orbit solution computed by DORIS and normally used for onboard satellite control. Its main content is ocean elevation, wind speed and wave height, and it is only made from the SIRAL low-rate-mode data over the oceans.

The CryoSat system was not designed for such operational purposes, however, and this product has only recently been introduced. Clearly, it can only be generated on a 'best effort' basis and will not always be available. For example the 3–4 blind orbits each day will not be available in near-real-time. Despite such caveats, the fact that it has been possible to introduce, at a late stage, such a radical feature as systematic near-real-time processing and distribution is a credit to the conceptual design of the CryoSat data-processing system.

How the System Works

The data-processing system is also named after an equivalent Envisat function, namely the PDS or Payload Data Segment, and it is the entity that is connected to the radio-frequency equipment of the receiving antenna at one end, and provides data products to users at the other. Much of what the PDS does is data management and cataloguing. The heavy-duty number-crunching and complex software is isolated to a specific part called the instrument processing facility, or IPF, which is embedded in the PDS.

The IPF, like most of the PDS, is actually implemented as a cluster of high-performance dual-processor PCs running Linux. The operation of the PDS is data-driven, which is to say that it is controlled by the presence and nature of unprocessed data, rather than by external commanding. It is an automaton. The arrival of a signal at the demodulators at the front end triggers the level 0 processor to extract and archive the level 0 products. It also writes their details to a database.

A central control function that watches this database notes their arrival and checks what type of files they are. For each type of file, it knows what has to be done – it has a list. It puts together a job order that identifies the type of processor which must be run on it (SIRAL low-rate-mode data is processed differently from star-tracker data, for example) and the auxiliary data that will be needed. These auxiliary data files may include atmospheric-correction data and precise orbit determination, for example, and the relevant time coverage needed is also noted in the job order.

When any member of the IPF cluster is not busy, it will pick up a job order and, if it specifies a processing task it can do, it will check the database to see if all the needed auxiliary files are there. For newly generated job orders they will not normally be, so another one is checked until it finds one where all of the pre-requisites of the particular job order are satisfied. Then the processor gets on with its job and eventually stores the results into the archive, informing the PDS controller via the central database.

This concept applies to all the product levels. The PDS controller also has a list of all the CryoSat users and what data products they are registered for. For each new product appearing in the database, it goes through its user list and puts a copy of the new product file in the local FTP directory of each relevant user. For voluminous data products (e.g. full bit rate), it prepares physical media such as burning a DVD.

From this description, it is clear that the operation of the CryoSat data processing system is actually configured by a set of lists that define what has to be done. There are no commands and little operator intervention, except for physical media handling.

Despite the rigidity of the operations flow, the system provides flexibility by, for example, allowing the addition of a new type of processing algorithm and more entries in the configuration lists. This is how the new FDMAR capability is being added. Even specific activities like calibration, which also require rapid data access, are handled in the same way.

As we noted earlier, this system is characterised by a one-way flow of data from the satellite to the users. There is no dynamic feedback/request loop, with users systematically involved in the planning process.

How *do* Users Interact?

The only way in which scientists can become users of CryoSat data is via the Announcement of Opportunity (AO) process. ESA's Earth-observation missions are supported by two AO mechanisms: an infrequent formal AO, and a continuous 'Category 1', or Cat1, mechanism. This latter name is meaningless unless one is familiar with the categorisation of data users agreed between ESA and the member states. What it means however is that scientists may make proposals to a rolling AO process, with the only drawback, compared to a formal AO, that if accepted they have to pay data reproduction costs. However, with CryoSat's principally electronic transfers this distinction is academic.

There have been two AOs for CryoSat and 80 proposals have been accepted. Many of the proposals will exploit data from CryoSat's baseline mission, but others led to an extension of the geographical masks as we described earlier. In all cases though, with the acceptance of his/her proposal the Principal Investigator (PI) has been registered to receive the data products that they need. Again we should emphasise that this is a static configuration of the user needs into the planning, processing and distribution system.

For new Cat1 users, a similar procedure will apply. Any changes that users wish to introduce will also follow the same route and lead to a change in the static configuration.

We have already explained that it is intended to distribute CryoSat data to most users by electronic means. Possible exceptions to this are the level 1b and full-bit-rate users, where the volume of the data may make this prohibitive. Tests are underway which should reveal, by mid-2005, if the level 1b data can be distributed by FTP, but it appears likely that the few users who need full-bit-rate data will be receiving them on physical media.

As with previous missions, the data products will not be made fully available to users until after the commissioning phase, which we expect to last 6 months. Principal Investigators who are participating in the calibration and validation activities will receive unvalidated data earlier.

The Approach to Product Validation

The validation of the CryoSat data products is essential if all the hard work in building up the rest of the system is to be fully exploited. In his earlier article Prof. Wingham identified that the residual uncertainty in the determination of ice thickness trends should be "… no more than 10% greater than the limit of natural variability".

There are two contributing factors to this residual uncertainty. The first source is the imperfections of the measurement system itself. These have been addressed during the mission and equipment design, and now that the satellite is under final testing their contribution to the overall uncertainty is relatively well known.

Drilling cores into the ice sheet to measure fluctuations in snow fall and near-surface density

The locations of the main CryoSat validation sites in the Arctic

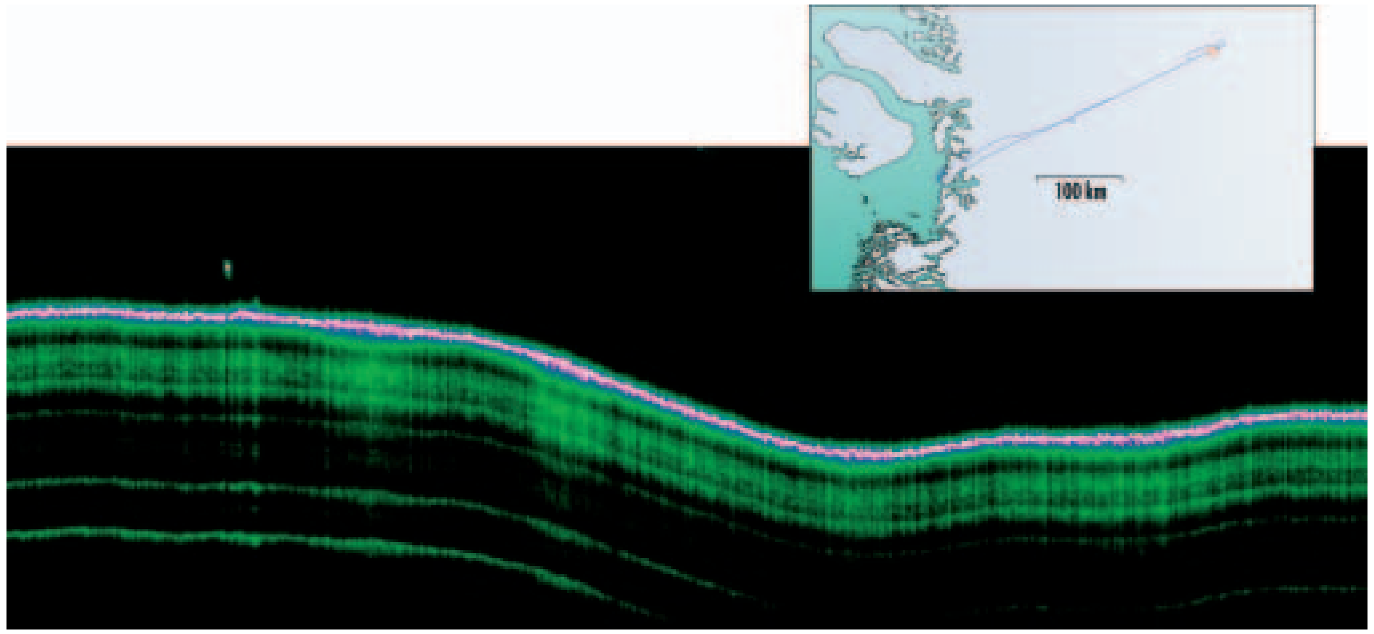
The second and more troublesome source are the geophysical uncertainties affecting the transformation of level 1b products (which are essentially radar-echo delay-time measurements) into level 2 products, containing parameters such as surface elevation or ice thickness. The uncertainties stem from the complexity and changing nature of natural ice surfaces. For land ice, the main sources of error include uncertainties in snowfall fluctuations and near-surface density required for mass-balance calculations and the variable penetration of the CryoSat signal into the snow cover as snow conditions change with location and time of year. For sea ice, variable penetration of the signal into the snow covering the ice is also a source of error. Additional errors arise from the weight of snow on the ice (which reduces the freeboard measured by the radar), preferential sampling by CryoSat of the larger ice floes, as well as lack of knowledge about ice-density statistics.

Validation is the process by which we will quantify the overall uncertainties in the ice trends that will be derived from the CryoSat data. In practice though, as the measurement-system contribution is relatively well understood, this really means the quantification of the uncertainties in the CryoSat products. Recognising that this would inevitably mean the collection of independent measurements of the quantities in the CryoSat data products, and that such measurements would require venturing into cold and hostile conditions, we sought the help of experts – the polar scientists who routinely collect such data.

The main mechanism for this was the first CryoSat AO, which focused exclusively on calibration, validation and consequent improvement in the CryoSat data processors. As a direct result, we set up the CryoSat Calibration, Validation and Retrieval Team (CVRT) and together have elaborated a comprehensive validation programme. Derived from a detailed breakdown of the problem, this programme includes a coordinated strategy and a plan for a series of field experiments. The validation implementation plan that we have evolved defines a series of experiments over the period 2003–2007.

The principal means for carrying out independent measurements for validation is through dedicated independent, ground-based and airborne campaigns, along with detailed investigations of retrieval methods applied to the satellite measurements.

The AWI Dornier 228 aircraft carrying the ESA radar altimeter ASIRAS along with a laser altimeter. This aircraft was used for 2004 pre-launch validation experiments focused mainly on land-ice validation



Radar-echo data from the ASIRAS instrument, collected on 14 September 2004 over one of the validation sites on the EGIG line in Greenland. The plot shows about 3.5 km of ground track laid out along the horizontal axis. The vertical axis represents range from the radar and is colour-coded according to the power of the echo. The span of ranges in the plot covers just over 22 m, with a resolution of 8.7 cm, substantially better than SIRAL. The radar wave clearly penetrates the surface, showing a strong return near the surface (white) and several subsurface layers in green. The radar flew over a corner reflector mounted 2 m above the ground (marked on the map by a star) and this echo can be seen as a 'blip' about 20% of the way along the track

There are three key elements in the validation plan:

Repeated experiments

Errors due to the variable penetration of the CryoSat radar signal into the snow cover can only be addressed through repeated experiments, at different times during the annual cycle, to capture the effect of different snow conditions. The preferred dates for the experiments are in Spring and Autumn, which represent the maximum and minimum snow depth during the seasonal cycle.

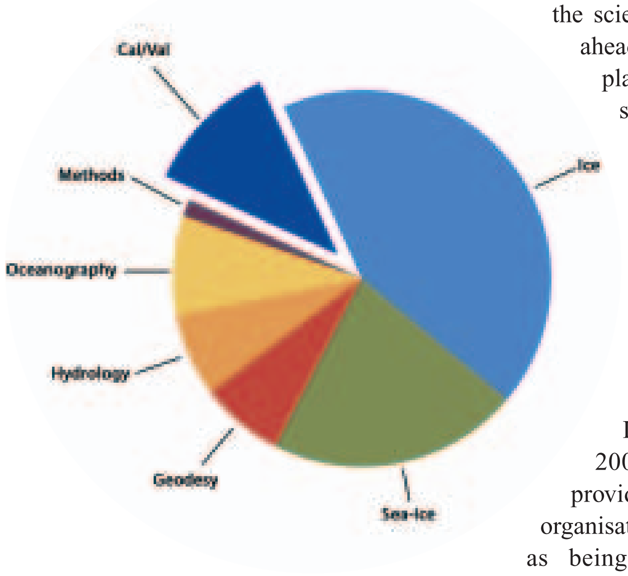
Co-ordinated ground and aircraft experiments

CryoSat traces its ground track at high speed – over 6 km/s – and covers the polar regions very quickly. As the ice properties vary on a whole range of spatial scales, it is not reasonable to compare individual ground measurements, made at just a few sites on the ice, directly with CryoSat. The solution is to make measurements with systems that encompass all the spatial scales, and to establish traceability from one to the other. This principle is applied to both land ice and sea ice, though the details of the measurements may differ slightly. We shall take sea ice as an example.

Direct measurements of ice thickness are made in-situ by drilling boreholes in the ice. At very local scales this is a direct measurement, which can be extended to larger scales by using an electromagnetic sensor hung beneath a helicopter as it flies low over the ice. The helicopter's range is limited and its speed is relatively low, so both range and speed are increased by using an aircraft. This also involves a change of sensor: the aircraft carries a scanning laser altimeter and a radar altimeter with the same operating principle as SIRAL. The ASIRAS airborne radar, developed by ESA, is used for this. With the range and speed of the aircraft, we have the possibility to bridge the gap to the satellite scales.

Such experiments require careful coordination between all activities, to ensure overlap between ground, helicopter, airborne and satellite coverage of the ice, particularly if, like sea ice, it is moving.

Logistics in the difficult Arctic environment are one of the main challenges of the CryoSat validation experiments. This is the camp on Canada's Devon Island where scientists making the ground measurements stayed for up to 4 weeks



Distribution of the 61 accepted proposals received in response to the Data Announcement of Opportunity (AO). A further 19 Cal/Val proposals were accepted for the Cal/Val AO

Pre-launch validation activities

Several of the CryoSat validation experiments, in particular those requiring co-ordinated ground and aircraft experiments, have never been carried out before. Pre-launch trials have therefore been critical in order to validate the experimental concept and get a head start in addressing the validation objectives.

Since 2003, we have carried out several major validation experiments with polar scientists from the UK, Germany, Norway, Finland, Denmark, Canada and the USA. In a typical experiment, the airborne team flies up to 10 000 km over Arctic sea and land ice. The airborne data acquisition over the scientists on the ice is coordinated ahead of time through a series of planning meetings, and then via satellite phone during the experiment itself. The airborne acquisition campaign lasts about two weeks, whereas some of the surface teams have spent up to three months on the ice-cap making in-situ measurements of ice conditions to be compared later with the airborne radar.

Initial results from the 2003–2004 experiments have provided valuable feedback on the organisation of future campaigns, as well as being scientifically interesting in themselves. In particular, one of the objectives of the activities in 2003 was to demonstrate that measurements from platforms moving at substantially different speeds (helicopter, aircraft and satellite) could make measurements at the same place on sea ice floes moving in the ocean currents, and do it reliably over long distances. This experiment, which involved estimating the ice movement and flying along compensated headings, had not been attempted before and its success was vital to the validation approach that we have adopted.

After the CryoSat launch, the subsequent validation activities will be used to assess more directly the retrieval errors in the CryoSat products, through comparison with the airborne data. The understanding of the uncertainties in the CryoSat measurements will enable the full and proper exploitation of the data products.

Applications of CryoSat Data

As mentioned earlier, the two CryoSat AOs have resulted in 80 accepted proposals from scientific groups all over the World. While many of these groups intend to exploit CryoSat data for research into the fundamental questions of large-scale cryospheric mass-balance which originally prompted the CryoSat mission, others plan to use the data for more localised research. Some of these projects partially overlap the original primary goals of the mission, such as detailed surveys of Antarctic drainage basins, and others, studies of European glaciers for example, represent applications that were also foreseen and included in the planning of the baseline mission.

Indeed, all of the ice-covered regions of the Earth were included for SARIn coverage, and such detailed but localised research into glaciers has been accommodated with no extension of the baseline mission needed.

A further set of applications involve the exploitation of the SAR or SARIn mode over surfaces that were not included in the baseline mission. This can be seen in the map of the geographic mode switching mask, which we showed earlier. These applications intend to explore the potential of the much higher along-track spatial resolution of the SIRAL for investigations into hydrology and fine-scale marine geodesy and bathymetry, for example. The need for improvements in detailed bathymetry on a global scale was brought home by the serious collision of a US nuclear submarine with an uncharted sea-mount on 7 January 2005.

Finally, in addition to the 80 accepted AO proposals, we now have an additional user community joining the CryoSat team, with the introduction of the FDMAR near-real-time ocean product. This community includes up to 50 operational entities, such as meteorological services.

The CryoSat mission will provide useful information to such vital services; it will show the way in the development of satellites for high-resolution global measurement of ocean topography and bathymetry; it will provide a high-precision data set, which can be used to further study the on-going shrinking of temperate glaciers, and finally it will substantially reduce our uncertainty in answering one of the major questions of our time, namely: Are the ice masses of the cryosphere in retreat, and if so how long do we have before this starts to have a fundamental impact on human society?

Remote Sensing and Humanitarian Aid

- A life-saving combination

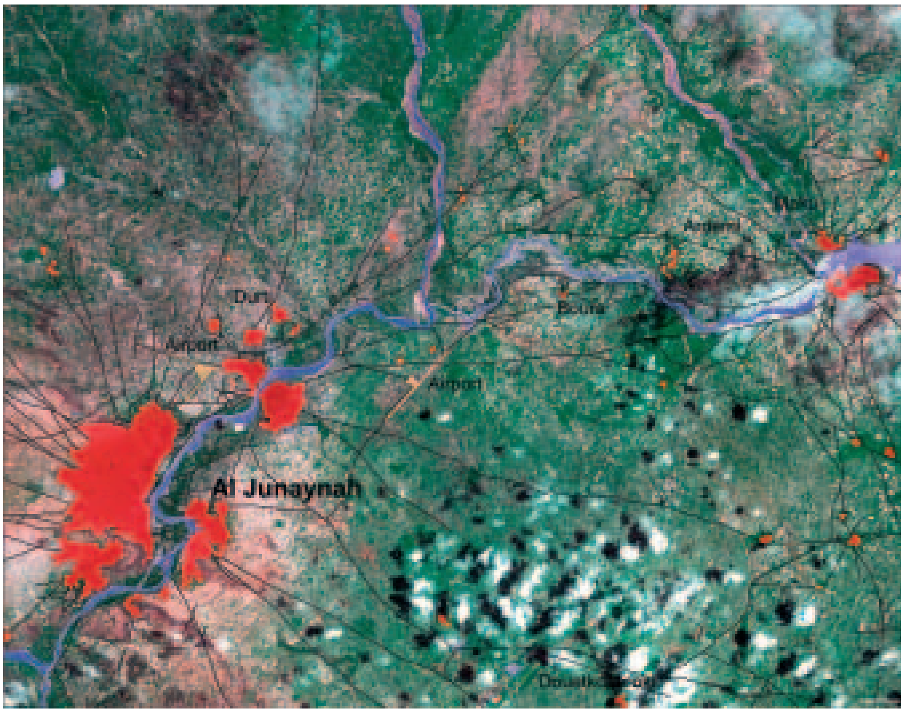
Remote Sensing and Humanitarian Aid

Philippe Bally, Jerome Béquignon, Olivier Arino & Stephen Briggs
Directorate of Earth Observation Programmes, ESRIN, Frascati, Italy

The earthquake and the tsunami which struck the coastline of the Indian Ocean on 26 December 2004, along with the cataclysmic images of the disaster that followed, will form part of our collective memory for ever more. However, this should not cause us to forget all the other emergency situations that arise: virtually every week, the mass media publish images of some other disaster or conflict. According to the World Disasters Report published by the International Federation of Red Cross and Red Crescent Societies (IFRC), in 2004 up to 300 million people were affected by natural disasters, conflicts or a combination of both (referred to as complex emergencies).

Since the foundation of the Red Cross in 1863 in Geneva and of the IFRC in Paris in 1919, Europe has earned World recognition for its competencies in emergency management and humanitarian assistance. The overall annual budget for humanitarian aid amounts to some six billion Euros, of which 1.2 billion are used in response to natural disasters. Summing the contributions from its member states and from the European Commission, Europe is the biggest donor in the World.

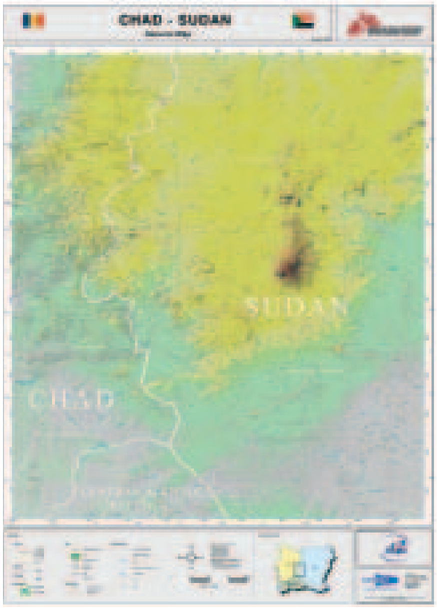
Europe is channeling its humanitarian assistance through a wide range of actors in the broad humanitarian-aid community, which comprises the United Nations with its specialised organisations, such as the Office for Coordination of Humanitarian Affairs and the Office of the High



Space-derived map by GMES RESPOND of the Al Junaynah region in Sudan generated in rush production mode using Charter data (SPOT-5, Envisat and Radarsat images acquired on 19, 20 and 21 August) and delivered to German Red Cross and UN OCHA on 24 August 2004
(Credits: SERTIT, Charter. SPOT data - copyright CNES, distributed by Spot Image; Radarsat data – copyright CSA, distributed by RSI; Envisat data - copyright ESA)

Commissioner for Refugees, the Red Cross and Red Crescent movements, government agencies such as Germany's Techniches Hilfswerk, the French Sécurité Civile, or the Räddningsverket in Sweden. In addition, there are a wide range of non-governmental organisations (NGOs), including such famous ones as Médecins Sans Frontières, Action Contre la Faim, Care and Oxfam, but also myriads of others that are less well-known to the public but still play a key role in the field under sometimes extremely difficult conditions, often through long-lasting missions in countries regularly affected by conflicts and natural disasters.

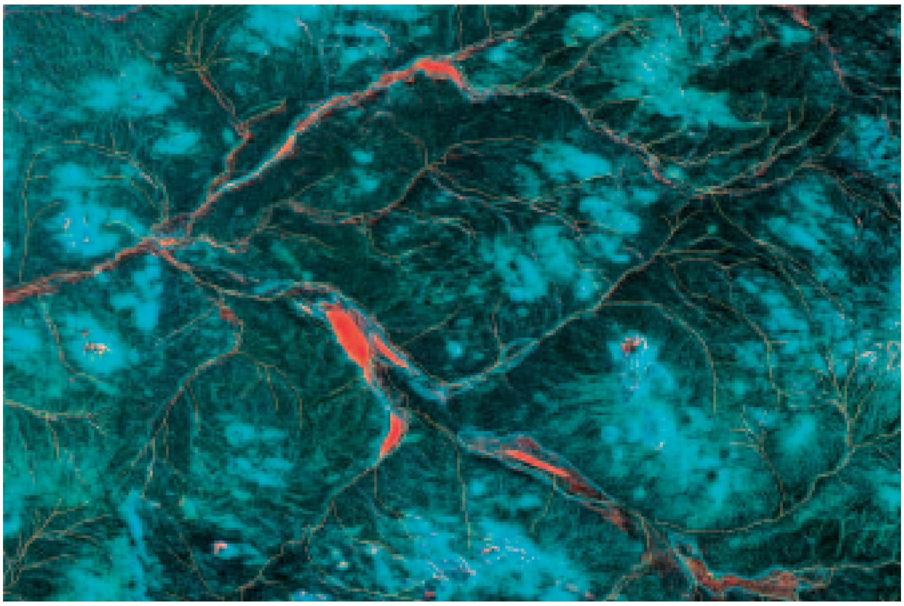
Emergency and humanitarian practitioners want to stay focused on their job at all times, not on technology. They all need better tools to support their tasks at all levels of decision-making and in the field, but they often have different cultures, languages and working practices. In this context, ESA, in supporting the action of the European Commission and its member states, is well placed to set up a European capacity based on value-adding companies and the service industry, involved in international co-operation, with the aim of providing user-driven services to the humanitarian-aid community. Over the years, a working relationship with key humanitarian organisations has been established, from the DUP HUMAN and the EOMD UNOSAT projects and maturing into RESPOND, the consortium of European value-adding companies (led by Infoterra UK) and public agencies involved with geo-information resources to support humanitarian aid. RESPOND is a project of the GMES (Global Monitoring for Environment and Security) initiative.



Example of an emergency mapping product for the Chad-Sudan border generated by Keyobs less than 48 hours after the request from Médecins Sans Frontières
(Credit: Keyobs)

The key issues that humanitarian-aid organisations have to face are numerous and complex, including water, sanitation, habitat, health, nutrition, crisis relief – either conflict or natural disaster – and post-crisis recovery and reconstruction. Their major objectives are to prevent or relieve human suffering and, linking to longer-term issues, to help prepare for risks or prevent disasters and help reduce poverty and vulnerability both at community and national level. A careful understanding of the activities that humanitarian staff carry out is needed to assess the relevance of geographic information – and Earth Observation as one component. These are primarily planning and management: planning humanitarian response actions, post-crisis reconstruction projects, planning within disaster management, of which disaster prevention is a crucial component, and within international development programmes all over the World. In addition to the activities they conduct, it is crucial for aid organisations to have the means to monitor the effectiveness and efficiency of their actions. This is all the more critical when aid programmes are dependent upon donors, and objective information is needed to derive the so-called 'needs assessment'.

When a humanitarian crisis develops, be it in the form of a slow-onset scenario as in Darfur in 2003-2004, or a sudden disaster such as that in Asia on 26 December 2004, a first task for the European Community Humanitarian Office (ECHO) is to evaluate its impact and determine what the needs are, in order to size the necessary



SAR-based image map of Eastern Chad used for hydro-geological interpretation in a water-resource development project of the UN High Commissioner for Refugees
(Credits: UNOSAT and Radar Technologies France. ERS data - copyright ESA; JERS data - copyright JAXA)

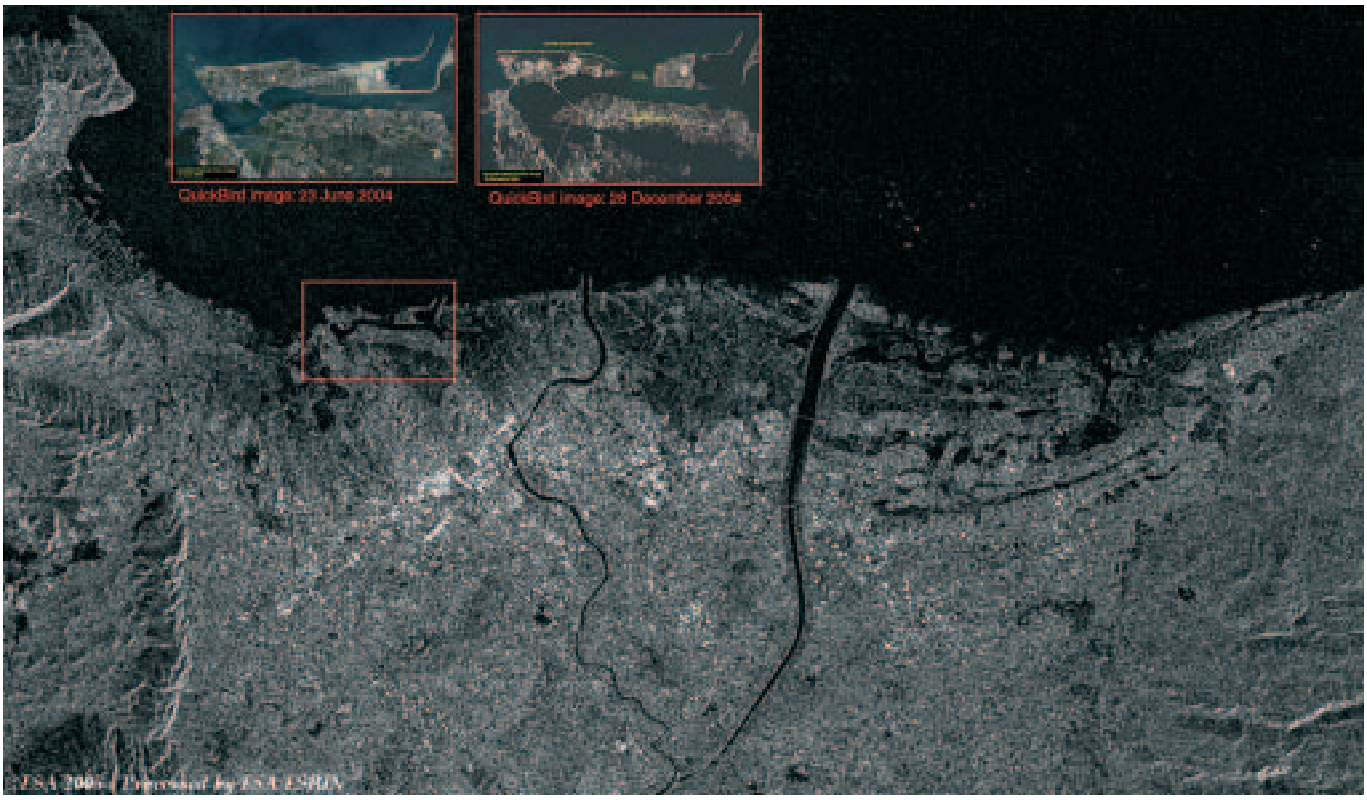
response appropriately. Satellite imagery can help to achieve this, as it has no frontiers and can be used to derive the hard facts when other information sources are impossible to access directly. In the case of the Asian tsunami, Earth-observation satellites have demonstrated a unique ability to provide donors with a synoptic view of extended remote areas in a relatively quick and cost-effective manner.

Although geographic information is only one of the many tools that humanitarian organisations are using, it represents an important element of the jigsaw puzzle, and more and more of them use geographic information systems and satellite imagery in their headquarters, in their crisis rooms and in their intelligence reports for decision makers in New York, Geneva or Brussels. The humanitarian emergencies in Northern Afghanistan and in Angola at the end of 2001 showed the need to establish an anticipative database including satellite images, vector data, elevation data, global land-cover maps and a refugee-camp positioning spatial analysis tool in order for an organisation such as the International Committee of the Red Cross to be operative as soon as any new request comes in. In addition, with the increased levels of utilisation of geographic information in the field, organisations such as the UN Office for Coordination of Humanitarian Affairs and the UN Department of Peace-Keeping Operations have set up networks of specialised local units such as the humanitarian information centres.

One of the generic requirements of humanitarian aid workers is for objective, accurate and up-to-date topographic maps of the theatre of operation. In many places in the World, accurate maps are still not available, or are treated as classified military information. This is why Médecins Sans Frontières and other NGOs regularly require base maps that service suppliers like the UK-based MapAction and Keyobs derive from old topographic maps or from recently archived satellite imagery, which they combine with information concerning the road network where distances are measured in hours rather than in kilometres, to account for traffic conditions. Quite importantly, these maps are delivered to the field as robust, large-format plasticised sheets. The German Red Cross and the relief agency Techniches Hilfswerk report that such maps had not only been useful to assist their work in Darfur, but they further explain that, after having had reports of bombardment some 15 km from their position in Al Fashir, these were the only maps that were not taken from them at Sudanese customs, and which they could use to verify their staff evacuation plans – saving expensive helicopter time and allowing them to keep on working.

As a matter of fact, Darfur is one of those regions of the globe, like Africa's Great Lakes region, affected by endemic, very long conflicts or civil wars coupled with disasters, known as 'complex emergencies'. These represent the primary cause of population displacement, which led the UN High Commissioner for Refugees and the NGOs to set and manage camps in Darfur and across Sudan's border in Chad. It is hard to overstate the scale of the humanitarian emergency unfolding in this region: by current estimates, 1.45 million people have been displaced from their homes across an area the size of France. Earth-observation data not only help in finding appropriate locations fulfilling camp-setting criteria: because they help in the identification of each and every individual tent or building, very-high-resolution images are used to manage camps and urban clinics around Al Fashir, the capital of north Darfur State and a crucial distribution point for food and supplies. The service is based on the census, a kind of 'zip code' and address for each inhabitant and family, and allows the management of the evolution of the camp and its population.

In parallel, caring for more than 180 000 Sudanese refugees gathered in eastern Chad, the UN High Commissioner for Refugees has used satellite data to identify hidden water resources and to site new camps. Conventional methods of extracting water are based on coarse geological analysis, and drilling has a success rate of typically 50%. To address the problem, UNOSAT teamed up with the consulting firm Radar Technologies France (RTF) and provided services combining Landsat optical data with ESA ERS C-band and Japanese JERS-1 L-band radar satellite data and expert knowledge of local geology and geophysical exploration. Using techniques previously employed for oil and gas and mineral



Post-tsunami image map of the Banda Aceh area (Sumatra) produced by ESA using Envisat ASAR data from 3 January 2005. The two small inserts are QuickBird optical images before and after the disaster, showing damage to the island facing the shoreline, similarly visible in ASAR imagery. Because of its all-weather capability and extended swath, ASAR has the capacity to detect damage over the complete area
(Credits: Envisat data - copyright ESA; QuickBird data - copyright DigitalGlobe)

exploration, the Earth-observation-based water target maps covering 22 500 square kilometres were used by aid workers to drill water boreholes and wells, and confirmed their ability to more accurately assess the water-supply potential. Using multispectral imagery from the Disaster Monitoring Constellation (DMC) provided by Surrey Space Technologies, RESPOND has been providing information on regional vegetation change over time. The United Nations Joint Logistic Centre team in Khartoum have explained that the processed vegetation imagery was essential to estimate where wood was available, in order to assign cooking-fuel priorities to settlements and camps.

Relief operators need not only an initial estimation of the disaster's impact, but also an accurate picture of the extent and degree of damage at the level of individual buildings, roads and other features of interest. The primary mechanism for providing imagery worldwide following the occurrence of a natural or technological disaster has become the International Charter on Space and Major Disasters. Operational since 2000, this European initiative has earned international recognition and has been extended to include specialised UN agencies, in addition to national emergency authorities. It has already been activated more than 80 times for 65 different disasters. Currently, space agencies in Europe, France, Canada, India, the United States, Argentina, and most recently Japan, offer resources from a constellation of a dozen satellites.

In Darfur, imagery from ten different sensors and nine separate spacecraft were delivered and used in near-real time. Roads in the region were inundated, as wadies – normally dry desert riverbeds – were flooded, crippling communication links in remote areas. Some agencies reported that it could take as long as ten days to travel 120 km by road. Rain conditions were such that the Charter was activated in mid-August, and on this basis SERTIT and DLR provided additional flood-map products, which were delivered to humanitarian workers and relief crews active in the area.

Immediately following the tsunami on 26 December 2004, the Indian, French and German authorities and the United Nations invoked the Charter. Thousands of images from SPOT, Envisat, ERS, IRS, Radarsat, Landsat and US commercial satellites were acquired. Partners of the RESPOND consortium, a rich network of organisations and agencies such as the European Commission Joint Research Centre, UNOSAT, the German space agency, Alertnet from the Reuters Foundation, as well as a range of service suppliers including Infoterra, Keyobs, Sertit, Metria, Kayser-Threde and Scisys,

The GEOSS Reference Document and Implementation Plan

prepared nearly 300 maps on scales ranging from 1:400 000 to 1:10 000 over Sri Lanka, the Indian coast, the Andaman islands, Africa, the Maldives, Myanmar, Thailand and Indonesia, together with the French space agency and other international actors.

Through the GMES RESPOND consortium, the Agency is not only providing support in the aftermath of the Asian disaster, but is also preparing to contribute to post-disaster recovery and reconstruction. In the context of international collaboration for reconstruction programmes that involve the United Nations and the European Commission in particular, aid organisations and the World Bank are defining the needs, while agencies and service providers are preparing geo-information services to support a variety of actions. As described by the World Bank in their assessment report concerning Indonesia, these needs are as diverse as getting people back to work, getting children back to school, supporting community-driven reconstruction, re-building houses, roads, bridges, ports and airports, and reconnecting people: electricity and telephones, reviving the economy, rebuilding irrigation systems, bringing clean water and sanitation, rebuilding health services, restoring damaged ecosystems and protecting the environment, restoring local and provincial governments, managing reconstruction transparently, and developing a disaster-mitigation strategy.

This implements the continuum from relief to rehabilitation and development: *"emergency assistance must be provided in ways that will be supportive of recovery and long-term development"*, as laid down in United Nations Resolution 46/182. It implies that development activities should be involved in the early stages of the aid, and that satellite imagery acquired at this time can, and should be used to support reconstruction and sustainable development.

As another example, the European and the French space agencies provided data from their ERS and SPOT satellites covering Nicaragua, San Salvador and Honduras in the aftermath of Hurricane Mitch in October 1998. This was used locally via the mapping agencies such as INETER in Managua as well as NGOs and local municipalities in Central America. Similarly, the whole SPOT data set acquired over San Salvador after the 2001 earthquakes was donated to the national geographic survey, which used it to issue a brand new set of topographic reference maps.

The first summit of nations and organisations involved in Earth Observation, held in Washington DC in July 2003, was a first step in putting in place a global system of systems for improved coordination of observations of the Earth, whether from satellites or ground-based oceanographic and atmospheric in-situ sensors. Summit participants launched the intergovernmental ad-hoc Group on Earth Observations (GEO) to set up a Ten-Year Implementation Plan for the development of such a system of systems. Following the second Earth Observation Summit hosted in April 2004 in Tokyo, the third Summit, hosted by the European Commission (EC) in Brussels, adopted the plan and authorised its implementation. The parties of the International Charter have offered it as a practical mechanism of the Global Earth Observation System of Systems (GEOSS) for responding to disasters at the local, national, regional and global level. The primary European contribution to GEOSS is the Global Monitoring for Environment and Security (GMES) initiative. Jointly led by the European Commission and ESA, this initiative is bringing together the capacities in Europe to collect and manage data and information on the environment and civil security, for the benefit of the European citizen. The recent tragic events in Asia and the long-term crisis that is affecting Darfur have shown the important benefits that can be derived from the successful implementation of the GEO plan.

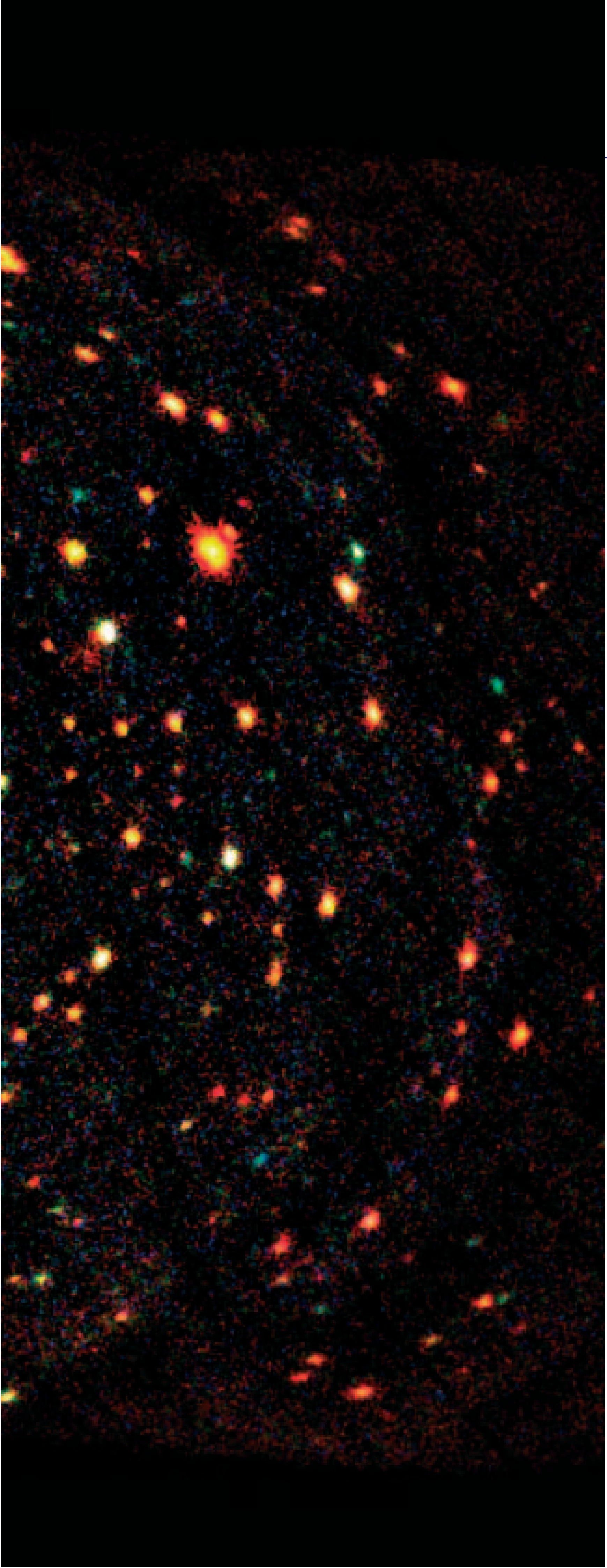
Conclusion

The above examples of large-scale services provided by European networks of value-adding companies and the service industry illustrate that a long and patient process is underway with key stakeholders and user organisations to fulfil the ambitious challenge of GMES in the domain of humanitarian aid and disaster reduction.

Five Years of Newton Science

Combining the images from all XMM-Newton EPIC cameras, the Lockman Hole provides the deepest ever X-ray survey of this region where observation of the early Universe is facilitated by the relative absence of intervening, absorbing material. The view gives a 'real colour' representation of all the sources, coded according to their X-ray hardness: red, green and blue correspond to the 0.5-2, 2-4.5 and 4.5-10 keV range, respectively. More than 60 new sources are detected in the 4.5-10 keV band alone

(Image courtesy of G. Hasinger, MPE Garching, Germany and ESA)



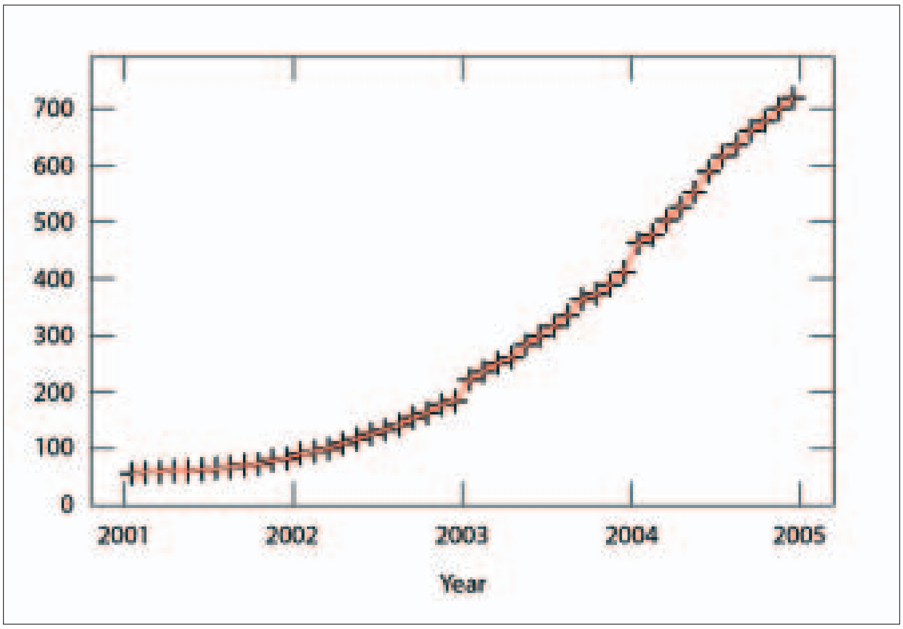
Norbert Schartel
ESAC, ESA Directorate of Scientific Programmes,
Villafranca, Spain

Fred Jansen
ESA Directorate of Scientific Programmes,
ESTEC, Noordwijk, The Netherlands

On 10 December 2004, it was five years since ESA's XMM-Newton observatory was successfully put into orbit. It is therefore time to stand back and ask where we stand with the scientific results and what new perspectives the mission has brought us. The answers are to be found in more than 700 publications in the refereed literature and the manifold oversubscription for every observing Announcement of Opportunity for the mission.

XMM-Newton was conceived as an observatory-type mission, which means that its observing programme is selected through a peer-reviewed, open submission process, resulting in observations of all kinds of astronomical objects. They range from comets and planets in our own Solar System, to the most distant quasars, which we observe at a time when the Universe was only 7% of its current age, which is estimated to be 13.7 billion years.

The fascinating aspect of the Newton observatory is that three main areas of science are addressed by this one mission: classical astrophysics, fundamental physics, and cosmology. This article highlights typical examples of the scientific research being conducted with Newton in each of these three areas, together with some of the most important results to date.



By 31 December 2004, 718 publications in refereed journals were based directly on XMM-Newton observations, 306 of them published during 2004 alone. These cumulative statistics from 2001 onwards demonstrate that the number of publications per year is still increasing

Astrophysics

Solar-type stars

Although a significant fraction of the X-ray sources in the sky are stars, surprisingly little is known about their X-ray variabilities. As the variability of our Sun's emission, including that at high energies, is fundamentally important for the Earth's climate, it is essential to study the variability patterns of stars in the X-ray domain also. But the Sun itself must be put into context.

To this end, XMM-Newton has been observing four nearby solar-type stars every six months since the beginning of the mission. One of the first successes was the detection of a solar-type X-ray cycle in HD 81809 by F. Favata (see accompanying figure). HD 81809 is a so-called 'G2-type' star, which is a little bit more evolved than the Sun and shows a pronounced 8.2-year cycle in the optical band. The initial three years of XMM-Newton data show a large variation (a factor of ~10) in its X-ray luminosity, with a clearly defined maximum in mid-2002. Comparing the X-ray activity with the optical activity cycle, the data may imply a phase shift between them.

Hot stars

The heaviest stars (O and early B stars) can have masses about 100 times that of the Sun and show emission temperatures of up to 50 000 K. Their X-ray emission originates in their stellar wind, a concept that has been confirmed by high-resolution XMM-Newton observations. However, the first RGS spectra of this class of object already showed extremely broad emission lines of highly ionised elements: for example, hydrogen-like and helium-like ions of nitrogen, oxygen, neon and magnesium, indicating velocities of the order of 1000 - 1700 km/s (see figure). The magnitude of these observed velocities is far above the range expected before the launch of XMM-Newton and the scientific discussion about their origin is now underway. Further XMM-Newton observations will expand the observational database to allow solid testing of the current theoretical developments.

XMM-Newton and Its Instruments

XMM-Newton carries two different classes of X-ray instruments. The three European Photo Imaging Cameras (EPICs) – one based on pn-CCD technology and two on MOS-CCD technology – provide images of the X-ray sky, as well as spectra with moderate resolution and timing information. Two Reflection Grating Spectrometers (RGSs) produce spectra with very high energy resolution. An Optical Monitor complements the instrumentation.

The main scientific characteristics of the X-ray instruments are as follows:

	EPIC-pn	**EPIC-MOS**	**RGS**
Energy bandpass (keV)	0.15-15	0.15-12	0.35-2.5
Field-of-view (arcmin)	30	30	5
Spatial resolution (arcsec)	6	5	N/A
Temporal resolution (ms)	0.03	1.5	16
Energy resolution at 1 keV (eV)	80	70	3.2

Supernovae and Gamma-Ray Bursts

The end point in the lifecycle of high-mass stars is reached through a luminous supernova explosion. The XMM-Newton observations of Gamma-Ray Bursts (GRBs) are important in this context. The satellite follows the X-ray afterglows through rapid (reaction time ~5 hours) Target of Opportunity (TOO) observations (as described by M. Santos-Lleó in ESA Bulletin No. 107) of selected bursts detected by other satellites, such as ESA's Integral mission. Outstanding results achieved so far have included the detection of emission lines in the afterglows of GRB

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* Gamma-Ray Bursts, or GRBs, are internationally referred to by the last two digits of the year, followed by the month and day of their detection, i.e. this is the GRB of 11 December 2001

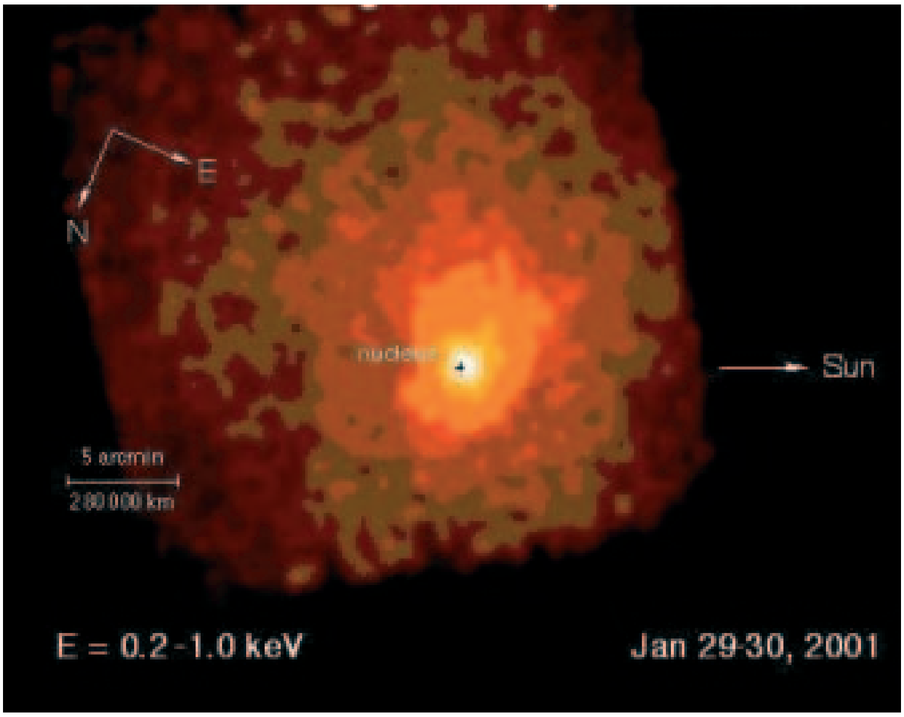
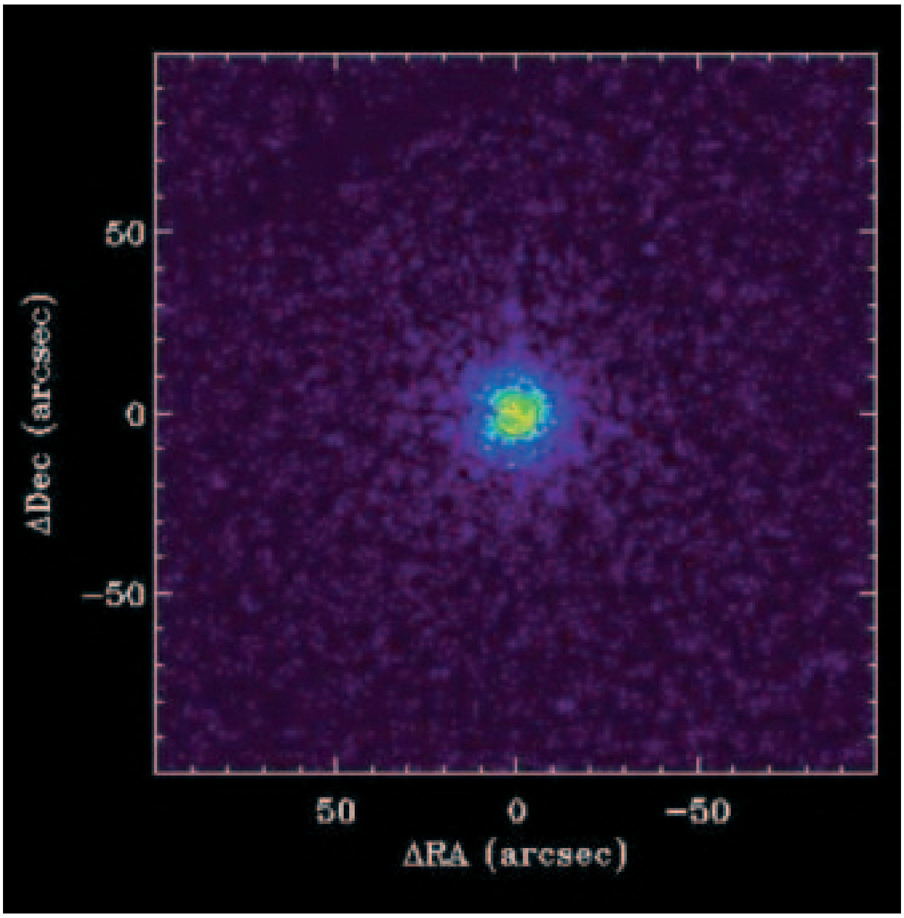


Image of comet McNaught-Hartley (C/199 T1) taken with XMM-Newton's EPIC-pn camera
(Courtesy of K. Dennerl, MPE, Germany, and ESA)



XMM-Newton EPIC-pn image of Mars showing X-ray fluorescence emission from its atmosphere, mainly from oxygen
(Courtesy of P. Rodríguez, XMM-Newton SOC, Spain, and ESA)

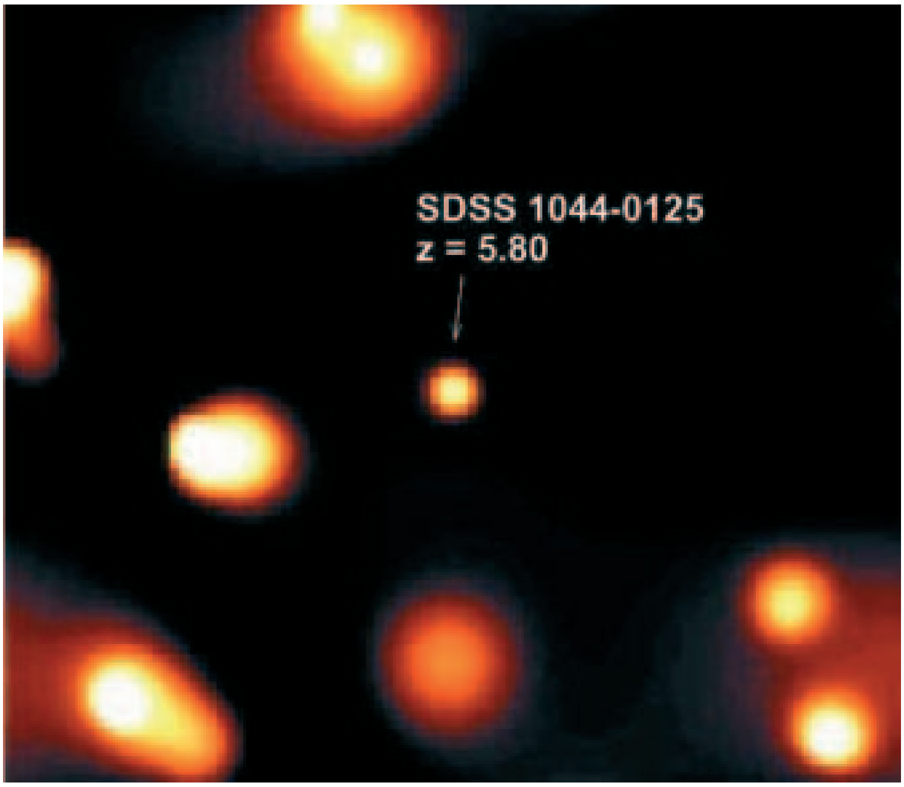
011211* by J. Reeves and of GRB 030227 by D. Watson. The first of these detections was the starting point for a scientific discussion that has led to our current understanding that GRBs are closely connected with supernova explosions.

One of the most fascinating XMM-Newton TOO observations so far was that of GRB 031203. The images reveal the first detection of a time-dependent X-ray halo, which appeared as concentric ring-like structures centered on the GRB location (see accompanying figure). The radii of these structures increased with time, consistent with small-angle X-ray dust-scattering. The rings are due to dust concentrated in two distinct slabs in our Galaxy, located 2900 and 4500 light-years away. Although the detected halo was caused by dust in our Galaxy, it must be realised that halos around GRBs provide enormous potential for making very accurate cosmological distance measurements. With a little luck, future XMM-Newton observations will be able to demonstrate this.

Neutron stars

Supernovae not only 'announce' the death of a high-mass star, they also give birth to compact objects. As an example, we can look to a star with a mass ten times that of the Sun. During the explosion, most of the material of the pre-supernova star is ejected into space, but its inner core, which is only about 1000 km across, collapses under its own gravity and creates a neutron star. Neutron stars are typically the equivalent of 1.4 solar masses and have radii of about 20 km. In these objects, the gravitational force is so strong that it becomes energetically advantageous to unify electrons and protons into neutrons. Therefore the great majority of their nuclear particles are neutrons – hence the name 'neutron star'. In some senses, they are both a star and a giant atomic nucleus.

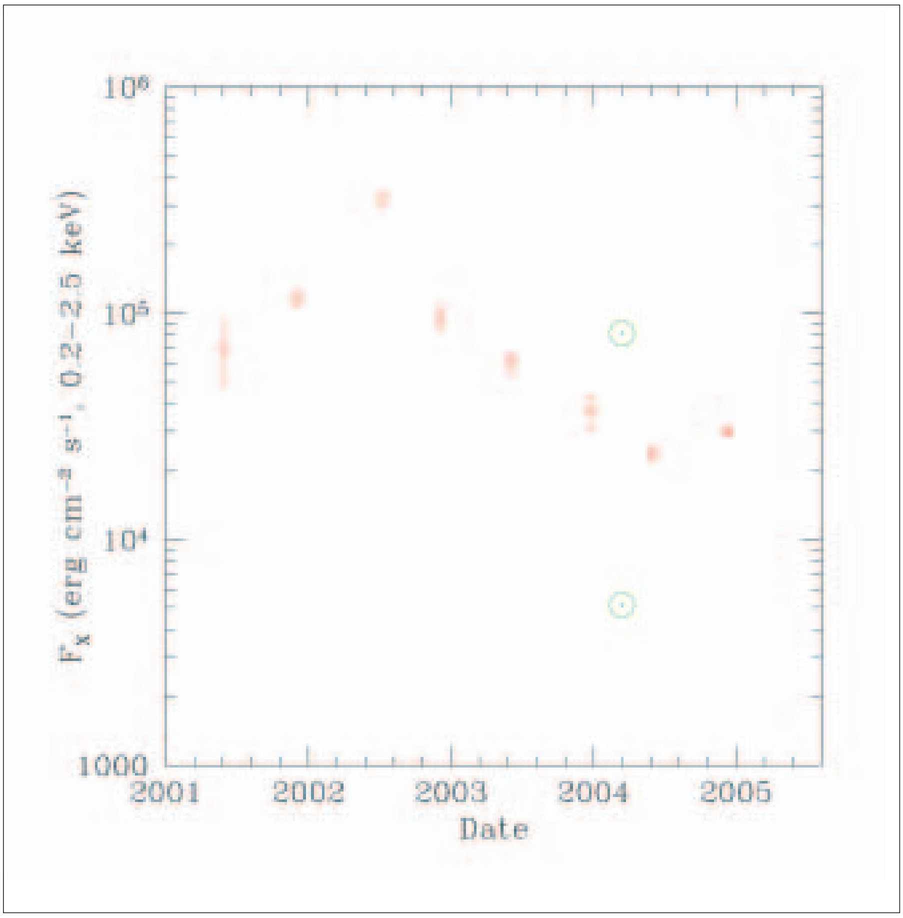
XMM-Newton's observations of neutron stars brought a great surprise in that the



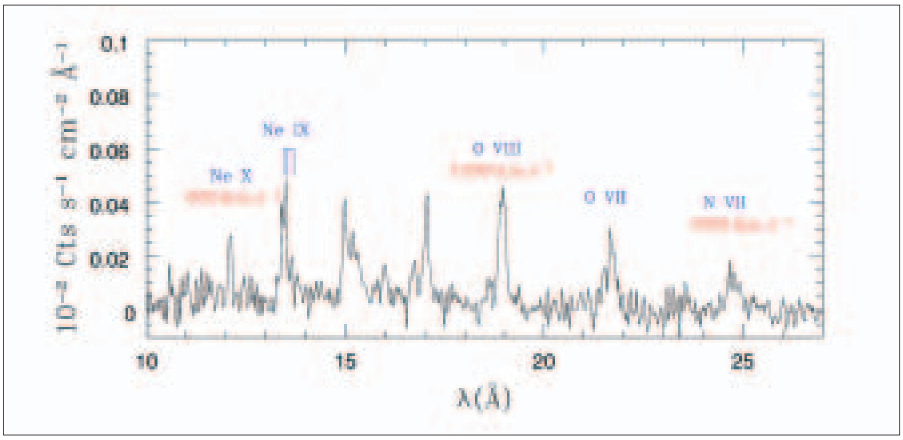
XMM-Newton EPIC-pn image of the high-redshift quasar SDSS 1044-0125 at z = 5.8
(Courtesy of M. Guainazzi, XMM-Newton SOC, Spain, and ESA)

measured spectra are in contradiction with the pre-XMM-Newton expectations. Most neutron stars have featureless X-ray spectra, but the high effective area of Newton's detectors has allowed impressive progress in unexpected directions. Based on EPIC data, P. Caraveo detected two elongated parallel X-ray tails trailing the pulsar Geminga (see accompanying figure). They are aligned with the object's supersonic motion through the interstellar medium, and have a spectrum produced by electron-synchrotron emission in the bow shock between the pulsar wind and the surrounding medium. The detection of a pulsar bow shock allowed the pulsar's electron injection energy, the shock's magnetic field and the local matter density to be gauged.

G. Bignami published the first detection of so-called 'resonant cyclotron absorption' in an isolated neutron star based on XMM-Newton spectra of the object designated 1E1207.4-5209. The star's spectrum shows four distinct features, regularly spaced at 0.7, 1.4, 2.1 and 2.8 keV, which vary in phase with the star's rotation (see figure). A further highlight of XMM-Newton pulsar observations is the detection by P. Caraveo et al. of hot-spot(s) long thought to exist as a result of heating from accelerated particles, but hitherto not found. It may provide the missing link between the X-ray and gamma-ray emissions of pulsars. Phase-resolved spectroscopy of Geminga reveals a hot thermal emission originating from an ~60 metre-radius spot on the pulsar's surface. A. De Luca has found such hot-spots in the XMM-Newton observations of two further isolated neutron stars: PSR B0656+14 and PSR B1055-52. These hot spots have very



The red data points show the evolution of the X-ray surface flux (in the 0.2-2.5 keV band) of HD 81809 from April 2001 to November 2004. For comparison, the typical X-ray surface flux of the Sun at the minimum and maximum of the solar cycle is plotted in green
(Courtesy of F. Favata, ESTEC, The Netherlands, ESA)



Combined RGS spectrum of the hot star 9 Sgr. Emission lines of ionised neon, nitrogen and oxygen are identified in blue. The velocity-widths of three lines are provided in red
(Courtesy of G. Rauw, Université de Liège, Belgium, and ESA)

different apparent dimensions and lack any common phase alignment: in the case of PSR B1055-52 they vary in phase, but in anti-phase in the case of PSR B0656+14. These findings indicate that neutron-star magnetic-field configuration and surface-temperature distribution are much more complex than was expected from pre-XMM-Newton assumptions, and further observations are clearly needed.

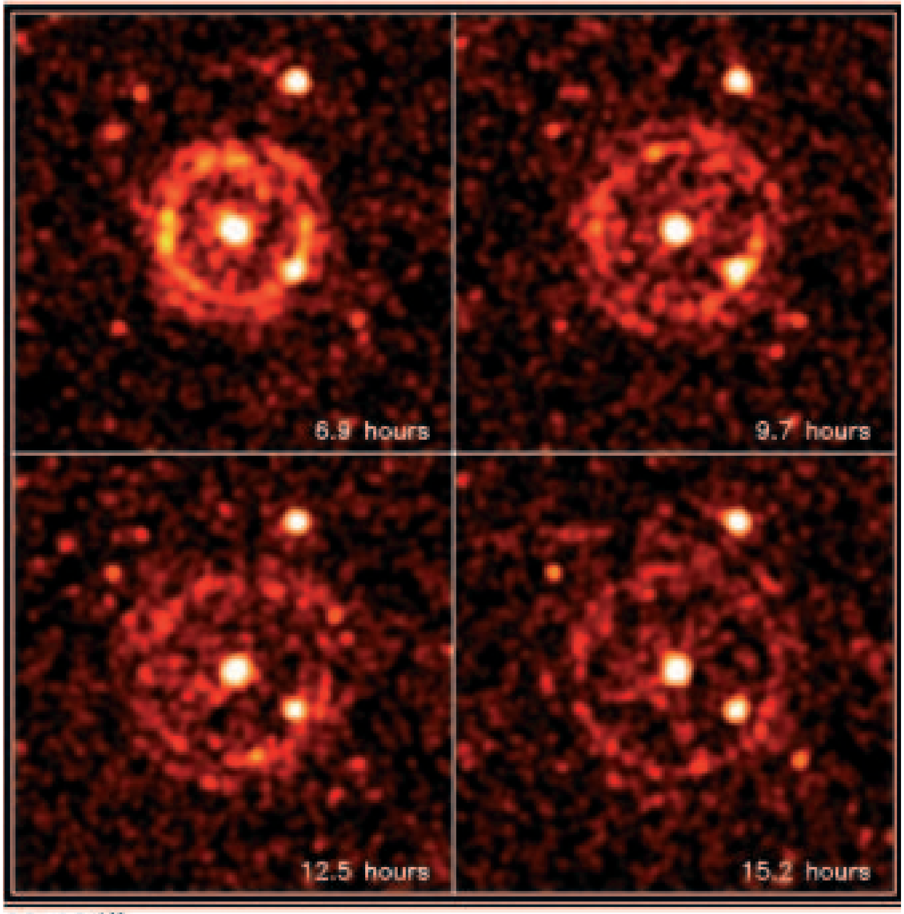
Isobaric cooling-flow clusters of galaxies

Our previous examples of XMM-Newton results have concerned stars and their lifecycles. To round off the astrophysics section, we turn in contrast to extragalactic objects. Clusters of galaxies are one of the classical topics in X-ray astrophysics. Whereas in the optical energy band they are recognised only through the detection of, often small, fluctuations in the galaxy distribution, they are among the brightest objects in the X-ray sky, where the hot gas between the galaxies is observed. Before XMM-Newton, the physics of many clusters was described with the isobaric cooling-flow model: in the outer parts of the cluster the density is too low to allow effective cooling though radiation, i.e. the cooling time is longer than the lifetime of the cluster. The situation is different in the innermost parts: here the density allows an effective cooling, which should lead to a reduction in the material’s temperature. The first XMM-Newton observations of cooling-flow clusters already showed completely unexpected spectra. The lines that should be characteristic for the emission of low-temperature gas, i.e. the cooled gas expected in the centre of the cluster, are missing (see figure). The cores of clusters must therefore be cooling much more slowly than expected according to the isobaric cooling-flow model favoured before XMM-Newton. A huge number of studies, theoretical as well as experimental, based on further XMM-Newton observations are currently ongoing, reflecting the universal importance of cooling mechanisms in astrophysics.

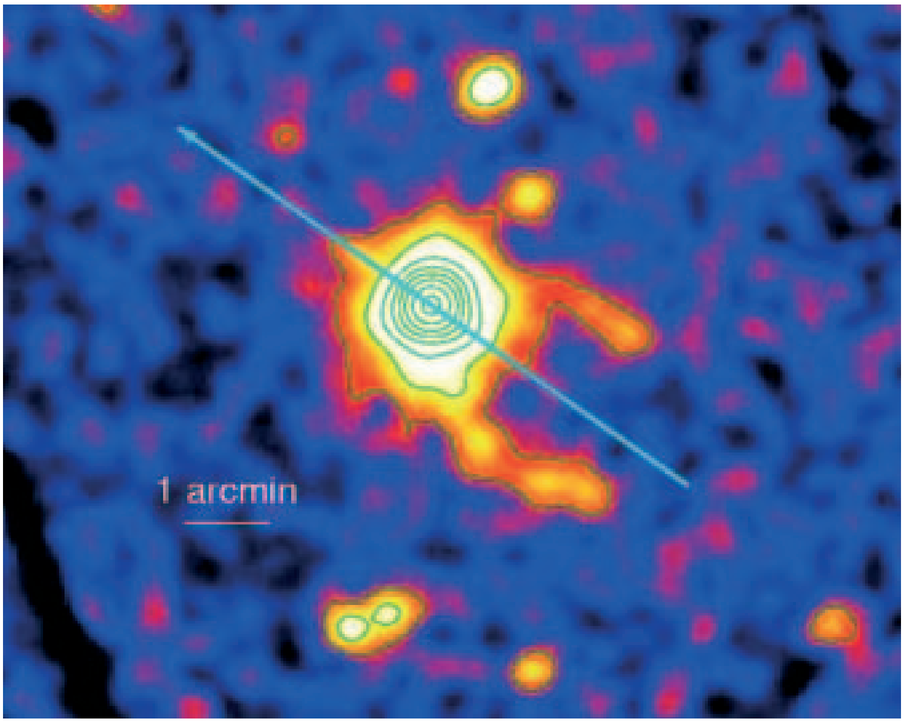
Fundamental Physics

The equation of state of cold nuclear matter

The equation of state, i.e. the relationship between pressure and density, of cold nuclear matter can be studied only for a restricted parameter range with accelerator experiments in Earth-based laboratories.



EPIC-MOS images of the time-dependent, dust-scattered X-ray halo around GRB 031203 at four different times after the burst. The ring-like structures increased with time, which is consistent with small-angle X-ray scattering.
(Courtesy of S. Vaughan, University of Leicester, UK and ESA)

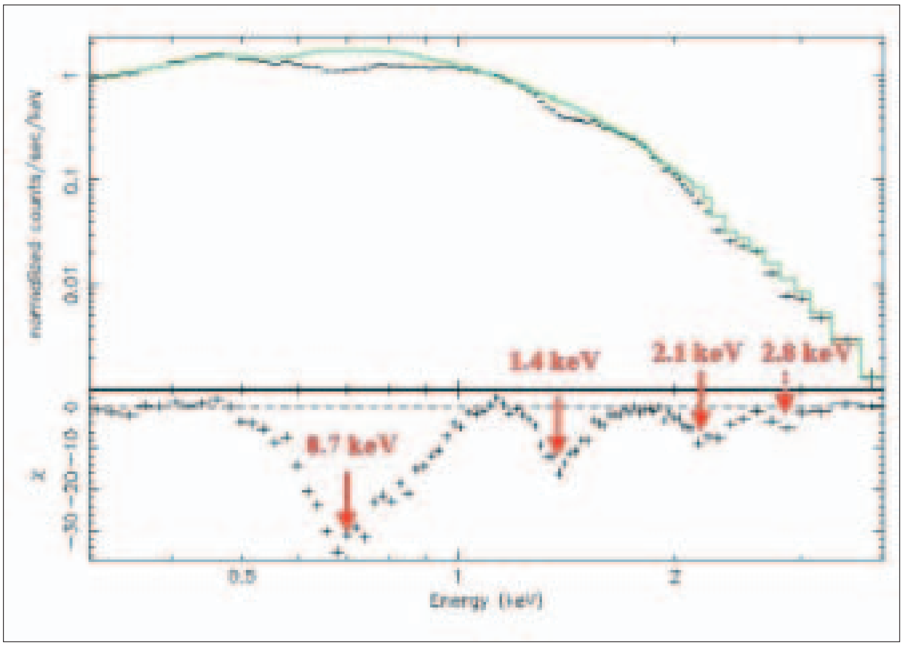


XMM-Newton image of Geminga, captured using the EPIC camera, showing the discovery of the twin tails. The motion of Geminga across the sky is indicated, showing that the tails are trailing the neutron star
(Courtesy of P.A. Caraveo, INAF/IASF, Italy, and ESA)

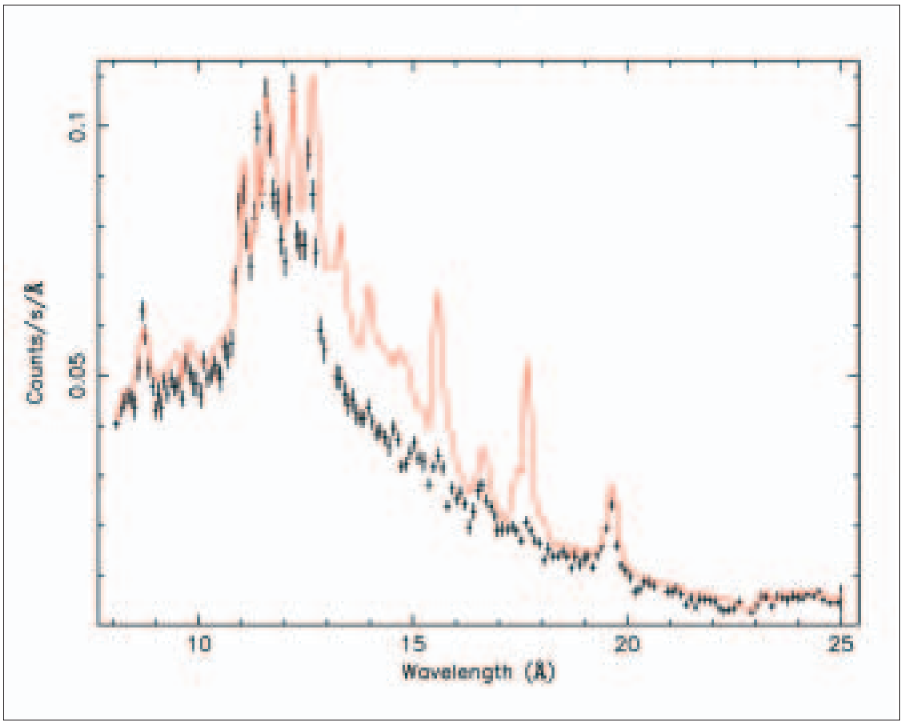
Given the fundamental properties of neutron stars, the most straightforward method of determining these quantities is by measuring the gravitational redshift of lines originating at the neutron star's surface. As the equation of state of nuclear matter implies a mass/radius relation for neutron stars, a measurement of the gravitational redshift at the neutron star's surface directly constrains the mass-to-radius ratio. J. Cottam et al. have discovered absorption lines in the XMM-Newton spectra of 28 bursts of EXO0748-676. The authors identify the most significant features with ionised iron transitions, all with a redshift of z = 0.35. For a plausible range of masses (M ~ 1.3-2.0 solar masses), this value is consistent with models of neutron stars composed of normal nuclear matter, while it excludes some models in which the neutron stars are made of more exotic matter. Given the importance of this question, XMM-Newton will observe 1E 1207.4-5209, one of the most promising neutron stars for a further gravitational redshift measurement, several times during the next year.

General relativity

X-ray observations of astronomical objects are among the most important approaches for studying the strong gravitational field. Observations near to the event horizon of black holes might even be possible. An overview of XMM-Newton observations of several objects showing broad iron emission lines, which are explained by material rotating with relativistic velocities around a black hole, was given in ESA Bulletin No. 114 by M. Guainazzi. A very fortunate observation led to the detection of the brightest X-ray flare detected so far from Sgr A, the super-massive black hole in the centre of our Galaxy. Its power/density spectrum shows five distinct peaks at periods ranging from ~100 s to 2250 s. Aschenbach could identify each period with one of the characteristic gravitational cyclic modes associated with accretion disks in such a way that a consistent value for the black hole's mass and its angular momentum is obtained. Recently the high effective imaging area of XMM-Newton has allowed an extremely



EPIC-pn spectrum of the neutron star 1E1207.4-5209. The data points are given in black, whereas the continuum model is coloured green. The residuals with respect to the continuum fit (lower panel) show the 'harmonic' marks due to the resonant cyclotron absorption
(Courtesy of G.F. Bignami, Centre d'Etude Spatiale des Rayonnements, France, and ESA)



Combined RGS spectrum of the cluster of galaxies 2A 0335+096 from an ongoing study. The black crosses are data points and the red line shows the predicted spectrum according to the previously favoured isobaric cooling-flow model. Between 12 and 18 Angstroms, the data are clearly different from the model, because the predicted lines from ionised iron are absent in the RGS data. This indicates that the cores of clusters are cooling much slower than expected (Courtesy of J. de Plaa & J. Kaastra, SRON, The Netherlands, and ESA)

important step to be made: K. Iwasawa et al. have detected the modulation of a transient FeK$_\alpha$ emission feature in the XMM-Newton spectra of the Seyfert galaxy NGC 3516. This feature varies systematically in flux at intervals of 25 ksec, whereas the peak moves in energy between 5.7 and 6.5 keV (see figure). The spectral evolution of the feature agrees with emission arising from a spot on the accretion disc at between 3.5 and 8 Schwarzschild radii (the radius of a black hole below which nothing, not even light, can escape). A similar transient behaviour for the iron line is reported by J. Turner for the XMM-Newton spectra of the Seyfert galaxy Markarian 766. In order to study the innermost region of this black hole in more detail, and especially to 'see' the strong gravitational field, XMM-Newton will observe Markarian 766 for more than 500 ks during 2005.

Redshift

The light emitted by a source has undergone a 'redshift' if emission or absorption features are seen at longer wavelengths than expected from measurements on Earth. In visible light, this causes the features to be shifted towards the red end of the spectrum, hence the name. In this article, two kinds of redshift are mentioned: cosmological redshift and gravitational redshift. Both can be properly understood only in the context of the famous general Theory of Relativity published by Albert Einstein in 1916 (Annalen der Physik, Band 49, page 50).

Cosmological redshift is a consequence of the Big Bang and the fact that the Universe is expanding: the greater the distance to an object, the larger its redshift. For example, all the stars that can be seen with the naked eye have a redshift (z) of 0. At present, the most distant objects known have z-values of around 6.5. Gravitational redshift is observed when we study objects with a high mass. With increasing mass (or decreasing radius) the spectra become redder, i.e. they show a higher z-value. To understand gravitational redshift, we can imagine that light needs energy to escape from the gravitational field, similar to a rocket being launched into orbit.

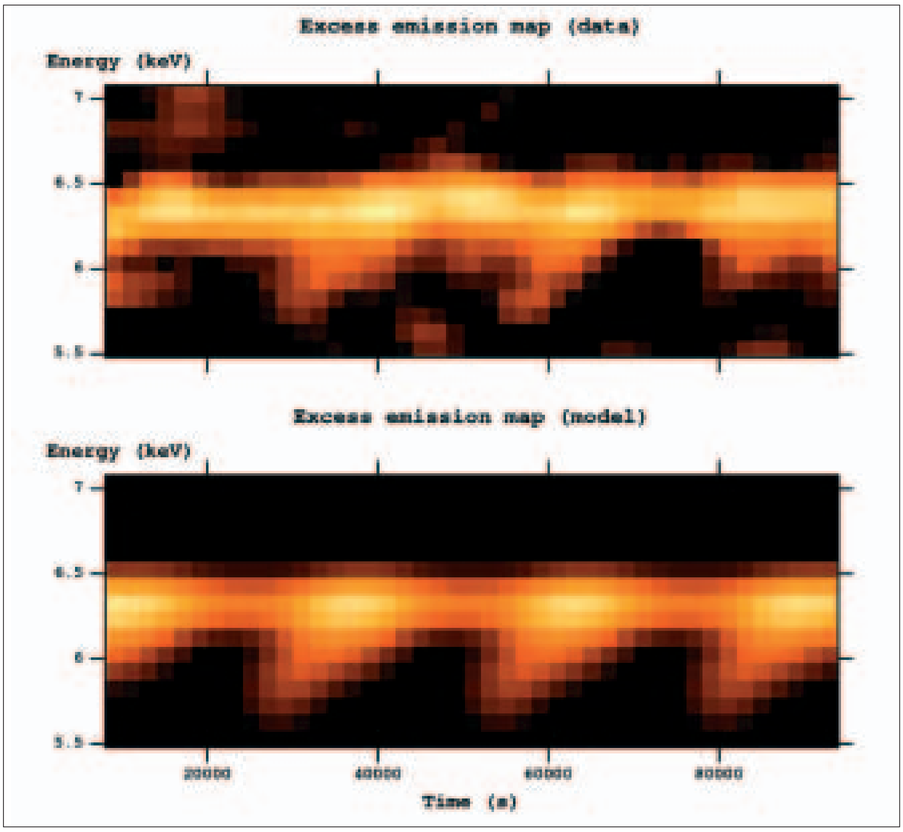
Cosmology

Absorption in high-redshift quasars

The quasi-stellar object (quasar) APM 08279+5255 is one of the most luminous objects in the Universe and therefore a promising candidate for answering cosmological questions. The XMM-Newton EPIC spectrum of this high-redshift ($z = 3.91$) quasar reveals a high-column-density absorber in the form of an absorption edge of significantly ionised iron and corresponding ionised lower energy absorption (see figure). These findings confirm a basic prediction of phenomenological geometry models for the quasar outflow. The iron to oxygen ratio of the absorbing material is significantly higher than the solar ratio, putting an important lower limit on the age of the Universe, which is in agreement with the results of the background measurements of the COBE mission, but in contradiction with previous estimates.

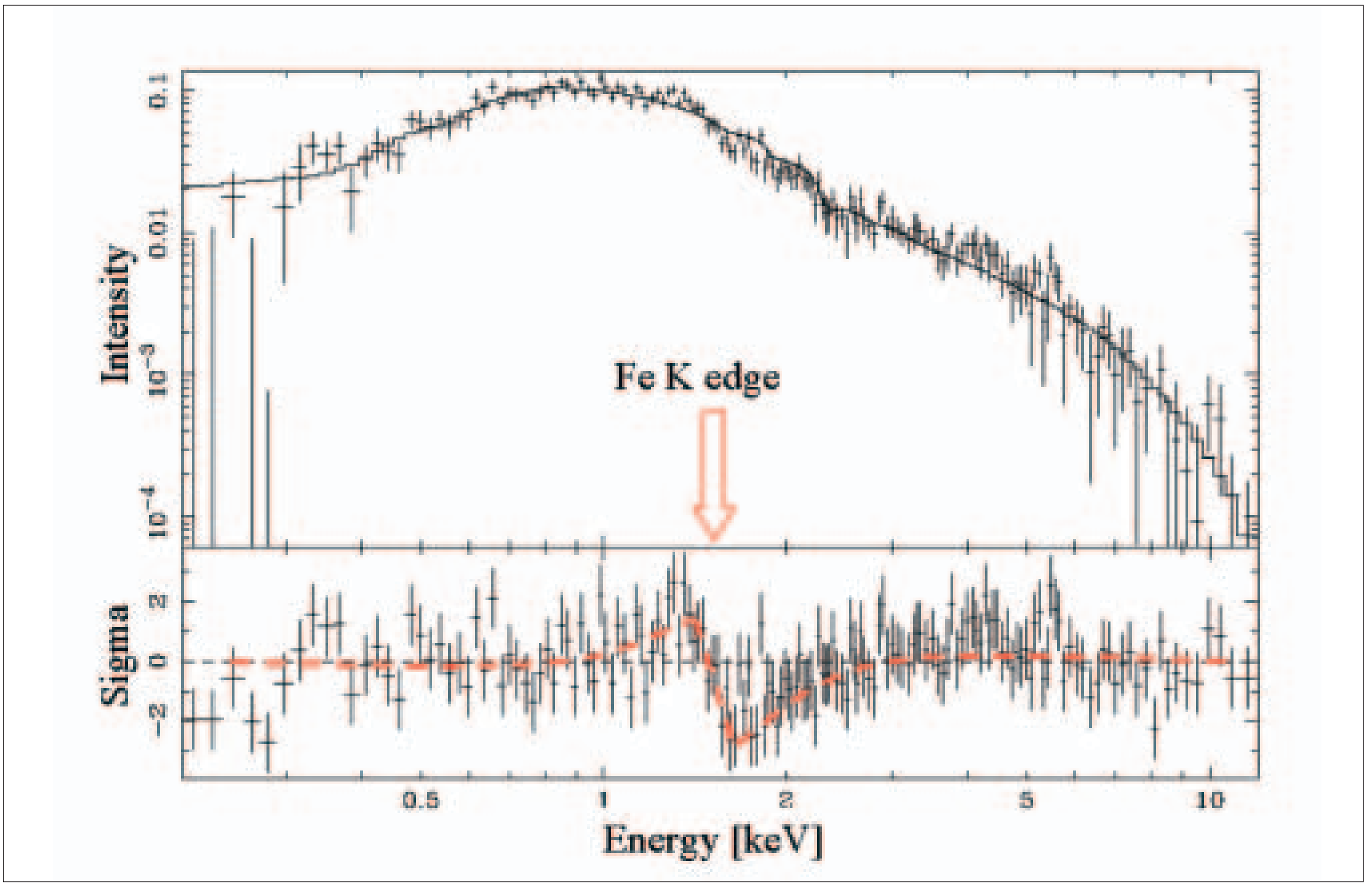
The luminosity/temperature relation for clusters of galaxies

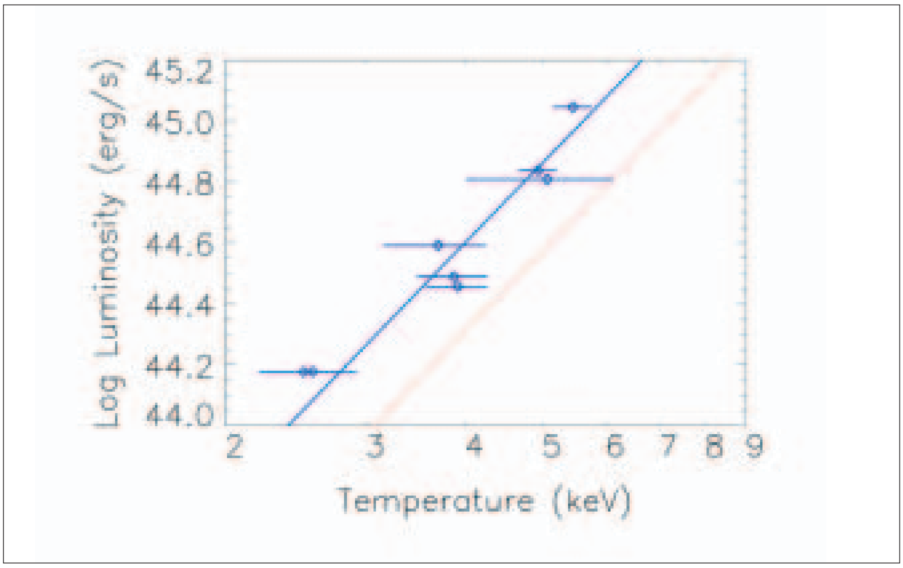
Clusters of galaxies are the largest gravitationally bound structures in the Universe, and as such are preferred objects for studying the large space-time scale structure. Based on XMM-Newton observations, D. Lumb et al. have studied galaxy clusters in a redshift range from $0.45 < z < 0.62$ to constrain the luminosity/temperature relation, and with this to ultimately determine the values of the matter



The upper panel shows the smoothed excess-emission map in the time-energy plane for the FeK$_\alpha$ as measured for NGC 3516. The colour-coding is according to a 'black body'. The spectral evolution agrees with emission arising from a spot on the accretion disc located 3.5 - 8 Schwarzwschild radii from the black hole. The lower panel shows a theoretical picture for comparison (Courtesy of K. Iwasawa, University of Cambridge, UK and ESA)

EPIC-pn spectrum of the quasar APM 08279+5255 (z = 3.91) revealing a high-column-density absorber in the form of an absorption edge of significantly ionised iron (Courtesy of G. Hasinger, MPE, Germany, and ESA)





The blue data points were obtained from XMM-Newton observations of galaxy clusters for a redshift range $0.45 < z < 0.62$. The blue line represents the best fit of the luminosity/temperature relation for these clusters of galaxies. For comparison, the luminosity/temperature relation for low-redshift clusters is provided in red (dotted line). The difference between the two reveals an evolution of the relation with redshift (Courtesy of D. Lumb, ESA/ESTEC, The Netherlands)

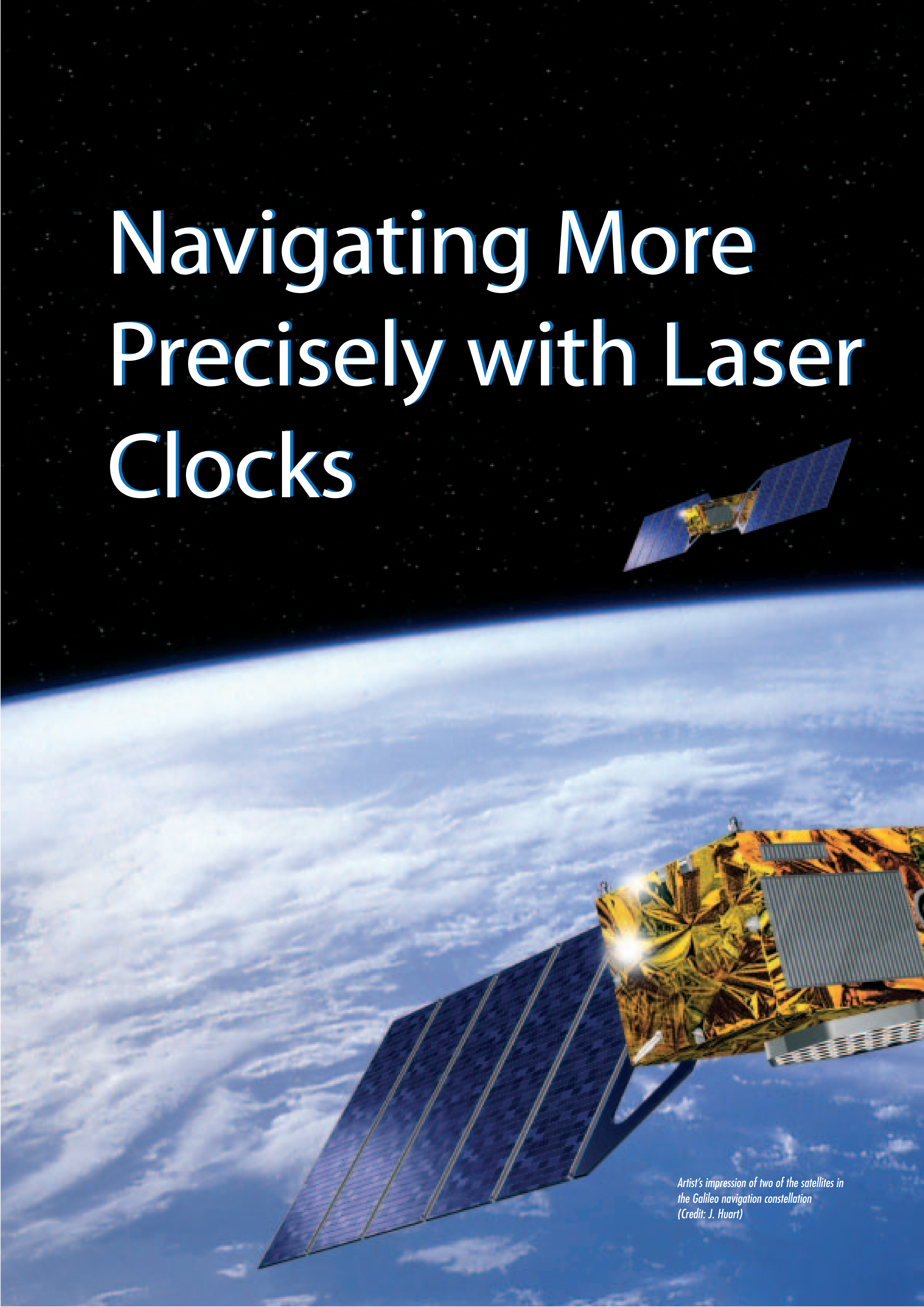
density and, to a lesser extent, the cosmological constant. Comparing the luminosity/temperature relation that they found with the relation for low-redshift clusters of galaxies, the data reveal an evolutionary trend in the luminosity/temperature relation with redshift (see figure). These results are highly interesting as the trend found allows several different interpretations, thereby affecting both our understanding of the cluster physics and the evolution of the cosmological parameters. A main aspect of future XMM-Newton studies will be to expand the sample of long-exposed galaxy clusters to even higher redshifts in order to provide data for further studies.

Conclusion

Although the space available here has allowed only a cursory sampling of the main areas addressed by XMM-Newton observations, there can be little doubt that the mission has already answered an enormous number of scientific questions, and that its observations have radically changed our understanding of many astrophysical objects. But this is not the end of the road, as even more questions have been thrown up by the latest progress and are now also awaiting answers. Given the unique characteristics of XMM-Newton's instruments, we are confident that many of these questions will be answered in the coming years.

The fact that so many scientific challenges remain to be addressed is underlined by the continuously high over-subscription rate (between 7 and 9 times) for XMM-Newton observing time in the proposals received in response to every Announcement of Opportunity issued.

Navigating More Precisely with Laser Clocks



Artist's impression of two of the satellites in the Galileo navigation constellation (Credit: J. Huart)

Navigating with Laser Clocks

Gaetano Mileti, Christoph Affolderbach
Observatoire de Neuchâtel, Neuchâtel,
Switzerland

Fabien Droz
Temex Neuchâtel, Neuchâtel, Switzerland

Eamonn Murphy
ESA Directorate of Technical and Quality
Management, ESTEC, Noordwijk,
The Netherlands

Space-borne atomic frequency standards are the backbone of today's advanced satellite navigation and positioning systems. Rubidium* gas-cell clocks constitute the ideal frequency standard for this kind of space application, since they combine excellent short- and medium-term stability with small size, as well as low weight and power consumption. The development of the key technologies, particularly in terms of reliable diode lasers and atomic vapour cells, will pave the way towards low-power and miniature – ultimately chip-scale – atomic clocks for industrial and domestic use.

Introduction

With today's satellite navigation and positioning systems like Galileo, GPS and Glonass, the position of the receiver unit is determined by measuring and evaluating tiny differences in the arrival times of signals originating from several different satellites. The positioning accuracy of these systems therefore critically relies on the precision of each satellite's timing signal. With the growing demand for satellite navigation providing positioning accuracies of just one or two metres, satellite onboard clocks with superior stability are a key system component, needing to be accurate to within a few nanoseconds per day.

** A silvery-white, highly reactive chemical element found in just a few minerals*

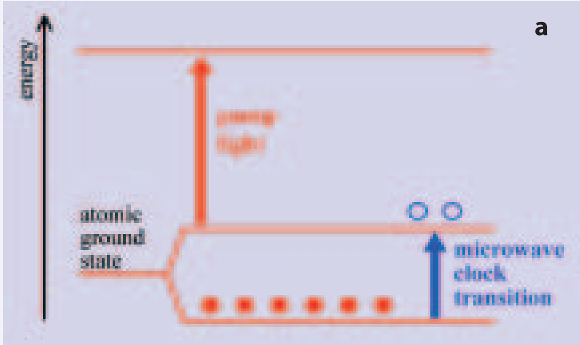
How a Rubidium Gas-Cell Clock Works

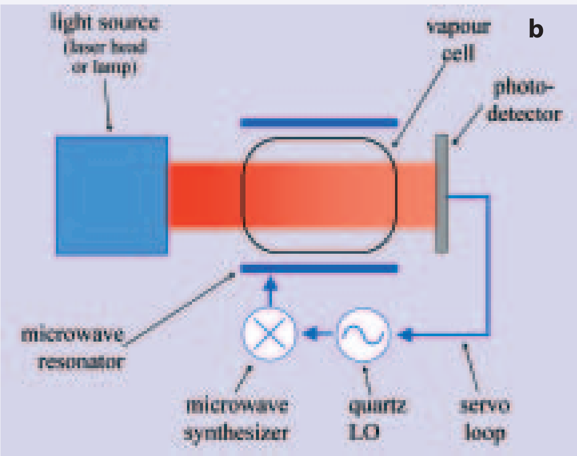
In a rubidium gas-cell clock, a signal obtained by interrogating atoms contained in a small vapour-cell is used to adjust the frequency of a local oscillator (LO) in such way that a fixed multiple of this frequency coincides with the atomic reference transition frequency. This results in the local oscillator frequency being effectively stabilized to the atomic reference, and profits from its superior stability over long time periods. The clock thus consists of two main parts:

- a physics package, in which the atomic transition is probed using the optical-microwave double-resonance technique, and
- an electronics package, which controls the frequency of the local oscillator (typically 10 MHz), which constitutes the instrument's output signal.

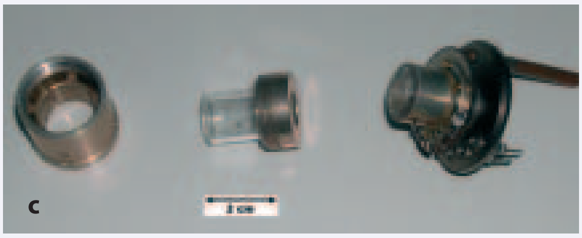
The optical-microwave double-resonance technique represents a powerful, well-established, and still simple way to probe the atomic transition, which allows one to make very compact clocks with high frequency stabilities. Its basic scheme (see Fig. a) relies on indirect detection of the microwave transition: resonant light from a discharge lamp selectively prepares all atoms in the lowest atomic energy ground-state by an optical pumping process and makes them transparent for the pump light. If the applied microwave frequency exactly coincides with the atomic reference 'clock' transition, part of the atoms are transferred back into the de-populated, second ground-state level, where they can undergo optical pumping again and absorb part of the pump light's intensity. The microwave transition thus manifests itself as a decrease in pump-light power transmitted through the atomic vapour cell. In a rubidium clock, this transmitted light power is detected with a photodiode and this signal is used to stabilise the clock's quartz local oscillator.

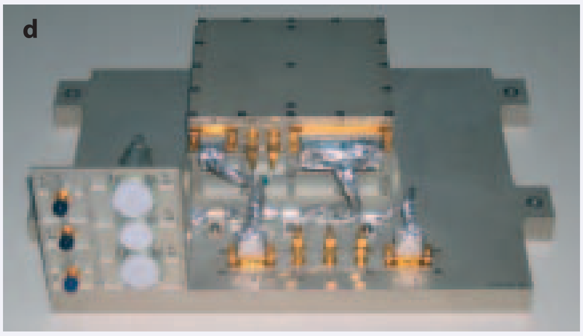
The gas-cell double-resonance technique has the advantage that the main components can be small. Typical devices can occupy a volume of less than half a litre and still have frequency stabilities of a few parts in 10^{11} over one month. Optically-pumped rubidium clocks are therefore widely applied today in industry, telecommunications and other fields.

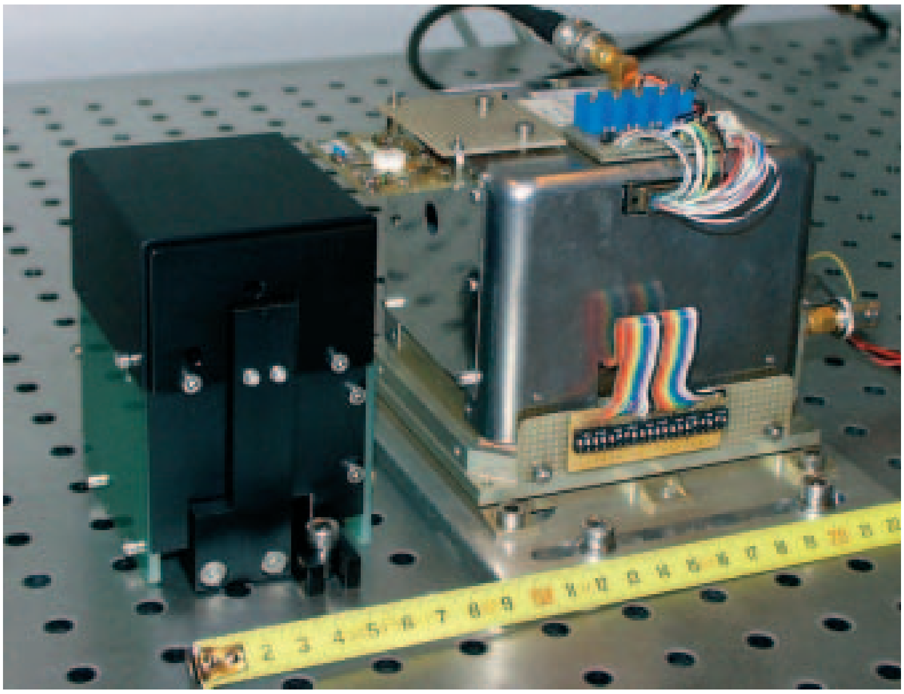




a. Optical/microwave double-resonance scheme for probing atomic reference transitions
b. Elements of a rubidium gas-cell atomic clock
c. Key components of a rubidium gas-cell atomic clock: from left to right, the microwave resonator, atomic vapour cell and discharge-lamp light source
d. Flight model of the ESA space rubidium atomic clock for the Russian Radioastron-1 mission (ESA In-Orbit Technology Demonstration Programme, TDP-II)





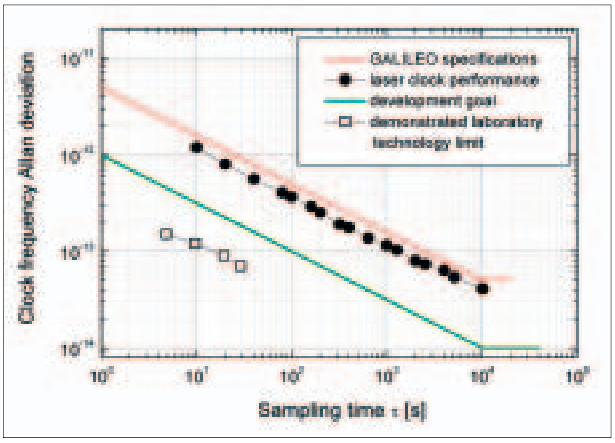


Laser-pumped rubidium clock breadboard demonstrator, developed within the ESA ARTES-5 Programme. Left: stabilised laser source. Right: clock resonator module

Today, atomic clocks are the most stable and accurate timepieces available and they have become an integral part of modern life in such diverse fields as public time keeping, modern high-speed communication links, and local frequency references for industrial and scientific applications. In these atomic clocks, the 'length' of a second is determined by counting a certain number of oscillations of an atomic transition in the microwave frequency range (see accompanying panel, left). This exploits the superior frequency stability of the atomic transition compared with the last century's timing methods, which relied, for example, on counting the oscillations of a quartz crystal, on a mechanical pendulum, or on measuring the rotation of the Earth.

How Accurately Can We Tell the Time?

Since 1967, the SI second has been defined as equal to 9,192,630,700 periods of the ground-state microwave transition oscillation in an unperturbed caesium atom. So-called 'primary' atomic clocks match this definition by probing thermal atomic beams or laser-cooled atomic fountains of caesium atoms flying freely in well-shielded vacuum chambers, and form the basis for public timekeeping. The most accurate primary clocks occupy the space of a large wardrobe and are accurate to one part in 10^{15}. So-called 'secondary' atomic clocks use different technologies, for instance to probe caesium or rubidium atoms contained in small gas-filled cells, or to probe atomic transitions in materials other than caesium. With these technologies, the atomic reference transition frequency is shifted from its value in primary standards, and thus the clock frequency always needs to be calibrated. However, such secondary atomic clocks can be very compact and still offer competitive stabilities over one to several days, which makes them the instruments of choice for navigation and telecommunications satellites. More generally, compact secondary clocks can be implemented as upgrades to conventional quartz technology for stable time and frequency references in basically all satellite applications where superior performances are required.



Stability performance of the laser-pumped rubidium clock

Today's state-of-the-art lamp-pumped rubidium clocks for space applications occupy a volume of 2 litres, weight around 3.5 kg, and dissipate only 35 W of power. They are stable to within just a few nanoseconds per day. They are already being used by a number of ESA projects, including the Cassini-Huygens mission to Saturn and Titan, and have also been successfully developed for the future Galileo system by Temex Neuchâtel Time (CH).

The limitations arising from the discharge-lamp light source currently represent one of the main obstacles in terms of further improving on the frequency-stability limits of these types of clocks whilst still maintaining their compactness. Here the implementation of advanced diode lasers as pump light sources, together with refined gas-cell production technologies, can lead to improved clock performances to meet future, even more demanding requirements in navigation and telecommunications applications.

Laser Optical Pumping and Detection

Compared with discharge lamps, diode lasers offer an extremely narrow spectrum of the light emission, which in rubidium

ARTES-5 Project Results

From 2001 to 2004, a development project funded within the ESA's ARTES-5 Programme was conducted by Temex Neuchâtel Time and Observatoire de Neuchâtel (CH) to demonstrate and evaluate the potential arising from the implementation of laser optical pumping in compact and high-performance Rubidium clocks for space telecommunications and satellite navigation. A laser-pumped Rubidium clock demonstrator was breadboarded using a modular design, consisting of a modified, lamp-removed Rubidium space clock, and a frequency-stabilised laser head as pump light source (see accompanying figure). With this approach, the laser head can be easily modified to incorporate new laser diodes becoming available for evaluation in the actual clock application.

The laser-head physics package occupies 200 cm^3 and includes a small Rubidium reference cell for frequency stabilisation to saturated absorption spectroscopy reference lines. As no European intrinsically single-mode laser diodes were available at the start of the project, the laser design is based on a compact (54 cm^3) extended-cavity diode laser (ECDL) with feedback from an external diffraction grating. The complete laser head represents, to our knowledge, the most compact realisation of an ECDL including frequency stabilisation. The laser frequency stability is $\leq 2x10^{-12}$ from 1 to 10^5 s. The laser head emits 2 mW of optical power within a 500 kHz line width at 780 nm, with frequency noise of order 3 kHz/√Hz and an amplitude noise of order $1x10^{-13}$ (Relative Intensity Noise at 300 Hz) and thus fulfils the requirements for a high-performance Rubidium clock.

Owing to the crucial importance of the laser frequency stability for the clock performance, different spectroscopic schemes were studied in order to evaluate the stability obtainable from a compact reference setup. Among the possibilities evaluated, a saturated absorption scheme was identified as the optimal solution. It provides a narrow and inverted atomic reference line that simultaneously allows simple and unambiguous line identification together with excellent frequency stability. Other, simpler spectroscopic schemes did not show sufficient frequency stability for the high-performance space Rubidium clock envisaged. Such schemes can, however, be of advantage for less-demanding clock applications, where compactness and robustness of the stabilisation are crucial.

The clock module is based on a Temex Neuchâtel Time RAFS type clock for Galileo, where the discharge lamp was removed and the electronics modified in order to adapt it to laser pumping. By introducing a buffer-gas mixture to the reference vapour cell, the cell's temperature sensitivity could be reduced by a factor of order 30, allowing clock stabilities of a few 10^{-14}. Limitations on the long-term stability arising from light shift effects were reduced by adjusting the total buffer-gas pressure in the resonance cell such that the point of zero light shift closely coincides with the reference line used for the laser frequency stabilisation. These techniques show the potential for optimised suppression of the long-term stability limitations arising from both the light shift and the cell's temperature sensitivity towards the level of 10^{-14} or below. To reach this goal, full optimisation and control of the vapour-cell technology will be needed. This includes the development of refined cell-filling processes, predictability and reproducibility issues, as well as more general studies on, for example, possibilities for cells using novel wall coatings, or other methods.

The Elegant Breadboard (EBB) that was realised shows a short-term stability of about $3x10^{-12}\ \tau^{-1/2}$, which meets the specifications for the Galileo Rubidium clocks. The signal-to-noise ratio of the double-resonance signal allows a stability corresponding to the project goal of $1x10^{-12}\ \tau^{-1/2}$, and thus is not the limiting factor here. Full optimisation of several components will allow further reduction of the short-term stability to the signal-to-noise limit, and eventually towards its demonstrated technology limit of around $3x10^{-13}\ \tau^{-1/2}$. The long-term stability of $4x10^{-14}$ at 10^4 s is limited by both temperature and light-shift effects and consistent with the determined cell parameters. Measured long-term drifts of around 3 – 5 x 10^{-13} /day measured during operation under normal atmospheric pressure are already comparable to or lower than those for conventional lamp-pumped clocks under the same conditions.

The EBB's overall mass of some 3 kg and volume of approximately 2 litres are already much lower than those of other atomic clocks. Future miniaturisation of the laser head and its complete integration into the clock-module envelope can be expected now that the advanced single-mode laser diodes are available. This will result in a further reduction in the mass and volume and improved robustness of the clock.

A final optimisation of the resonance cell's buffer-gas content and adaptation of the clock electronics will provide improved medium-term and short-term stability, respectively. Pushing these two aspects to their limits will result in a compact laser-pumped Rubidium clock for space applications like telecommunications or satellite navigation, delivering performance figures of $1x10^{-12}\ \tau^{-1/2}$ or better and $1x10^{-14}$ at 10^4-10^5 s.

Specifications for Different Rubidium-Atomic-Clock Applications

	High performance (space)	Compact telecommunication	Miniature/chip-scale
Short-term stability	$< 10^{-12}\ \tau^{-1/2}$	$< 10^{-11}\ \tau^{-1/2}$	$< 3\text{x}10^{-10}\ \tau^{-1/2}$
Long-term stability	$< 10^{-13}$ /day	$< 5\text{x}10^{-11}$ /month	$< 10^{-11}$ /hour
Volume	< 4 litres	< 0.3 litres	$< 1\ \text{cm}^3$
Mass	< 4 kg	< 0.3 kg	–
Power consumption	< 25 W	< 10 W	< 50 mW

where τ is the sampling time

clocks results in improved short-term frequency stability. The smallness of diode lasers offers the opportunity to realise more compact light sources, and their excellent quantum efficiency also holds potential for reduced power consumption compared with discharge-lamp optical pumping. Laboratory experiments have confirmed that the introduction of laser optical pumping improves the signal contrast and detection signal-to-noise ratio, resulting in improved short-term rubidium clock stabilities down to $3\text{x}10^{-13}\ \tau^{-1/2}$, which is superior to those obtained with discharge lamps.

Well-established technologies allow for excellent control of the laser spectrum, making it possible to separate different physical effects connected to the temperature, light intensity or frequency, and to minimise separately the limitations arising from each of these effects. They are also of special importance for improving the clock stability over the long time scales of primary interest for an atomic clock. Here, optimisation of the vapour-cell technology and fine-tuning of the cell's buffer-gas content can reduce limitations due to the cell's temperature coefficient. Important contributions to clock instabilities also stem from so-called 'light-shift effects' due to interactions of the atoms with the pump light, unless the latter is perfectly resonant and its spectrum well-controlled. These effects also occur with discharge lamps, but are more strongly pronounced for the narrow laser spectrum.

Until recently, the availability of suitable laser diodes offering the required intrinsic single-mode emission and spectral quality directly from the laser chip represented the predominant obstacle to reliable laser-pumped rubidium clocks. The existing laser diodes required spectral control by optical feedback from mechanically moving external parts, which is a standard technique in laboratory applications but makes the laser source comparably bulky and susceptible to mechanical shocks and vibrations. The last few years, however, have seen increased activities in industry and ESA-funded projects to provide advanced single-mode laser diodes, such as new Fabry-Perot laser diodes, Distributed Feedback, and Distributed Bragg Reflector lasers. The first diodes operating at a variety of wavelengths and suitable for gas-cell atomic clocks became commercially available in 2004 from several European manufacturers. Early samples of such diode lasers have been spectrally characterised at Observatoire de Neuchâtel, using dedicated test benches specially installed for the purpose. The tests showed encouraging single-mode operation with emission line widths around 6 MHz, both for commercial Distributed Feedback samples and Fabry-Perot diodes from ESA contract developments, making them ideal candidates for making reliable and spectrally well-controlled pump laser modules for rubidium clocks. The use of fibre or volume Bragg gratings for spectral control in diode lasers may also offer interesting alternatives in the near future.

Thanks to the ongoing effort within ESA's ARTES-5 Programme directed towards the development of diode lasers for space atomic clocks, several projects are already pursuing the realisation of suitable diodes of different types and wavelengths. These activities also include the independent characterisation of diode performance both in solitary operation and when integrated into an atomic clock. Naturally, qualification issues connected with the laser's lifetime, reliability and ageing under different radiation and vacuum conditions in space also have to be addressed. The first samples of such diode lasers have been spectrally characterised at Observatoire de Neuchâtel, with respect to, for example, their single-mode operation, line width, continuous tuning range, and frequency and intensity noise, and the tests are showing encouraging results.

The Future

The studies undertaken to date show that there are excellent prospects for the realisation of improved next-generation, laser-pumped, gas-cell atomic clocks. Continued development is needed to fully master the critical key technologies, such as the availability and spectral control of advanced single-mode diode lasers, as well as enhanced vapour-cell technologies such as the use of better wall coatings, and the control and reduction of light-shift effects. Pushing the existing technologies to their physical performance limits should help to bring significant improvements in terms of realising compact and high-performance rubidium atomic clocks. The miniaturisation of the clock components and dedicated novel clock schemes should allow the production of miniature atomic frequency references for mass-market applications, and which could replace quartz oscillators in a variety of devices. A modular approach to these topics will also open the way for the development of a whole family of gas-cell clocks that can respond to the needs of a variety of space- and ground-based applications.

Two main directions for the future development of laser-driven vapour-cell clocks can be identified. One line aims for the realisation of compact but nevertheless high-performance rubidium frequency standards with improved stability ($< 10^{-12}$ $\tau^{-1/2}$ short-term, $< 10^{-14}$ over one day) for satellite navigation as well as for use as a local oscillator in optical combs and cold-atom frequency standards. A second line concerns miniature, low-power-consumption and comparably low-performance atomic clocks in the spirit of a chip-scale clock that eventually could compete with quartz oscillator references in a variety of electronics systems or end-user applications, offering reduced sensitivity to shock and environmental parameters. For such developments, the availability and miniaturisation issues in terms of suitable diode lasers, vapour cells and microwave resonator and electronics will have to be addressed, as well as the reliability, lifetime, and ageing behaviour of these clock components.

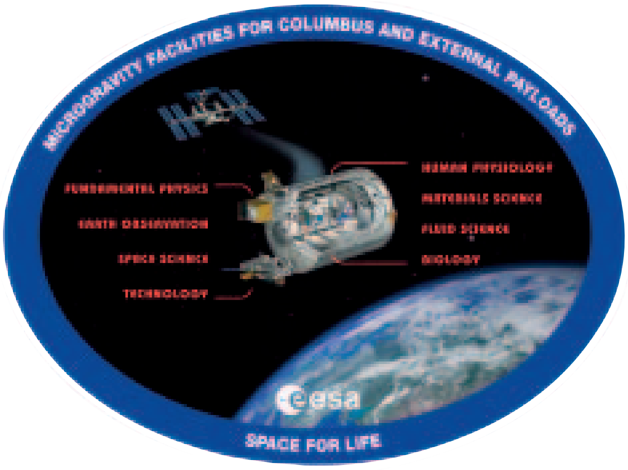
The progress made during the last years in many of the key technology fields makes it realistic to expect the production within the next few years of compact high-performance vapour-cell atomic clocks that could find application in those fields calling for stability levels of around 10^{-14} /day, which are currently served by far bulkier masers and caesium-beam clocks. The miniaturisation of the clock components and dedicated novel clock schemes should allow one to produce miniature atomic frequency references for mass-market applications, or to replace quartz oscillators in a variety of systems.

Acknowledgements

We thank Compound Semiconductor Technologies Ltd. (Glasgow, UK) and the Ferdinand-Braun Institut für Höchstfrequenztechnik (Berlin, D) for fruitful cooperation. We also thank the Ecole d'Ingenieurs de l'Arc Jurassien (Le Locle, CH) and the Institute of Electronics, Bulgarian Academy of Sciences (Sofia, BG) for their contributions to the work. The Observatoire de Neuchâtel acknowledges financial support from the Swiss National Science Foundation, Canton de Neuchâtel, and the Swiss Confederation (Article 16).

The ESA Payloads for Columbus

– A bridge between the ISS and exploration



Giuseppe Reibaldi, Rosario Nasca, Horst Mundorf, Pierfilippo Manieri,
Giacinto Gianfiglio, Stephen Feltham, Piero Galeone & Jan Dettmann
ESA Directorate of Human Spaceflight, Microgravity and Exploration,
ESTEC, Noordwijk, The Netherlands

As part of the European contribution to the International Space Station (ISS) Programme, ESA has developed a number of complex, pressurised and unpressurised payloads for conducting scientific investigations in a variety of disciplines, such as the life and physical sciences, technology and space science. The majority of these payloads will already be installed in ESA's Columbus Laboratory when it is launched in 2006. Many of them are ready for flight, whilst the others are approaching final acceptance. The development of these payloads and their utilisation on the ISS can be considered as a bridge to ESA's future Exploration activities.

Introduction

When the ESA Member States confirmed their participation in the International Space Station (ISS) Programme back in 1995, it consisted of both ISS infrastructure elements (e.g. Columbus Laboratory, Automated Transfer Vehicle and others) and utilisation elements (e.g. Microgravity Facilities for Columbus, European Drawer Rack, External Payloads and others).

Once in orbit, Columbus will be outfitted with several multi-user payloads, located both inside and outside the Laboratory. The experiments that will be performed using these payloads will provide a much-needed boost to the European scientific and industrial community. Equally importantly, they will greatly increase the competitiveness of European industry by fostering innovative research, which is a major priority for both ESA and the European Union. The utilisation of these multi-user payloads will also contribute to the preparation of the Agency's new Exploration Programme.

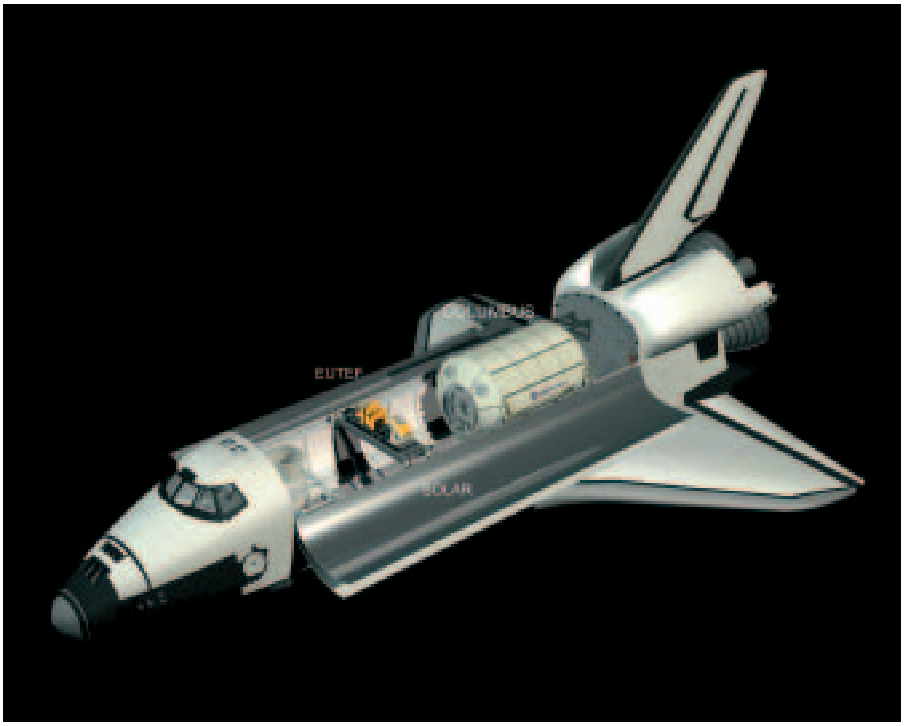
When Columbus is launched by NASA's Space Shuttle (Fig. 1) in 2006, it will be outfitted with the following payloads:

Pressurised payloads:
(a) Biolab
(b) Fluid Science Laboratory (FSL)
(c) European Physiology Modules (EPM) Facility
(d) European Drawer Rack (EDR)
(e) European Transport Carrier (ETC)

Unpressurised payloads:
(f) SOLAR
(g) EuTEF.

Payloads (a), (b) and (c) are being developed within the Microgravity Facilities for Columbus (MFC) Programme, while (d), (e), (f) and (g) fall under the Utilisation Programme.

Together with the pressurised payloads, there will be an allocated stowage volume (e.g. one quarter of the stowage rack for each facility) to upload a minimum set of spares for maintenance, as well as the necessary experiment hardware in terms of containers,



The Space Shuttle Flight-1E launch configuration cartridges, etc. All this equipment will be contained in the European Transport Carrier (ETC). Once in orbit, the Columbus Laboratory can accommodate up to ten active payload racks.

In the framework of the Space Station Agreements with NASA, ESA is allocated 51% usage of the Columbus Laboratory, which is equivalent to five active rack locations, the other five rack locations being allocated to NASA.

Physical and Life Science research under microgravity conditions embraces a wide range of disciplines, including fundamental physics, physical chemistry, fluid science, solidification physics (e.g. crystal growth, and metallurgy), biology, biotechnology, human physiology and medicine, making it the largest European user of the Space Station. The ESA Microgravity Life and Physical Science Programme's primary goal is to offer European scientists the possibility to perform materials and fluid sciences, biology and human-physiology experiments in space using mainly the pressurised payloads.

The ESA ISS Utilisation Programme is designed to offer the capability to conduct experiments in additional disciplines, such as space science, technology, Earth observation and fundamental physics, primarily using the unpressurised payloads

Each active multi-user payload is supported by a dedicated Science Team, composed of respected European scientists, who advise the Agency on the scientific requirements to be fulfilled by each payload. They also review the facility design to ensure that it can meet those requirements.

The ESA Columbus External Payload Facility (CEPF) will provide four locations for the unpressurised payloads (i.e. platforms to accommodate external payloads). The initial set of multi-user payloads are: SOLAR, which is a solar observatory with three scientific instruments, and EuTEF, which is an ensemble of nine individual instruments dedicated to in-orbit technology experiments.

In order to select experiments for the pressurised payloads, Life and Physical Science Announcements of Opportunity (AOs) have been released over the past few years, resulting in the selection of several batches of peer-reviewed experiments for each payload. New experiment solicitation AOs are planned every 1 to 2 years. The selection of instruments for the unpressurised payloads follows a similar approach, but then via the user Directorate, such as Space Science, Earth Observation or Technology.

The Pressurised Payloads

The starts of the main development phases (Phase-C/D) for these payloads were staggered over a two-year period, from 1997 to1999, depending on the level of maturity reached during the definition phases. The industrial contracts were awarded to major European prime contractors, such as EADS Astrium (F) for the Biolab, Alenia Spazio (I) for the FSL, and EDR and OHB Systems (D) for the EPM.

The flight models of Biolab, FSL and EPM underwent verification of their Columbus interfaces using the Rack-Level Test Facility (RLTF) at EADS-ST in Bremen (D) in 2003. They completed their qualification in 2004 with their delivery for the Integrated System Test (IST) and the end-to-end System Validation Test (SVT) that was successfully performed inside the flight model of the Columbus Laboratory in Bremen. Their final integration into Columbus is planned to be completed by autumn 2005.

The training models of Biolab, FSL, EPM and EDR have already been delivered to the European Astronaut Centre in Cologne (D), and the engineering models will be delivered to the User Support Operations Centres (USOCs) in the course of 2005, in order to retrofit the late changes introduced into the flight models as a result of the scientifically required upgrades.

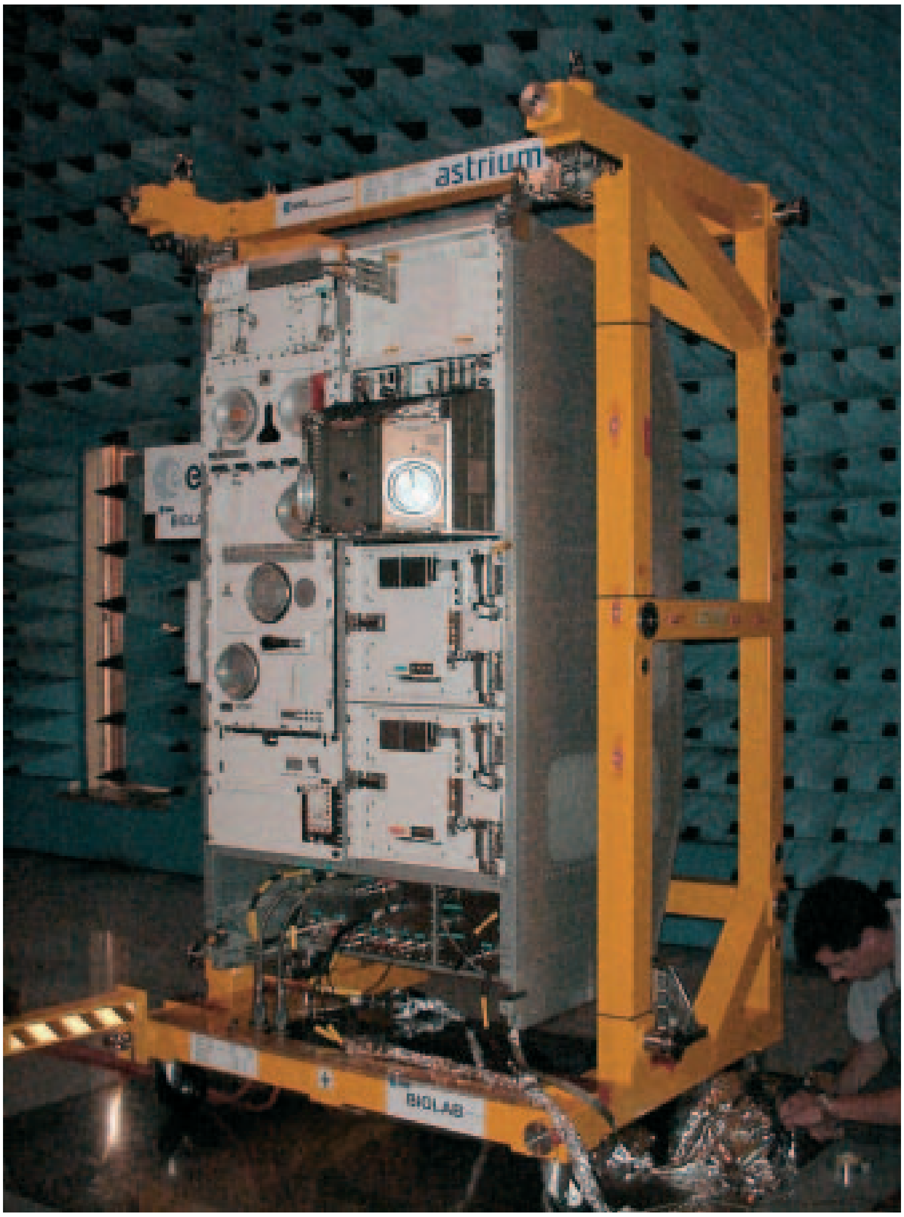
The specific features of each multi-user payload are as follows:

Biolab

Scientific objectives

Life Science experiments in space are aimed at identifying the role that microgravity plays at all levels of life, from the organisation of a single cell to the

The flight models of the pressurised payloads inside Columbus during IST testing in Bremen



The flight model of Biolab

nature of gravity resisting and detecting mechanisms in the more highly developed organisms, including man. Whilst the effects of microgravity on humans will also be investigated by other payloads (e.g. EPM), it is important to start the investigation with the smaller elements of the biological structure. At the science community's behest, ESA has always had a strong involvement in supporting the investigation of biological samples, with for example the Biorack on the Space Shuttle and the Biobox on a Russian carrier. The scientific results from these flights can certainly influence our everyday lives, particularly in the areas of immunology, bone demineralisation, cellular signal transduction and cellular-repair capabilities. Such results could eventually have a strong bearing on crucial products in the medical, pharmacological and biotechnological fields.

The current Biolab concept is that of a multi-user payload for conducting biological experiments on cells, micro-organisms, small plants and small invertebrates, as well as research in biotechnology. The design respects the science recommendations, the outcome of the scientific and feasibility study performed (i.e. Phase-A/B), the experience gained from payloads flown previously, and the requirements and possibilities offered by the utilisation of the Space Station.

Payload operation

Biolab is divided physically and functionally into two sections: the automatic section in the left-hand side of the rack, and the manual section on the right-hand side. In the automatic section, also known as the 'Core Unit', all activities are performed automatically by the payload, after manual sample loading into the centrifuge in the incubator by the crew. By implementing such a high level of automation, the demands on crew time are drastically reduced. The manual section, in which all activities are performed by the crew, is mainly devoted to sample storage and crew-specific activities.

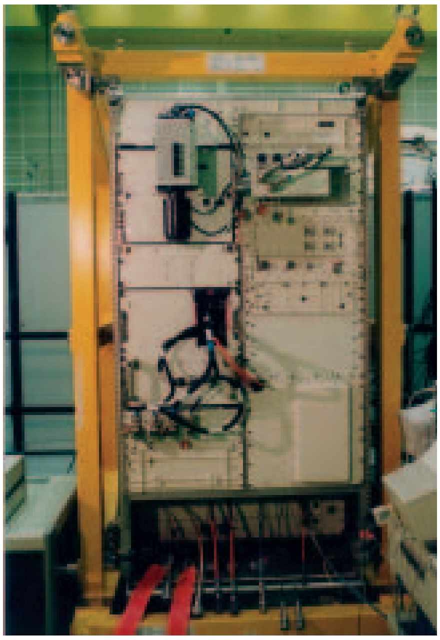
The biological samples are contained in standard 'Experiment Containers', which have standard external interfaces with the Biolab, an approach that has been well proven with the Biorack. The internal volume available to experimenters is 60 x 60 x 100 mm^3 for the standard container; a larger one is also available.

Fluid Science Laboratory (FSL)

Scientific objectives

Fluid-science experiments in space are designed to study dynamic phenomena in the absence of gravitational forces. Under microgravity conditions, such forces are virtually eliminated, including their effects in fluid media (e.g. gravity-driven convection, sedimentation and stratification and fluid static pressure). This allows fluid-dynamics effects that are normally masked by gravitation to be studied, such as the diffusion-controlled (rather than convective-flow-dominated) heat and mass transfer in crystallisation processes.

The absence of gravity-driven convection eliminates the negative effects of



The flight model of the FSL

density gradients (inhomogeneous mass distribution), which always arise on Earth in processes involving heat treatment, phase transitions, diffusive transport or chemical reactions (i.e. convection in earthbound processes is perceived as a strong perturbing factor, the effects of which are seldom predictable with great accuracy and dominate heat and mass transfer in fluids).

The ability to control such processes is still limited; their full understanding requires further fundamental research by conducting well-defined model experiments for the development and testing of related theories under microgravity. This will allow the optimisation of manufacturing processes on Earth.

ESA has already been involved in the study of fluid-science phenomena under microgravity conditions for several years, notably with the BDPU (Bubble, Drop and Particle Unit), which has already been flown twice on Spacelab missions, providing valuable results.

Payload operation

The kernel of the FSL payload is made up by the Optical Diagnostics Module (ODM) and the Central Experiment Modules (CEM), into which the Experiment Containers (EC) (see figure) are sequentially inserted and operated. Together, these modules represent the Facility Core Element (FCE), which is complemented by the functional subsystems for system and experiment control, power distribution, environmental conditioning, and data processing and management. The FCE will be suspended using the Microgravity Vibration Isolation System (MVIS) provided by the Canadian Space Agency. It will improve the microgravity conditions during experiment processing by reducing the residual dynamic forces present on the ISS. The MVIS will offer unique research capabilities to both European and Canadian scientists.

European Physiology Modules (EPM)

Scientific objectives

Human Life Science experiments in microgravity not only increase our knowledge of how the human body reacts to long exposure to weightlessness, but also contribute to a better understanding of Earth-related problems such as: cardiovascular, neurophysiology, ageing processes, osteoporosis, balance disorders, biomedical research, cancer research and muscle wasting during limb immobilisation (casts) and bed-rest.

The flight model of the EPM

Investigations into the effects of microgravity on the human body have been conducted for many years and ESA in particular has successfully flown related facilities (e.g. Sled, Anthrorack, etc.) on several Spacelab missions.

To be able to a make proper evaluation of the data collected onboard the Space Station, it is essential that reference (or baseline) data be collected both prior to the mission and after the crew returns to Earth. For this purpose, the EPM will include a Baseline Data Collection (BDC) system composed of functional replicas of the instruments on board. The BDC will be easily transportable to ensure that it can be available at the crew's location shortly before their launch and immediately after their landing.

NASA is developing a similar payload known as the Human Research Facility (HRF). It consists of two racks, the first of which was launched early in the ISS assembly sequence; the second will be launched with the Shuttle's return to flight, in advance of the Columbus Laboratory. ESA and NASA plan to collocate these two payloads within Columbus, thereby allowing the execution of experiments utilising scientific instruments from both payloads and increasing the scientific return.

Payload operation

The EPM payload is a multi-user facility intended to support research in the area of human physiology in a weightless environment. It consists of a complement of Science Modules plus the infrastructure, the Carrier, needed to support the coordinated operation of these modules. The Carrier provides the data handling, thermal control and mechanical accommodation to the Science Modules, nine of which can be active at any one time.

The Science Modules are accommodated in standard-sized drawers (4 and 8 PU, where 1 PU = 4.45 cm) and interface to the rack via a standardised guide system that simplifies Module installation and exchange in orbit. All rack-mounted Science Modules are cooled via a ducted air system provided as part of the Carrier.

Two Science Modules will be launched inside the EPM:

(a) *Multi-Electrode Electroencephalogram Mapping Module (MEEMM)*
Developed by ESA, the MEEMM is dedicated to non-invasive studies of brain activity by measuring EEG and evoked potentials in the stationary and a bulatory modes (e.g. sleep studies). In addition, the MEEMM can be used for EMG measurements to investigate muscle deconditioning/atrophy.

(b) *Cardiolab (Cardiovascular Laboratory)*
Developed by CNES (F) and DLR (D), Cardiolab's main objective is to study the cardiovascular system, particularly its central and peripheral regulation, and its short- and long-term adaptation to altered gravity levels. Research areas include the autonomous control of heart rate, and circulation and fluid volume regulation.

The EPM will also carry a NASA stowage container that will include HRF instruments.

Future modules under development include the Bone Analysis Module (BAM) for the investigation of bone loss in space, an issue of paramount importance in terms of conducting the long-duration missions required by the Exploration Programme, and a Portable Pulmonary Function System (PPFS).

European Drawer Rack (EDR)

The EDR is a multi-user payload, providing the infrastructure to accommodate and service experiment modules housed in International Subrack Interface Standards (ISIS) drawers and in standard Shuttle-type Mid-Deck Lockers (MDLs). The main drivers in its design are modularity and standardisation of experiment interfaces. The use of the standard drawers and lockers will ensure quick experiment turnaround, thereby increasing the number of flight opportunities for the user community.

The training model of the EDR

Payload operation
The EDR provides accommodation for small and modular experiments accommodated in ISISs and MDLs with access to the Columbus Laboratory services. A fundamental goal of the EDR is to support the accommodation of smaller sub-rack payloads (so-called 'Class II payloads' - the experiment modules) through the provision of accommodation resources and flight opportunities when quick turnaround is required. The EDR has been designed for maximum user-friendliness and flexibility of experiment accommodation and operation.

Future pressurised payloads

New payloads such as the Electro-Magnetic Levitator (EML) and Plasma Physics payloads are currently being defined to respond to the evolving requirements of the scientific community.

The Unpressurised Payloads

The ESA external payloads are a unique asset since no other ISS Partner will have comparable capabilities in place. Several multi-user payloads are already in an advanced stage of development, including SOLAR, EuTEF and ACES, and more are under definition, such as SPOrt-Plus, EUSO, Lobster, ASIM, and ROSITA. The first ESA external payload, Matroshka, is already in orbit attached to the Russian Service Module and is fully operational.

In-orbit transfer of the unpressurised payloads from the Shuttle to the Columbus External Payload Facility, and vice-versa, will be performed by Extra Vehicular Robotics (EVR) using the ISS Robotic Systems, i.e. the Space Station Robotic Manipulator System provided with the Special-Purpose Dexterous Manipulator. For SOLAR and EuTEF, the transfer will be carried out by the astronauts, via EVAs, as the EVR will not yet be operational.

The current status of the individual payloads is as follows:

SOLAR

SOLAR will measure the Sun's spectral irradiance over a wide energy range and with unprecedented accuracy. Apart from contributing to solar-physics research, SOLAR is expected to contribute to our knowledge of the interaction between the solar-energy flux and the Earth's atmospheric chemistry and climatology, which will be important for future environmental predictions.

The payload accommodates three complementary science instruments able to measure the solar flux across the electromagnetic spectrum, from the extreme ultraviolet to the infrared:

- SOVIM (SOlar Variability & Irradiance Monitor, developed by the Observatory of Davos (CH), covering the near ultraviolet (UV), visible and thermal regions of the spectrum and the total solar irradiance
- SOLSPEC (SOlar SPECtral Irradiance measurements, developed by CNRS (F), with support from BIRA (B), covering the 180 – 3000 nm range with high spectral resolution, and studying the solar variability
- SolACES (SOlar Auto-Calibrating

EUV/UV Spectrophotometers, developed by the Fraunhofer Institute, (D)) measuring the extreme UV and UV spectral region.

Manufacture of the flight models of the three instruments has been completed and they have already been tested, showing performances meeting or even exceeding specification.

The three instruments will be pointed towards the Sun using a multi-purpose, two-degree-of-freedom, Coarse Pointing Device (CPD) that compensates for the Space Station's orbital motion.

The prime contractor for SOLAR is Alenia Spazio (I).

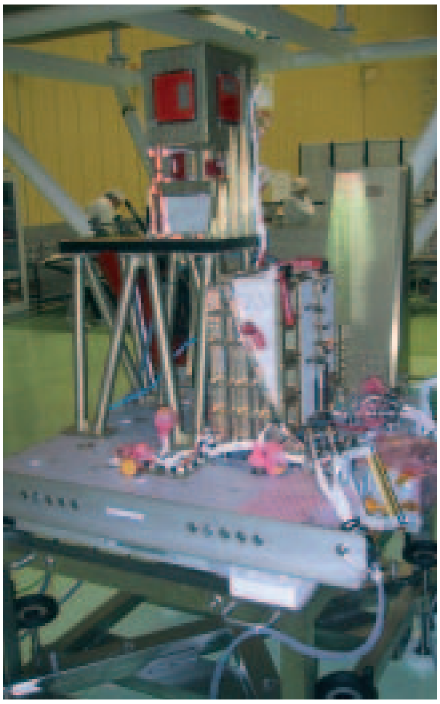
Integration of the SOLAR proto-flight model is in progress and will be completed by summer 2005. Integration with a launch carrier for the unpressurised payloads that will share the accommodation in the Shuttle together with the Columbus Laboratory will begin at Cape Canaveral four to five months before launch.

EuTEF

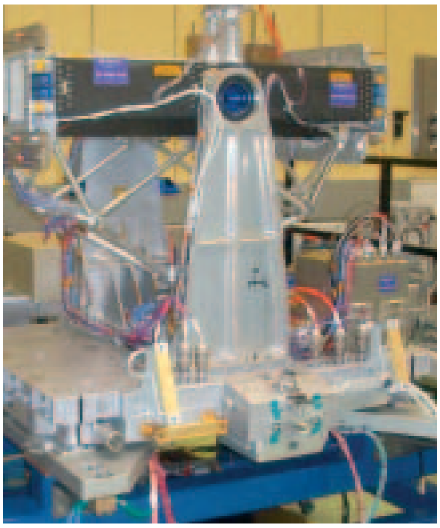
The European Technology Exposure Facility is a programmable, fully automated multi-user payload. A modular architecture provides uniform interfaces for up to nine instrument modules, all of which can be operated simultaneously. The following instruments are currently under development:

- TRIBOLAB: a Tribology Testbed, developed by INTA (E)
- PLEGPAY: a Plasma Electron Gun Payload, developed by Laben (I), used for protection against charged particles
- MEDET: a Material Exposure and Degradation Experiment, developed by CNES/ESA/ONERA/University of Southampton (UK)
- DEBIE-2: a debris detector, developed by ESA/Patria Finavitech (SF)
- FIPEX: a Flux Probe Experiment, developed by the University of Stuttgart (D)
- EXPOSE: an exobiology facility, developed by Kayser-Threde (D)
- DOSTEL: a dosimetric radiation telescope, developed by DLR (D)
- EuTEMP: a EuTEF temperature measurement device, developed by ESA/EFACEC
- EVC: an Earth Viewing Camera, developed by ESA/Carlo Gavazzi Space (I), for outreach activities.

The EuTEF flight unit, including the first set of instruments, is currently being integrated and will be completed by summer 2005. The prime contractor is Carlo Gavazzi Space (I).



The flight model of EuTEF



SOLAR model during Columbus interface testing in Bremen

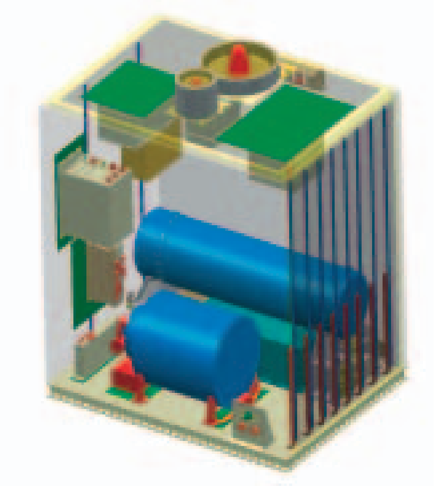
ACES

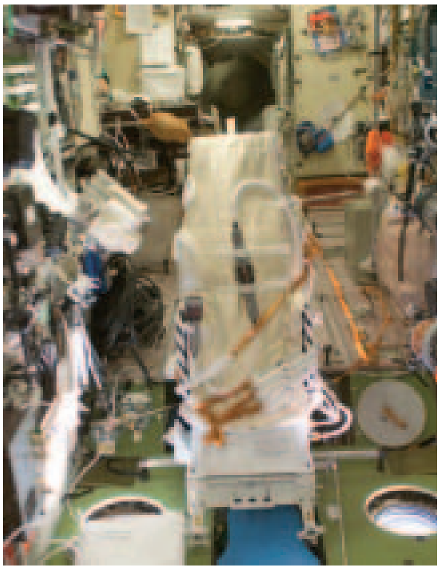
The Atomic Clock Ensemble in Space payload will test a new generation of atomic clocks in space. Important experiments will be performed in several scientific domains including, fundamental physics (cold atoms), high-precision geodesy, and global network synchronisation.

The payload supports two clocks working in unison. The cold-caesium-atom clock PHARAO (Projet d'Horloge Atomique par Refroidissement d Atomes en Orbite) is funded by France and developed by CNES. The Space Hydrogen Maser (SHM) is funded by Switzerland via ESA's PRODEX programme (Programme de Dévelopment d'Experiences scientifiques) and developed nationally by the Observatory of Neuchâtel. Both clocks will be characterised and compared in a microgravity environment to explore their ultimate performances in space.

The ACES payload is being developed and integrated by an industrial team led by EADS-ST based in Friedrichshafen (D). Unique to ACES is the possibility for worldwide participation involving a global array of User Home Bases (UHBs) procured by national time and frequency scientific institutes. The payload is currently in Phase-C/D, involving the

The ACES payload





The Matroshka phantom in orbit

development, manufacture and verification of engineering and flight hardware. ACES will be ready for launch no earlier than 2010.

Matroshka

Matroshka is a human dummy for studying the radiation doses to which astronauts' bodily organs are exposed during Extra-Vehicular Activities (EVAs). It consists of a simulated human upper torso, outfitted with special radiation-measurement devices.

Matroshka was transported to the ISS on Progress flight 13P on 29 January 2004 and installed on the outside of the Russian 'Zvezda' module. The scientific results are providing important information about astronaut radiation exposure during EVA. It is planned to retrieve Matroshka by the end of 2005, exchange its sensors onboard the ISS, and then re-expose it outside 'Zvezda' for further investigations.

SPOrt-Plus

This payload will include the grouping of the SPOrt science instrument with an additional instrument(s), currently being evaluated by ESA, able to share the same accommodation requirements.

SPOrt (Sky Polarization Observatory), an astrophysical instrument selected by ESA and developed by ASI (I), is designed to measure the sky polarisation in the unexplored microwave frequency range from 20 to 90 GHz. The scientific goals include production of the first polarisation map of our Galaxy at 22, 32 and 60 GHz, and full-sky measurements of unprecedented accuracy in the so-called 'cosmological window' at 90 GHz.

The SPOrt science instrument design phase (Phase-B) has been completed, and the main development phase (Phase-C/D) will be initiated by ASI in 2005. The prime contractor is Alenia Spazio (I). The earliest launch opportunity is foreseen 18 months after Shuttle flight 1E.

Future unpressurised payloads

Extreme Universe Space Observatory (EUSO)

EUSO is devoted to the investigation of the highest energy processes present and accessible in the Universe. By using the Earth's atmosphere as a giant cosmic-ray detector, EUSO will observe the flash of fluorescence light and the reflected Cherenkov light produced when an Extreme-Energy Cosmic Ray (EECR), with energy greater than 3×10^{19} eV, interacts with the Earth's atmosphere. EUSO will take advantage of the continuous Earth-pointing provided by the lowest balcony of the Columbus External Payload Facility and, by looking to nadir with a 60-degree field of view, will detect around 1000 such events per year, allowing a sensitive search for EECR-producing objects.

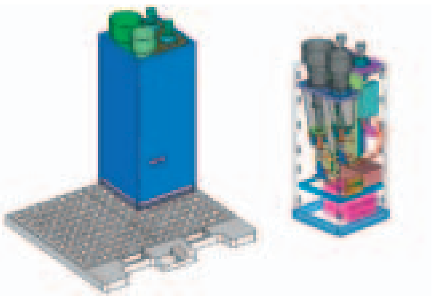
A worldwide consortium of investigators from the USA, Japan and several European countries, led by IASF-CNR of Palermo (I), is developing the Observatory. It consists of a UV telescope, with a lightweight double-Fresnel-lens optics system, a highly segmented focal-surface detector array, sophisticated onboard image processing, a Lidar, and an atmospheric sounding device that will provide 'real-time' knowledge of the atmospheric scattering and light-absorption properties.

The EUSO study phase (Phase-A), completed in July 2004, demonstrated that it is indeed possible to transport and accommodate such a large payload – 2.5 m in diameter and 4 m long – on the ISS. However, in view of the large amount of resources required to implement the mission, continuation of the project is currently under discussion.

Lobster

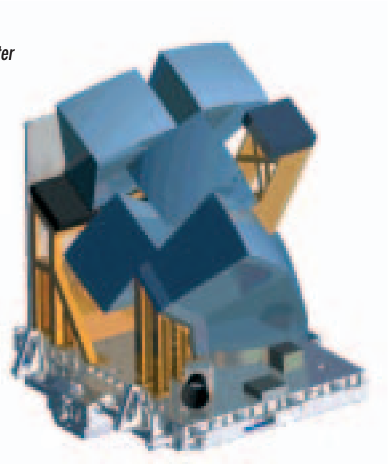
Lobster is an all-sky monitoring package operating in the soft-X-ray band (0.1 – 3.5 keV), with a main instrument consisting of

The SPOrt instrument



The EUSO payload

Lobster



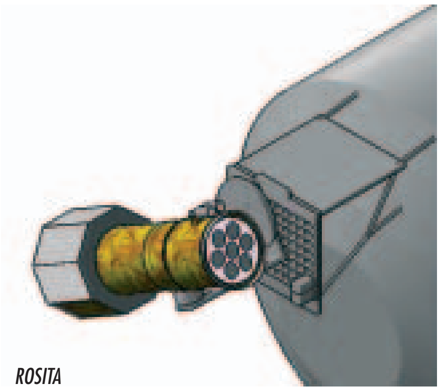
six microchannel-plate X-ray telescopes accommodated on the Columbus External Payload Facility. It uses a novel microchannel-plate arrangement to provide an extremely wide field of view, allowing it to generate a catalogue of about 250 000 sources every two months with a spatial resolution of a few arc-minutes.

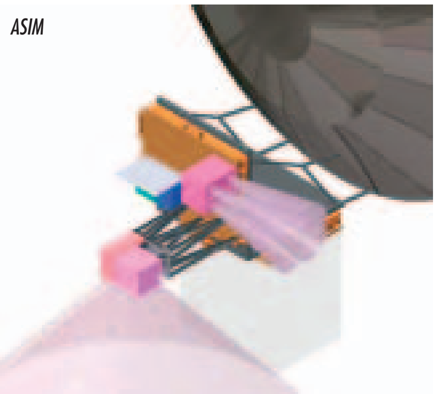
The instrument is being developed by the University of Leicester (UK) together with various co-investigators. The instrument design study (Phase-A) was completed in early 2005.

Röntgen Survey and Imaging Telescope Array (ROSITA)
ROSITA will perform an all-sky survey and imaging mission in the medium-energy X-ray range up to 10 keV, with unprecedented spectral and angular resolution. The telescope, supplied by MPE-Garching (D), will consist of a replica of the Wolter-I mirror systems already flown on ABRIXAS, and a novel detector system, currently under development, based on the XMM pn-CCD technology. The feasibility of accommodating this large payload – about 1 m in diameter, 2.5 m long and weighing more than 500 kg – has been preliminarily demonstrated in the context of a pre-Phase-A study performed by the ESTEC Concurrent Design Facility.

Atmosphere Space Interactions Monitor (ASIM)
ASIM will study the high-altitude optical emissions from the Earth's stratosphere and mesosphere using two types of instruments: an optical Miniature Multi-spectral Imaging Array (MMIA) with four imagers, and a single module of a Miniature X- and gamma-ray Sensor (MXGS). The instrument is being developed by DNSC (DK).

The ASIM pre-Phase-A study, completed by the ESTEC Concurrent Design Facility in October 2004, confirmed the feasibility of the payload. The Phase-A study has been initiated in 2005.


ROSITA


ASIM

The Challenges

Developing state-of-the-art pressurised payloads has meant meeting several major challenges. They have to comply with very challenging scientific requirements established by the science teams, and must also include the greatest possible degree of automation in order to minimise crew involvement. Telescience operation from the ground allows the scientists to interact directly with their experiments in space, while the high level of modularity means that the payloads can be refurbished in-orbit rather than having to be returned to the ground. This minimises the upload requirements for the scientific experiments.

Cooperative endeavours such as MVIS and Cardiolab have added value to the programme. MVIS will greatly enhance the FSL, providing good isolation for experiments from the Station's microgravity disturbances, while Cardiolab will offer a wide range of physiology instruments for cardiovascular studies in space.

The ESA External Payload Programme was initially based on the NASA Express Pallet Programme. The payloads were originally designed for launch and retrieval with the Express Pallet System and when NASA suspended this programme ESA had to face a completely new situation. The unpressurised payloads were relocated to the Columbus External Platform by means of a dedicated payload adapter called the Columbus External Payload Adapter (CEPA). This had important impacts on payloads already under development.

As far as the development of SOLAR is concerned, it called for innovative design solutions for the Coarse Pointing Device (CPD) and the science instruments. The CPD's structural design was particularly challenging because of the demanding combination of mechanical and structural requirements (loads, stiffness, mass, pointing requirements, return to Earth after a 1.5 to 3-year long mission). The design therefore involved the use of composite materials, supported by test campaigns to characterise the materials and processes being used in orbit for the first time.

The main development challenge for EuTEF was linked to the spread in maturity of the nine instruments that make up the payload. Difficulties experienced with the instruments' development had to be resolved by work-around solutions on the platform side.

Other important challenges are being met during the development of ACES and the other external payloads.

Both the pressurised and unpressurised payloads have been developed within very tight financial budgets set by ESA. Contracts totalling more than 50% of the overall budget have been awarded to several small- and medium-sized enterprises (SMEs), developing skills in these companies that will be exploited in future programmes, even outside ESA.

A Bridge between the ISS and Exploration

The ESA pressurised payloads incorporate state-of-the-art technology with an optimum blend of automation and human intervention. They are the most complex and productive payloads yet built for the ISS and are the result of the shared expertise and close cooperation of the ESA and Industry teams. The technology and know-how developed will have immediate applications in ESA's Exploration Programme, which is seeking to expand human frontiers through activities linked to evolution beyond the current ISS or to technology preparation for Moon/Mars missions. Research into human physiology conducted with the EPM payload will be fundamental to understanding the limits of human endurance in weightlessness (e.g. bone loss) and the development and verification of appropriate countermeasures.

A further contribution to the Exploration activities will come from the unpressurised payloads, such as the research into radiation effects on astronauts conducted with Matroshka, which has already been in orbit for a year. The EuTEF payload for conducting in-orbit technology experiments can be used to test new technologies, as well as for exobiology research, required by the Exploration Programme. All of the payloads developed will provide ESA with unique operational and sustaining-engineering experience that is also important for Europe's future Exploration Programme.

Conclusions

Pressurised and unpressurised payloads are being delivered to the ISS that not only meet, but in many cases exceed even today's challenging technical requirements. The robustness built into their designs, through modularity and in-orbit upgrade capabilities, will allow them to be operated in orbit for at least 10 years, well beyond the planned retirement of the Space Shuttle in 2010. With its unpressurised payloads on the ISS, ESA will have the unique capability of installing and operating complex instruments that can not only look down on the Earth, but also peer out into the far distant cosmos. They will offer unique opportunites to European scientists.

First Announcement

Sixth ESA/CNES International Workshop: Applications of Pyrotechnics in Space Systems

25/26 October 2005, ESA/ESTEC, Noordwijk, The Netherlands

The main aim of this Workshop will be to stimulate discussion and exchange of ideas, and to promote contacts between all those involved in or affected by the use of pyrotechnics in space systems.

The main theme of this particular Workshop will be: 'Engineering Reliability: What it means and how it is quantified'. It is planned to devote a full day to statistics, focussing on the standards and requirements, the best analysis methods, the available tools, and the results of recent work. Lectures will be given by professional statistics consultants, who will be happy to discuss statistical solutions and assist participants with problems related to reliability quantification.

There will be presentations by invited speakers and time will be allocated for questions and discussion to explore topics more fully. More such opportunities will be available during the several breaks. Presentations will also be given on contract work performed for ESA and CNES in their respective R&D programmes. Topics to be covered will include: Reliability and Statistical Methods, Pyrotechnic Composition and Pyrotechnic Device Lifetime, Shock Measurement and Testing, Approaches to Cost Reduction, Release-Nut Development, Pyrotechnic-Valve Development, Laser Ignition, Subsystem Design, Computer Simulation, Spacecraft Solid Propulsion, Testing, Standards for Pyrotechnics (ECSS, ISO, GTPS, etc.), Databases, Information Media, and current and future ESA and CNES activities. Suggestions are welcome regarding other topics to be included and should be sent to the address below.

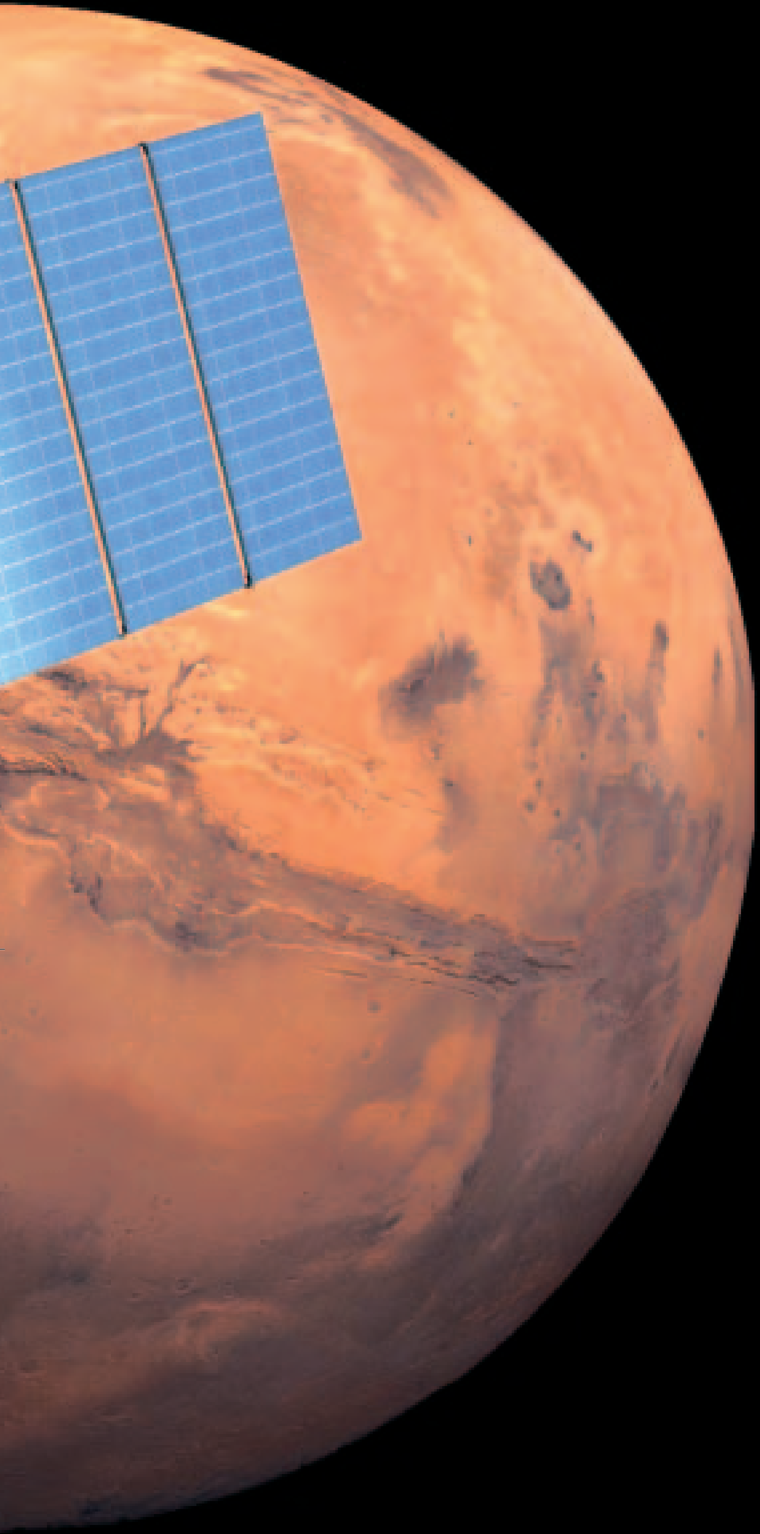
No fee will be charged for this ESA/CNES Workshop. Registration and accommodation arrangements can be made once the Preliminary Programme has been published. Forms for these purposes will be available in both paper and electronic form.

Contact Person :
Neil Cable
ESTEC/TEC-MCS
PO Box 299, 2200 AG Noordwijk
The Netherlands

E-mail: neil.cable@esa.int

Engineering Standardization at ESA

– Improving technical quality and cost-effectiveness in space



Jean-Leon Cendral
ESA Directorate of Technical and Quality Management, ESTEC, Noordwijk,
The Netherlands

Mario Merri
ESA Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

Ravinder Choda
SERCO, ESTEC, Noordwijk, The Netherlands

with contributions from ESA Engineering Standardization Board (ESB) Members

The importance of standardization for space activities in Europe is growing as the space agencies and industry are faced with new technical challenges within more demanding economic constraints. Missions and satellites have challenging performance and lifetime requirements; the technology is becoming more sophisticated, with more and more reliance on onboard intelligence and autonomy, while both schedule and costs have to be reduced. Engineering Standards contribute to the technical quality of the space products and the cost-effectiveness of the development and operations, thereby helping to make these achievements possible.

Why Space Engineering Standards?

Standardization is important to ESA and the space industry as a whole as they reach for new frontiers and strive to meet new challenges, but with the knowledge that their satellites need to be delivered on schedule and within budget and still be of very high technical quality.

Everyone knows that space missions are a risky business, where technology is pushed to the limit and the associated cost is significant. In addition, the space environment often does not offer the option of correcting problems that were not identified before launch. All this imposes a very strict approach to the engineering of the space segment, the mission element actually operating in space, and the ground segment.

For these reasons, space agencies and industry have invested in Engineering Standardization as a mean of reducing both the risk of failure and the development and operations costs. The risks are decreased because standardization offers proven and consolidated processes, methodologies and interfaces. Cost is reduced as standardization spreads the investment for technological developments across various space missions, and requires less-expensive test campaigns.

Furthermore, standardization typically supports interoperability: this means that if Standards are properly applied, the testing and operations facilities of several space agencies can be shared, thereby further reducing investment and maintenance costs.

An example of where a technical issue is overcome by the development of a standard can be found in the communications and data-handling interface between the space and the ground segments. Prior to 1994, new space missions basically re-developed each time the way of performing routine and troubleshooting operations and defined ex-novo the data structure of the telemetry sent from the spacecraft to the ground, and of the telecommands sent from the ground to the spacecraft. In 1994, the Packet Utilization Standard (PUS) was developed to define a common operational framework that is implemented via a standard set of monitoring and control services, each having a standard information model and data structures. Since then, most ESA missions, including all foreseen future spacecraft, use the PUS, with significant technical quality and economic benefits for both the space and ground segments.

Whilst standardization of technical processes can reduce the risk of anomalies and failures by using proven technologies, it also plays its part in determining the cost-effectiveness of a product or a process. Standards defining common procedures, interfaces or methods enable compatibility of technology in a specific sector or within a specialised domain, allowing industry to invest in fewer methods and tools, and reducing the development risks.

For businesses, the widespread adoption of Standards means that suppliers can base the development of their products and services on specifications that have wide acceptance within their sectors. This in turn means that businesses are able to compete in many more markets around the World. For customers, the worldwide compatibility of technology that is achieved when products and services are based on common Standards brings them an increasingly wide choice of offers, and they also benefit from the effects of greater competition between suppliers. For consumers, conformity of products and services to Standards provides assurance about their quality, safety and reliability.

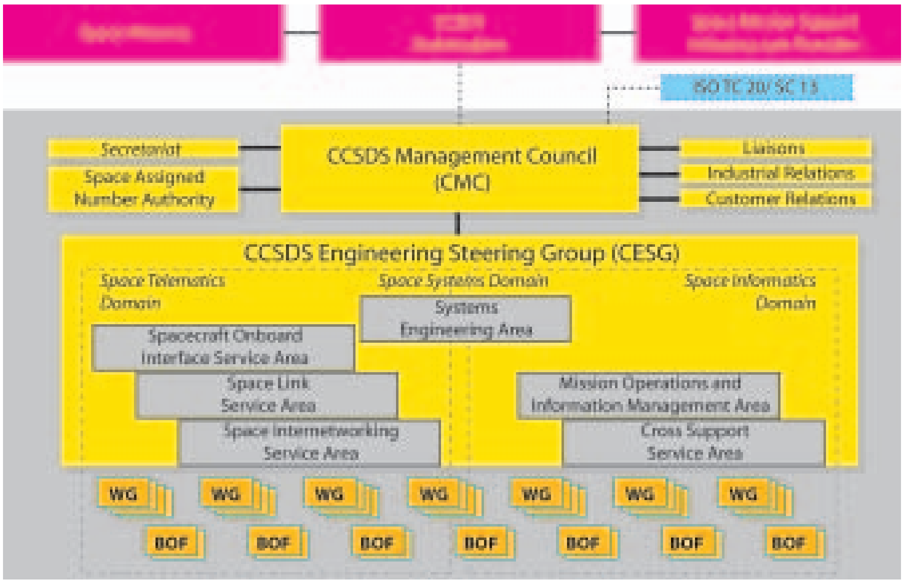
International and European Standards

As space exploration is a comparatively recent endeavour in mankind's history, engineering standardization has developed just over the last 20 years. Before that, the various space agencies were either developing their own internal or proprietary systems using no standards, or using internal standards that implied bespoke multiple developments and little interoperability.

In 1982, ESA, NASA and CNES (France's Centre National d'Etudes Spatiales) established the Consultative Committee for Space Data Systems (CCSDS), an international standardization body intended to address communications and data-handling techniques for data-system interoperability and standardization of space-related information technologies. Today, CCSDS's membership includes no less than ten space agencies: Agenzia Spaziale Italiana (ASI), British National Space Centre (BNSC), Canadian Space Agency (CSA), Centre National d'Etudes Spatiales (CNES), Deutsches Zentrum fuer Luft- und Raumfahrt (DLR), European Space Agency (ESA), Instituto Nacional de Pesquisas Espaciais do Brazil (INPE), National Aeronautics and Space Administration (NASA), National Space Agency of Japan (JAXA), and the Russian Space Agency (RSA). In addition, the CCSDS counts on several other participants in the form of observers, associates and collaborators. The CCSDS's recommendations, once approved, become International Organisation for Standardization (ISO) standards. The accompanying figure shows the body's high-level organisation and the breakdown into technical domains. Engineering work is mainly performed either within dedicated Working Groups for the development of Standards, or within 'Birds of a Feather' Groups for initial feasibility investigation.

The European Cooperation for Space Standardization (ECSS) (see accompanying figure) was established in 1993 to develop a coherent, single set of standards for use in all European space design and development activities. The set-up was devised in a spirit of true cooperation between the agencies and industry. Historically, the European space business had to support a multiplicity of different standards and requirements emanating from the various space agencies in Europe. Although the latter's requirements were essentially similar, the impact of these differences in standards was serious and led to higher costs, lower effectiveness and, moreover, a less-competitive industry. Input to the ECSS Standards comes from European space agencies and from industry. Initially, the thrust was mainly on Management and Product Assurance standards, but later Engineering standards were also addressed. ECSS Standards, once approved, are adopted as CEN (European Committee for Standardization) and ISO standards. The accompanying figure shows the main areas of standardization now covered by the ECSS.

Engineering standardization, which covers a very large technical domain in terms of processes, design techniques and interfaces, has been divided into seven separate space-engineering branches to cover the essential elements needed for space projects:



The structure of the Consultative Committee for Space Data Systems (CCSDS), showing the various technical domains addressed

- *System Engineering:*

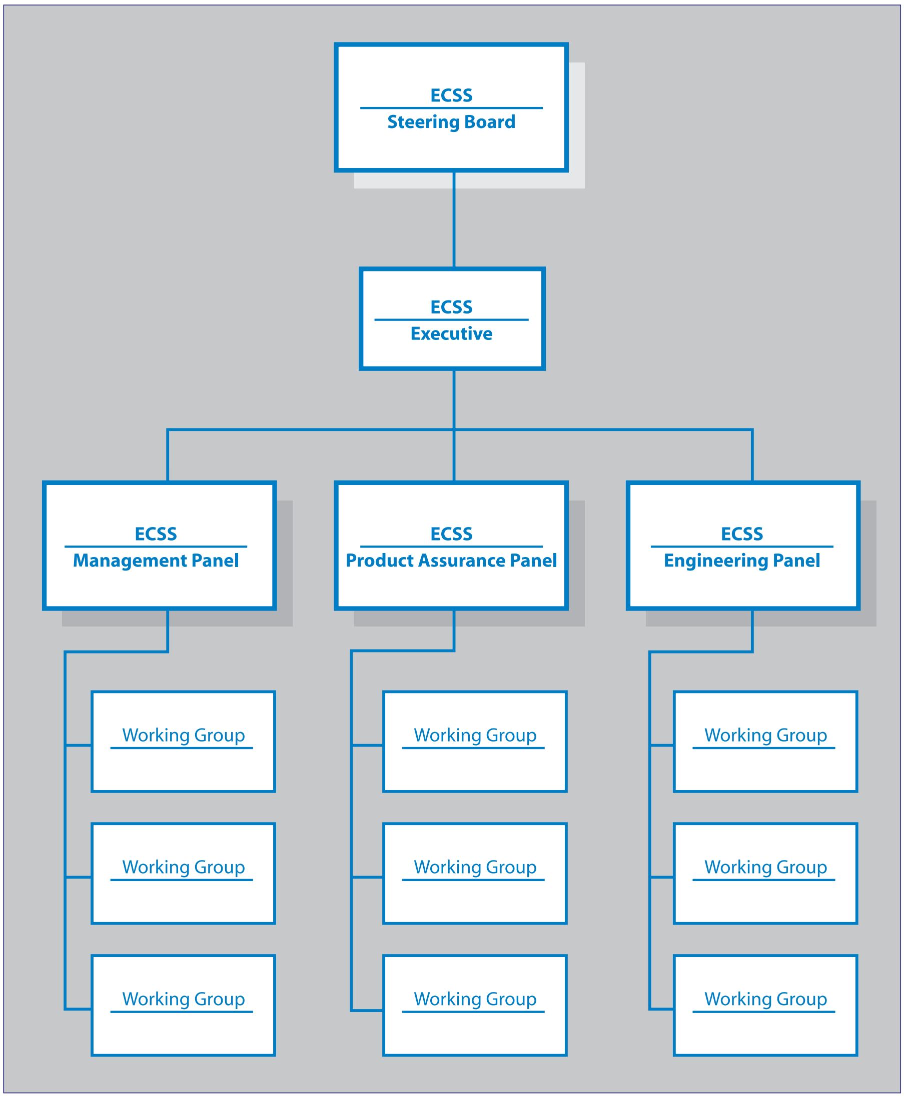
Development has been undertaken by both the ECSS and the CCSDS. As an example, the System Engineering Process Standard, ECSS E-10 Part 1, is considered to be the keystone Standard for all space projects, as it introduces the system-engineering principles into a space-dedicated process and provides a process framework, modulated through all affected project phases. Several other ECSS standards covering inherent system-engineering aspects and disciplines, like verification, data exchange, mechanical engineering, software, communications, etc., refer to ECSS E-10 Part 1 as a process framework. Additionally, the CCSDS covers complementary Systems Engineering aspects such as data security and information modelling.

- *Electrical and Electronic Engineering:*

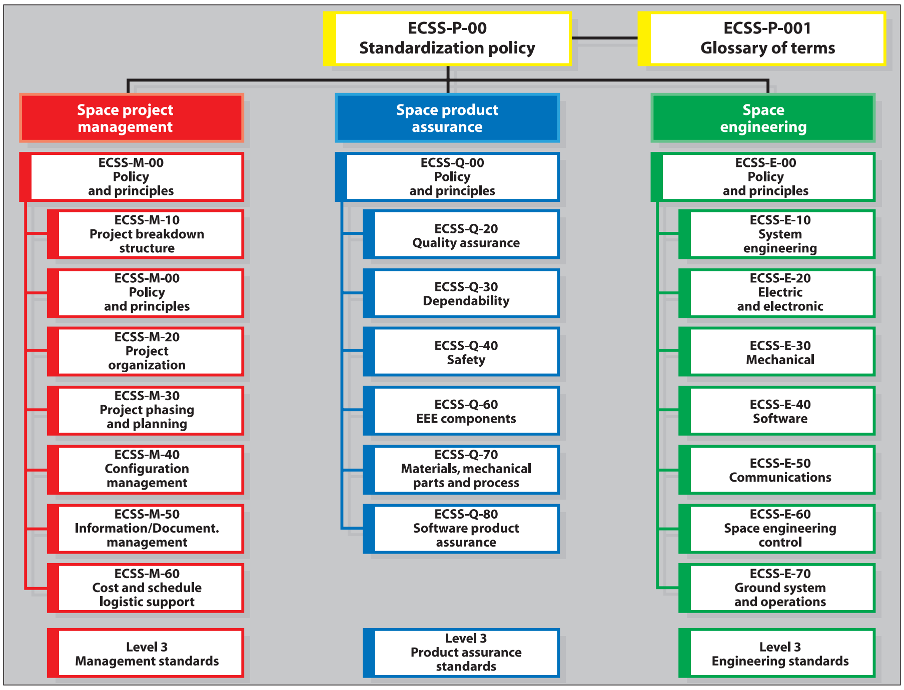
As an example, the Electrical and Electronic Standard, ECSS E-20A, establishes the basic rules and general principles applicable to the electrical, electronic, electromagnetic, microwave and optical engineering processes. Currently, a Standard on electromagnetic compatibility is being developed.

- *Mechanical Engineering:*

As an example, the Structural Standard, ECSS E-30 Part 2A, defines the requirements to be considered in all engineering aspects of structures: requirement definition and specification, design, development, verification, production, in-service and eventual disposal. Other topics covered are thermal control, mechanisms, Environmental Control and Life Support (ECLS), propulsion, pyrotechnics, mechanical parts and materials.



The structure of the European Cooperation for Space Standardization (ECSS)



The main areas covered by the European Cooperation for Space Standardization (ECSS)

• *Software Engineering:*
As an example, the software standard ECSS E-40 covers all aspects of space software engineering, including requirements definition, design, production, verification and validation, transfer, operations and maintenance.

• *Communications Engineering:*
Covers space-to-ground communication. Standards development has been undertaken by both the ECSS and the CCSDS Space Telematics Domain. As examples, the CCSDS Packet Telemetry and Packet Telecommand Standards have been and are being used systematically by several spacecraft. The Radio Frequency and Modulation Standard, ECSS E-50-05, defines the radio-communication techniques used for the transfer of information between spacecraft and Earth stations in both directions, while the Ranging Standard, ECSS E-50-02, covers the tracking systems used for orbit determination. The Proximity-1 Space Link Protocols suite, CCSDS 211, covers the communication between the Earth and a lander on a planet via a spacecraft orbiting that planet.

• *Control Engineering:*
Covers the engineering guidelines for the control of space systems and ground control systems (if control loops are closed via the ground). Currently, the main fields of standardization are related to control performance and star sensors.

• *Ground Systems and Operations Engineering*
Covers ground facilities for mission operations (ground stations, mission-control centres, ground interconnection infrastructures) and ground-support equipment for spacecraft assembly integration and testing. Standards development in this branch has been undertaken by both the ECSS and the CCSDS Space Informatics Domain. As an example, the Telemetry and Telecommand Packet Utilization Standard, ECSS-E-70-41, addresses the utilisation of telecommand packets and telemetry source packets for the purposes of remote monitoring and control of subsystems and payloads. The Space Link Extension suite, CCSDS 911 and 912, provides a standard protocol between ground station and mission-control centre.

ESA and Standardization

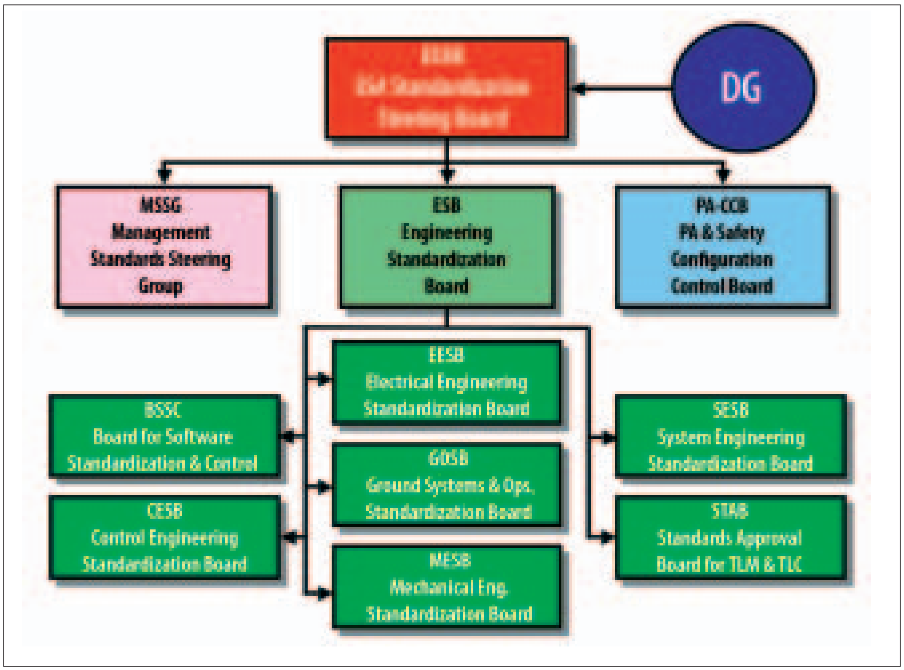
ESA is a major contributor to the European Engineering Standardization effort. Approximately 20 man years of effort are spent annually to support the related activities. ESA personnel participate at various levels of the ECSS and CCSDS organisations, to help guide the Standardization efforts and develop Standards within the various Working Groups put in place for this purpose.

The development of Standards is extended by a proactive approach to applying them in ESA projects and to improving them. ESA has in place a list of approved Standards applicable at large to all of its activities. The list includes mainly standards from the ECSS and CCSDS, and a few previously existing standards, e.g. Military standards (MIL-Std) and ESA Procedures, Standards and Specifications (PSS), which do not yet have an ECSS or CCSDS equivalent.

Within ESA, the coordination of standardization is the responsibility of the ESA Standardization Steering Board (ESSB), an inter-Directorate steering group mandated by the Director General to address the three branches of standards - Management, Product Assurance and Engineering - focusing on the support of space projects through standardization. This Steering Board is supported by the Engineering Standardization Board (ESB), which is responsible for identifying the standardization needs for ESA projects and contributing to the generation of relevant standards. The ESB is currently also involved in developing procedures for enhanced feedback on the utilisation of Standards by collating data gathered through the experiences of its members, and feedback from projects through lessons learnt, from agencies, and from industry. This ensures that Standards are not only being fully and correctly utilised by projects, but are also revised if necessary.

The ESB has formed the following sub-Boards in order to mirror the various space-engineering areas:

– Systems Engineering Standardization Board (SESB)
– Electrical and Electronic Standardization Board (EESB)



The organisation of Engineering Standardization in ESA

- Mechanical Engineering Standardization Board (MESB)
- Board for Software Standardization and Control (BSSC)
- Standards Approval Board for Telemetry and Data Handling (STAB)
- Control Engineering Standardization Board (CESB)
- Ground Systems and Operations Standardization Board (GOSB).

These sub-Boards are composed of ESA technical experts in the relevant fields and by project representatives, who ensure that space Standards developments are technically sound and meet the needs of the ESA projects. The experts on these sub-Boards, who come mainly from the ESA technical departments, also provide guidance and support on meeting the project requirements through the tailoring of standards. The sub-Boards are also responsible for recommending to the ESSB, via the ESB, the Standards that should be adopted by ESA and included in the List of Approved Standards. It includes only those standards that are applicable and to be used for all ESA space projects, and is maintained through feedback from the projects and industry.

Achievements

Major progress has been achieved since the time when each European agency and industry was using disparate sets of documents as standards. There is now a solid base of Engineering Standards, widely accepted by all European actors, which has been generated within the framework of the ECSS and CCSDS. Fifty such standards are in daily use by ESA. This represents the synthesis and the result of most of the cumulative experience of the European space actors, agencies and industry over the last decades.

A good example of ESA's achievements is in the fracture domain, where in the late eighties it initiated the definition of proper requirements, resulting in the issuing of one of the first Mechanical Engineering Standards. It was subsequently improved and issued as an ECSS Standard, E-30-01. It has now become the definitive Standard for this discipline for all ESA and many non-ESA projects. NASA has accepted it for application for Space Station (ISS) and Space Shuttle payloads, thereby simplifying the process of structural-integrity clearance for ESA/European payloads destined for Shuttle and ISS flights.

Thanks to the introduction of the CCSDS Proximity-1 Protocol, ESA's Mars Express mission was recently able to relay data to Earth from NASA's Mars Exploration Rovers 'Spirit' and 'Opportunity', overcoming the great distance between the two planets and the rovers' limited transmitter capability and allowing the scientific data return to be maximised. In future, any ESA, NASA, CNES or JAXA (Japan Aerospace Exploration Agency) Mars orbiter will be able to relay the telemetry data from any lander or rover from these agencies.

The benefit of standardization is also evident in the use of CCSDS Space Link Extension (SLE) services, which allows NASA Deep Space Network of ground stations to be used in support of ESA's Integral, Mars Express and Rosetta missions. This protocol between mission control centre and ground station facilitates the cross-support and maximises the performance and cost benefits to ESA projects.

Today, more than 300 space missions worldwide have applied the CCSDS- and ECSS-developed standards. All ESA missions currently under development also rely heavily on these standards.

Conclusion

Engineering standardization has proved itself to be an essential part of European space activities. It contributes to the achievement and improvement of the technical quality of space projects and products by optimising design solutions and reducing the risk of anomalies. Cost-effectiveness is also increased by the minimisation of development problems and the sharing of knowledge and common requirements. Through the ECSS and CCSDS organizations, today Europe has in place a strong base of Engineering Standards that span all of the technical fields involved in space-programme development and operations.

Future work is needed to consolidate and improve the existing standards and ensure the thorough coverage of all processes. New technologies and increased space system design complexity will also require the availability of new standards.

Coherent with its role in European space activities, ESA's continued proactive standardization involvement, both through the effective application of existing standards and in the development of new standards, ensures that all projects can benefit from its technical competence and experience accrued in numerous projects. It is also essential that other European space agencies and industry remain extensively involved in standards development and their effective application in their activities.

Clearly, Engineering Standardization has its cost, with funds needed to cover expert resources for development and prototyping activities as well as for participating in the standardization organisations. This is, however, an investment for the future, which should allow the successful completion of ever more challenging space missions and enhance the competitiveness of European space products. esa

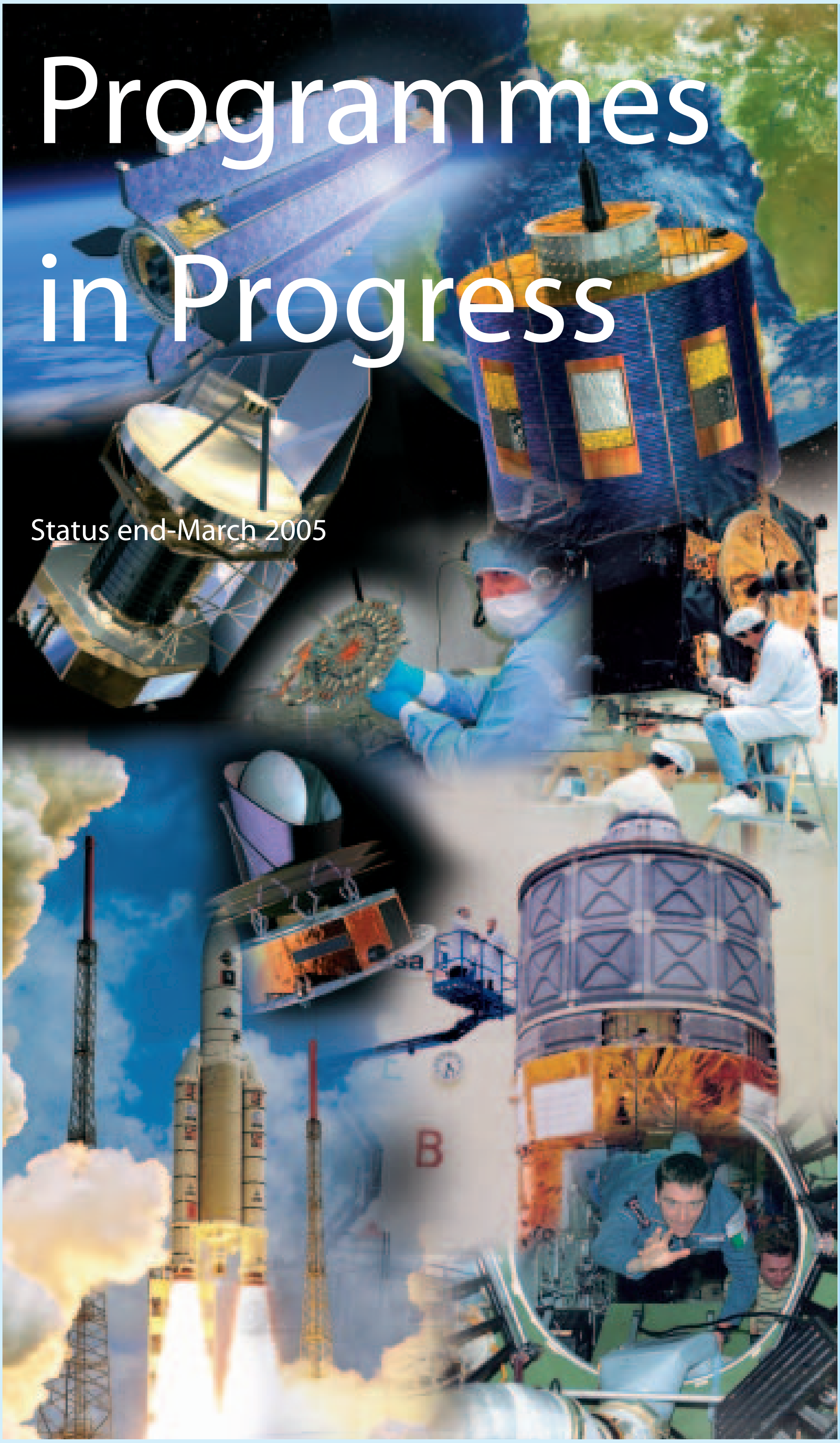
Further Information

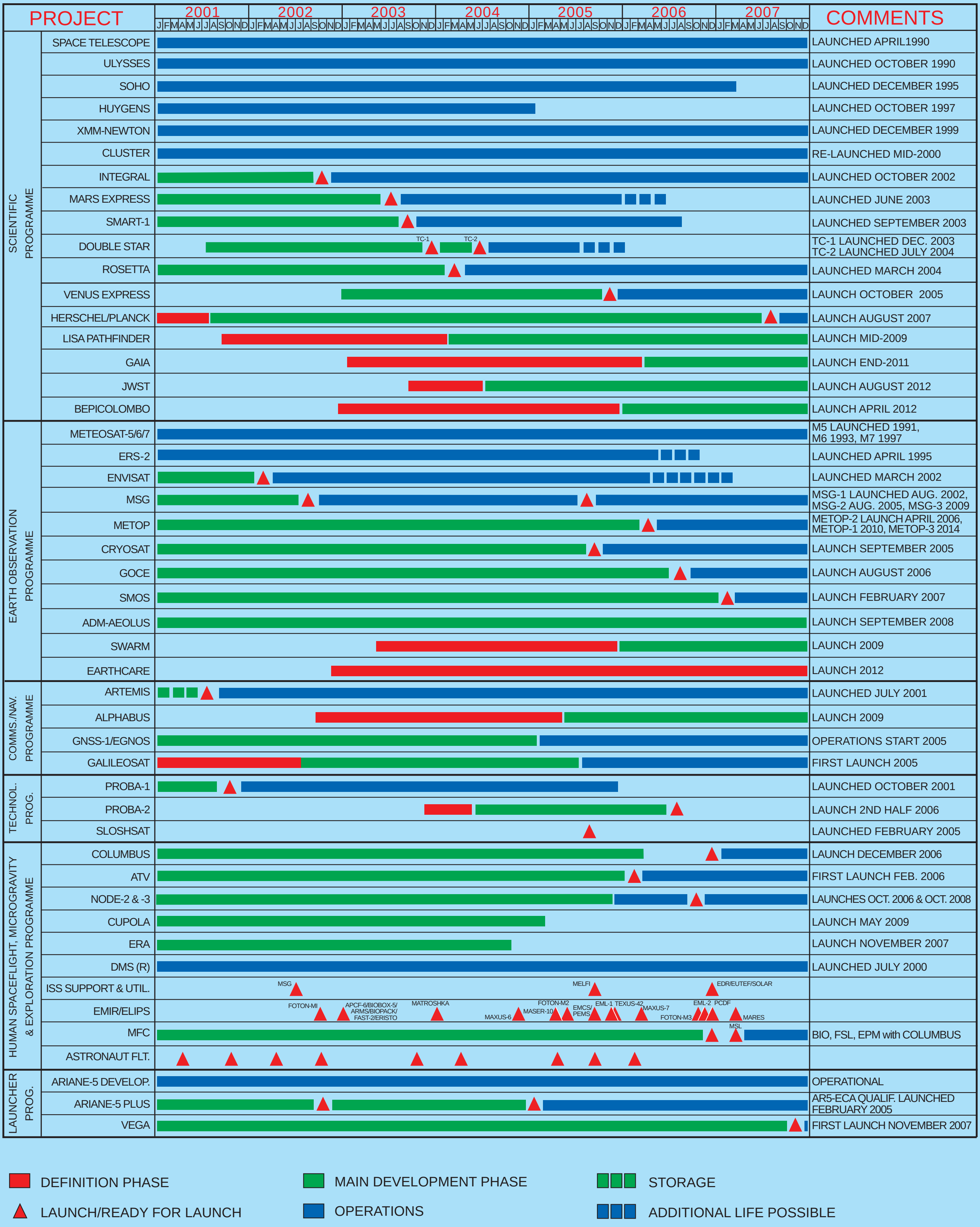
For additional information visit:

- Consultative Committee for Space Data Systems (CCSDS), at **www.ccsds.org**
- International Organization for Standards (ISO), at **www.iso.ch**
- European Cooperation for Space Standardization (ECSS), at **www.ecss.nl**
- European Committee for Standardization (CEN), at **www.cenorm.be**

Programmes in Progress

Status end-March 2005





	PROJECT	COMMENTS
SCIENTIFIC PROGRAMME	SPACE TELESCOPE	LAUNCHED APRIL1990
	ULYSSES	LAUNCHED OCTOBER 1990
	SOHO	LAUNCHED DECEMBER 1995
	HUYGENS	LAUNCHED OCTOBER 1997
	XMM-NEWTON	LAUNCHED DECEMBER 1999
	CLUSTER	RE-LAUNCHED MID-2000
	INTEGRAL	LAUNCHED OCTOBER 2002
	MARS EXPRESS	LAUNCHED JUNE 2003
	SMART-1	LAUNCHED SEPTEMBER 2003
	DOUBLE STAR	TC-1 LAUNCHED DEC. 2003 TC-2 LAUNCHED JULY 2004
	ROSETTA	LAUNCHED MARCH 2004
	VENUS EXPRESS	LAUNCH OCTOBER 2005
	HERSCHEL/PLANCK	LAUNCH AUGUST 2007
	LISA PATHFINDER	LAUNCH MID-2009
	GAIA	LAUNCH END-2011
	JWST	LAUNCH AUGUST 2012
	BEPICOLOMBO	LAUNCH APRIL 2012
EARTH OBSERVATION PROGRAMME	METEOSAT-5/6/7	M5 LAUNCHED 1991, M6 1993, M7 1997
	ERS-2	LAUNCHED APRIL 1995
	ENVISAT	LAUNCHED MARCH 2002
	MSG	MSG-1 LAUNCHED AUG. 2002, MSG-2 AUG. 2005, MSG-3 2009
	METOP	METOP-2 LAUNCH APRIL 2006, METOP-1 2010, METOP-3 2014
	CRYOSAT	LAUNCH SEPTEMBER 2005
	GOCE	LAUNCH AUGUST 2006
	SMOS	LAUNCH FEBRUARY 2007
	ADM-AEOLUS	LAUNCH SEPTEMBER 2008
	SWARM	LAUNCH 2009
	EARTHCARE	LAUNCH 2012
COMMS./NAV. PROGRAMME	ARTEMIS	LAUNCHED JULY 2001
	ALPHABUS	LAUNCH 2009
	GNSS-1/EGNOS	OPERATIONS START 2005
	GALILEOSAT	FIRST LAUNCH 2005
TECHNOL. PROG.	PROBA-1	LAUNCHED OCTOBER 2001
	PROBA-2	LAUNCH 2ND HALF 2006
	SLOSHSAT	LAUNCHED FEBRUARY 2005
HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME	COLUMBUS	LAUNCH DECEMBER 2006
	ATV	FIRST LAUNCH FEB. 2006
	NODE-2 & -3	LAUNCHES OCT. 2006 & OCT. 2008
	CUPOLA	LAUNCH MAY 2009
	ERA	LAUNCH NOVEMBER 2007
	DMS (R)	LAUNCHED JULY 2000
	ISS SUPPORT & UTIL.	
	EMIR/ELIPS	
	MFC	BIO, FSL, EPM with COLUMBUS
	ASTRONAUT FLT.	
LAUNCHER PROG.	ARIANE-5 DEVELOP.	OPERATIONAL
	ARIANE-5 PLUS	AR5-ECA QUALIF. LAUNCHED FEBRUARY 2005
	VEGA	FIRST LAUNCH NOVEMBER 2007

🟥 DEFINITION PHASE
🟩 MAIN DEVELOPMENT PHASE
🟩🟩🟩 STORAGE
▲ LAUNCH/READY FOR LAUNCH
🟦 OPERATIONS
🟦🟦🟦 ADDITIONAL LIFE POSSIBLE

ISO

Recent highlights include direct evidence from ISO data that shock waves generated by galaxy collisions excite the gas from which new stars will form. This is revealed in the Antennae galaxies pair by exceptional H_2 rotational line emission at a wavelength of 9.66 microns, detected via ISOCAM Circular Variable Filter observations. The H_2 line luminosity, normalised by the far-infrared luminosity, exceeds that of all other known galaxies, and the strongest H_2 emission is spatially displaced from the known starburst regions. This result also provides important clues as to how the birth of the first stars was triggered and speeded-up in the early Universe. Published in the April issue of *Astronomy & Astrophysics* by Haas *et al*., the findings are also reported on the ESA News portal as an outreach story.

Hubble Space Telescope

The 15th anniversary of the launch of HST was celebrated on 24 April 2005. The Telescope continues to operate exceptionally well, and during its lifetime has changed the paradigm and understanding in all areas of astronomical research. Operational efficiency remains high at ~50%, which means that even in its current low-Earth-orbit HST is observing for 50% of the time. Scientific observations are processed within a few hours, and accessibility to the data and archival information is assured within just a few hours also.

To assess the impact of Hubble observations on astrophysical research, standard objective measures of productivity and impact need to be used. One of these is the number of papers published annually based on Hubble data. The numbers for 2004 became available in February. Following a strong and regular increase during the first eight years of Hubble, the number of papers published continued to increase, although at a slower pace. However, 2004 saw another significant increase, with a record 601 papers published, over 100 more than in 2003. The current total of refereed papers based on Hubble data is over 4700.

Current projections for the lifetime of HST are that it should continue to be scientifically operational until late 2008, if the deliberate switch to a ‘two-gyro science mode’ is implemented sometime this summer. The lifetime of the observatory may ultimately be decided by that of the batteries, which are now 15 years old but continue to degrade gracefully. The current prediction is that they should continue to operate until 2010, thus giving considerable time for either a robotic or Shuttle servicing mission to be implemented, should this course of action be decided upon.

Ulysses

The spacecraft and its scientific payload are both in good health, with no anomalies having occurred during the last quarter. The budgetary situation regarding NASA’s contribution to the mission is, however, a concern, as a number of operational missions, including Ulysses, are presently under threat of termination. It is hoped to resolve this question at a NASA Review to be held later this year, and that the mission will continue as agreed until the end of the next polar passes in March 2008.

All science operations during the reporting period have been nominal. A proposed switch-on of the Ulysses’ Gamma-Ray Burst (GRB) instrument to support post-launch calibrations of instruments on NASA’s Swift satellite was deemed unnecessary based on the satisfactory in-orbit performance of its payload. GRB will therefore remain switched off until the onboard power/thermal situation improves (probably not before April 2007).

One of the principal goals of the Ulysses mission is to achieve a deeper understanding of how energetic charged particles are transported through the complex plasma environment created by the solar wind. Jupiter’s location with respect to the source of the magnetised solar wind – the Sun – is both non-central and precisely known, making the electrons that it emits ideal test particles for studying particle propagation throughout the inner heliosphere. Ulysses electron observations during the close (1992) and distant (2004) Jupiter encounters have recently been analysed to study the time-dependence of the particle transport parameters. Since the observations from both periods were obtained during the declining phase of the solar cycle, it was expected that the electron intensities in 2004 would vary in the same way as in the 1992 observations.

This was found not to be the case, however. In mid-2002, the electron flux started increasing and displaying large short-term variations. These features lasted throughout the distant encounter, making the electron intensities less obviously correlated with the proximity to Jupiter compared with the first (close) Jovian encounter in 1992. The suggestion is that the transport parameters, and in particular those governing movement perpendicular to the magnetic field in the polar direction, are highly time-dependent.

Ulysses is presently some 5 AU (astronomical units) from the Sun, on its way to the 3rd passage over the solar south pole.

Cassini/Huygens

The Huygens industrial consortium, led by Alcatel in close coordination with the Huygens Mission Team, is carrying out an engineering analysis of the Probe’s performance. The aspects being addressed include: software performance, entry detection, thermal behaviour, power budgets, parachute performances, spin and attitude profiles, radar-altimeter calibration, and the radio-link budget.

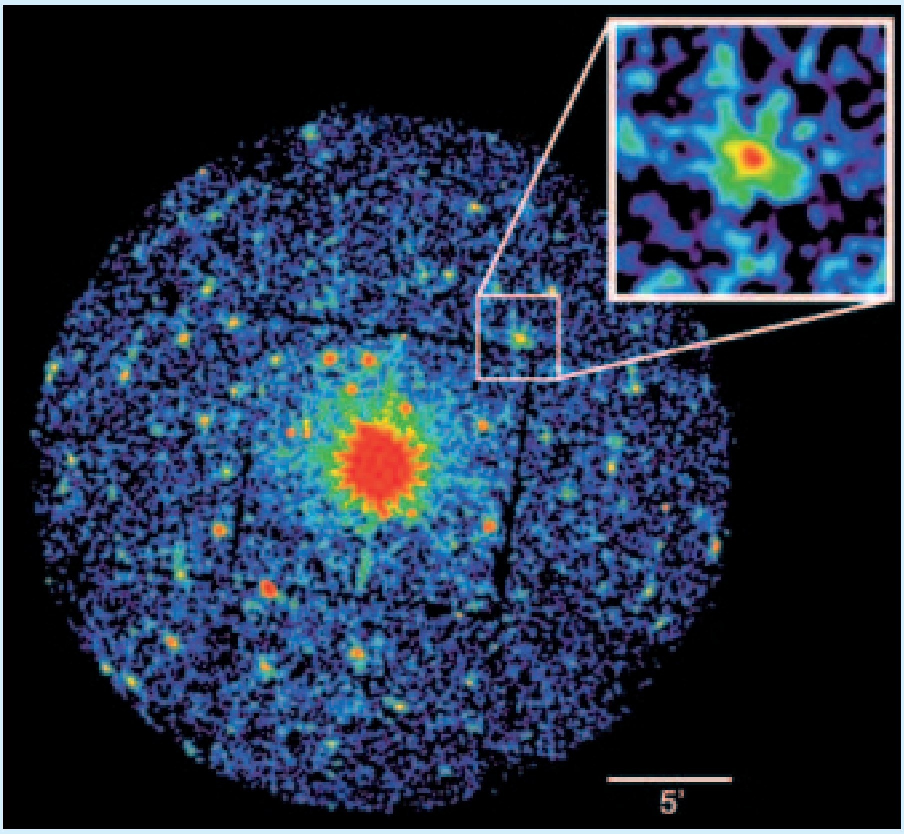
An anomaly has been observed in the Probe’s direction of spin under the parachutes. It separated from the Orbiter with the expected spin rate and direction. A value of 7.5 rpm was measured by the Cassini magnetometer and confirmed by JPL after post-mission analysis of the separation dynamics using Orbiter attitude data. At the end of the entry phase, the Probe was still rotating at about 7.5 rpm, but the spin rate slowed more than expected under the main parachute. In fact, it stopped spinning after about 10 min and began to spin in the reverse direction. It then kept spinning in that direction with the expected spin profile for the rest of the descent. No explanation has yet been found for this anomalous behaviour, which is still under investigation. The Sun sensor of the DISR instrument was affected by the fact that the solar disc came into its field of view from an unexpected direction.

Highlights from among the many unique scientific results already gleaned from Huygens include:

- Atmospheric structure (temperature, density and pressure) from the surface up to 1500 km. Titan's atmosphere was found to be highly structured during the whole entry phase, and turbulent in the lower stratosphere and upper troposphere.
- First detection of the cosmic-ray ionised layer at round 60 km altitude.
- Atmospheric methane concentration of 1.5% in the stratosphere and the upper troposphere. The concentration increased during the last 20 km of the descent, reaching 5% near the surface. The evaporation of methane after touch-down indicates that the surface at the landing site was soaked with methane.
- A 120 m/s wind at high altitude, but the winds are generally less strong than expected. A peculiar layer was detected between 80 and 60 km altitude, where the wind decreased to a very low value. Meteorologists are working to find an explanation.

XMM-Newton

XMM-Newton operations continue to run smoothly, with the exception of an anomaly in one of the EPIC MOS cameras. On 9 March, XMM-Newton registered an event in the focal plane of the EPIC MOS-1 instrument, the characteristics of which were reminiscent of very similar events registered earlier in the mission. Those were attributed to micro-meteoroid impacts scattering debris into the focal plane. It seems likely that CCD-6, one of the six peripheral MOS-1 CCDs, will not be usable for scientific observations in future. Evidence of a limited number of new hot pixels elsewhere in the focal plane of MOS-1 was also found. These other effects are relatively minor. XMM-Newton scientific observations are continuing normally, including those with MOS-1, but with CCD-6 switched off. Investigations are underway to fully characterise changes in the instrument's status.



The massive, X-ray-luminous cluster of galaxies, designated XXMU J2235.3-2557, detected from an XMM-Newton observation

For the scientific output of the mission, it is important to point out that MOS-1 is operated in parallel with the MOS-2 and the pn cameras. Therefore, the sky area that is no longer covered by CCD-6 is still covered by the two remaining cameras. The net effect of the loss of CCD-6 is therefore limited to only 3% of the total grasp of EPIC, and as such will not have a significant impact on the mission's scientific output.

The ground segment is still being run with SCOS-1b and SCOS-2000 in parallel. At a review on 14 April, the final switchover to SCOS-2000 was set for 1 June 2005.

The completion status of the observing programme is as follows:

AO-2 programme:	99.9% completed
AO-3 programme:	92.0% completed
AO-4 programme:	4.6% completed.

The AO-4 observations have been started slightly ahead of schedule, largely for sky-visibility reasons. Currently, over 3920 observation sequences have been executed and the data for 3801 of these have already been shipped.

In March, 1200 separate data sets were downloaded from the XMM-Newton Science Archive (XSA) by 115 external users.

The Astrophysical Journal has accepted a letter by C.R. Mullis *et al.* reporting the discovery of a massive, X-ray-luminous cluster of galaxies at z = 1.393, which makes it the most distant (X-ray selected) cluster found to date. This source, designated XMMU J2235.3-2557, was serendipitously detected as an extended X-ray source in an archival XMM-Newton observation.

Ground-based imaging using VLT-FORS2 R- and z-band snapshots revealed an over-density of red galaxies in both angular and colour spaces coincident in the sky with the X-ray emission. Subsequent VLT-FORS2 multi-object spectroscopy unambiguously confirmed the presence of a massive cluster based on 12 concordant red shifts in the interval $1.38 < z < 1.40$ (i.e. when the Universe was about 40% of its current age). Though this cluster is likely to be the first confirmed $z > 1$ cluster found with XMM-Newton, the relative ease and efficiency of the discovery demonstrates that it should be possible to build up large samples of such clusters through the joint use of XMM-Newton and large ground-based telescopes.

A total of 795 papers based completely or partly on XMM-Newton observations had been published in the refereed literature by 1 April 2005.

Cluster

The four spacecraft and their instruments are operating according to plan. The short eclipse (less than 1 h) season has been passed successfully. On spacecraft 1, one of the two batteries suffered a voltage drop about 3 min before the end of eclipse and the second battery was not powerful enough to keep the spacecraft and instruments working. A switchover from the main to the redundant onboard computer was triggered and all instruments were switched off. They were successfully switched on again after reconfiguring the spacecraft. To prevent this problem from happening again, a third battery was brought on line on each of the four spacecraft.

JSOC and ESOC operations are continuing nominally, and the data return from January to early March was more than 99.1%.

The Cluster Active Archive is progressing well. The first data have been delivered and it is planned to have most of 2001 data available by May 2005. The startup phase has been slower than expected, but with the formats and metadata dictionary now defined for all instruments the delays should soon be recovered. The implementation review is planned for end-May 2005.

Magnetic reconnection at the Earth's magnetopause is considered to be the most efficient mechanism for solar material to penetrate the Earth's magnetic shield. Complex geometrical properties of a transient and spatially confined type of reconnection have been observed in the past but so far not explained, due to the high velocity of the magnetopause and the use of single-spacecraft measurements. A case study based on multipoint measurements by Cluster reveals, for the first time, a direct observation of a 3D magnetic field topology at the magnetopause, resulting from magnetic reconnection at multiple sites, which could explain these geometrical properties. It also provides a direct picture of the entry of particles through the magnetopause.

High-speed flows of plasma (BBFs), propagating from the magnetotail to the Earth at velocities greater than 300 km/s, are the carriers of decisive amounts of mass, energy and magnetic flux. A statistical study based on multipoint measurements by Cluster reveals their typical spatial scales for the first time. More than 1600 data points of earthward flow events were used to deduce the size of the BBFs around 2–3 R_E in the dawn-dusk direction, and 1.5–2 R_E in the north-south direction.

Integral

The galactic bulge is a region rich in bright and variable X- and gamma-ray sources. From 17 February onwards, as part of an approved AO-3 programme, Integral has been observing this region every 3 days. As a service to the scientific community, light curves and images are made publicly available as soon as possible after the monitoring observations have been performed. More information about the programme and its results can be found at: http://isdc.unige.ch/Science/BULGE/.

On 27 December the Earth was hit by a huge wavefront of gamma- and X-rays. It was the strongest flux of highly energetic gamma radiation ever recorded from an astronomical object. It was detected by the Integral Burst Alert System (IBAS) and the anticoincidence shield of the SPI spectrometer. Within the first 0.2 s of the burst, the same amount of energy was emitted as comes from the Sun in about a quarter of a million years. An even more remarkable aspect of this discovery is the origin of this radiation: it comes from a tiny celestial body with an extremely high density, a neutron star, or so-called 'magnetar'. These are objects with incredibly strong magnetic fields – about 10^{14} times stronger than on the Earth's surface. The magnetar that emitted this burst, known as SGR 1806-20, is located on the other side of our Milky Way galaxy, at a distance of about 50 000 light years. Astrophysicists are confident that this event will cast new light on the physics of magnetars and contribute to solving the puzzle of the origin of gamma-ray bursts.

Mars Express

The first quarter of 2005 was marked by the start of the mission's second eclipse season. Some of the longest eclipses left only very little margin in which science operations could be conducted, yet this was successfully achieved. As the eclipse durations got shorter again, science data taking was gradually resumed at full speed.

A problem in maintaining the correct thermal environment for the OMEGA instrument resulted in a week of missed science operations in February. The problem has subsequently been fixed. A Solid-State Mass Memory (SSMM) anomaly, this time only affecting HRSC data taking, also occurred and was investigated. A new delivery of the SSMM software (fixing known anomalies) has been received and should be ready for uploading to the spacecraft towards the end of June.

Preparations for the MARSIS radar's deployment have almost been completed and an overall schedule has been agreed. A final review on 12 April confirmed the start date for the deployment window as 2 May. A number of activities associated with data recovery and the implementation of new procedures for

Radio Science and new pointing modes have been postponed to free sufficient manpower to prepare for the MARSIS deployment operations.

Science operations are proceeding well. Illumination conditions are gradually degrading and are starting to favour the nightside observations.

The first version of the Planetary Science Archive, containing the public Mars Express data, was released in February. While not all data that should have been available were actually delivered by the Principal Investigator teams, the archive is already being actively exploited.

After more than one year of Mars Express in-orbit operations, the First Mars Express Science Conference took place on 21-25 February at ESA/ESTEC in Noordwijk (NL), attracting some 250 participants from Europe, the United States, Japan, Russia, etc. The programme included 120 oral presentations and 120 posters covering all scientific aspects of the mission, from an historical perspective to the latest intriguing findings. The topics addressed included results from the interior and subsurface of Mars; Mars geology, mineralogy and surface chemistry; the polar regions and their ice caps; the climate and atmosphere of Mars and the interactions between surface and atmosphere; the space environment around Mars, and the planet's moons. There was also a special session on exobiology and the search for life.

A series of papers based on the results from OMEGA, focusing mainly on Mars surface diversity and seasonal measurements of the polar caps, have been published in the journal Science. These papers were also discussed in a session of the recent Lunar and Planetary Science Conference (LPSC, 14-18 March) dedicated to OMEGA. A number of HRSC results on the presence of a 'frozen sea' close to the Martian equator and recent glacial and volcanic activity on Mars, have been published in the journal *Nature*. These results were also discussed at the LPSC, making it clear that the Mars Express results are having an important impact on current thinking about Mars and its (recent) past.

Double Star

The two spacecraft and their instruments are operating well. The magnetometer data are being used to derive spacecraft attitude, while the satellite manufacturer, CAST, has modelled the attitude's evolution. The spin axis of TC-1, the equatorial spacecraft, will have drifted by about 9 deg by the end of 2006. TC-2's spin axis is drifting faster, and it will reach 30 deg by July 2006. There will therefore be enough power beyond the nominal end of mission (end-July 2005), and an extension until the end of 2006 will be proposed.

The European instruments are operating nominally. Resets on PEACE (electron sensor) are still occurring, and it is now being switched off and on regularly along the orbit to be able to recover from eventual resets.

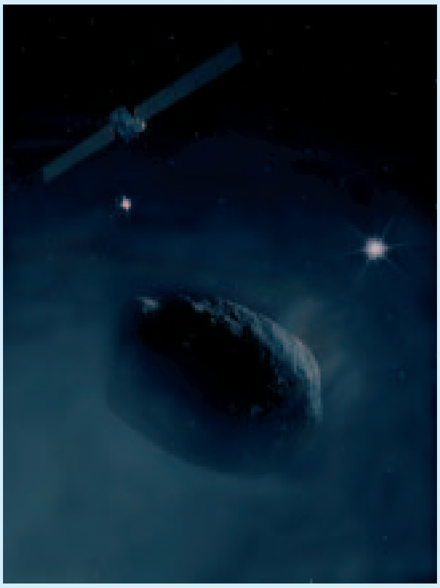
The European Payload Operation System (EPOS) co-ordinates the operations for the seven European instruments on TC-1 and TC-2 and is running smoothly. ESA/ESOC acquires data for an average of about 3.3 hours per day with the VILSPA-2 antenna, availability of which was above 99% between December and February.

Previous Cluster observations have shown that the flapping motions of the Earth's magnetotail are of internal origin and that waves are emitted from the central part of the tail and propagate toward the tail flanks. Using conjunctions between Double Star and Cluster, simultaneous observations were made both at 10-13 and 16-19 Earth radii (R_E). Neutral-sheet oscillations were observed by the Cluster and Double Star satellites on 5 August 2004. Their study showed that such waves can be observed as close to the Earth as 11 R_E, in the neighbourhood of the magnetotail hinge point.

Rosetta

Rosetta performed its first Earth-swingby manoeuvre on 4 March. The sequence started with a successful trajectory-correction manoeuvre on 17 February to put the spacecraft on its final course towards Earth. It was then gradually configured for the swingby, which included the activation of the fourth reaction wheel, switching the radio-frequency link from X-band to S-band, and from the high-gain to the low-gain antenna. On 1 March the first two instruments of the payload were activated, RPC and PHILAE ROMAP. SREM remained active as usual. VIRTIS and MIRO operations were initiated on 4 March. PHILAE CIVA was operated for three hours around closest approach to Earth. The OSIRIS Imaging System did not participate in the observations, due to some still unresolved problems with the instrument cover.

The Earth-swingby operations included various open-loop tracking tests with the navigation cameras, using the Moon as a target. The closest approach to Earth occurred at 22:09 UTC on 4 March at an altitude of 1954 km. Shortly afterwards, at 01:00 UTC on 5 March, the spacecraft was commanded into Asteroid Flyby Mode, using the navigation camera pointed to the Moon for attitude control. This was the first and actually the only inflight-test opportunity for this mode, which will be used during the flybys of asteroids Steins and Lutetia in 2008 and 2010, respectively. The test, which lasted 9 hours, was a complete success. The spacecraft survived the radiation-belt crossings and the Earth-proximity manoeuvres very well, with all systems working as expected.



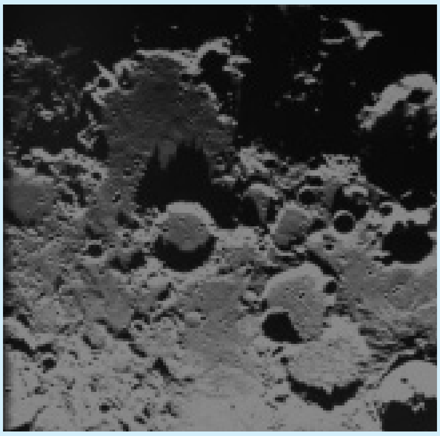
Artist's impression of the Rosetta spacecraft and lander

At the end of the test, the spacecraft was re-pointed to allow the payload and the navigation cameras to observe the Earth. It was also reconfigured to nominal mode, and by 10 March all of the science data generated had been transmitted to Earth.

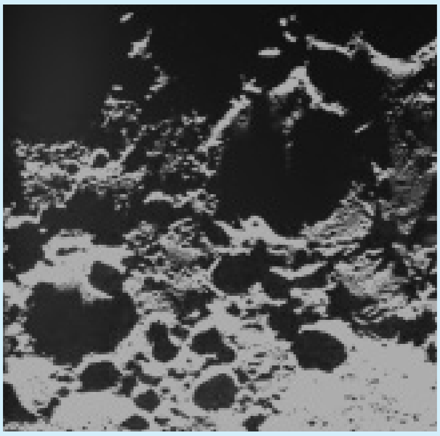
After successfully completing further testing, the spacecraft was put into near-Sun hibernation mode in order to make the most efficient use of onboard resources. Preparations have started for monitoring the Deep Impact spacecraft encounter with comet Tempel-1, for which a two-week payload operations sequence starting on 28 June has been introduced into the mission timeline. All of Rosetta's remote-sensing instruments, including OSIRIS, will be used.

SMART-1

SMART-1 reached its final lunar-observation orbit at the end of February. After an inadvertent electric-propulsion thrusting, the orbit had to be re-established with a correction manoeuvre on 12 March, after which a detailed calibration phase could begin. Unfortunately, this first part of the science phase has been further disrupted by another glitch, which caused some delay in the observation campaign. The mass memory store concerned has subsequently been downloaded and most of the science data recovered. The planned observations were promptly restarted on 16 April. The Moon's surface illumination is now approaching the optimum, and it is therefore imperative to have the instruments well-calibrated.



A 275 km wide area close to the Moon's north pole (upper-left corner) observed by SMART-1 on 29 December 2004 from a height of 5500 km. It indicates heavily cratered highland terrain, and can be used to monitor the illumination of polar areas, and the long shadows cast by large crater rims.

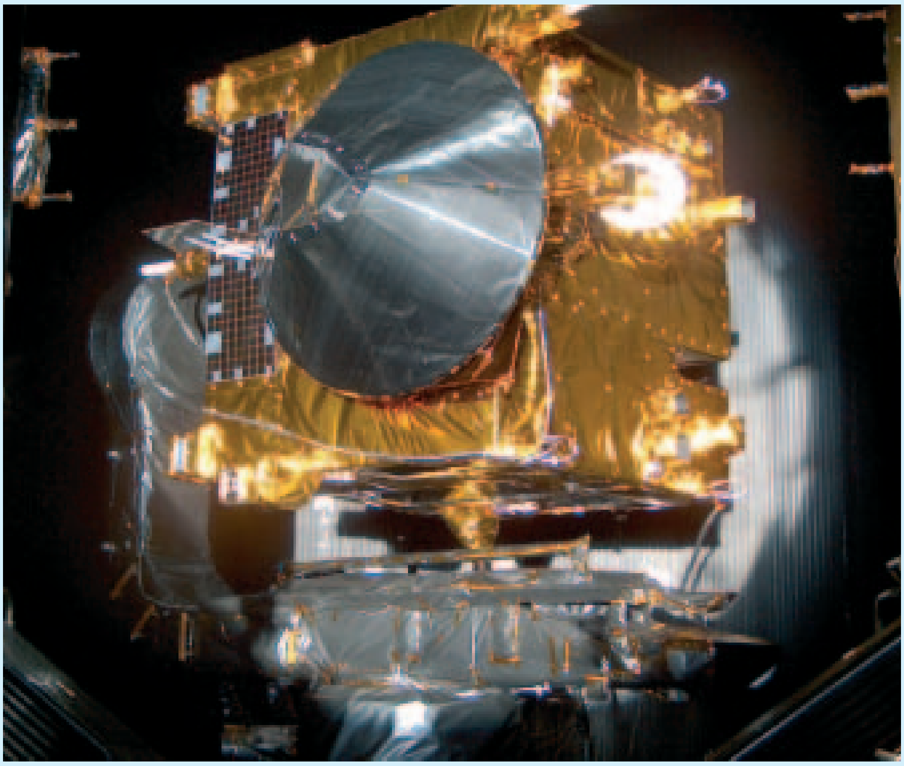


This image shows a 250 km-wide area at the lunar north pole observed by SMART-1 on 19 January 2005 (close to the northern winter solstice) from a height of 5000 km. The illuminated part of the crater rim at the very top of the image is a candidate for having peak eternal sunlight

Venus Express

The project continues to progress according to plan, with the spacecraft having successfully completed its crucial thermal-balance/thermal-vacuum test at Intespace in Toulouse (F) to prove its flight-worthiness for the hot Venus environment. The only remaining environmental test to be performed is that for electromagnetic compatibility. The spacecraft has also successfully passed two command and data compatibility tests with the ESA/ESOC Mission Operations Centre in Darmstadt (D), thereby successfully demonstrating its functionality within the overall Venus Express mission system.

The Venus Express ground segment is also progressing well, and interface testing with the scientific community is showing positive results. The new ESA station at Cebreros in Spain, which will be the Venus Express operations station, continues to advance well.



The Venus Express spacecraft mounted in the vacuum chamber at Intespace in Toulouse (F) and illuminated by simulated solar beam

The Venus Express launch will take place on 26 October 2005 from the Baikonur Cosmodrome in Kazakhstan. The agreed launch mass for the spacecraft and adaptor is 1270 kg.

Herschel/Planck

Significant progress is now apparent in the development of the spacecraft hardware. All of the Service Module structures built by CASA in Madrid (E) - the Herschel structural model and the Herschel and Planck flight models - have been delivered to Alenia in Turin (I) and a significant part of the mechanical integration activities have already been completed. The Herschel structural and thermal model will be shipped to ESA/ESTEC in Noordwijk (NL) in April to start its environmental test campaign. Testing activities on the electrical spacecraft models, and the avionics model of Herschel and Planck continue in parallel. The qualification model of the Planck Payload Module has been equipped with the qualification model of the HFI instrument and is presently being prepared at Alcatel Space in Cannes for the most significant environmental test, namely the cryogenic performance test.

Planck structural model in the acoustic chamber at Alcatel Space in Cannes (F)

The Herschel telescope's primary mirror polished at Opteon in Finland

The Herschel proto-flight model cryostat is in the final integration phase at Astrium in Friedrichshafen (D).

The polishing of the Herschel telescope's primary mirror at Opteon in Finland has now been completed and the next step will be the coating of its surface. The hardware development for the Planck reflectors has been completed and all mechanical testing successfully carried out. Both Planck reflectors are now ready for optical verification testing at cryogenic temperatures at the CSL facilities in Liege (B).

With the qualification models delivered, all instrument teams have already started the flight-model development phase.

SMART-2/LISA Pathfinder

The SMART-2/LISA Pathfinder implementation-phase activities are progressing well in industry. The main activity at the contractor's site is the preparation of the System Preliminary Design Review to be held in July 2005. Another important activity is the preparation and issuing of the various Invitations to Tender for the spacecraft subsystems and equipment. Earlier this year, however, a slowdown in activities was required to keep the spacecraft's development in phase with the delayed start-up of the LISA Technology Package (LTP) consortium. The project is now investigating with industry how best to adapt the spacecraft's development schedule to the LTP delivery delays in order to minimise the impact on cost and launch date.

The LTP is the spacecraft's 'core instrument'. Its development is being carried out under a multilateral agreement between ESA and seven of its Member States: Germany, Italy, United Kingdom, Spain, Switzerland, France and The Netherlands. The various arrangements required for the procurement of the different elements of the LTP by the Member States involved and ESA took considerably longer to complete than was expected. Consequently, the project team is now concentrating on redressing the situation, with the help of the industrial contractors and the national partners involved.

Given these circumstances, the launch is not expected to take place before the first half of 2009.

Microscope

The CNES Preliminary Design Review (PDR) at spacecraft level is planned for November 2005, though inertial-sensor development delays could shift it to the end of the year. The launch is now scheduled for December 2008, with the Critical Design Review in April 2007. The PDR, co-chaired by ESA and CNES, for the ESA-provided Electrical Propulsion System is scheduled for end-May/early-June 2005.

The activities at thruster and subsystem level are progressing well. In particular, a second engineering-model slit emitter test has logged more than 1300 hours of continuous operation, representing more than 400 Ns of total thrusting. This is the highest impulse ever achieved using this type of thruster. The test is providing important data about lifetime expectations.

Gaia

Both competing study contractors have reworked their designs to make them compatible with the available resources. Although this delayed the completion of the studies, the results now emerging clearly confirm the benefit and timeliness of the redesign effort.

As regards the front-end electronics with interfaces to the CCDs, a new technology activity has been initiated via a Call for Proposals to industrialise, i.e. mass-produce, these modules. The response from companies was overwhelming, and two contractors have been selected to work in competition. Early procurement of the flight CCDs was also initiated to safeguard the overall schedule of the Gaia project.

Meetings of the Gaia Science Team are continuing on a regular basis, and members of this body frequently provide advice to the Gaia Project.

The Invitation to Tender (ITT) for the Gaia development phase is in preparation for its release this summer.

James Webb Space Telescope (JWST)

As a result of a NASA internal JWST review (especially of the total spacecraft mass), a number of decisions were made that also affect the NIRSpec and MIRI instruments. In particular, the MIRI cooling system has been changed from a cryostat to a cryo-cooler. As the changes mainly affect the design of the spacecraft and its instrument compartment, the most critical path in the overall programme, namely the primary mirror manufacturing, is not affected. The overall programme has recently been slowed down by NASA due to financial constraints, resulting in a one-year delay and a new launch date of August 2012.

NIRSpec

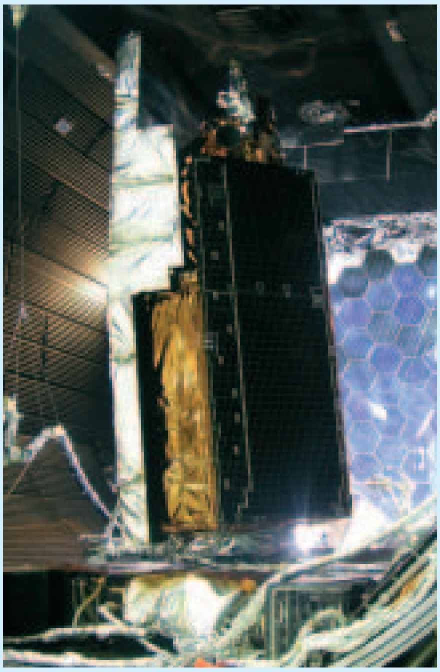
The procurement activities for NIRSpec are now well underway, with the industrial proposals for the mechanisms under evaluation. Instrument-to-system interfaces could not yet be finalised, which has prevented initiation of the manufacturing of ceramic mirror substrates and several structural parts. Schedule delays will therefore be unavoidable.

MIRI

The MIRI Cryostat and MIRI System PDRs have been successfully completed. Unfortunately, this work has now been made partly obsolete, as the Cryostat will no longer be implemented. A cryo-cooler consolidation study is now underway with the aim of freezing the cooler performance specification and interface requirement to the MIRI Optical Assembly (OA), thus avoiding significant impact and delay on the development of the European-provided Optical Assembly. The cryo-cooler contractor is expected to be selected by the end of the year. The MIRI Optical Bench structural model was successfully vibration tested in January.

Full-scale model of the James Webb Space Telescope (JWST)

CryoSat



The CryoSat satellite ready to undergo a thermal-vacuum test at IABG in Ottobrunn (D)

Good progress has been made in recent months on the development of the CryoSat satellite, particularly with the testing programme conducted by the Prime Contractor, EADS Astrium GmbH (D), at IABG in Ottobrunn (D). The spacecraft is now being prepared to undergo the two major remaining tests: a thermal-vacuum/thermal-balance and an acoustic test. However, to improve the reliability of the SIRAL radar altimeter, the test sequence will be interrupted in mid-May to allow the replacement of a critical electronic component that has recently been found to be potentially sensitive to vibration during launch.

Activities associated with the CryoSat ground segment are progressing nominally. The fourth Satellite Validation Test (SVT-2) has been successfully performed by ESA/ESOC (D) in February. A full Ground Segment Overall Validation (GSOV) has also been performed at system level. These two major test campaigns have demonstrated that the CryoSat ground segment is in a healthy state.

To prepare for the CryoSat level-2 product-validation activities, a complementary scientific campaign involving scientific experts from Finland was performed early in March in the Gulf of Bothnia.

Overall, there has been significant progress in the development of the CryoSat mission over the past months. Unfortunately, 'repair' activities are hampering overall progress, and the launch, which will take place from the Plesetsk cosmodrome on a Rockot vehicle, has now been re-scheduled for 15 September 2005.

GOCE

The main emphasis in the space-segment development activities continues to be on the conclusion of payload and equipment-level testing, and on the execution of the corresponding series of Critical Design Reviews (CDRs).

Alcatel Space has successfully completed the electrical integration of the Gradiometer engineering model, and functional testing is also close to completion. The stiffness anomaly detected in three flight-model accelerometer sensor heads integrated at ONERA (F) continues to be investigated through tests and analysis based on an agreed fault-tree.

Following completion of the electrical integration of the platform Engineering Model Test Bench, Astrium GmbH is focusing its efforts on the Bench's functional testing. In addition, the platform flight-model integration activities have continued with the installation of the electrical harness, the propulsion pipework and the heater lines.

As reported in the previous issue, experience from other ESA missions currently under development has shown a potential problem with the qualification of the European triple-junction gallium-arsenide (GaAs) solar cells used in the GOCE solar array, with the cell shunt diode showing anomalous behaviour during testing at high temperatures. This issue continues to be addressed by an ESA ad-hoc working group. In parallel, a life test is being conducted with a simulated GOCE thermal environment to assess the suitability of the baseline GaAs solar cells for the GOCE application. Also, a case of substrate delamination has occurred during the thermal-vacuum qualification testing of a solar-wing panel, for which recovery and backup solutions are currently under investigation.

On the ground-segment side, all development activities are progressing according to plan. The Preliminary Design Review (PDR) for the Calibration and Monitoring Facility (CMF) and the CDR for the PDS and the related Instrument Processing Facilities have been successfully concluded.

SMOS

The payload development programme is progressing according to plan. The 'reduced engineering model' involving a complete set of electronic payload elements is being assembled step-by-step. Only two more elements are still to be delivered in the second quarter of 2005 to complete the entire end-to-end chain.

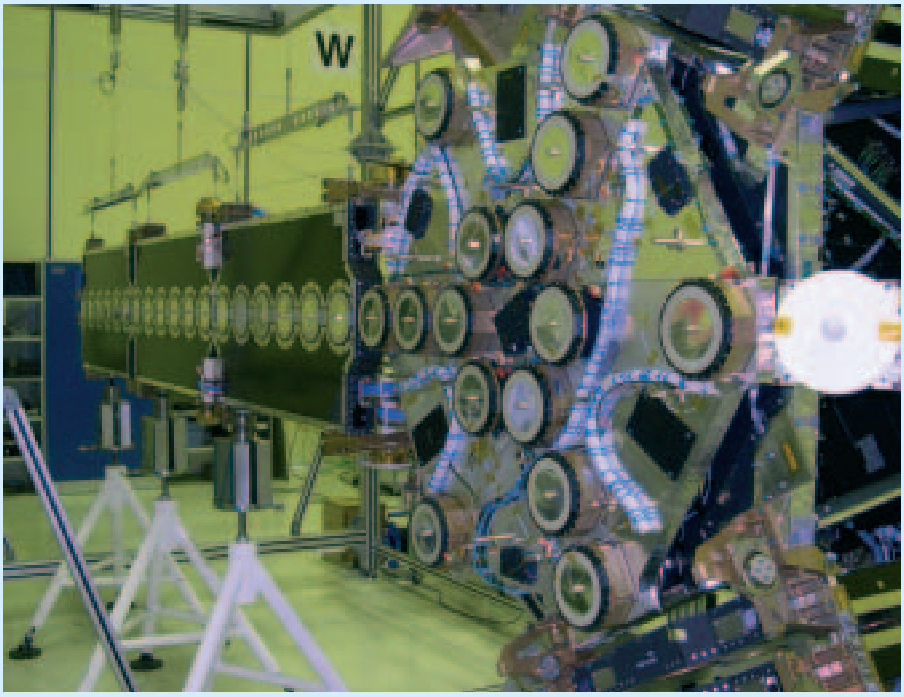
In parallel, a full-sized structural/thermal model has been built in order to achieve full environmental qualification of the payload. After the completion of some initial tests (pyro-shock, arm deployment) it is now at ESA/ESTEC in Noordwijk (NL) ready for the test campaign to start in the last week of April.

For those subsystems for which the engineering-model programme has been completed, Critical Design Reviews (CDRs) have been held to release flight-unit production. Some of the first flight units – elements of the structure, bandpass filters and antennas for the LICEF receivers – have already been delivered.

The Preliminary Design Review at satellite level is being conducted in cooperation with CNES (F). Once successfully concluded, it will authorise assembly of the recurrent Proteus platform used by SMOS.

The launcher for SMOS is under procurement from Eurockot in Bremen (D) and Khrunichev in Moscow (Russia).

Significant progress has been made on the ground segment. The algorithm approach for the level-1 processor has been selected and is



SMOS Payload Module structural/thermal model during deployment testing now under implementation. For the level-2 processors, two consortia have been selected and are now getting up to speed. The overall ground segment within which these processors will have to work is the subject of a Request for Quotation for the main development phase (Phase-C/D) addressed to a Spanish consortium led by INDRA (Madrid).

Unfortunately, a major airborne campaign called 'COSMOS', intended for collecting representative data for algorithm and processor development, had to be postponed due to unavailability of the aircraft. Recovery possibilities are presently being investigated.

ADM-Aeolus

The structural model of the Aeolus platform has been delivered to ESA/ESTEC in Noordwijk (NL). The optical structural thermal model of the instrument is currently being tested in the optical vacuum chamber in Liège (B). It will be delivered to ESTEC in early May for mating with the platform and mechanical testing.

Progress with the majority of flight-model satellite units is good, and most will be delivered in mid-year. However, the challenges posed by the onboard laser remain significant. Preparations are well underway, but the physical integration of the engineering qualification model will not start until June. The laser pump chambers for this model are working.

The first two batches of pump diodes for the flight-model laser have been delivered. However, manufacture of the pump chambers for the flight model is delayed as a result of new information concerning the susceptibility of the coatings of the YAG bars to laser-induced damage. A number of different solutions are being investigated.

The first results from the LID testing of other coatings in vacuum at DLR (D) show that at least the low-fluence optics are likely to achieve the necessary lifetime. Tests on high-fluence surfaces are continuing.

A first version of the flight software has been delivered and is working on the Software Verification Facilities.
The Aeolus Critical Design Review (CDR) will take place as scheduled in August and September 2005. The difficulties with the laser, and other less-critical delays, have led to April 2008 being the earliest possible launch date. A further five-month contingency in the contract with the prime contractor, Astrium, means that the launch is now scheduled for September 2008.

MetOp

The integration campaign for the first MetOp satellite to be launched, MetOp-2 (MetOp-A), is now drawing to a close, and the Flight Acceptance Review (FAR-2), aimed at declaring readiness for launch, will be held in the coming months. Thereafter, MetOp-2 will be stored for a short period alongside MetOp-1 (already in storage since end-2004) until its re-activation and preparation for shipment to the Baikonur launch site. These activities are presently planned for early 2006, with the launch slot retained as April 2006. Currently, all elements – satellite, ground segment and launcher – are on track to achieve this.

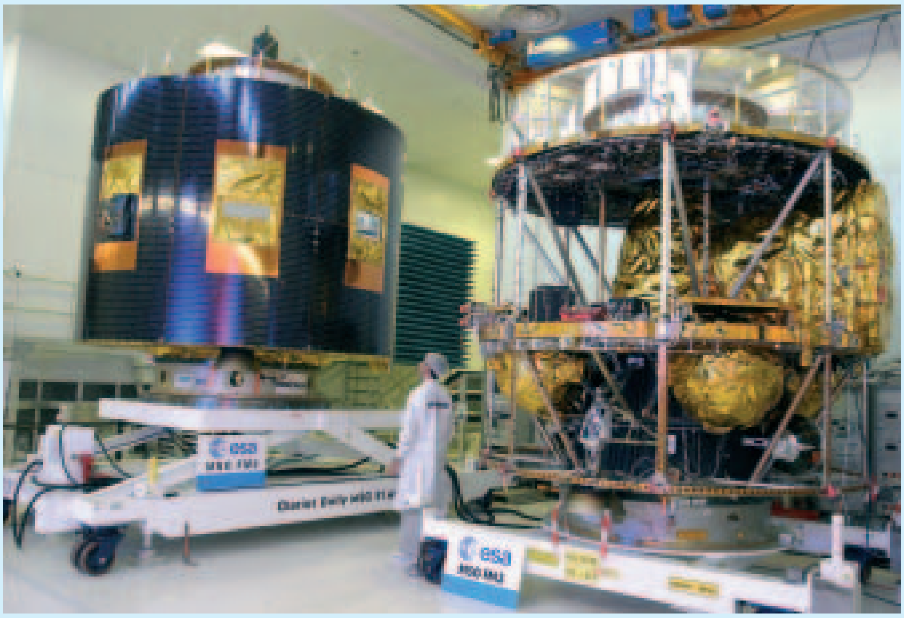
The IASI second flight model (FM-2) was delivered on time and exchanged for the non-flight-ready FM-1 on MetOp-2 without difficulty.

Preparations are well advanced for MetOp-2's launch campaign and the subsequent Commissioning Phase, and more specifically for the Satellite In-Orbit Verification subphase which will check correct functioning of the satellite after launch but prior to the (extensive) calibration/validation activities required.

Following completion of the in-orbit commissioning, the MetOp programme will nominally go into 'hibernation' until 2008, when the team will be re-activated to de-store MetOp-1, complete its integration and make it ready for launch. The industrial proposals for these activities and the MetOp-3 activities in the 2014 time frame are currently being iterated.

Meteosat Second Generation (MSG)

MSG-1 (Meteosat-8)
Meteosat-8 has been operating nominally, with no spacecraft behavioural anomalies reported. De-contamination of the SEVIRI instrument



Flight models of MSG-2 and MSG-3 in the clean room at Alcatel Space in Cannes (F) optics was performed at the beginning of 2005, followed by an east/west station-keeping/spin-rate manoeuvre on 8 February. The instrument's performance remains excellent.

MSG-2

The satellite remains in a short-term-storage configuration, awaiting its Consent to Ship to the Ariane-5 launch site in Kourou (Fr. Guiana). Launch is currently foreseen in August 2005, but timely availability of the co-passenger, the launch vehicle and the satellite's shock compatibility with the Ariane-5 GS launcher cannot be taken for granted.

MSG-3

MSG-3 remains in short-term storage in the clean-room at Alcatel Space (F). After the re-integration of missing units, some UHF investigations will still have to be performed. The MSG-3 spacecraft will be kept available as a source of spares for MSG-2 during its launch campaign. Thereafter, it will be put into long-term storage awaiting its own launch, currently foreseen in 2009.

MSG-4

Progress with the MSG-4 assembly, integration and test activities is nominal. The propellant subsystem has been delivered and mated and the complete harness has been delivered and integrated. The antenna platform has been delivered to Alenia. The SEVIRI instrument is in the final stages of integration.

Human Spaceflight, Research and Applications Programmes

Highlights

Agreements have been reached with Roskosmos and NASA for a seven-month ESA astronaut mission on Shuttle flight ULF1.1 to the ISS in 2005, and return on flight 12A.1 in early 2006.

The Heads of Space Agencies, who met in Montreal on 26 January, have endorsed the ISS configuration and reaffirmed their commitment to meet all of their ISS obligations, to complete ISS assembly by the end of the decade, and to use and further evolve the ISS in a manner that meets their research and exploration objectives.

As a result of this meeting, the launch of Columbus is now formally advanced in the assembly sequence, such that it immediately follows the launch of Node-2. The assembly sequence also now foresees the establishment of a permanent crew of six in January 2009 and the completion of the ISS assembly in 2010, at which time NASA plans to retire the Space Shuttles from service.

The Russian cargo spacecraft Progress 17P was launched on 28 February and docked with the ISS on 2 March.

Space infrastructure development

All payload facilities have been removed from Columbus and returned to their developers for storage/risk-mitigation testing, and the Columbus module has entered a hibernation phase.

In January, the Automated Transfer Vehicle (ATV-1) *Jules Verne* Crew Equipment Interface Test and the Late Cargo Access Means Test were successfully performed. The initial part of the System Qualification Review will start in mid-April. The last outstanding hardware needed before the arrival of ATV-1 at the ISS has been installed. The Global Positioning System (GPS) antennas were installed outside the Russian Zvezda module during a four and a half hour Extra Vehicular Activity (EVA) on 28 March. Current *Jules Verne* planning leads to an earliest possible launch-availability date of end-February 2006.

The Element Leak Test on Node-2 was successfully performed in February. Meanwhile manufacturing and assembly activities for Node-3 are progressing, with cone assembly having started in March.

Leak testing of the Cupola spare window was successfully completed in February, and manufacture of a top window flex-hose protective box to prevent leakage, as occurred in the USLab several months ago, started in March.

Also in March, ESA was informed that the European Robotic Arm (ERA) spares would be launched on an 'as needed' basis after ERA's launch. The industrial proposal for the launch of ERA onboard the Russian Multipurpose Laboratory Module will be evaluated in May/June 2005.

Operations and related ground segments

The Columbus Control Centre (COL-CC) Distributed Monitoring and Control System V2 Factory Acceptance Test was successfully completed in January, and the Test-Readiness Review was successfully performed in March. In February, the first of a series of three COL-CC stand-alone simulations for Columbus started.

The Data Gateway V2.0 and the Monitoring and Control System V3.2 for the ATV Control Centre (ATV-CC) have passed the Site Acceptance Test.

Deactivation of the Interconnected Ground Subnet Phase-1, and migration to Phase-2, has been completed.

A new ESA Control Room at TsUP (Russian Mission Control Centre) has been outfitted to support Soyuz and ATV missions.

The Data Management System onboard the Russian Service Module (DMS-R) continues to perform flawlessly.

In March, in-orbit science operations using the external Matroshka payload were stopped due to repeated communication failures. Trouble-shooting measures are in preparation.

Utilisation planning, payload developments and preparatory missions

In January, the accession contracts for all 40 academic and industrial partners in the IMPRESS Integrated Project (Material Science) were signed at ESTEC (NL).

In March, the TMA-Bridge Interoperability Workshop was concluded and the mid-term review of the project was successfully held at the European Commission.

Agreement on the participation of the Canadian Space Agency (CSA), through ESA, in the CNES-ESA-NASA Womens' International Space Simulation for Exploration (WISE) Bed-Rest Study on females, was reached on 3 March, and the three-month study is now underway.

Peer review of the proposals received following the 2004 Announcement of Opportunities (AO) in Life and Physical Sciences has been concluded, and the Microgravity Application Promotion (MAP) project proposals are being evaluated.

Definition studies for human-physiology projects, received following the 2004 International Life Sciences Research Announcement, are ongoing.

The implementation of upgrades and robustness testing on the Columbus payload-rack facilities is progressing towards final delivery of the flight models to Columbus in September. The Acceptance Reviews for the Science Reference Models of Biolab and of the Fluid-Science Laboratory were successfully performed in February. The overall breadboard architecture of the Bone-Analysis Module for the European Physiology Module was defined, and work is proceeding according to schedule. Acceptance Reviews for the Ground Model-1 and the Baseline Data-Collection Model were completed in March. Following recovery after failure of the European Drawer Rack (EDR) engineering-model Video Management Unit, final system tests for both the EDR engineering and flight model re-started, and the flight-model Acceptance Review was kicked-off at the end of March.

Following NASA's cancellation of its Materials-Science Research Rack utilisation, the Materials Science Laboratory (MSL) engineering model was shipped back to Europe from Marshall Spaceflight Center. Meanwhile integration of the MSL flight model has progressed and testing has started.

Columbus system and payload stowage integration with the European Transport Carrier (ETC) is progressing.

In March, tests on the integration of the European Modular Cultivation System (EMCS) facility flight model into an Express rack, were successfully completed at Kennedy Space Centre (KSC), and the EMCS is now being prepared for launch with flight ULF1.1 this summer. The Percutaneous Electrical Muscle Stimulator was shipped from Johnson Space Center to KSC in preparation for launch on the same flight.

Integration and refurbishment at KSC of the MELFI Flight Unit 1 (FU-1) was completed and the module is currently being prepared for launch on ULF1.1. Some corrosion-repair activities are being carried-out on FU-2, and FU-3 activities are on hold pending resolution of the Brayton machine problem.

The Protein Crystallisation Diagnostics Facility (PCDF) engineering-model Preliminary Acceptance Review was successfully closed in January. The flight-model Acceptance Review, delayed due to technical problems, will take place in May.

In January, the Muscle Atrophy Research and Exercise System (MARES) Critical Design Review (CDR) was closed and qualification of the ground model started in March.

The Engineering Change Request to improve the design of the Flywheel Exercise Device for utilisation in Columbus has been issued, and delivery of the device is planned for the autumn.

The Pulmonary Function System (PFS) will fly on Shuttle flight LF1 in May. Breadboard development of the Portable PFS (Phase-B) is proceeding according to plan.

Acceptance of instruments for SOLAR and EuTEF continued during January and the second Batch of EuTEF instruments is currently being reviewed. Integration of both of these Columbus external payloads is progressing, and the System Validation Test-2 involving the Columbus module is planned for July.

The Atomic Clock Ensemble in Space (ACES) Authorisation to Proceed has been extended in order to continue Phase-C1/D activities up to 31 January 2006. The status review for the Swiss Hydrogen Maser was concluded in February, and the Software System Readiness Review Board meeting was successfully held. In March, CNES confirmed its commitment to fund the PHARAO engineering model and confirmed a plan towards commitment to fund the flight model. Agreement was also reached on the execution of a Mission System Requirements Review, planned for the second quarter of this year.

The preliminary agreement for EXPOSE-R has been reached and the draft contract is being finalised. Testing and verification of the experiments is ongoing.

After completion of the CDR, development of the Portable GloveBox is progressing with both training- and flight-model deliveries on schedule for a launch with ATV-1 as an ESA upload.

In February, programmatic discussions about NASA requirements for the CryoSystem were concluded, and a Phase-C/D industrial proposal is being evaluated.

The Crew Refrigerator development activities and contract are being closed-out with the delivery of the hardware to NASA Johnson Space Center.

The 39th ESA Parabolic Flight campaign, with 12 experiments, was successfully performed from 14 to 25 March 2005.

The final integration/testing for the FOTON-M2 payload complement was successfully completed at TsSKB/Samara and the final preparations are taking place in Baikonur for a launch on 31 May. The FOTON-M3 payload agreement was approved and signed by ESA, TsSKB-Progress and Roskosmos, and the development of two new payloads started.

The Maser-10 sounding-rocket mission, with five experiments, is approaching readiness for launch on 30 April. Work for Texus-42 and Texus EML-1 is progressing according to schedule for a launch in November. The Maxus-7 contract rider was placed with Industry and development of the experiment module is ongoing.

ISS education
In February two new funding members joined the ISS Education Fund with a contribution of 61.5 kEuro.

In early February, a Workshop was held in order to solicit feedback from teachers on new projects concerning the ISS Education Kit on the Web and the 3D Education Tool. A new DVD lesson titled 'Mission 2: Body Space' is now available in 12 languages, and all education products continue to be in great demand.

The Dutch authorities have confirmed their sponsorship of the first Dutch European Space Education Research Office in the Erasmus User Centre at ESTEC.

In the framework of the Erasmus-supported Life in Space Project, a 'virtual campus' was established, consisting of a network of five universities and ESA sharing information and lectures on-line. The first interactive on-line session was successfully held on 16 February.

In March, the education experiments for FOTON-M2 and the Italian Soyuz mission were proceeding as planned and good candidate experiments have been selected for the Long Duration Mission and the ATV-1 mission.

Commercial activities
The Prime Contractor EADS-ST has joined the ISS Business Club (IBC).

On 11 March, the first commercial event in the Erasmus User Centre at ESTEC was successfully conducted for the Swiss company Phonak, who launched their new product line.

The trademark label for the ESA Health Care Network has been deposited in March.

Astronaut activities
The training of R. Vittori for the Soyuz mission 'Eneide' in April 2005 was successfully completed by end-March and both the ESA prime and back-up crew (R. Thirsk from the Canadian Space Agency) for the 10S mission were certified by the Russian Medical Commission. T. Reiter and his backup for the Long Duration Mission, L. Eyharts, have received training both at Johnson Space Center and the Gagarin Cosmonaut Training Centre (GCTC).

The training of C. Fuglesang for STS-116 is intensifying. ESA astronauts P. Nespoli and H. Schlegel are also currently training at NASA.

Numerous training courses have been held at the European Astronaut Centre (EAC), including: the first part of the ATV Pilot Course with international participation (February); Columbus User-Level Training for ground-support personnel (February), and for an international class of astronauts (March); and Columbus Payload Advanced Training for Facility Responsible Centre personnel and EAC biomedical engineers (March).

AlphaBus

The Phase-C0 released in February is providing a bridging period for industrial system activities until the placement of the full Alphabus development contract (Phase-C/D).

Besides the ESA contribution, in March CNES secured further national funding for the Alphabus programme as agreed under the terms of the cooperation between the two agencies. The ESA Programme Declaration is open to Member States for subscription until the end of April, with the Phase-C/D planned to start in June, towards the end of the bridging period.

Final selection of design-driving elements for the chemical propulsion architecture is a last critical hurdle before consolidation of the Phase-C/D industrial consortium and AlphaBus technical implementation.

In parallel with the core AlphaBus Programme, up to 25 pre-development contracts have been running with selected suppliers as part of the preparatory programme providing critical technology for the Phase-C/D and enabling-technology for growth potential. The critical technology areas include high-specific-energy Li-Ion cells, and primary-structure developments, an improved apogee-boost engine, and new gyroscopes and star-trackers. Enabling technologies address such issues as high-thrust electric propulsion, deployable radiators, thin-film solar arrays, improved heat pipes, and active-fluid-pump systems. Critical elements are encompassed for further development within the AlphaBus Phase-C/D, whilst promising enabling-technologies for AlphaBus product-line growth potential will be continued through parallel technology development, once the relevant pre-development contracts gradually run out in 2005/2006.

Vega

During January through March, several important milestones have been achieved, including the holding of the Critical Design Reviews (CDRs) for the launcher's fairing, multi-functional unit, onboard computer, and main safety unit.

The documentation for several key stages/assemblies – aimed at verification of assembly/stage layout, as recommended in the System Design Review – has been delivered, allowing the first key point to be addressed at the beginning of April.

Negotiations with Sabca (B) on the Zefiro and Avum thrust-vector-control subcontract have been concluded.

The Recovery Plan for the Zefiro inert motor cases has made significant progress. The authorisation to start Z9 DM0 manufacture was released at the beginning of February, and the model subsequently manufactured is now undergoing non-destructive inspection. Manufacture of the second model of Zephyr 23 started in early April in the Avio (I) workshops.

A major decision at system level has been to implement a new device using hydrazine thrusters to control the launch vehicle's roll during the solid-rocket propulsion phases. Such a device could be located on Interstage-2/3 or on the AVUM fourth stage.

The recovery plan relating to the P80 motor case is proceeding satisfactorily. Improvements to the Bolentz machine used to wind the case have been validated, and the manufacture of a full size skirt model has been started. The proof pressure test on the technological model takes place in mid-April.

The contract change for the integrated and expanded Sabca (B) thrust-vector-control activities has been agreed and implemented. The first battleship tests on the P80 igniters have been performed with good results.

A package issued by Vitrociset (I) in response to the Agency's request for clarifications regarding the ground segment, has been assessed by an Evaluation Board. Contract negotiations are ongoing.

The industrial Preliminary Design Reviews for the mechanical (mobile gantry and mast), civil-engineering and fluids infrastructures have now been completed.

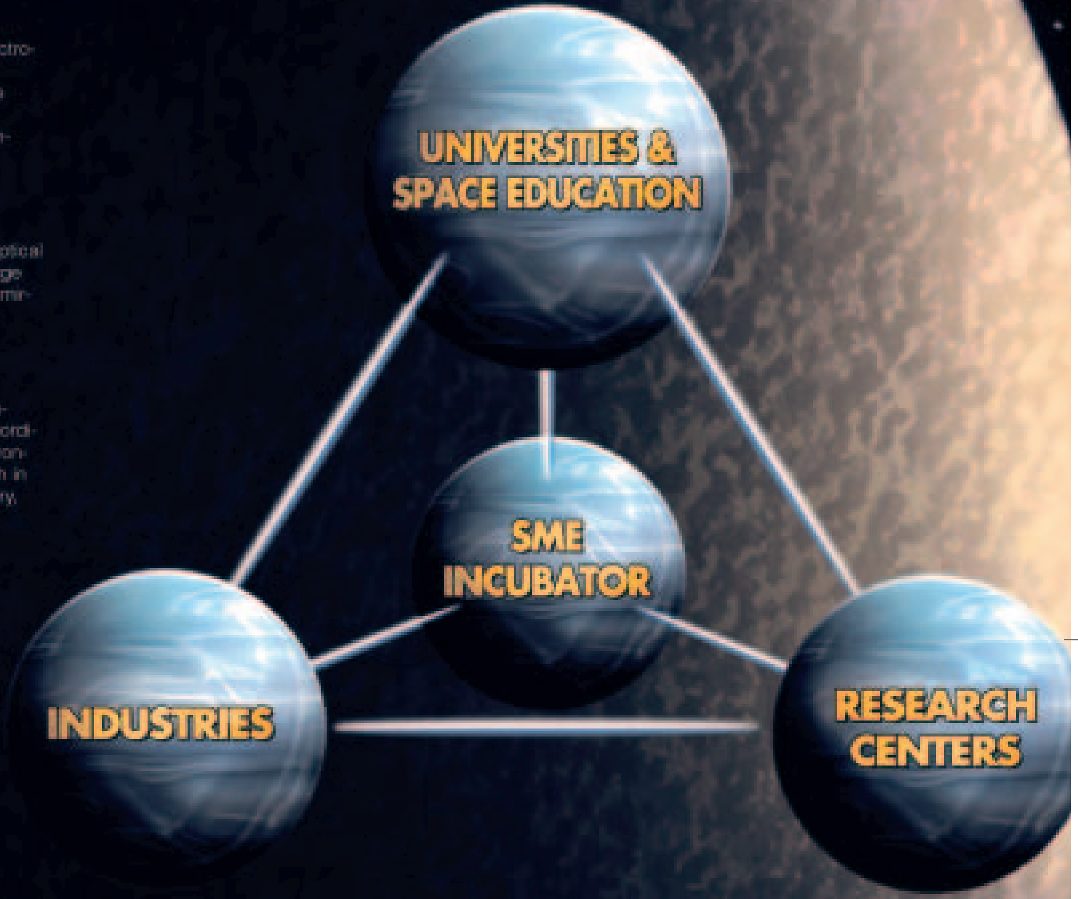
A number of demolition and refurbishment activities have been completed in the launch zone foreseen for Vega at the Guiana Space Centre in Kourou.

A Vega Industry Day held at ESA/ESRIN in Frascati (I) on 11 March was attended by all of the industrial companies working on Vega. The goal was to review the overall status of the programme and to present the way forward for the initial step of the Vega exploitation phase.

CLUSTER WALLONIE ESPACE

The Cluster Wallonie Espace is an association of industrial companies, universities, laboratories active in the sector of space research and development in Wallonia and in Brussels. The members are actively demonstrating expertise and excellence in space systems, services, applications, spin-offs.

High performance products and studies based on decades of experience.



ALCATEL ETCA
Power Conditioning and Distribution , Power electronics for satellite platforms, DC/DC converters. Electronic Power Conditioner for Travelling Wave Tubes. Safety and control boxes for launchers. Overall check-out systems for boosters and launchers.

AMOS
Design and manufacturing of mechanical and optical systems for ground and space applications: Large vacuum chambers and space simulators.Large mirrors light weighting and polishing.

CSL
Design and development of space optical instruments for astrophysics and geophysics. ESA coordinated facilities for tests in simulated space environment (thermal vacuum and vibrations). Research in opto-electronics, optical metrology, radar imagery, interferometry, holography.

EHP
Design, development, manufacturing and testing of thermal control equipments for satellites and spacecrafts. Heat pipes, "two-phase loops".

EURO SPACE CENTER
Initiation and space education - Space school, Space Camp, Astro Camp, Rocket Camp, Earth Camp and Space Odyssey.

GDTech
Customized Solutions in Engineering : Design (CAD), Dimensioning (Structural and Fluid FEA), Manufacturing (Prototype), Validation (Management of Tests), Production (Tools), Documentation (Manuals), Management (of Projects / Teams).

GILLAM- FEI
Telecom network synchronization, remote control (SCADA) for satellite communications - Development and production of atomic clocks for synchronization and navigation.

PROBEL SPACE
Space consulting services for new applications and spaceconcept.

SABCA
Thrust vector actuation systems for space launchers. Design and production of complex stuctures for spacecrafts. Damping devices for Ariane 5 boosters.

SONACA
Development and manufacturing of lightweight, high-stability and critical space structures. Spacecraft platform and optical benches structures, meteoritic and debris protection systems.

SPACEBEL
Space mission definition.
Design, development and implementation of "tailor-made" software systems for aerospace: on-board and ground segment; simulators. Development of land-use and environmental management information systems.

TECHSPACE AERO
Design, development, and production of flow control equipment for liquid propulsion (engines and stages). Expertise from cryogeny to hot gases, from vacuum up to 400 bars. Studies on advanced propulsion concepts for reusable launch vehicles.

UCL (Catholic University of Louvain)
Earth-satellite channel modelling
Technological support for satellites communications
Earth observation data management
Space radiation center for ESA tests.

ULB (University of Brussels)
Fluid physics experiments in microgravity (capillar interfaces, phase change and diffusion) Experimenta and numerical investigations of heat transfer proces (boiling and evaporation). Holographic metrology for protein crystal growth, temperature and concentration mappings. Medical experiments.

ULG (University of Liège)
Space astrophysics; atmospheric and planetary physics Vibration and space environment testing facilities; aerospace structures.Exploitation of satellites. Bio/medical technologies in space.

VITROCISET EPB
Ground station system engineering. M & O ESA Red Station. Services and facilities provided: Satellite Mission and Payload control, Backup hosting, TT&C, IOT & Earth Station Validation.Development, installation and validation of satellite ground facilities for Data, TT&C & IOT operations.

WSL
Incubator of actually 17 SMEs exploiting space innovative technologies and services for commercial purposes.

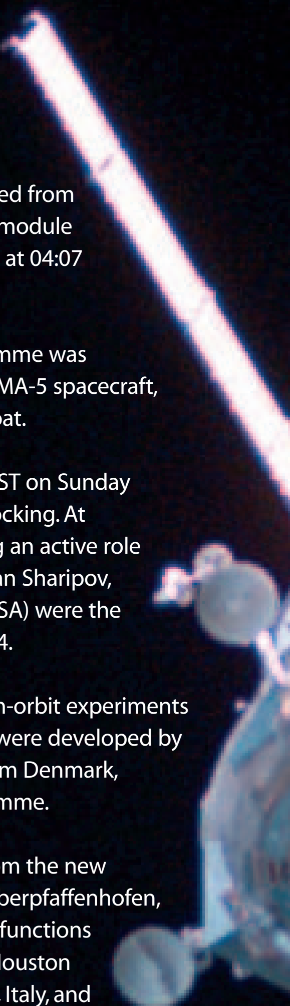
WALLONIE ESPACE

Website: www.wallonie-espace.be

RÉGION WALLONNE

In Brief

TMA-5 landing with ESA astronaut Roberto Vittori marks completion of European Eneide Mission



ESA astronaut Roberto Vittori, accompanied by the ISS Expedition 10 crew, has returned from the International Space Station (ISS) after a successful 10-day mission. The command module of the Soyuz TMA-5 spacecraft touched down near the town of Arkalyk in Kazakhstan at 04:07 local time (00:07 Central European Summer Time) on Monday 25 April.

All the major objectives of the Eneide mission were achieved: the experiment programme was successfully completed, and the ISS Expedition crew changed along with the Soyuz TMA-5 spacecraft, which has been stationed at the ISS for the past six months, serving as the crew lifeboat.

The hatches between the returning Soyuz TMA-5 and the ISS were closed at 17:34 CEST on Sunday 24 April, and the crew then carried out standard procedures and checks prior to undocking. At 20:44 CEST Soyuz TMA-5 undocked from the ISS, with Vittori, as Flight Engineer, taking an active role in the re-entry, descent and landing operations, alongside Russian cosmonaut Salizhan Sharipov, the Soyuz Commander. Sharipov and the Soyuz 2nd Flight Engineer Leroy Chiao (NASA) were the returning Expedition 10 crew, having been stationed on the ISS since 16 October 2004.

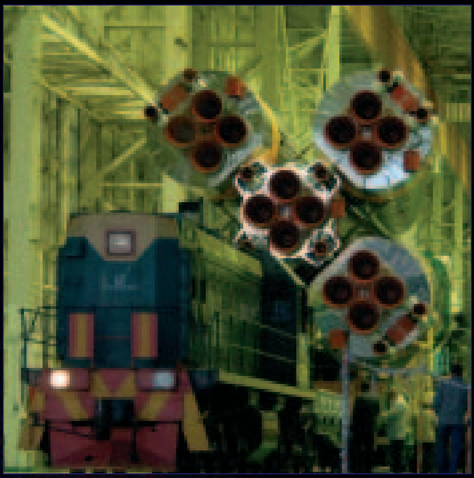
During the Eneide Mission, Roberto Vittori carried out a programme comprising 22 on-orbit experiments in the fields of biology, human physiology, technology and education. Many of these were developed by Italian researchers and built by Italian industry and research institutions. Scientists from Denmark, Germany, Russia, Switzerland, the USA and from ESA were also involved in the programme.

Mission control for the Eneide Mission was performed by an ESA Operations Team from the new Columbus Control Centre on the premises of the German Aerospace Center DLR at Oberpfaffenhofen, near Munich, Germany, who provided all essential coordination and decision-making functions for the mission in close cooperation with the ISS partner control centres in Moscow, Houston and Huntsville (Alabama), the Lazio User Centre at the Tor Vergata University in Rome, Italy, and ESA's Eneide Mission Management Team in Noordwijk, the Netherlands.

The crew during the final checking of the pressure suits, three hours before launch on 15 April.

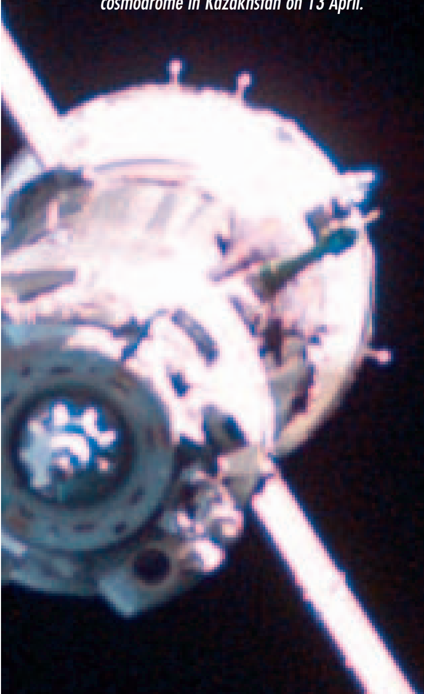
The Eneide Mission was co-sponsored by the Italian Ministry of Defence and the Region of Lazio, in the framework of an agreement between ESA and Roskosmos, the Russian federal space agency.

During the mission, Roberto Vittori had numerous contacts with representatives of the Italian government, the Ministry of Defence, the Region of Lazio, the media and schoolchildren.



The Soyuz FG rocket on its way to the launch pad at the Baikonour cosmodrome in Kazakhstan on 13 April.

ESA astronaut Roberto Vittori on board the ISS during the Eneide mission.



Ready for lift-off!

Roberto Vittori on his way to the ISS.

Roberto Vittori back on Earth after a successful mission. Soyuz TMA-5 touched down on 25 April.

The Soyuz TMA-6 crew gave a press conference before the launch: from left to right Second Flight Engineer John Philips (NASA), Commander Sergei Krikalev (Roskosmos) and Flight Engineer Roberto Vittori (ESA).

Greece joins ESA

Greece is now officially ESA's 16th Member State. The announcement was made to the ESA Council on 16 March by Per Tegnér, Chairman of the ESA Council.

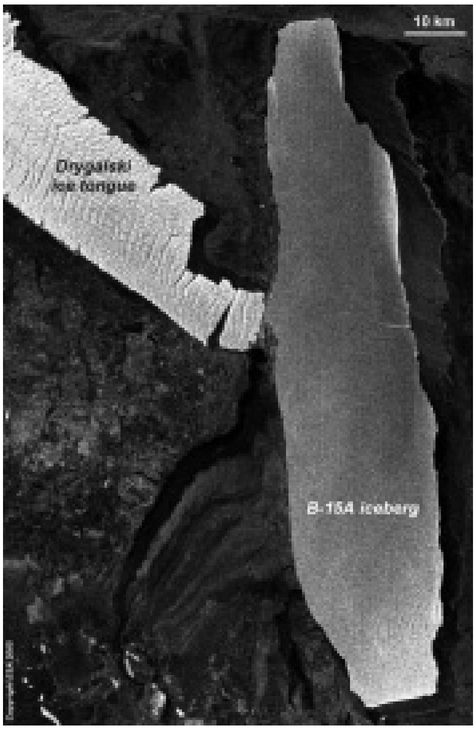
Cooperation between ESA and the Hellenic National Space Committee began in the early 1990s. In 1994 Greece signed its first cooperation agreement with ESA. This led to regular exchange of information, the awarding of fellowships, joint symposia, mutual access to databases and laboratories, and studies on joint projects in fields of mutual interest.
In September 2003 Greece formally applied to join ESA. Subsequent negotiations were followed in the summer of 2004 by an agreement on accession to the ESA Convention. Greece already participates in ESA's telecommunications and technology activities, and the Global Monitoring for Environment and Security Initiative. Now, with the deposition of its instrument of ratification of the Convention for the establishment of ESA with the French Government on 9 March 2005, Greece becomes the 16th ESA Member State.

Iceberg on collision course

We have to redraw our maps of Antarctica. Scientists have expected it for a long time – now the collision between the vast B-15A iceberg and the landfast Drygalski ice tongue has taken place. An Envisat radar image shows that the ice tongue – large and permanent enough to feature in Antarctic atlases – has come off worst.

An image acquired by Envisat on 15 April 2005 shows that a five-kilometre-long section at the seaward end of Drygalski has broken off after the collision with the drifting B-15A. The iceberg itself appears so far unaffected. With more than half the iceberg still to clear the floating pier of ice, Drygalski may undergo more damage in the coming days.

The scale of B-15A is best appreciated from space. The bottle-shaped Antarctic iceberg is around 115 kilometres long, with an area exceeding 2500 square kilometres, making it about as large as the entire country of Luxembourg. From January the iceberg has been drifting towards, then past, the 70-kilometre-long Drygalski ice tongue in McMurdo Sound on the Ross Sea. In the last month, prevailing currents slowly edged B-15A along past the northern edge of Drygalski.



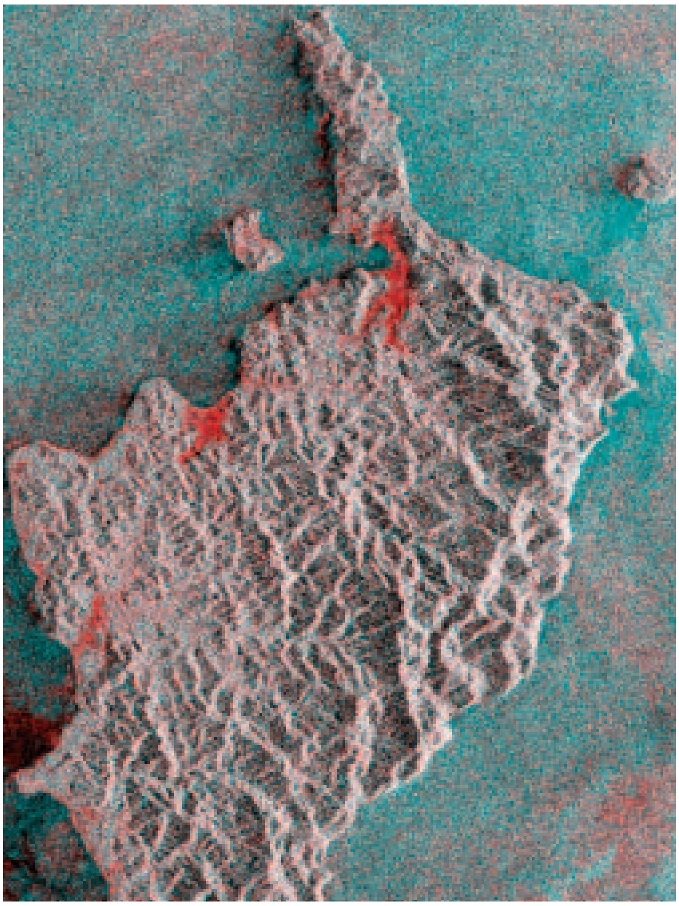
This detail comes from a wide-swath-mode image acquired by Envisat's ASAR on 15 April 2005, and shows a broken-off section of the Drygalski ice tongue after the collision with B-15A iceberg

A decade after launch, ERS-2's mission continues

Ten years and 52 289 orbits after its launch, the Earth Observation mission of ESA's ERS-2 satellite continues, with all instruments functioning well. A growing global network of ground stations is receiving data from the veteran spacecraft, providing data for a worldwide community of more than 3000 users.

When the Asian tsunami struck in December 2004, satellites provided rapid damage mapping. The continued availability of ERS-2 enabled the only change assessment via radar, complementing optical satellite views because radar can see through tropical clouds. A new January 2005 ERS-2 high-resolution radar image of the Nicobar Islands north of Sumatra, near the epicentre of the tsunami, was combined with an archived image acquired in 1992 by sister spacecraft ERS-1.

The resulting multi-temporal composite highlights the stricken state of the island's west coast. The composite was only possible due to the wide coverage of the 15-year combined ERS archive.



ERS-2 is also regularly needed for disaster mapping during activations of the International Charter on Space and Major Disasters, which provides space-derived information to emergency responders.

ERS-2 also carries a C-band scatterometer measuring ocean wind fields – the only instrument of its type currently in orbit, capable of making observations in the very worst of weather, even peering into the centre of hurricanes and typhoons. Processed by the Royal Dutch Meterological Institute (KMNI), these unique data are assimilated operationally by users including the European Centre for Medium-Range Weather Forecasts, improving the quality of weather forecasting and short-term 'nowcasting'.

Another ERS-2 sensor working in near-real time is its Global Ozone Mapping Experiment (GOME), delivering atmospheric global coverage of ozone, other trace gases, supporting operational services such as the Tropospheric Emission Monitoring Internet Service (TEMIS), and providing daily ozone, ultraviolet and air pollution monitoring.

"The GOME instrument on ERS-2 has given us more than we ever dreamed of," explains Professor Paul Crutzen of the Max Planck Institute in Germany, winner of the 1995 Nobel Prize for his work on ozone. *"GOME has been a pioneering instrument. Such instruments are of great value for international negotiations on air quality and climate."*

ERS-2 was launched on 21 April 1995. In 2001 the spacecraft was struck a blow as the last of its pointing gyroscopes failed. However, all instruments were still functioning perfectly, so ESA engineers worked with industry to develop a new 'gyro-less' working mode to resume data delivery.

Making up its other sensors, ERS-2's Radar Altimeter (RA) measures land, ocean and ice altimetry, while its Along-Track Scanning Radiometer (ATSR) works like a space-based thermometer, taking the temperature of cloud tops as well as the sea surface – the best means of assessing the long-term extent of global warming – as well as land surface changes. Since 2002, ESA's Envisat satellite has also been monitoring sea surface temperature and atmospheric ozone, as well as making altimetry and radar observations.

A multitemporal composite of an ERS-1 SAR radar image acquired on 21 December 1992 and an ERS-2 image acquired on 12 January 2005. The composite highlights the massive damage to the west coast of one of the Nicobar Islands during the December 2004 tsunami disaster, seen here in red.

Collisions on a greater scale: star-birth mystery solved

Data from ISO, ESA's infrared observatory, have provided the first direct evidence that shock waves generated by galaxy collisions excite the gas from which new stars will form.

By observing our own galaxy and others, scientists have long concluded that the explosion of massive stars like supernovae generates shock waves and 'winds' that travel through and excite the surrounding gas clouds. This leads to the birth of new stars.

The signature of this process is the radiation emitted by molecular hydrogen. When hydrogen molecules are 'excited' by the energy of a nearby explosion, they emit a distinctive type of radiation that can be detected in the infrared.

This type of radiation is also observed in places where galaxies have collided with one another and the formation of new stars goes on at a very high rate. So far, however, there was no clear picture of what happens in the time between the collision of two galaxies and the birth of the first new stars.

The missing link has now been found by a team of German astronomers from the AIRUB Institute in Bochum and the Max-Planck-Institut für Astronomie in Heidelberg who have analysed ISO data on the galaxy pair nicknamed the 'Antennae' (NGC 4038/4039). These two galaxies, located 60 million light-years away in the constellation 'Corvus', are at an early stage of encounter. The scientists noticed that the overlapping region of the two colliding galaxies is very rich in molecular hydrogen in an excited state.

The excitation of the molecular hydrogen must be the signature of an observationally rare, pre-star birth phase in which hydrogen is excited by the mechanical energy produced in the collision and transported by shock waves. In other words, these results provide the first direct evidence of the missing link between gas collision and the birth of the first stars. The team estimates that when the gas collapses to form new stars, during the next million years, the Antennae galaxy will become at least twice as bright in the infrared.

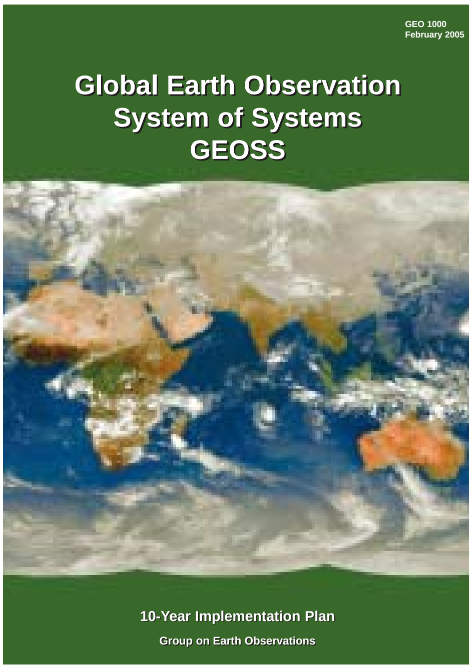
Formal inauguration of the intergovernmental 'Group on Earth Observations (GEO)'

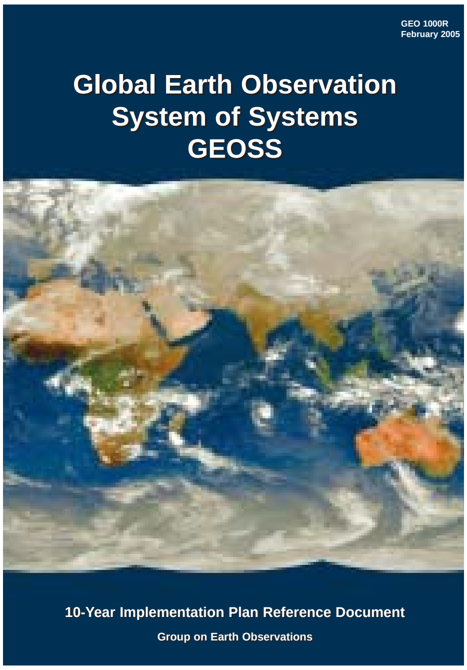
Understanding the Earth system – its weather, climate, oceans, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards – is crucial to enhancing human health, safety and welfare, alleviating human suffering including poverty, protecting the global environment, reducing losses due to disasters, and achieving sustainable development. Observations of the Earth system constitute critical input for advancing this understanding.

On 31 July 2003, 33 nations plus the European Commission adopted a Declaration that signifies political commitment to move towards development of a comprehensive, coordinated, and sustained Earth-observation system(s). This Summit, joined by 21 international organisations, recalled the commitments of the World Summit on Sustainable Development in Johannesburg 2002 (WSSD), as well as a meeting of the Heads of State of the Group of Eight Industrialised Countries (G8) in June 2003 in Evian, France, both of which affirmed the importance of Earth Observation as a priority activity.

This first Earth Observation Summit established the *ad hoc* intergovernmental Group on Earth Observations (*ad hoc* GEO), co-chaired by the European Commission, Japan, South Africa and the United States, and tasked it with the development of an initial 10-Year Implementation Plan by February 2005. The *ad hoc* GEO established five technical subgroups and a small secretariat. A series of subgroup meetings and a plenary meeting led to a Framework Document, negotiated in Cape Town and adopted at the Second Earth Observation Summit in Tokyo in April 2004 by 43 countries and the European Commission, joined by 25 international organisations. The Framework defines the scope and intent of a Global Earth Observation System of Systems (GEOSS). In particular, it sets out nine societal benefit areas (SBAs) for which there was recognition that clear societal benefits could be derived from a coordinated global observation system.

The nine SBAs include:
- Reducing loss of life and property from natural and human-induced disasters.
- Understanding environmental factors affecting human health and well-being.





- Improving management of energy resources.
- Understanding, assessing, predicting, mitigating and adapting to climate variability and change.
- Improving water-resources management through better understanding of the water cycle.
- Improving weather information, forecasting and warning.
- Improving the management and protection of terrestrial, coastal and marine ecosystems.
- Supporting sustainable agriculture and combating desertification.
- Understanding, monitoring and conserving biodiversity.

A small task team was charged by the *ad hoc* GEO with the drafting of the 10-Year Plan, building on inputs from the subgroups and other sources.

The GEOSS 10-Year Implementation Plan establishes the intent, operating principles, and institutions relating to GEOSS. It is supported by a longer Reference Document, which is consistent with the Plan and provides the substantive detail necessary for implementation. The Plan was negotiated by the *ad hoc* GEO in Ottawa in November 2004, and adopted at the Third Earth Observation Summit in Brussels, in February 2005.

The Third Earth Observation Summit established the Group on Earth Observations (GEO). Membership in GEO is open to all member States of the United Nations and to the European Commission. GEO welcomes as 'Participating Organisations' intergovernmental, international, and regional organisations with a mandate in Earth Observation or related activities, subject to approval by Members. GEO may invite other relevant entities to participate in its activities as 'Observers'.

Following the first Plenary Meeting (GEO-I) held on 3-4 May 2005 at the World Meteorological Organization (WMO) in Geneva, current Members of the GEO include 56 countries (from all continents) and the European Commission. In addition, 43 International Organisations are also participating in the GEO, including in particular from Europe such intergovernmental organisations such as ESA, EUMETSAT, ECMWF and EEA.

At the GEO-I Plenary, a new Executive Committee was elected and a GEO subsidiary committee structure was discussed to ensure both that proper mechanisms are in place to provide for scientific and technical advice, and that GEOSS is driven by user needs and requirements. Concurrently, the new GEO Secretariat offices were established in Geneva.

Based on the 2, 6 and 10-year targets identified for each SBA in the GEOSS 10-Year Implementation Plan Reference Document, a small group (the Work Plan Team) from the GEO Secretariat, assisted by a large number of external experts, is starting the elaboration of a comprehensive Work Plan for 2006/7, with preliminary activities to be already started in the second half of 2005. This Plan will be submitted for approval, and subsequent implementation, at the next GEO Plenary (GEO-II) scheduled for 14-15 December 2005 in Geneva.

The formal inauguration of GEO in Geneva marks the fulfilment of 18 months of intergovernmental planning and the first step on the path to the successful realisation of GEOSS and its benefits for society.

Guy Duchossois, *GEOSS Work Plan Manager*

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 Newletters

ECSS NEWS NO. 8 (APRIL 2005)
NEWSLETTER OF THE EUROPEAN COOPERATION FOR SPACE STANDARDIZATION
ASQUIER J. & BATTRICK B. (EDS.)
NO CHARGE

CONNECT NO. 01/05 (APRIL 2005)
NEWSLETTER OF ESA's DIRECTORATE OF APPLICATIONS
MENNING N. & BATTRICK B. (EDS.)
NO CHARGE

ESA Brochures

TANIA – EUROPESE ASTRONAUTE (DUTCH EDITION, MAY 2005)
PAULIS P.-E. & HET TEAM VAN HET EUROPESE ASTRONAUTENCENTRUM
(ED. A WILSON)
ESA BR-219 - NL // 42 PAGES
PRICE: 5 EURO

CASSINI/HUYGENS – REIS NAAR DE ORANJE MAAN (DUTCH EDITION, APRIL 2005)
WARMBEIN B. & WILSON A. (EDS.)
ESA BR-228 - NL // 30 PAGES
PRICE: 5 EURO

CASSINI/HUYGENS – REISEZIEL TITAN (GERMAN EDITION, APRIL 2005)
WARMBEIN B. & WILSON A. (EDS.)
ESA BR-228 // 30 PAGES
PRICE: 5 EURO

CASSINI/HUYGENS – OBJETIVO: TITÁN (SPANISH EDITION, APRIL 2005)
WARMBEIN B. & WILSON A. (EDS.)
ESA BR-228 // 30 PAGES
PRICE: 5 EURO

BENEFITS OF HUMAN SPACEFLIGHT (MARCH 2005)
WILSON A. (ED.)
ESA BR-230 // 70 PAGES
PRICE: 10 EURO

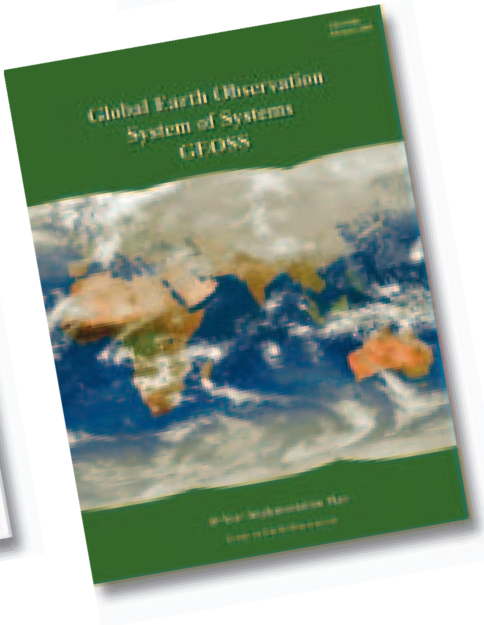
ADM-AEOLUS – ESA'S WIND MISSION (FEBRUARY 2005)
RIDER H., RAST M. & BATTRICK B. (EDS.)
ESA BR-236 // 15 PAGES
PRICE: 10 EURO

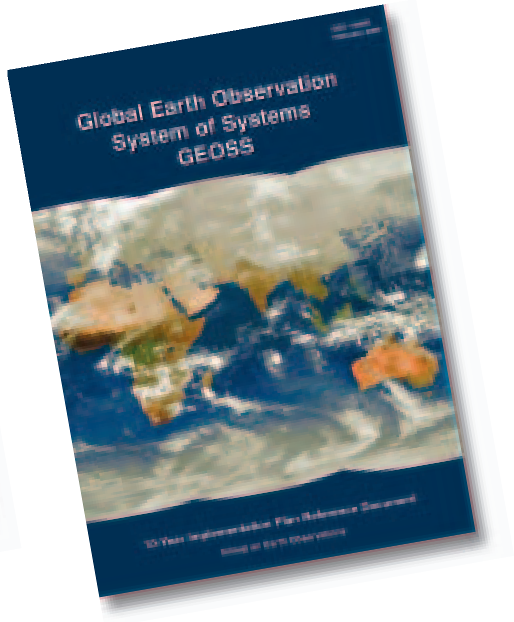
THE IMPACT OF SPACE ACTIVITIES UPON SOCIETY (FEBRUARY 2005)
RAITT D. & BATTRICK B. (EDS.)
ESA BR-237 // 137 PAGES
PRICE: 10 EURO

SPACE DEBRIS (APRIL 2005)
DANESY D., FLURY W. & KLINKRAD H. (EDS.)
ESA BR-239 // 13 PAGES
PRICE: 5 EURO

GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS (GEOSS): 10-YEAR IMPLEMENTATION PLAN (FEBRUARY 2005)
GROUP ON EARTH OBSERVATIONS
(ED. B. BATTRICK)
ESA BR-240 / GEO 1000 // 27 PAGES
PRICE: NO CHARGE

THE EUROPEAN SPACE SECTOR IN A GLOBAL CONTEXT – ESA'S ANNUAL ANALYSIS 2004 (MAY 2005)
ESA POLICY COORDINATION DEPARTMENT
(ED. B. BATTRICK)
ESA BR-242 // 104 PAGES
PRICE: 10 EURO





ESA Special Publications

GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS (GEOSS):10-YEAR IMPLEMENTATION PLAN REFERENCE DOCUMENT (FEBRUARY 2005)
GROUP ON EARTH OBSERVATIONS
(ED. B. BATTRICK)
ESA SP-1284/GEO 1000R//209 PAGES + CD-ROM
PRICE: NO CHARGE

PROCEEDINGS OF THE SYMPOSIUM ON NEW SPACE SERVICES FOR MARITIME USERS: THE IMPACT OF SATELLITE TECHNOLOGY ON MARITIME LEGISLATION, 21-23 FEBRUARY 2005, UNESCO, PARIS, FRANCE (MARCH 2005)
WARMBEIN B. (ED.)
ESA SP-584 // CD-ROM
PRICE: 10 EURO

PROCEEDINGS OF THE SEVENTH EUROPEAN SPACE POWER CONFERENCE, 9-13 MAY 2005, STRESA, ITALY (MAY 2005)
WILSON A. (ED.)
ESA SP-589 // CD-ROM
PRICE: 70 EURO

ESA History Reports

AN OVERVIEW OF UNITED KINGDOM SPACE ACTIVITY 1957-1987 (APRIL 2005)
MILLARD D. (ED. B. BATTRICK)
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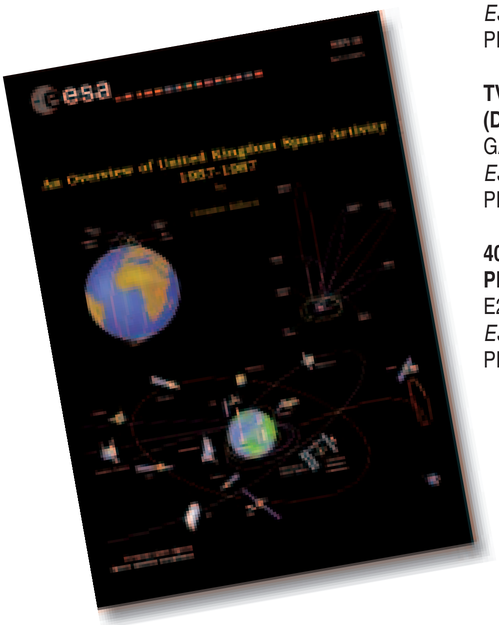

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