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bulletin

SPACE FOR EUROPE

Building the Future

European Space Agency
Agence spatiale européenne

european space agency

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

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

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by coordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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

ESRIN, Frascati, Italy.

Chairman of the Council: S. Wittig

Director General: J.-J. Dordain

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agence spatiale européenne

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

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

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

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

Le SIEGE de l'Agence est à Paris.

Les principaux Etablissements de l'Agence sont:

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

ESRIN, Frascati, Italy.

Président du Conseil: S. Wittig

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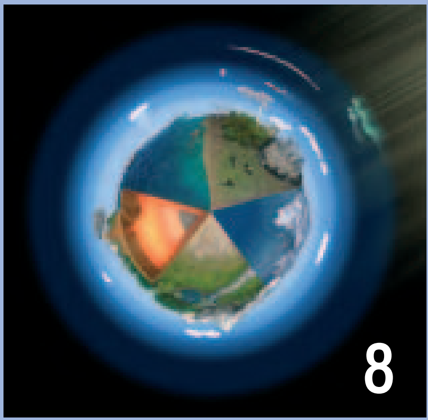
ESA astronaut Christer Fuglesang during the second of his three spacewalks in December 2006 to reconfigure the power system of the International Space Station. *(NASA)*



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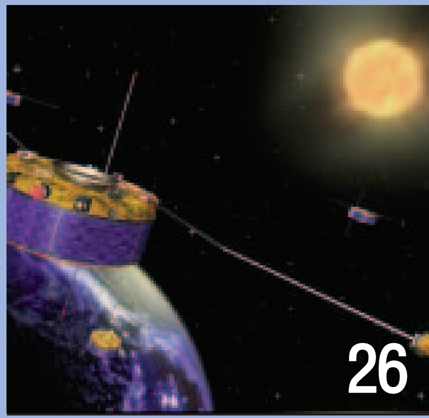

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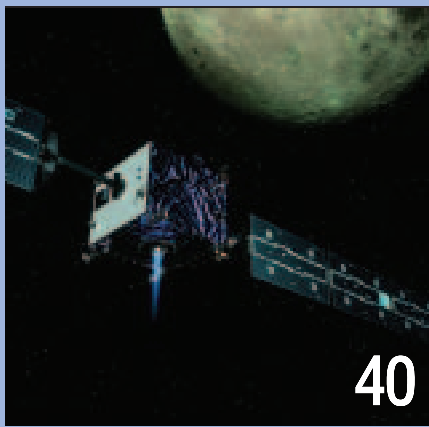

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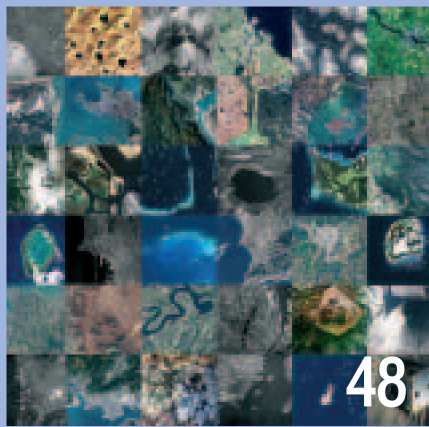

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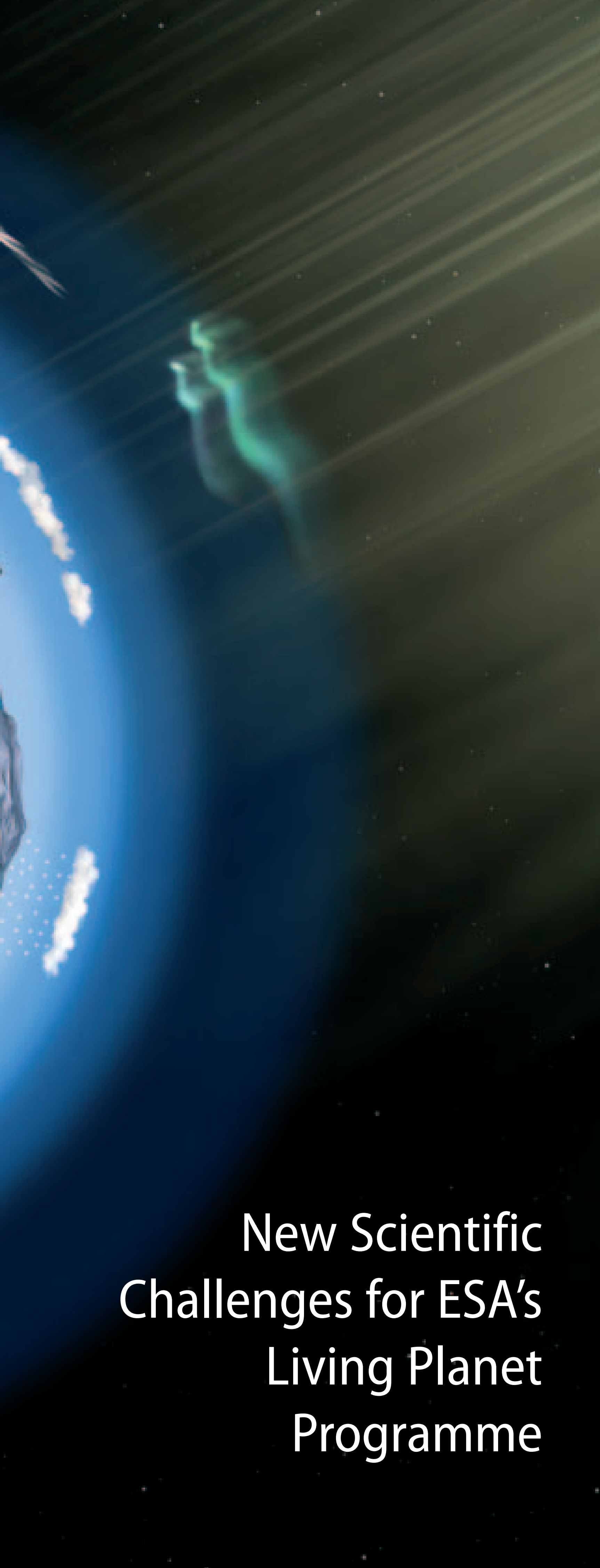


New Scientific Challenges for ESA's Living Planet Programme

Volker Liebig, Einar-Arne Herland & Stephen Briggs
Directorate of Earth Observation Programmes

Hartmut Grassl
Chairman of the Earth Science Advisory Committee

Global change is the most fundamental challenge facing humanity today. As we begin to understand more about the Earth as a system, it is clear that human activity is having a profound and negative impact on our environment. For example, our understanding of carbon dioxide as a greenhouse gas and the strong link between atmospheric carbon dioxide concentrations and temperature both point to human activity leading to a warmer world, unlike anything seen over the last million years. A better knowledge of the Earth System and of the effect of increasing human activity is crucially important for managing our environment and our ability to derive sustainable benefit.

Introduction

Since observing the Earth from space became possible more than 40 years ago, satellite missions have become central to monitoring and learning about how the Earth works. When ESA established its Living Planet Programme in the mid-1990s, a new approach to satellite observations for Earth science began, with focused missions defined, developed and operated in close cooperation with the scientific commun-

The strategy report is available as ESA publication SP-1304

In 2005 a committee of six external scientists and six Earth Science Advisory Committee members undertook a thorough review of the scientific value of ESA's Earth Observation Envelope Programme. The review report was overall extremely positive in evaluating the science output of the Programme and contained 11 recommendations to the Agency. These are all being implemented

ity. A comprehensive strategy was formulated for implementing the Programme, which has resulted in the selection of six Earth Explorer missions covering a broad range of science issues. Six candidates for the seventh mission have been identified. At the same time, significant advances have been made in Earth science using data products and services from the Agency's ERS and Envisat satellites.

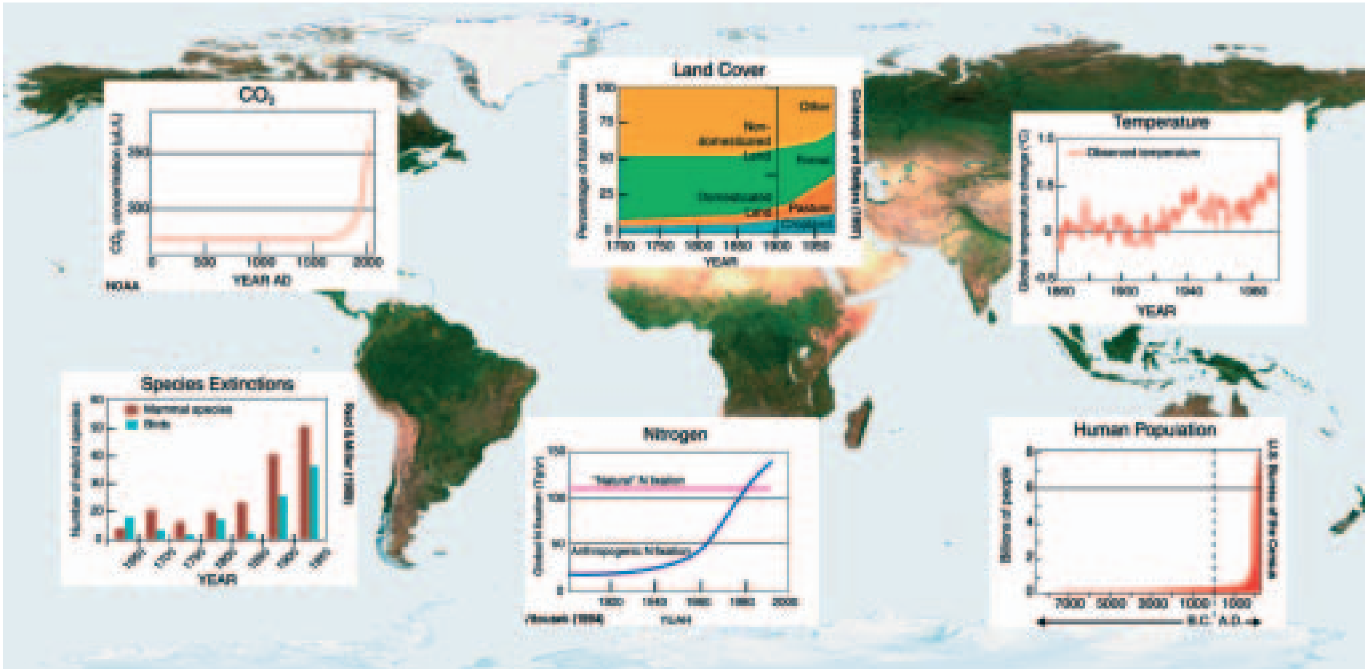
At the Ministerial Council meeting in Berlin in December 2005, ESA Member States reconfirmed their commitment to the concept of the Living Planet Programme by funding the third phase covering the period 2008–2012. In addition, they approved the initiation of the space component of the Global Monitoring for Environment and Security (GMES), in close cooperation with the European Commission. Although this programme is designed to provide data that underpin operational services, it will also contribute significantly to Earth science, in particular through the collection of long time series of observations. In turn, the Earth Explorers will provide new understanding that paves the way for new operational services. In this sense, the Living Planet Programme comprises complementary elements of research and operations. This synergy has long been demonstrated by the development and scientific exploitation of meteorological satellites, which continue to be an important part of the Living Planet Programme.

Recent developments and advances already made in the Earth sciences have emphasised the need for an updated science strategy. The recent Stern report (*http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm*) assesses the impact of climate change on the global economy and concludes that while 'business as usual' might have very high costs, preventive measures implemented from today would have a relatively minor impact on the economy. Another recent study, on the socio-economic benefits of GMES, performed by Pricewaterhouse Coopers, concluded that the benefits of GMES are potentially very large, but they require political will in order to be efficiently implemented.

The updating of the strategy was recently undertaken under the guidance of the Agency's Earth Science Advisory Committee and in wide consultation with the scientific community.

Looking to the future, the new strategy aims to assess the most important Earth science questions to be addressed in the years to come. It outlines the observational challenges that these raise, and the contribution that the Agency can make through the programme. These challenges will guide ESA's efforts in providing essential Earth observation information to the

The ESA SP-1304 report emphasises the different components



Selected aspects of global change (atmospheric composition, land cover, temperature, biodiversity, nitrogen fixation and human population) based on information compiled by the International Geosphere-Biosphere Programme

user communities, in close cooperation with our international partners.

Underpinning the new strategy is a set of ambitious objectives, which includes:

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

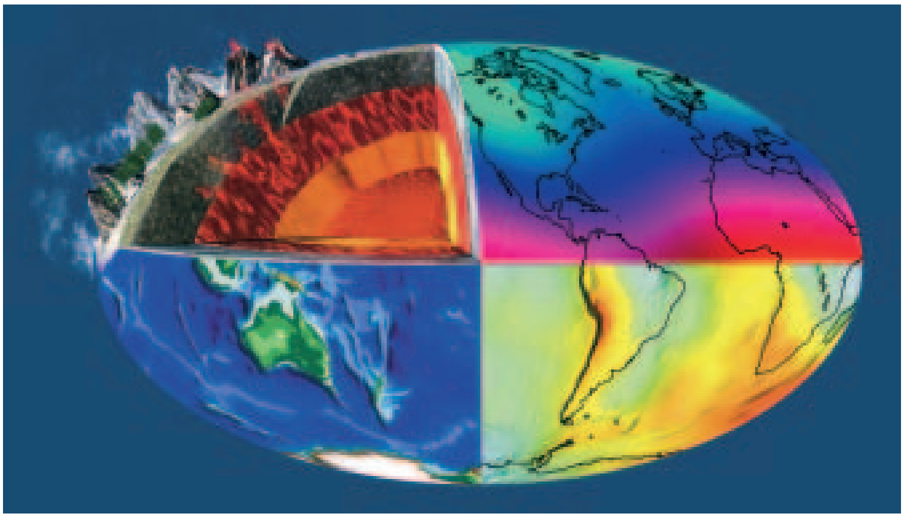
The overall vision for ESA's Earth observation activities is to play a central role in developing the global capability to understand our planet, predict changes and mitigate the negative effects of global change on its population.

The Challenges of a Changing World

Records show that the Earth has always undergone major changes. Change is a natural property of the Earth System, but there is mounting evidence that those imposed on the system during the last 150 years cannot be compared with any previous changes. In the last century, mankind has driven the greenhouse-gas concentrations far beyond the maxima reached during the last million years. It has become responsible for 70% of the nitrogen and 95% of the phosphorus cycle on Earth, and has reduced tropical forest areas by 50%. To determine whether these human-induced recent changes could ultimately destabilise the Earth System, both natural system variability and the consequences of human activities have to be fully understood and quantified. This is the scientific basis required for the sustainable future management of the Earth System as a whole.

While the large-scale processes of global change are increasingly stressing the biosphere, other less wholesale changes may have equally serious consequences for the viability of ecosystems. The loss and fragmentation of habitat, forest degradation and loss of wetlands all remove ecological niches occupied by species. Over-exploitation of the natural world, as by over-fishing and over-grazing, will lead to loss of renewable resources and biodiversity. Still more stress, and even a health hazard, is placed on populations by water and air pollution, either through catastrophic events such as oil-spills and explosions at chemical plants, or more insidious effects from the long-term use of insecticides, run-off of nitrogen-based fertilisers and air pollution in metropolitan areas. In addition to these threats to the natural world, managed systems are also subject to processes such as loss of fertility, desertification, water stress and erosion.

Two issues are at stake here. The first is sustainability. Human life draws heavily on resources provided by the living world: clean air, fresh water, food, clothing and building materials. In the interest of future generations, we have to find ways to guarantee that the functioning of the life-support system and the ability of the ecosystems to deliver goods and services are maintained.



Information that can be acquired from space relevant to Solid Earth and Earth System Science

The second is biodiversity. On our own planet, we are pursuing a course that is reducing the richness of life, and diminishing the world that we will hand on to future generations. The fact that life on Earth has existed continuously for several billion years is due to its diversity. It is very likely that in the course of the present reduction of biodiversity, the Earth System's extraordinary stability in the face of external forcing is also being reduced.

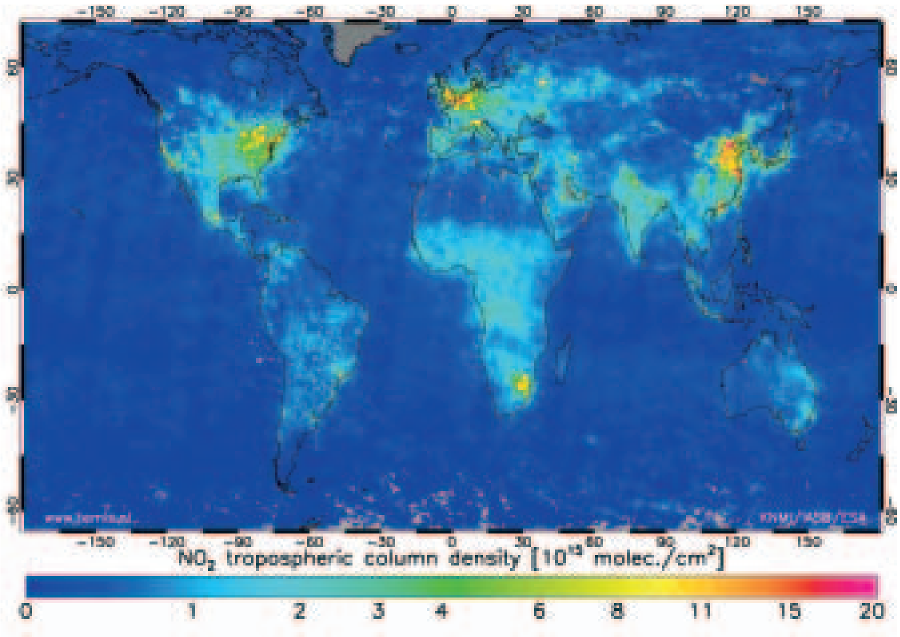
Global variations in the Earth System display very large regional differences. The human inputs to the system also show widely different patterns of change across the globe, be it deforestation, manipulation of hydrological resources, occurrence of fires, fossil-fuel burning or land-use management. What seems clear is that these highly variable local and regional types of environmental management sum together to produce global changes with major influences on the Earth System. We are only just beginning to understand the related feedbacks and consequences for the Earth as a living planet, with humanity as one of its life-forms. Measurements of the Earth's properties provided by satellites are critical in providing access to many of the key elements of the Earth System.

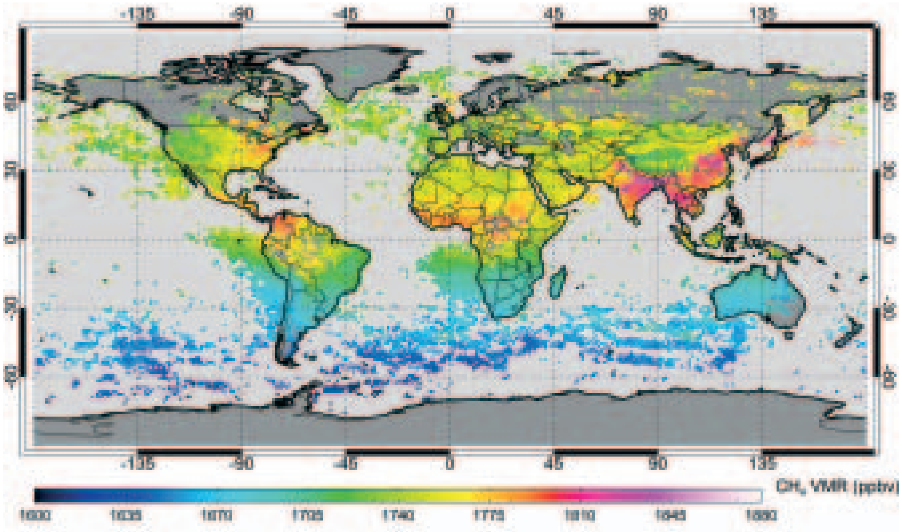
The Rationale of Earth System Science

The latter half of the 20th century saw the full emergence of the concept that the behaviour of planet Earth can only be understood in terms of the coupling between the dynamic processes in the atmosphere, solid Earth, hydrosphere, cryosphere, biosphere and anthroposphere. All of these components are interlinked by a network of forcing and feedback mechanisms that affect the other components. Global-scale effects can arise from regional processes, and global-scale behaviour can have widely different regional manifestations. In addition, processes acting at one time scale can have consequences across a wide range of longer time scales. This paradigm, in which the Earth is seen as a coupled set of dynamical systems, constitutes the scientific discipline known as 'Earth System Science'.

Major progress in many Earth science disciplines has revealed that traditionally separated disciplines, such as oceanography and atmospheric dynamics, are in fact intimately connected on a range of time and spatial scales. For example, the irregular El Niño Southern Oscillation (ENSO) shows strong coupling of atmospheric and oceanic processes, which are in turn strongly connected to the spatial patterns and overall mean of global vegetation productivity. Spectacular new evidence from Antarctic ice cores has shown that, over long time scales driven by orbital fluctuations, the Earth's mean atmospheric temperature is intimately connected to the atmospheric composition, notably the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). It is very striking that over at least six periods of about 100 000 years duration the atmo-

The mean tropospheric nitrogen dioxide content for 2003 as measured by Envisat's SCIAMACHY instrument. Hot spots are the industrialised areas of Europe, China, the USA and South Africa. Many mega-cities elsewhere can also be identified as localised spots with enhanced concentrations. (KNMI/BIRA-IASB/ESA)





Envisat SCIAMACHY measurements of column-averaged methane volume mixing ratio (VMR), in parts per billion, averaged over the period August – November 2003 on a 1 x 1° horizontal grid. At least five (and up to 150) measurements are taken for each grid cell. Only a few observations are available over the ocean, since low ocean reflectivity substantially reduces the retrieval quality. Occasionally, Sun-glint or clouds at low altitudes do allow measurements over the ocean. (University of Heidelberg/ESA)

spheric concentrations of these trace gases lie naturally within well-defined bounds.

A primary lesson learned is that understanding the strongly nonlinear behaviour of the Earth System requires atmospheric, ocean, land, cryospheric and Earth-interior processes all to be considered, in addition to the external solar driver. The Earth needs to be thought of as a system that naturally regulates itself through a complex web of interactions and feedbacks between processes.

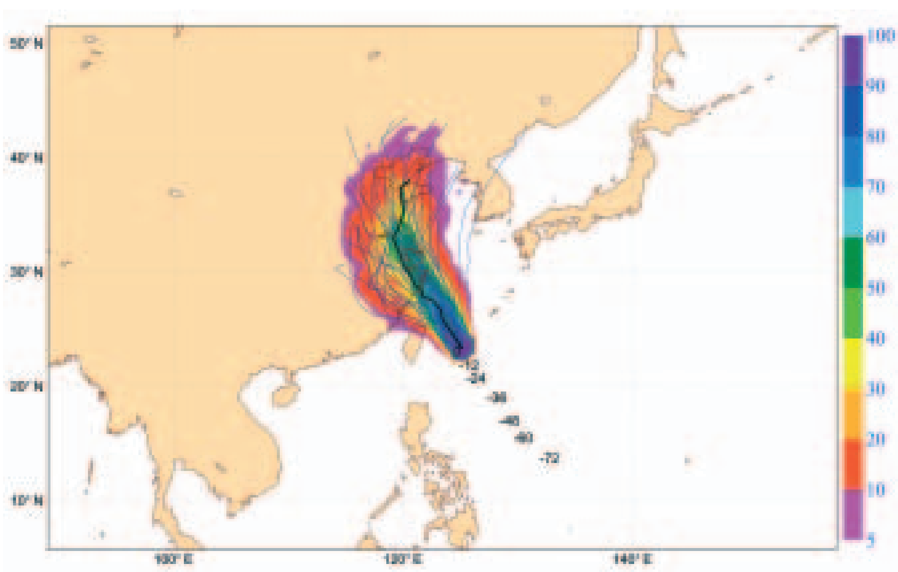
At the same time as we began to understand better the Earth as a system, it became clear that recent human activities are having a profound impact on this system, pushing it into states with unknown consequences for the planet and mankind. An unequivocal indicator of this is the atmospheric CO_2 concentration, which, since the Industrial Revolution and the mass use of fossil fuels, has risen far beyond its natural limits. Our understanding of CO_2 as a greenhouse gas, and the strong link between its concentration and temperature, both point to human activity leading to a warming world, unlike anything seen over at least the last million years.

Our perception of the Earth as a system finds its scientific expression in a modelling spectrum running from the conceptual to the highly computational. These models encapsulate our understanding of the Earth's processes, their dynamic behaviour, their relations and their feedbacks. Quantitative models, by their very nature, consist of equations whose solution requires input data, and evaluating the models also requires data. Hence our total knowledge about the system is contained in our models, our measurements and how we put them together. Improved understanding of how to represent the dynamics of the Earth processes, together with the explosion in computing power, has allowed the construction of ever more powerful computer codes capable of solving the coupled equations that make up an Earth System model with a spatial resolution as high as about 10 km. An equally influential development has been the explosion in the size of databases, both from models and satellite data, and the interconnectivity of computer systems and databases. Pinning these together has led to enormous advances in the methods of model-data fusion and data assimilation. These have been driven primarily by the needs of Numerical Weather Prediction, but the methods are cascading down to encompass all aspects of the Earth System.

The Wider Context

From the outset, ESA's Living Planet Programme had the ambition to facilitate international cooperation and use existing facilities and competences within the ESA Member States and

Strike probability of Typhoon Matsa, starting from the European Centre for Medium-range Weather Forecasts ECMWF) analysis of 4 August 2005 00:00 UT. The ECMWF operates an 'Ensemble Plotting System' in which, in addition to the operational high-resolution forecast, alternative forecasts are made at a lower resolution. (ECMWF)



The Major Challenges for Understanding the Earth System – the Scientific Direction for ESA's Living Planet Programme

Key characteristics of satellite measurements
They are global, enabling us to deal meaningfully with the overall properties of the system, while also providing observations of spatial heterogeneity.

They are repetitive and homogeneous, so that time-varying phenomena can be discriminated. In many cases, long time-series are available, so that oscillations and trends can be recognised, and signatures of anthropogenic change can be distinguished from natural fluctuations.

Near-simultaneous observations of many different variables can be made, allowing the state of the whole system to be diagnosed, and interrelations within the system to be identified.

Near-realtime data delivery (within a few hours) can be ensured, which facilitates assimilation of satellite data into complex models of the behaviour of the Earth System.

The Challenges of the Oceans
Challenge 1: quantify the interaction between variability in ocean dynamics, thermohaline circulation, sea level, and climate.
Challenge 2: understand physical and bio-chemical air/sea interaction processes.
Challenge 3: understand internal waves and the mesoscale in the ocean, its relevance for heat and energy transport and its influence on primary productivity.
Challenge 4: quantify marine-ecosystem variability, and its natural and anthropogenic physical, biological and geo-chemical forcing.
Challenge 5: understand land/ocean interactions in terms of natural and anthropogenic forcing.
Challenge 6: provide reliable model- and data-based assessments and predictions of the past, present and future state of the oceans.

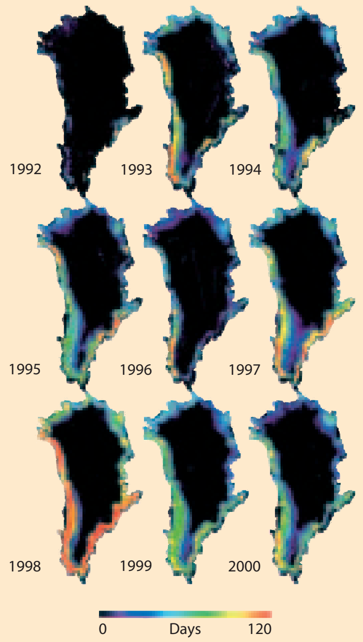
The Challenges of the Atmosphere
Challenge 1: understand and quantify the natural variability and the human-induced changes in the Earth's climate system.
Challenge 2: understand, model and forecast atmospheric composition and air quality on adequate temporal and spatial scales, using ground-based and satellite data.
Challenge 3: better quantification of the physical processes determining the life cycle of aerosols and their interaction with clouds.
Challenge 4: observe, monitor and understand the chemistry-dynamics coupling of the stratospheric and upper tropospheric circulations, and the apparent changes in these circulations.
Challenge 5: contribute to sustainable development through interdisciplinary research on climate circulation patterns and extreme events.

The Challenges of the Cryosphere
Challenge 1: quantify the distribution of sea-ice mass and freshwater equivalent, assess the sensitivity of sea ice to climate change, and understand thermodynamic and dynamic feedbacks to the ocean and atmosphere.
Challenge 2: quantify the mass balance of grounded ice sheets, ice caps and glaciers, partition their relative contributions to global eustatic sea-level change, and understand their future sensitivity to climate change through dynamic processes.
Challenge 3: understand the role of snow and glaciers in influencing the global water cycle and regional water resources, identify links to the atmosphere, and assess likely future trends.
Challenge 4: quantify the influence of ice shelves, high-latitude river run-off and land ice melt on global thermohaline circulation, and understand the sensitivity of each of these fresh-water sources to future climate change.
Challenge 5: quantify current changes taking place in permafrost and frozen-ground regimes, understand their feedback to other components of the climate system, and evaluate their sensitivity to future climate forcing.

The Challenges of the Land Surface
Challenge 1: understand the role of terrestrial ecosystems and their interaction with other components of the Earth System for the exchange of water, carbon and energy, including the quantification of the ecological, atmospheric, chemical and anthropogenic processes that control these bio-chemical luxes.
Challenge 2: understand the interactions between biological diversity, climate variability and key ecosystem characteristics and processes, such as productivity, structure, nutrient cycling, water redistribution and vulnerability.
Challenge 3: understand the pressure caused by anthropogenic dynamics on land surfaces (use of natural resources, and land-use and land-cover change) and their impact on the functioning of terrestrial ecosystems.
Challenge 4: understand the effect of land-surface status on the terrestrial carbon cycle and its dynamics by quantifying their control and feedback mechanisms for determining future trends.

The Challenges of the Solid Earth
Challenge 1: identification and quantification of physical signatures associated with volcanic and earthquake processes from terrestrial and space-based observations.
Challenge 2: improved knowledge of physical properties and geodynamic processes in the deep interior, and their relationship to Earth-surface changes.
Challenge 3: improved understanding of mass transport and mass distribution in the other Earth System components, which will allow the separation of the individual contributions and a clearer picture of the signal due to solid-Earth processes.
Challenge 4: an extended understanding of core processes based on complementary sources of information and the impact of core processes on Earth System science.
Challenge 5: the role of magnetic-field changes in affecting the distribution of ionised particles in the atmosphere and their possible effects on climate.

Melting duration for the Greenland ice-sheet surface for the years shown, estimated using ERS Scatterometer image data. The conclusion is that melting is increasing. (I. Ashcraft, Brigham Young University)

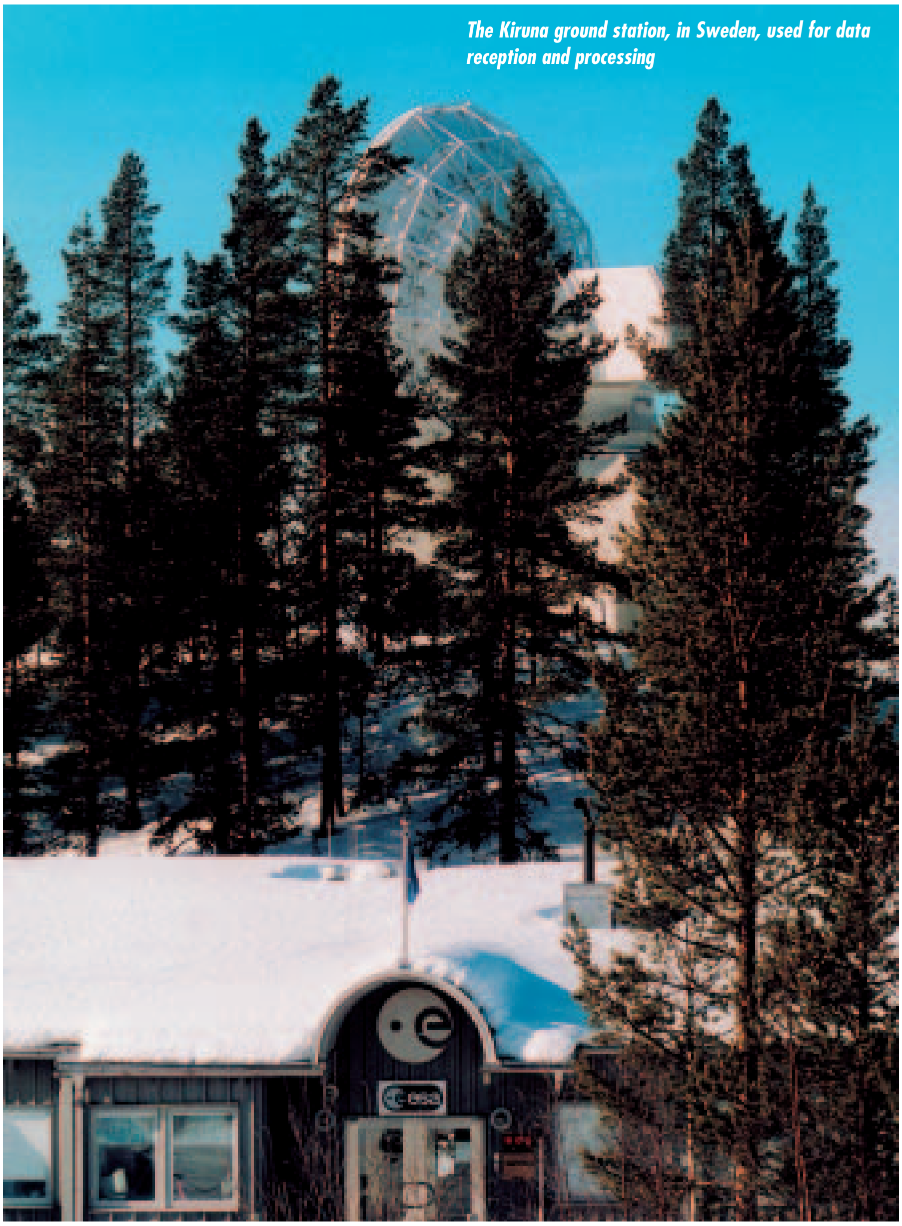


Canada. This cooperation takes several forms, from direct cooperation on the implementation of specific missions, through joint science activities in connection with ESA's and other agencies' missions, to interaction with international scientific research programmes, in order to ensure that ESA's activities have an optimum impact from a global point of view.

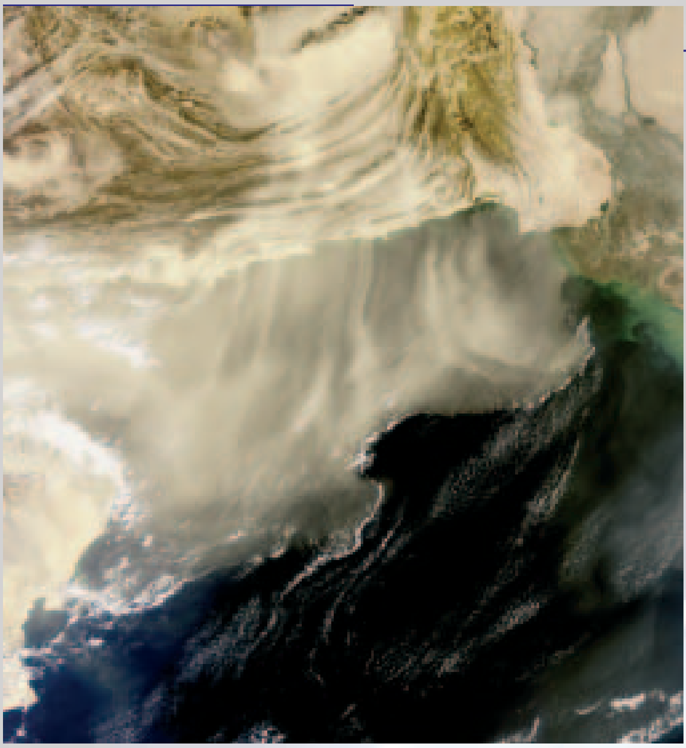
Over the years, European countries have developed a strong leadership in Earth System Science. The development of fully coupled Earth System models is well underway at the Hadley Centre and the University Global Atmospheric Modelling Programme (UGAMP; UK), at the Max Planck Institute for Meteorology in Hamburg (D) and at the Institut Pierre Simon Laplace and Meteo-France (F), to cite but a few. Many other European organisations are working in the same direction. Europe also holds a strong position in other key areas of Earth System Science, such as oceanography and glaciology. Furthermore, several European organisations with an interest in Earth System modelling have grouped together within the European Network for Earth System Modelling (ENES).

Earth System models are developed through a complex and systematic process of comparison with observations at the relevant scale. Systematic differences between model simulations and observations, called 'biases', point to the incorrect representation of some process that must be improved in the models, or to systematic observational errors that must be corrected. Once the biases are reduced to a minimum, the remaining random differences between the models and the observations can be exploited to improve further the model's formulation, or to create a set of model variables representing the reality at a specific point in time. The model can then be used for predictions. This whole process is called 'data assimilation' and lies at the heart of Earth System Science. Europe has developed a very strong leadership in pioneering the variational approach to data assimilation. This approach was first successfully developed in meteorology, where the European Centre for Medium-Range Weather Forecasts, together with partner European meteorological centres, has acquired an undisputed lead. Similar data-assimilation techniques are also being developed in the other fields of Earth science.

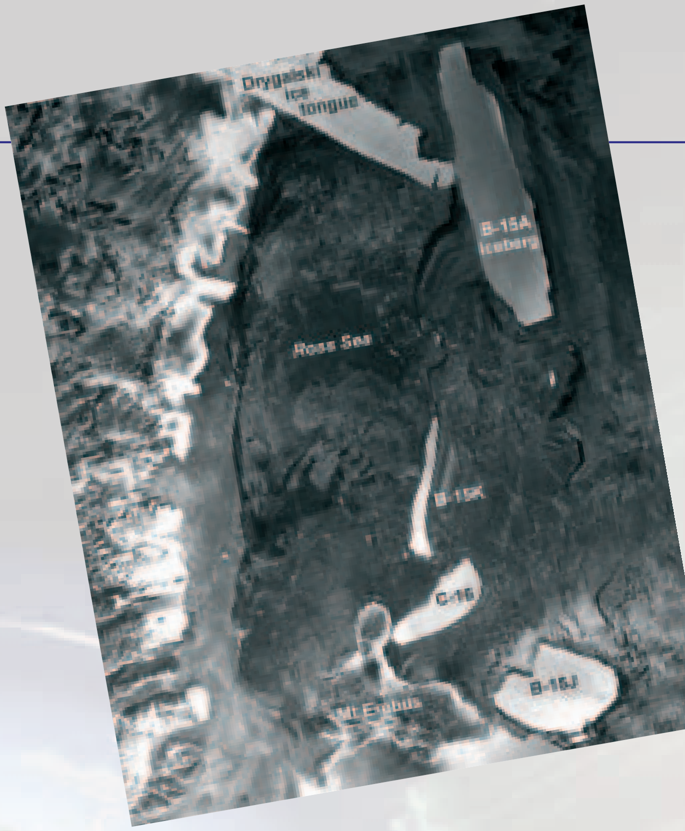
An important benefit of Earth Science satellite missions and other activities is the well-established potential they provide for developing new Earth observation applications, the development of operational systems for meteorology being a prime example. Other areas are also progressing, and political decisions like international treaties on, for example, ozone and carbon, emphasise and formalise the need for related applications. The link between science and applications works both ways. On the one hand, scientific progress forms the basis for the development of new applications, but operational systems also make important contributions to scientific



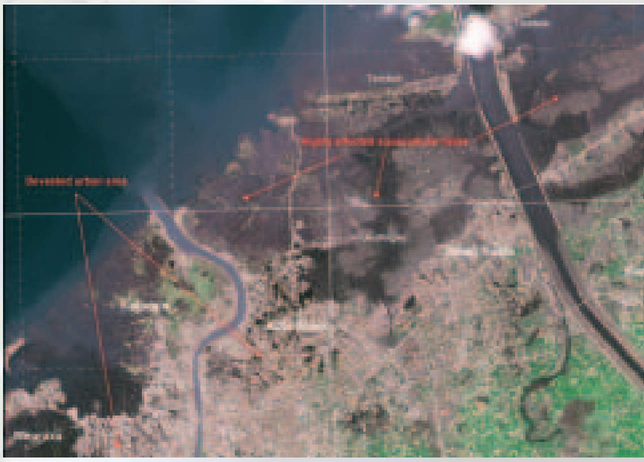
The Kiruna ground station, in Sweden, used for data reception and processing



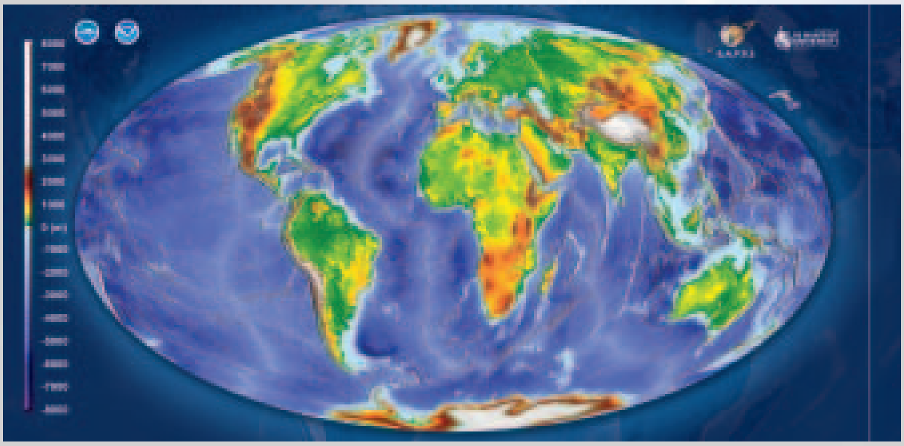
This Envisat/MERIS image of 13 December 2003 is dominated by a dust and sand storm covering the Gulf of Oman. The scene includes a large part of Baluchistan, a mountainous region with some deserts and barren plains, and parts of southwestern Pakistan and southeastern Iran (top right & top centre). It shows the dust particles (aerosols) of a continental air-mass interacting with a humid marine boundary layer (Somali jet), leading to cloud at the edge of the outbreak. (ESA)



Envisat ASAR image of the Scott Coast, Antarctica, showing the collision of the B15A iceberg with the Drygalski ice tongue in April 2005. (ESA)



Banda Aceh as seen by Spot-5 before (2003; left) and after (30 December 2004) the devastating Indonesian tsunami. The damaged infrastructure and areas still under water are clearly visible. (CNES/SpotImage, 2004; processing SERTIT)



Global topography and bathymetry measured by space-based radar altimetry. (ESA, using bathymetry data courtesy of: W. Smith, NOAA Geosciences Lab., USA, D. Sandwell, Scripps Institute of Oceanography, USA, and altimeter-corrected elevations from P. Berry, DeMontfort Univ., UK) research, particularly by providing long time-series of global data, something that is notoriously difficult to justify in research-oriented space activities. A good example in this respect are the missions of Eumetsat and similar organisations.

During the last decade, the Integrated Global Observing Strategy Partnership (IGOS-P) has formulated global observing needs for a number of themes. Other more recent developments are the GMES intiative by the European Union, ESA and other partners, and the Global Earth Observation System of Systems (GEOSS), to which GMES is Europe's planned contribution. Although these initiatives go well beyond the scientific needs, these are also included and these intiatives therefore provide a natural link between science and applications.

Development of specific collaborations with major science initiatives through, for example, the Earth Systems Science Partnership and with international user organisations such as the United Nations Conventions, have also been a feature of the Programme. In all its aspects, it has also been a major contributor to the development of European industry in the technology-development, manufacturing and service sectors.

Living Planet Contributions

ESA's primary contribution to Earth Science is the provision of data products and associated services from the Agency's Earth observation satellites. In addition to data from its own satellites, ESA also facilitates the provision of data from other organisations' satellites.

Earth observation satellites for Earth science are identified, selected and developed in close cooperation with the scientific community. Identification of candidate missions or mission concepts is regularly conducted via open calls for proposals to the scientific community, where the newly identified challenges guide future calls. New concepts usually require a stepwise approach, where studies and campaigns are undertaken in order to advance the concepts. The Agency undertakes preparatory activities in order to ensure that the concepts finally selected for implementation correspond to the highest priority user needs and have the broadest possible scientific impact.

The goals of the science strategy will be achieved only if the data gathered are validated and exploited thoroughly by all the research communities concerned. To achieve the envisaged scale of impact within the science community and in society at large, a strong European role, innovation and commitment in the area of data exploitation must be maintained. Data exploitation under the Living Planet Programme should, in terms of its prime objectives, maximise advances and achievements in European scientific understanding of the Earth System, develop new applications that can benefit society and contribute to improved quality of life, and demonstrate new techniques and technologies that can strengthen European industry's competitiveness. Specific attention should be given to stimulating and facilitating the use of Earth observation data by research communities that do not specialise in remote sensing.

Manifested in ESA's day-to-day contacts with the science community, the requirements associated with Earth observation mission operations, ground segments, data and information handling can be summarised as:

– easiest possible data access, continuously adapting to the latest technology;
– coherent access to many (ideally all) sources of Earth observation data and even other geo-data;
– fast access, ideally in near-realtime;
– long-term access over many (tens of) years;
– adaptation of mission, acquisition planning and operations strategies to user demand.

Today's users can handle and process, and therefore request, substantially higher volumes of Earth observation data than ever before. This trend is increasing exponentially. Payload ground segments must anticipate such an exponential increase in the demand during the design phase, in order to meet the actual demand at the start of mission operations. Modelling and long-term trend monitoring have led to a large increase in the demand for time-series and historical data, including regular reprocessing.

The evolution in the scientific requirements, where the science projects represent large investments both financially and in terms of manpower, means that operations and ground segments for scientific missions now have to:

– offer the same level of reliability and operability as former 'operational' missions;
– additionally provide a higher degree of flexibility in adjusting and tuning the operations schemes to new projects and technologies, and offer a much closer and intelligent dialogue with the user community.

Science today relies on a multitude of Earth observation data sources, which can no longer be characterised as science-only missions. Data from public, operational or commercial missions, as well as non-space data, are often indispensable inputs to science projects. A technically simple and coherent (and financially affordable) access mechanism needs to be established.

It is essential for the success of the science strategy that the technology developments, scientific investigations and applications developments carried out under the Programme are accompanied by a systematic and concerted effort to communicate the achievements to a much wider audience, both within Europe and beyond. This effort should address the general public, political decision-makers, schools and universities, all of whom need to be made aware of, kept regularly informed about and kept interested in Europe's achievements in Earth observation. They must be convinced of the tangible benefits of investing public funds in this effort.

Reaping the Rewards

Coordinating Europe's Earth Observation Ground System

The torrents of data from a wide range of different Earth observation satellites must be handled in a harmonised way for maximum benefit. This image shows the eruption of Mt. Etna on Sicily 25 November 2006, seen by the MERIS instrument aboard ESA's Envisat

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The Global Monitoring of Environment and Security (GMES) programme is based on a fleet of European Earth observation satellites, built and operated by ESA, member states and commercial entities. GMES will also offer data from non-European satellites. In order to provide operational and sustainable user services and to avoid unnecessary duplication in technologies, the challenge is to harmonise the various approaches to the ground segments of the different satellites and to involve the users. To begin this harmonisation process, a Ground Segment Coordination Body was created to adopt a common, coordinated and cost-effective approach that responds to the needs of Earth observation users.

Introduction

The demand for Earth observation (EO) data has evolved dramatically in recent years: the volume of requested data has increased by a factor of 10 over the last 8 years, and more than 80% of the users request data from more than one satellite or satellite operator.

This, in turn, increases the challenge for satellite operators, space agencies and providers of EO data to offer the access to the different data as coherently and easily as possible. It also demands optimisation in allocating the available financial resources to handle an increasing number of different EO missions through closer cooperation in developing the ground segment, the operations and exploiting the data.

A task force set up by ESA's Earth Observation Programme Board (PB-EO) in 2003–2004 came up with a set of recommendations on how to deal with these challenges. One was the creation of a Ground Segment Coordination Body (GSCB), composed of member-state agencies managing EO data ground segments.

GSCB was established in June 2005 and shares the expertise in the development and operation of payload ground segments of missions such as:

- Meteosat, MSG and MetOp by Eumetsat;
- TerraSAR-X, Rapid Eye, TanDEM, EnMAP and third-party missions handled by the German Aerospace Center (DLR);
- Radarsat-1 and -2 by the Canadian Space Agency (CSA);
- COSMO-Skymed by the Italian Space Agency (ASI);
- Spot, Topex-Jason and Pleiades by the French Space Agency (CNES);
- ERS-1 and -2, Envisat, Earth Explorer missions and third-party missions by ESA.

The group coordinates and shares its findings with other coordination and standardisation entities such as CEOS (Committee on Earth Observation Satellites), OGC (Open Geospatial Consortium) and CCSDS (Consulta tive Committee for Space Data Systems), and it plans for regular consultation with industry and commercial missions.

European GMES Earth Observation Missions

The first task of GSCB was to coordinate the ground segment and data management of the most important European and Canadian EO missions during the lifetime of GMES. These existing and planned missions are outlined below.

COSMO- SkyMed (Italy)

COSMO-SkyMed is funded by ASI and the Italian Ministry of Defence. The system, now being built, consists of a constellation of four low Earth orbit mid-sized satellites, each carrying a multi-mode high-resolution X-band Synthetic Aperture Radar (SAR), and a global ground segment. Launch of the first is planned for 2007.

The primary mission is to provide services for land monitoring, territory strategic surveillance, management of environmental resources, maritime and shoreline control and law enforcement, topography and scientific applications.

Pleiades (France)

The Pleiades optical system will consist of two small satellites (1 tonne each) offering resolutions of 70 cm panchromatic and 2.8 m multispectral with a field of view of 20 km, better than its Spot predecessors. In addition, the system can acquire near-instantaneous stereoscopic doubles (or even triples) of 20 x 300 km, and provide highly accurate pinpointing of the images (< 1 m with ground control points) for optimal use of the data in geographical information systems. The first launch is planned for 2009.

TerraSAR-X (Germany)

Based on their experience with SAR technology from various national (SIR-C, SRTM) and ESA missions (ERS, Envisat), DLR and Astrium signed a public-private partnership agreement in March 2002, under which DLR is procuring from Astrium the innovative TerraSAR-X satellite.

The 1023 kg satellite will deliver X-band SAR data in various modes. The Spot-Light mode will yield the finest resolution data, with 1 m pixels for a 10 x 10 km image. The ScanSAR mode will deliver 16 m resolution in a 100 km-wide swath. A special 'split antenna' mode will allow experimental in-track interferometry, such as the mapping of moving objects. The satellite will fly in a 514 km-high dawn-dusk orbit and is scheduled for launch in February 2007 from Baikonur.

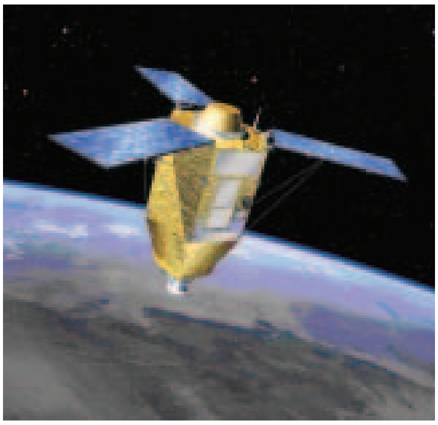
TanDEM-X (Germany)

In 2003, DLR issued a call for proposals for a national follow-on to TerraSAR-X. One of the two accepted proposals is TanDEM-X, which consists of a near-identical satellite flying in a close tandem configuration with TerraSAR-X by 2009. This will allow interferometric digital elevation models to be generated globally to the highest precision ('DTED-3' quality, with 10 m footprint and 2 m vertical accuracy).

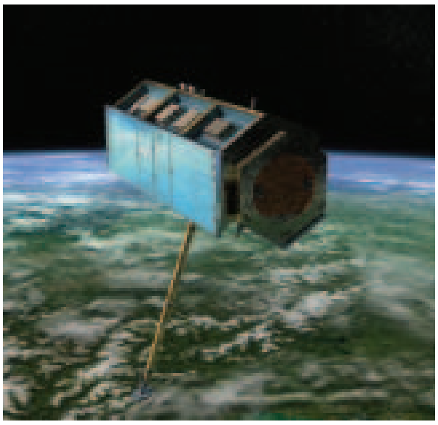
EnMAP (Germany)

The second national German mission, to be launched around 2010, is the hyperspectral EnMAP (Environmental

The Pleiades satellite



The TerraSAR-X satellite



Mapping and Analysis Programme). EnMAP covers the spectral range 420–2450 nm with more than 200 bands of 5–10 nm spacing. The 30 m pixels cover a swath of 30 km; off-nadir viewing enables 5-day repeat coverage. EnMAP will help the study of ecosystems and the monitoring of natural resources.

Radarsat-1/2 (Canada)

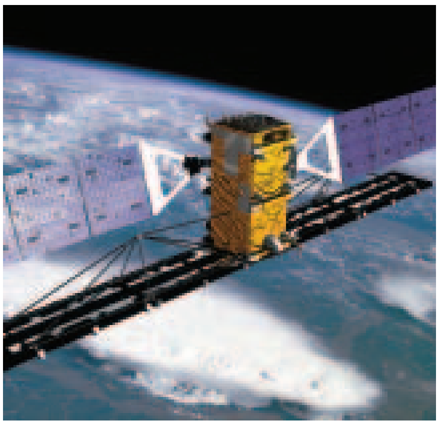
The Radarsat-2 follow-up to Radarsat-1, launched in 1995, is a collaboration between government (CSA) and industry (MacDonald, Dettwiler and Associates Ltd). It is designed to provide C-band SAR data similar to those from Radarsat-1 for continuity. Significant technical improvements were made, including a 3 m high-resolution mode, a full range of signal polarisation modes to improve discrimination between various surface types, superior data storage and more precise measurements of satellite position and attitude.

Radarsat-2 will operate in a Sun-synchronous orbit identical to that of Radarsat-1 but with an offset. It is planned for launch around March/April 2007.

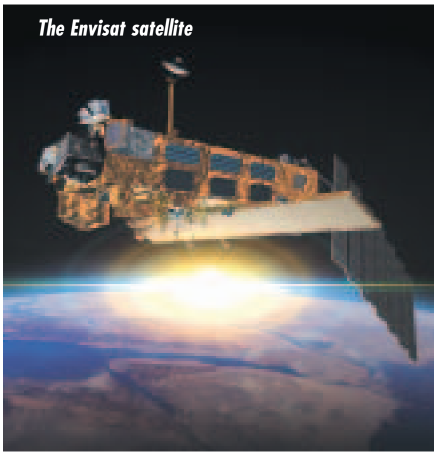
Envisat (ESA)

Envisat was launched on 1 March 2002 and since then has operated with a 35-day repeat cycle, 30 minutes ahead of ERS-2. The instruments address four major areas: radar imaging; optical imaging over oceans, coastal zones and land; observation of the atmosphere; altimetry.

The Radarsat-2 satellite



The Envisat satellite



About two-thirds of the data are transmitted to the ground via ESA's Artemis relay satellite, providing Europe with data acquisition for any location worldwide. A total of 78 product types is generated, amounting to 250 GBytes per day. Most of these products are available on the Internet in near-realtime.

The Envisat data are used in many fields of Earth science, including atmospheric pollution, fire extent, sea-ice motion, ocean currents and vegetation change, as well as for operational activities such as mapping land subsidence, monitoring oil slicks and watching for illegal fisheries.

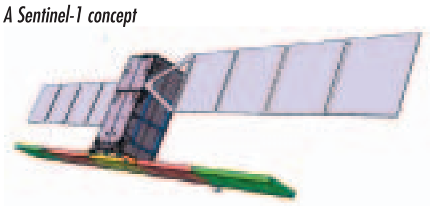
GMES Sentinels (ESA)

Drawing on the preliminary work of the definition studies (Phases-A/B1), the key aspects of the individual Sentinel missions are described below.

Sentinel-1

Sentinel-1 will provide continuity of ERS and Envisat SAR data, but at higher ground resolution and data-take per orbit. It will carry a SAR in a precisely controlled dawn-dusk Sun-synchronous orbit, at about 700 km altitude with an exact repeat of 12 days and a swath of about 240 km. The first launch is planned for 2011.

A Sentinel-1 concept



Sentinel-2

Sentinel-2 will provide improved continuity for the Spot multispectral optical data, carrying a push-broom imager operating in the visible/near-IR and shortwave IR in a Sun-synchronous orbit at about 800 km altitude. The resolution in the visible and near-IR channels will be 10 m. The swath width of the multispectral imager will be about 280 km, ensuring systematic coverage of all land surfaces every 10 days. The first launch is planned for 2011.

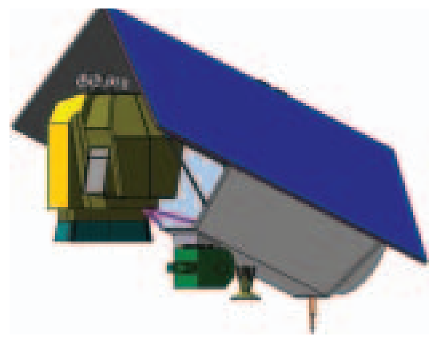
Sentinel-3

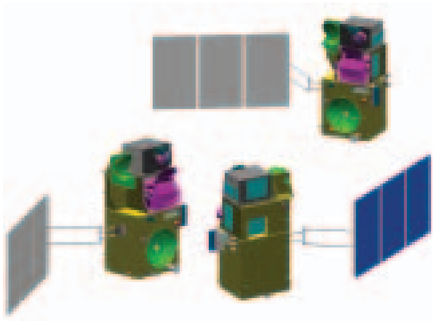
Sentinel-3, with a first launch in 2012, will monitor oceans and land/ atmosphere at a global scale. It will carry, in a Sun-synchronous orbit of around 800 km altitude:

- a microwave altimeter, with a microwave radiometer for atmospheric correction and a satnav receiver for precise orbit determination;
- a 15-channel super-spectral imager for ocean/land colour observations;
- a visible/IR imaging dual-view radiometer for sea/land surface temperature observations.

The land imaging mission will provide continuity for Spot's Vegetation instru-

A Sentinel-2 concept





A Sentinel-3 concept

ment, providing global coverage every 4 days.

All Sentinels will fly in a two-satellite constellation to satisfy the coverage requirements. All have design lifetimes of 7 years and, depending on their mass, are compatible either with the Soyuz (Sentinel-1: 2.5 tonnes) or the Vega launchers (Sentinel-2: 800 kg; Sentinel-3: 1.3 tonnes).

Eumetsat Missions

Meteosat First Generation

The first generation of Meteosat geostationary satellites has provided images of the full Earth disc and data for weather forecasts in a continuous and reliable stream for a quarter of a century. The first was launched in 1977, with the last (Meteosat-7) following in 1997 and still operational. These satellites provide data 24 hours a day from the three spectral channels (visible, IR, water vapour) of the main instrument every 30 minutes.

Meteosat Second Generation

The Meteosat Second Generation (MSG) is a significantly improved follow-on system. It consists of four geostationary meteorological satellites, along with their ground infrastructure, that will operate consecutively until 2018. MSG has brought major improvements in response to user requirements and serves the needs of Nowcasting and Numerical Weather Prediction, in addition to providing important data for climate monitoring and research. The key instrument is the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) radiometer, which delivers daylight images of weather patterns with a resolution of 3 km. The Geostationary Earth Radiation Budget (GERB) instrument measures the Earth's radiation balance.

Eumetsat Polar System

The Eumetsat Polar System (EPS) is Europe's first polar-orbiting operational meteorological satellite system. It is the European contribution to the Initial Joint Polar-Orbiting Operational Satellite System (IJPS) with the US National Oceanic & Atmospheric Administration (NOAA). The prime objective is to provide continuous, long-term datasets for operational meteorology, environmental forecasting and global climate monitoring.

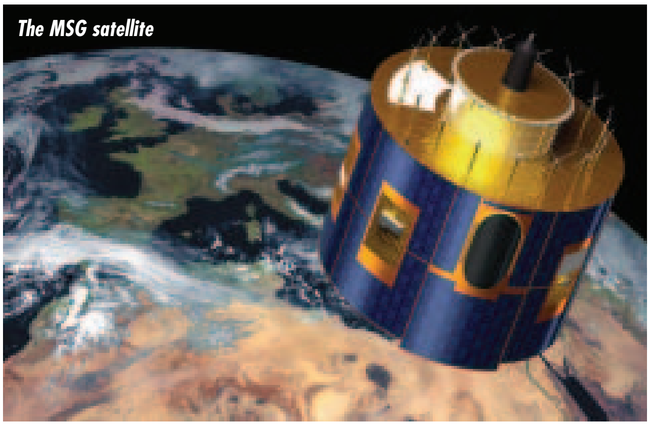
EPS consists of a series of three MetOp satellites, together with their ground system, with an operational life of at least 14 years. The first was launched in October 2006. MetOp is flying in a Sun-synchronous orbit at an altitude of about 840 km, carrying a payload of 11 instruments that includes a new generation of operational instruments developed by Eumetsat, ESA and CNES, in addition to core instruments already flown on NOAA satellites. Global data from new NOAA satellites hosting a subset of MetOp instruments will also be received and processed by the EPS ground segment.

GSCB in GMES and GEOSS

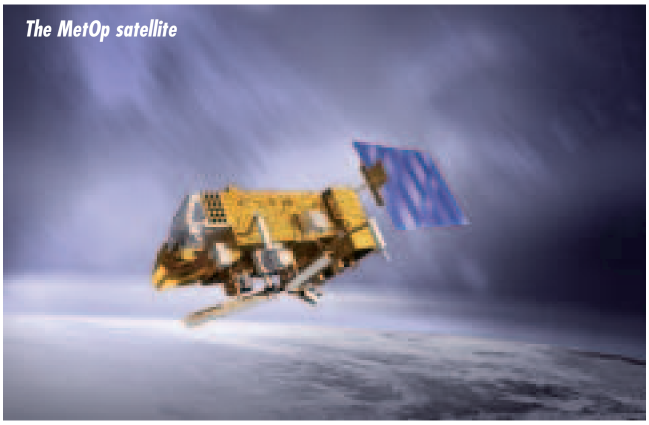
The GMES programme is based on a fleet of European satellites built and operated by ESA, ESA member states and commercial entities. It will also provide access to data from non-European satellites. GMES will therefore rely on existing, planned and new dedicated space and *in situ* observation capabilities to provide services to users. This open approach involves a complex scenario of data-providers, operators and system developers.

GSCB is intended to respond to this need for harmonised and coordinated ground-segment services at the European level, in particular for providing EO data to the GMES services.

The results from GSCB will be fed into the work plan of the Group on Earth Observation (GEO) and will contribute to similar activities under way beyond Europe, in an effort to built existing systems and initiatives into a single system, the 'Global Earth Observation System of Systems' (GEOSS), within 10 years.



The MSG satellite



The MetOp satellite

GSCB Work Plan

Based on an initial 3-year plan defined at the end of 2005, GSCB began to work on the more critical domains for which harmonisation at the European level would bring cost savings in the ground segments and a discernible improvement in access to the EO data for users and service providers.

The first (and main) project, the Heterogeneous Mission Accessibility (HMA) study, aims at the joint definition and adoption of inter-operability standards required to guarantee seamless and harmonised access to heterogeneous EO datasets.

The initial step is to define standards for the discovery, cataloguing, ordering, accessing and delivery of EO data. To do this, the GSCB is relying on the experience of its members, while following international standards and coordination with the European Commission's INSPIRE programme. The first standardisation version through the Open Geospatial Consortium (OGC) and the European Committee for Standardisation (CEN) is targeted for 2007, with initial implementation in 2009. Standardisation through the European Cooperation on Space Standardisation (ECSS) will follow.

The following steps of the project are devoted to defining the harmonised format of EO data products and their quality certification and reporting. The first milestone for the data and quality harmonisation definition is 2008.

The second project is the definition of the Payload Ground Segment reference architecture by identifying the different building blocks and interfaces, and exploiting the experience of the different ground segment operators. The adoption of a reference EO ground architecture for a simple, user-friendly, cost-efficient and inter-operable infrastructure will eventually be recommended, to:

– ease the implementation and integration of new missions and EO data;
– reduce competitiveness in ground segment development by industry;
– serve the European EO data user community in a harmonised way;
– provide a unified European technical standard towards GEOSS.

The third project is the definition and adoption of a common strategy for the long-term preservation of EO data. The strategy will define the technical and managerial approach and provide recommendations for data access, security and archive operations, maintenance and evolution, including data reprocessing and data integrity. The activity will capitalise on policies already in force for preserving digital data archives (at ESA, national space agencies, Eumetsat) and will consider European Union initiatives like the CASPAR project. The first strategy proposal is planned for 2007.

Other areas of common interest are:

– the sharing of telecommunications networking infrastructure, both ground and satellite. The concept relies on the cost-benefit advantages of procuring a common higher capacity network infrastructure, aggregating the needs from different EO operators, rather than proceeding with independent procurements;
– the optimisation of security requirements for the future benefit of dual European missions;
– the identification and sharing of tools for the description, test data generation and manipulation of EO products and ground system interfaces.

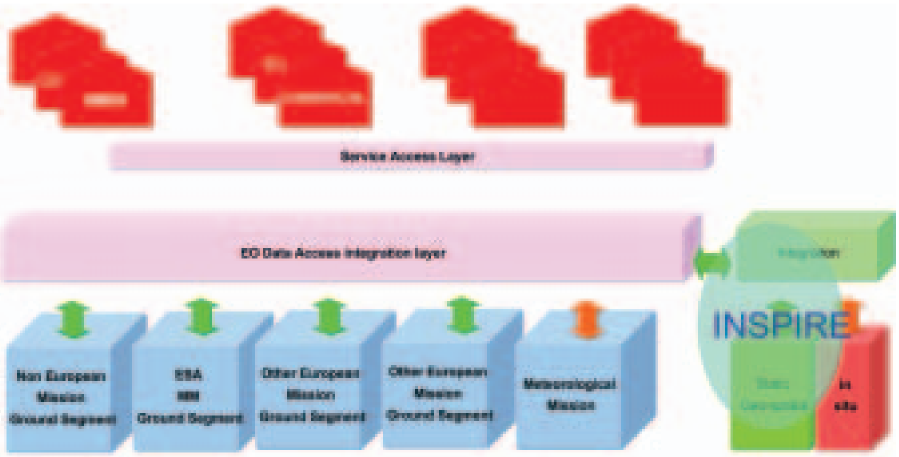
GSCB is not a new standardisation body. Its purpose is to identify and promote the use of a common set of standards to perform the above activities. In doing so, it liaises with the various existing standardisation bodies or initiatives, such as OGC, GEO and INSPIRE.

Achievements

The major achievement of GSCB is the Heterogeneous Mission Accessibility project, started in mid-2005 as part of the GMES Preparatory activities, to:

– consolidate the interoperability scenarios and the related requirements;
– define the EO Data Access Integration Layer (DAIL) architecture;
– define and prototype the interoperable protocol for cataloguing, ordering, mission planning and data distribution;
– define the approach for user and security management;
– address the interoperability requirements arising from, for example, data quality and formats, data policy and Service Level Agreements.

HMA is focused on defining, and later implementing, the interoperability concept across the ground segment of the missions contributing to the GMES



Functional view of the HMA DAIL interactions with EO missions initial phase. It provides a harmonised and standardised access to ESA and third-party mission data through the DAIL, which is a set of standard functions and interfaces. The concrete implementation of DAIL will take into account the requirements of specific missions and the constraints of national facilities.

In the initial phase, HMA gathered the experience of the agencies and EO data ground segment operators by collecting the detailed descriptions of all the data access functionalities used in the existing operational ground systems. The output is a set of specifications for data discovery, cataloguing, ordering and programming services across a range of satellites.

These results were validated by the System Requirements Review in April 2006.

In parallel, the detailed work on the interface specifications derived from the scenarios was performed and submitted to the OGC, an international standards organisation that is leading the development of standards for geospatial and location-based services, and reviewed in close cooperation with the INSPIRE initiative headed by the European Commission. Several standardisation workshops have been organised for discovery and catalogue services to exploit the synergies among the EO datasets (targeted in the HMA) and the geospatial information (addressed by INSPIRE).

In September 2006, the DAIL architecture was assessed and reviewed by all the project partners and external advisors from the Food and Agricultural Organisation of the United Nations, INSPIRE and GEO.

Additional contracts will be in place in early 2007 to implement DAIL and the interfaces in the ground segments of participating missions. The implementation phase will include an HMA testbed to allow testing and evolution of standards proposed to OGC, and the standards compliance test of any entity implementing them.

Conclusions

In response to the increasing need for Earth observation data to monitor the state of our environment and support policy decisions and investments, Europe has introduced the GMES programme. Driven by the needs of users for highly sophisticated geo-information products, GMES will also minimise the effort required for cross-use of the data from these systems.

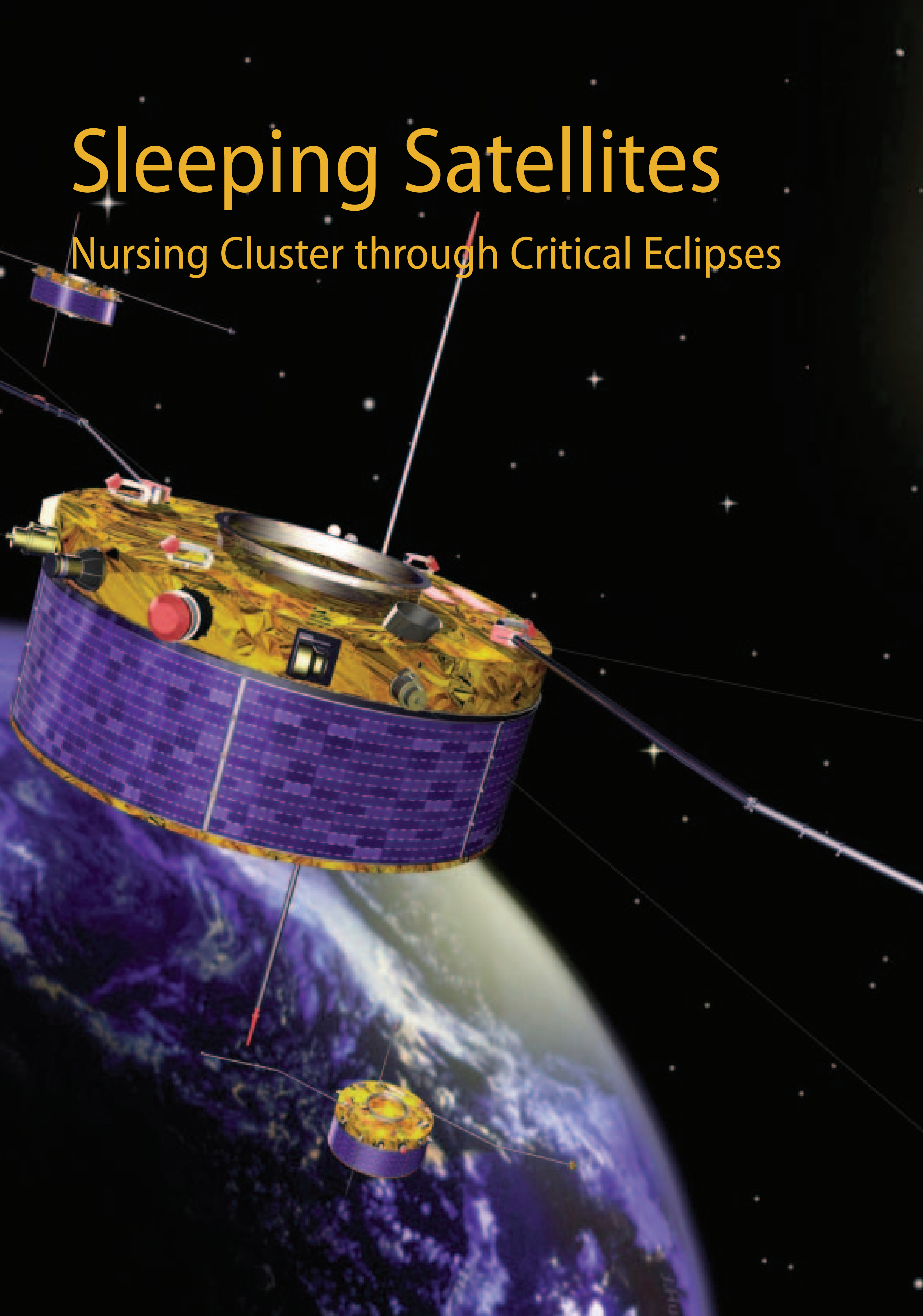
GSCB was created to harmonise the development of the different ground infrastructures and to ensure maximum data availability for a wide variety of users. Although GSCB is not a standardisation body, this coordinated approach has made a significant contribution towards the definition of interoperability and inter-accessibility standards.

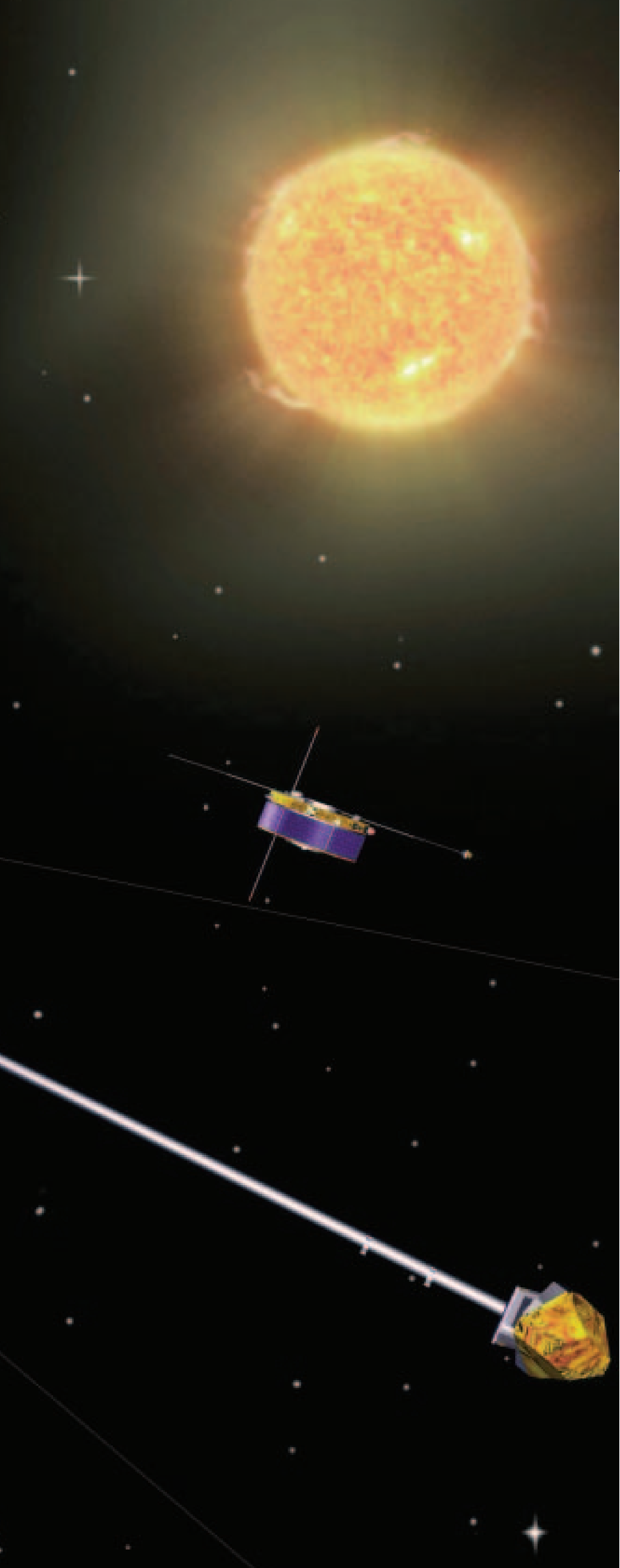
The Body has to cope with the challenge of different national programmes and of bringing together systems already in operation with others still in planning. Various GSCB initiatives are being organised to foster the exchange of information among mission-developers in Europe and Canada, the most important being the HMA study.

A GSCB workshop in 2007 will bring together key players in the ground segment industry and governments. Updates on the initiatives and studies under way will be presented and advice from participants will be sought on how the GSCB can do better. esa

Sleeping Satellites

Nursing Cluster through Critical Eclipses





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ESA's fleet of four Cluster satellites was launched in 2000 to investigate the magnetic interaction between the Sun and Earth. Designed to last 3 years, the mission has now been extended to the end of 2009. But the batteries of the satellites are well beyond their design lives and are starting to fail – the power situation first became critical during the long eclipses in September 2006. The battery aboard one could not power the heaters or computer, so new options had to be developed to avoid dangerous low temperatures and to regain control after each eclipse.

The Cluster Mission

The Cluster mission is a critical part of an international effort to resolve questions about the Earth's magnetic connection with the Sun. For 6 years, the four satellites have been making 3-D measurements of the fine detail in our magnetosphere to discover how the magnetic field responds to solar activity. The scientific achievements so far were summarised in *Bulletin* #121 (February 2005).

Since launch in 2000, the fleet has been controlled from the Agency's European Space Operations Centre (ESOC) in

Darmstadt (D). Originally planned to last until 2003, the mission has been extended twice: into 2005 and then to the end of 2009, with a review in 2007. Before the second extension was approved, the satellites' health was analysed to predict whether they could reach the new end-date. The most difficult conditions occur during long eclipses, when the Earth shadows the power-generating solar cells. Each year, there are short eclipses of 15–40 minutes around the orbit's perigee in March and long eclipses around apogee in September. The three or four long eclipses each last about 3 hours.

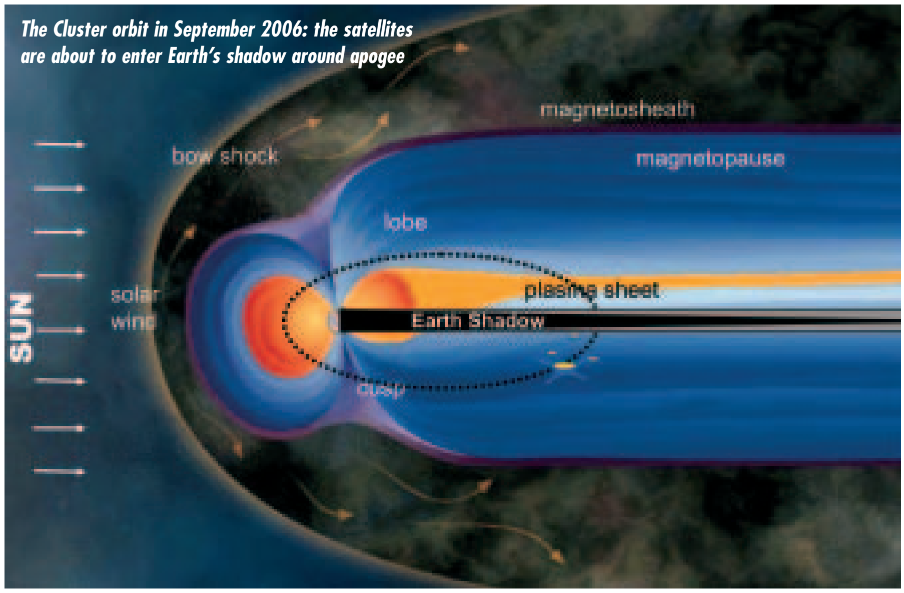
The batteries that power the satellites during eclipses are clearly the most critical units. It was evident they would fail before the end of the extended mission and that Cluster would have to find ways to survive eclipses without electrical power. The satellites would be without onboard control, the high-power amplifier and propellant pipes could cool too far and the computer would require recovery after each eclipse.

With 4 years' operational experience, the Flight Control Team in ESOC was confident that the satellites could be operated during eclipses using only a fraction of the power specified by the Spacecraft User Manual. However, there was the concern that, under certain circumstances, the command decoder might not restart correctly after loss of power. Without the decoder, ESOC's commands could not be routed to their target units to revive the satellite.

Preparations

The Flight Control Team held regular discussions with industry and ESTEC experts to come up with new approaches, and in 2004 a strategy to prolong the battery lives was in action. Meanwhile, the team concentrated on adapting the power, thermal and data-handling operations: individual treatment of the 20 batteries, warming the satellites, recovery from all low-power situations, and rules to allow fast decisions when necessary.

The Cluster orbit in September 2006: the satellites are about to enter Earth's shadow around apogee



Months before the eclipses, a ground station plan was prepared to enable real-time contact with the satellites at the start and end of each eclipse. Extra ground stations – Kourou (French Guiana) and the deep space antenna in New Norcia (Australia) – were prepared for Cluster.

Working with Ageing Batteries

During eclipses, each satellite is powered by five silver-cadmium batteries. In the early 1990's, when Cluster was designed, these were the only non-magnetic batteries available (as Cluster's instruments were intended to measure magnetic fields, the internal fields had to be minimised). Their short lifetime of typically 2.5 years is limited by the amount of cadmium, which is gradually dissolved by the aggressive electrolyte.

The lives are also limited by mismatch between the individual cells of a battery building up over time. On Cluster, the Battery Realignment Facility reduces this mismatch by discharging each cell individually. Monitoring by the computer also checks the batteries, preventing over-charging/discharging, which can generate gas.

Since 2004 two strategies have been used to extend the batteries' lives: the satellite temperature has been lowered, slowing the rate that cadmium is dissolving, and all the batteries have been completely discharged and left unused for months at a time. The associated risks were accepted because these measures dramatically reduce the rate of deterioration.

By April 2006, 16 of the 20 batteries were still operational but their capacity had halved. Three had cracked cells and leaking gas and electrolyte had caused small orbit changes. To minimise the risk of further cracking, the performance of all the batteries was being monitored individually.

To decide on the approach for each satellite it was important to forecast battery behaviour: how much energy could each store and provide? The measurements taken in April after the short eclipses could not be relied on months later for such aged batteries. Measurements taken when the batteries

Each satellite carries five batteries

	BAT 1	BAT 2	BAT 3	BAT 4	BAT 5	Total	Eclipse Need
Spacecraft 1	dead	2.5 Ah	2.9 Ah	1.1 Ah	5.1 Ah	11.6	17.8 Ah
Spacecraft 2	7.3 Ah	8.2 Ah	7 Ah	7.4 Ah	6.7 Ah	36.6	21.6 Ah
Spacecraft 3	dead	1.3 Ah	9.2 Ah	8.8 Ah	7.3 Ah	26.6	19.5 Ah
Spacecraft 4	8.3 Ah	10.3 Ah	9.7 Ah	2.3 Ah	9.4 Ah	40	19.7 Ah

Healthy Battery

Weak Battery

Battery showing major anomaly

The projected storage capacities of the Cluster batteries in August 2006 compared to the needs for a nominal configuration during the longest eclipse of each satellite (3 h 4 min for Spacecraft 1)

were brought out of empty storage in September would have been too late. Procedures for all the possible cases had to be prepared in advance.

New Power Scenarios

The main problem was with Spacecraft 1: three of its five batteries had been declared 'non-operational'. Two had cracked and one had a suspected 'failed cell'. The energy drawn by the satellite's units that cannot be switched off was more than could be stored in the remaining batteries. Tests on the three non-operational batteries, looked for any way to bring them back to life. The results were positive: two could be used with some constraints. Even with these results, the situation for this satellite remained critical: one battery non-operational, two requiring precautions, one showing a large internal electrical leakage and the only 'healthy' battery had low capacity. Altogether, the capacity was around 12 Ah (4 A for 3 hours). This equated to 45 W available for the subsystems, whereas 92 W would normally be required during an eclipse, even with the payload, transmitter and all other non-essential units switched off.

The problem was clear: either find ways to reduce the consumption to a level the batteries could handle, or they would run flat and the satellite would shut down, and possibly die. Operating the satellite with critical systems switched off had never been considered before and it was not covered by either the Spacecraft User Manual or Operating Procedures. It was time to think 'outside the box'.

The first step was to switch off the data recorder and to disable all heaters, leaving only the computer powered. This reduced the average consumption to 75 W – still too high.

The only other load that could be switched off is the computer. The others are permanently connected to the power bus. These 'non-switchable' loads are the main and redundant receivers and decoders that handle commands from ESOC, and the power unit, which conditions, controls and distributes the power. With the computer off, the power needed was finally around the target value of 45 W.

If it turned out before an eclipse that the available power would be less than 45 W, then only one option remained: disable 'battery discharge' after the eclipse began, instantly shutting down the entire satellite. This 'power-down' strategy would protect the batteries from cracking and reserve their energy for use during the restart after leaving eclipse.

Keeping the Satellite Warm

Given that the power shortage had serious thermal implications and considering the increasing battery differences between the satellites, Markus Pietras began studying the problems for his Masters Thesis at Darmstadt University. The effects of different heating strategies were studied using an existing computer thermal model, updated with flight data, and a new model developed for this Thesis.

As the satellite cools down during eclipse, the most critical items are the transmitter's High Power Amplifier (HPA) and the propellant pipes. The HPA might be damaged if it drops below –30ºC and the oxidiser might freeze if the pipes drop below –12ºC.

In sunlight, the solar array generates more electrical power than needed for the instruments and subsystems, so the excess is used to regulate the temperature of the Main Equipment Platform (MEP). Enough power to maintain the MEP at about 15ºC is directed into a network of heaters. During eclipse seasons, more power can be made available for heating only by switching off other units.

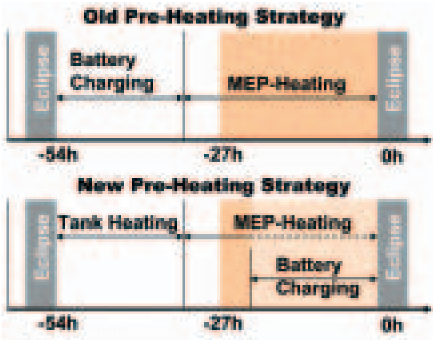
During eclipses, the HPA and propellant pipes are protected from getting too cold by three heaters that turn on when the temperatures drop below set values. The 80 W drawn by these heaters is a large burden on the weakened batteries, so in previous years their activation was delayed by pre-heating the spacecraft to 20ºC before each eclipse. The extra power was made available by switching off the HPA and payload. In 2006, with the batteries of Spacecraft 1 even weaker, these heaters could not be used. To prevent the satellite from getting too cold it needed to be pre-heated to more than 22ºC.

The orbital period of 57 hours allows 54 hours between eclipses to charge the batteries and to warm the satellite. The solar arrays do not provide enough power for simultaneous heating and charging, so in the past the batteries were charged for the first 30 hours after eclipse, leaving the rest for the heaters to raise the MEP temperature.

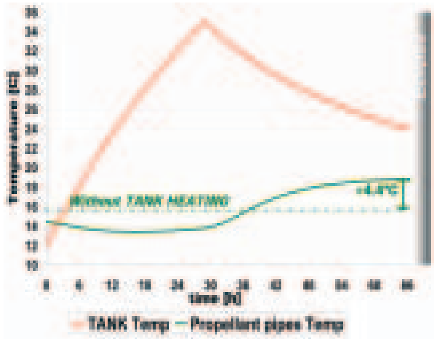
By September 2006 several batteries on Spacecraft 1 showed such large internal leakage currents that this could not be done; a large part of the energy in the batteries would leak away while the MEP was being heated. Conversely, if the satellite were heated during the first 24 hours, it would then have 30 hours to cool while the batteries were charging. Another solution was needed!

Propellant Tanks as Thermal Capacitors

Whereas there was no way of storing enough electrical energy, perhaps it



In the new pre-heating strategy, heat stored in the propellant tanks frees the time for the batteries to be charged close to the eclipse



A simulation shows how warmed propellant tanks raised pipe temperature before an eclipse

could be done for thermal energy. Previously, pre-heating concentrated on warming the MEP, but perhaps heating other 'thermal masses' could be a more effective way of keeping critical units warm.

Each Cluster houses six propellant tanks, weighing 6 kg each and currently containing a total of 50 kg of oxidiser and fuel. The tanks are well insulated and have 40 W of heaters. The thermal models suggested that any heat stored in the tanks could 'buffer' the temperature of the rest of the satellite.

Tests on the flying satellites were encouraging: the tanks could be heated from 16ºC to 35ºC in 24 hours and the insulation was just right to store the heat and release it slowly into the rest of the satellite during the eclipse. This would be enough to slow the temperature drop of the HPA and propellant pipes, keeping them above their critical temperatures.

Operating Without a Computer

It was clear that Spacecraft 1's battery situation required the decoder-only configuration. However, given the fragile state of the batteries, the Flight Control Team had to be ready to switch to the power-down option at short notice. Even if power-down was not used in 2006, it will be needed some time as the batteries on all the satellites continue to age.

Yet the power levels were not the only consideration when deciding between these options. With the decoder-only approach, all possible loads such as the computer are switched off. This is against the usual philosophy of 'safe' spacecraft operations; the commands to turn off the computer were intended to be used only during ground testing. With the computer off, the battery voltages cannot be monitored to prevent them from discharging too deeply. This risks generating gas that could damage the batteries.

After a power-down eclipse, power can be restored only when the solar array is illuminated by the Sun as the eclipse ends. The amount of electricity generated gradually increases over about 15 minutes as the satellites emerges from the eclipse penumbra. The decoder circuits were neither designed nor tested to cope with this slow power 'ramp-up' and the manufacturer was concerned that they might not restart correctly. If both decoders were affected, the satellite would no longer be able to process commands from the ground.

The return of power also triggers the System Reconnection Logic (SRL), automatically turning on the computer, activating the batteries and turning on thermostatic heaters. As the satellite is cold, the heaters may try to draw more power than is available, causing the voltage to collapse and triggering a restart of the computer. This might repeat several times until enough power is available.

The decoder problem is considered unlikely, but its consequences would be far more serious than the other potential problems. Whenever possible, the decoder-only option should be used, even if this means operating the batteries without monitoring. Unlike power-down, the SRL would not trigger, allowing the Team to choose when and how to turn on the computer after the eclipse.

The power-down option should be used only if there is not enough battery capacity to keep even the decoders powered; the potential restart problem could not then be avoided anyway. This would prevent over-discharging the batteries and keep some energy in them. This energy would power the heaters when the SRL triggers at eclipse exit, preventing multiple restarts of the computer.

Flight Rules and Procedures

In addition to preparing for all the possible operating scenarios, the Flight Control Team also needed a set of rules to decide which to choose for each eclipse. The priorities for maintaining the health of the satellites were defined:

Priority 1: maintain power to the decoders. All other units would be powered down in preference to losing power to the whole satellite during an eclipse and thereby risking loss of commanding through the decoder.

Priority 2: protect the batteries. New monitoring schemes were introduced to ensure that batteries were neither over-charged nor over-discharged. With the computer off, the batteries could not be monitored, so battery predictions should always be calculated with conservative margins.

Priority 3: maintain critical units within thermal limits. Pre-heating the MEP and propellant tanks should follow the thermal-model predictions. Any additional power requires powering down the payload and other non-essential units.

These priorities were used to establish the Flight Rules:

– for any satellite and any eclipse, a particular strategy should be adopted only if there is enough capacity even if the weakest battery fails and if the

Spacecraft 1	Eclipse#1	Eclipse#2	Eclipse#3	Eclipse#4
Nominal Eclipse	13.7 Ah	17.8 Ah	15.1 Ah	0 Ah
Decoder Only Eclipse	6.1 Ah	8.1 Ah	6.8 Ah	0 Ah

Spacecraft 1 eclipses. Comparison of the battery capacity needed for the nominal and decoder-only configurations

Critical operations in the Cluster control room

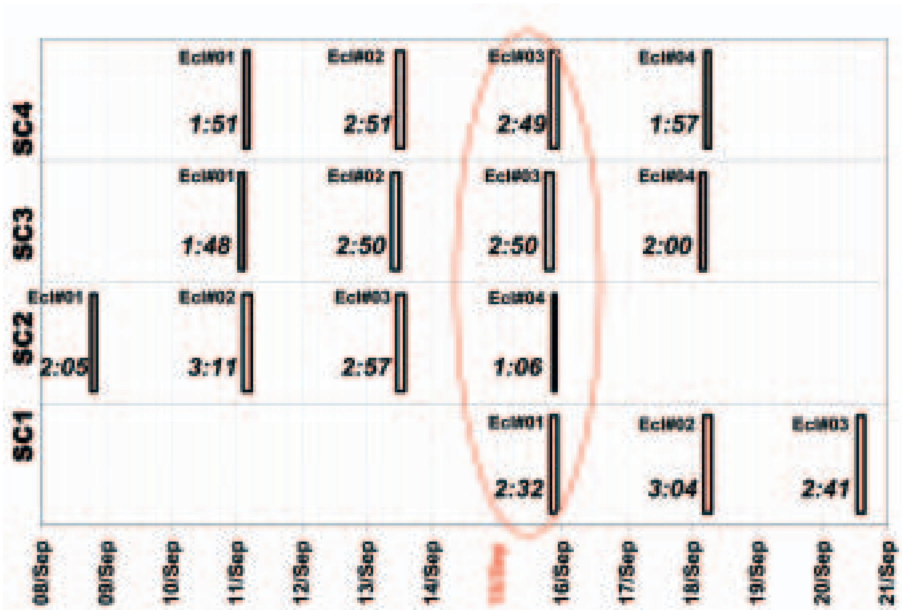
available battery capacity is 20% greater than required for nominal and heater-off scenarios and 10% greater than for the decoder-only option.
– if the battery situation worsens on spacecraft 2, 3 and 4, no attempt will be made to restart payload operations between eclipses

.

These priorities and Flight Rules superseded those previously laid down in the Spacecraft User Manual and Flight Operation Plan. They were approved by the Cluster Project Management shortly before the start of the eclipse season.

The uncertainty in the capacity prediction and the need to be prepared for the worst case meant that new procedures had to be ready for all three power options (heaters-off, decoder-only and power-down) on all four satellites. As the new procedures took shape, they were approved by experts and industrial partners before being tested on the Cluster Simulator. The new procedures worked well and there was a growing optimism that they would bring the satellites safely through the eclipses. But the true test was still to come.

The timeline of Cluster eclipses in September 2006. The eclipse durations are indicated (hr:min); 15 September (red) was the only day when all four satellites were eclipsed



Eclipse Operations

Before each eclipse, the batteries' latest parameters were compared against requirements and the rules were invoked to decide which option should be followed. In all cases, the batteries were stronger than expected. Spacecraft 2, 3 and 4 adopted standard strategies for all the eclipses. For Spacecraft 1, the decoder-only option was used, avoiding the feared command lock-out.

The satellites are separated by 10 000 km so did not all experience eclipses on the same days; fifteen eclipses were spread across 12 days. The first orbit saw an eclipse only for Spacecraft 2, the coldest but with the strongest batteries. The second orbit had eclipses for #2/3/4. The only day when all four were eclipsed was 15 September, beginning with #1. The Team was still refining and testing procedures on the Simulator right up to this day.

Then, while part of the Team took care of the others, a Tiger Team prepared #1 for its first eclipse. Some 30 minutes before it began, they used high-level commands processed by the computer to switch off all the satellite systems one by one, until only the transmitter and the computer remained. As the computer is required to process the commands to turn off the transmitter, it was left until last. By then, of course, the transmitter was off and all signals from the satellite had ceased. Then, although it contradicts accepted practice, the low-level commands to turn off the computer were sent in the blind, with no way of confirming that the commands had been executed. These commands were distributed directly to the power switches and did not need to be processed by the computer. Spacecraft 1 was now in 'sleep mode', ready to enter the Earth's shadow a few minutes later.

After 2.5 hours, as Spacecraft 1 exited the eclipse, it was time to switch on the computer and recover the satellite. The low-level commands to turn on the computer were sent, again in the blind. Allowing time for the computer to boot, the high-level commands were sent a minute later to turn on the transmitter.

A few more nail-biting seconds and an alarm sounded on the control system – a signal from the satellite, woken from its hibernation!

But there was no time to relax. The team had only 2 hours' contact time to restore the satellite to its normal configuration and load the commands to prepare for the next eclipse. Some 50 hours later, the operation was repeated for the second eclipse and then again for the third, until finally the most critical and stressful operations since Cluster's launch were completed!

Although the focus was on Spacecraft 1, the team also managed the eclipses for the other three. Fortunately, they behaved as predicted and there was no need to resort to the special strategies.

Conclusion

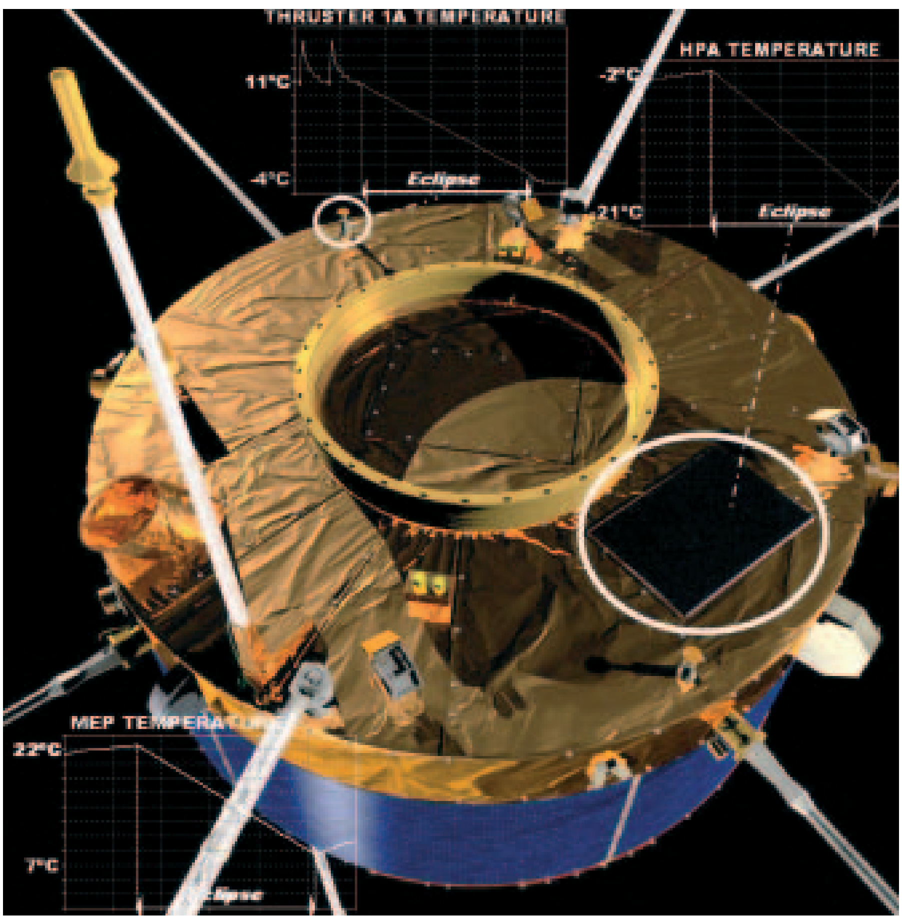
With the pre-heating, none of the satellites' units reached critical temperatures. In fact, the effect of using the tanks as heat stores was greater than expected: the temperatures at eclipse exit were above expectation.

The groundwork was also laid for future eclipse operations:
- a new strategy for heating the satellites was developed and validated;
- the decoder-only configuration was validated;
- the procedures for the power-down scenario are ready for use if they are ever needed.

One major uncertainty remains with the command decoders – will they function after a power-down eclipse? The answer will come in September 2007 when the worsening situation will demand that approach.

The overall problem was simple: reduce the power consumption in eclipses to what could be supported by the reduced battery capacity. The resolution however required a multi-faceted approach from an international, multi-institution team involving the Flight Control Team at ESOC and experts from ESTEC and industry. They identified the critical areas, discovered hidden design margins and conceived new ways of operating the satellites. Through this team effort, the Cluster fleet survived the long eclipses unscathed to continue their valuable scientific mission.

Top view of Spacecraft 1, with the temperature plots of the most critical units during the 3 h 4 min eclipse of 18 September 2006



Acknowledgements

The authors thank the experts who contributed to the discussions and the development of new strategies, drawing on their knowledge from the Cluster design, integration and test phases: G. Lautenschläger and H. Sondermann (Astrium), and T. Aielli (AAS-I Laben). The time-critical operations during the intensive eclipse season would not have been successful without the excellent support provided by the ESTRACK operations teams at ESOC and the ground stations and the dedication of the entire Cluster Flight Control Team.

Further information on Cluster and its mission can be found at http://sci.esa.int/cluster

Building the Future

Acquiring Experience for Space Station and Columbus Operations

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In the run-up to launching and operating Columbus, ESA has gained broad experience in operations on the International Space Station. This includes four Soyuz visits and the 6-month Astrolab mission, involving European astronauts, ground teams and infrastructure in a challenging collaboration with Russian and American partners.

Introduction

With the launch of its Columbus laboratory module at the end of 2007, ESA will become fully responsible for operating the European segment of the International Space Station (ISS). The Agency has developed the internal and industrial set-up to manage the module's integration with the ISS and its full-time operations, both independently and in collaboration with the Station's international partners.

Five European astronauts have already flown Soyuz missions of up to 11 days to the Station: Claudie Haigneré on the Andromède mission, Roberto Vittori (Marco Polo and Eneide), Frank De Winne (Odissea), Pedro Duque (Cervantes) and André

Kuipers (DELTA). ESA's centres and teams were major players in four of these missions, with Andromède directly supported by CNES and Eneide by ASI. The Russian cosmonauts were involved in ESA's experiments during these missions as part of the Soyuz contracts, and NASA's crewmembers also contributed. In all, more than a hundred European experiments were performed.

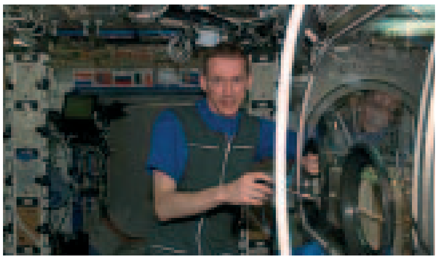
ESA astronaut Thomas Reiter completed his 6-month stay aboard the Station with the Astrolab mission in December 2006. This in particular has given ESA first-hand experience of long-term and multi-crew operations, helping greatly to create and test the management and organisation techniques for working in the challenging Station environment.

The Soyuz Missions

The Odissea mission began with the Soyuz launch from Baikonur Cosmodrome on the morning of 30 October 2002. Aboard the maiden Soyuz-TMA spacecraft were commander Sergei Zalyotin and flight engineers Frank De Winne and Yuri Lonchakov. Nine days of intense effort aboard the Station saw a range of scientific and educational activities successfully completed. On 10 November, the visiting crew returned in Soyuz-TM 34, making a rare night landing in Kazakhstan.

Being able to deliver experiments via the unmanned Progress ferries and the manned Soyuz, combined with the available time of the three visiting crewmembers, created a unique opportunity for a long schedule of experiments. Odissea made full use of this opportunity. A total of 23 experiments were performed, some with more than one human test subject and four in the ESA-developed Microgravity Science Glovebox. The glovebox was installed in May 2002 in the US Destiny laboratory; the other experiments were carried out in Russian facilities.

Odissea was the first ISS mission requiring a distinct ESA structure. It also confirmed the need for careful coordination of ESA's support for the experiments conducted in the Station's Russian and US segments. This was provided by the Operation Support Centre in ESTEC, linked to the Belgian User Support Operations Centre (USOC), Mission Control Centre Moscow (MCC-M) and to NASA's Huntsville Operational Support Center (HOSC) and Mission Control Center Houston (MCC-H).



Odissea: Frank De Winne with the ESA-built Microgravity Science Glovebox

The Cervantes mission began on 18 October 2003, with Pedro Duque flying on Soyuz-TMA 3 with cosmonaut Alexander Kaleri and astronaut Michael Foale. Duque became the sixth European astronaut to visit the Station, and during his 8-day stay he performed 21 experiments in life and physical sciences, Earth observation, education and technology.

Cervantes: Pedro Duque in October 2003

DELTA: André Kuipers in the Station's Zvezda module

Real-time operations were coordinated from the Erasmus Payload Operation Centre at ESTEC. Invaluable experience was gained by the Flight Control Teams in different support centres, such as the Spanish and Belgian USOCs, which assisted the ESA experiments.

A broad range of international cooperation was involved. The European Astronaut Centre (EAC), NASA Marshall Telescience Support Center, ESA's Moscow Mission Operation Support Team (MOST), Increment Management Control at NASA's Johnson Space Center, NASA Payload Operation Integration Center at the Marshall Space Flight Center and the communications network team at ESA's European Space Operations Centre (ESOC) all contributed to the mission success.

The DELTA mission began with the Soyuz-TMA 4 launch on 19 April 2004, carrying André Kuipers, Gennadi Padalka and Michael Fincke to the Station. This mission saw deep cooperation between ESA and the Dutch authorities – a difficult set of 28 experiments was prepared by a joint team from ESA and Dutch industry. This collaboration was a key element in the mission's success, and important experience for handing over operations to industry. This mission also allowed ESA to run some experiments before and after André's visit.

Eneide: Roberto Vittori in the Destiny laboratory module

ESA's real-time operations were coordinated from the new Erasmus Facility Responsible Centre, which was gaining its first experience for working with Columbus.

DELTA also saw the first experiments activated during the 2-day journey of Soyuz to the Station – several biology experiments were carried out in the two ESA Kubik incubators.

The Eneide mission confirmed the objectives of the previous missions: expand the experience of European astronauts, obtain scientific results, promote research in science and technology, stimulate educational interest in young people, expand operational experience with the Station, and promote political and commercial international links.

During his 10-day flight and 8 days aboard the Station in April 2004, Roberto Vittori successfully carried out 27 experiments developed mainly by Italian industry and research centres and ESA. Roberto also made numerous education and public relations contacts with Italian organisations.

For the first time in these missions, the real-time operations were coordinated from the Columbus Control Centre (Col-CC), in Oberpfaffenhofen (D). This was the interface between Roberto, the USOCs and the control centres in Moscow and Houston. All medical and crew aspects were managed from EAC in Cologne (D). Overall mission management was provided from ESTEC.

The Astrolab Mission

The long-duration Astrolab mission began on 4 July 2006 when Space Shuttle *Discovery* lifted off from Kennedy Space Center in Florida with Thomas Reiter and six NASA crewmembers. Thomas remained aboard the Station as the third crewmember, and returned in December 2006 on the next Shuttle, after 6 months of working as a flight engineer. He was accompanied on the descent by ESA astronaut Christer Fuglesang, who played a key role in *Discovery*'s Station assembly mission. Reiter's stay spanned Increments 13 and 14 (an 'Increment' denotes a resident crew's period aboard the Station). This was the first time since the *Columbia* tragedy there had been a 3-man ISS crew.

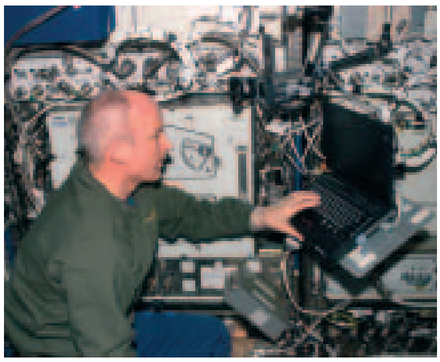
For ESA, Astrolab marked a new phase in human spaceflight. It was a unique mission that witnessed numerous firsts for the Agency. As part of the Station crew, Thomas performed ISS systems tasks, routine tasks, scientific, technology and educational experiments, and a spacewalk. This was his third venture outside, having already undertaken two spacewalks during his Mir mission of 1995–96.

The system tasks normally demand most of the crew time, involving maintenance to onboard systems, upgrading and adding facilities to meet new requirements and accommodating modules. For example, during his mission, Station assembly flight 12A took place in September 2006 and Soyuz-TMA 9 docked a few days later. Those were very intense working days for the astronauts and ground teams alike.

Routine tasks involve housekeeping, inspection of vital life-support systems, inventory checks, personal hygiene, physical exercise, eating and private medical conferences with the crew surgeon on Earth. These are all part of a normal day for ISS crewmembers.

Astrolab: Thomas Reiter working on the Pulmonary Function System in Destiny. ESA provided the PFS for the Human Research Facility

Astrolab: Thomas Reiter working on the Station's internal thermal control system



NASA astronaut Jeff Williams with the European Modular Cultivation System behind

ESA's complement of experiments during Astrolab totalled 40, and several others were performed as part of the overall set-up. In fact, the mission itself extended beyond Reiter's residence. Astrolab was part of the ESA Long Duration Mission (LDM). Owing to the repeated deferrals of the ULF-1.1 (Utilization & Logistics Flight-1.1) Shuttle launch, the LDM experiments had already started at the beginning of Increment 12, when the first hardware was uploaded and operated by Valery Tokarev and Bill McArthur. The same happened at the beginning of Increment 13, when Station Commander Pavel Vinogradov took over 13 experiments for ESA. Mikhail Tyurin, the Russian cosmonaut of Increment 14, continued with some ESA activities. ESA experiments were continued by Greg Olsen, a member of the visiting crew on Soyuz-TMA 7 and Anousheh Ansari, part of the Soyuz-TMA 9 visiting crew.

For the first time, preparation and mission operations were run by industry, paving the way for ESA's Automated Transfer Vehicle (ATV) and Columbus in 2007.

Astrolab was a commercial procurement from the Russian Federal Space Agency (Roskosmos) for a European astronaut to stay aboard the ISS for 6 months. With that, Thomas Reiter became part of the ISS crew as a 'Russian cosmonaut', able to work in both the Russian and American segments.

Coordinating the mission with the various international partners was critical. All the Astrolab hardware was delivered by Russian and US spacecraft, mostly for use in the Russian segment but some throughout the entire ISS. This involved ESA in close and continuous contact with Russian and NASA organisations.

The same flight that took Thomas to the Station also delivered three ESA facilities: the Minus Eighty-degrees Laboratory Freezer for the ISS (MELFI), the European Modular Cultivation System (EMCS) and the Percutaneous Electrical Muscle Stimulator (PEMS). Thomas helped to commission EMCS and MELFI into routine use.

LDM's key objectives were to extend European knowledge and experience in human space missions, and to conduct microgravity experiments. ESA selected 40 experiments that fitted into the available crew time, from educational demonstrations for school children to advanced plasma physics.

The full achievements of the Astrolab mission are still being assessed. Interim reviews with everyone involved and the preliminary results confirm a very positive outlook.

An Eye on Columbus

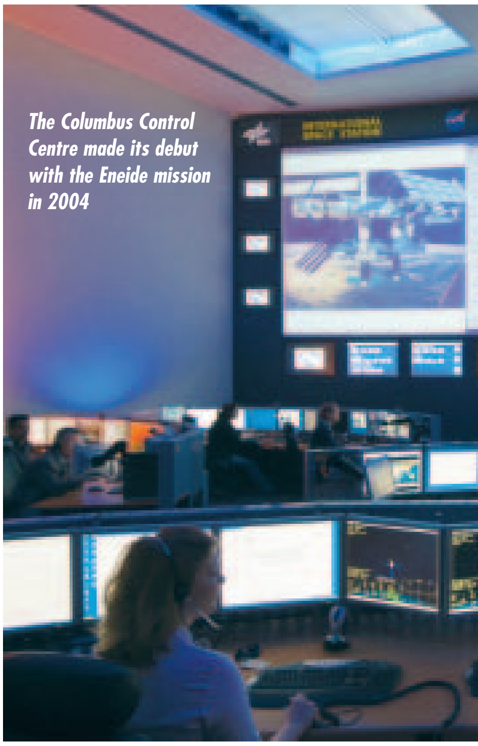
With an eye on Columbus operations, ESA has exercised most of the infrastructure and teams before the module's launch. This was particularly the case for Astrolab. ESA assigned the technical management to an industry consortium: the Industrial Operator Team (IOT). This is a joint industrial effort, led by Astrium-ST-Germany and Alcatel Alenia Spazio-Italy, with the participation of German space agency DLR, aimed at providing an end-to-end turnkey service to ESA. In addition, the USOCs help to prepare and operate the payloads and experiments.

In this set-up, ESA retains the overall management of the mission, while the IOT is responsible for the day-to-day technical management of European assets such as laboratories, ground network, space experiments and astronauts involved in the ISS Increments.

ESA manages the contracts for procuring IOT and USOC resources and services, and procures flight resources from NASA via specific barter agreements and from Roskosmos via commercial contracts.

The interfaces with NASA for specific missions and overall programme management involve the Mission Management Team, the Increment Integration Team, the Training Control Board, the Payload Control Board, and the Ground Segment Control Board.

The interfaces with the Russians are much more streamlined. They are largely managed by RSC Energia as the hardware integrator for Progress and Soyuz launches and as operator of the Russian portion of the ISS. The Gagarin Cosmonaut Training Centre takes care of the Soyuz crew training, while the Institute of BioMedical Problems is responsible for the medical aspects of manned flights.



The Columbus Control Centre made its debut with the Eneide mission in 2004

ESA's Mission Coordination and Control Board (MCCB) has the ultimate authority over ESA activities aboard the Station. It is chaired by the ESA Mission Manager and co-chaired by IOT and USOC representatives.

The MCCB mandates the Mission Management Team (MMT) to provide programme oversight and direction during real-time operations in order to assure crew safety, proper operations and to improve mission success. It is specific to each Increment and becomes active upon the positive conclusion of the ESA Operations Readiness Review. The MMT then coordinates all functional areas running the mission and is key to the success of the mission.

The Increment Integration Team (IIT) is the forum where the mission elements are assembled into an integrated package. It is chaired by the Increment (Integration) Manager, who is responsible to the ESA Mission Manager for timely mission reviews and deliveries.

Crew training for the ESA crew is coordinated by EAC in close cooperation with its Russian and NASA counterparts. For the Astrolab mission, most of Reiter's payload training took place at EAC. There was also some at NASA in Houston because of his schedule and the location of the training hardware.

Some experiments, especially biomedical, require baseline data to be collected on the astronaut before and after a flight for comparison with the flight results. Most of the Astrolab Baseline Data Collection (BDC) sessions took place at EAC, but for those in Russia and the US the BDC coordinator worked closely with his counterparts there.

For Astrolab, the ESA control centres were in regular operation for an entire Increment for the first time. ESA has set up its own ground network to interconnect the European centres as well as to the US and Russian centres.

The Columbus Control Centre in Germany is a key player in Europe's Station operations. It will be ESA's main control centre once Columbus is launched. It provides online services (communications, monitoring, archiving, commanding), distribution of databases and coordination of all the centres. Astrolab's Flight Control Team was hosted there. The communications for real-time operations between Col-CC and the international partners, the Engineering Support Centres, USOCs and EAC are provided by the IOT Ground Segment service.

ESA's Moscow Operations Support Team in MCC-M provides Col-CC with direct interfaces to the Russian team when needed.

European scientists are supported by several USOCs throughout Europe. The USOCs interface with, and can host, the science teams. They are connected to the ESA ground network and work closely with the Flight Control Team at Col-CC for real-time operations of their experiments, facilities or payloads.

Training and simulations for real-time mission operations are conducted in the ESA ground control centres (Col-CC, MOST and USOCs). Personnel train not only on ESA's various operations tools and processes, but also those of the ISS partners. Several simulations take place before each mission, divided into standalone simulations with only one centre, integrated simulations with multiple European centres, and Joint Multilateral Simulation Training involving all European centres and partner centres.

Conclusions

Preparing for Station missions is comparable to combining a number of different projects on a single road leading to the flight and its activities. These different projects each have their own organisations and teams that, most of the time, want to bring their own elements to the flight and have their own direct and exclusive control over the process. In practice, of course, this is not feasible. The necessity is to deliver to a team that integrates and operates all the elements efficiently and effectively; this is the industry mission integration and operations team that is taking shape within ESA. It is developing infrastructures, organisation, experience and a strong team spirit, thanks to the opportunities offered by previous missions.

After each mission and Increment, the integration and operations processes are evaluated, and recommendations are made on improvements. Odissea was the first ISS mission with an ESA organisation behind it. That organisation has developed and adapted as it has supported subsequent missions.

Apart from its undisputed value as a long-duration mission, Astrolab was also important as the première of the working mode for Europe involvement in future Increments. It was a testbed for improving processes, reinforcing working modes and building working relationships among industries, research centres and space agencies in preparation for the launch and exploitation of the main European Station assets: ATV and Columbus.

In almost all the activities, it was necessary to have fully integrated European, Russian and US teams. This was also the case for the European teams: the science, commercial and educational users, the communication teams, and the mission implementation teams from ESA, IOT and USOCs. All needed to work closely together. This challenging set-up demands great effort but ESA can proudly display important results for all to see.

The missions so far were unique opportunities for ESA to gain significant operational experience rapidly and to develop expertise for future European space activities. This does not mean by any stretch of the imagination that it is time to rest on our laurels. The missions have been highly successfully, but not totally so. They have given ESA confidence, experience and working relationships with their international partners, but it is now the time for consolidating, improving and ironing out the wrinkles ready for adding and exploiting the Columbus laboratory in orbit.

Electric Propulsion on SMART-1

A Technology Milestone

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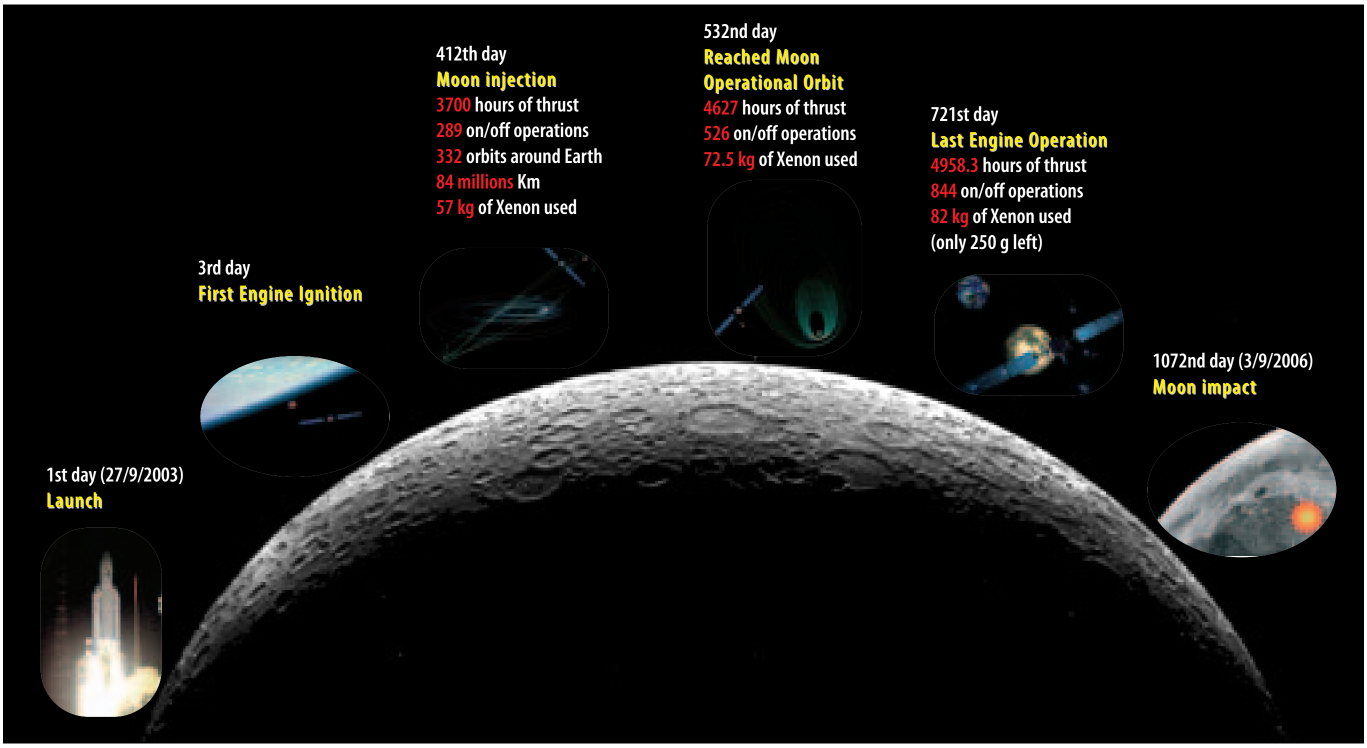
In December 2002, when France's Stentor satellite was all set to use electric propulsion for stationkeeping, ESA's SMART-1 was just completing its first end-to-end spacecraft test. Then Stentor was lost in the Ariane-5 launch failure, making SMART-1 the first and only technology demonstration mission with Hall-effect plasma propulsion. As a result, there was a great deal of interest in the electric propulsion community in SMART-1's flight.

Introduction

SMART-1 was the first of ESA's Small Missions for Advanced Research in Technology. The objective was to test new enabling technologies for the forthcoming ESA Cornerstone science missions, the next being the BepiColombo Mercury orbiters. SMART-1 was launched from Kourou, French Guiana, on 27 September 2003, as an auxiliary passenger on an Ariane-5; its highly successful mission concluded with a deliberate impact on the Moon on 3 September 2006.

The critical technology demonstrated by SMART-1 was the main solar-electric propulsion using a PPS-1350G Hall-effect plasma thruster, developed



and qualified by SNECMA (F). This demonstration created an impressive number of 'firsts' and broke a number of ESA, European and world records.

A Number of Firsts

The SMART-1 electric propulsion system (EPS) was directly managed and procured by the Electric Propulsion Section of ESA's Directorate of Technical and Quality Management, and delivered as 'customer-furnished equipment' to the SMART-1 Project in ESA's Science Directorate and then to the industrial prime contractor, the Swedish Space Corporation. This was the first time that EPS was used for something as critical as primary propulsion. It was also the first time that:

– electric propulsion was used to escape Earth from a geostationary transfer orbit;
– electric propulsion was in conjunction with gravity-assist manoeuvres;
– electric propulsion achieved capture using the weak-stability boundaries and a descent around a celestial body;
– ESA flew a lunar orbiter;
– a lunar orbiter had a propellant fraction as low as 22% (only 82 kg of xenon propellant).

Finally, from a technology point of view, it was the first time that:

– a Hall-effect plasma thruster was used for primary propulsion;
– a Hall-effect propulsion system was used under variable power conditions;
– a plasma thruster had operated continuously for more than 240 hours in space;
– a plasma thruster had accumulated nearly 5000 hours of operations in space.

A demonstration mission was key for full acceptance of the maturity of electric propulsion (EP), and to show that it could benefit from the latest advances in space power generation. The mission not only showed that the propulsion system performed as expected, but also that the system reliability (designed mostly as 'single string') was very good, despite the challenging environmental conditions throughout the mission (repeated crossings of radiation belts, solar flares, lunar albedo).

In addition, an understanding of flight operations with EP was fundamental. EP was often viewed as inconvenient owing to the long thrust periods needed to compensate for the low thrust. Compared to the much shorter thrust periods required by chemical propulsion, EP must be paired with relatively high onboard autonomy and accurate pointing of the thrust vector and solar array over long periods.

This certainly requires a new way of controlling missions from the ground. SMART-1 has paved the way while collecting important experience, such as in the sensitivity to the proton environment, the need to interrupt thrust during eclipses and open-loop onboard power regulation.

From a mission point of view, the long low-thrust manoeuvres have the great advantage that, because changes occur slowly, errors can be easily corrected at negligible propellant cost. Failures can be more easily recovered from than with traditional manoeuvres because there is much more time available for a second attempt or to decide on a fall-back solution. Finally, EP is very often a mission 'enabler' for propellant-demanding scientific missions or long-duration commercial missions.

With its mission, SMART-1 has made a very valuable contribution to spreading the use of EP.

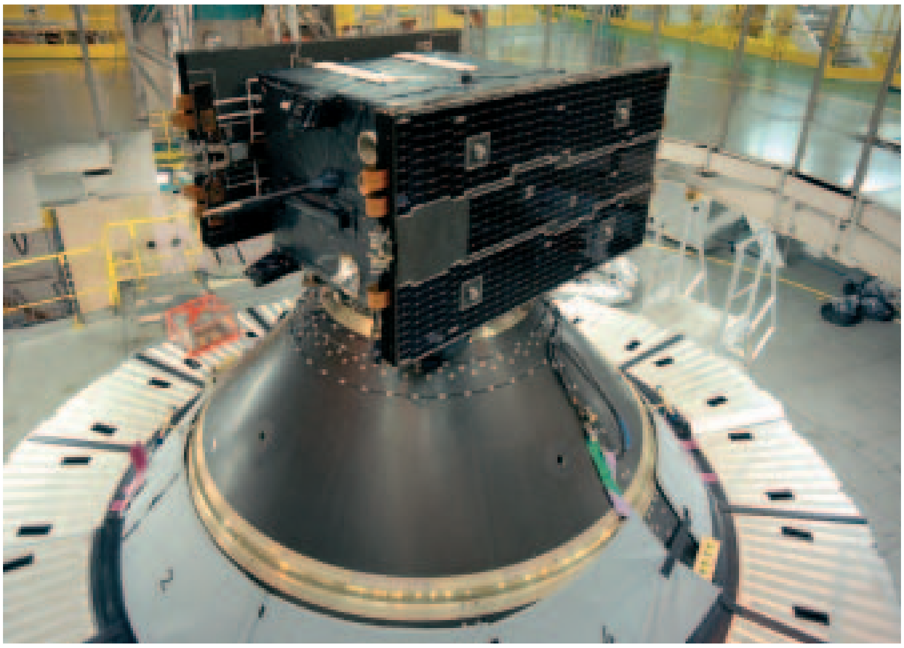
EP Mission Phases

The 3-day Low Earth Orbit Phase starting after separation from Ariane, commissioned all the critical subsystems and rapidly raise the altitude in order to limit radiation exposure of the solar cells and sensitive electronics. The Van Allen Belts Escape Phase used near-continuous thrust to minimise the passage time through the radiation belts, although battery capacity was not enough for thrusting during eclipses. Also, thrusting below 3600 km altitude was not possible because blurring of the startracker images prevented fine pointing. During this phase, the thrust was directed along the velocity vector in order to raise the perigee height quickly above 13 600 km, well beyond the radiation belts.

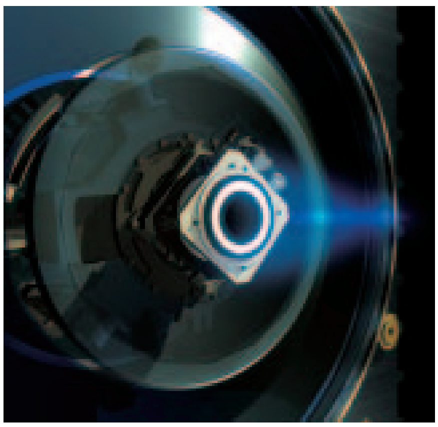
During the Earth Escape Cruise Phase, EP was active for only half of each orbit because thrusting was performed only around the perigee, where it used the propellant more efficiently.

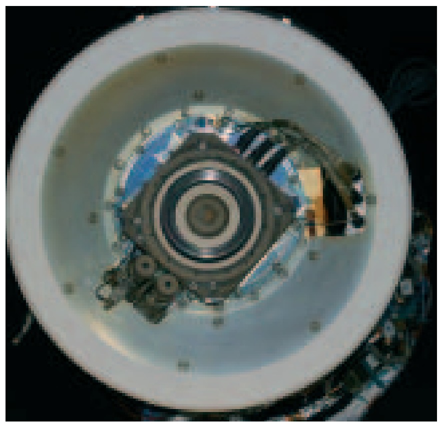
As SMART-1's orbit spiralled out beyond 200 000 km it began to feel significant tugs from the Moon's gravity, until the critical capture manoeuvre with 4.5 days of EP thrust. During 950 hours of cumulative thrust, EP then lowered SMART-1 into a polar orbit of 2000 x 4600 km, where the Lunar Science Phase began in February 2005.

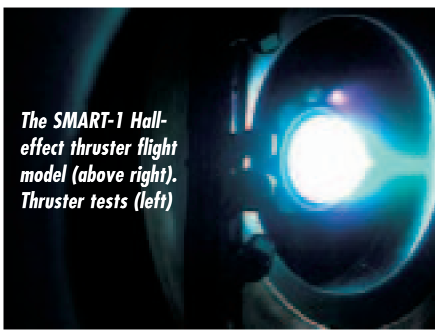
After 6 months of science operations in 'free drift', a new EP phase of 340 hours of thrusting extended the life of the lunar observation orbit by 1 year.



SMART-1 ready for encapsulation on its launcher (ESA/CSG)







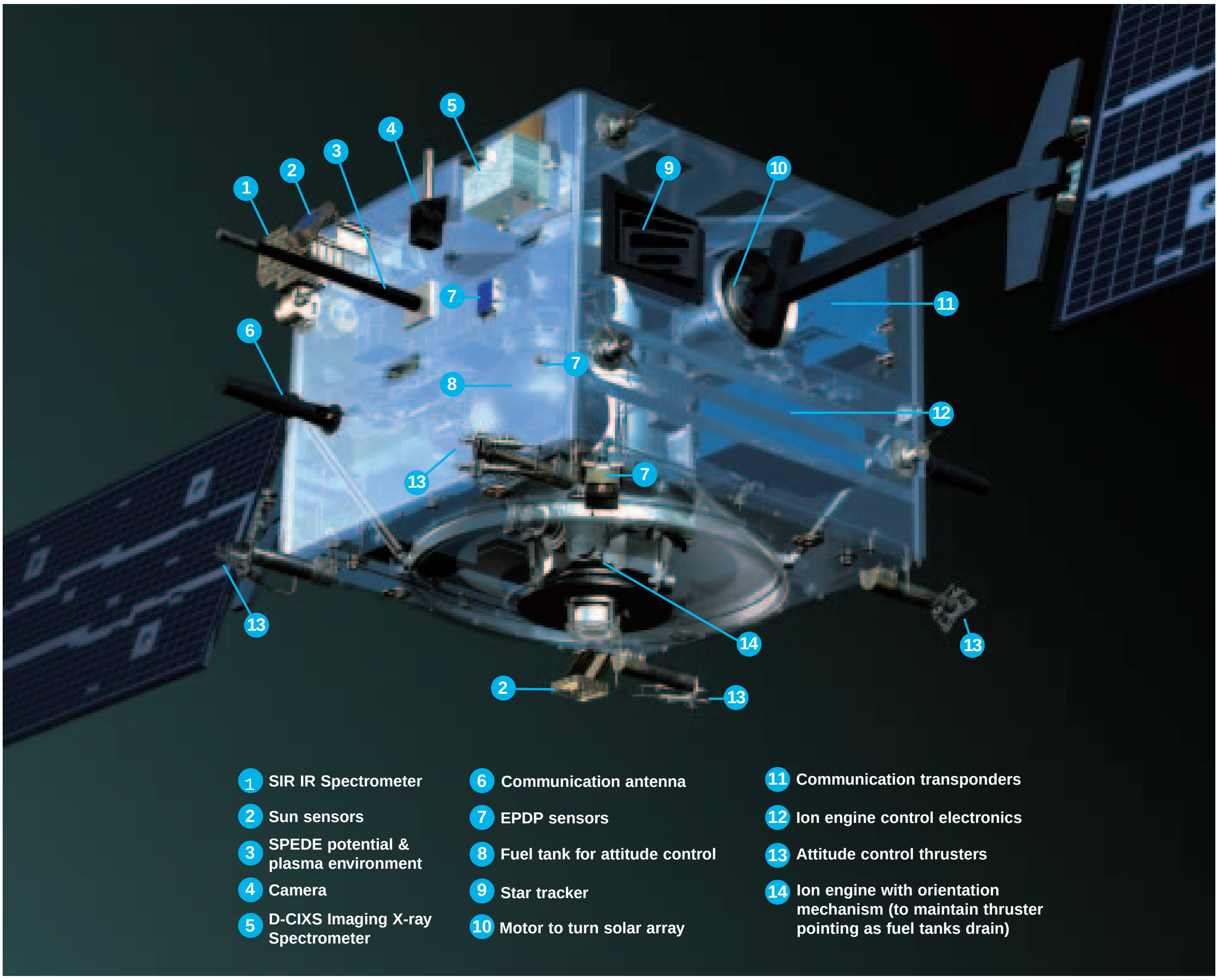
The SMART-1 Hall-effect thruster flight model (above right). Thruster tests (left)

The SMART-1 Platform

Using EP required a 3-axis stabilised spacecraft with two solar wings. The central structure was designed around a 49-litre cylindrical tank containing 82 kg of xenon at launch. Since the thrust vector and solar wings had to be optimally pointed simultaneously, the wings were fitted with a drive mechanism. For maximum power, they used integrated triple-junction gallium-arsenide solar cells of 23.7% efficiency (beginning of life), reduced to 18–19% in the 40–50ºC operating temperature range, with cover glass and at fixed bus voltage. They were sized to deliver 1850 W at the beginning of the mission.

Power was delivered to the EPS via a 50 V fully regulated bus. State-of-the-art lithium-ion batteries provided power during eclipses, for a maximum 2.1 hours without thrusting.

The thruster was mounted on an orientation mechanism (developed by Contraves Space AG) to point through a centre of mass that was moving owing to propellant depletion and thermal effects. SMART-1 also demonstrated the use of a gimballed electric thruster for unloading the reaction wheels, thereby saving precious kilograms of hydrazine.



A key milestone in the project was the full-scale integrated test of the propulsion system. During the end-to-end test in December 2002, SMART-1 (sans solar array) was installed in the HBF-3 vacuum chamber in ESTEC for a 1-hour trial of the thruster and its orientation mechanism, thereby validating all the interfaces and control hardware.

The SMART-1 Electric Propulsion System

The SNECMA PPS-1350G Hall-effect thruster is the European version of the Russian Fakel SPT-100, but using European technologies and quality standards required by western telecommunications satellites. The thruster's ground qualification totalled 9200 hours of cumulative operation and 7200 on/off cycles for a total impulse of 2.9 MNs. This covers the Alphabus requirement, for which the PPS-1350G(4) engine has been chosen, to perform 15 years of daily stationkeeping in geostationary orbit.

Hall-effect, or plasma, thrusters operate with a noble gas such as xenon, well-known for good storability and user-friendliness during ground operations. This is a major advantage over chemical propulsion, which requires costly safety procedures during propellant handling.

The xenon is ionised and accelerated to 60 000 km/h by an electric field, thereby producing thrust. Ionisation occurs when an electron current is generated by the external cathode. This current is constrained by a radial magnetic field. The Hall effect means that the ions and electrons swerve in opposite directions in the magnetic field, creating an electric field. This expels the xenon ions as a propulsive jet. Electrons from an external cathode neutralise the beam to prevent the spacecraft from becoming electrically charged.

On SMART-1, the xenon was stored in the central tank under supercritical conditions, at 1.7 times the density of water and high pressure (up to 150 bars). A pressure regulator, designed by SNECMA Moteurs and Iberespacio (E), reduced the xenon pressure to a nominal 2 bars. The low-pressure gas was then fed into the Xenon Flow

Controller (XFC). A simple and robust control loop algorithm in the regulation electronics (PRE Card) controlled the pressure delivered by the regulator by opening or closing two solenoid valves in series following a predefined sequence. Then the XFC delivered, in a control loop with the discharge current, the xenon flow to the thruster anode and cathode.

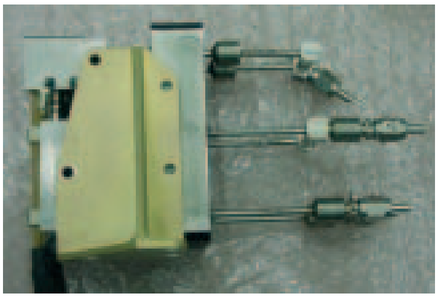
The thruster was controlled and powered by the Power Processing Unit (PPU), developed and qualified by Alcatel ETCA (B). All telemetry and telecommands were interfaced through the PRE Card. An electrical Filter Unit, produced by EREMS (F), reduced the thruster discharge oscillations to an acceptable level and protected the PPU electronics. Both the PRE Card and PPU carried software with 'automatic mode' subroutines that minimised the number of commands to be supplied routinely to the EPS through spacecraft telemetry.

To cope with decreasing and varying power from the solar array as the mission progressed, the EPS was designed to be throttled easily over a wide range of input power. The PPU allowed 117 power levels to be specified, ranging from 462 W up to 1190 W. It also performed the automatic ignition sequence. After the 'auto exec' command was given, the cathode was heated, the xenon flow began and the thruster was turned on by the ignition pulse.

The EPS was a single-string system, but with some internal redundancy. The pressure regulator valves were duplicated, as were the thruster's hollow cathodes and their XFC connections.

In routine operation, EPS was relatively simple to manage. It was commanded to thrust by a pre-built sequence of 35 commands, and switched off by one unique command. It was then a simple matter of supplying the desired thrust level and ignition time whenever a thrust arc was required. Based on the desired orbital change, there were only two events and one parameter for each thrust arc: EP-ON time, thrust level, and EP-OFF time. This information was then processed by the control system and automatically incorporated into the SMART-1 command sequence and the mission planning system as part of the routine command uplinks.

The PRE Card controlled the xenon flow



The Xenon Flow Controller delivered the propellant to the thruster

Electric Propulsion Performance

SMART-1 launch mass	370 kg
Cumulative EPS duration	4958 hours
Cumulative regulated thrust	4913 hours
Total impulse	1.2 MNs
Velocity increment	3.7 km/s
Longest burn duration	240 hours
Number ON/OFF cycles	844
Number valve activations	1 256 505
Xenon at launch	82 kg
Xenon remaining at impact	0.28 kg
Discharge power range	462–1190 W
Average discharge power	1140 W
Average projected thrust	65.7–9.1 mN
Average measured thrust	67 mN
Average effective mass flow	4.44 mg/s
Average effective specific impulse	1540 s

SMART-1 Plasma Diagnostic Instruments

The potentially undesirable effects from EPS included surfaces contaminated with sputtered material and eroded by ion impingement. The Electric Propulsion Diagnostic Package (EPDP) was developed by Alcatel Alenia Space (I) to measure the effects and prove whether they affected spacecraft operations. Surfaces could have charged up, creating electrical problems. Measurements in vacuum chambers were not very representative and the real spacecraft configuration could not be reproduced; flight experience was essential.

In order to measure these effects, EPDP included:

Retarding Potential Analyser (RPA): measured the ion energy and current density distribution.

Langmuir Probe (LP): measured the plasma potential, electron density and electron temperature. The LP and the RPA were on the same panel with the thruster at the centre; RPA's axis was oriented towards the thruster.

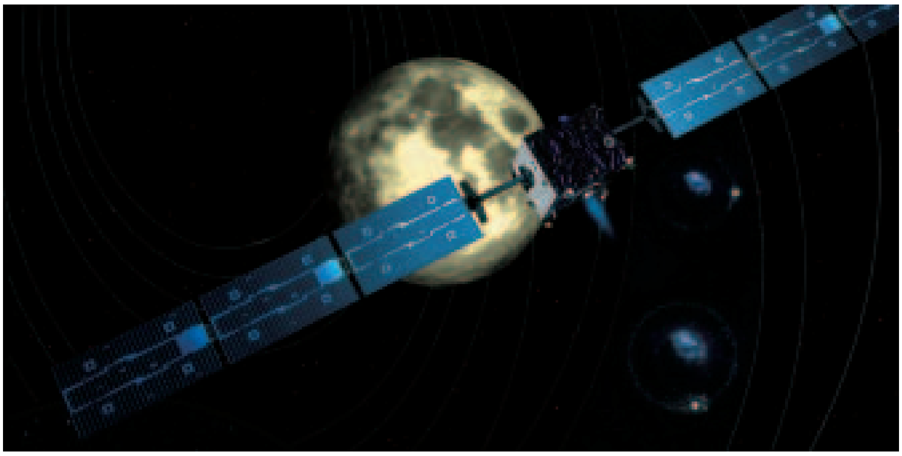
Solar Cell (SC): positioned away from the solar array.

Quartz-Crystal Microbalance (QCM): used to 'weigh' deposited material, providing real contamination data. SC and QCM were installed on the spacecraft's outer –X panel.

EPS Flight Performance

SMART-1 successfully completed all of its EP operations, including some advanced low-pressure thrusting for the 1-year extended mission up to the impact in September 2006. Orbital changes were monitored by ESA's European Space Operations Centre (ESOC) in Darmstadt (D), and the craft's acceleration measured. From these data, the actual thrust levels were accurately determined – valuable feedback from SMART-1 to compare with ground data and to confirm the good behaviour of the thruster and EPS overall.

During ground tests, the thrust was measured with an accuracy of ±2.5% and the variable thrust-versus-power relationship was mapped using an older Qualification Model thruster. These correlated data were used to predict the thruster's flight performance.



The EPS was used in the variable power mode, especially at start-up, but the thruster power used remained close to its maximum (1140 W *vs.* 1190 W). The average measured thrust over almost 5000 hours was well within the predicted average thrust range (67 mN *vs.* 65.7–9.1 mN), even though the projection was done using measurements from a different, older thruster. SMART-1 therefore demonstrated the very good reproducibility and stability in time of thruster performance.

Operation History of the EPS

Up to 1.3 million valve activations were counted, with no signs of propellant leakage even though the qualification limit of 1 million cycles was well exceeded. The procedures developed during flight allowed the residual xenon mass in the tank to be reduced from 1.8 kg to 0.28 kg.

Thanks to the plasma diagnostic instruments, correlated data from the local plasma potential and from the energy of the backflow particles showed the very good operation of the cathode. A cathode is usually considered to be a sensitive component and is therefore made with redundancy. The main parameter for controlling its good health is the working reference potential. Because of the periodic variations of the spacecraft reference potential, a second independent reference potential was required. However, the potential of the nominal cathode was shown to be highly stable throughout the mission. In addition, the thruster always (844 times) started at the first ignition pulse on the cathode. Thus SMART-1 proved this type of hollow cathode developed by SNECMA.

Furthermore, none of the EPS performance parameters was affected by the artificial plasma surrounding the spacecraft or by the periodic oscillation of the spacecraft potential.

Interaction with the Environment

In the initial stage of the mission, the main effect on SMART-1 from its environment was on the solar cells, damaged by the protons in the radiation belts. Taking into account the Earth-Sun distance changing with season, the solar array power fell by around 8%, which included the effect of the very intense solar flare of October 2003. The degradation ended after only 2 months, when the perigee altitude rose above 5900 km. The solar array was sized to cover a 12.3% drop in power at 40ºC, and 17.7% at the maximum cell temperature of 100ºC. Most of the time during EPS operation, the cell temperature was around 60ºC.

From the analysed EPDP flight data, the artificially generated plasma from the propulsion system had no critical effect on SMART-1. No indication of increased erosion or contamination was found; no surface-charging effects were detected. On the contrary, the dense artificial plasma generated by the EPS had a neutralising and stabilising effect on the spacecraft potential, which could otherwise have had a large positive potential, in particular when crossing the radiation belts.

The spacecraft potential was extremely neutral, stable and fully independent of the surrounding natural plasma, including that of the proton and electrons belts. This would have certainly not been the case for a spacecraft without EP and unprotected by a dense, surrounding artificial plasma. Furthermore, the small variations in spacecraft potential are fully understood and exactly correlated to specific thruster operating conditions and solar array attitude with respect to the thruster plume.

Conclusions

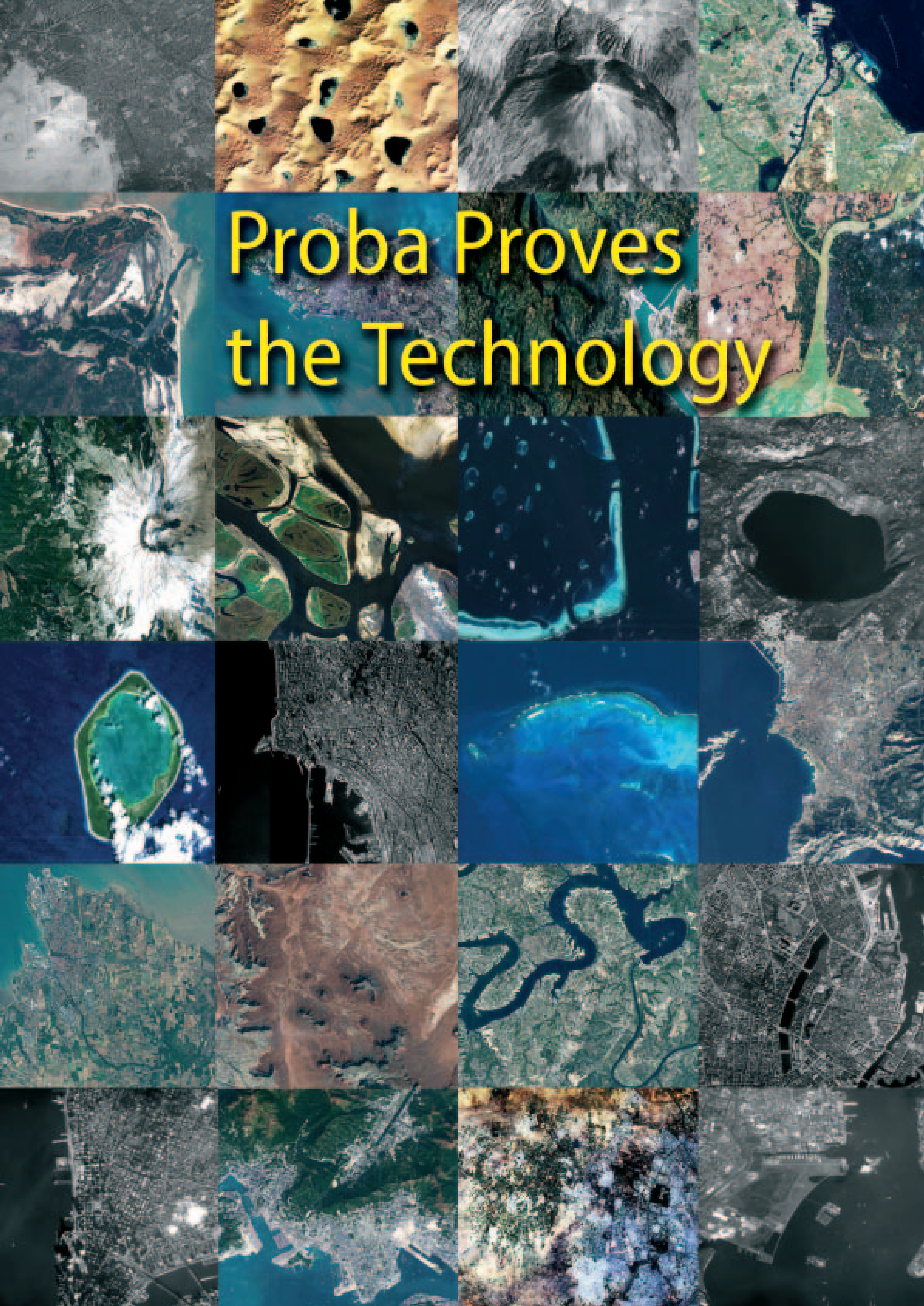
By exceeding its mission objectives, SMART-1 has made a very significant contribution to the promotion of electric propulsion. The impressive results from Europe's first scientific lunar experiments have also helped EP enormously in gaining a larger audience around the world.

In addition, thanks to the EPS performance, the limited degradation of the solar arrays and the optimised transfer strategy, SMART-1 completed a 1-year mission extension, thereby tripling the scientific observation period. On 11 November 2004, SMART-1 became the first ever mission to escape Earth using electric propulsion, and the first to use it for capture by the gravitational field of another celestial body.

All the operational elements of this highly successful spacecraft were demonstrated, paving the way for future missions. The performance of a single thruster, in various operating and environmental conditions, is clear evidence of the robustness of the SMART-1 EPS design, and of the capability of this type of thruster to accomplish a wide range of space missions, including scientific and commercial.

Detailed information on SMART-1 and its mission can be found at www.esa.int/smart1

Proba Proves the Technology



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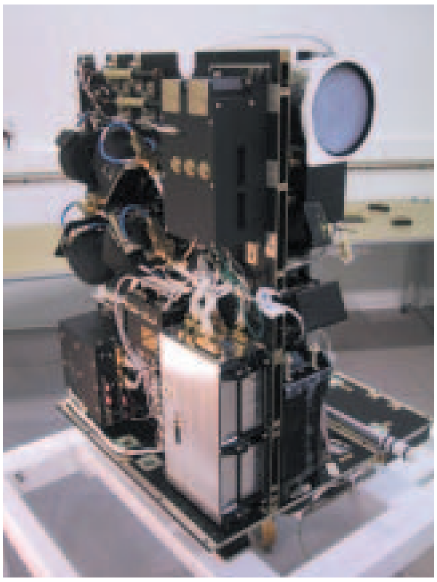
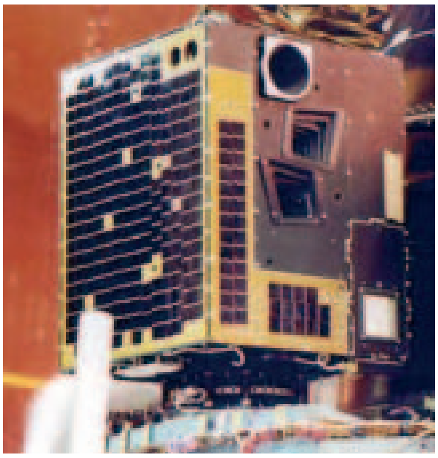
The Proba-1 microsatellite has been remarkably successful in demonstrating the use of new technologies in space. Even after 5 years in orbit, it remains fully operational, with no backup systems called into service. Having achieved its technology goals long ago, it is now working as an Earth-observation mission, returning thousands of valuable images.

Introduction

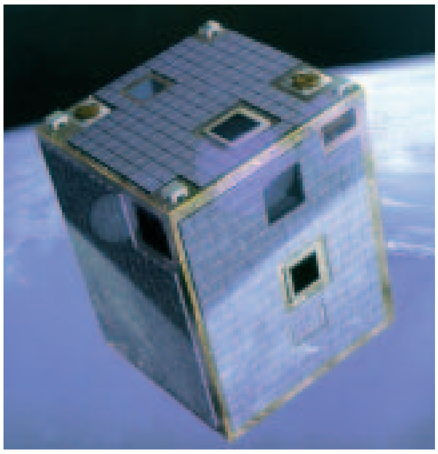
The first PRoject for On Board Autonomy (Proba) is part of an overall effort to promote technology missions using small satellites; it is part of ESA's General Support Technology Programme. An industry team led by Verhaert Design and Development (B) was responsible for Proba-1, supported by several European and Canadian subcontractors and suppliers. Five years after its launch in October 2001, the mission is still fully operational. In addition to the main technology experiments, a suite of scientific instruments was provided to the industrial team by ESA to broaden the mission base. The Compact High Resolution Imaging Spectrometer (CHRIS) was selected from a number of proposals for its technical merit, the scientific value of its data and, particularly,

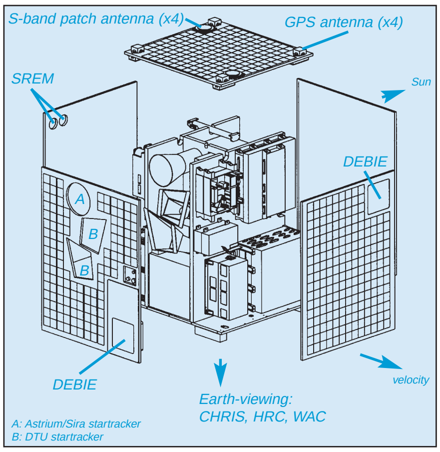


Proba-1 during final integration. The industrial cost for satellite and ground segment design, development, integration, launch and commissioning was €15.6 million (excluding CHRIS and DEBIE)



Proba-1 installed on the launch vehicle





because its multi-imaging techniques exploits Proba's advanced technologies. As a result of the success of the technology and the continuing excellent performance of the satellite and its payloads, Proba-1 became an ESA Earth observation 'third party mission' in 2004, rather like the Meteosat weather satellites.

Proba-1 Summary

The 94 kg 60 x 60 x 80 cm Proba-1 was launched on 22 October 2001 aboard India's Polar Satellite Launch Vehicle, and injected directly into its final polar, Sun-synchronous, slightly elliptical orbit. The orbital plane drifted towards the Sun from 10:30 (the local time it crosses the equator heading north) to 10:46 for the first 3 years and is now drifting back (it is currently 10:36). The satellite can provide useful science data until the drift reaches about 10:00. Meantime, the altitude has decayed by about 20 km, to 540 x 665 km, which does not affect operations. Target revisit time is no longer than about a week. The orbit is therefore acceptable for the mission to be extended if the science return continues to warrant it. Contacts with the Redu (B) and Kiruna (S) ground stations are routine.

The main goal of leaving Proba-1 to operate itself with minimum ground control was long ago achieved. The high level of autonomy requires only the coordinates of an imaging target on Earth to be provided, and the onboard computer navigates to the correct location, tilts, shoots and delivers the scene.

Other achievements include the use of commercial-off-the-shelf components, a star-only attitude determination system (that is, no Earth or Sun sensors), ESA's first flight of a lithium-ion battery in low orbit, novel gallium-arsenide solar cells and 'autocoding' for generating software.

The science payloads, in addition to the CHRIS imager, include a high-resolution camera (HRC), a space-debris detector (DEBIE: DEBris In-orbit Evaluator) and two radiation monitors (SREM: Standard Radiation Environment Monitoring; MRM: Miniaturised Radiation Monitor).

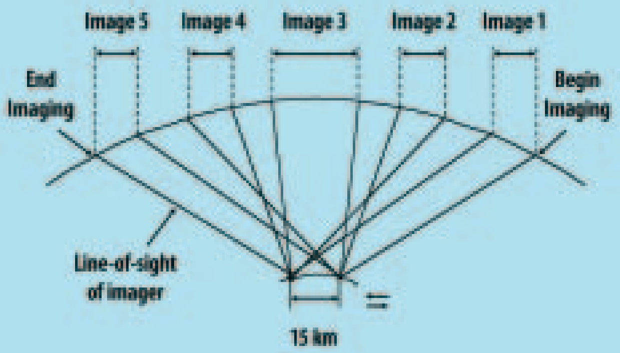
Proba-1 was designed to be compatible with several launchers, including Ariane-5, to help find a cheaper piggy-back launch opportunity. Its structure uses standard aluminium honeycomb panels. Body-mounted solar panels providing 90 W at peak are supported by a 9 Ah Li-ion battery; a centrally switched regulated bus distributes the power. The satellite is controlled by an ERC32 computer, a space version of a standard commercial processor, and intended by ESA to validate a computing core for future spacecraft such as the Automated Transfer Vehicle. The separate TSC21020 Digital Signal Processor provides the processing power for the imaging payloads.

The control system allows both Earth-pointing and inertial 3-axis stabilised attitudes, with onboard navigation and manoeuvring computation; pointing accuracy is 1 arcmin. Thermal control is completely passive. To satisfy the mission's technology goals, all software components in the central computer or embedded in other units can be reprogrammed in flight.

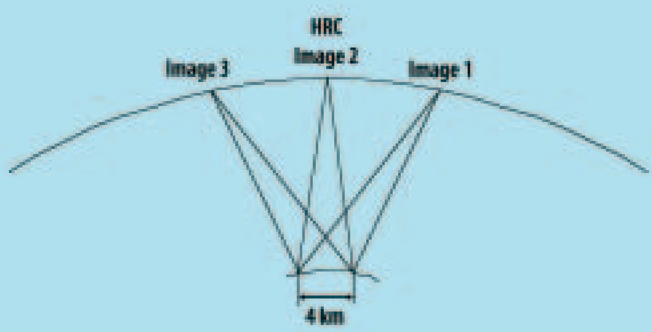
Autonomy and Technology

The autonomy and technologies of Proba-1 can be illustrated by looking at how the satellite captures images of targets on Earth.

Proba can acquire images in several ways. For CHRIS, five images of the same scene are scanned from different



CHRIS can record five images of a target as Proba-1 rotates to remain locked on. The satellite's pointing agility reduces the apparent ground-speed five-fold compared to the actual orbital velocity



The fixed-target mode for HRC is very demanding, requiring that the line-of-sight is held towards a fixed point on Earth. When the mode is commanded, Proba autonomously manoeuvres at high speed to point ahead to the target. Once the target is acquired, Proba rotates in synchronism with its orbital motion to keep the camera pointing at the same fixed area. Proba reverts to its normal mode once the target disappears beyond the horizon behind the satellite

angles as it passes overhead. For HRC, the satellite points and stares at a given target on the ground to take high-resolution images. In both cases, users need only to key in the target's location (latitude, longitude, altitude) via a website. This is routed to the control centre for uplinking to the satellite, which then acts autonomously to calculate when the scene is in view, point itself, programme the camera, record and store the image and finally transmit the image to the ground station during the next available contact period. These operations use the advanced onboard processors running mission and attitude/navigation software taking inputs from the autonomous startracker and GPS navigation system. Using accurate onboard models of the Earth's motion and Sun angles, the position, attitude and speed of Proba are calculated and the orientation adjusted to fulfil the ground requests. Experimenters may refine their requests by adding extra information such as the earliest time to attempt the observation, the maximum angle to the left or right of the ground track, and camera settings like the number of spectral bands to be recorded. But the whole job can be done by specifying only the target's location – the other parameters have default values that have been optimised during the mission to satisfy the majority of requirements.

In order to keep down costs, Proba-1 carries only a minimum set of sensors for normal operations: a startracker and a GPS receiver. Nevertheless, there is still a high level of onboard autonomy. Software adds the equivalent of gyroscopes and Sun and Earth sensors.

During normal operations, the attitude is provided by the startracker viewing two star fields. The orbit is calculated autonomously from GPS data, which also provide the Universal Time required for coordinating all calculations and operations.

Knowing the orbit (GPS) and the attitude (startracker) allows the satellite to adopt any orbital attitude (including the normal nadir pointing) and to point to any user-selected Earth target.

Attitude control is classically generated by a set of four reaction wheels mounted in a tetrahedral configuration. The momentum stored in the wheels can be dumped via magnetorquers – electro-magnets interacting with Earth's magnetic field. The low-power safety standby mode uses the 3-axis magnetorquers to align the satellite to the Earth's magnetic field; it is the mode that Proba returns to in the event of an onboard anomaly.

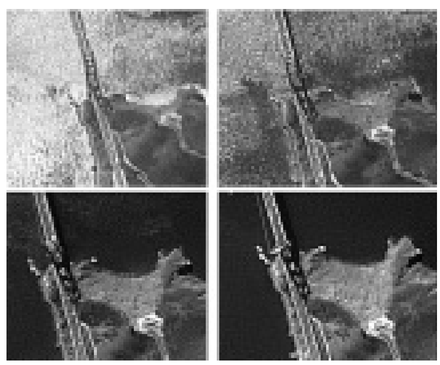
The satellite is operated from the ESA ground station in Redu (B). This station is in charge of mission control, meaning that it receives the requests from the payload users; monitors and manages the overall satellite; acquires payload data, both directly in Redu and via the station in Kiruna (S): and distributes the various data products to the scientists and the Proba technical team. Proba-1 is the first ESA satellite commanded through automated ground procedures. The 2.4 m-diameter S-band terminal is used for telemetry, telecommand and payload data acquisition. The mission planning and control team is kept to a strict minimum and works only normal office hours. Data distribution is done via the Internet.

Payloads

CHRIS

Proba's largest instrument is the Compact High Resolution Imaging Spectrometer. It records quasi-

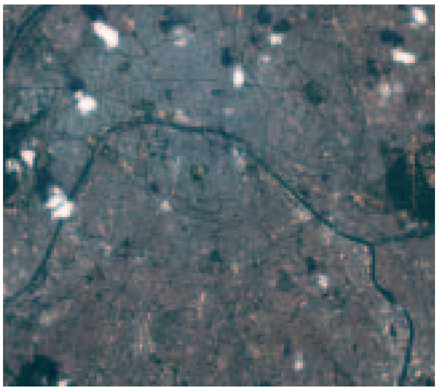
Proba's agility can be seen in these images of San Francisco. Four HRC frames of the Golden Gate Bridge were taken at different times using the 'point and stare' manoeuvre as Proba moved along its orbit



Flooding in Arles, France, 4 December 2003, observed by CHRIS (ESA/SSTL)

HRC image of Sydney, Australia, 22 May 2006 (ESA)

HRC image of Oostende, Belgium 6 March 2006 (ESA)



CHRIS image of Paris, 20 July 2006 (ESA/SSTL)

CHRIS image of Mont St. Michel, France 19 November 2006 (ESA/SSTL)

hyperspectral surface images in the visible/near-infrared (VNIR) band (415–1050 nm), with a sampling interval adjustable between 2 nm and 10 nm at high spatial resolution (15 m at nadir). CHRIS uses Proba's pointing capabilities to measure the variation in light intensity as the viewing angle changes for a selected scene on the Earth's surface. The mission has also proved techniques for future imaging-spectrometer missions on agile small satellites, particularly for precision farming observations, regional yield forecasting and forest inventory.

HRC

The High Resolution Camera is a miniaturised black & white imager with 5 m ground resolution. The Cassegrain telescope has an aperture of 115 mm and a focal length of 2296 mm. The CCD, using 3-D packaging technology, contains 1024 x 1024 pixels of 14 µm size. The field of view (across the CCD's diagonal) is 0.504º. Images are digitised to 10 bits before being passed to the satellite. HRC requires highly stable and accurate pointing of its CCD at an Earth-fixed target using Proba's 'point and stare' feature.

SREM

ESA's Standard Radiation Environment Monitor, being flown on a range of satellites such as Integral and Rosetta, is helping engineers and scientists to understand the radiation hazards in space. Proba's path covers Earth's 'polar horns', where energetic electrons of the outer Van Allen radiation belt are transported to low altitudes. It also passes through the South Atlantic Anomaly, where the inner radiation belt dips down and damages satellites with its proton streams. Proba-1 is also exposed to solar particles when the Sun is active. Likewise, cosmic rays are modulated by Earth's magnetic field. SREM is mapping all of these radiations and their variations. The measurements are also correlated with radiation damage to Proba's electronic components, CCDs and solar cells.

DEBIE

The DEBris In-orbit Evaluator is measuring the fluxes of sub-mm meteoroids and space debris. A combination of impact ionisation, momentum transfer and foil penetration provides the mass (down to about 10^{-14} g) and speed of the impacting particles.

Proba Results

The satellite, with a design life of 2 years, has now completed 5 years in orbit without calling on any backup systems. The reaction wheels, battery and solar array have aged, of course, but can cope with extending the lifetime even further. By November 2006, more than 17 000 CHRIS and 12 000 HRC images had been returned.

The satellite routinely fulfils requests from the scientists exploiting CHRIS and HRC: on average, six sets of five images are produced each day (60% from CHRIS). In addition, data are provided to other experimenters, particularly SREM and DEBIE, which operate independently of the imagers, and to those monitoring the long-term effects of the space environment on the other experimental technologies.

Scientific use

Proba data are currently supporting 98 Earth-observation research projects in 26 countries. More than a thousand sites have been monitored worldwide so far during the mission. The CHRIS spectrometer in combination with Proba's agility is helping to study: soils, land biochemical and biophysical properties; aerosols; forests; agriculture; and water (coastal and inland).

Campaigns are also being run to help potential future Earth observation missions, such as Fuegosat. These campaigns use the flexibility and capabilities of Proba and CHRIS to obtain images with characteristics as close as possible to the future operational needs, such as the viewing angles and spectral bands.

Disaster monitoring

Proba has also demonstrated its capabilities for disaster monitoring. Its high degree of onboard autonomy, which requires only a single ground command specifying a target's longitude and latitude, means that it offers rapid response times and can handle last-minute requests. Since the end of 2003, Proba has been supporting the 'International Charter on Space and Major Disasters' and collecting images of disaster areas on request, such as volcano eruptions, floods and forest fires.

Proba is imaging regions of Spain, Portugal, Siberia and Australia at regular intervals to map the extent of burnt areas and to identify vegetation regrowth. This project to survey the long-term damage done by forest fires is a joint research programme with Grman space agency DLR, which is also using its own Bird satellite.

Proba is also participating in flood research for the joint ESA-China Dragon programme, monitoring flood-prone areas near Beijing.

For more information, visit *http://earth.esa.int/earthimages/*

Proba-2 will be launched in 2007 to demonstrate more advanced technologies (Verhaert)

Education and public relations

Some of Proba's observation time is allocated for educational and public relations purposes. Proba images are used to increase public awareness of space missions and show the benefits of Earth observation and monitoring space missions. Some of the images have now been incorporated into Google Earth.

For more information, visit *http://earth.esa.int/proba/*

Proba-1 Conclusions

Having completed its demonstration objectives, Proba-1 became an Earth Observation third-party mission in order to continue exploiting the excellent performance of its main scientific payload. During its lifetime, Proba-1 has in particular demonstrated that:

- a technology demonstration mission can also support a user-oriented mission;
- a microsatellite with advanced platform and payload technologies can support demanding and new scientific missions;
- embedded autonomy allows low-cost and highly reactive missions;
- advanced development methods (such as code generation) are sufficiently mature and are cost-efficient;
- an attitude control system based only on an autonomous startracker is sufficient for the pointing and stability needs of an Earth observation mission, as well as for the fast and accurate attitude manoeuvres required by 'point and stare' imaging, for example.

Proba-3 will test formation-flying for future scientific satellites

The Future

The Proba-1 mission can continue operating for several more years. Every year, the collected images are analysed and reviewed in a CHRIS/Proba workshop (*http://www.esa.int/esaEO/SEMAQVRMD6E_index_0.html*). Following each workshop, the decision to continue with the mission is then taken and the plan of observations for the following year defined.

A Proba-2 mission is now in final development, for launch together with ESA's SMOS satellite in late 2007. Like its predecessor, it is dedicated to technology demonstration. Some are evolutions of Proba-1 technologies, such as the new-generation startracker providing improved performance at lower mass and power. A scientific package consists of Sun and plasma monitors. Information is available at *http://www.esa.int/techresources/ESTEC-Article-fullArticle_par-50_1134728792936.html*

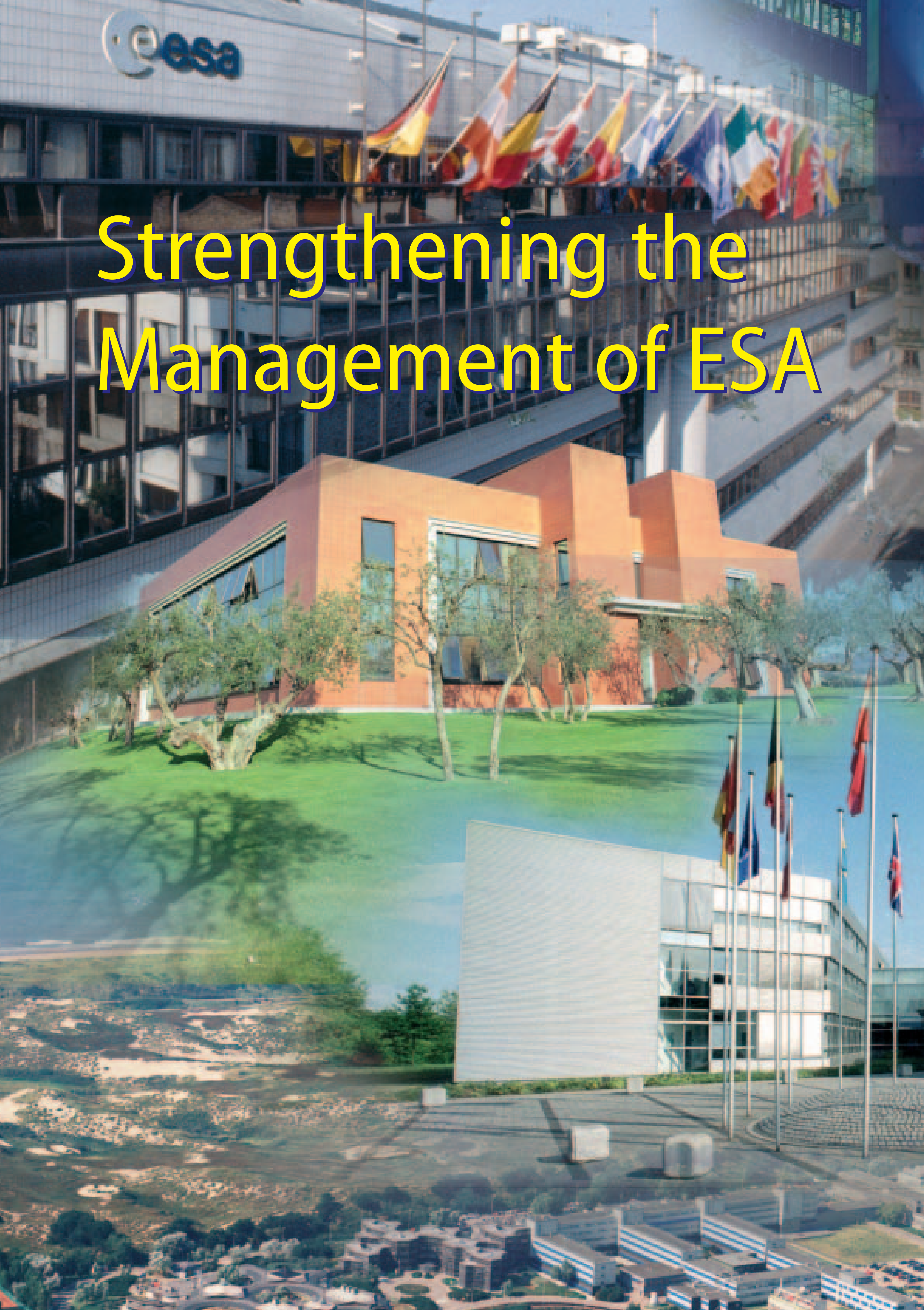
A Proba-3 mission is in the early definition stage; it will demonstrate formation-flying technologies and techniques using two satellites.

Acknowledgements

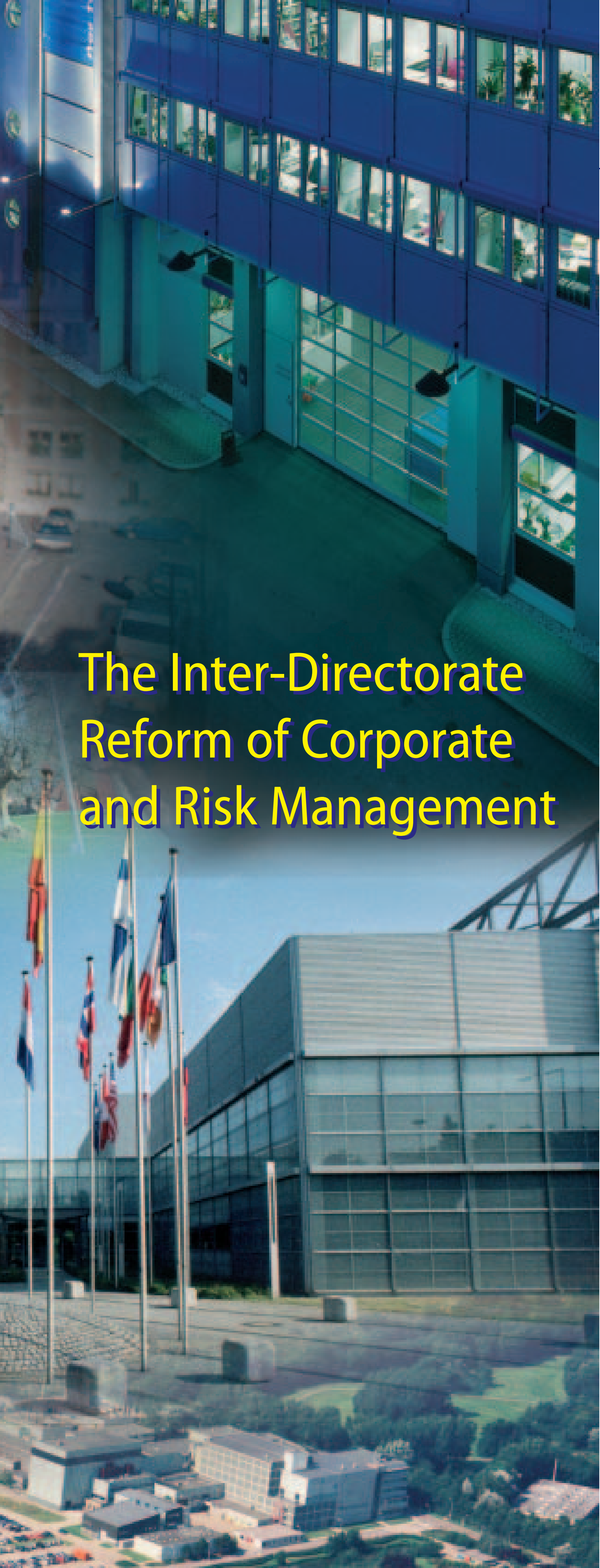
The authors thank the Third Party Mission at ESRIN for their contributions.

More information on Proba-1 and the industrial participation can be found at:
http://www.esa.int/proba
http://earth.esa.int/missions/thirdpartymission/proba

Strengthening the Management of ESA



The Inter-Directorate Reform of Corporate and Risk Management



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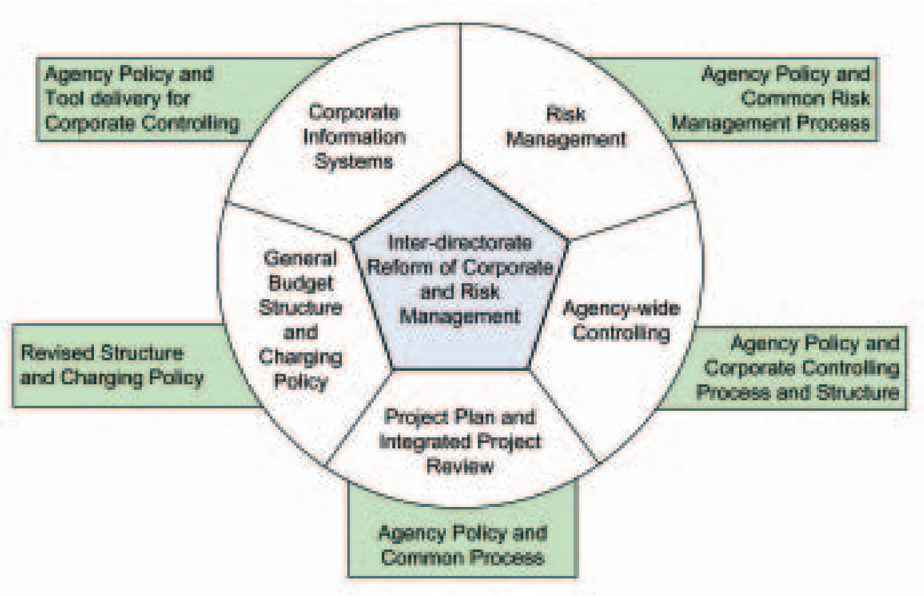
Inter-Directorate Reform Team, Paris, France; Frascati, Italy; Noordwijk, The Netherlands; Darmstadt, Germany

ESA has undertaken the Inter-Directorate Reform of Corporate and Risk Management to strengthen the Agency's internal operations. The reform was completed at the end of 2006, encompassing five dedicated projects on Risk Management, Agency-Wide Controlling System, Project Plan and Integrated Project Review, General Budget Structure and Charging Policy, and Corporate Information Systems. It has contributed to improved management of the Agency's internal operations by engaging all internal stakeholders in a common objective, introducing improvements to planning and management methods, elaborating consolidated information structures and tools, contributing to enhanced transparency and accountability, and by providing qualified new policies, processes and tools.

Why Do We Need to Change?

All organisations, whatever their activities, markets, products or services, must adapt to a rapidly changing environment in order to maintain their ability to operate and compete successfully.

By any standards, ESA is rated worldwide as a success. Its challenging environment requires that it must



The Inter-Directorate Reform projects, objectives and main results: the five projects performed during 2006 with objectives both in the corporate and Directorate domains

constantly strive to keep pace with trends and evolutions within Europe and internationally, adapting to the demands that these place upon it. It must respond quickly and effectively to the demands from the ESA Council of Ministers, from Member-State Delegations, from industry and from its various partners. It has to stay at the forefront of modern management practice, while taking care to balance this with the realities of the political context in which it has to operate.

The Ministerial Council in Berlin in December 2005 passed a Resolution calling on the Agency to strengthen further the management of its internal operations. In addition, the targets set by the Director General in his Agenda 2007 and Agenda 2011, the requirements of the various delegate-bodies of the Agency, as well as other internal and external factors, will continue to have an impact on ESA activities.

These requirements call for an appropriate and timely response within the Agency in order to reinforce its role and efficiency. The Inter-Directorate Reform takes up the need to improve the internal corporate and Directorate management through dedicated projects.

The Five Inter-Directorate Reform Projects

The Inter-Directorate Reform Projects are aiming to improve the internal working methods, and so touch all of the Agency's nine Directorates. The Director of Reforms (D/REF) was mandated by Council and the Director General to lead these projects, involving all the implicated partners in an agreed way and reporting regularly to the ESA Director's Committee. He has led, together with his project managers, each project up to full qualification of a new or revised policy and process, and has then handed it over to the relevant Directorates for implementation.

Objectives, Content and Results

Risk Management

Risk management plays an important role in the management of Agency projects and in managing ESA as a whole. As critical as it is to projects to ensure their delivery, it is for the Agency to demonstrate its capabilities and preparedness for setting up and pursuing its objectives. The fact that ESA has been able to deliver successful projects in an environment dominated by uncertainties is clear evidence that project managers are managing risks. The weakness in the current risk-management practices is the multitude of different approaches.

The objective of the project was therefore to consolidate a framework for a coherent and effective Agency-wide risk-management policy and process, enhancing existing practices and providing for meaningful risk reporting at Directorate and corporate level in support of project management and informed decision-making.

In order to achieve these objectives, the project reviewed existing risk-management practices, which provide the basis for a common process framework. The major result from the project is the elaboration of an updated Agency risk-management policy accompanied by a detailed process description for practical risk management for projects and activities.

The updated policy and the newly

The risk management cycle and responsibilities

The Multi-Year Plan for the Agency-Wide Controlling System

established process aim to support the coherent flow of critical information provided and required by the various management layers, while highlighting the role and responsibilities of the managers to achieve their objectives. The other significant improvement has been made to the Agency-level risk management. The risk information is consolidated at Agency level and supports the decision-making, both for strategic 'executive risks' and those related to projects or activities that concern ESA as a whole.

As a result, the Agency's risk-management capability and awareness are expected to benefit from these improvements, with the implementation by managers of the revised policy and the new and coherent process in their daily tasks throughout the Agency.

Agency-Wide Controlling System

In view of the lack of a thorough corporate information and controlling concept, the Director General decided to establish an Agency-Wide Controlling System (AWCS). The objective is to enhance the Agency's capacity for forecasting and planning expenditures and achieving better cost-control at Directorate and corporate levels. This system comprises controlling functions at the corporate level and in all business units, that is, in all Directorates. This federated approach to control is compatible with the present overall organisation of ESA and supports the Director General and his Directors in their executive-level decision-making.

In order to ensure an efficient implementation of the AWCS, the new Corporate Controlling Division is charged with enhancing and harmonising the controlling procedures and processes of the Agency, with the objective of establishing and applying a common set of standards throughout ESA. This Division is intensively cooperating with the also-new Business Unit Controllers in programme and support Directorates.

The major task of the project was to define and implement a system for integrated planning, monitoring and reporting of the progress, financial commitments and expenditures, workforce, schedule, risks and geographical return of all Agency activities.

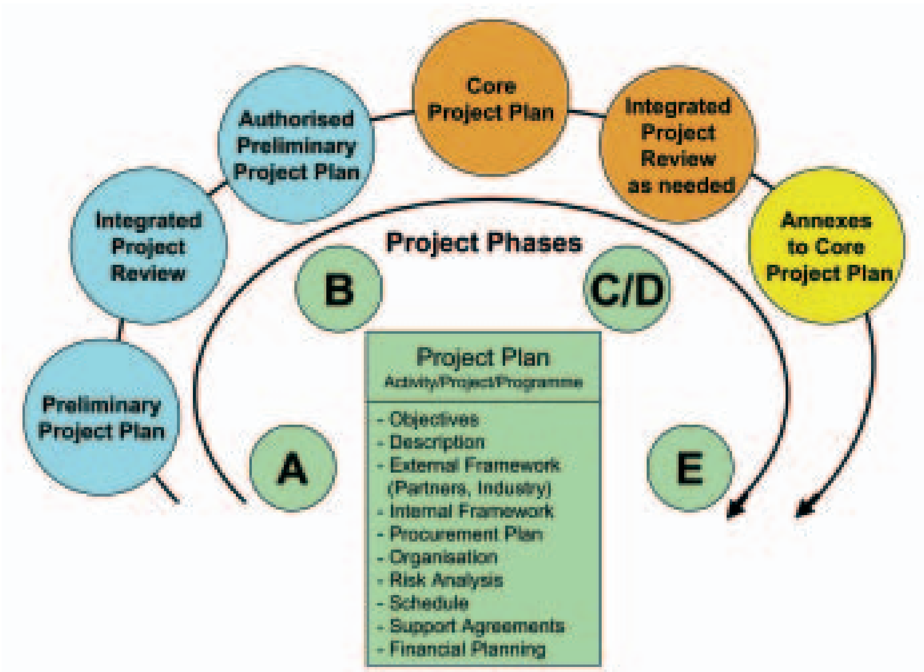
The reform project encompassed the following detailed activities:

– the definition of an overall approach, uniform methods and procedures for establishing plans, forecasting, monitoring and reporting;
– the development of common cost-management methods and procedures;
– the selection and implementation of enhancements and the deployment of appropriate information-technology tools;
– the validation of overall processes, procedures and tools;
– the harmonisation of reporting requirements of Delegations.

Building upon and enhancing and harmonising the existing methods and procedures for control, as applied in the Agency, the reform project ensured that there is continuity of operations and that ESA fully exploits its existing knowhow in this field. The AWCS project worked closely with the Project Plan and Integrated Project Review project, and established a planning tool that is essential for corporate planning and monitoring.

As a result of this project we can consider the following elements:

– an Agency-wide controlling organisation with a Corporate Controller and Business Unit Controllers in all Directorates is operational.
– a regular In-Year Reporting system with monthly reports to the Director General and the Directors Committee has been implemented. It reports on the financial status, workforce, major achievements and issues, geographical return, schedule and risks per business unit, provides overall Agency status and proposes internal management actions and decisions.
– a common database, the Multi-Year Plan, has been established, incorporating short-, medium- and long-term data such as financial commitments and expenditures, workforce, schedule, risks and geographical return of all Agency activities.



The Project Plan and Integrated Project Review cycle

This corporate tool is already fully supporting the In-Year reports and will be continuously improved to be used as the corporate database for the Long Term Plan (LTP), the Quarterly Report to Council (QRC), the Budget Planning and other reporting elements using this common base.

Project Plan and Integrated Project Review

The overall objective of the Project Plan and Integrated Project Review (IPRev) project was to support the coherent definition, planning, implementation, review and follow-up of Agency programmes, projects and other major activities.

To achieve this objective, the project defined the policy and process for the elaboration of Project Plans and for the preparation and conduct of IPRevs, and determined requirements for the configuration control of Project Plans and their data consolidation at the overall Agency level. This included the selection of an associated information system tool. The overall Project Plan and IPRev process was validated through the development of a set of priority Project Plans decided by the Director General, and the conduct of the associated IPRevs.

Project Plan

The Project Plan is a new internal standard tool that defines an ESA project through three major elements:

– the project description, encompassing the project objectives, scope, external and internal framework, the procurement and phasing plan, the project organisation, the risk assessment and the master schedule and key milestones.
– the support agreements, addressing internal support (e.g. technical, operational, procurement) and the associated manpower deployment.
– the financial planning, covering commitment and expenditure plans and geographical return targets.

There are three types of plans, which evolve in scope and granularity over a project's lifetime. A Preliminary Project Plan is elaborated at the end of Phase-A, before preparing a Programme Proposal to ESA Member States. It defines the global project objectives, parameters and risks. A Core Project Plan is elaborated before entering Phase-C/D/E and provides the detailed project planning elements. Periodic Detailed Annexes are established in Phase-C/D/E to identify any necessary updates to the Core Project Plan.

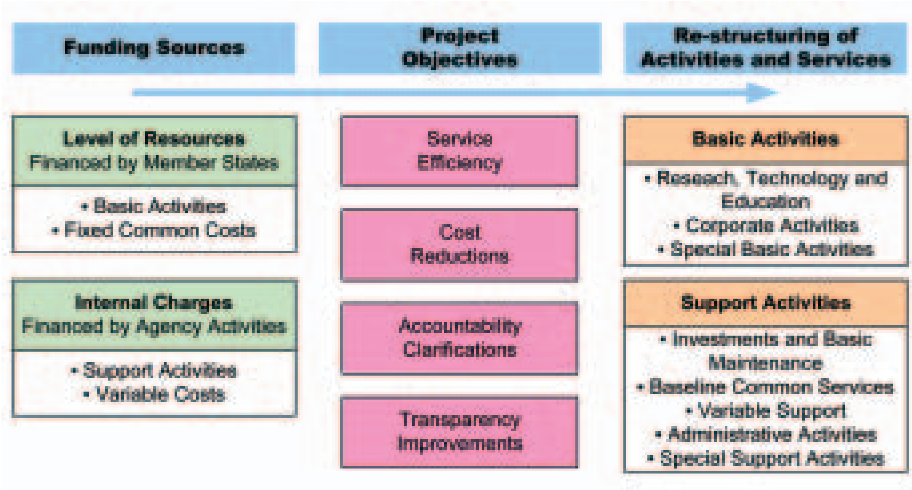
Integrated Project Review

The Integrated Project Review is a versatile optional tool, which the Director General may apply for two major purposes: either to clear Project Plans for authorisation, or to assess the status or risks of projects. The review thus supports ESA top management at the time of major project decisions. IPRevs are chaired by the Director General and attended by the key Directors involved in the project, in particular the support Directorates. An independent assessment by a small team of ESA experts from other Directorates can support the IPRev upon request by the Director General. Such an independent assessment is mandatory for all Preliminary Project Plans.

The main result of the project is the fully qualified policy and process for the establishment of Project Plans and Integrated Project Reviews. This policy and process were successfully applied for the definition of 16 Project Plans (GMES Space Component, Alphabus, Alphasat, ExoMars, Artes 11 Small Geo Platform, FLPP-2, Gaia, Soyuz@CSG, ELIPS-2, ESAC, Asbestos Removal, Corporate Controlling, General Budget, Risk Management, Corporate Information Systems, Financial Reform), the conduct of 14 Integrated Project Reviews and the performance of nine independent assessments.

The Project Plan and IPRev will be an essential tool for the preparation of all new proposals prior to the submission of programme proposals to ESA Member States, in particular in view of the Ministerial Council meeting in 2008. It will be an equally important tool for following projects throughout their entire life-spans.

The General Budget



General Budget Structure and Charging Policy

In the past decade, ESA's General Budget has grown considerably and its structure has become more complex, owing in particular to the evolution of the associated charging policy. In 2005, the Director General initiated a thorough internal management investigation to identify potential improvements and simplifications.

The General Budget Structure and Charging Policy reform project is a follow-on activity of a project carried out in 2005, which encompassed the following activities:

– identification within the current corporate and administrative costs of the sustaining activities to be financed by the mandatory contributions (Level of Resources) and of the non-corporate activities to be financed by programmes through the recharging mechanism;
– reinforcement of a more transparent and user-oriented structure and clarification between support and programme Directorates;
– provision of a simple framework for support Directorates to charge costs of services provided to programmes;
– provision of a basis for analytical cost accounting and effective management of costs and charges, through a clearer, user-oriented structure.

The proposed revision of the General Budget structure and its charging policy leads to greater transparency and accountability of the various services and activities performed within this budget. Particular emphasis was put on achieving the following benefits:
– improved definition of end-to-end functions and their cost charging for the various activities and services;
– increased user orientation of administrative and support services.

A final report has been provided in order to use further the results within the Financial Reform.

Particular emphasis has been put on achieving an improved definition of end–to-end functions and their cost charging for the various activities and services, as well as an increased user orientation of administrative and support services.

For this purpose a clear grouping has been established, with 'Basic Activities' to be funded by the Level of Resources and 'Support Activities' to be funded through a charging process. The salient points of the new structure are the creation of a family regrouping all activities relating to: Research, Technology, Education and now including Basic Technical activities and the separation between corporate and administrative cost. The grouping of all corporate investments into a single family including basic maintenance and their related management costs, and the extension of the principles of customer/supplier relationship for a wider range of services and support activities are further essential proposed changes.

For the Charging Policy, the present system has been considered generally sound and it is proposed largely to maintain it. However, some adjustments are proposed to allow a fairer and more equitable implementation, a leaner operating effort and an incentive to optimise service delivery, resulting in cost reductions.

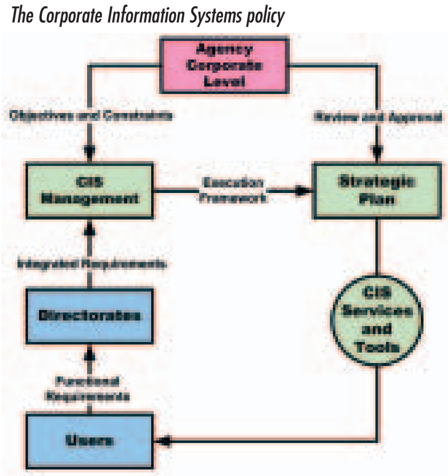
All this should should lead to a more direct costing of services to programmes, a redistribution of indirect recharges and, last but not least, greater responsibility and accountability on the part of service suppliers and, through that, a more user-oriented General Budget and increased cost-effectiveness

Corporate Information Systems

The main objective of the project was to establish the framework for providing adequate corporate information systems support for users throughout ESA.

The Agency's corporate information systems are currently based on several

The Corporate Information Systems policy



application and technological frameworks, providing often incoherent and fragmented data structures. In order to consolidate and solidify these existing systems and their future development, the project aimed to elaborate requirements for a solid and viable information system service at the Agency level. Furthermore, it aimed to deliver according to these principles solutions for the new corporate needs in order to support the new corporate functions instigated by the other reform projects, in particular those of Corporate Controlling and Project Plans, and supporting other needs such as the establishment of financial plans for the ESA Long Term Plan.

In order to achieve the above objectives, a policy was established outlining the guiding principles for developing and maintaining efficient and effective information systems and tools at the corporate level supporting the users Agency-wide. The policy also identifies the roles and responsibilities governing the management of corporate information systems services, and introduces key features, such as the technology and application architecture and common data structures.

Further, the project succeeded in delivering for Corporate Controlling an operational tool using existing data structures and supporting users in all Directorates. The establishment of this common tool engaged all stakeholders into a common dialogue and took benefit of the existing solutions in the Agency. The policy framework established in parallel aims at ensuring that such synergies are pursued in other undertakings in the future.

Acknowledgement

The Inter-Directorate Reform effort was completed by the end of 2006 with proposals for new policies and processes that should improve the Agency's managerial effectiveness. The challenge now is to put them into effect, for the benefit of ESA, its managers and projects, programmes and activities. The generation of all these results was possible only due to the strong support of participants in all Directorates, working together towards common goals, seeking to improve the way we manage our activities and ESA as a whole.

Developing Trends in Public Procurement and Auditing

A Unique Symposium for Space and Defence Procurement

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Space projects are marked by their high technologies and their lengthy development and operations. The procurement process is a critical element that must adapt to a changing industrial landscape and new methods and tools, such as electronic procurement. ESA will host an international symposium in May to bring all the major players together.

Introduction

What is the connection between a launcher and a submarine, an aircraft carrier and a manned spacecraft, or an antitank missile and an Earth observation satellite? At first sight, there seems to be none, their purposes being completely different.

They do have, however, one thing in common. The processes governing their procurement are totally different from those for off-the-shelf goods, owing to two key aspects of their nature: the high technology involved and the long duration of the programmes.

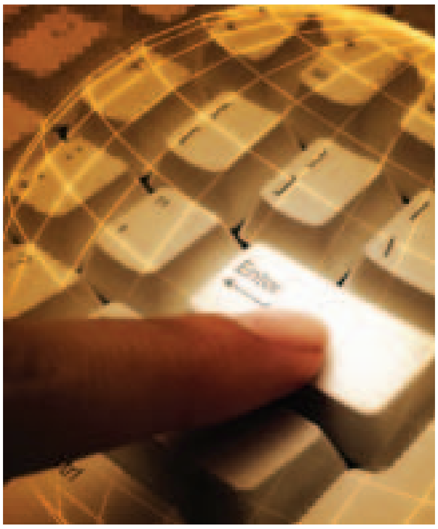
These aspects, often coupled with monopoly or duopoly contractors, and influenced by international and/or domestic industrial policy considerations, significantly determine the procurement path and the price/ cost-auditing methods to be used. In the space and defence domain, these issues are part of the day-to-day decision-making processes for both the public procurement authorities and the supplying industries.

Procurement is often the mandatory channel for a public organisation, whether national or international, to fulfil the mission assigned to it. Procurement tends to be at the centre of an organisation's daily activities, and the efficiency of the process reflects on the overall working of the organisation.

The natural requirement to ensure the most economical use of resources takes on a particular dimension for public procurement, where these resources usually stem exclusively from the taxpayers.

It is therefore important to build processes and practices that satisfy the programme they are serving, while at the same time remaining flexible enough to incorporate new trends throughout the procurement cycle, such as invitations to tender and requests for proposals, evaluation of offers, cost auditing, contract conditions, price type, industrial policy, risk-sharing and risk-management.

A major element of the reform



programmes under way within ESA is to improve procurement, both in terms of internal processes and policies for the contractual relationships with industry.

ESA covers the whole spectrum of procurements: minor-value purchase orders, off-the-shelf procurements, maintenance services, manpower service contracts, technical assistance activities, software procurements (with or without open source codes), research and development contracts, co-funded contracts with industry, major development contracts for ESA satellites, in-orbit infrastructures and launcher development contracts.

All of these are handled by the ESA Procurement Department.

Auditing is directly linked to the process, before, during and after the procurement. It plays a major supporting role by auditing the labour, facility and overhead rates used by industry for its proposals to and contracts with the Agency. Detailed audits are conducted under cost-reimbursement and co-funded contracts.

While the industrial landscape has drastically changed in recent years, with continual mergers and take-overs, the procurement procedures, processes and tools used by the Agency have basically remained the same. Within Agenda 2011, the Director General and his Directors have targeted the evolution of ESA's procurement process and industrial policy for urgent action.

Within the Procurement Department, a dedicated structure will be set up to handle the actions and the associated plan leading to the required improvements.

The ESA Procurement Evolution

The evolution of the procurement process is outlined below:

Small procurements

The vast majority of ESA contracts are for less than €250 000, but their administration by both the Procurement Department and the initiating Directorate demands a disproportionate amount of time for all concerned. The main reason is that these contracts are based on the same procedures as used for large development contracts.

A range of measures has simplified the process, leading to shorter procurement cycles, which also benefits industry. All the changes accommodate the standard checks and balances of the public procurement process. Lessons-learned will studied after the new procedures have been introduced.

E-procurement tools

The main objective for ESA in electronic procurement is to meet the target set by the European Union: to carry out at least 50% of the procurements that have values above the EU's specific threshold for each activity.

To achieve this, the first priority is to focus on the labour-intensive small procurements, following published standards on inter-operability and functional requirements.

Evolution of procurement regulations

The Agency's fundamental texts regulating procurement were drafted at the end of 1970s; only Part II of the General Clauses and Conditions for ESA contracts has been fundamentally revised recently. It is obvious that Europe's space industry has evolved significantly during the same period. It will therefore be reviewed in detail in order to reflect better the regulatory and industrial environment.

Restructuring of industry

The restructuring of European industry into monopolies or duopolies entities has implications for ESA's procurement process. This restructuring affects not only the satellite manufacturing industries but also the satellite operators.

Important questions on strategic industrial capabilities, capacities and skills need to be reviewed carefully, taking due account of the local situations and investments in each of the ESA member states.

Industrial contractual issues

With the maturing of industry capabilities and competences and the increased complexity of ESA programmes, the time is opportune for a deep review of contractual issues governing the relationship between ESA and industry.

For end-to-end procurements, it is essential that the ESA programme requirements are properly understood by industry during a project's Phase-A and -B. It is equally important to ensure that adequate financial envelopes are available for these initial phases, in order to avoid costly development risks during the later Phase-C/D.

The full range of issues will be reviewed in consultation with industry, both with individual companies and Eurospace. This will be followed by a detailed evaluation and decisions by the Agency's Industrial Policy Committee and Council.

Developments in Procurement and Auditing

Most, if not all, of the different topics being pursued are not unique to the ESA environment, but are being reviewed in parallel by other large public procurement entities. The key common denominators are the high technology involved and the lengthy durations of the programmes.

It is predominantly the space and defence sector that is confronted by these specialised procurement and auditing factors, which cannot be controlled by market conditions to a great extent.

The process of studying, reviewing and/or implementing the various new concepts for procurement and auditing cannot be handled by ESA in isolation. It needs to be done in concert with our counterparts in industry, and to accommodate the experiences and developments under way in similar public procurement bodies, notably those in defence.

As a consequence, ESA will host an international symposium from 14 May to 16 May 2007 at ESTEC. The organising committee is finalising a programme that ensures overall coverage of the main topics, with various plenary and parallel sessions. Committee representatives are from the space and defence sector, involved in both awarding contracts and receiving them.

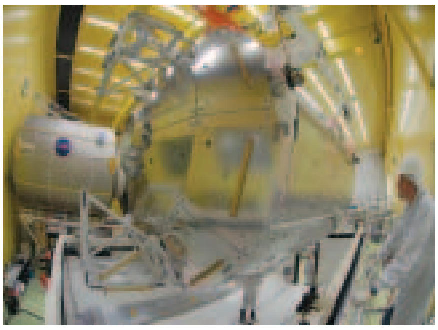
The symposium alternates plenary sessions with keynote addresses and splinter/parallel sessions.

The topics

Bringing the key actors and decision-makers together in this symposium from both sides of the procurement fence will allow for a stimulating and interesting forum. The very essence of procurement is based upon an established partnership of agreed objectives, principles and outputs. Against this background, the main objective of the symposium is to determine whether the lessons learned from past high-technology/long-duration procurements, as seen from both sides, can lead to new ways of doing business together.

Contractual options in high-technology/long-duration procurements

The symposium addresses the impact of the prevailing legal framework, the various types of contract models, contractual tools such as incentive/penalty schemes, variable profit schemes, risk-sharing, price types, earned value schemes, and the elements linked to



performance (monitoring and measurement) and those relating to contract termination.

Procurement authorities and industry
The relationship between procurement authorities and the industrial reality will be addressed. This includes the industrial policy dimension, Intellectual Property Rights, and the effect of the evolving industrial landscape on the procurement process and rules.

Procurement techniques, approaches and tools
The various workshops will address procurement phasing/cycles and competition, such as frame contracting, spiral development and smart procurement. The use of lists and pre-qualification of bidders will also be discussed, as well as the form of dialogue between procurement authorities and (potential) bidders during the tendering process. The increasing role of e-procurement will also be addressed.

The audit process
This topic deals with the operational aspects of the audit process. The presentations will focus on the involvement of public audit authorities in the agreement and acceptance of industrial labour, facilities and overhead rates baselined for industrial offers.

Important aspects of agreeing the industrial rates is the handling of the recovery of self-financed research and development costs and the role of the institutional procurement authorities.

The costs of maintaining industrial capabilities during periods of overcapacity is a recurring issue for the space and defence institutional procurement authorities. The role of the procurement authorities, the planning process and the responsibilities of industry will be addressed during presentations and/or workshops. This will thus also touch upon the practical implications of the changing industrial business bases.

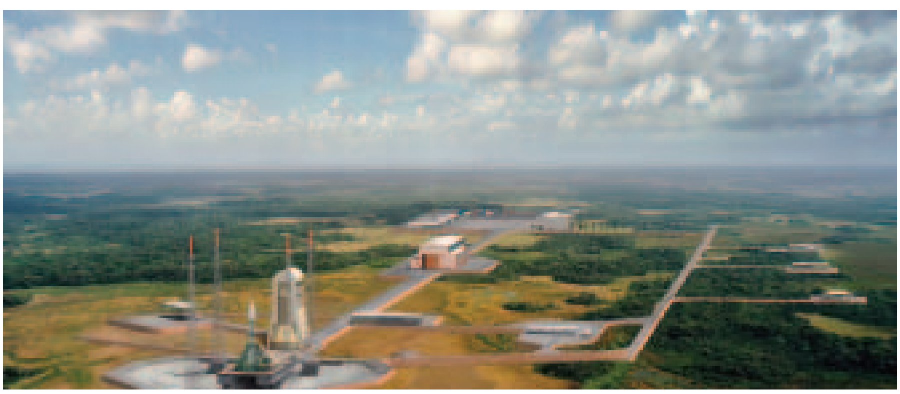
Long-term strategic partnerships between procurement authorities and industry, via multi-year rate agreements, is one of the options being applied.

Audit interfaces
For international procurement organisations, the approach to cooperation with other international or national audit authorities is an essential factor. The symposium will reflect on the different international methodologies and approaches to auditing in the space and defence sectors.

Another important issue will be the basic question of the right approach to auditing competitive and non-competitive procurements.

Different public procurement audit authorities have different approaches for insourcing or outsourcing of the audit activities. Presentations will be made on the advantages and disadvantages of the different approaches, as well as presenting the rationales for the decisions made.

Finally, the role of the procurement auditor within the overall procurement process will be highlighted.



For further information on the symposium, please see
http://www.congrex.nl/07a01/

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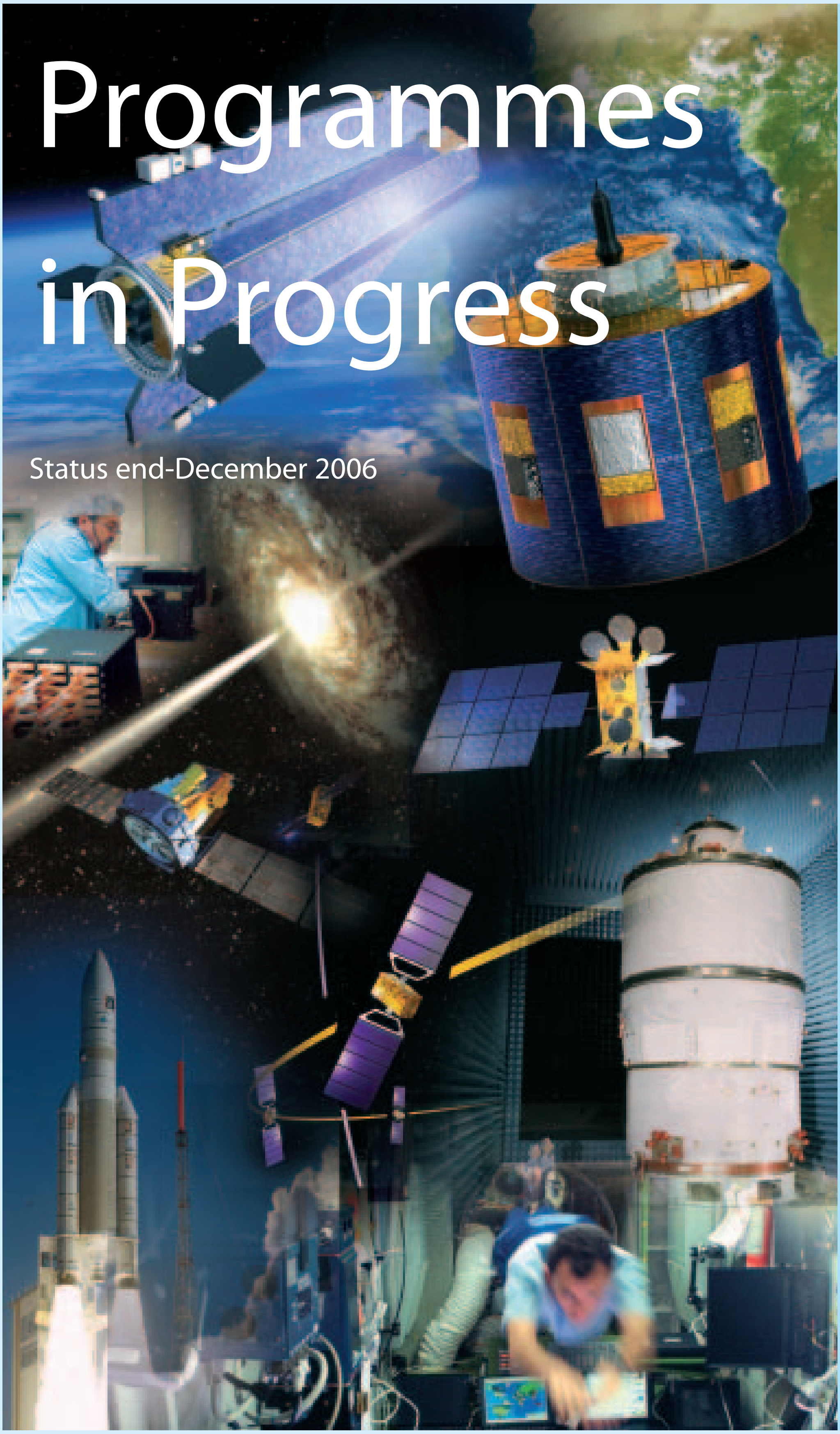
Conclusion
The procurement and auditing process needs to adapt to the changing industrial landscape, the contractual models, new tools and the roles and responsibilities of the contractual partners.

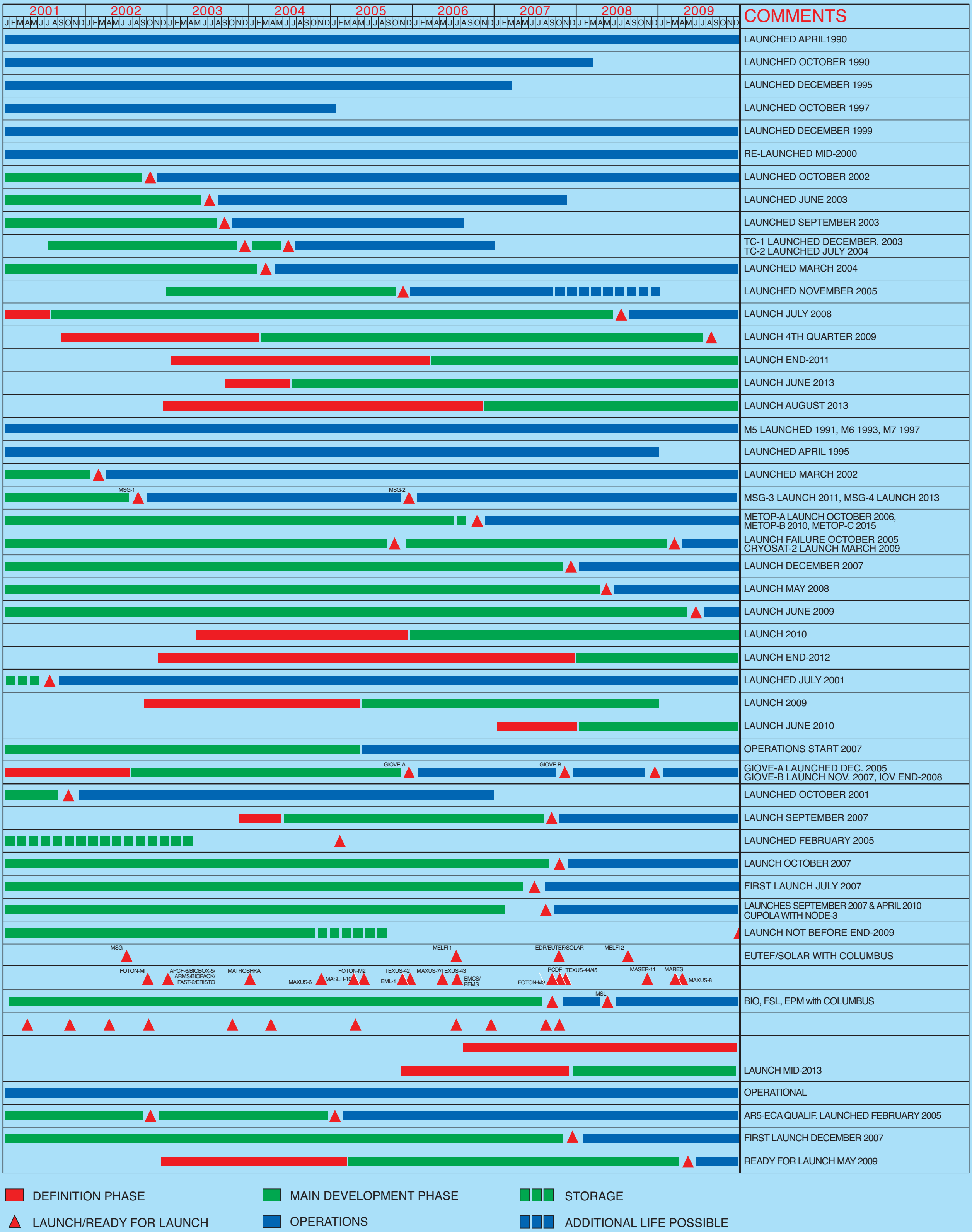
This process of change is under way within ESA, with the approval of the Council and the Industrial Policy Committee. Extensive consultation has begun with the different players, and it is envisaged that the organisation of the international symposium will contribute new ideas, suggestions and experiences.

Programmes in Progress

Status end-December 2006



	PROJECT
SCIENTIFIC PROGRAMME	SPACE TELESCOPE
	ULYSSES
	SOHO
	HUYGENS
	XMM-NEWTON
	CLUSTER
	INTEGRAL
	MARS EXPRESS
	SMART-1
	DOUBLE STAR
	ROSETTA
	VENUS EXPRESS
	HERSCHEL/PLANCK
	LISA PATHFINDER
	GAIA
	JWST
	BEPICOLOMBO
EARTH OBSERVATION PROGRAMME	METEOSAT-5/6/7
	ERS-2
	ENVISAT
	MSG
	METOP
	CRYOSAT
	GOCE
	SMOS
	ADM-AEOLUS
	SWARM
	EARTHCARE
COMMS./NAV. PROGRAMME	ARTEMIS
	ALPHABUS
	SMALL GEO SAT.
	GNSS-1/EGNOS
	GALILEOSAT
TECHNOL. PROG.	PROBA-1
	PROBA-2
	SLOSHSAT
HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME	COLUMBUS
	ATV
	NODE-2 & -3 & CUPOLA
	ERA
	ISS BARTER & UTIL. PREP.
	EMIR/ELIPS
	MFC
	ASTRONAUT FLT.
	AURORA CORE
	EXOMARS
LAUNCHER PROG.	ARIANE-5 DEVELOP.
	ARIANE-5 PLUS
	VEGA
	SOYUZ AT CSG


2001
2002
2003
2004
2005
2006
2007
2008
2009
COMMENTS
LAUNCHED APRIL1990
LAUNCHED OCTOBER 1990
LAUNCHED DECEMBER 1995
LAUNCHED OCTOBER 1997
LAUNCHED DECEMBER 1999
RE-LAUNCHED MID-2000
LAUNCHED OCTOBER 2002
LAUNCHED JUNE 2003
LAUNCHED SEPTEMBER 2003
TC-1 LAUNCHED DECEMBER. 2003
TC-2 LAUNCHED JULY 2004
LAUNCHED MARCH 2004
LAUNCHED NOVEMBER 2005
LAUNCH JULY 2008
LAUNCH 4TH QUARTER 2009
LAUNCH END-2011
LAUNCH JUNE 2013
LAUNCH AUGUST 2013
M5 LAUNCHED 1991, M6 1993, M7 1997
LAUNCHED APRIL 1995
LAUNCHED MARCH 2002
MSG-1
MSG-2
MSG-3 LAUNCH 2011, MSG-4 LAUNCH 2013
METOP-A LAUNCH OCTOBER 2006,
METOP-B 2010, METOP-C 2015
LAUNCH FAILURE OCTOBER 2005
CRYOSAT-2 LAUNCH MARCH 2009
LAUNCH DECEMBER 2007
LAUNCH MAY 2008
LAUNCH JUNE 2009
LAUNCH 2010
LAUNCH END-2012
LAUNCHED JULY 2001
LAUNCH 2009
LAUNCH JUNE 2010
OPERATIONS START 2007
GIOVE-A
GIOVE-B
GIOVE-A LAUNCHED DEC. 2005
GIOVE-B LAUNCH NOV. 2007, IOV END-2008
LAUNCHED OCTOBER 2001
LAUNCH SEPTEMBER 2007
LAUNCHED FEBRUARY 2005
LAUNCH OCTOBER 2007
FIRST LAUNCH JULY 2007
LAUNCHES SEPTEMBER 2007 & APRIL 2010
CUPOLA WITH NODE-3
LAUNCH NOT BEFORE END-2009
MSG
MELFI 1
EDR/EUTEF/SOLAR
MELFI 2
EUTEF/SOLAR WITH COLUMBUS
FOTON-MI
APCF-6/BIOBOX-5/
ARMS/BIOPACK/
FAST-2/ERISTO
MATROSHKA
MAXUS-6
FOTON-M2
MASER-10
TEXUS-42
EML-1
MAXUS-7/TEXUS-43
EMCS/
PEMS
FOTON-M3
PCDF
TEXUS-44/45
MASER-11
MARES
MAXUS-8
MSL
BIO, FSL, EPM with COLUMBUS
LAUNCH MID-2013
OPERATIONAL
AR5-ECA QUALIF. LAUNCHED FEBRUARY 2005
FIRST LAUNCH DECEMBER 2007
READY FOR LAUNCH MAY 2009
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
STORAGE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE

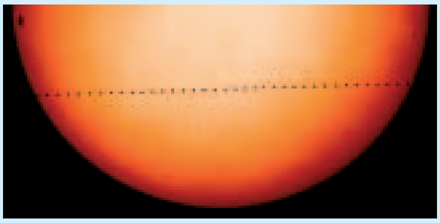
Ulysses

On 17 November 2006 Ulysses reached 70ºS solar latitude, marking the start of the third South Polar Pass. Preparations for the next nutation season, predicted to start in February 2007 and last for approximately 12 months, continued. During this period, the motion of the spinning spacecraft is disturbed by non-symmetric heating of the axial boom. Activities included scheduling and testing in connection with the planned use of ESA's Kourou and New Norcia ground stations that will be employed to fill gaps in coverage arising from incomplete spacecraft visibility from NASA's Canberra Deep Space Network complex. A joint ESA/NASA Nutation Readiness Review was held in JPL on 24 January. The subsystems and science instruments remain in good health.

At the beginning of November, more than 80 scientists from Europe and the US gathered in Oxnard, CA, to pore over the latest results from the Heliospheric Network. The Network is the collective name for the international fleet of spacecraft studying the Sun and heliosphere, of which Ulysses is a key member. The four themes of the Workshop were 'The Outer Heliosphere and Interstellar Connection', 'Solar Wind Transients', 'Energetic Particles' and 'Solar Cycle Variations'. With its comprehensive dataset already covering almost a full 22-year magnetic cycle of the Sun, Ulysses is playing a central role in all of these areas.

SOHO

On 8 November 2006, Mercury passed directly between the Sun and Earth. The innermost planet was seen not as a bright point in the sky but as a tiny black dot, silhouetted against the brilliant surface of the Sun. In previous centuries, transits (especially of Venus) were used to measure the Sun-Earth absolute distance. Nowadays, they are mostly observed for enjoyment. For the SOHO instrument teams, however, a transit provides a unique opportunity for better characterising their imagers and

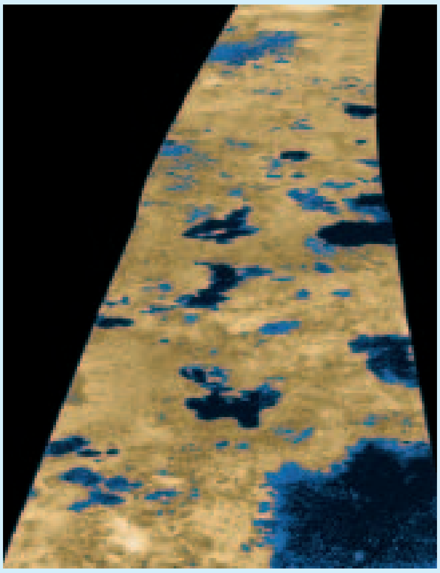


Mercury's path across the solar disc as seen by SOHO/MDI

spectrometers. The data that MDI, CDS and EIT recorded during the transit are being used to characterise better the point spread function of the optics, understand image distortions better and improve stray light models. There was also considerable public interest in this event, with over 2.4 million requests to the SOHO web server and a total download volume of over 215 GByte on that day. The next Mercury transit is on 9 May 2016.

Cassini-Huygens

The nominal 4-year Cassini-Huygens mission ends in June 2008; a 2-year extended orbiter mission is being contemplated. Extended mission scenarios were extensively discussed at the Cassini-Huygens Project Science Group (PSG) held in Pasadena on 16–20 October 2007, and the selection of the 2-year extension trajectory in January 2007 will be on the agenda of the next PSG meeting. NASA's decision on the extended mission is expected in early 2007.



Radar data from the 22 July 2006 flyby of Titan by Cassini provides convincing evidence for large bodies of liquid on the moon. Intensity in this colorised image is proportional to how much radar brightness is returned (more specifically, the logarithm of the radar backscatter cross-section). The colours are not representative of what the human eye would see. The lakes, darker than the surrounding terrain, are emphasised by tinting regions of low backscatter in blue; radar-brighter regions are shown in tan. The strip of radar imagery is foreshortened to simulate an oblique view of the highest latitude region, seen from a point to its west. The image is centred near 80ºN/35ºW and is about 140 km across; the smallest details are about 500 m across. (NASA/JPL/USGS)

On the science side, the confirmation that the northern 'lakes' contain liquid methane (*Nature*, 4 January 2007) provides another piece of the puzzle regarding the complex methane hydrological cycle on Titan.

XMM-Newton

XMM-Newton operations continue smoothly, with the satellite, instruments and ground segment all performing nominally. A total of 594 proposals were received in response to the 6th Announcement of Observing (AO-6) opportunity; the requested time was 6.9 times more than that available. Proposals were received from 425 different principal investigators from 29 different countries. Including co-investigators, a remarkable 1550 individual scientists were involved in the response to AO-6.

An international team of astronomers has found a black hole where few thought they could exist – inside a globular star cluster. These are dense bundles of thousands to millions of old stars. Computer simulations show that a black hole formed in a globular cluster will be rapidly ejected owing to gravitational interactions with the cluster's myriads of stars. Black holes are, by definition, invisible. However, the region around them can become bright, particularly in X-rays, when nearby gas falls onto the black hole and is heated to high temperatures. Using XMM-Newton, the team found a bright variable X-ray source in a globular cluster around galaxy NGC-4472, about 50 million light-years away. The extreme brightness and variability indicates that the source is almost certainly a black hole. But what sort? It could be a black hole with a mass a few times more than our Sun (these are relatively common in our Galaxy) or it could be an intermediate-mass black hole. These are black holes with masses of 100–1000 solar-masses and are intermediate between the million or more solar-mass giants found at the centre of many galaxies and the few stellar-mass black holes resulting from stellar explosions. Such a black hole may have a better chance of surviving in a globular cluster. How such objects form and evolve is a key question for astronomers which these observations may help to answer.

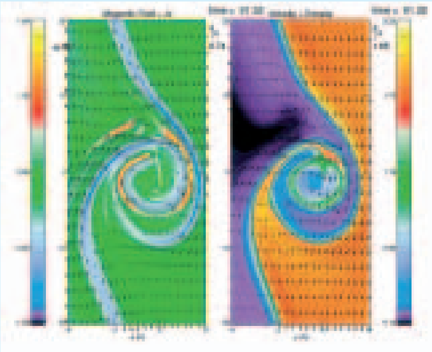
Cluster

The four satellites and instruments are operating nominally. Constellation manoeuvres were executed in November-December 2006 to change the configuration from a 10 000 km tetrahedron to a multi-scale configuration (like a 'flat pyramid'), where the distance between Cluster-3 and Cluster-4 is 500 km and between C1, C2 and C3 is 10 000 km.

JSOC and ESOC operations are following the master science plan. The data return from September to December 2006 was on average 99.1%.

The Cluster Active Archive (CAA) is operating nominally. User access is growing every month and a total of 351 users were registered at the end of December (about a 30% increase from last report). The system was optimised to increase the efficiency of the ingestion process and all data delivered are online. The CAA team is developing new software to provide additional quicklook plots and on-demand plots to the users.

As of end-December 2006, 560 papers were published in the refereed literature and 30 PhDs had been obtained using Cluster and

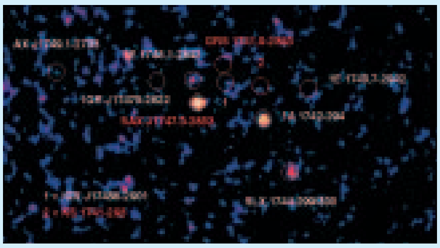


Magnetohydrodynamic simulation result of the Kelvin-Helmholtz wave. The magnetic field (arrows) and the z-component of the current density Jz (colour coded) are plotted on the left panel. The right panel represents the plasma flow (arrows) and the plasma density (colour coded). The black lines are magnetic field lines. Magnetic reconnection is initiated in the centre of the vortex. (N. Nykyri, Imperial College, UK)

Double Star data. N. Nykyri from Imperial College (UK) published a paper in *Annales Geophysicae* using Cluster data, showing that, surprisingly, reconnection can take place within giant vortices produced by Kelvin-Helmlotz instabilities. Previous studies favoured one of these processes to occur, depending on the interplanetary magnetic field, but not both at the same time.

Integral

Integral operations continue smoothly, with the satellite, instruments and ground segment all performing nominally. The 9th annealing of the SPI spectrometer was successful. Targets selected in response to AO-4 are being performed. AO-5 observations will start in August 2007 and will include Key Programme peer review-selected observations of the galactic centre and Cygnus regions and an extragalactic field. A Key Programme is a scientific investigation that requires a significant



Integral's view of the centre of our Galaxy

fraction of the annual observing time in order to achieve its objectives. Now that the AO-5 Key Programme observations are known, potential Integral users will be able to propose for targets in these fields that are not part of the original scientific investigations, using the large fields of view of the Integral instruments.

One of the most interesting regions for Integral is the galactic centre as it contains many bright hard X-ray and gamma-ray sources – at least it normally does! Whenever the galactic centre region is visible, Integral makes frequent and regular observations in order to study this variability. Surprisingly, in April 2006 nearly all the well-known sources around the galactic centre were too faint to be detected. The figure shows an image of the galactic centre with circles indicating the positions of the normally bright sources. Old favourites include the normally bright black hole candidate and the micro-quasar 1E 1740.7-2942.

Mars Express

The spacecraft successfully passed through the Mars solar conjunction, and signals were picked up again. Mission science resumed on 6 November 2006, following a small orbit control manoeuvre required to return to the nominal orbit. This ended a 10-week science blackout period (except for some radio science) induced by the longest eclipses experienced so far, while at aphelion, being followed by the solar conjunction.

During the blackout, all the instruments were in hibernation (except for a very small window during which HRSC and OMEGA were active). After, all payloads began functioning normally again. The only problem related to the pre-heating of OMEGA. With the instrument having been off for an extended time, coupled with the generic reduction of heater power during the blackout, it took much more heating to get the OMEGA interface back to the required temperature. The problem was fixed with a minimal loss of OMEGA science.

The problems in operating the SPICAM instrument, as reported earlier, continue. These affect about 50% of the data, but the instrument can still perform its science observations and it continues to deliver excellent science data.

A Mars Express science team meeting was held at ESTEC 5–7 December 2006. Discussions included the requirements on the evolution of the orbit, and agreed to change the orbit, at the earliest convenience, to a '18/5 resonance'. This predominantly influences the night-day distribution of pericentre passages such that the visible-light instruments will also have (provided a mission extension is approved) excellent observation opportunities. The meeting also discussed the data-return allocation for the first quarter of 2007.

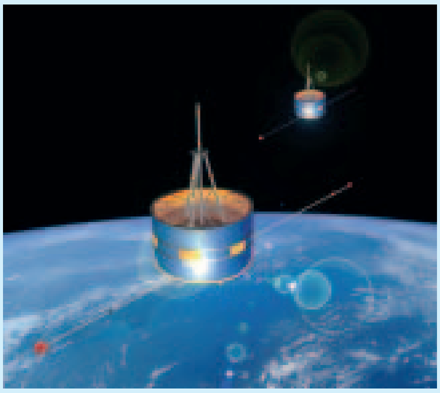
A very successful dedicated session on Mars Express took place at the American Geophysical Union meeting on 11 December 2006.

The Second Mars Express Science Conference will take place in ESTEC on 12–16 November 2007, possibly including a topical workshop on 'The Meaning of Methane on Mars' and dedicated sessions on future Mars Exploration in Europe.

A few major Mars Express papers based on MARSIS results have been submitted for publication, and more are in preparation. One was published in *Nature* on 14 December 2006 and describes the impact of the fact that MARSIS found evidence that buried impact craters – from about 130–470 km in diameter – are under much of the northern lowlands.

Double Star

The Double Star mission has been extended a second time, from January 2007 up to end-



September 2007. Operations of the equatorial TC-1 satellite will end then with entry into the Earth's atmosphere; it will have operated more than 2 years beyond its nominal lifetime of 1.5 years.

The two satellites and their instruments are operating nominally. TC-1 successfully passed the long eclipse season in November 2006.

The European Payload Operation System (EPOS) coordinates the operations for the seven European instruments and is running smoothly. Data are acquired using the VILSPA-2 ground station and the rate has reduced to 2–2.5 h per day because TC-2's apogee is now in the southern hemisphere.

A study on substorm generation mechanisms was published in *Geophysical Research Letters* by Takada et al. from IWF (Austria) using Double Star and Cluster data. It examined the bursty bulk flow (BBF) events observed at Cluster and magnetic dipolarisation observed at Double Star. It showed that 33% of dipolarisations are associated with BBFs. This suggests that BBFs dissipate over a limited range, around 4–8 Earth-radii, and that the magnetotail topology is a key element in the dissipation. Such studies help to further the understanding of the generation and development of magnetospheric substorms.

Rosetta

Rosetta is cruising towards Mars, which it will pass at an altitude of 250 km at 01:57 UT on 25 February 2007. This is one of the mission-critical operations, requiring intense preparations, because the spacecraft has to achieve the proper trajectory for the subsequent Earth-gravity assist in November 2007. Frequent tracking passes for precise orbit determination are carried out, including the use of the 'Delta-DOR' technique, based on radio signal interferometry using two ground stations in parallel. This technique is being used both with NASA Deep Space Network stations and with the ESA Deep Space Antennas at New Norcia and Cebreros. At ESOC, the special spacecraft configurations and operations timeline around Mars closest approach have been defined and validated using the spacecraft simulator and the Rosetta Engineering Model. A simulations campaign, required to train all the mission controllers in the execution of all nominal and contingency operations for this critical phase will be performed in January-February 2007. The Rosetta Science Operations Team in close collaboration with the Experiment Teams and the Mission Control Team at ESOC prepared the science operations sequences for the Mars flyby, which will include a Mars observation campaign and a joint observation campaign of Jupiter with NASA's New Horizon Mission to Pluto, which will perform its Jupiter-gravity assist when Rosetta is close to Mars.

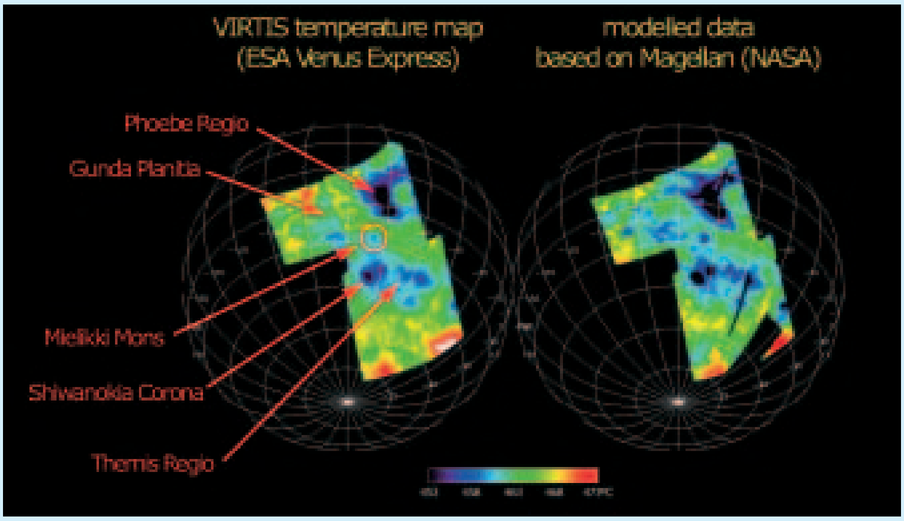
After the periodic checkout of the Attitude and Orbit Control Subsystem in October 2006, a small (10 cm/s) trajectory correction was executed on 13 November, to improve the targeting of the Mars swingby. The payload was inactive until 22 November, when the first payload active checkout campaign of the mission began. This consisted of a month of intense payload operations, including activation and checkout of all instruments, pointing and calibration activities. In addition, onboard software maintenance, followed by inflight verification tests, were carried out on several instruments, including OSIRIS, ROSINA, RPC, MIDAS and the Lander Philae. OSIRIS observed Lutetia, Rosetta's second asteroid target, on 3 and 4 January 2007,

With the completion of the payload active checkout on 22 December, the critical period of the Mars approach began. From mid-January 2007, all spacecraft operations will focus on determining and achieving the correct trajectory for the swingby. This will include further trajectory corrections in February if necessary.

Venus Express

The mission is now well into its nominal operational phase and the day-to-day activities have reached a routine level. Nevertheless, the small teams working on science planning in the PI institutes and the science operations centre in ESTEC, as well as the mission operations team in ESOC, are very busy because new onboard activities are carried out eveery day. Several measurements addressing a large number of scientific topics are made daily and these have to be carefully planned to match the different constraints. The available data link and the thermal environment are normally the most constraining restrictions. Between mid-October and early November 2006, Venus passed behind the Sun ('superior conjunction') and all the instruments were switched off for about 3 weeks. The most critical spacecraft parameters could be monitored on a daily basis in spite of the very limited telemetry link.

The spacecraft and the active instruments all work very well and provide a continuous stream of data for the individual science teams. The data acquired so far have addressed topics in all of the seven Science Themes that were defined as part of the scientific objectives of the mission. Among the many interesting results are the crisp VIRTIS images of the south pole double vortex structure and the measurements of the global wind fields at different altitudes and latitudes. Both topics are strongly related to the unexplained atmospheric super-rotation that makes the atmosphere circle the planet in only 4 days, while the rotation rate of the solid planet is as slow as one revolution in 243 days. Another important result is the construction of the first surface temperature maps (see the illustration), relying on usage of the near-IR windows where it is possible to see very deep, and even down to the surface, through the thick and hot carbon dioxide-rich atmosphere.



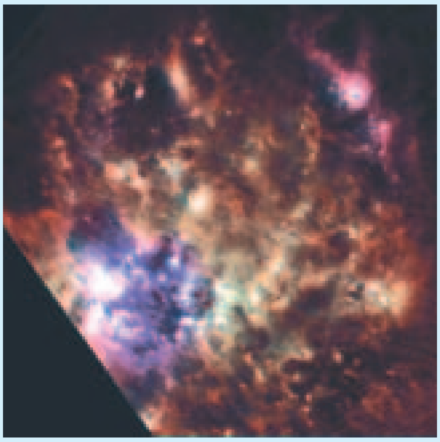
The map above left shows the surface temperature derived from several VIRTIS measurements during orbit 122 on 10 August 2006; the map at right shows a synthetic temperature distribution created from a topographic map based on data from NASA's Magellan orbiter (1990–1994) and assuming a temperature dependence on altitude, with the temperature decreasing linearly with increasing altitude. Comparing such maps can reveal surface hotspots due to, for example, volcanic eruptions or fresh lava fields

Akari (Astro-F)

The Akari IR surveyor, a Japanese mission with ESA participation, has completed its first scan of the entire sky. During this phase, it supplied the broadest wavelength coverage of the Large Magellanic Cloud to date, and provided fascinating new images of this galaxy.

The Large Magellanic Cloud is the closest neighbouring galaxy to the Milky Way. The far-IR view by Akari reveals the distribution of interstellar matter (dust and gas) over the entire galaxy. Dust grains in these interstellar clouds are heated by the light from newborne stars, and they subsequently reradiate this energy as IR. This emission indicates that many stars are currently being formed. The nature of the Large Magellanic Cloud is further revealed by the contrasting distribution of the interstellar matter and the stars. The interstellar matter forms a disc structure, while the stars are located in the 'spindle' in the lower half of the image. This shows that the two components are clearly displaced. Astronomers believe that the observed star formation and the displacement were both triggered by the gravitational force generated by our own Galaxy. These and new data obtained by Akari will unlock the secrets of how both the Large Magellanic Cloud and our own Galaxy formed and evolved to their current states.

ESA's contributions to the mission are working well: regular and efficient ground



This false-colour view of the Large Magellanic Cloud is a composite of images taken by Akari at 60, 90 and 140 micron. Interstellar clouds in which new stars are forming are distributed over the entire galaxy. The bright region at bottom-left is the 'Tarantula Nebula' – a highly productive factory of stars. (JAXA) station coverage from Kiruna (S) and pointing reconstruction software, developed at ESAC. The ESAC team is in close contact with the Open Time users in Europe, to maximise the overall scientific return of the pointed observations programme, despite increasing operational constraints. More than 100 European observations were performed in the period.

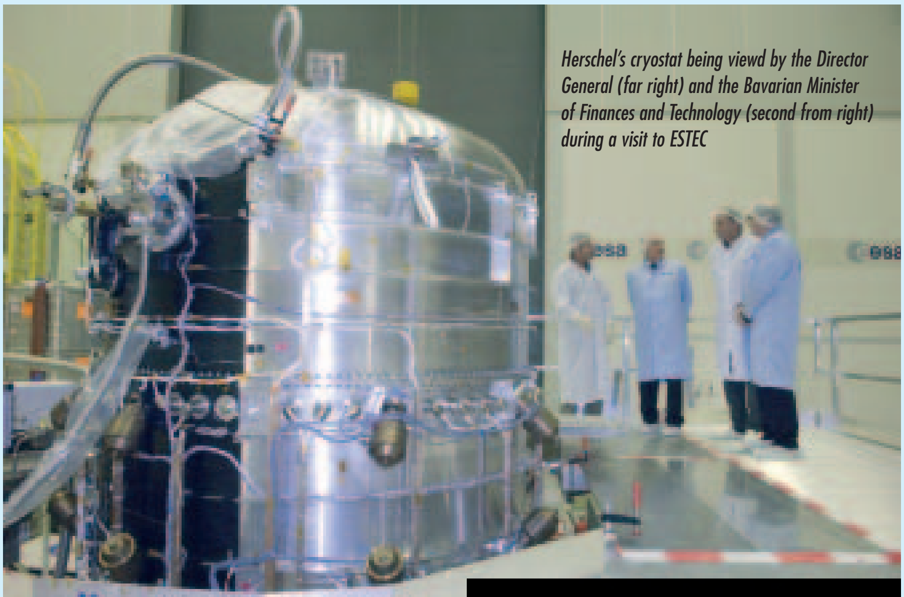
COROT

COROT, the satellite developed by CNES to detect exoplanets and to probe stellar interiors, arrived at Baikonur Cosmodrome on 14 November 2006. The checkout and launch campaign proceeded normally until the filling of Fregat's with hydrazine. Originally planned for 21 December, the launch was delayed owing to a Fregat leak, which turned out to be a false alarm.

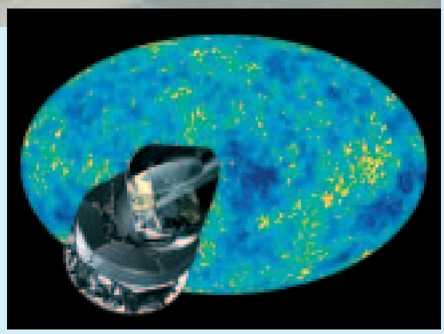
The launch took place 27 December at 14:43:00 UT. The first complete Soyuz 2-1b/Fregat injected COROT into an orbit so near-perfect that the planned inclination correction was cancelled. As a consequence, COROT began operations with a larger propellant reserve than expected, which may be used for a mission extension. The satellite and all the scientific instruments were switched on and tested during the first 7 days in orbit; all systems were found to be nominal. The telescope door was planned to be opened in mid-January, with science operations starting at the beginning of February. ESA's contribution to this mission included the telescope baffle and onboard processing units.

Herschel/Planck

The development activities in industry for Herschel and Planck flight hardware are progressing well, with the delivery of the Service Modules and the completion of the Herschel cryostat qualification testing. The cryogenic qualification test campaign of the Herschel cryostat continued with the verification of the launch autonomy capability of the system, the demonstration of a very low cryostat internal straylight level and measurement of the electromagnetic sensitivity of the SPIRE Engineering Qualification Model focal plane unit. A final qualification step will be the demonstration of the lifetime of the cryostat. This will be measured with near-orbital temperatures in the Large Space Simulator at ESTEC in February 2007. The Herschel Service Module FM completed its electrical, functional and performance testing and was delivered to Astrium for system integration.



Herschel's cryostat being viewd by the Director General (far right) and the Bavarian Minister of Finances and Technology (second from right) during a visit to ESTEC



In 2003, NASA's WMAP satellite provided the first detailed all-sky map of temperature irregularities in the Cosmic Microwave Background. That map is shown behind Planck as a false-colour image of the whole sky, highlighting the structure of the Universe about 300 000 years after the Big Bang. The cosmological information that astronomers look for is buried in the precise shape and amplitude of all the little bumps and wiggles in this map. Planck will enormously improve the sharpness and clarity of all the features in the map and increase the amount of useful cosmological information by around a factor of 15

The Planck spacecraft FM integration is in the final stage. The LFI and HFI instruments were integrated in the Payload Module, with the final stage being the mating of the Payload Module with the Service Module in early 2007. The FM acceptance tests will continue throughout the year.

The Herschel telescope is being stored until its integration with the spacecraft.

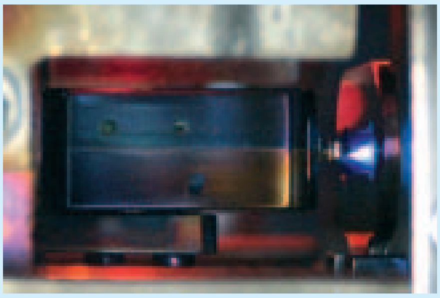
Both Planck instruments have been delivered and are being integrated with the spacecraft. The Herschel instruments are undergoing their final phase.

LISA Pathfinder

All SMART-2/LISA activities are proceeding largely according to schedule. The main system activity in the reporting period was the consolidation of the satellite design and the modification of the LISA Technology Package (LTP) Central Assembly (LCA) accommodation inside the spacecraft. The LCA will now be installed on eight struts; the hyperstatic mounting will guarantee LTP Zerodur structural integrity during launch and the high level of thermal stability needed during the science phase.

In parallel, many satellite subsystems and equipment have undergone their PDRs and

The LISA Technology Package Central Assembly, showing the two inertial sensors, containing the proof masses, the Zerodur optical bench and side slabs supported by eight carbon fibre struts



A caesium ion slit emitter during validation testing for LISA

some CDRs have been conducted. The PDRs for the two European micropropulsion technologies (needle indium thrusters and slit caesium thrusters) took place. Many development tests are being performed to prove the readiness of the technologies for the final selection in the second half of 2007.

Many LTP CDRs have already taken place; good progress is being made despite the many technical challenges. The most critical subsystems are still the inertial sensor vacuum enclosure, the electrostatic suspension front-end electronics and the caging mechanism. The caging mechanism assembly breadboard showed that the design is viable; manufacture of the qualification model is under way. The front-end electronics breadboard tests were performed, and the Engineering Model is now under test.

NASA has made progress on its Disturbance Reduction System (DRS) contribution to LISA Pathfinder: the first colloidal micropropulsion cluster has been assembled and is ready for acceptance. The other cluster is under assembly.

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

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

Microscope

CNES approved extra funding to ONERA for the T-SAGE accelerometer development for Microscope, which proved more complex than originally envisaged. CNES continued system-level work in particular on magnetic field effects that require shielding on the payload.

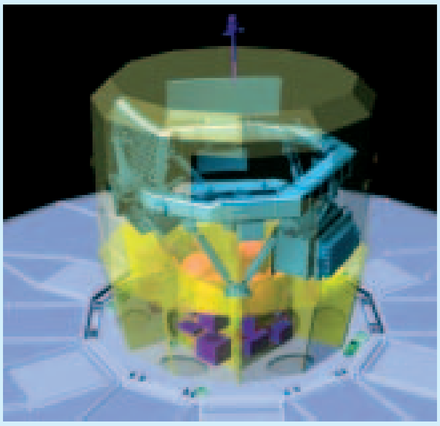
Progress on the Electric Micropropulsion System, to be provided by ESA, is under way within LISA Pathfinder.

The inertial sensor (ONERA) and the Field-Emission Electric Propulsion (FEEP) remain the most critical technologies to qualify. The next ESA/CNES electric propulsion system key-point review now coincides with the LISA Pathfinder Interim Test Review, planned for mid-2007.

Gaia

The competitive selection of subcontractors for the software, flight and ground equipment continues in quite good agreement with the schedule. More than two-thirds of the suppliers for spacecraft equipment have been selected and the remaining part of the competitive bidding phase is going according to plan. The progress of this activity is highly critical for maintaining the schedule and the launch date.

The flight CCD production continued satisfactorily and the handover of the procurement contract from ESA to the Prime Contractor is imminent. Polishing of the technology mirror was successful and the companies to produce and polish the flight mirrors have been selected. The schedule for a launch at the end of 2011 is maintained.

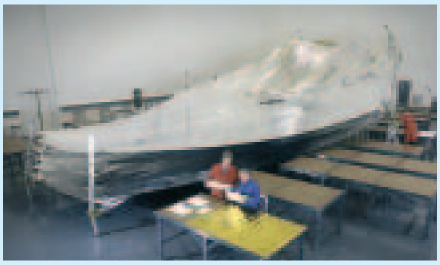


Artist's impression of the Gaia satellite

The Announcement of Opportunity for the Gaia Data Analysis and Processing Centre was released and a response was submitted by a European Consortium of scientific institutes. Their proposal is under evaluation by an ESA team and a recommendation will be submitted to the Agency's advisory structure in early 2007.

JWST

Nine out of the ten specific JWST critical technologies have reached Technology Readiness Level 6, including the lightweight beryllium optics (primary mirror), wave front sensing and control (WFSC), near-IR detectors, mid-IR detectors, micro-shutter assembly, large cryogenic structures (Backplane Stability Test Article, or BSTA), sunshield membrane, cryogenic ASIC and cryogenic heat switch; the tenth technology (MIRI cryocooler) is under testing and should be completed before the end of January. TRL-6 requires a system or subsystem model or prototype demonstration in a relevant environment (ground or space) and is one of the main formal criteria to pass the gate to mission implementation phase (Phase-C).



JWST's Sunshield Pathfinder at NASA

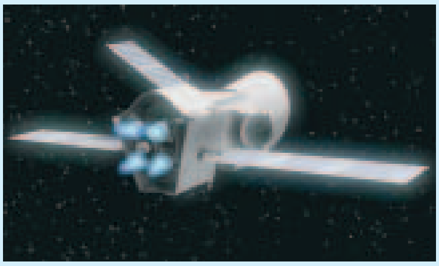
The NIRSpec assemblies' procurement campaign has concluded and the industrial consortium is complete. The detailed design phase of all the SiC ceramic parts were completed and the release of the manufacturing of the remaining optical bench and camera optics ceramic blanks is imminent.

Problems encountered with acoustic and random vibration tests for the micro shutter assembly (MSA) developed by NASA were solved and verified by test. This enabled the MSA to pass the TRL-6 gate

Subassemblies and parts for MIRI's Instrument Verification Model are nearing completion. The system-level integration is due to start early March. The instrument-level CDR kicked off in early December; the Board meeting is planned for mid-February. The finalisation of the detailed design phase for the filter wheel assembly remains the main open engineering issue.

The Definition Phase of the Launch Services began with Arianespace. This will cover activities from now until 3 years before launch, and is meant to assist NASA and JWST Prime Contractor NGST during development of the mission.

BepiColombo



BepiColombo cruising to Mercury using ion propulsion

The proposed core team for the satellite industrial procurement was strengthened in the autumn. The contract proposal was submitted at the end of the year to ESA's Industrial Policy Committee for approval. The BepiColombo cost-at-completion will be submitted to the Scientific Programme Committee (SPC) for approval in February 2007.

The Mercury Polar Orbiter (MPO) Science Working Group meeting was held at ESTEC 29–30 November. The instrument design and prototyping is proceeding according to plan and the interface definition and payload accommodation work is now proceeding on the basis of the selected spacecraft design. The commitment from the Lead Funding Agencies to support the BepiColombo payload was formalised in a Multi-Lateral Agreement between ESA and those agencies. The involved SPC delegates supported the iterations on this document, which will be submitted for final approval to the SPC in February 2007.

The Memorandum of Understanding with JAXA for the Mercury Magnetospheric Orbiter (MMO) was approved by JAXA and the SPC.

Detailed work with the launch provider has begun and the launcher performance has been confirmed.

LISA

The main activity of the Mission Formulation has been completed, with the definition of a reference baseline architecture for the mission. Some recent achievements, though, indicated the possibility of simplifying the architecture of the scientific complement and for this reason it was decided to extend the Mission Formulation contract until mid-2008. This extension will allow finalisation of a system trade-off involving in-field guidance, a technique that allows pointing the laser beam within the telescope field-of-view, in order to compensate for seasonal constellation breathing, as opposed to moving the whole telescope to obtain the correct pointing towards the opposite spacecraft. This activity will be completed by September 2007 and will be followed by the definition of requirements. In parallel, a LISA simulator is being developed to support the requirements definition process.

The LISA spacecraft

The first round of the Mock LISA Data Challenge (MLDC) was completed in December. These challenges are blind tests and serve the dual purpose of fostering the development of LISA data analysis tools and capabilities and of demonstrating the technical readiness achieved by the gravitational-wave community. Ten groups took part to the first round of MLDCs.

Cooperation with NASA is proceeding well; the two projects are operating like a single virtual project, providing good results.

The review for the prioritisation of the NASA Beyond Einstein programme initiated by NASA HQ and performed by the National Research Council is under way.

GOCE

The completion of the gradiometer flight hardware is progressing well. The first two pairs of Accelerometer Sensor Heads (ASHs) have been integrated and aligned. In parallel, the final functional testing of the Gradiometer Proto-Flight Model (PFM) electronic units, namely the three Front-End Electronic Units, the Thermal Control Electronic Unit and the Gradiometer Accelerometer Interface Electronic Unit, was performed. The integration and test of the sixth ASH, which suffered significant delays in the last quarter of 2006, was completed at the beginning of January 2007. All six ASH FMs have therefore been completed – a major milestone for GOCE.

Astrium GmbH pre-delivered the Platform PFM to the prime contractor Alcatel Alenia Space Italy (AAS-I) at the beginning of October 2006. Since then, AAS-I has mechanically and electrically integrated the Gradiometer PFM electronic units and the upgraded Gradiometer Core Structural & Thermal Model on the Platform PFM and started Gradiometer instrument functional testing.

For the ground segment, the Acceptance Review of Version 2 of the Level 1 to Level 2 High Level Processing Facility of the European GOCE Gravity Consortium was held in October 2006; in addition, a bridging phase was kicked-off in November. The On-Site Acceptance Test of the Reference Planning Facility was completed at ESRIN in October. The ground segment overall validation activities were kicked off and are expected to last until summer 2007.

Finally, the third in a series of International GOCE User Workshops was held at ESA-ESRIN 6–8 November 2006. This workshop was timed to take place prior to the closure of the GOCE Data Announcement of Opportunity, released in October 2006. Plenary sessions were designed to provide potential users of GOCE data products with the opportunity to obtain the latest information on the spacecraft and mission performance, as well as details on flight operations, calibration and validation, ground segment operations, data products and user services.

CryoSat-2

During the last quarter of 2006 the build-up to the system-level delta-CDR continued, through a number of lower-level delta-CDRs, and in late November the system-level review itself started. This review process is intended to scrutinise the parts of the satellite design that have changed, for reasons of obsolescence, design improvement or to cope with the redundancy that was introduced into the payload. This process has been very efficient and most of the updated satellite equipment has been released for manufacture, while unchanged equipment had been released already. In many cases, equipment manufacture is now well underway.

The carbon-fibre composite antenna reflectors for SIRAL have been manufactured and an aluminium layer deposited. The thermal stability of these antennas is of crucial importance to the overall mission performance.

In November the solar array test sample was delivered to ESTEC. This consists of a representative composite of solar array substrate, with inserts, solar cells and other electrical hardware. Following preliminary testing, it was placed in a thermal cycling facility where it will undergo a representative set of cycles to simulate the full mission lifetime. This accelerated cycling should be completed by March 2007.

Some production problems have occurred, including the delay in the Star Tracker delivery, as mentioned in the previous *Bulletin*. As expected, that delay has been ameliorated by harmonising deliveries with another ESA project. Overall, the problems have been absorbed within the schedule without affecting the launch date, which remains March 2009. However, there is now negligible scope to absorb any further slippage.

SMOS

During execution of the antenna pattern measurement campaign at the Technical University of Denmark, one antenna showed abnormal behaviour. Detailed analyses revealed a problem with the way the antenna patch was produced and soldered to the support, resulting in the need to reprocure all the antenna patches and solder them with an improved process. All of this rework was completed, including the mounting of the antennas in the LICEF receivers and the mounting of the LICEF receivers in the arms and the hub of the proto-flight model of the payload.

The last remaining subsystem for the payload, the 12 Command and Monitoring Nodes and the Command and Correlator Unit, completed their AIT programme and were delivered to EADS CASA. With that, the payload integration was completed in 2006. Electrical functional tests at payload level began in early January 2007, to be followed by deployment tests of the three arms.

The integration of the SMOS platform, based on the recurrent Proteus bus, was completed at Alcatel Alenia Space (Cannes, F). After the successful Corot launch using the same platform, the communication protocol between payload and platform will be verified on the generic simulator bench with the payload engineering model.

For the ground segment, most of the elements of the Flight Operations Ground Segment were delivered and installed in the respective facilities at Toulouse (Satellite) and ESAC (Payload). The Data Processing Ground Segment is lagging behind but not significantly. Installation work at ESAC (computer and operator rooms, offices, antenna base) is progressing nominally.

ADM-Aeolus

Integration of the Platform FM at Astrium Friedrichshafen (D) continues. Most units have now been integrated.

Thermal/mechanical problems with the laser continue. A Tiger Team is investigating their systematic resolution; results are expected in February. In October 2006, the Aladin Airborne Demonstrator completed its first ground campaign at the Lindenberg site of the German Meteorological Office (DWD). About 100 h of data were obtained in parallel with five other lidars and a series of ground instruments. This will allow confirmation of important instrument design assumptions.

A review of the Ground Segment Design in November 2006 concluded that the design was good for the present stage of the project.

Launch of Aeolus is now expected in June 2009.

Swarm

The definition phase of the satellite and its instruments (Phase-B) is ongoing and will be completed in early 2007 by the Satellite PDR. The PDR of the Absolute Scalar Magnetometer (ASM) and Electrical Field Instruments (EFI) was completed. The procurement activity of the satellite's instrument and equipment is well advanced and will be completed within the early Phase-C of the project.

MetOp

MetOp-A, launched successfully on 19 October 2006 from Baikonur Cosmodrome in Kazakhstan, passed through its early operations phase, under ESOC control, without incident. This phase included the automatic deployment sequence of the solar array, release of the reaction wheels, attitude acquisition and deployments of the payload antennas (ASCAT, LRPT, CRA and GRAS). The orbit was adjusted to reach the final operational orbit. Activities were completed by 22 October, when control of the satellite was passed to Eumetsat.

The satellite In-Orbit Verification phase was then started, with the successive switch-on and check-out of the payload instruments. A delay is required in this process to allow the cooled instruments (IASI, AVHRR, HIRS and GOME) to decontaminate their sensitive optical and thermal surfaces.

By the end of 2006, all instruments had been switched on and first-light data were available. No major anomalies were encountered with the instruments; their performances were as expected. The Eumetsat data-processing ground segment performed well during this phase. One anomaly with the LRPT (Low-Rate Picture Transmission) downlink transmitter was encountered; a failure of Side-A was identified. No definite cause for this failure has been so far established. Operations have continued with the B side. No mission impacts are implied with this anomaly.

Other than this, all anomalies so far have been minor and could be corrected by procedural or software updates.

Following in-orbit verification, the work of the MetOp Single Space Segment team switched to a support role for Eumetsat, who are now starting the Commissioning phase, including calibration/validation, for the overall system. This should be completed around March, and routine operations will then begin.

The project and industrial activities are now transitioning into a standby mode, with MetOp-1 (MetOp-B) and MetOp-3 (MetOp-C) in storage, waiting for the restart in 2009 for the next launch (MetOp-B) in 2010.

MSG

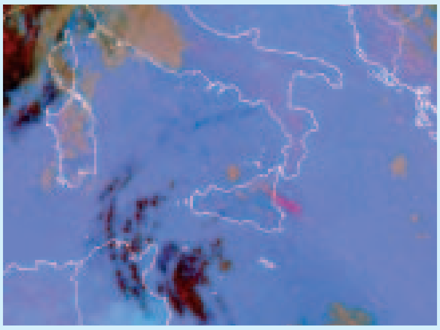
Meteosat-8/MSG-1

The autumn eclipse season ended on 15 October 2006, with fully nominal satellite behaviour. Instrument performance remains of excellent quality.

Meteosat-9/MSG-2

Meteosat-9 also showed fully nominal

Mount Etna's latest eruption was captured on 24 November 2006 by MetOp-A and Meteosat-8. Ash fell on Catania, closing Fontanarossa airport. The satellites witnessed the thin ash cloud and its movement towards the south-east. They also recorded the heat emitted from the new lava flows. Left: Metop-A, AVHRR, 09:30 UT, RGB composite, VIS0.6, VIS0.8, IR11.0; right: Meteosat-8, 12:00 UT, RGB Composite, IR12.0-IR10.8, IR10.8-IR8.7, IR10.8 (Eumetsat)



behaviour at the end of the autumn eclipse season. Winter decontamination took place for the SEVIRI instrument on 11 December. On 22 December, Meteosat-9 celebrated its first year in orbit. It remains the hot backup for Meteosat-8.

MSG-3

It is planned to move MSG-3 from intermediate storage in the Alcatel Alenia Space cleanroom into long-term storage in spring 2007. Launch is projected for early 2011.

MSG-4

MSG-4's Thermal Vacuum Test and Optical Vacuum Tests were successfully completed. MSG-4 is now prepared for its final test in the Compact Antenna Test Range. The Pre-Storage Review is planned for April 2007, after which MSG-4 will be prepared for long-term storage. Launch is planned for no earlier than 2013.

Human Spaceflight, Microgravity & Exploration

Highlights

The highlight of the period was the Celsius mission of Christer Fuglesang, who performed three EVAs during his 13-day mission, and the completion of the very successful long-duration Astrolab mission by Thomas Reiter, who spent 171 days in space. They were both brought back to Earth by Space Shuttle *Discovery* during the night of 22 December. Fuglesang was the first Nordic citizen to fly in space, while Thomas Reiter is now the European record-holder for the longest cumulative time spent in space.

The Heads of the International Space Station partners met at ESA Headquarters on 23 January 2007 to review ISS cooperation. The Heads of Agency expressed their continued appreciation for the outstanding work by the ISS crews and ground personnel to bring the Station to its full productive capacity.

Space Infrastructure Development

The period was characterised by the successful STS-116 assembly flight 12.A1, including the three EVAs conducted by Fuglesang.

For ATV-1 'Jules Verne', a successful thorough review was conducted in front of several NASA officials, including the Administrator and senior officials. The Flight Model testing and integration activities are progressing well. The launch target date is no earlier than July 2007.

The provision of additional ATVs to NASA is under discussion.

With the Columbus module in storage at the Kennedy Space Center (KSC, Florida), the Flight Acceptance Review 1 close-out was completed. The next System Validation Test (SVT2b), involving the EuTEF external payload and the Columbus Control Centre (Col-CC) is being conducted. A delay in Soyuz flights and reassessment of activities before STS-122 may result in a delay of the Columbus launch. The Flight Operations Readiness Review was successful at the beginning of December at Col-CC, and included experts from ESA, NASA, the German Aerospace Agency (DLR), the Japanese space agency (JAXA) and industry. It concluded that ESA and its partners are on track for the launch of Columbus.

The Technical Assessment Board for the Atomic Clock Ensemble in Space (ACES) Space Hydrogen Maser (SHM) was concluded, confirming the SHM design feasibility and readiness to start development of the Engineering and Flight Models.

The Eurobot Wet Model (EWM) was built and tested at Alcatel Alenia Space (AAS-I); technical issues are being addressed and solved.

Utilisation

A series of experiments was performed by Thomas Reiter and Christer Fuglesang (ALTEA-CNSM, Altcriss, Low-Back Pain, Neocytolysis). A NASA experiment (Tropi) was successfully run in the European Modular Cultivation System in the Express Rack in the Destiny module. ESA's GRAVI experiment is in progress with the support of the Norwegian User Support and Operations Centre (USOC).

Thomas Reiter works with the Cognitive Cardiovascular (Cardiocog-2) experiment in Zvezda. Cardiocog-2 is being used to determine the impact of weightlessness on the cardiovascular and respiratory systems and cognitive reactions. The results will help in developing countermeasures to keep crewmembers healthy during long missions

For ISS Increment-15, the utilisation package for Charles Simonyi, who will be launched as a 'space tourist' onboard Soyuz-14 in April 2007, is being prepared following the agreement with Roskosmos.

Discussions with ASI are progressing concerning a joint utilisation plan (including scientific and educational and public outreach) for Paolo Nespoli's mission during STS-120 for further formal submission to NASA.

The USOCs are focusing their efforts on Columbus commissioning and utilisation preparation.

The payload development for Foton-M3, with an expected launch around mid-September 2007, is in its final stage, with the integration of flight payloads scheduled to start in late spring.

Astronauts

The period was dominated by the two highly successful missions carried out by Christer Fuglesang (Celsius) and Thomas Reiter

(Astrolab). In particular, Fuglesang performed three EVAs: two as planned and a third added as a contingency during the mission. The Space Shuttle mission, launched on 9 December, delivered a new ISS Truss segment, Station supplies, equipment and research payloads, such as additional shielding panels to protect the Russian Zvezda Service Module from micrometeoroids and space debris. The crew also undertook a major reconfiguration of the ISS power supply and thermal control system, patching in the new set of solar wings and radiators delivered by Shuttle *Atlantis* in September 2006. This reconfiguration prepares the way for further growth of the ISS, including the arrival of Columbus later this year.

Thomas Reiter took up his duties as ISS Flight Engineer on 4 July 2006, thereby reopening the third permanent crewmember slot, which had had to be discontinued following the Shuttle's grounding after the *Columbia* accident in February 2003. During the Astrolab mission, Reiter carried out numerous operational and maintenance activities for both the US and Russian segments, and operated research facilities in support of international science experiments. He conducted a programme of European experiments in human physiology and psychology, microbiology and plasma physics, and performed technological demonstrations and industrial and educational experiments for universities and schools.

This was the first long-duration mission for an ESA astronaut aboard the ISS, providing invaluable experience in the operations of such missions.

A series of debriefings on the two missions was held at the European Astronaut Centre in Cologne throughout January.

ATV, Columbus and payload training was conducted November – December with several astronauts from ESA, Roskosmos and NASA.

Exploration

Mission-system activities continued under prime contractorship of Alcatel Alenia Space-Italy. The System Requirements Review is scheduled to start mid-February. In the meantime, a Concurrent Design Facility (ESTEC) study was carried out addressing the ExoMars alternative launchers with positive results.

The Rover Vehicle contract was kicked off, while negotiations on the industrial teaming for the main subsystems are under way.

Several Invitations to Tender (ITTs) were released, including the Rover Chassis and Locomotion Design and Breadboarding, the Drill Breadboarding and the Rover Operation Control Centre hardware, software and Mars Simulation Terrain.

The Pasteur Payload Confirmation Review is under way. Science Peer Review meetings were completed and Technical Panel work is being conducted.

Following the selection of the ExoMars Project Manager, Don McCoy, the selections for the second management layer in the ESA project team is under way; the nominations of a Payload and AIV manager, a System Engineering Manager and a Rover Manager are expected in the near future.

The Mars Sample Return Phase-A2 1-year study is under way under the prime contractorship of AAS-I. The study, due to end in autumn 2007, is focusing on refining the mission architecture. A Mission Definition Review is due in the coming months, marking the start of the study's second phase. This will concentrate on the Pre-Phase-A of 'precursor missions'. Two studies of these missions were included in the original contract. Two additional studies are subject to a change-to-contract notice in the original contract; proposals were due in the last week of January (restricted competition procurement).

A series of ITTs was released on various technology aspects, such as the integration of radioisotope heater units, low-temperature sterilisation, and a vision-based hazard avoidance system experiment; proposals were due by the end of February 2007 or early March.

The approved activities (Planetary Protection, Radiation Effects and Radioisotope Power Sources) are being committed. Further ITTs (mainly in Entry, Descent and Soft-Precision Landing and Autonomous Rendezvous) are under preparation.

Phase-B2 of the ARES air-revitalisation system was concluded with a final review. Further ARES activities are being prepared and discussions held with international partners to find a suitable location for an ARES flight experiment aboard the ISS. The SpaceHaven Habitation study was also completed. Future activities in this domain will be the subject of a Request for Quotation.

Significant progress has been made in developing the science-driven scenario. The consolidation of scientific interests and priorities will be completed at a science workshop planned for 14–15 May in Athens. This workshop is organised by an ad-hoc group of the European Science Foundation in close collaboration between D/SCI and D/HME. Work on the industrial/ economic-driven scenario is underway. A milestone will be a workshop organised by the Fraunhofer Institute for Industrial Engineering on 26–27 April in Stuttgart with representatives from the (non-space) applied research and industrial community to assess the broader innovation potential of enabling space exploration capability development and research.

The Edinburgh workshop was held on 8–9 January to review the status of the scenario and architecture work as well as to discuss the drivers for different stakeholder groups and discover the status of the exploration initiatives of European nations and other international partners.

The work on the framework strategy document for space exploration with 14 space agencies worldwide has progressed well. The document is being finalised along with the principles for the international coordination mechanism and the open reference architecture.

In Brief

"This is the dawn of a new era for ESA's manned space missions. We are no longer visitors in orbit; we are now among the proprietors ..."

Astrolab and Celsius: 'All of Europe in One Glance'

On 22 December 2006, Space Shuttle *Discovery* landed at Cape Canaveral, bringing back ESA astronauts Christer Fuglesang and Thomas Reiter, and after completing one of the most complex assembly missions to the International Space Station to date.

The STS-116 mission delivered a new Truss segment to the ISS as well as supplies and equipment. For ESA, it marked the completion of two manned missions: Fuglesang, the first Swede in space, had travelled into orbit on 10 December with *Discovery* to carry out his Celsius mission, and Reiter had just set a new European record for days spent in space, on his Astrolab mission.

Astrolab and Celsius were the first in a series of ESA missions to the Station, as Europe fulfils its obligations as a fully-fledged ISS partner, contributing to maintenance and assembly, with European modules set to be delivered. Astrolab began on 4 July 2006 with the launch of Reiter on the preceding *Discovery* flight. Two days later, he reported for duty aboard the ISS as flight engineer, reopening the third permanent crewmember slot that had been discontinued 38 months earlier after the tragic loss of *Columbia* in February 2003.

Reiter carried out numerous operational and maintenance activities for both the US and Russian segments of the ISS. He also conducted a programme of European experiments in human physiology and psychology, microbiology, plasma physics and dosimetry. He also performed technological demonstrations as well as industrial and educational experiments for universities and schools.

During his stay, Reiter tested a 3-D camera and a high-definition camera, vividly capturing life aboard the Station. In future, such cameras will allow us all to share the unique feel of living and working in space. (A set of 3-D imagery is planned for publication in the May issue of the *Bulletin*.) On 3 August, during his 6-hour spacewalk with NASA astronaut Jeffrey Williams, he installed new equipment in preparation for future assembly work and to mount a number of instruments and experiments outside the Station. Reiter and Williams finished the EVA ahead of schedule and completed several extra tasks, speaking well of European astronauts' physical conditioning and preparation.

On Astrolab, Reiter spent over 171 days in space which, when added to his previous 179 days on Euromir-95, makes him the new European record-holder for the longest cumulative time in space. ESA colleague Jean-Pierre Haigneré held the previous record of 209.5 days.

Fuglesang spent 13 days in space, with a very dense schedule. His role as a Mission Specialist on the NASA crew included securing the Shuttle's docking with the ISS, assisting the retraction of one of the Station's 34 m-long solar wings, transferring equipment between the Shuttle and the ISS, and releasing three microsatellites from the Shuttle's cargo bay after undocking.

His most important role was to make three highly demanding spacewalks with NASA's Robert

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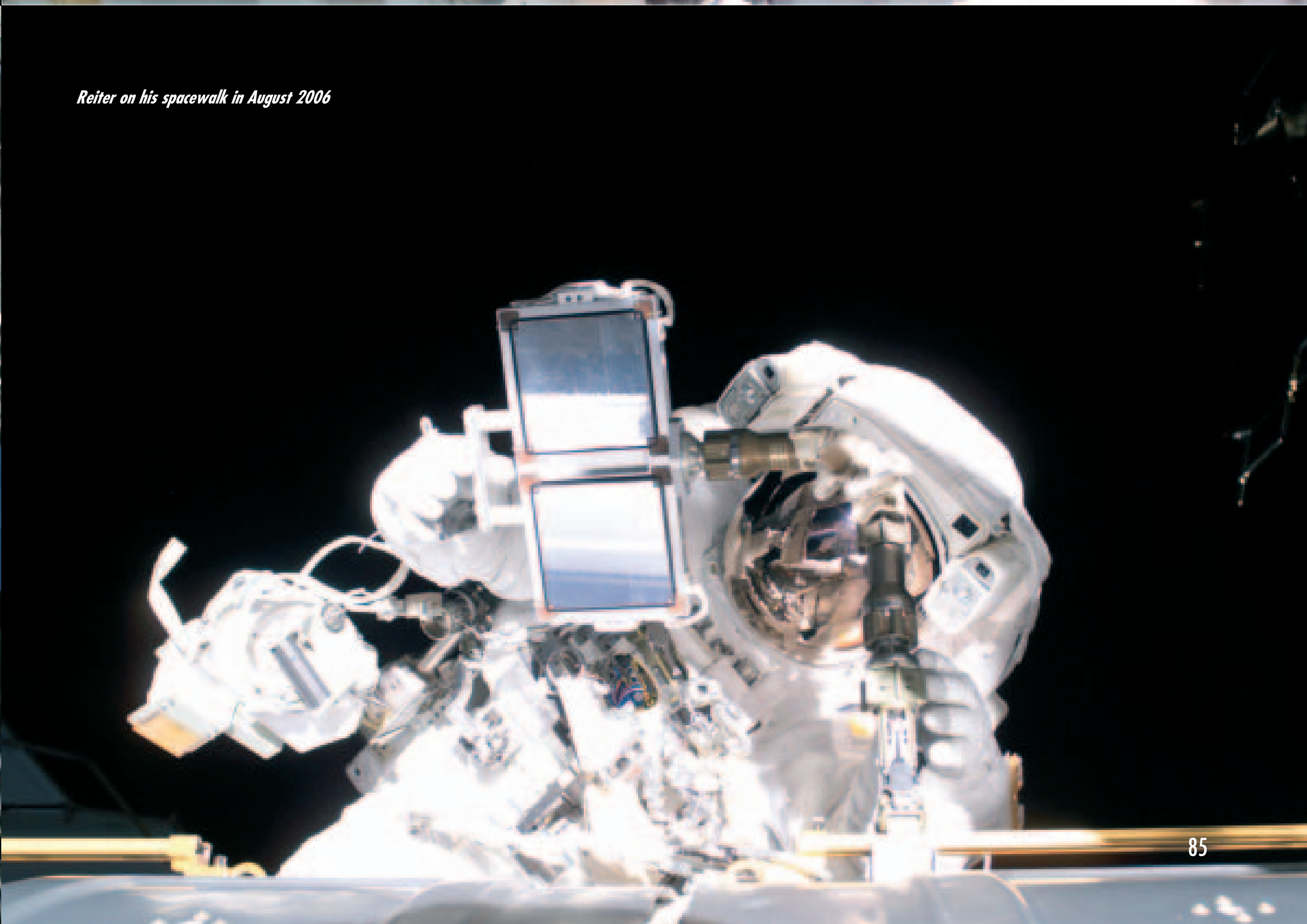
Main image: the ISS viewed by the departing Shuttle. Far left: Thomas Reiter and Christer Fuglesang prepare a meal aboard the Station. Partly in view at right is NASA astronaut Nicholas Patrick. Centre: Fuglesang during his second EVA. Right: Reiter greets Fuglesang on arrival of STS-116 at the Station. (NASA)

Fuglesang replaces a faulty TV camera on the outside of the ISS during his first spacewalk

Reiter works with the Passive Observatories for Experimental Microbial Systems in Micro-g (POEMS) payload in the MELFI cryogenic freezer

Fuglesang returns inside the Quest airlock following his first spacewalk, 12 December



Reiter on his spacewalk in August 2006

Christer at the galley on the middeck of Space Shuttle Discovery

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Curbeam. The first two included attaching a new segment to the Station Truss, rewiring power lines and thermal control loops, and replacing a camera to prepare for the arrival and assembly of a new Truss segment.

The third spacewalk was a bonus. After difficulties in retracting the solar wing remotely, Fuglesang and Curbeam ventured outside and manually freed it.

Reiter and Fuglesang both collected data on the amount of radiation they were exposed to while working inside and outside the ISS. These data will help to assess the radiation risks of future long-duration missions and flights beyond low-Earth orbit.

The Astrolab and Celsius missions also provided an opportunity to broaden the Station's food supply. In late November, Reiter and crewmates Michael Lopez-Alegria and Mikhail Tyurin tested a space meal prepared by famous French chef Alain Ducasse as part of a programme to improve the quality of life on long missions. Later, Fuglesang brought some traditional Swedish food, including elk sausages and toffees, to add a Scandinavian flavour to his stay.

Despite being an experienced astronaut, Reiter was still enthralled by the view of the Earth from space, as well as seeing the many sunrises and sunsets every day. "*We can see parts of continents and are amazed by the variety of colours and forms created by the combination of land, sea and clouds. It's something that leaves you breathless.*"

One of the high points of his 6 months in space was the spacewalk. "*Working outside the Station means clambering around the exterior at an altitude of 400 km and a speed of 27 000 km/h – this is an amazing and indescribable feeling,*" said Reiter.

Fuglesang was impressed by the views of Europe from space. "*I didn't have as much opportunity as I would have liked to – we were very, very busy – but I was particularly pleased the first time I saw Sweden. We also saw the aurora over Sweden – that was beautiful,*" he said. "*One of the best passes was on the very last day. It was nighttime over Europe. We came in over Ireland and England. I could see London. You could clearly see the Netherlands because there was so much light. Then I saw all of the Scandinavian countries, even the southern coast of Norway. I could see clouds covering Oslo lit up. I could see up to the middle of Sweden and Finland. On the opposite side of the gulf, Tallinn and St. Petersburg. It is just like flying over a map. The light tells you where the cities are, and then just the complete darkness over the water – it was a beautiful pass. All of Europe in one glance,*" said Fuglesang.

"*Both Thomas and Christer have demonstrated that Europe now plays a major role in the ISS operations and assembly. This is the dawn of a new era for ESA's manned space missions. We are no longer visitors in orbit; we are now among the proprietors, which means we take on our responsibilities and benefit from the advantages,*" said Daniel Sacotte, ESA's Director for Human Spaceflight, Microgravity & Exploration. "*Celsius marks a further step forward in the development of our international infrastructure in orbit. Thanks to Christer and all the crewmembers of STS-116, the ISS is now ready to receive the new solar wings that will power the new modules, including ESA's own Columbus laboratory and the Automated Transfer Vehicle, two of ESA's highlights for 2007.*"

This year, ESA plans to fly at least two more astronauts to the ISS on assembly missions. It is also negotiating a flight opportunity for a third, with a view to a second European astronaut being assigned a permanent crewmember slot. Approved contributions include the flights of Paolo Nespoli (I) on the STS-120 mission to deliver the Node-2 module this summer, and Hans Schlegel (D) on STS-122 to accompany ESA's Columbus laboratory in the autumn. The long-duration flight of Leopold Eyharts (F) is under discussion with NASA.

esa

The northern lights as seen from STS-116 by Christer Fuglesang

ISS Reviewed by Heads of Agency

The International Space Station partners met at ESA Headquarters on 23 January to review the status of ISS cooperation. The Heads of Agency noted the significant accomplishments in the assembly sequence endorsed at their last meeting in March 2006.

The milestones include reinstating three-person crews; restarting Station assembly; three extremely challenging Shuttle missions; outstanding spacewalks by US, Russian, Canadian and European astronauts; continued exceptional performance of Canadarm2 (including operation by a Canadian astronaut); and the uninterrupted flow of Russian Soyuz and Progress vehicles that provide essential crew and cargo delivery and return.

The ISS Heads of Agency met in Paris to review the project's status. From left: Jean-Jacques Dordain (Director General of ESA), Anatoly Perminov (Director General of Roskosmos), Carole Lacombe (Acting-President, Canadian Space Agency), Michael Griffin (Administrator of NASA) and Keiji Tachikawa (President of JAXA)

These achievements have paved the way for the arrival of Node-2, Columbus and Kibo, as well as Canada's two-armed Dextre manipulator within a year.

The Heads reviewed the status of ISS development, configuration and operations across the partnership. The critical issue of transportation was discussed, including ESA's ATV, Japan's HTV, Russia's Soyuz and Progress, and the US Shuttle, Commercial Orbital Transportation and Crew Exploration Vehicle. The timely introduction of six-person crews and completion of Station assembly were reviewed.

Artemis First

ESA's Artemis satellite achieved a world-first in early December when it established optical laser links with an aircraft. The connection was made across 40 000 km during two aircraft flights at altitudes of 6000 m and 10 000 m. Six 2-way laser links were achieved between a Mystère 20 carrying the LOLA (Liaison Optique Laser Aéroportée) unit and the SILEX payload of Artemis in geostationary orbit.

The tests were made by Astrium SAS (F), the prime contractor for LOLA and SILEX, as part of the airborne laser optical link programme of the DGA (the French defence procurement agency) from its Flight Test Centre at Istres (F). ESA's ground station at Redu (B) managed the SILEX operations.

Optical links can provide high data rates using lightweight, low-power terminals. Earth-observation satellites will particularly benefit from this new technique of transmitting data around the planet.

Solar Storm Disrupts Satellites

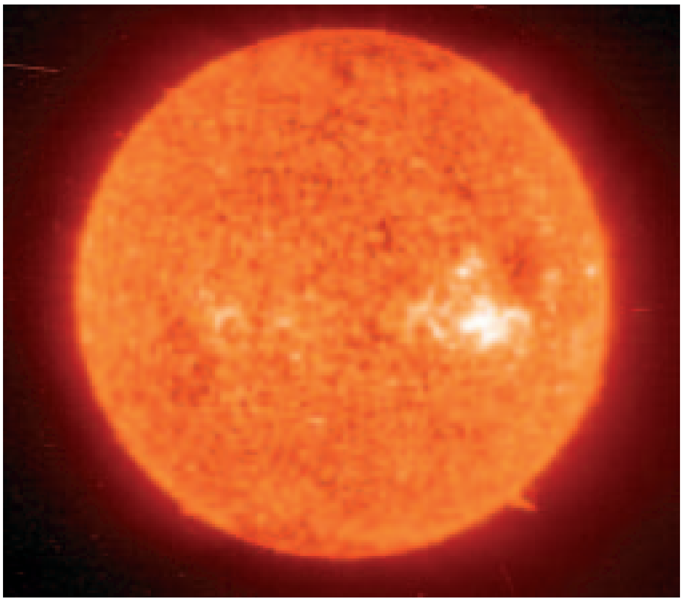
A powerful solar storm in December showered several ESA satellites, including Integral, Cluster and Envisat, with energetic particles, highlighting the need for the Agency's development of space weather forecasting tools.

The ESA/NASA SOHO solar observatory imaged a large flare on 13 December. The LASCO instrument detected a powerful coronal mass ejection (CME; a stream of fast atomic particles) directed towards Earth. The flare also generated X-rays. The CME arrived at Earth on 14 December between 12:00 UT and 18:00 UT, where it produced a strong geomagnetic storm. Another peak came during the night of 14 December, and ground controllers reported varying effects on their satellites.

Cluster's four satellites were among the most affected. "*We saw three anomalies on 13 December. Cluster 1 had a minor instrument anomaly, while Cluster 2 and 4 had onboard systems affected*," said Juergen Volpp, Spacecraft Operations Manager for Cluster at ESOC. "*The Attitude and Orbit Control unit on Cluster 2 lost power and autonomously switched over to its redundant unit, while the High-Power Amplifier on Cluster 4 switched itself off. This was a new occurrence*," he said.

"*Operation of the Envisat Payload Module Computer was autonomously suspended, causing all payload instruments to be switched off. It happened around 19:00 CET, just before the particle peak on the 13th*," said Frank Diekmann, Spacecraft Operations Manager for Envisat.

Controllers working on Integral had perhaps the best sense of the



solar activity: the JEM-X and IBIS instruments are sensitive to X-rays and charged particles, respectively. Controllers had to take action to avoid damage to the sensitive sensors. "*JEM-X automatically switched itself into safe mode twice, and we manually switched IBIS off to avoid over-exposure*," said Michael Schmidt, Spacecraft Operations Manager for Integral.

ESOC's Advanced Mission Concepts and Technologies office is working with UNINOVA (Institute for the Development of New Technologies), an academic institute in Caparica (P), and Deimos Engenharia, a private company, in Lisbon (P), to develop automated tools that can assess and eventually forecast space weather.

SOHO images the solar storm, 13 December 2006. (ESA/NASA)

MIRAVI Site

ESA has created a website that gives access to the most recent images from the world's largest Earth observation satellite, Envisat. The 'MIRAVI' (MERIS Images RApid VIsualisation) site tracks Envisat around the globe, generates images from the raw data collected by Envisat's MERIS instrument and provides them online within 2 hours. MIRAVI is free and requires no registration.

"*ESA designed MIRAVI so that the public could have access to daily views of Earth. Seeing the most recently acquired images of the planet will allow people to witness the magnificent beauty of Earth and become more knowledgeable about the environment*," said ESA's Director of Earth Observation Programmes, Volker Liebig.

To enjoy the service, simply visit *www.esa.int/miravi* and either browse the latest images by clicking on the snapshots or view a specific location by either selecting an area on the world map or entering its geographic coordinates. MIRAVI also provides archived images since May 2006, searchable by date.

COROT on its Way

The unique COROT astronomy satellite is poised to begin detecting planets orbiting other stars and probing the mysteries of stellar interiors. Launched by a Soyuz-Fregat on 27 December 2006 from Baikonur Cosmodrome, COROT is a CNES-led mission with ESA and other European contributions.

COROT will monitor the light variations of some 120 000 stars with its 30 cm-diameter telescope. Since the discovery in 1995 of an exoplanet, more than 200 others have been detected by ground-based observatories. COROT promises to find many more during its 2.5-year mission, expanding our knowledge towards ever-smaller planets. Many are expected to be 'hot Jupiters' but some could be rocky planets little larger than Earth. It would be a breakthrough in the search for other worlds like ours.

COROT can also measure acoustic waves generated deep inside a star that send ripples across its surface, altering its brightness. The exact nature of the ripples reveal the star's mass, age and chemical composition.

ESA's crucial role covered the telescope optics at the heart of the satellite, payload testing and the onboard data processing units. As a result, scientists from ESA's Member States will have access to COROT data.

Further information on COROT is available at *http://www.cnes-tv.com/corot/*

ATV Passes Thermal Testing

The first Automated Transfer Vehicle (ATV) has passed its stringent thermal testing at ESTEC with flying colours. For 21 days, 'Jules Verne' demonstrated its flight software and hardware under the toughest conditions of vacuum, freezing temperatures and burning Sun.

ATV, the most complex spacecraft yet developed in Europe, is due to make its inaugural flight atop an Ariane-5 in July 2007 to resupply the International Space Station. "*Started on 22 November, the test campaign, with different cycles of cold and hot, has been performed according to schedule and the behaviour of this complex spaceship has been generally as expected,*" said Bachisio Dore, the ESA ATV Manager of Assembly Integration & Verification. "*The successful completion of this test campaign represents a major milestone for the ATV programme.*"

ATV 'Jules Verne' in the Large Space Simulator at ESTEC, Noordwijk, The Netherlands

Vega's P80 first-stage motor roared to life for the first time on 30 November 2006 when demonstration motor DM-1 was tested (left) in Kourou, French Guiana. This successful firing will be followed by a second and final test in mid-2007. Right: DM-1 is transferred to the test stand. (ESA/CNES-SOV)

New Director

Meeting on 12 December, the Agency's Council appointed Ludwig Kronthaler, of German nationality, as Director of Resources Management for a 4-year term.

Mr Kronthaler obtained a PhD in Law from the University of Augsburg in 1991. He began his career with the Bavaria Finance Ministry's tax administration. From 1993 to 1997, he was Regierungsdirektor (Bavarian representation) in Bonn and, from 1995, Kanzler of Munich Technical University, responsible in particular for resources, administration and organisation, human resources, controlling, procurement, legal affairs and facility management. Since 2005, Mr Kronthaler has been Federal Judge at the Bundesfinanzhof in Munich (German High Court for tax and customs duty affairs).

Mr Kronthaler will take up his ESA duties in April 2007, succeeding Hans Kappler, who will end his mandate on 31 May 2007.

SME Web Launch

ESA has launched a new website to encourage Small- and Medium-sized Enterprises (SMEs) to become involved in its space programmes. The site at *http://www.esa.int/sme* provides SMEs with up-to-date information on business opportunities, training, achievements and expert support, for example.

The website is an integral part of the Space Intelligence, Engineering and Quality Network (SineQuaNet), the latest initiative from ESA's SME Unit. SineQuaNet was launched in November 2005, in cooperation with DG Research of the European Commission. The network is planned to become a structuring tool for SMEs already operating in, or wishing to enter, the space business, by offering them support in engineering and industrial processes.

Mars Express Reveals Old Mars

With results that the Principal Investigator of the Mars Express MARSIS radar, Giovanni Picardi, describes as unprecedented, Mars is showing that it has an older, craggier face buried beneath its surface. The discoveries were made by MARSIS, the pioneering sounding radar aboard Mars Express, and they provide important new clues about the mysterious geological history of Mars.

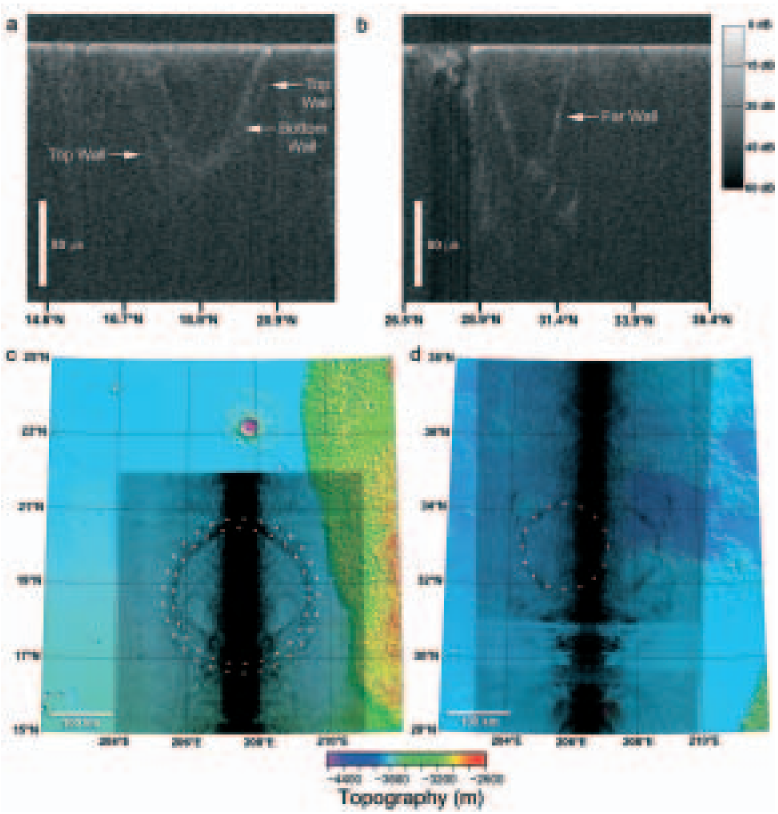
Observations by MARSIS, the first subsurface radar to explore another planet, strongly suggest that ancient impact craters of 130–470 km diameter lie buried beneath the smooth, low plains of the northern hemisphere of Mars.

"*With MARSIS, it's almost like having X-ray vision*," said Thomas Watters of the National Air & Space Museum's Center for Earth and Planetary Studies, Washington DC, USA, and lead author of the results published in the 14 December 2006 issue of *Nature*. "*Besides finding previously unknown impact basins, we've also confirmed that some subtle, roughly circular, topographic depressions in the lowlands are related to impact features.*"

The new findings bring planetary scientists closer to understanding one of the most enduring mysteries about the geologic evolution and history of Mars. In contrast to Earth, Mars shows a striking difference between its northern and southern hemispheres. Almost the entire southern hemisphere has rough, heavily cratered highlands, while most of the northern hemisphere is smoother and lower in elevation.

Since the impacts that cause craters can happen anywhere on a planet, the areas with fewer craters are generally interpreted as younger surfaces where geological processes have erased the impact scars. The surface of Mars' northern plains is young and smooth, covered by vast amounts of volcanic lava and sediment. However, the new MARSIS data indicate that the underlying crust is extremely old.

"*The number of buried impact craters larger than 200 km we have found with MARSIS tells us that the underlying crust in the northern lowlands must be very ancient, dating to the Early Noachian epoch (lasting from the planet's birth to about 4000 million years ago)*," said Jeffrey Plaut, MARSIS Co-Principal Investigator, from the Jet Propulsion Laboratory, California, USA, The Early Noachian was an era in which impact cratering was very intense across the Solar System.



Radargrams from MARSIS in July 2005 reveal ancient buried craters. 210 km (left) and 140 km (right) impact basins were found in Amazonis Planitia. (ESA/ASI/NASA/Univ. of Rome/JPL/Smithsonian)

The results suggest that the northern lowlands crust is as old as the oldest exposed southern highlands, also dated to the Noachian epoch, and that the dichotomy between the hemispheres probably formed very early in the history of Mars.

"*These results are truly unprecedented*," added Giovanni Picardi, MARSIS Principal Investigator, from the University of Rome 'La Sapienza'. "*MARSIS can contribute to understanding the geology of Mars through the analysis of the surface and subsurface morphology. In addition, with a detailed analysis of the instrument's data, we can also obtain valuable indications about the composition of the materials.*"

Asteroid for a Star

Heidi Graf retired as Head of the ESTEC Communications Office at the end of 2006, after 30 years with ESA. An enthusiastic supporter of space activities, Heidi was always looking for new ways to draw the attention of the public to the wonders of astronautics and space science; she was a driving force behind the creation of the Space Expo at Noordwijk (NL).

To mark Heidi's contributions, the International Astronomical Union has named asteroid 10252 after her. This object was discovered on 26 March 1971 by Dutch astronomers C.J. van Houten and I. van Houten-Groeneveld on Palomar Schmidt plates taken by T. Gehrels, and will be now known as 'Heidigraf'. The name was suggested by Prof. Frank Israel of the Leiden Observatory, University of Leiden.

Publications

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

ESA Brochures

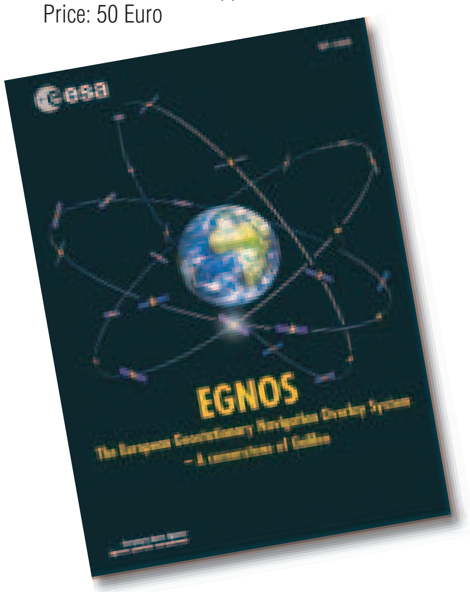
Tania, Europeisk Astronaut (Swedish, October 2006)
P.-E. Paulis/EAC & E. Fuglesang (Translation)
ESA BR-219 (S) // 32 pp
Price: 10 Euro

Die Ersten Galileo Satelliten (German, January 2007)
D. Detain & A.Wilson (Ed.)
ESA BR-251 (D) // 20 pp
Price: 10 Euro

ESA General Studies Programme (GSP) – Time Line (November 2006)
B. Battrick (Ed.)
ESA BR-263 // 10 pp
No Charge

ESA Special Publications

The European Geostationary Navigation Overlay System (EGNOS) – A Cornerstone of Galileo (December 2006)
J. Ventura-Traveset & D. Flament
(Eds. B. Battrick & D. Danesy)
ESA SP-1303 // 574 pp
Price: 50 Euro



The CoRot Mission – Pre-Launch Status – Stellar Seismology and Planet Finding (November 2006)
A. Baglin, M. Fridlund, J. Lochard & L. Conroy (Eds.)
ESA SP-1306 // CD
Price: 60 Euro

Proceedings of the 10th ISMSE / 8th ICPMSE, 19–23 June 2006, Collioure, France (September 2006)
B. Battrick (Ed.)
ESA SP-616 // CD
Price: 50 Euro

Proceedings of SOHO 18/GONG 2006/HELAS I – Beyond the Spherical Sun, 7–11 August 2006, Sheffield, UK (October 2006)
K. Fletcher (Ed.)
ESA SP-624 // CD
Price: 60 Euro

Proceedings of the 4S Symposium: Small Satellites, Systems and Services, 25–29 September 2006, Chia Laguna, Sardinia, Italy (November 2006)
D. Danesy (Ed.)
ESA SP-625 // CD
Price: 60 Euro

Proceedings of the European Conference on Antennas and Propagation – EuCAP 2006, 6–10

November 2006, Nice, France (October 2006)
H. Lacoste & L. Ouwehand (Eds.)
ESA SP-626 // CD
Price: 75 Euro

Proceedings of the 2nd International Workshop on Radiation of High Temperature Gases in Atmospheric Entry, 6–8 September 2006, Rome, Italy (November 2006)
A. Wilson (Ed.)
ESA SP-629 // CD
Price: 30 Euro

Proceedings of the GlobWetland: Looking at Wetlands from Space (November 2006)
H. Lacoste (Ed.)
ESA SP-634 // CD
Price: 30 Euro

Proceedings of the EPS-13 Conference – Beyond Einstein – Physics for the 21st Century, 11–15 July 2005, Switzerland
A.M. Cruise & L. Ouwehand (Eds.)
ESA SP-637 // CD
Price: 30 Euro

ESA Scientific & Technical Memoranda

Evaluation of Cleanliness Test Methods for Spacecraft PCB Assemblies (October 2006)
B. Battrick (Ed.)
ESA STM-275 // 32 pp
Price: 10 Euro

ESA Contractor Reports

Failure Criteria for Non-Metallic Materials – Summary Report (May 2005)
HPS, Germany
ESA CR(P)-4550 // 45 pp
Price: 10 Euro

Thin Film Solar Cell Demonstration Module – Final Report (December 2005)
Dutch Space, The Netherlands
ESA CR(P)-4551 // CD
Price: 25 Euro

Thin Film Solar Cell Demonstration Module – Final Report (November 2005)
HTS, Germany
ESA CR(P)-4552 // CD
Price: 25 Euro

Enhanced Performance Converters and Receivers – Executive Summary (November 2005)
Saab Ericsson Space, Sweden
ESA CR(P)-4553 // CD
Price: 25 Euro

Development of an End-to-End Tool to Simulate the Performance of the European Contribution to the GPM Mission (EGPM-Simulator) – Final Report (December 2005)
CNR/ISAC, Italy
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Price: 25 Euro

L-Band SAR Pre Development – LSAR PDM – Final Report (May 2006)
EADS Astrium, UK
ESA CR(P)-4555 // CD
Price: 25 Euro

High Performance ADC – ARTES Element 5 (GI 6.3) – Final Report (June 2006)
VTT
ESA CR(P)-4556 // CD
Price: 25 Euro

Ceverius – Executive Summary (2006)
Sacet, France
ESA CR(P)-4557 // CD
Price: 25 Euro

M2-ASIC – Executive Summary Report (December 2005)
Austrian Aerospace, Austria
ESA CR(P)-4558 // CD
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Univ. Bremen, Germany
ESA CR(P)-4559 // CD
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Industrialization of Highly Integrated Downconverters for Multimedia Satellites – Final Report (March 2005)
Saab Ericsson Space, Sweden
ESA CR(P)-4560 // CD
Price: 25 Euro

Multimedia Ground Terminals and Equipment – Dynamic MF-TDMA Multi-Carrier Demodulation – Final Report V3 (March 2006)
EMS Technologies Inc., Canada
ESA CR(P)-4561 // CD
Price: 25 Euro

Expanding Market Opportunities with New Functionalities – EMON – Final Report (May 2006)
NERA
ESA CR(P)-4562 // CD
Price: 25 Euro

ARTES-3: Hub Station & Communication Control Products “Network Management System” – Final Report (June 2003)
NEWTEC Cy, Belgium
ESA CR(P)-4563 // 40 pp
Price: 10 Euro

DIONISOS 2 – Two-Way Broadband Interactive Satellite System for Multimedia Services – Final Report (March 2005)
Alcatel Space
ESA CR(P)-4564 // CD
Price: 25 Euro

DVB-RCS Interoperability – Executive Summary (February 2004)
EMS Satellite Networks
ESA CR(P)-4565 // CD
Price: 25 Euro

Protocols and Signalling for Adaptive Fade Mitigation Techniques (FMT) in DVB-RCS Multi-Beam Systems – Executive Report, Final Report & Final Presentation (October 2005)
Audens' Act, Germany
ESA CR(P)-4566 // CD
Price: 25 Euro

ESA ARTES 1 Programme – High Definition Television: Opportunities for Satellite Broadcasting – Final Report (September 2005)
Eutelsat
ESA CR(P)-4567 // CD
Price: 25 Euro

DDSO – Digital Divide: The Satellite Offer Public Deliverables (June 2006)
EADS Astrium, France
ESA CR(P)-4568 // CD
Price: 25 Euro