



# bulletin

SPACE FOR EUROPE

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- (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;
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*ESRIN, Frascati, Italy.*

*Président du Conseil: S. Wittig*

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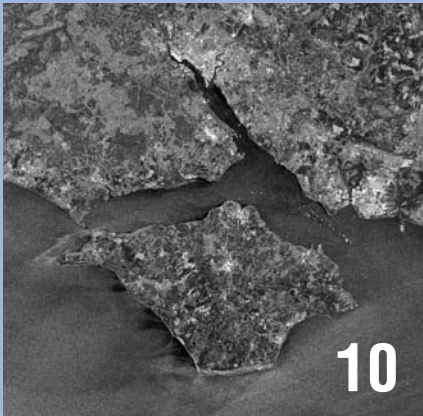
Lorraine Conroy

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This Envisat image features the ice-connected Queen Elizabeth Islands, Baffin Island and the northwestern tip of Greenland – the world's largest island. The scene was captured by Envisat's Medium Resolution Imaging Spectrometer (MERIS) on 2 July 2007 at a resolution of 300 m. (ESA)



### **Sentinel-1**

Radar Imaging for GMES Land and Sea Services



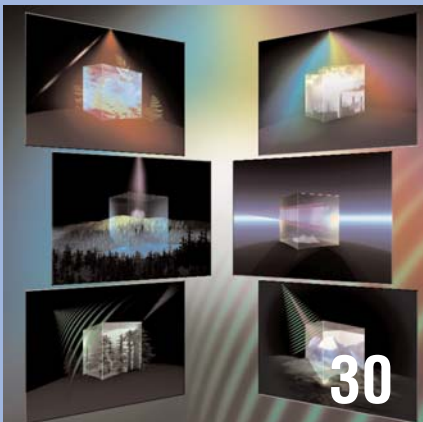
### **Sentinel-2**

High-Resolution Imaging for GMES Operational Services



### **Sentinel-3**

Ocean and Medium-Resolution Imaging for GMES Operational Services



### **A New Earth Explorer**

The Third Cycle of Core Earth Explorers



### **SMART-1 Impacts the Moon**

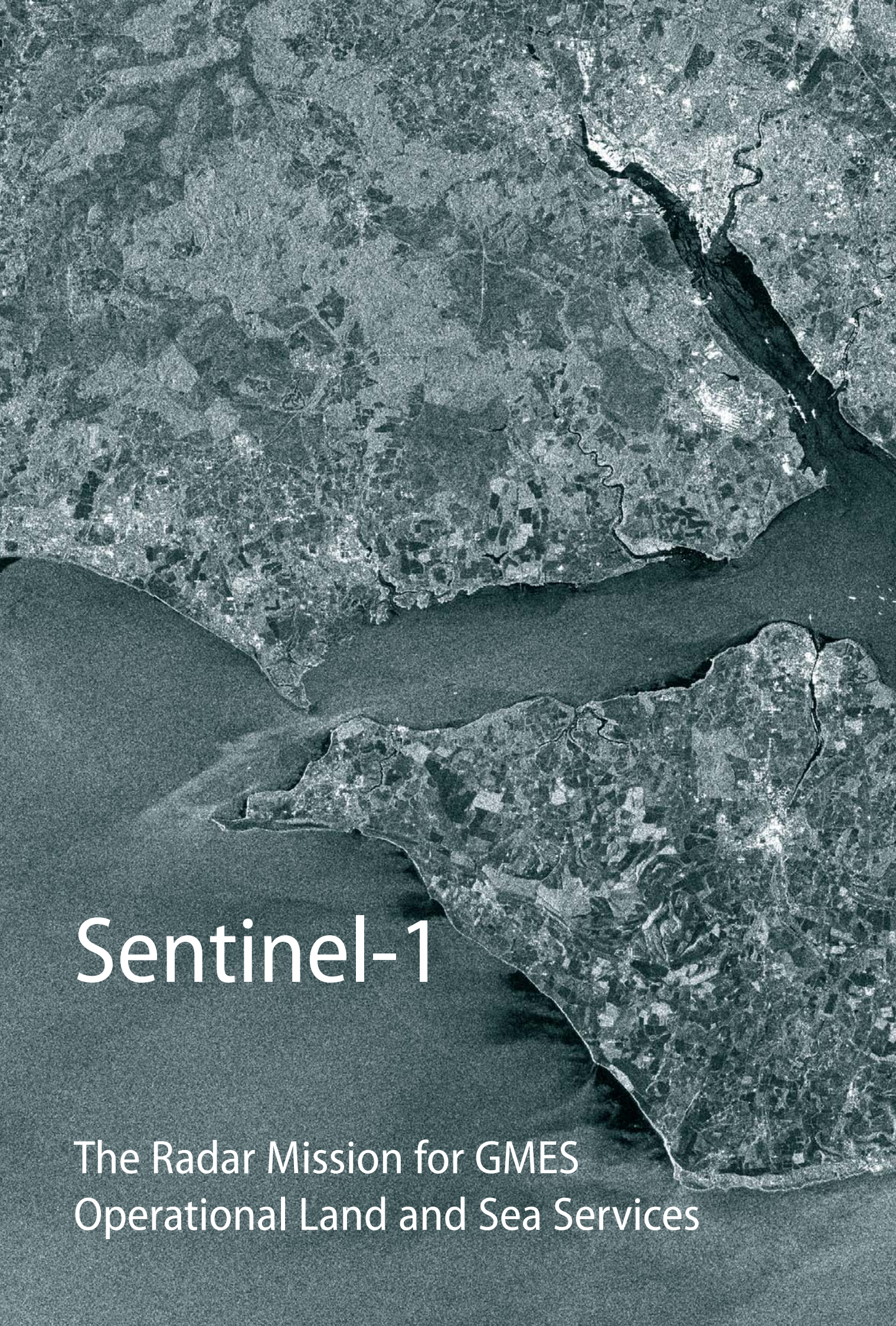
Moon Science, Orbit Reboosts and Impact Observations



### **Powering the Future**

A New Generation of High-Power Solar Arrays

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# Sentinel-1

The Radar Mission for GMES  
Operational Land and Sea Services

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**T**he ESA Sentinels will be the first series of operational satellites to meet the Earth observation needs of the European Union-ESA Global Monitoring for Environment and Security (GMES) programme. Existing and planned space assets will be complemented by new developments from ESA. The first is Sentinel-1, a pair of synthetic aperture radar (SAR) imaging satellites.

### Introduction

ESA is developing the Sentinel-1 European Radar Observatory, a polar-orbiting satellite for operational SAR applications. The constellation of two C-band radar satellites will provide continuous all-weather day/night imagery for user services, especially those identified in ESA's GMES service elements programme and on projects funded by the European Union (EU) Framework Programmes. Three priorities ('fast-track services') have been identified by EU user working groups: marine core services; land monitoring; and emergency services. These include:

- monitoring sea-ice zones and the Arctic;

*Envisat radar image of the Solent between the Isle of Wight and Portsmouth, UK. Resolution is 30 m. At the time, in June 2005, Britain's navy was gathering for a fleet review*

- surveillance of the marine environment;
- monitoring land movements;
- mapping land surfaces: forest, water and soil, agriculture;
- mapping for humanitarian aid in crisis situations.

The first satellite is expected to be launched in 2011 aboard a Soyuz from Kourou.

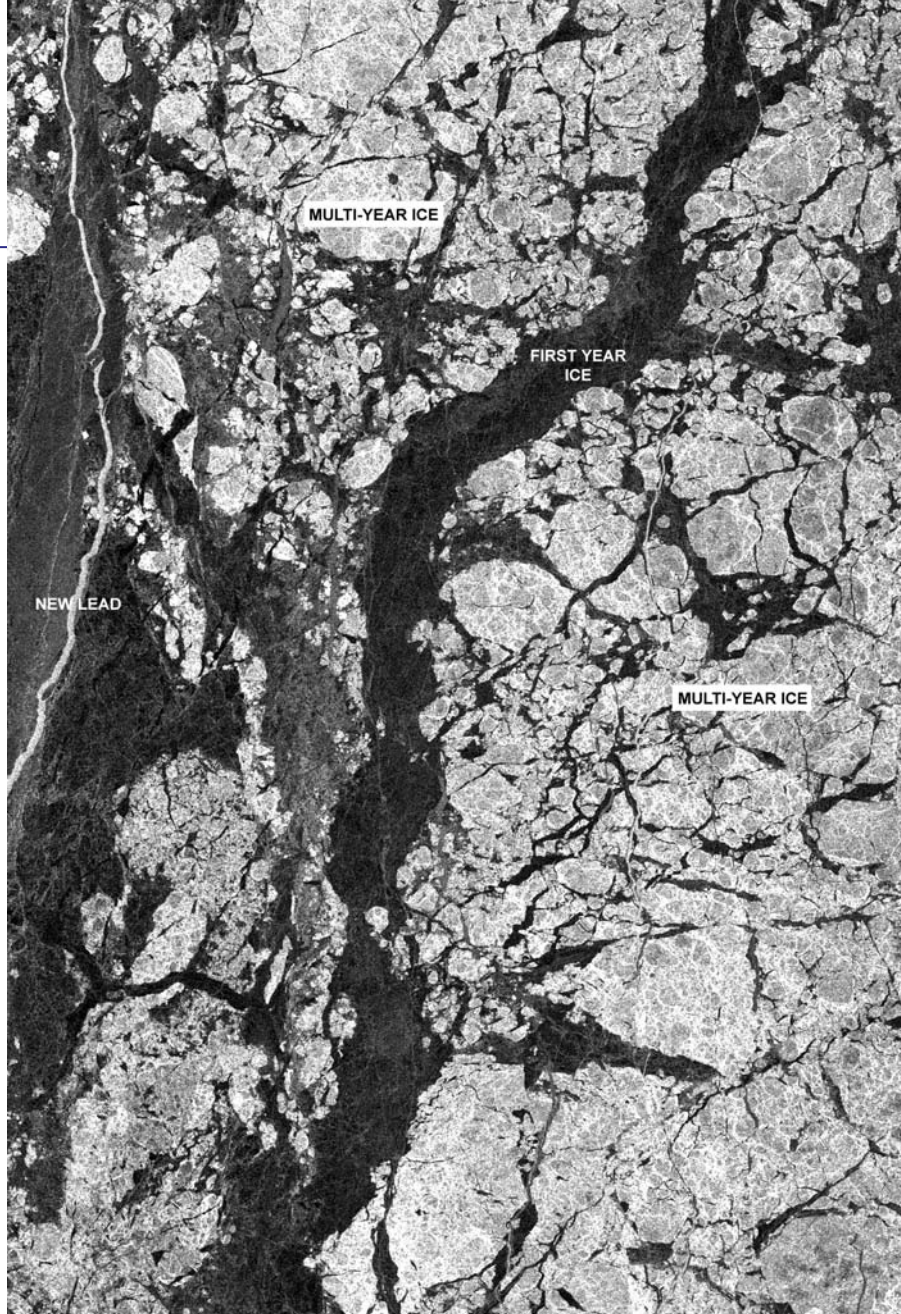
### ESA's SAR Heritage

A first glimpse of the potential of imaging radar from space was provided by the short-lived but successful US Seasat satellite in 1978. ESA's own programme to develop advanced microwave radar instruments culminated with the launches of ERS-1 (17 July 1991) and ERS-2 (20 April 1995). Remarkably, ERS-2 is still operating.

ERS demonstrated for the first time the feasibility of flying reliable, stable and powerful radar imaging systems in space. The dependability and all-weather capability of the instruments also provided a foundation for developing and exploiting radar images for a wide variety of applications. While the initial objectives for ERS-1 at launch were predominantly oceanographic, other applications were considered during the project's preparation. The ESA Remote Sensing Advisory Group in 1974, for example, emphasised commercial applications such as agriculture, land-use mapping, water resources, overseas aid and mapping of mineral resources in its advice on ERS objectives.

The rigorous design of the ERS SAR hardware – emphasising instrument stability in combination with accurate and well-calibrated data products – created new opportunities for scientific discovery, revolutionised many Earth science disciplines and laid the foundations for commercial applications.

For example, 'SAR interferometry', which can track land shifts of only a few millimetres, was developed mainly using ERS data and is now commonly used in Earth sciences and commercial applica-



An Envisat ASAR image in the Arctic's Beaufort Sea, demonstrating the ability of SAR to distinguish clearly between the thinner, more navigable first-year ice and the hazardous, much thicker multi-year ice. (Canadian Ice Service)

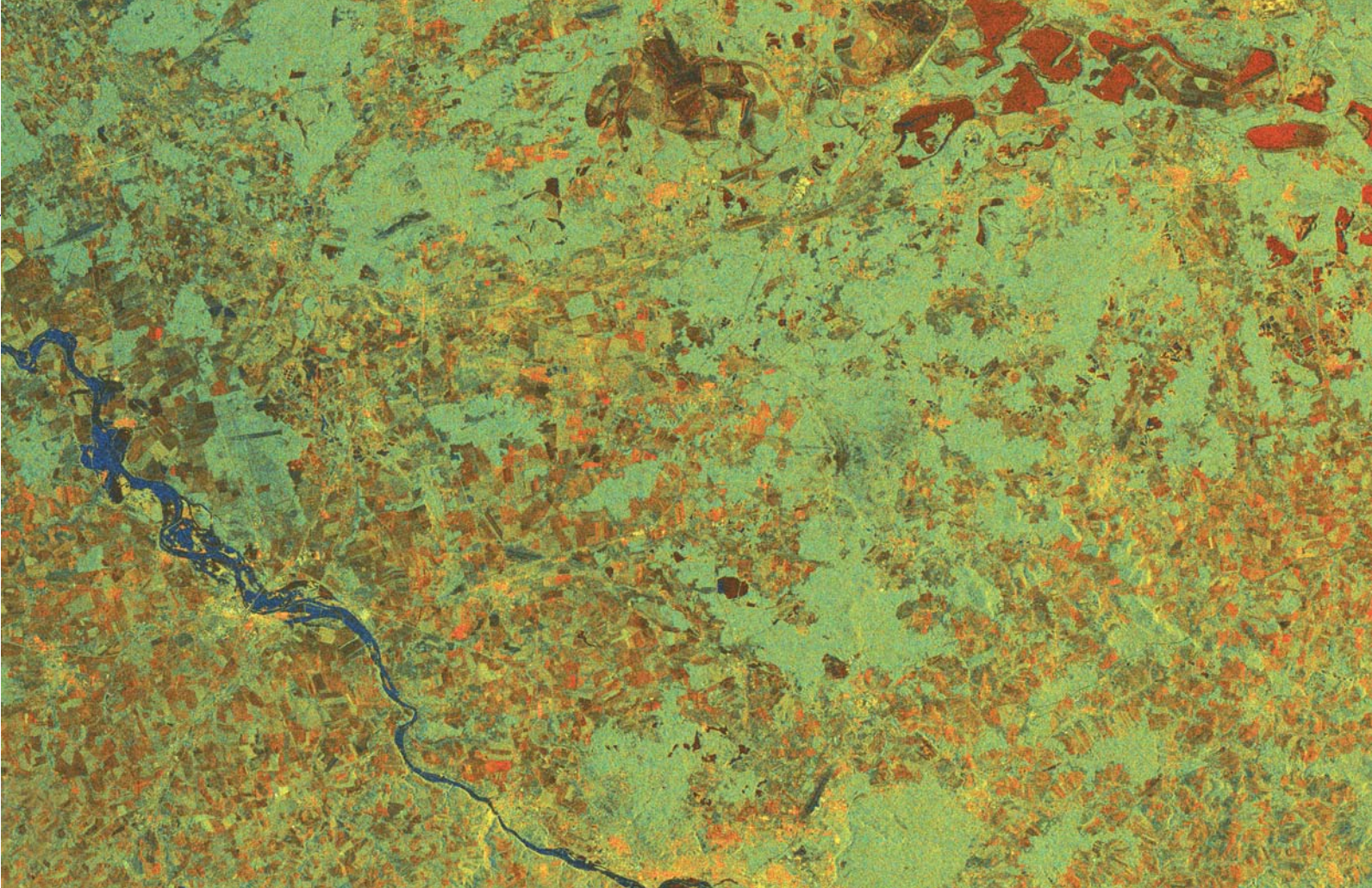
tions. The potential of space radars viewing the same scene only a short time apart was demonstrated in 1995 and 1996 during the ERS 'tandem mission', when the orbits of ERS-1 and ERS-2 were carefully matched but with a 1-day gap.

An important milestone was the launch of the Advanced SAR (ASAR) on Envisat on 28 February 2002. This ensured the continuation of C-band data and added enhanced capabilities such as wide swaths and dual polarisation, features that have since rapidly been integrated into and exploited by many applications. The archive of radar data since 1991 is extremely valuable for science and applications, providing a consistent set of data spanning 16 years.

### What GMES Users Want

Data products from ESA's successful ERS-1, ERS-2 and Envisat missions form the basis for many of the pilot GMES services. Sentinel-1 must maintain these quality levels in terms of spatial resolution, sensitivity, accuracy, polarisation and wavelength. Feedback from users indicate unambiguously that the crucial requirements for operational sustainable services are continuity of data, frequent revisits, geographical coverage and timeliness.

Compared to the current satellites in orbit, substantial improvements of data provision in terms of revisit frequency, coverage, timeliness and reliability of service are required. As an example, services encompassing ship and oil-spill detection, wind speed measurements



The flooded Elbe River in Germany, demonstrating the value of 'dual-polarisation' radar coverage for land-cover classification. Envisat transmits and detects radar waves polarised in the horizontal and vertical directions, yielding more extensive information than could a single polarisation on the ground surface reflecting them. Sentinel-1 will exploit this feature

and sea-ice monitoring require daily revisits (mostly at northern latitudes) and delivery of data within an hour of acquisition. In contrast, land services involving interferometry and cover classification require global coverage every 2 weeks at most and consistent datasets.

### Service Reliability: A New Challenge

The operational requirements present a new challenge for spaceborne radar. Unlike its ERS and Envisat experimental predecessors, which supply data to users on a best-effort basis, operational satellites like Sentinel-1 must satisfy user requirements and supply information in

a reliable fashion. The data provider accepts legal responsibility for delivering the information. Acquisition failures owing to conflicting requests from users (such as requesting different instrument modes at the same time and place) cannot be tolerated.

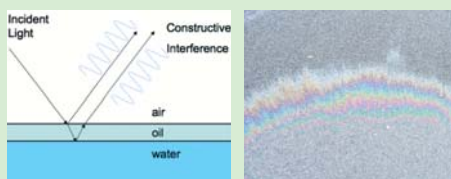
Sentinel-1 will work largely in a programmed conflict-free manner imaging all landmasses, coastal zones and shipping routes globally, and covering the oceans with imagerettes. This way, the reliability demanded by operational services is achieved and a consistent long-term data archive is built for applications based on long time-series.

Sentinel-1 revisit frequency and coverage are dramatically improved with respect to ERS and Envisat. The orbits of the two-satellite constellation repeat every 6 days, and conflict-free operations allow every single data-take to be exploited. The effective revisit and coverage performance could be further improved by access to Canada's planned SAR constellation.

User needs at both high and medium

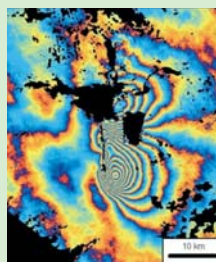
#### Radar Interferometry: How it Works

If light travels paths of different lengths, the observed brightness is either increased or reduced depending on the wavelength (colour) and the path length difference. This 'constructive' and 'destructive' interference shows up nicely as beautiful rainbow-like patterns when sunlight reflects off a thin film of oil (far right).



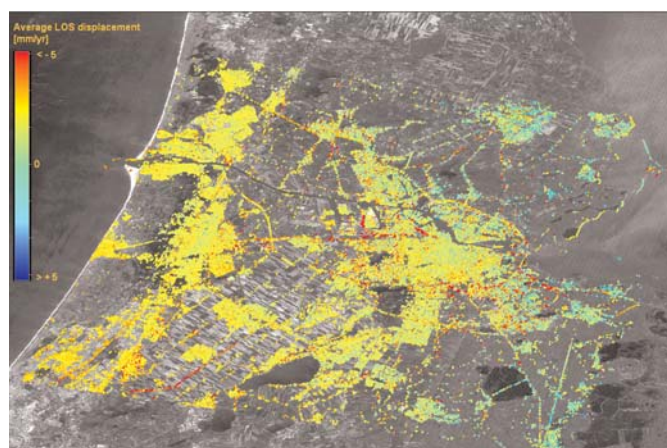
Radar waves can be made to behave in the same way when they are bounced off the Earth. If the satellite comes back another time in exactly the same orbit and the surface has not moved, adding the two measurements gives a brighter image because of constructive interference. However, if parts of the surface have shifted between observations, the destructive interference could dim areas of the combined images.

So combining two radar images from before and after an earthquake, for example, generates rainbow-like patterns from which surface movement can be determined to within typically 1 mm/year.





Detection by interferometric space radar of structural damage. The green spots show little movement, while the damage is highlighted in blue



Monitoring long-term surface vertical movements by interferometric SAR near Amsterdam, The Netherlands, 1993–2000. Red indicates sinking faster than 5 mm per year (Courtesy TerraFirma Project)



Revisiting a scene only a day later allows interferometry to distinguish between water bodies, forest, urban areas and agriculture. In this single ERS-1/ERS-2 image pair over The Netherlands, colours are assigned so that generally trees appear green, water appears blue and agricultural fields appear orange

resolution have meant so far that SAR systems include different operational modes that either optimise the spatial resolution (at the expense of the swath width, hence the coverage) or the swath width (at the expense of the resolution). GMES will provide access to very high-resolution SAR national missions (Germany's TerraSAR-X and Italy's Cosmo-SkyMed), so Sentinel-1 is designed to address medium-resolution applications with its main mode: a wide swath (250 km) and medium resolution (5 x 20 m).

### Products for Marine Core Services

SAR is the primary source of data for information on the oceans and the Arctic environment. The problems of access to the open oceans and the harsh Arctic often make radar, with its ability for observations in all weather and day or night, the only reliable information source. Typical products for the ice and snow services include monitoring glaciers and snow, icebergs, sea ice (floe edge) and the near-shore ice complex.

For determining the direction, wavelength and (extreme) heights of waves on the open oceans, SAR imageries are being used in near-realtime in conjunction with global ocean wave models. The extensive wave mode archive built up by ERS and Envisat is a critical resource for analysing regional wave climate and extreme wave events.

SAR is also the primary source of information on oil spills, such as surveillance and drift forecasting, and on ship detection for fisheries and security.

### Products for Land Monitoring Services

SAR data are not always the primary source for basic land-cover classification (forest, agricultural crops, urban areas, etc.) if multi-channel optical imagery with high spatial resolution is available. However, SAR is commonly used as a complementary or alternative data source under adverse atmospheric conditions such as cloud cover.

The contribution made by SAR to basic land-cover classification was greatly increased by the 'dual polarisation' mode introduced by Envisat's ASAR. Because the reflective properties of a surface depend on the polarisation of the incoming signal, the use of more than one type of polarisation provides valuable extra information. This has become a favourite for land classification. For this reason, Sentinel-1 is designed to exploit the full capabilities offered by dual polarisation.

A dramatic improvement is expected from the more frequent revisits to the same area by Sentinel-1. This feature enhances time-series by adding close to daily sampling. Combined with its interferometric capability, Sentinel-1 will routinely offer products that were only available experimentally from the

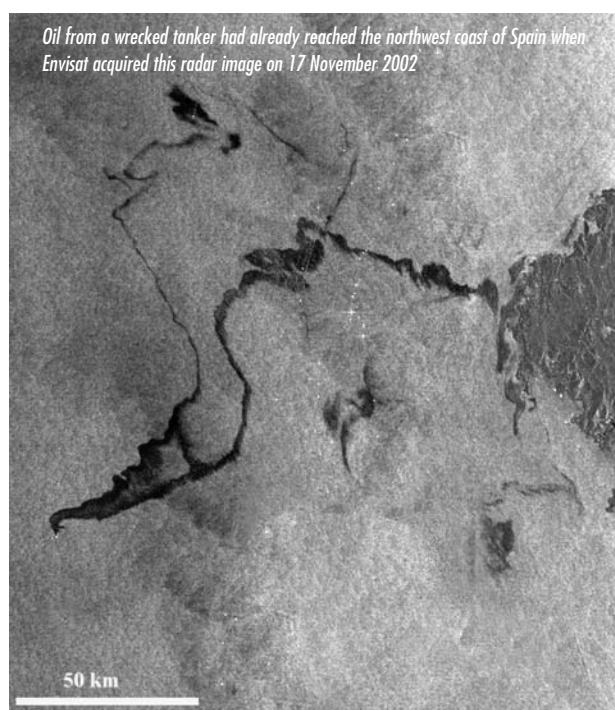


### ROMANIA - Timis Region Floodings, Spring 2005

1:75.000



Map of the flooding in the Timis region of Romania in May 2005, based on Envisat ASAR Narrow Swath and SPOT-5 data. (Image processing and map creation by DLR; SPOT © CNES 2005, distributed by Spot Image ENVISAT ASAR © ESA 2005)



Oil from a wrecked tanker had already reached the northwest coast of Spain when Envisat acquired this radar image on 17 November 2002

ERS-1/2 tandem mission. During the ERS tandem phase, data pairs were collected on successive days.

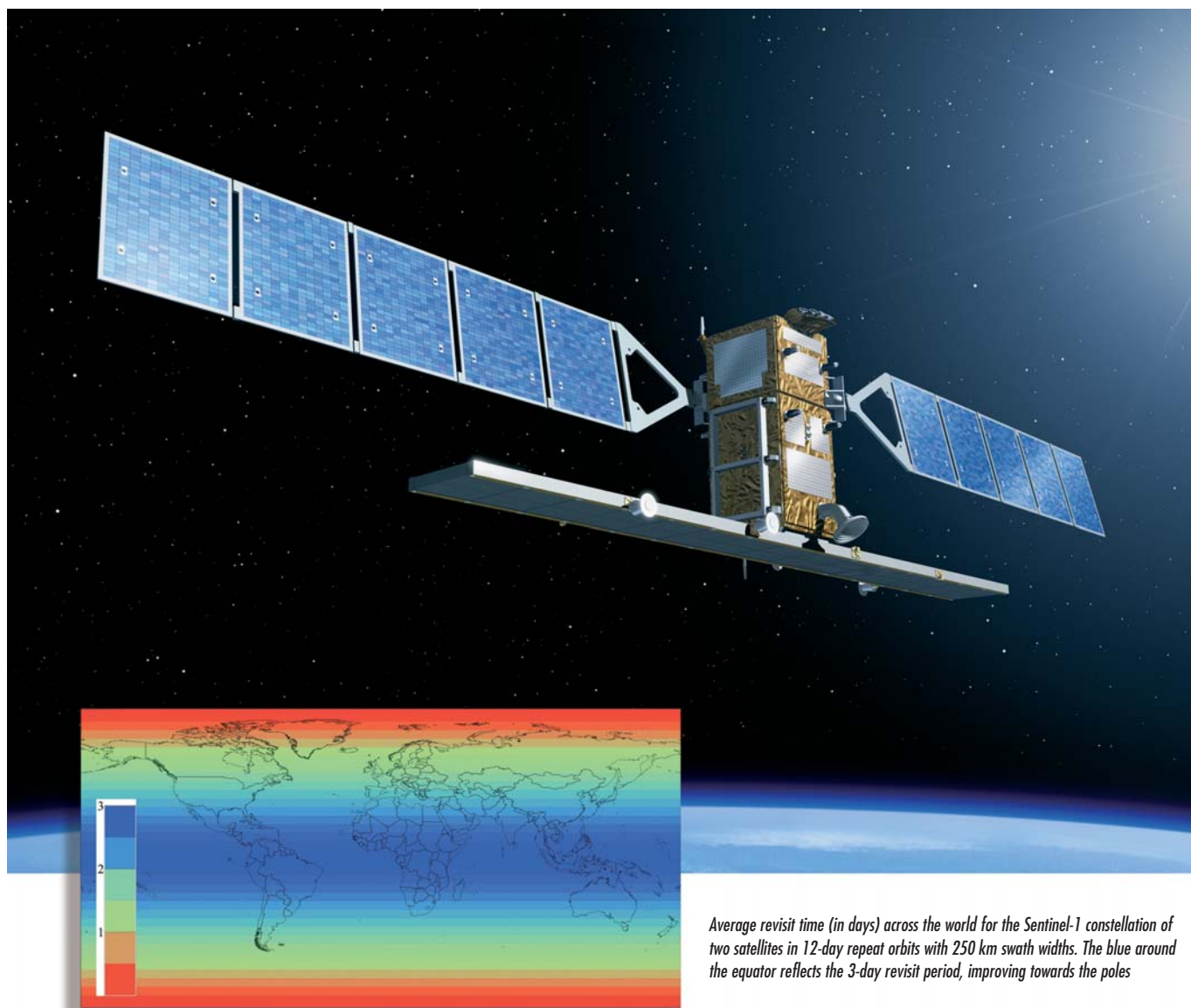
Classifying land cover is not the only important application of SAR to land monitoring. Since *i n t e r f e r o m e t r i c* radar can detect surface movements to within a few millimetres per year, it is now an established technique to monitor the effects of landslides, earthquakes and man-made activities such as building construction, tunnelling, water or natural gas extraction, and mining.

### Products for Emergency Services

Its all-weather day/night capability makes space-borne radar the ideal workhorse for providing information before, during and after emergencies. Sentinel-1's two-satellite constellation will routinely revisit all sites within 3 days at the equator and improving with latitude. In addition, an optional emergency procedure could accelerate access.

Agreements with other satellite operators will make daily access or even better a realistic assumption. This excellent revisit performance is feasible even while maintaining a spatial resolution of 5 x 20 m. In order to observe finer detail, regional coverage by satellites with higher spatial resolution (radar and/or optical) will be required.

Sentinel-1 will build a multi-temporal global interferometric image archive that can be called on in emergency situations.



Average revisit time (in days) across the world for the Sentinel-1 constellation of two satellites in 12-day repeat orbits with 250 km swath widths. The blue around the equator reflects the 3-day revisit period, improving towards the poles

For example, interferometric pairs will map the effects of earthquakes.

Even with the highly restricted coverage of today, C-band SAR is an established source of information in emergencies such as flooding and oil spills.

### The Sentinel-1 System

The Sentinel-1 satellites are being built by an industrial consortium headed by Thales Alenia Space Italy as Prime Contractor, with Astrium Germany responsible for the 'C-SAR' payload, incorporating the central radar electronics subsystem developed by Astrium UK. The industrial set-up will

be finalised during the project's initial phase. The satellite is based on the PRIMA (Piattaforma Italiana Multi Applicativa) bus, with a mission-specific payload module. Experience gained from Canada's Radarsat-2 and Italy's Cosmo-SkyMed projects, which also use PRIMA, will benefit Sentinel-1.

The design is driven by the payload requirements, with particular implications for data transmission and orbit control. The SAR data volume needs relatively large onboard storage capacity, and a downlink rate about six times that of Envisat. The X-band subsystem design has not yet been selected, requiring further analysis.

Likewise, the Sentinel-1 requirements for operational interferometry place stringent requirements on attitude accuracy, attitude and orbit knowledge, and data-take timing accuracy.

### Operational modes

Sentinel-1 has four standard operational modes, designed for interoperability with other systems:

- Strip Map Mode, 80 km swath and 5 x 5 m spatial resolution;
- Interferometric Wide Swath Mode, 250 km swath, 5 x 20 m spatial resolution and burst synchronisation for interferometry;

### Sentinel-1 Satellite Characteristics

Lifetime: 7 years (consumables 12 years)  
 Launcher: Soyuz from Kourou (baseline), Zenith-2 (backup)  
 Orbit: near-polar Sun-synchronous 693 km; 12-day repeat cycle; 175 revs per cycle  
 Mean Local Solar Time: 18:00 at ascending node  
 Orbital period: 98.6 minutes  
 Attitude stabilisation: 3-axis  
 Attitude accuracy: 0.01 deg (each axis)  
 Orbit knowledge: 10 m (each axis, 3-sigma) using GPS  
 Operating autonomy: 96 hours  
 Launch mass: 2300 kg (including 130 kg monopropellant fuel)  
 Size (stowed): 3900 x 2600 x 2500 mm  
 Solar array average power: 4800 W (end-of-life); battery capacity: >300 Ah  
 Spacecraft availability: 0.998  
 Science data storage capacity: 900 Gb (end-of-life)  
 S-band TT&C data rates: 4 kbit/s telecommand; 16/128/512 kbit/s telemetry (programmable)  
 X-band science data rate: 600 Mbit/s

- Extra-wide Swath Mode, 400 km swath and 25 x 100 m spatial resolution (3-looks);
- Wave Mode, low data rate and 5 x 20 m spatial resolution. Sampled images of 20 x 20 km at 100 km intervals along the orbit.

### Data delivery

With its continuous and conflict-free operations, Sentinel-1 will provide a high level of service reliability with near-realtime delivery of data within an hour after reception by the ground station, and with data delivery from archive within 24 hours.

### Polarisation

Sentinel-1 has selectable single polarisation (VV or HH) for the Wave Mode and selectable dual polarisation (VV +VH or HH+HV) for all other modes.

### Radiometric resolution

For the end-user of SAR imagery, the radiometric resolution is a critical parameter because it defines the typical image noise in radar images caused by thermal noise and speckle. Image noise

defines how well different surfaces, such as ice types, agricultural crops and soil moisture levels, can be classified. With its extra-wide swath, Sentinel-1 offers 30% improvement with respect to Envisat, while the interferometric wide swath offers a further improvement by a factor of three.

### Ground segment and operations

Once in orbit, Sentinel-1 will be operated from two centres. ESA's facilities in Darmstadt, Germany will command the satellite, while mission exploitation will be from Frascati, Italy, including the planning of the SAR acquisitions, the processing of the acquired data and the provision of the resulting products to the users. However, the ground segment design and operations concept allow operations to be handed over – partially or fully – to other operating entities in the future.

The satellite operations and mission exploitation present new challenges: the spacecraft needs to work within a tight orbital tube only 100 m in diameter, and must comply with GMES security requirements for command and control. Its operations will be largely automated during normal operations but emergency requests have to be accommodated at short notice.

Exploitation plans need to facilitate systematic acquisition, reception, processing, archiving and provision of large amounts of data to the users. The SAR instrument will be operated in conflict-free sensing modes as much as possible. The ground system must be able to handle data flows from the satellite exceeding 1 Terabyte ( $10^{12}$  bytes) per day and to provide large data volumes within an hour of reception on the ground.

The operations concept allows the satellite to operate autonomously and cost-effectively with a 4-day mission plan stored onboard, thus allowing automated operations over weekends. At the same time, it is possible to insert individual emergency requests up to 3 hours before the planned update of the mission plan to the satellite. This allows considerable shortening of the response time of

Sentinel-1 compared to its predecessors.

An extensive ground segment is required, with several ground stations receiving instrument data at 600 Mbit/s, with cumulative processing capacities above 500 GHz, archiving requirements exceeding 10 Petabytes ( $10^{15}$  bytes), and with data dissemination exceeding current systems by an order of magnitude.

In order to fully satisfy the GMES service requirements, the ground segment must include coordinated mission planning and data exchange with other missions contributing to GMES. It needs to guarantee a Quality of Service to the user in line with the operational nature of GMES, ensuring that the data products are accurate, complete and provided on time.

### Conclusions

The Sentinel-1 constellation is a completely new approach to SAR mission design by ESA in direct response to the operational needs for SAR data expressed under the EU-ESA GMES programme. The mission ensures continuity of C-band SAR data and builds on ESA's heritage and experience with the ERS and Envisat instruments, notably maintaining key characteristics such as stability and accurate well-calibrated data products. At the same time, mission parameters have been vastly improved to meet major user requirements collected and analysed through EU Fast Track and ESA GMES Service Element activities, especially in areas such as reliability, revisit time, geographical coverage and rapid data dissemination. As a result, the Sentinel-1 pair is expected to provide near-daily coverage over Europe and Canada, independent of weather with delivery of radar data within an hour of acquisition – vast improvements over the existing SAR systems.

In addition to responding directly to the current needs of GMES, the design of the Sentinel-1 mission is expected to enable the development of new applications and meet the evolving needs of GMES, such as in the area of climate change and associated monitoring.

An aerial satellite image of a city, likely Paris, showing a dense urban grid, a winding river (the Seine), and green spaces. The image is used as a background for the text.

# Sentinel-2

The Optical High-Resolution Mission for  
GMES Operational Services

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**T**he ESA Sentinels will be the first series of operational satellites to meet the Earth observation needs of the European Union-ESA Global Monitoring for Environment and Security (GMES) programme. The pair of Sentinel-2 satellites will routinely provide high-resolution (10–20 m) optical images globally with frequent revisits tailored to the needs of GMES land and emergency services. Sentinel-2 aims at ensuring continuity of Spot- and Landsat-type data, with improvements to allow service evolution. The first launch is expected in 2012.

### What Users Need

The pair of Sentinel-2 satellites will routinely generate valuable information for the European Union (EU) and its Member States as part of the Global Monitoring for Environment and Security (GMES) programme, in the areas of global climate change (Kyoto Protocol and ensuing regulations), sustainable development, European environmental policies (such as spatial planning for the Soil Thematic Strategy, Natura 2000, and the Water Framework Directive), risk management, the

*Sentinel-2 will extend land-imaging missions such as Landsat and Spot. Shown is a Spot image of Berlin in 2004. (© CNES 2004 – Distribution Spot Image)*

Common Agricultural Policy, development and humanitarian aid, and common foreign and security policy.

To meet these needs, Sentinel-2 data will underpin the routine generation of products such as: generic land-cover, land-use and change maps, and risk mapping and fast images for disaster relief. They will also evolve towards the generation of geophysical variables like leaf coverage, leaf chlorophyll content and leaf water content.

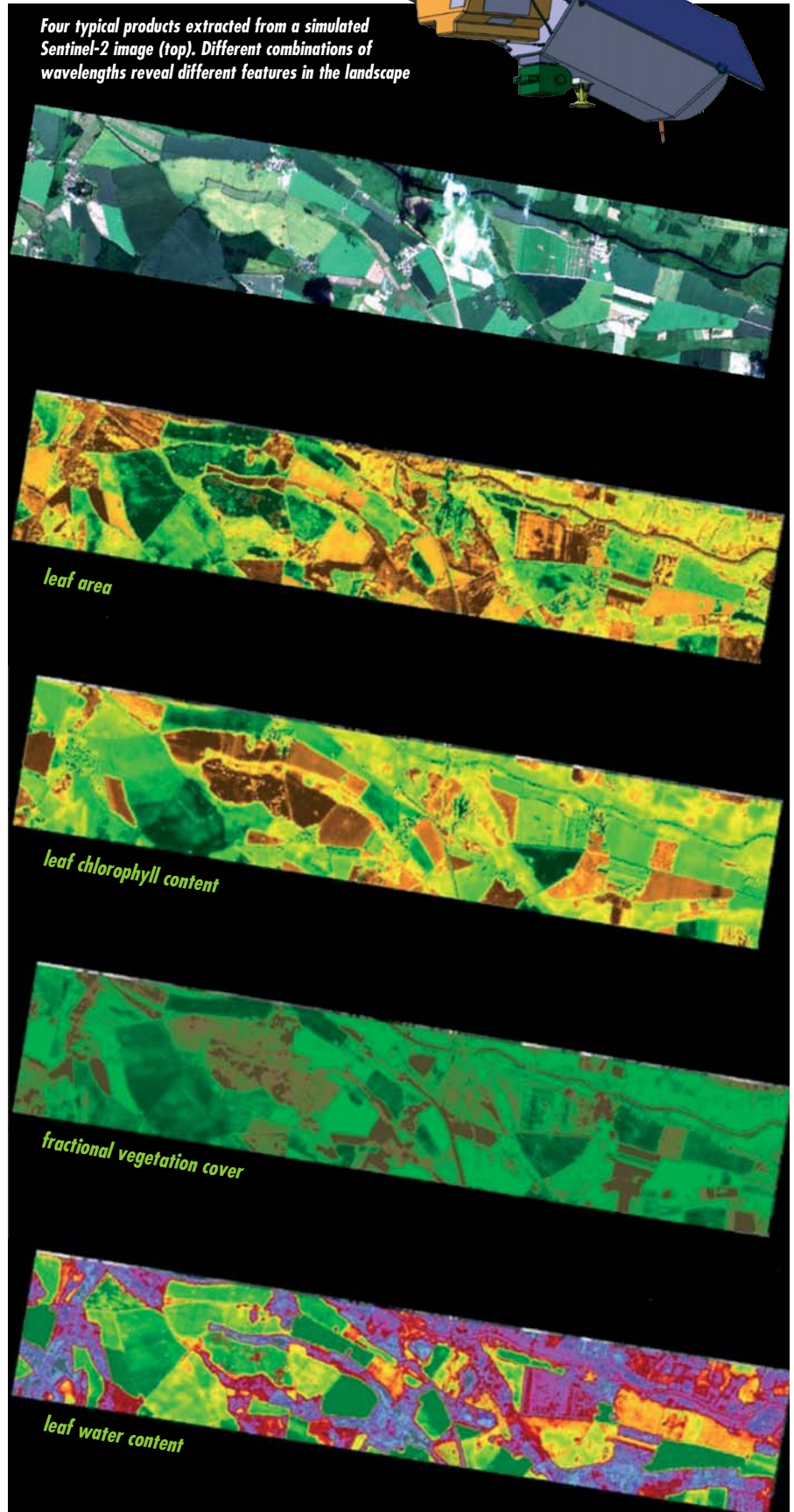
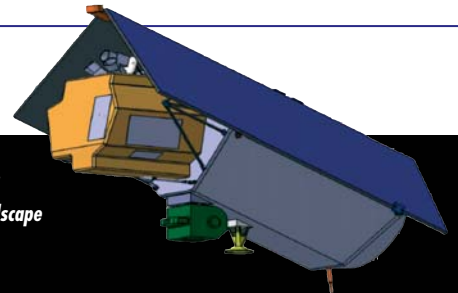
GMES will use Sentinel-2 along with other optical satellites to provide complete observations. Conversely, Sentinel-2 will be a member of the land-surface imaging constellation of the international Committee on Earth Observation Satellites (CEOS), who will coordinate access to the missions of the same type (especially for Landsat data-continuity) to improve the final information for users. Sentinel-2 will ensure European independence while contributing to the global push for improved land imaging.

These goals have driven the design towards a dependable multispectral Earth-observation system that ensures continuity for Landsat and Spot observations and improves data availability for users. That, in turn, has identified priority improvements over past satellites.

**Geographic coverage**

The mission is dedicated to the full and systematic coverage of land surfaces (including major islands) from 56°S (southern Americas) to +83°N (northern Greenland), providing cloud-free products every 15–30 days. To achieve this and for reliability, a constellation of two operational satellites is required, yielding 5 days between revisits. At the beginning, with only one satellite, the gap is 10 days (although optical instruments on other GMES satellites will help to fill the gaps).

Additionally, some limited geographical areas will be reachable within 1–3 days in emergencies such as floods and earthquakes by rolling and tilting the satellite.



By comparison, the US Landsat-7 has 16-day revisits and Spot 26-day revisits, and neither provides systematic coverage of land.

In order to support operational services for at least 15 years from the launch of the first satellites, a series of four satellites is planned, with two operating in orbit and a third in ground storage as backup.

**Spectral coverage**

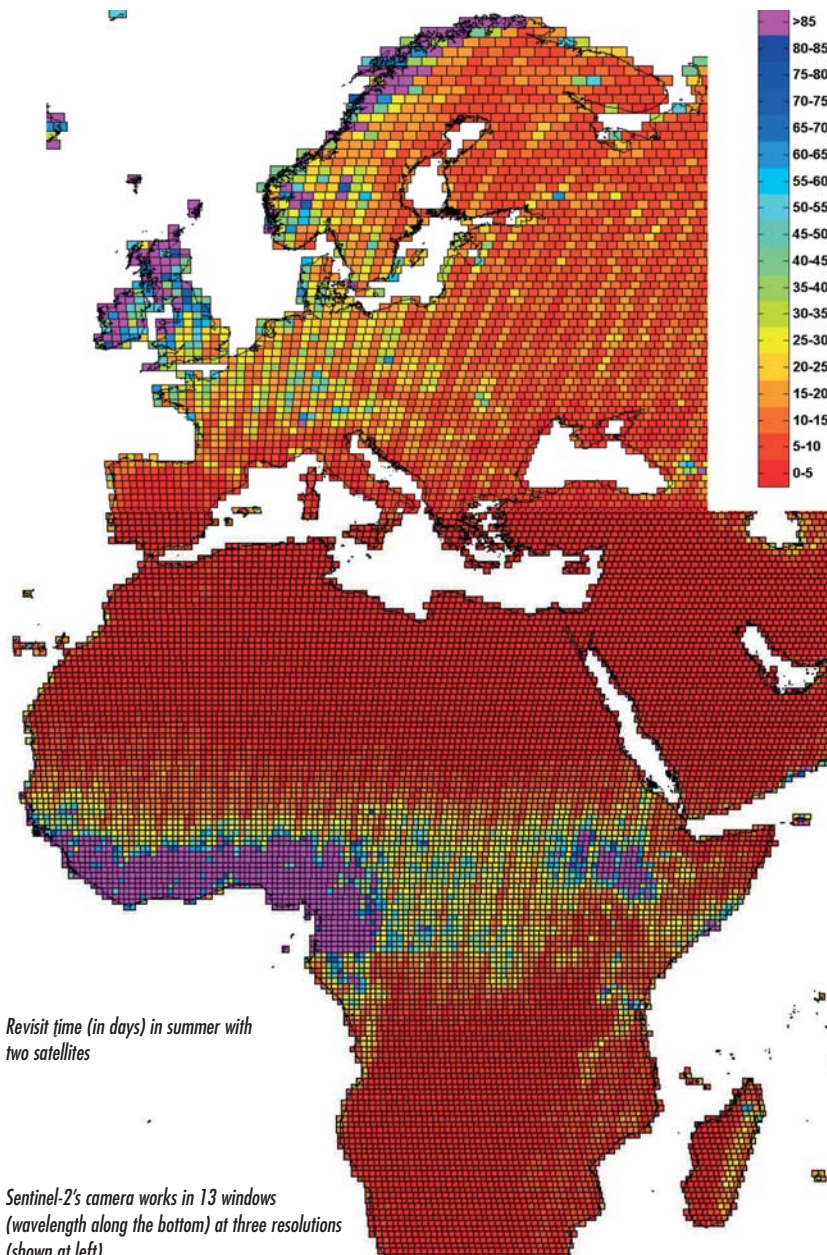
The Multi-Spectral Instrument (MSI) features 13 spectral bands from the visible and near-infrared (VNIR) to the short-wave infrared (SWIR), featuring four at 10 m, six at 20 m and three at 60 m resolution. The best compromise in terms of user requirements and mission performance, cost and schedule risk, it provides enhanced continuity for Spot and Landsat, with narrower bands for improving identification of features, additional red channels for assessing vegetation, and dedicated bands for improving atmospheric correction and detecting cirrus clouds.

**Processing and distribution**

After reception, the data will be processed systematically over predefined areas in predefined time windows, selected by user requests. The data will then be made available to users who have notified their interest in that particular set. Dissemination will be performed mostly online. This avoids individual ordering. It is made possible by the largely repetitive geographical coverage that can dispense with day-to-day mission planning. However, on-demand production and delivery will be provided for important specific cases like disaster management. Mission planning is required only for the roll-tilt manoeuvre in these unpredictable cases.

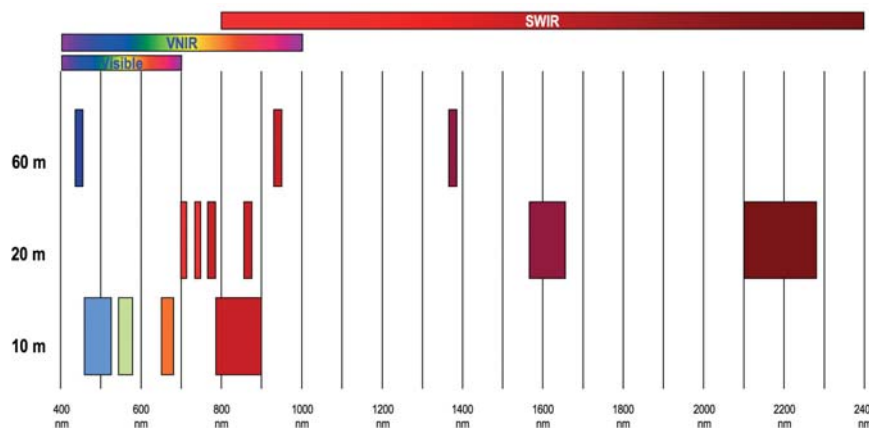
**Mission Description**

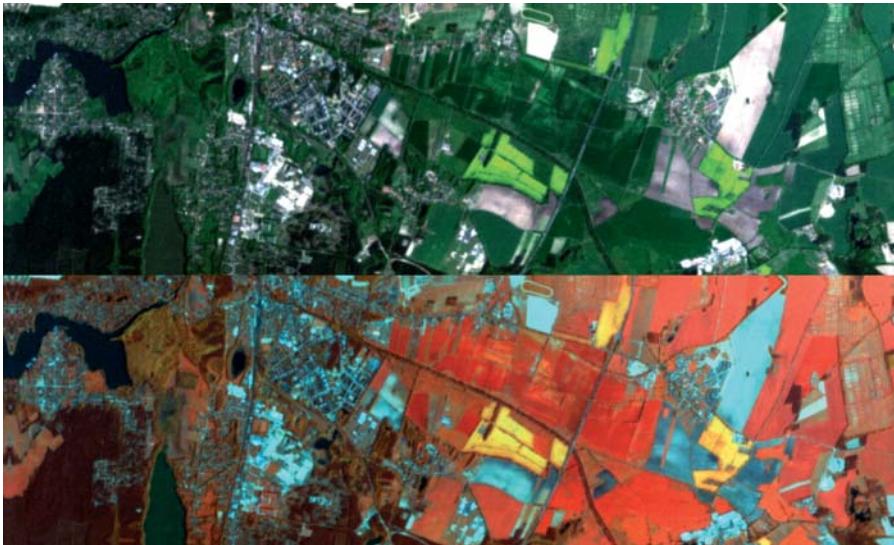
Frequent revisits and high mission availability require two Sentinels operating simultaneously, which dictates a small, cost-effective and low-risk satellite. The orbit is Sun-synchronous at 786 km altitude (14+3/10 revolutions



Revisit time (in days) in summer with two satellites

Sentinel-2's camera works in 13 windows (wavelength along the bottom) at three resolutions (shown at left)





Simulated Sentinel-2 colour composite images using the red/green/blue bands (above) and near-infrared/red/green (below)

**Multispectral instrument**

MSI features a three-mirror anastigmat telescope with a pupil diameter of about 150 mm; it is the key to the high image quality across the wide field of view of 290 km (Landsat 185 km, Spot 120 km). The telescope structure and mirrors are made of silicon carbide to minimise thermal deformation.

The VNIR focal plane employs monolithic CMOS (complementary metal oxide semiconductor) detectors, while the SWIR uses a mercury-cadmium-telluride detector hybridised on a CMOS read-out circuit. A dichroic beam-splitter separates the VNIR and SWIR channels. A combination of partial onboard calibration, using a Sun diffuser, and calibration with ground targets will guarantee high radiometric performance.

The detector signals are digitised at high resolution (12-bit), and state-of-the-art lossy data compression reduces the data volume. The compression ratio will be fine-tuned for each spectral band to ensure that there is no significant effect on image quality.

A shutter prevents direct viewing of the Sun in orbit and contamination during launch. The average observation time per orbit is 16.3 minutes, with a peak value of 31 minutes.

In order to mitigate the development risks and secure the development schedule, the technologies for building the critical VNIR and SWIR detectors and

per day) with a 10:30 a.m. descending node. This local time is the best compromise between minimising cloud cover and ensuring suitable Sun illumination. It is close to the Landsat local time and matches Spot's, allowing the seamless combination of Sentinel-2 data with historical images to build long-term time series. The two satellites will work on opposite sides of the orbit.

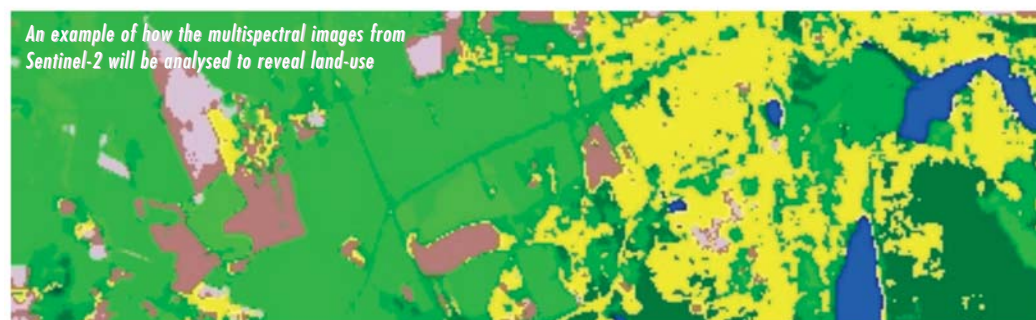
The ground station network must provide long contact times in order to downlink all the observations; at least four core stations are required. One polar station for telemetry, tracking and control is sufficient. To a limited extent, the system will also allow direct reception by local user stations for near-realtime applications.

**The Satellites**

A compact 1 t satellite will be launched on ESA's Vega (baseline, with Rockot as backup). The satellite is designed for a

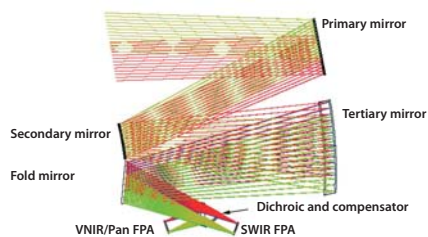
7-year lifetime, with propellant for 12 years of operations, including de-orbiting at the end. The roof-shaped configuration with a fixed body-mounted solar array as defined in Phase-A/B1 leads to a simple mechanical design, without solar array deployment or drive mechanisms. The satellite is controlled in 3-axes via high-rate multi-head startrackers, mounted on the camera structure for better pointing accuracy and stability, and gyroscopes and a satnav receiver. Power comes from high-efficiency gallium arsenide triple-junction solar cells and a lithium-ion battery. The satellite is tilted at 22.5° to its roll axis to maximise the illumination of its solar array.

Images are stored in a 2 Tbit solid-state mass memory before downlinking at 450 Mbit/s in the X-band. Command and control is performed through an omni-directional S-band antenna.



Yellow	Urban
Blue	Water
Dark Green	Forest1
Light Green	Forest2
Purple	Bare soil1
Brown	Bare soil 2
Light Green	Cultivated field 1
Yellow-Green	Cultivated field2





The complex light path within the camera allows a more compact instrument. FPA is the Focal Plane Assembly.

filter assemblies are being developed before the main project begins. Each pre-development involves two manufacturers to reduce risks, foster competition and meet ESA's geographical return requirements for the main phase.

**Ground segment**

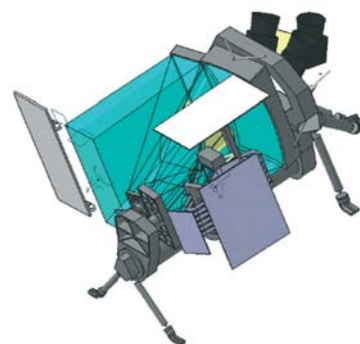
The ground segment includes a Flight Operations Segment for commanding the satellite, and a decentralised Payload Data Ground Segment, an evolving multi-mission infrastructure for mission planning, data reception, processing, archiving, quality control and dissemination.

The users in the dispersed Service Segment will take data from different satellites in combination with non-space data to deliver customised services to the final users.


Sentinel-2 will be a key European source of data for the GMES Land Fast-Track Monitoring Services and will contribute to the GMES Risk Fast-Track Services. It will provide continuity of data to ESA's GMES Service Element projects such as forestry (GSE Forest Monitoring), soil and water resources mapping, urban mapping and classification (SAGE, Urban Services, Coast-watch, GSE Land, RISK-EOS).

**Conclusion**

The Sentinel-2 wide-swath high-resolution multispectral system will provide improved continuity for Spot- and Landsat-type observations, with improved revisit time, coverage area, spectral bands, swath width, and radiometric and geometric image quality, meeting GMES needs for operational land and emergency services.



Sentinel-2's multispectral camera

The Sentinel-2 Definition Phase-A/B1 was performed by ESA in 2005 and 2006 with an industrial consortium led by Astrium GmbH (mission prime, platform, system engineering), with Astrium SAS as the major subcontractor (payload, system support). Following the completion of this phase in January 2007, the Invitation to Tender for the Implementation Phase was released in February 2007. This Phase-B2/C/D/E1 is expected to start in October 2007, with launch of the first satellite projected for 2012. 

# Sentinel-3

The Ocean and Medium-Resolution Land  
Mission for GMES Operational Services



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**T**he ESA Sentinels will be the first series of operational satellites to meet the Earth observation needs of the European Union-ESA Global Monitoring for Environment and Security (GMES) programme. The pair of Sentinel-3 satellites will provide global, frequent and near-realtime ocean, ice and land monitoring. It continues Envisat's altimetry, the multispectral, medium-resolution visible and infrared ocean and land-surface observations of ERS, Envisat and Spot, and includes enhancements to meet the operational revisit requirements and to facilitate new products and evolution of services. The first launch is expected in 2011/2012.

### What Users Need

The pair of Sentinel-3 satellites will routinely monitor ocean and land surfaces to generate valuable information for the European Union (EU) and its Member States as part of the Global Monitoring for Environment and Security (GMES) programme ([www.gmes.info](http://www.gmes.info)). The EU Marine Core Service (MCS) and the Land Monitoring Core Service (LMCS), together with the ESA GMES Service Element (GSE), have

*Sentinel-3 will continue the images provided  
by Envisat's MERIS instrument*

been consolidating those services where continuity and success depends on operational data flowing from the Sentinels.

For MCS, operational oceanography services are being developed within the MERSEA 6th Framework Programme ([w3.mersea.eu.org](http://w3.mersea.eu.org)) and through the ESA GSE Marcoast ([gmes-marcoast.com](http://gmes-marcoast.com)) and Polarview ([www.polarview.org](http://www.polarview.org)) projects. The MCS will deliver regular,

systematic products on sea-surface topography and sea-state and ecosystem characteristics over the oceans and the European regional and shelf seas. The information from Sentinel-3 will be assimilated into models in near-real-time to provide routinely the best-available estimate of the state of the oceans, together with forecasts (from days to weeks) and reanalyses ('hindcasts' of ocean state over long time-series in the

past). The fast-track component of the MCS focuses on ocean dynamics and primary ecosystem characteristics, but also covers sea-ice monitoring and oil-spill detection.

The Land Monitoring Core Service is being developed through the Geoland 6th Framework Programme ([www.gmes-geoland.info](http://www.gmes-geoland.info)) and ESA GSE projects such as Forest Monitoring ([www.gmes-forest.info](http://www.gmes-forest.info)), Global Monitoring for Food Security ([www.gmfs.info](http://www.gmfs.info)), and the disaster mitigation and humanitarian relief RESPOND ([www.respond-int.org](http://www.respond-int.org)) service.

LMCS focuses on exhaustive high-resolution continental-scale land-cover/land-use mapping complemented by land-monitoring based on daily land-cover mapping, vegetation characteristics and fire monitoring at continental and global scales. The dynamics of vegetation characteristics require an update frequency of days to weeks, and comprehensive global observations with the best revisit frequency possible (especially to minimise the effects of clouds and high levels of aerosols).

LMCS will evolve in Europe to include vegetation monitoring linked to Common Agricultural Policy requirements such as reviewing and monitoring EU policies (water framework directive, biodiversity strategy, common agricultural, regional policies) and reporting obligations under international treaties such as the Kyoto Protocol.

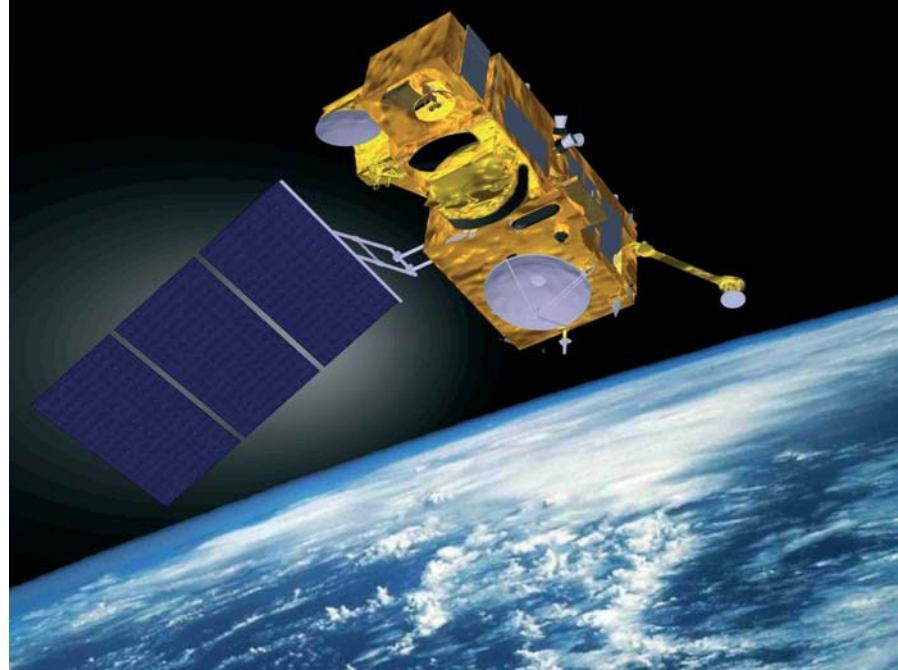
Sentinel-3 will frequently revisit all sites. This is useful, for example, for crop yield monitoring and food security, and forest cover mapping and change monitoring. Parameters include land cover, leaf area index, fraction of absorbed photosynthetically active radiation, burnt areas, and land surface and active fire temperature. These global vegetation data, together with atmospheric corrections, such as aerosol optical depth, will provide critical input data for numerical weather forecasting, global climate models and in climate and greenhouse gas monitoring.

To meet user needs, Sentinel-3 will support the routine generation of a

**GMES/Sentinel-3 Initial Services**

Sentinel-3 will deliver routine operational services to policy-makers and marine and land service users:

<p><b>Marine and Coastal Environment</b></p> <ul style="list-style-type: none"> <li>Sea-surface topography</li> <li>Mesoscale circulation</li> <li>Water quality</li> <li>Sea-surface temperature</li> <li>Wave height and wind speed</li> <li>Sediment load and transport</li> <li>Eutrophication (excessive plant growth in water bodies)</li> </ul> <p><b>Polar Environment</b></p> <ul style="list-style-type: none"> <li>Sea-ice thickness</li> <li>Ice surface temperature</li> </ul> <p><b>Maritime Security</b></p> <ul style="list-style-type: none"> <li>Ocean-current forecasting</li> <li>Water transparency</li> <li>Wind and wave height</li> </ul> <p><b>Global Change Ocean</b></p> <ul style="list-style-type: none"> <li>Global sea-level rise</li> <li>Global ocean warming</li> <li>Ocean carbon dioxide flux</li> </ul>	<p><b>Land Cover &amp; Land-Use Change</b></p> <ul style="list-style-type: none"> <li>Land-use mapping</li> <li>Vegetation indices</li> </ul> <p><b>Forest Monitoring</b></p> <ul style="list-style-type: none"> <li>Forest cover mapping</li> </ul> <p><b>Food Security Early Warning</b></p> <ul style="list-style-type: none"> <li>Regional land-cover mapping</li> <li>Drought monitoring</li> </ul> <p><b>Humanitarian Aid</b></p> <ul style="list-style-type: none"> <li>Land-use mapping</li> </ul> <p><b>Air Pollution (local to regional scales)</b></p> <ul style="list-style-type: none"> <li>Aerosol concentration</li> </ul> <p><b>Risk Management (flood and fires)</b></p> <ul style="list-style-type: none"> <li>Burned scar mapping</li> <li>Fire detection</li> </ul> <p><b>Global Change Land</b></p> <ul style="list-style-type: none"> <li>Forest-cover change mapping</li> <li>Soil degradation mapping</li> </ul>
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general suite of high-level geophysical products, with priority on:

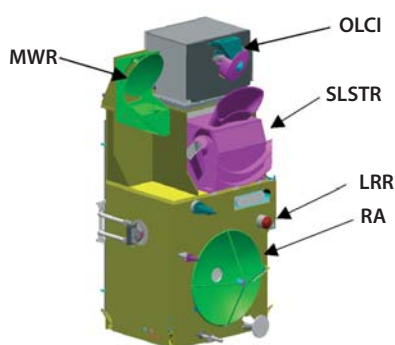
- ocean, ice, land and inland water surface topography;
- sea-surface temperature;
- ocean colour;
- land surface biophysical properties;
- land surface temperature.

These primary goals have driven the design towards a mission concept that can routinely and continuously (that is, operationally) deliver robust products with well-characterised accuracy and confidence limits. In turn, this will lead to improvements over previous missions and instruments, which, through their technology and data-processing, have guided the design of the Sentinel-3 system.

### Mission Definition

The sea-surface topography mission has the primary objective of providing accurate, closely spaced altimetry measurements from a high-inclination orbit with a long repeat cycle, to complement the Jason ocean altimeter series. Monitoring mid-scale circulation and sea levels requires measurement of ocean topography. Measuring wave heights is essential for operational wave forecasting. Sea-ice measurements similar to those from CryoSat-2 (though from a slightly different orbit) will be made. The single-antenna radar altimeter, with aperture synthesis processing for increased along-track resolution, balances the needs for continuity and improved performance. It will extend observations to inland waters and coastal zones.

Accompanying the altimeter will be a Precise Orbit Determination (POD) system and microwave radiometer (MWR) for removing the errors added as the signals are delayed by water vapour in the atmosphere. The altimeter will track over a variety of surfaces: open ocean, coastal sea zones, sea ice and inland waters. The chosen mode will depend on the surface below, with changes pre-programmed in the satellite to avoid data loss.



*Sentinel-3 in launch configuration*

The Ocean and Land Colour Instrument (OLCI), based on Envisat's MERIS instrument, fulfils ocean colour and land-cover objectives. The Sea and Land Surface Temperature Radiometer (SLSTR), based on Envisat's Advanced Along Track Scanning Radiometer (AATSR), is designed for ocean and land-surface temperature observations. Unlike AATSR, SLSTR has a double-scanning mechanism, yielding a much wider swath stretching almost from horizon to horizon. The OLCI and SLSTR swaths will broadly overlap, yielding extra information.

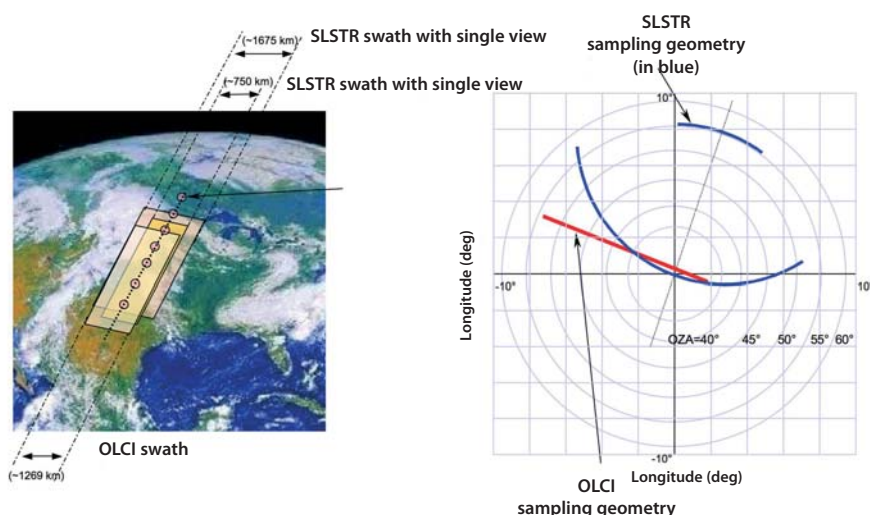
The Sun-synchronous orbit chosen is at 814 km altitude (14+7/27 revolutions per day) with a local equatorial crossing time of 10:00 a.m., as a compromise

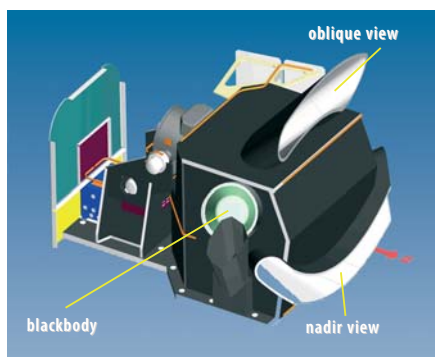
between the needs of the optical instrument and altimeter. The baseline of two satellites supports full imaging of the oceans within 2 days (even allowing for images spoiled by the Sun glinting off the water), while delivering global land coverage in just over a day at the equator and improving with latitude.

The continuous acquisitions of Sentinel-3 allow routine operations. An average of 103 Gbit of data will be downlinked once per orbit at 300 Mbit/s X-band to a single ground station with no blind orbits.

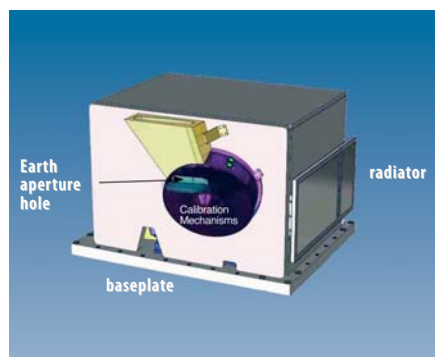
Four categories of products will be delivered: ocean colour, surface topography, surface temperature (land and sea) and land. The surface topography products will be delivered with three timeliness levels: NRT (Near-Real Time, 3 hours), STC (Standard Time Critical, 1–2 days) and NTC (Non-Time Critical, 1 month). Slower products allow more accurate processing and better quality. NRT products are ingested into numerical weather prediction and sea-state prediction models for quick, short-term forecasts. STC products are ingested into ocean models for accurate present state estimates and forecasts. NTC products are used in all high-precision climatological applications, such as sea-level estimates. The resulting analyses

*OLCI is pointed eastwards, away from the Sun, to minimise Sun-glint off the sea. SLSTR has a symmetric double-scanning geometry, producing two swaths. The wide swath totally covers the OLCI swath for product synergy. The narrow-swath data, corrected with information from the wide swath, provides nadir-centred high-accuracy sea-surface temperature*





SLSTR has a wide nadir view and a narrow oblique view



OLCI contains five cameras to continue the work of Envisat's MERIS

and forecast products and predictions from ocean and atmosphere adding data from other missions and *in situ* observations, are the key products delivered to users. They provide a robust basis for downstream value-added products and specialised user services.

### Satellite Configuration

Though carrying five instruments, Sentinel-3 is of moderate size – about 1.3 t, 3.9 m high and compatible with small launchers like Vega (baseline) and Dnepr-ST3 (back-up). It is designed for a 7-year lifetime, with 90 kg of hydrazine propellant for 12 years of operations, including deorbiting at the end.

The layout is driven by the need to provide a large anti-Sun side to cool the optical instruments.

### Optical instruments

The two optical instruments, OLCI and SLSTR, will provide a common quasi-simultaneous view of the Earth to help develop synergetic products.

The 150 kg OLCI benefits from MERIS heritage. The field-of-view is divided between five cameras on a common structure with the calibration assembly. Each camera has an optical grating to provide the minimum baseline of 16 spectral bands required by the mission together with the potential for optional bands for improved atmospheric corrections.

OLCI is an autonomous instrument with simple interfaces to the satellite, thus allowing easy integration and minimising development risks.

The 90 kg visible/infrared SLSTR measures sea- and land-surface temperatures, following the AATSR concept. Its rotary scan mirror mechanism produces the wide swath of 750 km. It features ~1 km resolution at nadir for thermal-infrared channels and 500 m for visible and shortwave infrared channels. Like AATSR, it offers dual views – inclined forward and near-vertical nadir – to provide robust atmospheric correction over the swath. The nadir and forward views are generated by separate scanners, allowing a wider swath than possible with the single conical scan of the original ATSR design.

The channel selection (1.6, 3.7, 10.8 and 12  $\mu\text{m}$  in the infrared and 0.55, 0.66 and 0.85  $\mu\text{m}$  in the visible) include the Envisat/AATSR and ERS/ATSR-2 channels for continuity. Additional channels at 1.378 and 2.25  $\mu\text{m}$  improve cloud detection, besides being used for new products.

The instrument includes onboard radiometric sources for accurate and stable in-flight calibration. The infrared detectors are cooled to 80K by active coolers.

### Topography package

The topography payload consists of the Synthetic Aperture Radar Altimeter (SRAL), MWR and POD (a satnav receiver supplemented by a laser retro-reflector). They will determine very accurately the height of the Earth surface, and in particular the sea surface, relative to a precise reference frame.

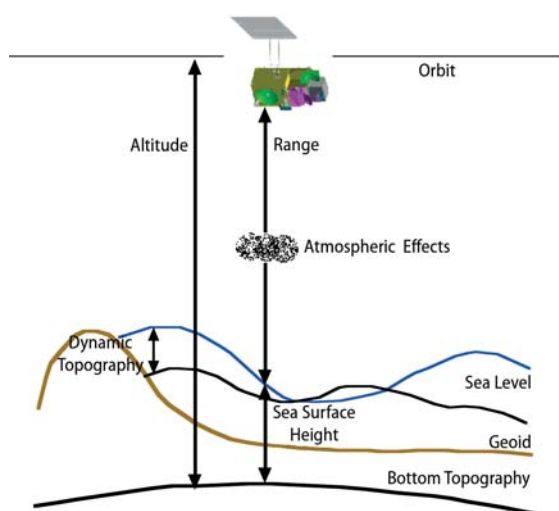
The radar altimeter determines the distance to the surface by bouncing microwave pulses off the surface. The time taken is derived very precisely by ground processing of the data. However, the propagation speed through the atmosphere is variable. The ionosphere and the troposphere add delays dependent on the density of electrons in the ionosphere, and the density of gases and the moisture content in the troposphere. The MWR determines the amount of water contained in the path of the radar pulses. The altimeter transmits pulses alternatively at two frequencies. Comparing their relative delay, the frequency-dependent part introduced by the ionosphere can then be found. The influence of gas density in the troposphere is less variable and can be determined sufficiently accurately using meteorological data and models.

Sentinel's own height will be measured with cm-accuracy by the geodetic-quality satnav receiver and laser retro-reflector.

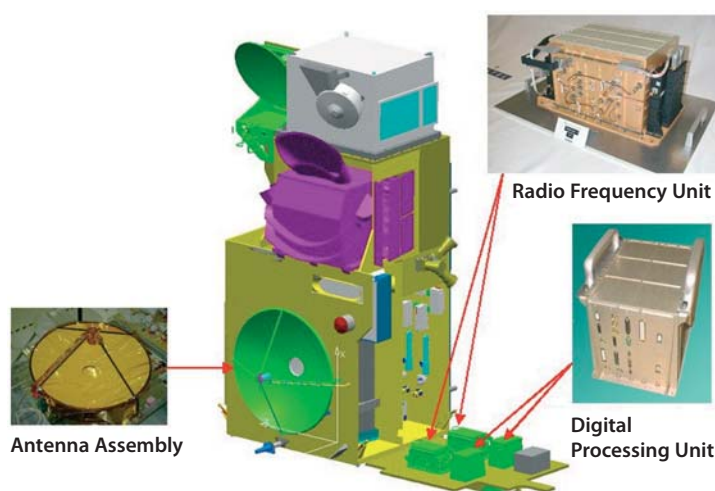
The 60 kg SRAL is a dual-frequency, nadir-looking microwave radar employing technologies from the CryoSat and Jason altimeter missions. The main range measurements are performed at 13.575 GHz Ku-band, while a second frequency at 5.41 GHz C-band allows compensation for ionospheric effects.

A conventional pulse-limited, low-resolution mode employs autonomous closed-loop echo tracking, and is the primary operational mode for observing level homogeneous and smooth surfaces, like open oceans or central ice-sheet plateaux.

For more variable surfaces, SRAL has two extra features that can be used independently or in combination: the SAR mode, similar to that of the CryoSat SIRAL instrument, and the open-loop tracking mode. In the SAR mode, the horizontal resolution is increased along the ground track by sending out signals some 10 times more often. This will be used mainly over sea-ice and ice-sheet edges and inland water. Open-loop tracking will be used mainly over discontinuous surfaces (like land-sea transitions) or rapidly varying



The measurement principle of the topography payload



Locations of the SRAL and MWR elements (green) on the satellite. SRAL is in the lower part and MWR in the upper part

topography like ice margins. In this mode, SRAL's tracking window is controlled based on *a priori* knowledge of the surface height, from existing high-resolution global digital elevation models, combined with knowledge of the location of the satellite from the satnav receiver. The main advantage is that the measurements are continuous, avoiding the data gaps typical of closed-

loop tracking, which has problems in tracking the rapid topographic changes at coastal margins and in mountainous regions.

The 26 kg MWR measures the thermal radiation emitted by Earth. The received signal is proportional to the abundance of the atmospheric component emitting at the observed frequency and the sea-surface reflectivity. This information reveals the delay added to the altimeter pulses by moisture in the troposphere.

Each of the three channels addresses a different geophysical parameter. The 18.7 GHz channel, where the troposphere is transparent, is influenced mainly by sea-surface reflectivity. This allows separation of the atmospheric signal from the sea-surface contribution in the other two channels. The 23.8 GHz channel is used mainly to determine the delay of the altimeter pulse by tropospheric water vapour. The 36.5 GHz channel primarily addresses the delay from non-precipitating clouds. The observed signals are calibrated by comparison with a precisely known and very stable electronic reference source.

The POD equipment provides the satellite altitude to an accuracy of 2 cm. The 11 kg satnav receiver will operate with Global Positioning System satellites for the Sentinel-3 first generation


and add Galileo for the following generations. The receiver can track up to 12 satellites at the same time.

The signals transmitted by the navigation satellites are also disturbed by the ionosphere. The effect is corrected by comparing two signals at different frequencies within 1160–1590 MHz.

The receiver produces an onboard height to within about 3 m, which is used to control SRAL's open-loop tracking and for Sentinel navigation. Ground processing yields the altitude to an accuracy of better than 8 cm within 3 hours for operational applications and 2 cm after some days of refinement.

Laser tracking stations will use the 1 kg retro-reflector to measure the distance to Sentinel-3 to within 2 cm. This will be done during the commissioning phase and regularly during the mission to check the other POD results.

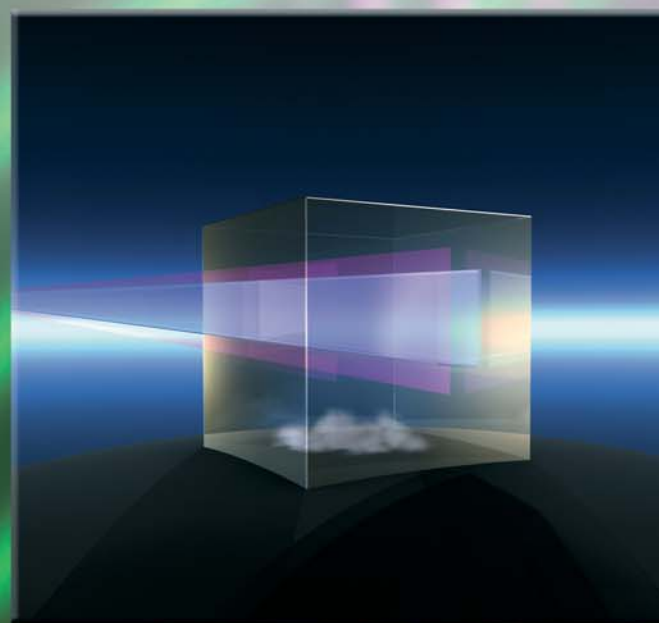
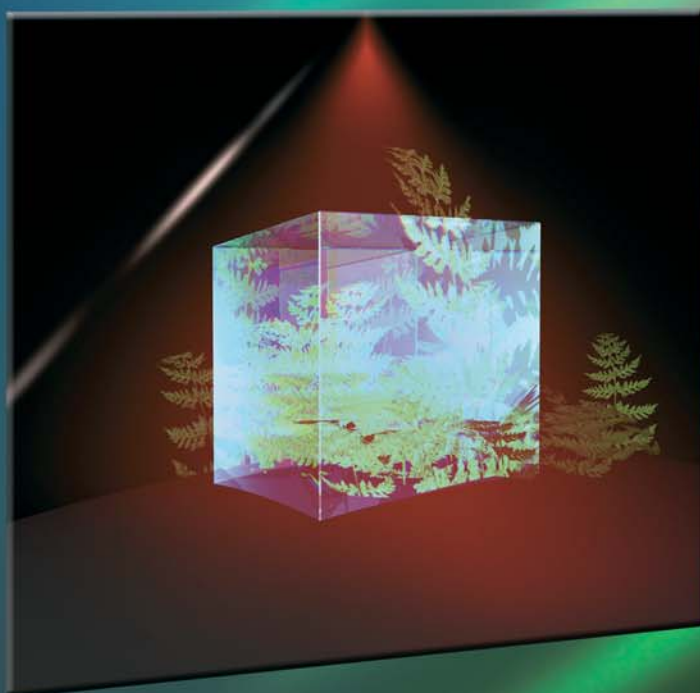
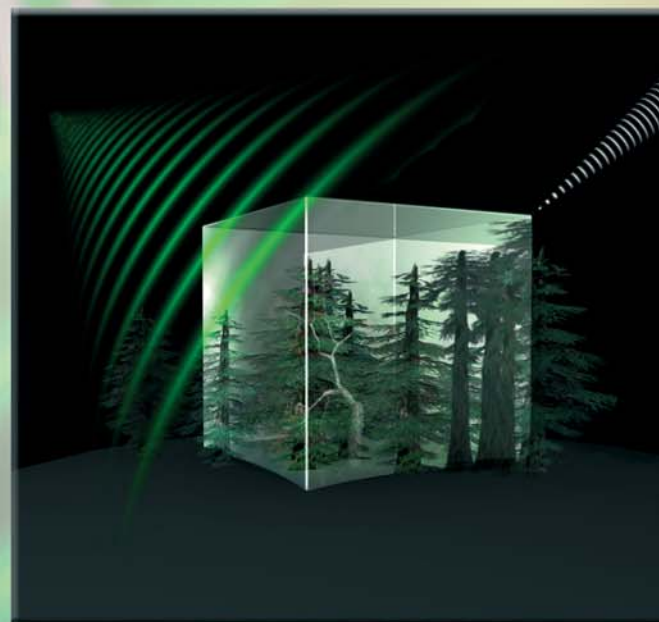
## Conclusion

GMES Sentinel-3 is a series of operational satellites that will guarantee access to an uninterrupted flow of robust global data products. Together with the other Sentinels, this mission will fulfil the monitoring needs of the GMES marine and land services and climate research communities for years to come. 

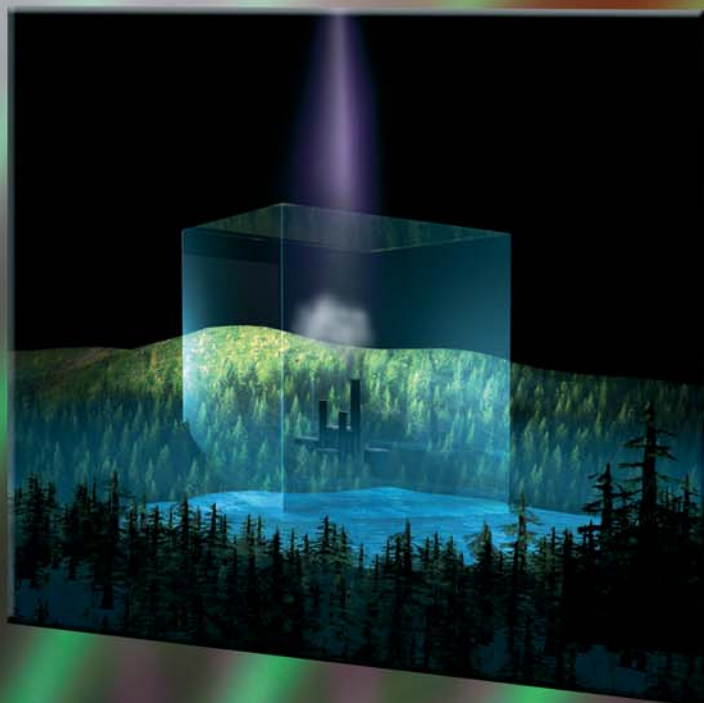
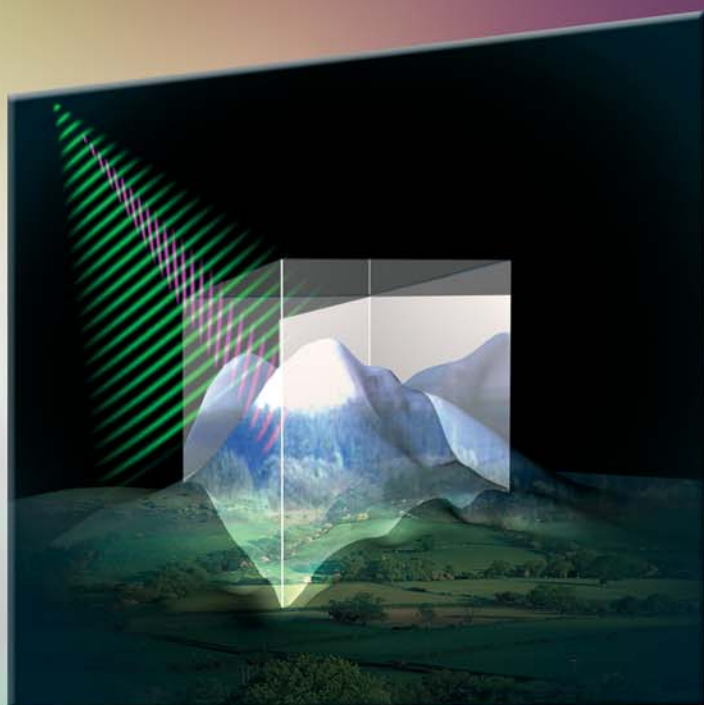


# A New Earth Explorer

The Third Cycle of Core Earth Explorers







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**E**SA's family of Earth Explorer satellites is designed in response to specific critical issues raised by Earth-scientists, while demonstrating new observation technologies. The first six Explorer missions are being prepared for launch and, in March 2005, the Agency released a new Call-for-Ideas focused on processes that are fundamental for understanding the changing 'Earth System'. Six candidates were selected in May 2006 for assessment. The final selection is expected in 2010, for launch in 2014/2015.

### Introduction

The Earth Explorer missions, as part of ESA's Living Planet Programme, seek to advance our understanding of the different 'Earth System' processes and to demonstrate new observing techniques. There are six missions already under development:

*GOCE (Gravity Field and Steady-State Ocean Circulation Explorer)*, due for launch in early 2008, will provide high-resolution gravity data to improve the global and regional models of Earth's gravity and 'geoid' (the shape

of a global ocean at rest used as a reference).

*SMOS (Soil Moisture and Ocean Salinity)*, due for launch in 2008, will globally map soil moisture and ocean salinity to improve the representation of land in global atmospheric circulation models and to characterise the role of the ocean in the climate system.

*ADM-Aeolus (Atmospheric Dynamics Mission)*, due for launch in 2009, will make novel advances in global wind-profile observations and provide global wind information that is crucial to climate research and numerical weather prediction.

*CryoSat-2*, due for launch in 2009, will determine the rate of change of variations in the thickness and mass of polar marine ice and continental ice-sheets in response to climate changes. *CryoSat-2* replaces *CryoSat*, the first Explorer mission, which was lost at launch in 2005.

*Swarm*, due for launch in 2010, is a constellation of three satellites to survey the geomagnetic field and its evolution. It will provide new insights into the Earth System by improving our understanding of the Sun's influence and Earth's interior.

*EarthCARE (Earth Clouds and Radiation Explorer)*, due for launch in 2012, is a joint European-Japanese mission to measure cloud and aerosol properties to help understand their interactions with Earth's radiative processes and climate-change predictions.

In March 2005, ESA released a new Call-for-Ideas to scientists from ESA Member States and Canada to solicit proposals for the next Earth Explorer. The scientific priorities focused on the global carbon and water cycles, atmospheric chemistry, climate and the human element as a cross-cutting issue. Twenty-four proposals were received and evaluated as 'Core' missions (these address specific areas of great scientific interest; 'Opportunity' missions are faster, cheaper and not necessarily led by ESA). Six candidates were short-listed

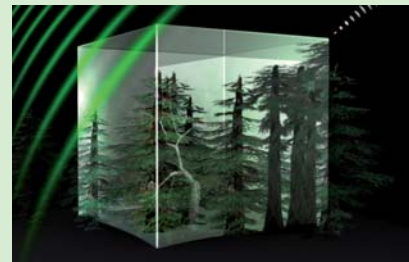
in May 2006 for dedicated assessments, with industrial activities beginning in May/June 2007:

- BIOMASS (to monitor Earth's biomass for carbon assessment);
- TRAQ (TRopospheric composition and Air Quality);
- PREMIER (PRocess Exploration through Measurement of Infrared and millimeter-wave Emitted Radiation);
- FLEX (FLuorescence Explorer);
- A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth);
- CoReH<sub>2</sub>O (Cold Regions Hydrology High-resolution Observatory).

## BIOMASS

The greatest uncertainties in the global carbon cycle involve estimating how carbon dioxide is taken up by land. The mission aims to improve the present assessment and future projection of the terrestrial carbon cycle by providing consistent global maps of forest biomass and forest area, forest disturbances and recovery with time, and the extent and evolution of forest flooding. Forest biomass is a key factor in the carbon cycle but it falls in a critical gap in existing measurement techniques. When coupled with biophysical models, above-ground biomass provides information on carbon dioxide stocks and fluxes and is a

## BIOMASS Characteristics



Mission duration: 5 years  
 Orbit: Sun-synchronous, local time ~06:00  
 Coverage: global, vegetated areas  
 Revisit time: 25 days  
 Instrument: P-band (435 MHz) synthetic aperture radar  
 Polarisation: full polarimetry and/or circular/dual polarisation  
 Data acquisition: single-pass/repeat-pass polarimetric interferometry  
 Resolution: ≤50 x 50 m (≥4 looks)  
 Swath width: ≥100 km

sensitive indicator of changes in land use and natural biophysical processes.

The BIOMASS primary objectives would be achieved through a P-band (435 MHz) synthetic aperture radar (SAR). Finding the above-ground biomass from calibrated SAR images will take advantage of the high sensitivity of P-band reflection to biomass.

Complementary classification techniques would exploit the polarisation of the radar signatures from different types of forest to label surface features by comparison with known reference cases.



BIOMASS: global measurements of forest biomass

Analysing the reflected radar beam would provide information on the forest vertical structure and height, with the potential to extend the observation range and/or to increase the estimation accuracy of biomass products.

The secondary objectives arise from the opportunity to explore Earth's surface with a longwave SAR for the first time. New information on ice structure, ice thickness and subsurface geomorphology in arid areas would be expected.

The satellite would carry the side-looking radar in a Sun-synchronous orbit optimised to reduce ionospheric effects on signal propagation. The orbit would cover all forested areas every 25 days globally to satisfy the major mission objectives.

BIOMASS would be the first mission dedicated to estimating biomass globally using low-frequency SAR observations.

## TRAQ

Changes in the composition of Earth's troposphere (altitude 0–17 km) are a serious and growing problem in many regions of the world. The composition affects air quality regionally and globally as well as the climate via radiatively active trace gases and aerosols. TRAQ would assess the air quality changes at global and regional scales, determine the strength and



*TRAQ: air quality and long-range transport of air pollution*

distribution of the sources and sinks of trace gases and aerosols influencing air quality, and help in the understanding of the role of tropospheric composition in the global change.

A new synergistic sensor concept is proposed: a high spectral resolution pushbroom shortwave spectrometer (SWS) in the range from ultraviolet to near-infrared; a high spectral resolution across-track scanning longwave spectrometer (LWS) in the thermal-infrared with an embedded cloud imager and a multi-view polarisation-resolving pushbroom radiometer. A shortwave-infrared band is also required; it would be included either in the LWS or SWS.

The cloud imager is a dual-band infrared instrument that would optimise in real time the pointing direction of the thermal-infrared spectrometer towards areas clear of clouds. The mission will offer a pixel size of 15–40 km, depending on the spectral bands.

TRAQ's orbit is selected to offer near-global coverage and unique diurnal time sampling with up to five daytime observations over Europe and other mid-latitude regions. This can be achieved by using a non-Sun-synchronous low drifting orbit with an inclination around 57°.

TRAQ would provide the following parameters: ozone, nitrogen dioxide, sulphur dioxide, HCHO (formaldehyde), water vapour and HCOOH (1,2-ethanedione) tropospheric columns from the ultraviolet/visible/near-infrared spectral region; carbon monoxide and methane tropospheric columns from the shortwave infrared spectral region; height-resolved tropospheric profiles of ozone and carbon monoxide from the thermal-infrared channels; detailed tropospheric aerosol characterisation from the multi-view polarisation-resolving radiometer and in combination with the ultraviolet/visible/near-infrared spectrometer.

TRAQ would be the first mission fully dedicated to air quality and the science issues around tropospheric composition and global change.

## TRAQ Characteristics



Mission duration: 3–5 years  
Orbit: drifting low orbit, inclination ~57°  
Coverage: latitudes 40°S–60°N  
Revisit time: 3 months  
Temporal sampling: up to 5 times/day over continental areas within 40–55°N  
Instruments: UV/visible/near-infrared spectrometer (SWS); thermal-infrared spectrometer (LWS); shortwave infrared (either SWS or LWS); infrared Cloud Imager; multi-view polarisation resolving radiometer  
Resolution: 15–40 km (UV/shortwave infrared), 15 km (thermal-infrared); 1 km (Cloud Imager); 1–4 km (multi-view polarisation resolving radiometer)

## PREMIER

The primary aim of PREMIER is to explore the processes that control the composition of the mid/upper troposphere and lower stratosphere (altitude 3/10–51/58 km). It would be the first mission to explore from space the links between atmospheric composition and climate globally in unprecedented detail and, for the first time, with sufficient resolution.

PREMIER would observe the distributions of trace gases, particulates and temperature in this region down to finer scales than any previous satellite mission. It would also facilitate integration with measurements made at higher resolution at particular locations and times by ground and airborne instruments.

The secondary aim is to explore processes that control the composition of the lower troposphere/boundary layer and the links to higher layers.

Through synergy with Europe's



**PREMIER:** atmospheric processes linking trace gases, radiation, chemistry and climate

MetOp satellite, flying in tandem, the composition of the lower troposphere will be clearly discriminated from that of higher layers. The mission objectives call for 3-D sounding of the mid/upper troposphere and stratosphere by two

complementary limb-sounders at infrared and mm/sub-mm wavelengths. The limb would be imaged at high resolution to account for the effects of clouds and to derive cloud/aerosol properties.

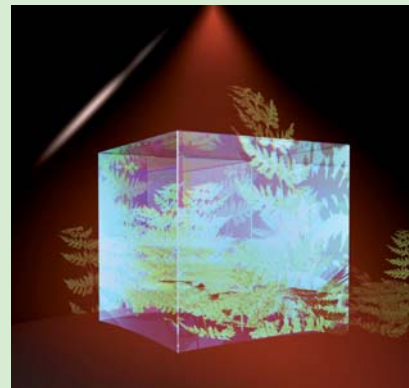
The infrared sounder is an imaging Fourier transform spectrometer either in a high spectral resolution mode, optimised for observation of minor trace gases or in a high spatial resolution mode, optimised to resolve atmospheric structure.

The mm/sub-mm sounder is a limb-sounding heterodyne receiver with a channel in the 320–360 GHz range for measurements of the main target species of water, ozone and carbon monoxide (or with a slight spectral shift to observe hydrogen cyanide, HDO water isotope, nitrous oxide, chlorine monoxide, nitric acid) in the upper troposphere/lower stratosphere altitude range, and a channel in the 488–504 GHz range with improved sensitivity to stratospheric target species (such as chlorine monoxide, nitrous oxide, water and its isotopes). The instrument would be developed as a Swedish national contribution to the mission.

### FLEX

The mission would improve our knowledge of the carbon cycle by globally measuring the efficiency of photosynthesis of ecosystems. Photosynthesis by land vegetation is an important

### FLEX Characteristics



Mission duration: 3–5 seasonal cycles in northern and southern hemispheres  
Orbit: Sun-synchronous, local time descending node around 10:00  
Coverage: global coverage of land surfaces (56°S–75°N)  
Revisit time: 1 week  
Instruments: Fluorescence Spectrometer; Visible/Near-Infrared Imaging Spectrometer (0.45–1  $\mu\text{m}$ ); Shortwave Infrared Imager (1.4–2.2  $\mu\text{m}$ ); Thermal Infrared Imaging Radiometer (8.8–12  $\mu\text{m}$ ); optional multi-view Visible/Shortwave Infrared Imager  
Resolution: 100–300 m

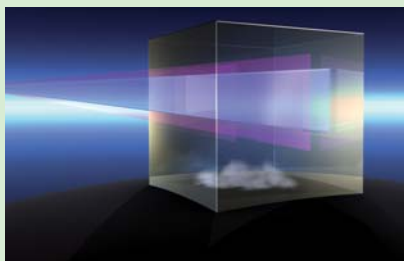
component of the global carbon cycle, closely linked to the hydrological cycle through transpiration. This type of information has never been available before from space observations.

Fluorescence under sunlight is a sensitive and direct probe of photosynthesis in both healthy and perturbed vegetation. It gives an early indication of plant stress before it can be observed by more conventional means. For FLEX, direct fluorescence measurements of vegetation chlorophyll are proposed, complemented by hyperspectral reflectance and canopy temperature to help interpret the fluorescence.

The core instrument is a spectrometer to measure the fluorescence in the blue, red and far-red using the ‘Fraunhofer Line Discriminator’ method.

The fluorescence of chlorophyll in the red and far-red is the key for monitoring photosynthesis. Blue-green fluorescence adds information about the vegetation’s status and health. The complementary

### PREMIER Characteristics



Mission duration: 4 years  
Orbit: Sun-synchronous in tandem with MetOp (835 km)  
Coverage: near-global, latitudes 80°S–80°N  
Instruments: Infrared Limb Sounder (IRLS); Infrared Cloud Imager (IRCI); Microwave Limb Sounder (MWLS)  
Vertical coverage: IRLS 48 km (3/10–51/58 km arctic/tropics); IRCI 25 km (3/10–28/35 km arctic/tropics); MWLS 23 km (5–28 km upper troposphere/lower stratosphere, 12–35 km stratospheric mode)  
Vertical sampling: IRLS 0.5–2 km (depending on mode and range); IRCI 0.5 km; MWLS 1.5 km  
Horizontal sampling: IRLS 25–80 km across-track, 50–100 km along-track; IRCI 4 km across-track, 8–50 km along-track; MWLS  $\leq 50$  km ( $\leq 300$  km in stratospheric mode) along-track



FLEX: global photosynthesis



A-SCOPE: global carbon cycle and regional carbon dioxide fluxes

instruments are: a coarse resolution visible/near-infrared spectrometer and a 6-channel shortwave infrared imager for basic vegetation parameters, a thermal-infrared radiometer with four channels for estimating the temperature of the vegetation canopy. An optional off-nadir two–three band visible/ short-wave-infrared imager would help to correct for atmospheric effects.

A single satellite in a Sun-synchronous orbit is the baseline for the mission. A local time of 10:00 would provide adequate balance between maximum fluorescence emission and maximum solar illumination. A spatial resolution of the order 100–300 m is required.

### A-SCOPE

A-SCOPE, like other missions to observe carbon dioxide from space, would be an innovative source of data for understanding the carbon cycle and validating inventories of greenhouse gas emissions. It would provide near-global coverage with good time resolution, mapping the sources and sinks of carbon dioxide on a scale of 500 km or better. This is a major improvement over today's observation network and forthcoming *in situ* and space systems.

A-SCOPE would be the first mission dedicated to measuring carbon dioxide with an active 'Differential Absorption Lidar' (DIAL) sensor. It would provide better accuracy and spatial and temporal coverage than the planned satellites carrying passive sensors: OCO (Orbiting Carbon Observatory; NASA)

and GOSAT (Greenhouse gases Observing Satellite; JAXA). Only active sensing would provide high-accuracy measurements and truly global, day/night coverage under both clear and broken-cloud conditions.

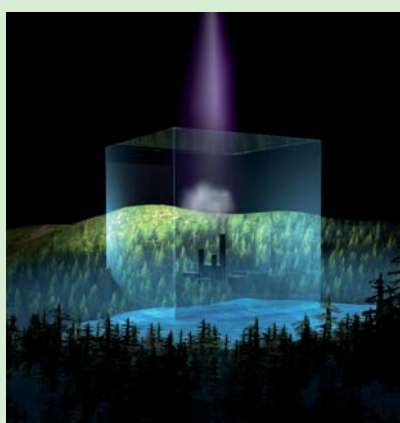
DIAL would measure the reflections from Earth's surface and clouds tops of laser pulses at slightly different wavelengths. Carbon dioxide in the atmosphere would absorb some of the laser light, varying with wavelength. The differences between the two wavelengths yields the concentration of carbon

dioxide, with a target minimum accuracy of 1.5 parts per million by volume and a goal of 0.5 ppmv. Suitable absorption can be found in the near-infrared around 1.6  $\mu\text{m}$  and 2.1  $\mu\text{m}$ .

In both spectral regions, temperature sensitivity and interference from water vapour and other trace gases can be minimised by careful selection of the laser's exact wavelengths.

A camera operating in the visible, near-infrared and thermal-infrared with a narrow swath width of 50 km would put the measurements in context with a broader view of the clouds and Earth's surface texture.

### A-SCOPE Characteristics



Mission duration: 3–5 years  
Orbit: Sun-synchronous  
Coverage: near-global  
Instruments: nadir-viewing pulsed-laser DIAL at 2.1  $\mu\text{m}$  or 1.6  $\mu\text{m}$ ; visible/near-infrared/thermal-infrared Imaging Camera  
Vertical resolution: total column  
Horizontal resolution: DIAL 50 km along-track; Imaging Camera 100 m

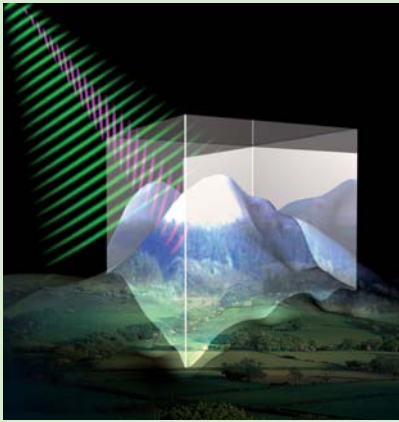
### CoReH<sub>2</sub>O

The mission aims at all four science priorities identified in the Call for Ideas, with emphasis on the global water cycle and significant contributions in understanding the global carbon cycle, atmospheric chemistry and climate, as well as assessing the human impact on these aspects.

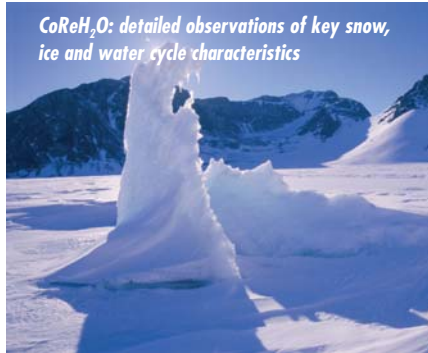
The mission would focus on detailed observations of important snow, ice and water-cycle parameters. It would improve our understanding and modelling of surface processes and surface/atmosphere exchange mechanisms in regions where snow and ice play a major role in the water and energy cycles, as well as in biospheric processes.

The key parameters to be found describe a snow layer: extent, thickness and water-equivalent (the amount of water from the instantaneous melting of

CoReH<sub>2</sub>O Characteristics



Mission duration: 5 years  
 Orbit: Sun-synchronous, local time 06:00  
 Coverage: test sites (phase-1); global coverage of snow and ice areas (phase-2)  
 Revisit time: 3 days (phase-1); ≤15 days (phase-2)  
 Instrument: dual-frequency (9.6/17.2 GHz) synthetic aperture radar  
 Polarisation: dual (vertical-vertical; vertical-horizontal)  
 Resolution: ≤50 x 50 m (≥5 looks)  
 Swath width: ≥100 km



CoReH<sub>2</sub>O: detailed observations of key snow, ice and water cycle characteristics

The secondary objectives aim at ice-surface parameters that would help the analyses of sea-ice dynamics in local and global climate models.

Producing this geophysical information depends on backscatter measurements from a synthetic aperture radar at X- and Ku-band at relatively high resolution. Ku-band is more sensitive to shallow dry snow, while X-band provides greater penetration of deeper snow layers. The combination of observations at two frequencies would improve the accuracy of the snow information and provide a high level of information on sea ice, ice sheets and glaciers.

Measurements of the polarisation of the reflected radar pulses are important for separating surface and volume scattering and for estimating the snow water equivalent.

a snow pack). These observations will help data-assimilation systems, numerical weather prediction and climate models, and the understanding and modelling of land-cryosphere-atmosphere exchange processes.

The mission is based on a single satellite in a Sun-synchronous orbit with a local time early in the morning at around 06:00 to avoid the effects of daily warming and melting. The mission would be divided into two phases: the first phase (2 years) with revisits every 3 days, in order to observe the more rapid processes in selected test areas. These frequent visits are at the expense of limited coverage. The second phase (2–3 years) would revisit every 15 days, with near-global coverage of snow and ice areas.

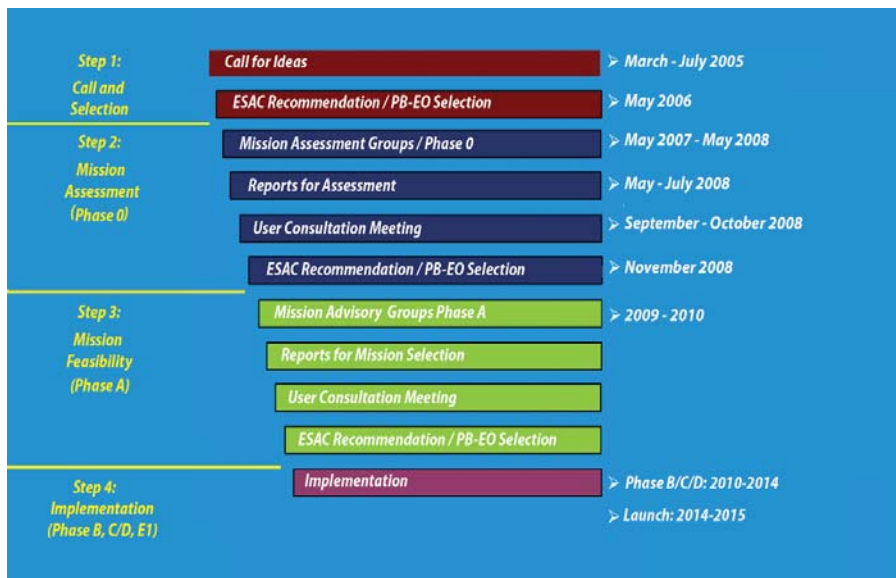
The Selection Process

The current cycle will lead to the selection in 2010 of the seventh Earth Explorer, due for launch in 2014/2015. As in the previous cycles, the process has four steps. The first step (Phase-0: mission assessment) began in 2006 with the nomination of the Mission Assessment Groups that provide independent advice to the Agency for the definition of the detailed scientific objectives of the missions, the consolidation of the mission requirements, the definition of required scientific support and the production of the Reports for Assessment. The other major element of this step is the Phase-0 industrial studies, beginning in May/June 2007 to identify end-to-end implementation concepts for each mission as well as their preliminary feasibility in terms of required technology and compliance with programme constraints. The assessment step will conclude with a User Consultation Process that reviews the assessments and proposes a short-list of candidates to enter the next step in 2009 (Phase-A: mission feasibility).

At the end of Phase-A in 2010, a second User Consultation Process will recommend the final candidate to enter the development phases (B/C/D) and finally join the Earth Explorer family as the seventh mission of the series.

Acknowledgments

The authors thank the members of the Mission Advisory Groups supporting ESA in the mission definition.



The background of the poster features a large, detailed image of the Moon in the upper left corner. The rest of the background is a dark space filled with stars. Several glowing blue lines represent orbital paths, some of which are complex and looping. In the lower right, there is a circular inset showing three men in red shirts working together at a desk, looking at a laptop and a tablet. A satellite with solar panels is shown in the lower left, with a blue arrow pointing towards the Moon. The overall theme is space exploration and satellite technology.

# SMART-1

## Impact on the Moon

- Moon Science, Orbit Reboots and Impact Observations

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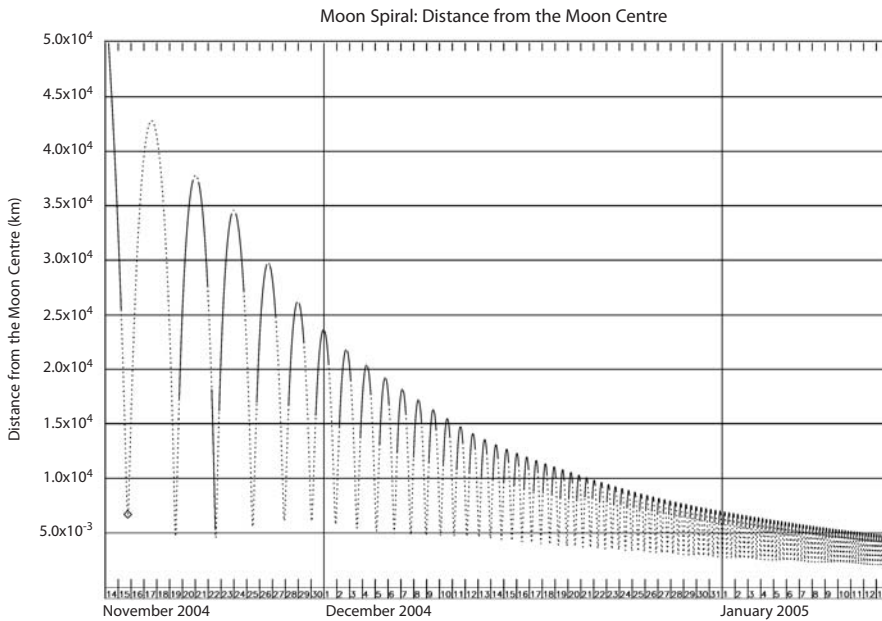
*Peter Rathsmann, Joakim Kugelberg  
& Per Bodin*  
Swedish Space Corporation, Sweden

**S**MART-1 was launched in September 2003 and impacted the Moon 3 years later. It was the first of ESA's Small Missions for Advanced Research in Technology, with the main goal of testing electric propulsion. Following a spectacular navigation strategy, the craft reached the Moon, where its orbit was optimised for scientific observations. The instruments provided data throughout the mission, interrupted only by manoeuvres. The last of these had to be done with the attitude thrusters after exhausting the ion thruster's xenon fuel. The impact was observed from Earth by radio and infrared telescopes worldwide in an international campaign.

### At the Moon

Immediately after the Moon's gravity captured SMART-1 on 15 November 2004, the ion engine was used to begin the spiral down into the final orbit. The operational lunar orbit was reached at the end of February 2005, requiring 13.5 kg of xenon and 236 thrust periods totalling 953 hours by the ion engine. The favourable launch date and the good performance of the electric propulsion system and the solar panels





SMART-1 spiralled down into its final orbit using its xenon thruster. The dotted parts of the curve show the thrust periods

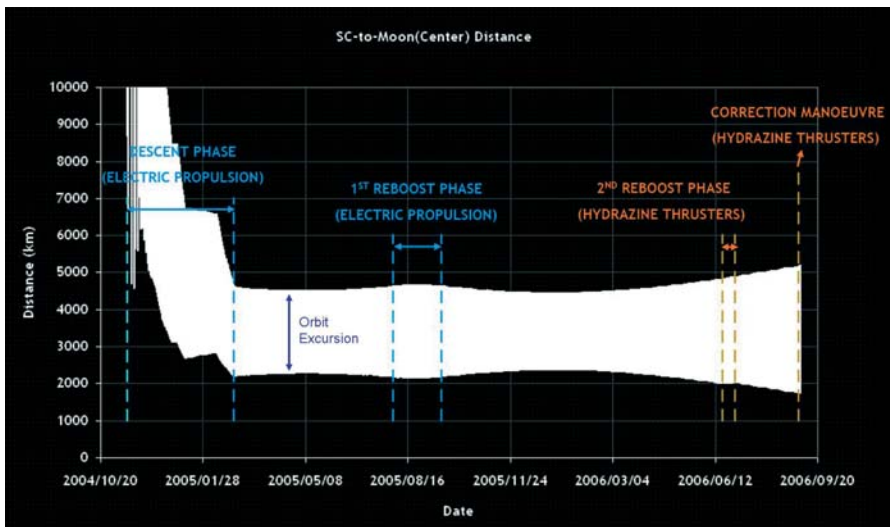
during the cruise from Earth saved 5.5 kg of xenon, which could then be used to lower the highest point of the orbit ('apolune') from the planned 10 000 km to 4600 km, improving the resolution of the science observations.

After achieving the primary goal of testing and validating SMART-1's new technologies – especially the electric propulsion system – the mission was

handed over to the Solar Systems Science Operations Division, who converted it into a scientific lunar mission. The main instruments were:

- D-CIXS (Demonstration of a Compact X-ray Spectrometer): an X-ray spectrometer to investigate the composition of the Moon;
- AMIE: Advanced Moon Micro-

SMART-1 at the Moon. The left scale shows the distance from the Moon's centre. The bottom of the white band shows the closest approach each orbit (perilune); the top marks the highest (apolune)



- Imager. A miniaturised camera with a 4-band filter;
- SIR: an infrared spectrometer to search for ice and make a mineralogical map.

The science phase began in March 2005. The new orbit period, reduced to 5 hours from around the 12 hours originally planned, had major consequences for some of the ground systems and the spacecraft. With more orbit revolutions available, more scientific observations could be made, so the mission planning system had to be upgraded to cope with the increased number of commands (>2000/day on average) and data dumps. SMART's memory stores, logic and distribution had to be redesigned to cope with the increased data load. All the payloads were put together in a single memory store, permitting the full automation of all science data dumps. This ultimately led to a high degree of automation of all ground and onboard operations: 70% of the ground station contact periods were unmanned towards the end of the mission.

Consideration of extending the mission started soon after SMART-1 was captured by the Moon. Several strategies and cases were evaluated, aiming at improving the scientific observations during the extension. The best option could only be achieved by increasing the 'argument of perilune' (the position of the closest approach to the Moon) to improve the illumination conditions, coincidentally avoiding early impact. This required using up the remaining xenon and giving up any further control over the orbit for the rest of the mission.

The manoeuvres began on 2 August 2005 and continued through 207 revolutions around the Moon, until 17 September 2005. The ion thrusting required new procedures to use the xenon beyond the minimum residual of 1.8 kg originally specified by the manufacturer. The last few days of operations consisted mainly of letting the almost empty high-pressure tank fill

up the downstream low-pressure tank to about 2 bars, the bare minimum that was needed to fire the ion engine before it flamed out. The last pulse lasted just 10 minutes before the engine flamed out for the last time.

### Science at the Moon

All of the scientific instruments were called upon during the observation phase. The team at the Science and Technology Operations Centre at ESTEC developed special tools to get the most out of these observations. Most observations were done with the instruments pointing towards the Moon's centre, with the solar array square-on to the Sun ('nadir pointing'). Two special pointing modes could also be used for short periods: push-broom and target tracking.

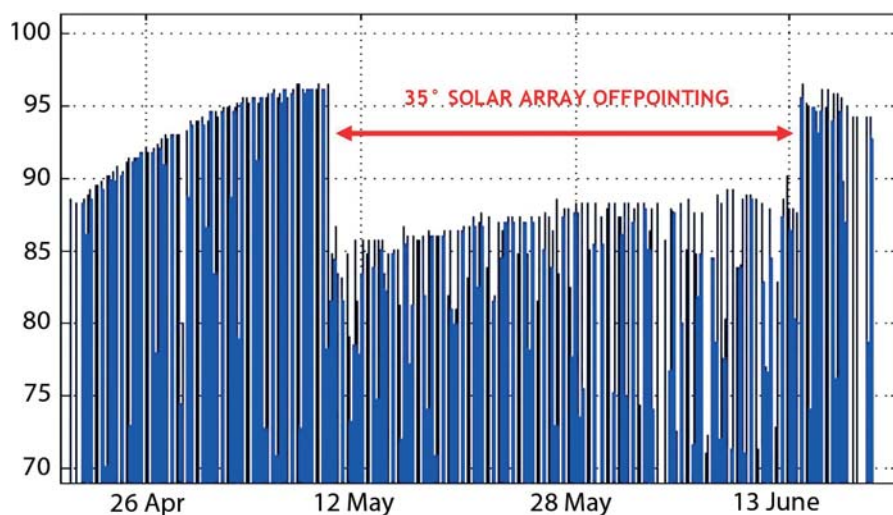
In the push-broom mode, AMIE took a sequence of images along the ground-track. Colour images were created by combining the same scenes shot through different filters.

Occasionally, SMART-1 used target-tracking: as the craft travelled around the Moon at several hundred metres per second, AMIE was kept pointing at the same target.

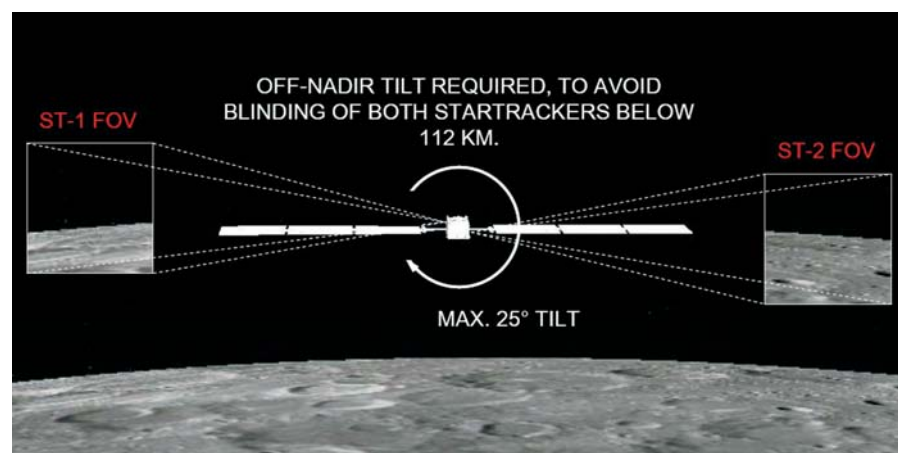
### Solar array off-pointing

Analysis of the expected Moon impact by the Thermal & Structures Division at ESTEC concluded that the solar array temperature could rise too high in May 2006. For some time during each orbit, SMART-1 was in full sunlight and close to the lunar surface. In that situation, the front sides of the solar wings were heated by the Sun as the backsides were exposed to a fully illuminated Moon. This caused the array temperature to rise to potentially dangerous levels, to around 97°C – up to 10°C higher than predicted.

Between 9 May and 13 June 2006, the Flight Control Team angled the solar wings 35° from the Sun, immediately cooling the panels by 13°C and eliminating the risk of damage, at the expense of an 18% drop in power generation.



Angling the solar wings 35° from the Sun solved the overheating problem. The vertical axis shows the array temperature in °C



Nadir-pointing was not possible below 112 km

### The Moon was everywhere!

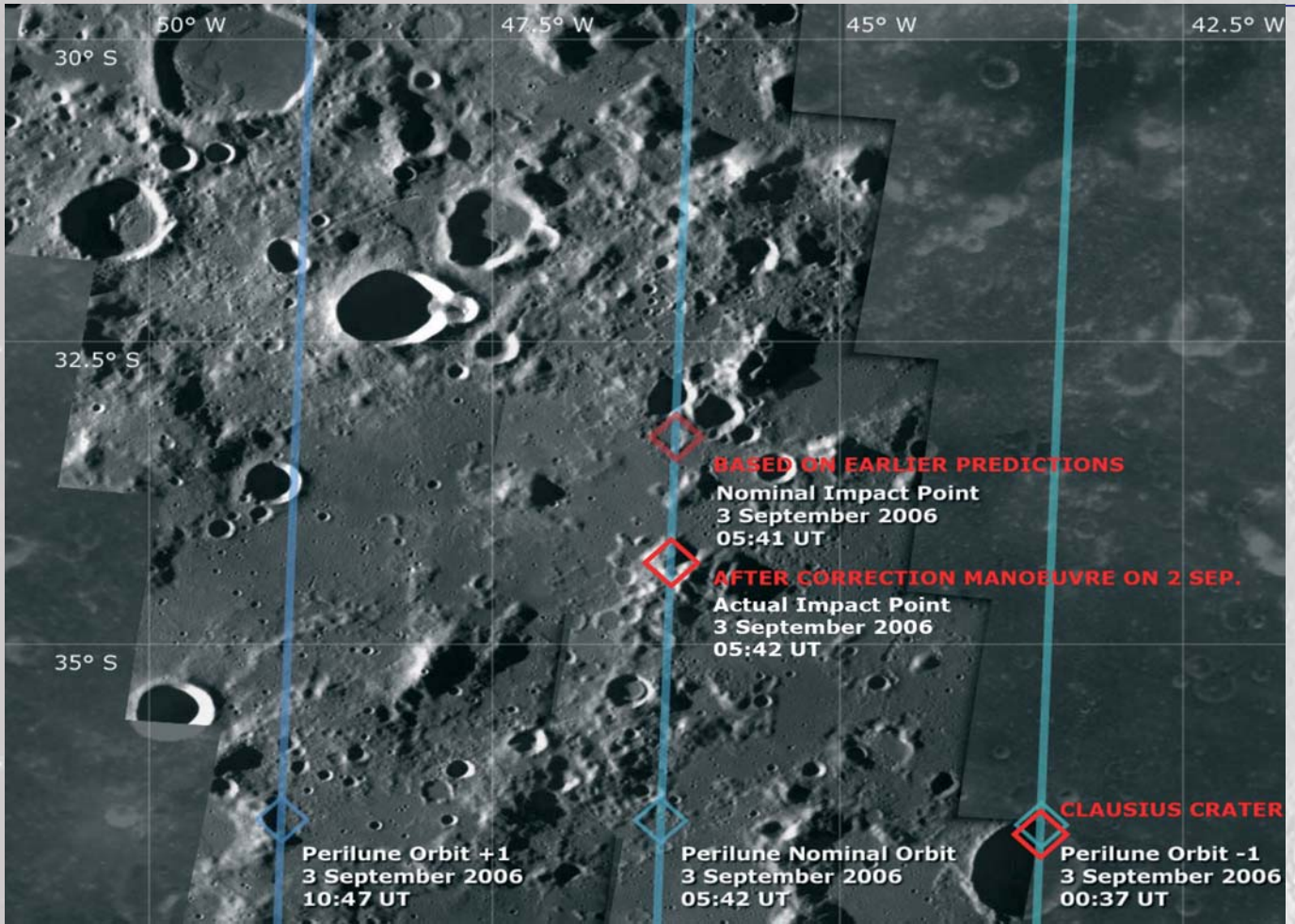
Getting closer to impact, it became increasingly difficult to avoid violating spacecraft rules. At low altitude, as SMART's sky was filled by the Moon, pointing was a problem, as both star trackers were threatened with blinding.

Pointing at a fixed spot was no longer feasible at altitudes below 240 km because SMART could not turn fast enough. Nadir-pointing was no longer possible below 112 km, because both star trackers had the surface in their fields of view. This was finally solved by tilting SMART by 25° from nadir during perilune passages.

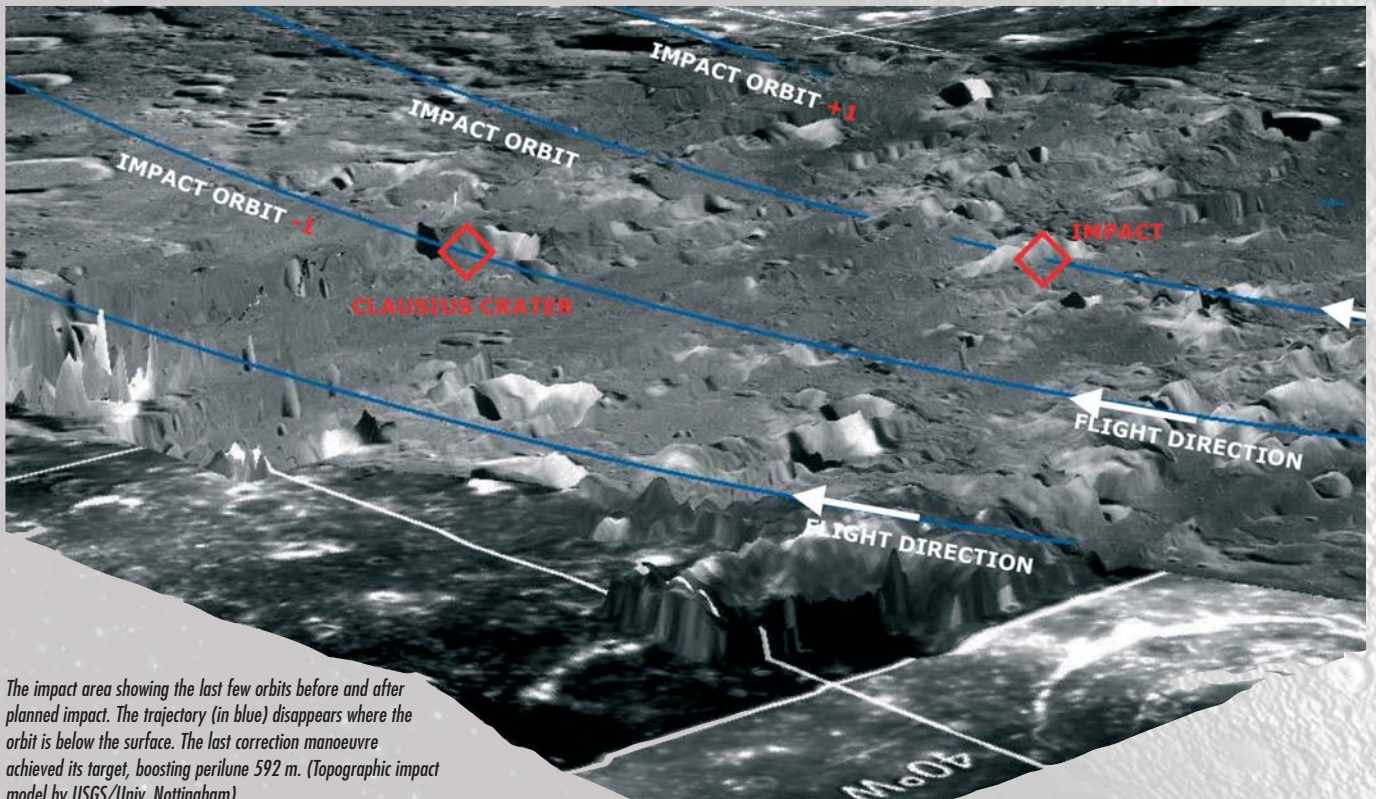
### Moon Impact

From the end of the reboost phase in September 2005, SMART-1 was flying around the Moon without orbit control. The height of its closest approaches () 'perilune' was gradually falling as perturbations from Earth's gravity took their inevitable toll.

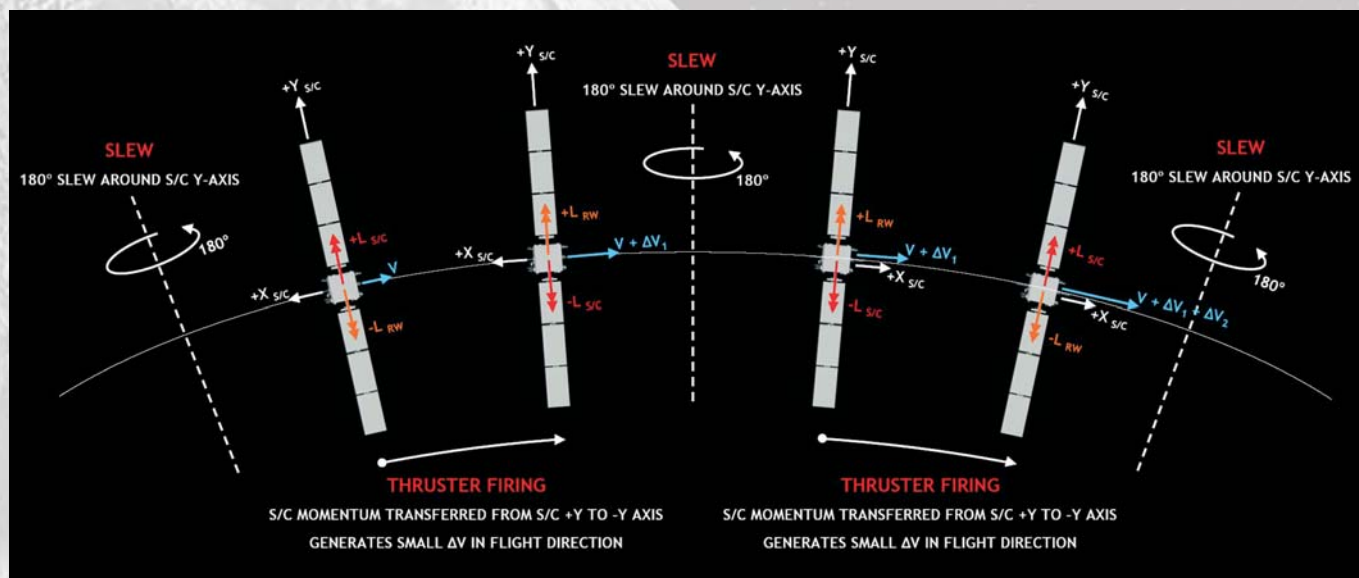
The orbit predictions carried out in early 2006 indicated that impact would occur on the far side by mid-August 2006. The scientific community, interested in organising a campaign to observe the impact, requested that ESOC and the Swedish Space Corp should investigate ways to shift the impact to the near side. This happened at



SMART-1 might have hit crater Clausius



The impact area showing the last few orbits before and after planned impact. The trajectory (in blue) disappears where the orbit is below the surface. The last correction manoeuvre achieved its target, boosting perilune 592 m. (Topographic impact model by USGS/Univ. Nottingham)



The reboost strategy

a stage when the ion engine had already exhausted its fuel.

The question was how to obtain the ~11.8 m/s change in velocity ('delta-V') to raise the orbit by just 90 km. The only option was to use the attitude thrusters. Since SMART-1 was designed to be propelled only by electric propulsion, the chemical thrusters were optimised for attitude control (by offloading the angular momentum built up in the reaction wheels).

The Flight Dynamics Team analysed the possibility of harnessing the small delta-V incidentally produced by firing the attitude thrusters as they offloaded the reaction wheels. They finally came up with a complex scheme involving a series of offloadings around apolune, transferring SMART's angular momentum from one side to the other, and vice versa. In between reaction wheel offloadings, the craft would then be slewed such that the delta-V was aligned with the flight direction. The overall effect was the desired orbital change.

The attitude-thruster reboost phase started on 19 June 2006 and finished on 2 July 2006. During 65 revolutions around the Moon, SMART-1 performed seven wheel offloadings per orbit in the ~3 hours centred around apolune, accumulating 520 offloadings.

For comparison, a similar delta-V would require only a few minutes' thrust by a satellite like Mars Express.

#### Approaching impact

A week before impact, the Mission Control Team together with Industry decided to take advantage of the frequent startracker blindings by the Moon. The startrackers gathered some 150 images between 12:15 and 13:06 UT on 1 September while going through perilune (altitude ~12 km). The images were compiled into a movie that can be viewed at:

[http://www.esa.int/SPECIALS/SMART-1/SEMZ16BVLRE\\_0.html](http://www.esa.int/SPECIALS/SMART-1/SEMZ16BVLRE_0.html)

[http://esamultimedia.esa.int/multimedial/smart-11060901\\_Startracker\\_Auto\\_Imaging\\_v4.wmv](http://esamultimedia.esa.int/multimedial/smart-11060901_Startracker_Auto_Imaging_v4.wmv)

#### The rim of Clausius Crater

For months, the best information the Mission Control Team could obtain about the surface in the impact area was derived from the US Clementine lunar orbiter. This was initially used to select the impact date and time. Four days before impact, the Flight Dynamics Team contacted Anthony Cook of the University of Nottingham (UK). Dr Cook, a specialist in 3-D digital image

interpretation and stereo image analysis, applied the SMART-1 orbit to his 3-D topographic model of the Moon – and obtained a surprising result. His analysis in cooperation with Mark Rosiek of the US Geological Survey indicated a high probability of hitting the rim of Clausius, a medium-sized crater at 43.5°W/36.5°S during the perilune passage on the penultimate orbit.

There was no time to confirm this result independently, so the Mission Control Team organised an internal meeting to decide what to do. If Cook and Rosiek were right, then the impact would occur an orbit earlier, jeopardising the observation campaign, unless a last-minute manoeuvre was done just 2 days before expected impact. The risk was that the orbit might be raised too much, causing the impact to occur an orbit later. It was a difficult dilemma, with a short time for a decision.

The Team gathered all the images already taken by SMART-1 of the potential impact area in order to correlate them with the 3-D topography model provided by Cook and Rosiek. This exercise confirmed the topography of the model. The Team accepted that the orbit could intersect the rim of Clausius, as the rim proved to be ~1500 m higher than expected from Clementine.



The impact site as viewed from Earth

The decision was to maximise the probability of impacting as planned during the morning of 3 September. As a result, during the night of 1–2 September, the controllers had to make a last correction manoeuvre to boost the penultimate perilune by a mere 600 m; 592 m was achieved.

**Impact observations**

Impact was now expected on the Moon's near side, in a dark area close to the terminator (the line separating day from night), at a grazing angle of 5–10° and a speed of ~2 km/s. The time and location were planned to favour observations of the event from telescopes on Earth.

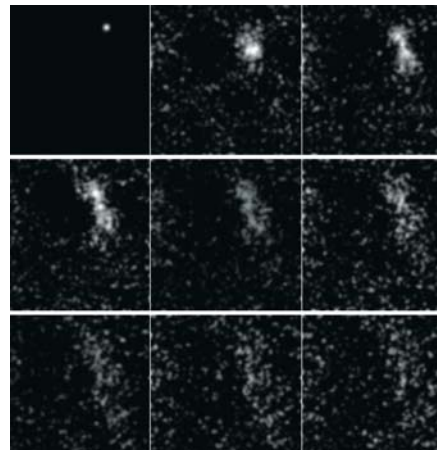
The predicted effects included a thermal flash and possible fireball from the leftover hydrazine fuel aboard

SMART-1, a crater perhaps 5–10 m across, and dust and other ejected material travelling some distance across the surface.

The observation campaign counted on professional and amateur observers worldwide, including South Africa, the Canary Islands, South America and the USA. It involved a core of participating telescopes, including: the South African Large Telescope (SALT), the Calar Alto observatory in Andalucía (E), the ESA Optical Ground Station on Tenerife (E), the CEA Cariri observatory in Brazil, the Argentina National Telescope, the Canada-France-Hawaii Telescope (CFHT), the Japanese Subaru Auxiliary telescopes on Hawaii, and Sweden's Odin satellite.

Five radio telescopes were coordinated by the Joint Institute for VLBI (Very Long Baseline Interferometry) in Europe (JIVE): the Medicina 32 m antenna in Italy, the Fortaleza 14 m antenna in Brazil, the German-Chilean TIGO 6 m antenna in Chile, the Mount Pleasant Observatory of the University of Tasmania (Australia) and the Australia Telescope Compact Array.

With the impact calculated to be at 05:42 UT, observers from North and South America and the East Pacific would be able to see it at night. The best view would be from the US west coast, Hawaii and the East Pacific.



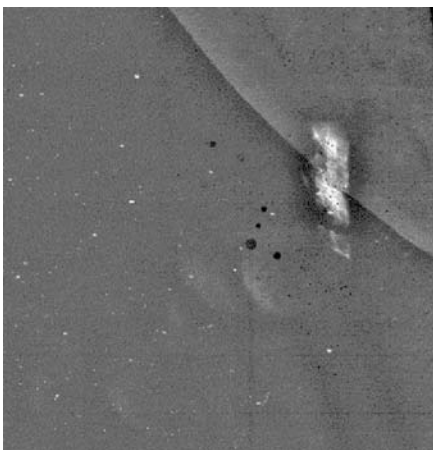
The flash and dust cloud following impact (CFHT)

**The impact**

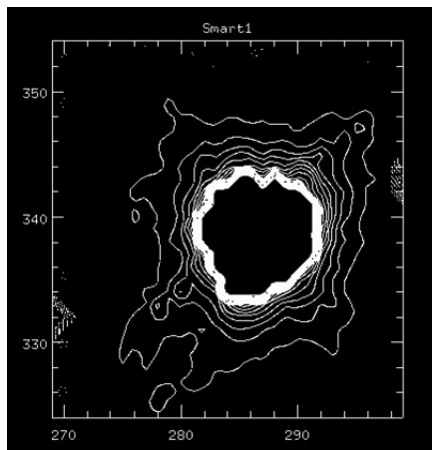
On 3 September, early in the morning, the SMART-1 team had to face another last-minute contingency: the servodrivers of ESA's antenna in New Norcia, Australia, signalled a problem and there was nothing that could be done remotely to resolve it. While an engineer was telephoned to drive from Perth to New Norcia as fast as possible, the Flight Control Team started developing a contingency procedure using the Perth antenna with the New Norcia antenna in fixed pointing. Fortunately, by the time journalists started gathering behind the glass wall of the ESOC's Main Control Room, the problem had been resolved at the station.

A wall screen displayed the last events programmed on board for execution

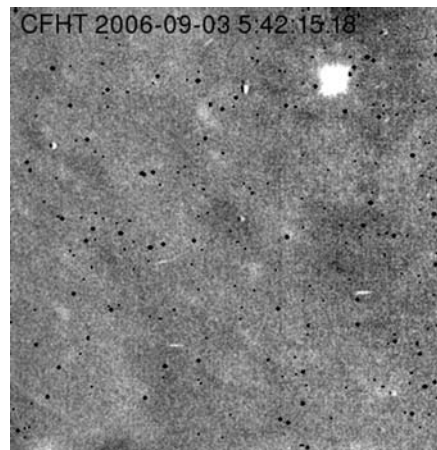
The lunar impact of SMART-1. (CFHT)



Brightness contours of the impact flash. (CFHT)



SMART-1 strikes the Moon. (CFHT)





before the impact. The team set up another big screen showing the telemetry scrolling down in real time. On both sides of the room, two large clocks displayed the count down.

A growing buzz of excitement took over the room as impact time approached. Starting at 17 s, everyone in the room found themselves chorusing the countdown – just as was done for the birth of the mission some 3 years before.

The freeze of the scrolling telemetry just a second after zero left everyone in the room in static silence for a few seconds until somebody broke the silence with applause that was joined in by all.

The mission team and the journalists had a few seconds to relax before all eyes went back to the main wall screen, now

showing the images being received from the Canada-France-Hawaii Telescope. The telescope, equipped with a new infrared mosaic camera, suddenly offered a stunning image of the SMART-1 impact, a very bright flash on the dim landscape lit by earthshine. The image was made available to ESA and the world via the internet just moments after SMART-1 radio silence had made clear that the mission had ended.

From a detailed analysis of the CFHT infrared movie, a cloud of ejecta travelling some 80 km in about 130 s was reported by Christian Veillet.

The last signal, from SMART-1's KaTE/Ka-band experiment, was received on Earth at 05:42:25 UT, through the NASA Deep Space Network radio station DSS13 in the California desert.

CSIRO, TIGO and the Mount Pleasant Observatory all heard the final signal. The radio observations were done with very high accuracy; SMART-1 sent its last signals to Earth at 05:42:21:759 UT. These times were in close agreement with the last flight dynamics prediction of 05:42:20 UT, and with the last telemetry frame received at ESOC through New Norcia.

### Conclusions

SMART-1 not only achieved its primary objective of validating the use of electric propulsion for interplanetary missions,

but also fulfilled all of its secondary objectives in technology demonstration and science.

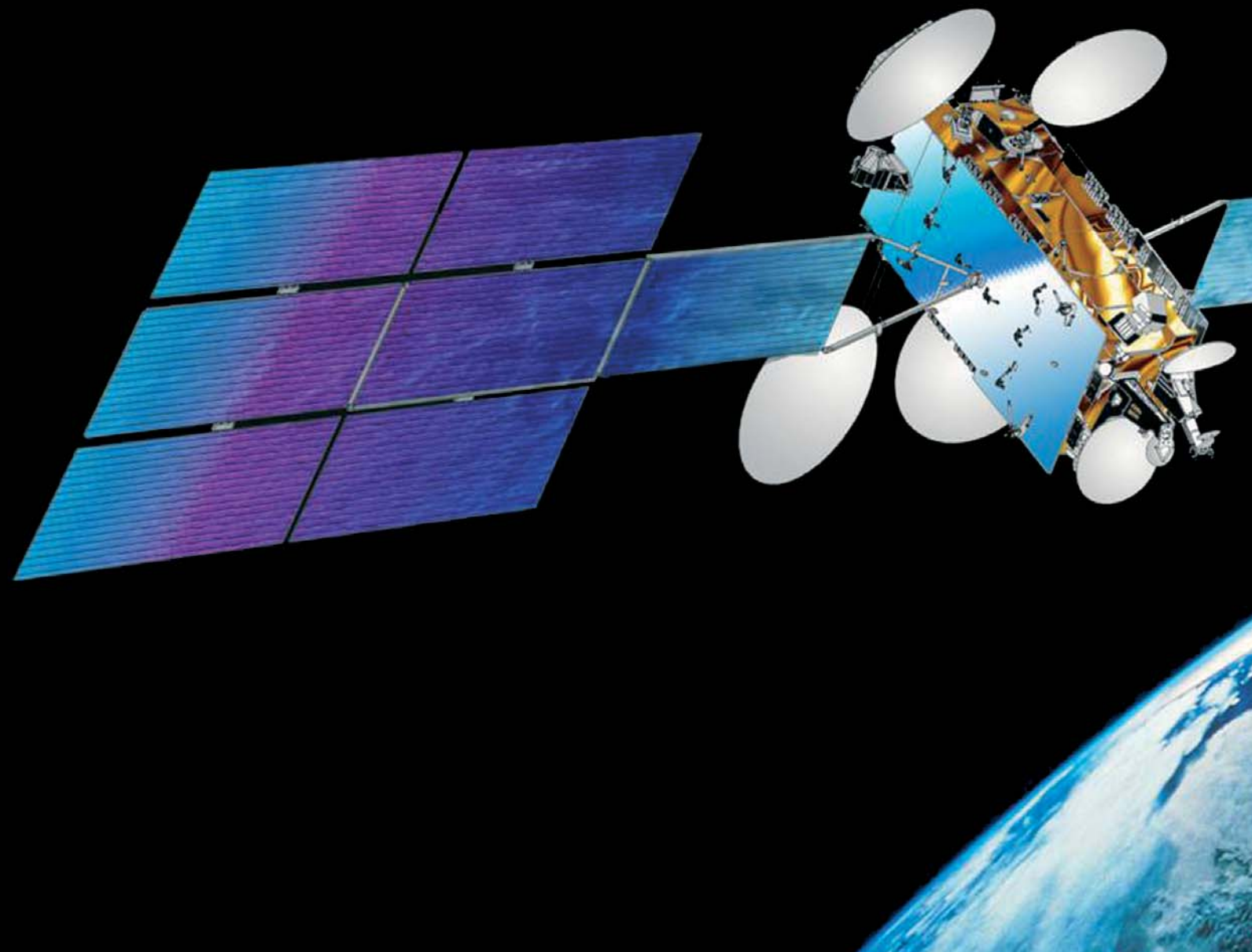
ESA gained valuable expertise in navigation techniques using low-thrust propulsion. The procedures used to exhaust the xenon fuel and the use of attitude thrusters to generate delta-V were a first for ESA. Similarly, ground operations experimented with innovative cost-effective operational concepts, such as reduced-staff spacecraft controlling, distribution of spacecraft housekeeping telemetry via the internet and a high level of automated operations.

In addition, SMART-1 sparked unexpected interest in international and cross-agency cooperation in areas such as ground station support (with Germany); tracking co-targeting and Moon exploration cooperation (with China and India); and VLBI science and Ka-band experiments (with NASA). In view of the recent plans for future scientific and human missions to the Moon by several agencies, SMART-1 can be seen as a pathfinder for renewed lunar exploration.

For the Mission Control Team, the end brought mixed feelings: the satisfaction of having accomplished a complex mission, but sadness in seeing the end of an adventure. All of those involved are looking forward to new adventures at the Moon and elsewhere in the Solar System.

# Powering the Future

A New Generation of  
High-Performance Solar Arrays



*Freddy Geyer*

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Head of the Power and Energy Conversion  
Division, Directorate of Technical and Quality  
Management, ESTEC, Noordwijk,  
The Netherlands



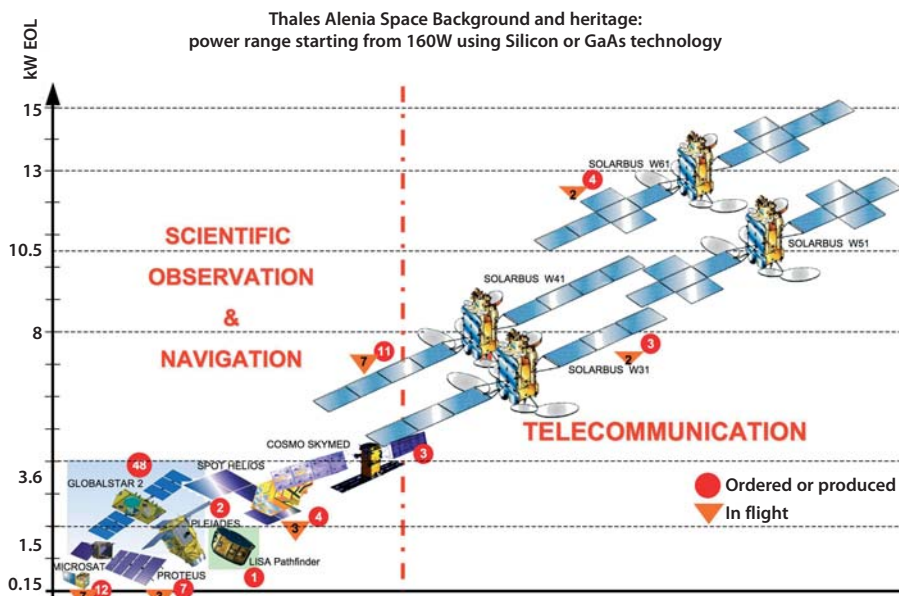
**F**unded by ESA's Advanced Research in  
Telecommunications (ARTES) programme,  
Thales Alenia Space has developed a new  
generation of high-power ultra-lightweight  
solar arrays for telecommunications satellites.  
Thanks to close cooperation with its industrial  
partners in Europe, the company has generically  
qualified a solar array to meet market needs.  
Indeed, three flight projects were already using  
the new design as qualification was completed.  
In addition, the excellent mechanical and  
thermal behaviour of the new panel structure  
are contributing to other missions such as  
Pleiades and LISA Pathfinder.

### Introduction

The standard 'Solarbus' solar array of Thales Alenia Space for the Spacebus telecommunications satellite platform was designed in 1998. The flight-proven technology deploys modular panels, using patented frictionless hinges, to provide up to 13 kW end-of-life (EOL) power with an EOL power-to-mass ratio of 48–50 W/kg, the best now available.

Thanks to the close cooperation with the Spacebus satellite team, exactly the same design has been used for all of the





The new Solarbus array (top right) has been added to the range. The 'lateral' panels unfold from the central panels

solar array panels: more than 150 identical panels have been produced over the last 5 years.

Now, to satisfy growing market demands, a new-generation design has been developed to provide more than 15 kW power EOL in a 7-panel version. In addition, a new Lightweight Panel Structure (LPS) has been introduced to increase the solar array W/kg and thus maintain the competitiveness of Spacebus in the commercial market.

2004 was a particularly bad year in the telecommunications business: half of the insurance payouts stemmed from solar array problems in space (from other suppliers!). This confirmed that products as critical as solar arrays must be robustly developed to ensure high reliability.

Robust and exhaustive development is mandatory but not compatible with flight schedules. In fact, as the market becomes more aggressive, the manufacturing cycles are being more tightly squeezed. The conclusion is that development must be done outside of flight programmes. This requires 'generic' development to ensure the product is ready for the market before the first missions requires it.

### Guidelines for Generic Development

The development of Thales Alenia's generic new-generation high-power solar array began in 2002 under guidelines that came directly from customers. Customers are sensitive on two main requirements that are difficult to test on the ground: safe deployment in orbit, and production of the required power during the 15-year lifetime.

Safe deployment is ensured by detailed dynamic analysis correlated with the flight experience of numerous identical solar arrays, together with the use of 'lateral' panels with the frictionless Adele

hinges flown in several programmes since 1998. Using only flight-proven solar cells satisfies the electrical aspects.

### Meeting Power Growth Needs

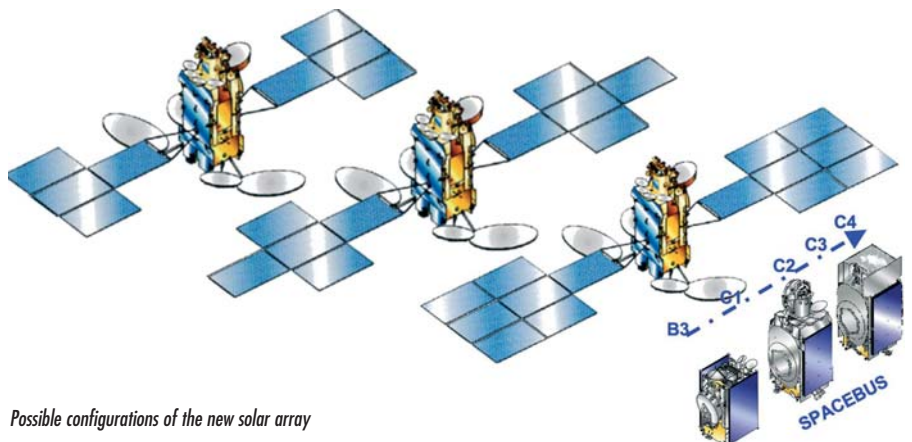
Usually, power growth is achieved by increasing the efficiency of the solar cells. This is how the 13% efficiency of standard silicon cells has grown to today's 28% for triple-junction gallium arsenide (GaAs) cells. More than 30% efficiency is expected in the near future for GaAs.

However, improving the power-to-mass ratio also calls for redesigning the mechanical and electrical architectures.

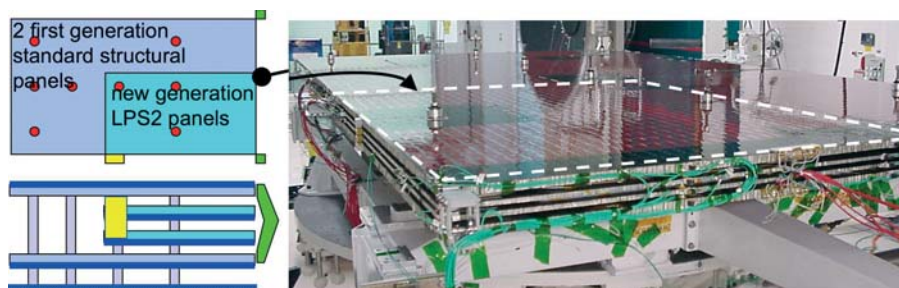
The mechanical improvement is in line with the logic of 1998: a standard modular panel multiplied to provide the desired area. The new array has seven panels per wing as the baseline, but offers a growth potential to a 10-panel version. Thanks to the novel way the array is stowed, non-structural ultra-thin lateral panels can be used. No other solar array does this.

Different cell technologies will cope with the power demand:

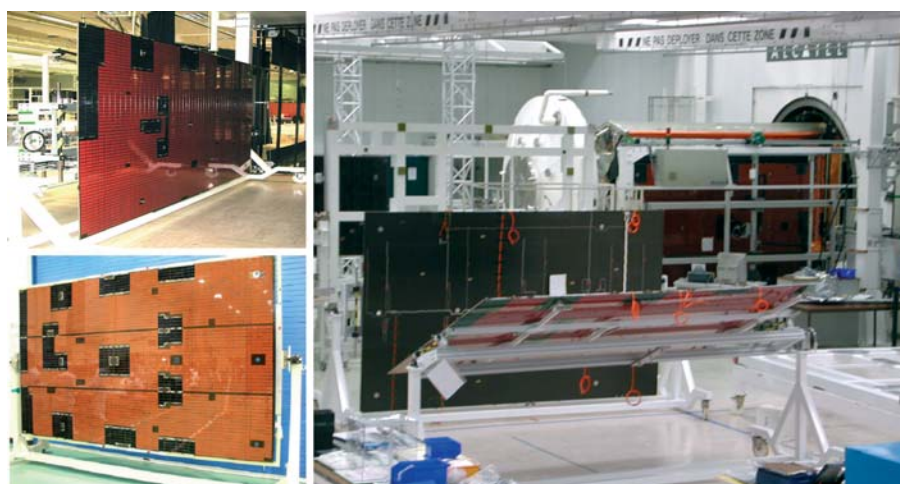
- for the near-term 15 kW EOL, thin high-efficiency silicon cells will be used for the first missions;
- GaAs cells will be called on in a second step if more power is needed;
- design novelties already under development will make the design more attractive.



Possible configurations of the new solar array



Vibration test of a folded array, with two ultra-thin panels sandwiched between standard panels for protection



Preparing a full-scale panel for thermal-vacuum tests

## Development Based on Design Heritage

The overall goal of this huge development effort is that the optimised mechanical structure will support continuous improvements in the electrical architecture over the next 10 years. After this robust generic development, proto-flight qualification will be provided by the first flight project.

### Design targets

The new design is based on the fact that, during the three major life phases of a solar array (launch, deployment and orbital life), the structural needs of the central panels are more important than for the lateral panels. The novelty of the LPS design rests on this difference, allowing the lateral panels to be half as thick as the central panels.

A central mast has a yoke plus two, three or four central panels. When more power is needed, lateral panels are added. The stowed configuration is the key to this innovative design. The panels

are stacked at launch so that the ultra-thin lateral panels are protected between two 'structural' central panels. Shims keep the launch loads away from the lateral panels.

This approach allows several configurations, with two or three panels in line and zero to six lateral panels.

### Step-by-Step validation

Qualification was achieved using a step-by-step approach that limited the risk during the programme. The first test campaign characterised the shims' dynamic behaviour during launch. A second test validated the load path through the shims, tuned the shims and validated the model's stiffness linearity.

Thanks to these two main tests at the start of the development process, it was possible to model the shim characteristics and to build a global mathematical model that represents the entire solar wing. Using this model, a detailed analysis was performed to size the new



Preparing for the acoustic vibration test to simulate the rigours of launch

substrates and the mechanical architecture of the 4–10-panel wing configurations.

Additional intermediate tests were performed on half-scale panels to verify early on the integrity of the solar cells after the vibration tests.

In addition, new manufacturing processes were developed for the lightweight panels, together with a robust database for mechanical and thermal design. Compatibility with all cell and bonding processes were verified via lifecycle testing. Finally, full-scale panels equipped with GaAs, silicon cells and representative cell dummies were subjected to thermal vacuum cycling.

In addition, the full Assembly, Integration and Test sequence was validated.

## Conclusion

The first two steps of this development programme are completed. Three commercial flight projects are already running using silicon high-efficiency cells for 15 kW EOL power. The use of GaAs cells is then foreseen to provide more power or reduce the number of panels. GaAs cells will allow the LPS architecture to satisfy future market needs easily. It will be possible to reach 23–29 kW BOL in a 7-panel configuration; more can be achieved because the LPS design offers 10 panels per wing.

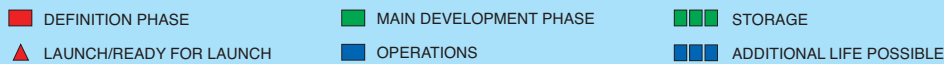
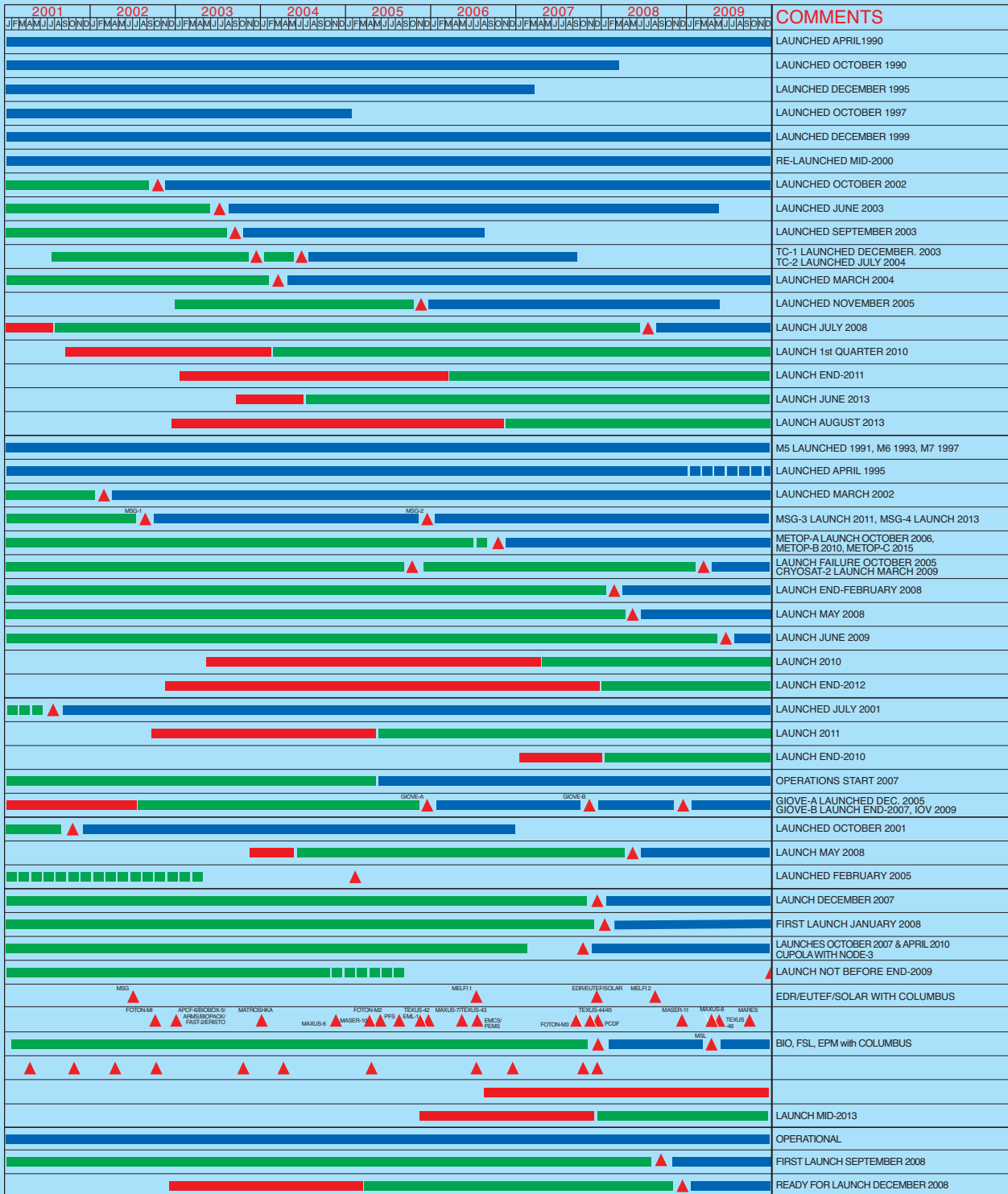




# Programmes in Progress

Status end-June 2007

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



## Ulysses

Ulysses completed its third passage over the Sun's south polar cap at the beginning of April and is now executing the rapid transit from south to north that will bring it over the northern polar cap at the end of the year. The subsystems and science instruments are in good health. The fact that Ulysses is now coming closer to the Sun means that the large onboard heaters are no longer needed and there is sufficient power to operate the full science payload without time-sharing.

As predicted, nutation returned in mid-February, and will last for about 12 months. During this period, the motion of the spinning spacecraft is disturbed by non-symmetric heating of the axial boom. The special operational measures developed during previous nutation episodes are being successfully employed to keep the disturbance under control.

On the science front, particular attention is being paid to the changes in the cosmic radiation detected by the instruments. The intensity of positively charged cosmic-ray particles measured by Ulysses during its slow climb to high southern latitudes showed little or no dependence on solar latitude. Current models predict that data from the 'fast latitude scan' (the rapid south-to-north

transit) should show an increase in both the galactic and anomalous cosmic ray components as Ulysses approaches the ecliptic. The most recent observations have yet to reveal a clear pattern, however.

## Cassini-Huygens

Cassini-Huygens held its 42nd Project Science Group meeting in Athens, Greece, on 4–8 June. Several press and media activities were included. A series of Huygens science results under publication in *Planetary and Space Sciences* was summarised in several web articles on ESA's web page in early June.

A 2-year Cassini mission extension (mid-2008 to mid-2010) is under consideration by NASA.

## XMM-Newton

XMM-Newton is finding new ways of investigating exploding stars. The image below shows an XMM-Newton X-ray image of the central regions of the Andromeda galaxy, or M31. XMM-Newton monitored M31 frequently for several months looking for new X-ray emission at the positions of known optical novae. The positions of ten

X-ray counterparts are shown as circles. Novae occur when material builds up on the surface of a white dwarf star and reaches sufficient density for nuclear burning. The resulting explosion creates a nova visible in the optical waveband for a few to a hundred days. The X-ray emission becomes visible some time after the explosion, when the matter ejected by the nova has thinned out. This allows astronomers to peer down onto the surface of a white dwarf that is undergoing nuclear burning, which continues until the fuel is exhausted.

The physics of these outbursts is still poorly understood and the well-constrained X-ray turn-on and turn-off times provided by XMM-Newton are important constraints for computer models of these explosions.

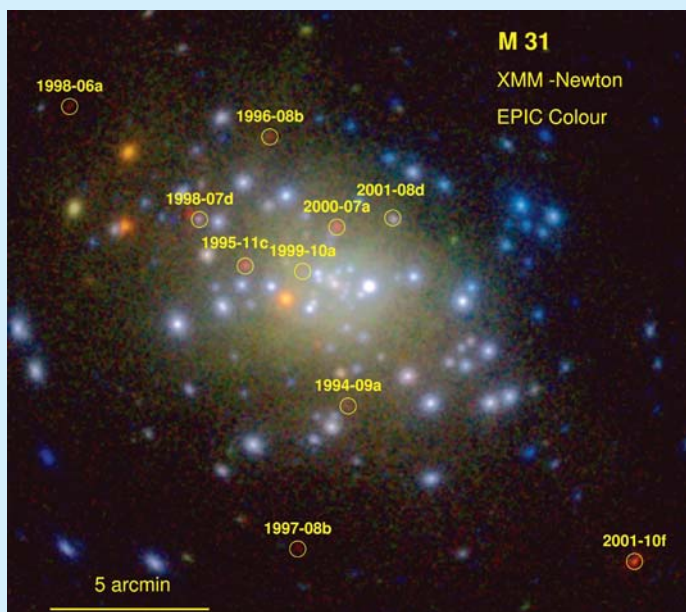
In addition, the frequent X-ray observations have revealed a new class of novae: ones that start to emit X-rays and then turn off within just a few months. Such novae would have been overlooked in previous surveys, which looked only once every 6 months or so. Within that time, the fast novae would have blinked on and off.

## Cluster

The four satellites and instruments are operating nominally and the short eclipse season was successfully passed. This year, the eclipse period lasted 1.5 months, with a total of 50 eclipses. Battery cycling rested some batteries in the middle of the eclipse season. In June–July 2007, the constellation changed the formation of the 10 000 km triangle formed by C1, C2 and C3 to move C3 to within 17 km of C4, the closest approach ever by two Cluster satellites.

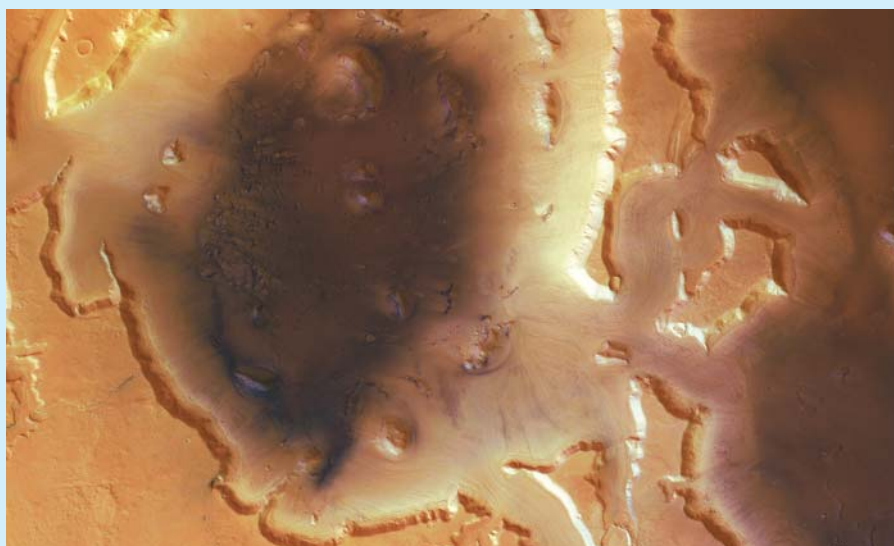
JSOC and ESOC operations continue to follow the Master Science Plan. The data return from January 2007 to end-May 2007 averaged 99.6%.

The Cluster Active Archive is operating nominally. User access is growing every month; 453 users (a 30% increase from December 2006) were registered at the end



An XMM-Newton EPIC image of the central region of M31 taken between 2000 and 2004. (W. Pietsch, MPE Garching)

*The Deuteronilus Mensae region on Mars, an area primarily characterised by glacial features, was imaged on 14 March 2005 by the High Resolution Stereo Camera of Mars Express. Resolution is about 29 m/pixel. (ESA/DLR/FU Berlin, G. Neukum)*



of May 2007. After some high downloading peaks in December and January (total downloading rate was about 1 TB), the rate has returned to a regular level of 30 GB per month. CAA will produce extensive sets of pre-generated plots (1-h, 6-h, 24-h, orbital plots from all spacecraft) that illustrate the various data products. This work is approaching completion and the system is expected to become available in summer 2007. The 2nd Operations Review, held on 15–16 May, was successful. Although there is still a lot of work to do before the end of the year (delivery of all data up to 2005), the Board acknowledged the considerable work that was accomplished in one year.

As of early June 2007, 614 papers had been published in the refereed literature and 35 PhDs obtained using Cluster and Double Star data. A. Retino, from IRF Uppsala, published a paper in *Nature Physics* using Cluster data showing, for the first time, magnetic reconnection taking place in turbulent plasma.

## Double Star

The two satellites and their instruments are operating nominally. The European Payload Operation System, which coordinates the operations for the seven European instruments, is running smoothly. Data are acquired using the VILSPA-2 ground station in Spain and the Beijing and Shanghai stations in China.

In October 2007, TC-1 will enter Earth's atmosphere. The Chinese have confirmed the intention to continue operations of TC-2. For ESA, operating only TC-2 will be much simpler because it involves only two

instruments instead of seven and VILSPA-2 will not be needed for the smaller volume of data.

As of early June 2007, 614 papers had been published in the refereed literature and 35 PhDs obtained using Cluster and Double star data. A recent paper published by Sergeev and co-workers showed a case study where magnetic reconnection was observed much closer to Earth than usual over the nightside (< 14 Earth radii or 90 000 km). The paper used data from TC-2, Cluster, IMAGE, GOES, LANL and DMSP-F15.

## Integral

Integral has discovered radioactive iron-60 in the interstellar space of our Galaxy. All past reported sightings have been subject to controversy, but now Integral has provided unequivocal evidence by clearly detecting the gamma-ray emission lines that are emitted when iron-60 decays into cobalt-60.

With the exception of the hydrogen and helium produced in the Big Bang, the majority of the chemical elements were built inside stars. Previously, astronomers had only one radioactive isotope, aluminium-26, to probe the build-up of chemical elements and their distribution in interstellar space. Indeed, Integral has produced detailed maps

of the distribution of aluminium-26 throughout our Galaxy. Iron-60 is produced deeper in stars by a different process and expelled into space only when the star explodes at the end of its life. By accurately measuring the amounts of aluminium-26 and iron-60 in our Galaxy, astronomers will be better able to understand the processes by which the elements are produced and how they are distributed into interstellar space, ready to condense to form the next generation of stars.

## Mars Express

Mars Express continues to perform its routine operations. The Science Team met at ESTEC 2–3 July.

The 2007 eclipse season started on 8 June and will last until the end of August, with the longest eclipses taking place at the end of June. The power situation is accurately modelled during the planning process, and in the current eclipse season the prime science goals (OMEGA/HRSC) are not affected by the power available. However, MARSIS, PFS and ASPERA science operations have had to be reduced during parts of the eclipse season.

A substantial effort, including orbit trim manoeuvres, is being made on the preparations for supporting the entry-

descent-landing phase of the NASA Phoenix mission, expected to land on Mars at either the end of May or early June 2008.

A highly successful Mars Express data workshop was held at ESAC 11–15 June. This new initiative was welcomed by the community. The first workshop focused on (co-)analysing HRSC and OMEGA data. More workshops on different topics will follow.

Preparation for the European Mars Science and Exploration conference (ESTEC, 12–16 November 2007) is under way.

## Rosetta

Rosetta continues its long cruise and is now on its way to its next Earth gravity-assist on 13 November 2007. After the successful Mars flyby earlier this year, the third Deep Space Manoeuvre on 26 April set it precisely on course for Earth.

On 9 May the joint Jupiter Observation Campaign of Rosetta's ALICE instrument and its twin instrument on NASA's New Horizon spacecraft was successfully completed. Shortly after, Passive Payload Checkout 5 was successful and the spacecraft was prepared for near-Sun hibernation. After a successful test on 4 June, Rosetta entered hibernation on 5 June.

A science workshop is scheduled for 22–24 October in Athens to prepare for the flyby of asteroid 2867 Steins on 5 September 2008.

## Venus Express

Venus Express continues to perform its routine operations. Several articles on the observations by ESA's Venus Express and NASA's Messenger spacecraft, performing a Venus flyby on its way to Mercury, were published at [www.esa.int](http://www.esa.int). One story describes the extensive ground campaign to observe Venus in order to place the spacecraft observations in a broader context.

A special section on Venus Express results (some nine papers) will be published in *Nature* after the summer. This will be accompanied by a press conference.

The Venus Express Science Team met in Rome 7–9 July.

A series of high temporal, spatial and spectral resolution sequences of data was acquired by Virtis during five consecutive days in April. The data turned out to be scientifically valuable and very useful as outreach material. It is planned to repeat this type of observation in future.

A final attempt to open the PFS scanner is planned for early July. This will be carried out during reaction wheel off-loading in the hope that the vibrations may help to overcome the initial friction.

During Vera bistatic radar operations with the Deep Space Network, the spacecraft S-band signal was lower than expected. This was confirmed during later measurements performed by New Norcia, Australia, and a significant (about –15 dB) reduction in power was detected. The situation is being investigated.

A major spacecraft activity was the 180° rotation around the z-axis to keep the solar illumination in line with thermal constraints. This was successful on 1 June.

## Akari (Astro-F)

Akari continues operations in a healthy state. More than 90% of the sky has been observed twice in the survey mode. The first results will be published as a special issue of *Publications of the Astronomical Society of Japan*, this autumn.

ESA's contributions to the mission are working well: the ground station coverage from Kiruna (S) continues at a very efficient level. More than 300 European pointed observations were successful by the end of June. The User Support team at ESAC updated the user documentation with a more

thorough coverage of the processing pipeline caveats, further to the testing performed in spring and confirmation by the Japanese teams. A workshop is planned at ESAC for 18–19 September to aid the European Open Time holders in the analysis of their data. The attitude reconstruction software, developed at ESAC, has been further upgraded with a distortion correction. Mass processing of the whole mission has started, but awaits consistently processed data from JAXA for last year's operations.

## COROT

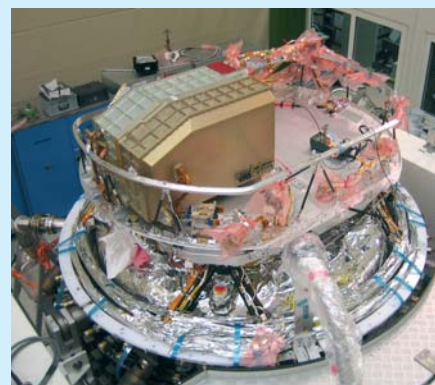
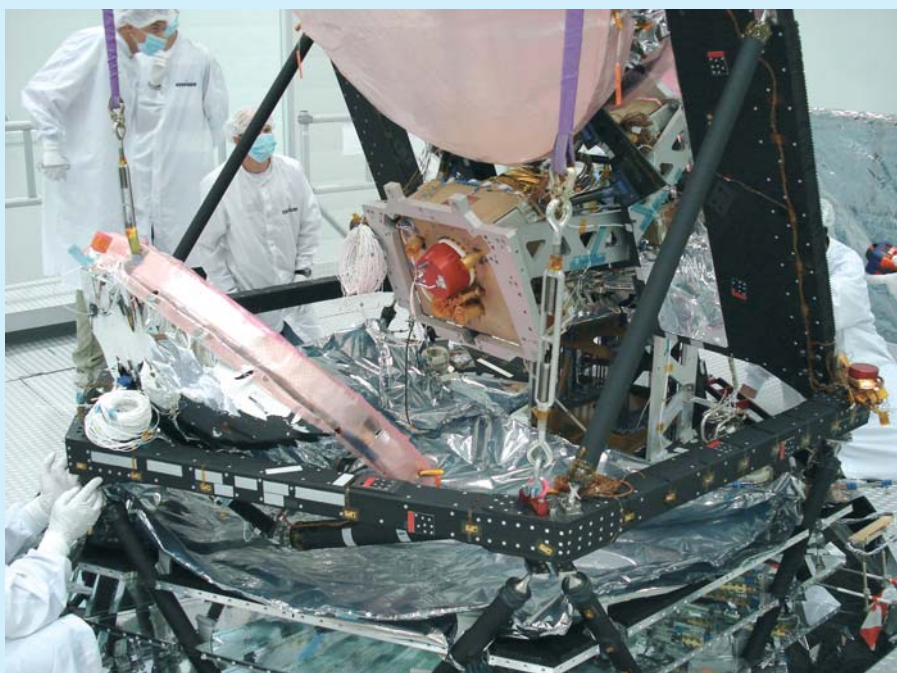
COROT (COncvection, ROTation and planetary Transit) was launched into a near-perfect orbit on 27 December 2006 and passed its verification phase up to 2 April 2007 without incident. Indeed, this process went so well that scientific operations could begin on 2 February.

Under the management of CNES and in a major partnership with ESA, Austria, Belgium, Brazil, Germany and Spain, COROT is the first satellite dedicated to the search for, and the study of, planets orbiting other stars. It is designed to detect planets as small as our own Earth for the very first time. A second major objective is the study of acoustic waves in stars.

All scientific specifications have been verified or surpassed, and the exploitation phase (nominally 2.5 years) is now running.

## Herschel/Planck

The final round of testing on the spacecraft Flight Models is starting, following completion of their integrations. The Herschel cryostat is open after return from the final qualification testing in ESTEC. It is in Astrium ready for the integration of the scientific instrument focal plane units. The Herschel SPIRE instrument was the first to be delivered and is already integrated on the optical bench. The two other instruments will follow in July with the final stages of their



Left: integration of the Planck telescope on the spacecraft's cryo-structure

Right: Herschel optical bench on top of the helium tank, with the SPIRE focal plane unit integrated

calibration testing completed. The Herschel Service Module activities progress well, with the debugging and preparation for the satellite testing later this year.

The activities on the Planck spacecraft continue in line with the Flight Model plan. The spacecraft is now fully assembled, with the focal plane units (HFI and LFI) and telescope mounted on top of the Service Module. Major work is being carried out in preparation for the electrical and functional testing later this year.

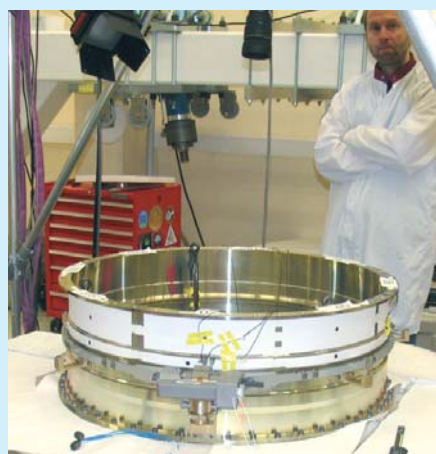
Good progress is also being made on the ground segment, with the completion of the science ground segment implementation reviews on both spacecraft.

## LISA Pathfinder

The challenging development of SMART-2/LISA is proceeding largely according to schedule. The main activity in the reporting period was the finalisation and consolidation of the satellite design, in preparation for the CDR. In parallel, some subsystems have had their CDRs: the Propulsion Module and the On Board Computer. The Flight Models of a few

subsystems have been delivered, such as the Science Module primary structure, the Digital Sun Sensors and the separation system. Some other units have been manufactured (gyro package, low- and medium-gain antennas) and are ready for acceptance testing.

The two European micropropulsion technologies (needle indium thrusters and slit caesium thrusters) continue their challenging development to prove the readiness of the technologies. Many problems have been solved and progress has been made in both technologies. The technology suited to the need will be selected at the beginning of 2008.



For the LISA Technology Package, many subsystem CDRs have taken place and good progress is being made. Many electrical units have been built and delivered to Astrium GmbH for the Real Time Test Bench. The most critical subsystems are still the inertial sensor vacuum enclosure, the electrostatic suspension front-end electronics and the caging mechanism. Progress has been made on all these subsystems, but they remain critical in terms of performance and schedule.

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

## Microscope

CNES began the Phase-C/D contract with ONERA for the development of the T-SAGE accelerometer. A CNES internal key-point review is planned for December 2007 to decide (in agreement with ESA) if the

*The LISA Pathfinder Separation System Device joins the spacecraft to the Propulsion Module. It provides the electrical connectors and the spring system to separate the modules. The Flight Model (shown here) was manufactured by SAAB Ericsson Space AB and delivered to the prime contractor Astrium Ltd (UK)*



Microscope drag-free propulsion remains FEEP or if it should switch to cold gas. This decision is pending the results of the LISA Pathfinder micropropulsion development activities.

## Gaia

All flight hardware suppliers have been competitively selected; a few procurements for support tasks and test equipment are still open. Around 80 procurements have been handled according to ESA's 'best practice', most of them competitively, while a very small number were performed in direct negotiations.

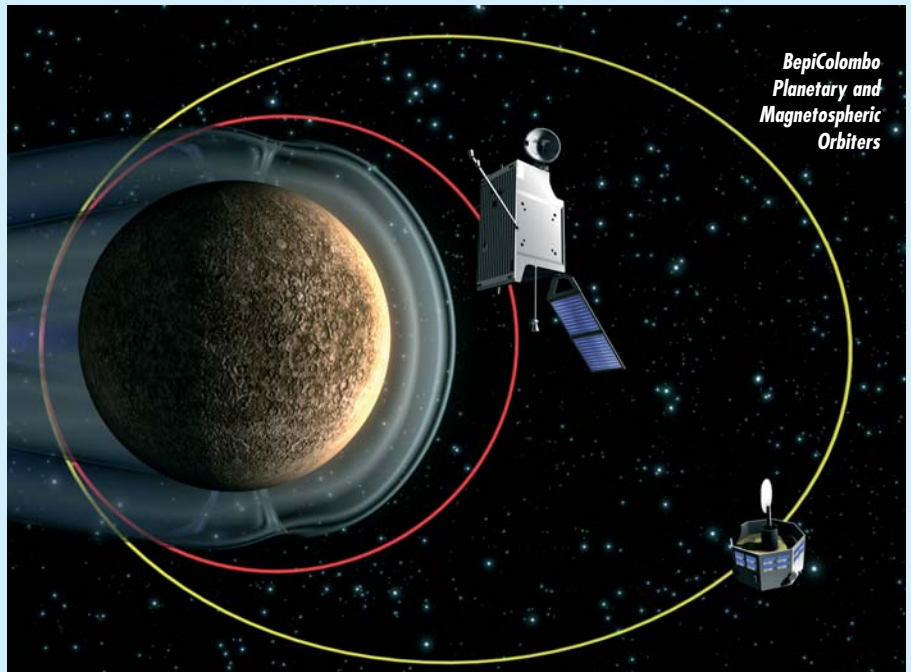
The workload during this reporting period focused on the preparation and execution of the PDR. About 40 project-independent engineers, predominantly from the Technical Directorate, reviewed the data package delivered by the Prime Contractor. The final step was the meeting of the Review Board on 29 June.

Meetings of the Gaia Science Teams and related working groups have taken place. The Science Team and the Radiation Calibration Working Group were briefed about the latest radiation test results on flight-representative CCDs. Both groups expressed their satisfaction about the results and agreed on a way-forward strategy to be developed through the Radiation Work Plan.

ESA's science advisory structure endorsed both the new composition of the Gaia Science Team and the formation of the Data Processing Analysis Consortium. Both endorsements conclude competitive selections following an Announcement of Opportunity.

## JWST

The Director General and the NASA Administrator, Michael Griffin, signed the JWST Memorandum of Understanding at a ceremony on 18 June at the Paris Air Show.



BepiColombo  
Planetary and  
Magnetospheric  
Orbiters

The JWST Partners Workshop (programme-level meeting) was hosted by the MIRI European Consortium in Dublin in mid-June. More than 200 participants representing the various parties involved in the JWST partnership took part. The full-scale JWST mock-up was on display during the meeting, attracting press interest.

The vibration test of NIRSpec's critical silicon carbide FORE optics was successfully completed. The FORE is NIRSpec's largest SiC subassembly – more than 1 m long. The FORE mirror polishing is nearing completion. Ion beam figuring was successful in accelerating the convergence of the mirror figure.

Qualification Model of JWST's NIRSpec FORE three-mirror anastigmat



The NIRSpec Intermediate System Review will be held in early July and will focus on a CDR-level verification of the design by analyses. This review will bridge the 2-year gap between the PDR and CDR.

All European Consortium hardware for the Optical Module of the MIRI Verification Model has been delivered to the Rutherford Appleton Laboratory (UK). The core assembly of deck, spectrometer, input optics and calibration module, and imager is complete. Several MIRI Flight Model units have completed their Manufacturing Readiness Reviews (MRRs). The MRRs of other units will follow throughout the summer until mid-October. The first flight-quality detector chips have been manufactured and successfully tested by Raytheon.

The planning for the PDR analysis campaign (RAMP) has been finalised and will constitute an input to the JWST mission-level PDR in March 2008.

## BepiColombo

The critical actions identified by the spacecraft System Requirements Review

have been completed and the close-out report written. The system, support and subsystem specifications have been consolidated and the equipment procurement phase is under way.

A number of activities have begun to advance key technologies before the start of equipment procurement. This involves work on multi-layer insulation, radiator, blocking diodes, solar array, high-temperature rotary joint and high-gain antenna. Both candidate electrical propulsion engines have successfully completed 5500 h of tests. The lifetime predictions are exceeding the project requirement. Work has started to upgrade the Large Space Simulator at ESTEC to 10 solar constants.

The System Requirements Review for all 11 instruments of the Mercury Planetary Orbiter has been conducted. The scientific performances were confirmed and the design definition is generally adequate. However, further work was requested for four instruments before close-out of the review, in particular to consolidate the thermal design. The overall payload mass could be brought back to within the allocation with some margin.

Work at JAXA on the Mercury Magnetospheric Orbiter design is progressing nominally and is being finalised in preparation for the PDR at end-2007. The mass of the spacecraft could be reduced by 10 kg, which almost satisfies the allocation.

## GOCE

The Gradiometer Core proto-flight model (PFM) passed its mechanical and thermal vacuum acceptance testing, respectively, in May and June. Satellite PFM integration and testing activities continued, in double shifts, at Thales Alenia Space in Turin (I). A satellite Integrated System Test, covering the launch and early orbit phase, and a System Validation Test involving ESOC were successful. The Ion Propulsion Assembly completed its final acceptance testing in QinetiQ (UK) and arrived in Turin at the end

of June ready to be integrated on the satellite.

Good progress has also been made on the launch vehicle; the Qualification Review with Eurockot was completed at the end of April. The GOCE Ground Segment Overall Validation activities are close to completion, with tests performed between the Flight Operations Segment and the Payload Data Ground Segment. Work on the Calibration and Monitoring Facility and the High Level Processing Facility of the European GOCE Gravity Consortium has progressed as planned.

## CryoSat-2

Mechanical preparation of the satellite is complete, with the installation of pipework for the thruster subsystem and other hardware such as brackets and fittings. The bare solar array panels were installed and alignment pins fitted before the panels were shipped to Emcore in Albuquerque (US), where the advanced solar cells and associated electrical hardware will be installed. Several equipment units were delivered and more are expected in the near future; integration of the satellite is starting. The main payload, the redundant SIRAL radar altimeter, is also coming together. Most

of the individual units are now delivered and tuning of the transmitters is well advanced. The antenna reflectors were found to have a manufacturing defect, so they were scrapped and replacements are being built. This work has been absorbed with no impact on the overall schedule.

The Ground Segment PDR was held during May 2007, covering both the Flight Operations Segment and the Payload Data Ground Segment. This review scrutinised the documents defining all of the requirements on the various facilities that constitute the ground segment, as well as higher level overall documentation. The documents were finalised by taking the review findings into account, and the various sets of contractual documents were prepared.

## SMOS

After completion of the thermal balance/thermal vacuum testing in ESTEC's Large Space Simulator, the payload was transferred to the Maxwell facility, which is a large chamber carefully shielded from all electromagnetic radiation. Two distinct measurement campaigns were conducted

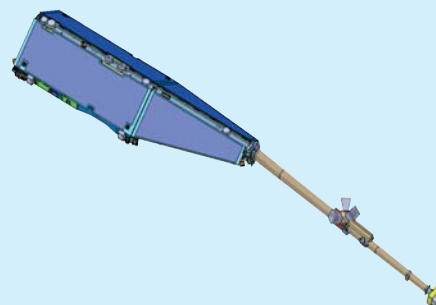
*Electromagnetic testing of the SMOS payload at ESTEC*





Left: the SMOS payload meets its Proteus platform in Cannes; the SMOS satellite is born!

Right: the latest Swarm satellite configuration. The optical bench with the startrackers and the vector field magnetometer sensors are in the middle of the boom. The absolute scalar magnetometer sensors are at the top of the boom. (Astrium GmbH)



there: the electromagnetic compatibility test demonstrated that the instrument is not disturbed by its own or the platform's operations, and the image validation test in which an artificial source mounted to the ceiling was used to produce an image and to exercise the sophisticated data processing. With this campaign successfully completed, the payload was transported to Cannes (F), where it was mated by Thales Alenia Space with the Proteus platform to form the integrated satellite.

The Final Mission Analysis Meeting was successful for the Rockot launcher, with only one thermal analysis case still to be refined and completed.

Step-by-step integration testing of the flight operations ground segment with CNES has started, while the data processing ground segment is still integrating alpha versions of all the facilities.

## ADM-Aeolus

The first Flight Model of the modified transmitter laser master oscillator was assembled and IR laser operation demonstrated. The modifications were necessary to improve the thermo-mechanical stability of the laser. Assembly of the mirror assemblies for the second Flight Model of the master oscillator is under way.

Assembly of the ALADIN instrument continues; all units with the exception of the Mie-Spectrometer (MSP) are now integrated. Delivery of the MSP was delayed because of anomalies detected during unit-level mechanical tests. The repair of this unit is under way.

The integration and test activities of the satellite platform at Astrium Friedrichshafen (D) are largely completed. Shipment of the platform to Astrium Stevenage (UK) for the integration of the remaining platform hardware and performance of further platform-level tests is planned for July.

The flight campaign of the Aladin Airborne Demonstrator (A2D) is planned for October 2007. In preparation for this milestone, the A2D hardware was assembled by DLR at the German Weather Service's Lindenberg test site for a final Aeolus ground campaign in July.

## Swarm

Progress has been made since the Satellite PDR in conducting lower level PDRs, in particular the satellite structure, boom assembly and thermal subsystem. The major elements are in progress: the engineering models of the accelerometer, vector magnetometer and scalar magnetometer are being built. The development of the optical bench that supports the vector magnetometer and the three startrackers has begun. Two startracker prototypes showed excellent results on the optical test bench of Astrium GmbH in Ottobrunn (D).

A peer review with experts from the Cluster, Oersted and CHAMP missions was held in

Potsdam (D) to review the methodology for the ground characterisation and in-orbit verification of the magnetic performance of the spacecraft, and to prepare a draft plan.

The latest meeting with Eurockot showed significant progress, in particular in flight dynamics and collision avoidance. There is a solid concept of the satellite dispenser.

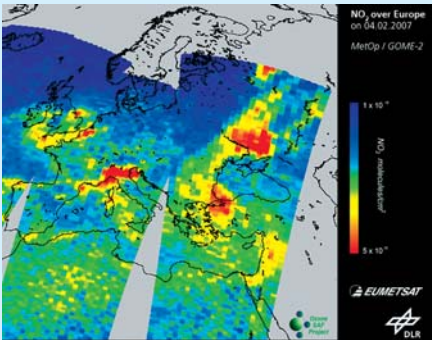
Subcontractors were selected for the boom, solar cells and tanks. Specifications were prepared for the harness, thrusters and magnetotorquers. The level-1b algorithms for the magnetic package and the EFI instrument were released by industry. Work is beginning on level-2 algorithms, with four studies starting on processing architecture, ionospheric current, mantle conductivity and air density.

## MetOp

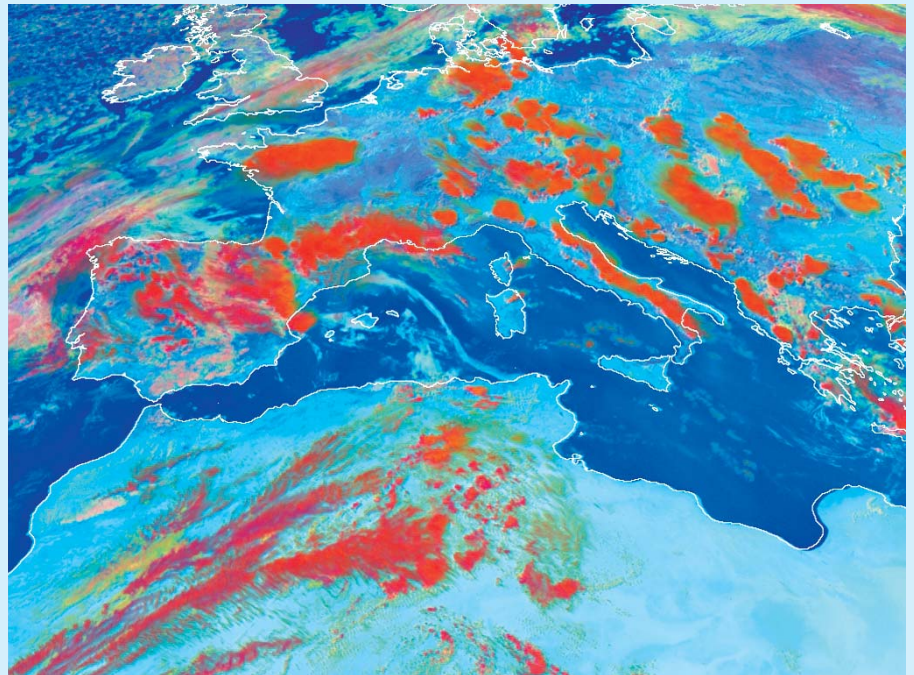
MetOp-A, Europe's first polar-orbiting meteorological satellite was declared operational on 15 May 2007, after only 6 months of commissioning, starting a new era of meteorology and climatology.

The first science data were received 2 days after the Launch and Early-Orbit Phase, but the full data flow from the 11 instruments is now available to users on an operational basis, offering unprecedented accuracy and resolution of variables such as temperature and humidity, wind speed, ozone and measurements of trace gases such as carbon dioxide, nitrous oxide and methane.

MetOp data will significantly improve weather forecasting by, for example, direct assimilation into numerical weather



Above: the total amount of nitrogen dioxide ( $\text{NO}_2$ ) in the atmosphere above Europe on 4 February 2007, as measured by the GOME-2 instrument on MetOp-A. GOME-2 can measure  $\text{NO}_2$  worldwide on a daily basis at a city-scale. (Eumetsat)



Right: severe thunderstorms developed along a low-level airmass boundary in France and Germany on 25 May 2007. In the afternoon, Paris and Berlin were hit simultaneously by major thunderstorms. The high repeat cycle of Meteosat-8 is essential for the early detection of rapidly developing thunderstorms

prediction models that compute forecasts ranging from a few hours to up to 10 days ahead.

The MetOp-A satellite shows excellent performance. The project and industrial activities are now in 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 satellite was hit by an object on 22 May that raised the orbit by about 130 m. Initial investigations revealed that the R1 thruster is bent and that some multi-layer insulation is damaged. The propulsion system shows no leakage; the unaffected redundant thruster branch became the nominal one.

Satellite performance, which is operating in Rapid Scan mode, and instrument performance remain of excellent quality.

### *Meteosat-9/MSG-2*

Meteosat-9 is now Eumetsat's nominal operational satellite at 0° longitude.

### *MSG-3*

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

### *MSG-4*

After successful completion of its Pre-Storage Review, MSG-4 will be prepared for long-term storage. Launch is planned for no earlier than 2013.

## Human Spaceflight, Microgravity & Exploration

### Highlights

The ExoMars Enhanced Baseline Mission configuration received a preliminary endorsement by the Participating States in a meeting of the HME Programme Board on 11 June.

The concluded work on, and the public release of, *The Global Exploration Strategy: The Framework for Coordination* document

of 14 world space organisations was the focus of the third ESA/ASI workshop, on 'International Cooperation for Sustainable Space Exploration', held in Spineto (I) from 30 May to 1 June. The workshop was opened by D/HME, the Administrator of the China National Space Agency and the ASI President. More than 70 representatives from 16 space agencies and organisations attended, plus non-governmental entities such as COSPAR. This group of space organisation representatives will continue to work on the principles that will inform the international coordination mechanism and the open reference architecture. These will be the topics of a meeting to be held in connection with the 'International Space Exploration Conference' in Berlin on 8–9 November.

At the Paris Air Show in Le Bourget, the ESA/ASI agreement for the joint management of Paolo Nespoli, as mission member of the STS-120 crew, was signed by the ASI President and D/HME. Also announced by ESA was the MARS-500 study, and a call was made for European and Canadian candidates.

### International Space Station

Space Shuttle *Atlantis*, STS-117, was launched from the Kennedy Space Center



The configuration of the ISS as STS-117 left in June 2007

(KSC) on 8 June. The launch followed repairs to the External Tank after a severe hailstorm at the end of February. During four EVAs, the crew attached the new S3/S4 solar array Truss segment on the starboard side of the Station's backbone, deployed a new set of solar arrays, and retracted the remaining P6 solar array in readiness for relocation to its final destination later this year. The Station has a new look, with two symmetrical solar panels mounted on each end of the Truss. After a 12-day mission, *Atlantis* touched down safely at the secondary landing site of Edwards Air Force Base in California because poor weather conditions over KSC prevented use of the primary landing site.

Space Shuttle *Endeavour*, flying STS-118, is targeted for a launch window no earlier than 7 August. It will carry the Spacehab Single Cargo Module, the starboard Truss segment S5 and External Stowage Platform 3.

STS-120, using Space Shuttle *Discovery*, scheduled to transport Node-2 'Harmony', along with ESA astronaut Paolo Nespoli, is targeted for launch no earlier than 16 October 2007.

STS-122, the mission for the transportation of the Columbus laboratory, is now targeted for no earlier than 6 December 2007, on *Atlantis* instead of *Discovery*. This mission will include ESA astronauts Hans Schlegel and Léopold Eyharts. While Eyharts will remain aboard the Station for up to 3 months to oversee the activation and commissioning of Columbus, Schlegel will return on the Shuttle 12 days after launch.

Progress-25P was launched from Baikonur Cosmodrome on 12 May carrying 2.5 t of

supplies: oxygen, water, food, propellant, consumables, scientific equipment and hardware, all necessary to maintain ISS operations and provide for the crew. Part of the scientific equipment aboard was GTS-2 (Global Transmission Service-2), a technology experiment for the test, validation and demonstration of radio transmission techniques for the synchronisation of Earth-based clocks and watches from the ISS. In addition, the GTS data services, based on a unique coding scheme, could ultimately lead to commercial services such as the blocking of stolen cars or lost credit cards, directly from space.

The Space Station Control Board baselined Shuttle, Progress, Soyuz and Automated Transfer Vehicle (ATV) launches through to April 2008.

#### Space Infrastructure Development

ATV *Jules Verne* integration and testing, together with system functional qualification tests, were successfully completed. On 28 June, members of the international media visited the cleanrooms at ESTEC to view ATV for the last time in Europe. They had the chance to interview D/HME, John Ellwood (ESA ATV Programme Manager) and Nicolas Chamussy (Astrium ATV Programme Director) on the programme.

The Pre-Shipment Review was held at ESA's premises in Les Mureaux (F) on 4 July. This review confirmed that all the required work had been performed on the spacecraft in Europe, giving the green light to ship it to the



ATV begins its journey to the launch site



launch site in Kourou, French Guiana. The spacecraft and all its ground support equipment, with a total weight of 400 t, left Rotterdam in mid-July. Once in Kourou, at the end of July, the launch campaign testing and integration continued. The launch schedule was revised to allow for the 'heavy traffic' to the ISS at the end of the year and will now be no earlier than January 2008. Meanwhile, the System Qualification Review is well underway, with the board meeting planned for September.

After delivery of the new version of the Russian Service Module Simulator, the ATV Control Centre is preparing to support the Joint Integrated Simulations Programme now established with NASA and Roskosmos. Engineering support tools were exercised during the ATV System Validation Test and the ATV Cargo Safety Review was conducted.

Columbus spares, for launch on the first ATV, have been identified and are being prepared for delivery. The spares will be stowed aboard the ISS to improve Columbus availability and reduce future upload transportation costs.

At KSC, the Columbus system checkout test was followed by the final modifications and adjustments to the payload racks, including the final integration of the Canadian Space Agency-developed Microgravity Vibration Isolation System into the Fluid Science Laboratory (FSL) of Columbus. The EuTEF

and Solar external payload packages are in the final stages of acceptance and will be shipped to KSC this summer. The FlyWheel Exercise Device, GEOFLOW and WAICO experiments, to be performed standalone and in the Biolab and FSL racks, respectively, are integrated in the European Transport Carrier rack. WAICO is expected to be delivered to KSC by September for Shuttle mid-deck stowage.

The Columbus Control Centre (COL-CC) development contract was completed; COL-CC is now maintained as a part of the ISS Operations Services Contract. The operations qualification, training and simulations programmes for both ATV and Columbus are progressing on schedule.

Node-2 'Harmony', having completed close-out, is in the cleanroom at KSC with its hatch closed waiting for integration and preparation for launch in October. Node-3, having completed its Element Leak Test, Engineering Review and Preliminary Acceptance Review, will be maintained in Europe, at the request of NASA, until mid-2009. Once delivered to KSC in 2009, it will undergo flight close-out and then be integrated with Cupola (currently stored at KSC) for launch together in late spring 2010.

#### Utilisation

A debriefing of the AstroLab mission operations was held at COL-CC, with the participation of all the parties, with the prime

objective of transferring the lessons-learned to Columbus operations.

In Paris, on 28 May, the 8th meeting of the HME Programme Board endorsed the results of the Announcement of Opportunity (AO-06-BR) for the Bed Rest Studies in ELIPS-2 during 2007–2009. Following the installation of ESA's first Short-Arm Human Centrifuge, at MEDES, Toulouse (F), the Human Exploration preparation benefits of bed rest activities have been enhanced by the combination with artificial gravity.

The Norwegian User Support and Operation Centre (N-USOC), having commissioned the European Modular Cultivation System (EMCS) in the Destiny ISS module and successfully performed NASA's TROPIC experiment, also completed ESA's GRAVI-1 experiment. TROPIC investigated cellular mechanisms of phototropism and determined the effects and influences of gravity on light perception in plants. GRAVI-1 subjected lentil (*Lens culinaris var. anicia*) seedling roots to centrifugal acceleration to determine the threshold acceleration at which the root responds to the gravity stimulus.

ESA's second EMCS experiment, Multigen-1, is ready for flight and due to be launched in August aboard STS-118 for installation in EMCS.

After agreements with Space Adventures, Ltd. and Roskosmos, Charles Simonyi, as a visiting Soyuz cosmonaut during the docked period in April, performed five human physiology experiments for ESA. The first results of the experimental package indicate a high success rate.

During ISS Increment-15, the Russian crew is performing several long-duration science experiments for ESA. In addition, GTS-2 and the radiation-measurement experiment Matroshka-2B will begin during the Increment.

ANITA (Analysing Interferometer for Ambient Air) was shipped to KSC for final interface testing with the host Express rack. Manifested for STS-118, ANITA will provide superior ISS cabin air analysis of more than 30 volatile

constituents, using novel process technology. The information from this analysis will be an asset for future long-duration missions.

Preparation of the ESA experiment package for launch on Soyuz-15 in early October is proceeding well. ANGKASA, the Malaysian Space Agency, agreed that their cosmonaut (Angkasawan is the Malaysian word for astronaut) will participate in some ESA medical experiments. In addition, three biology experiments will fly in a Kubik incubator and be managed aboard the ISS by the Russian Increment cosmonaut.

Early in Increment-16, Paolo Nespoli will perform a set of ASI and ESA science experiments during mission STS-120/10A, which also will deploy Node-2.

Foton-M3 payload developments are completed and Science Verification Tests were completed in ESTEC's Microgravity Lab and Mission Simulation Test in the Erasmus High Bay. The Payload Flight Models, transported to TsSKB/Samara during June, are undergoing payload integration in the carrier satellite. In August, the satellite and its integrated payloads will be transported to the Baikonur Cosmodrome, with a scheduled launch date of 17 September for a 12-day mission.

### Astronauts

On 26 April, Thomas Reiter participated in a joint European Commission/ESA press conference in Brussels, along with EC Vice-President Günter Verheugen and ESA's Director General, for the announcement of the European Space Policy, prior to the official adoption by the EC on 22 May.

Thomas Reiter and Christer Fuglesang (Celsius Mission) continue to be in demand for post-flight activities.

After the signature of the ESA/ASI agreement, work continues on the finalisation of the Joint Implementation Plan, the Joint Communication Plan and the Joint Education Plan. Paolo Nespoli is continuing his training at NASA's Johnson Space Center.

Hans Schlegel (D) continues training for his flight on STS-122 (1E), which will deliver the



*Paolo Nespoli at the Kennedy Space Center*

Columbus module to the ISS. Schlegel has, so far, participated in three 2-hour sessions in the Neutral Buoyancy Facility (NBF), training to carry out the various EVA practices and many emergency and safety drills, in preparation for his part in the docking of Columbus to the ISS.

Léopold Eyharts (F) was been named as an ISS crewmember for STS-122, with Frank De Winne (B) as his backup. Eyharts will be staying aboard the ISS for about 3 months to help commission Columbus and its payload facilities. He is due to return to Earth aboard STS-123 in February 2008.

Both Eyharts and De Winne underwent Columbus specialist training at the European

Astronaut Centre followed, during the second week in May, by Special Purpose Dexterous Manipulator training at the Canadian Space Agency. Later in May, they both went to the Gagarin Cosmonaut Training Centre to practise left-seat Soyuz procedures.

### Exploration

At the Programme Board meeting in May, the Executive presented a working document that emphasised the importance of converging on a single ExoMars configuration to secure the 2013 launch date. After a dedicated meeting on 11 June, the board approved the Enhanced Baseline Mission: the larger



*The Pasteur instrument exobiology payload on ExoMars will include a drill that will be able to look for traces of life forms beneath the surface of Mars*

19 June. The final selection of candidates is due to be concluded by November.

The evaluation of all proposals received for the Architecture Studies was completed.

ESA and the European Science Foundation organised a workshop held on 15–16 May in Athens. Scientists from 11 European countries agreed on the science goals for Europe's future planetary exploration programme. The draft recommendations provide an ambitious roadmap to examine Mars, the Moon and Near-Earth Objects.

science payload will accommodate the full selection of the 16.5 kg Pasteur Payload and a complete Geophysics/Environment Package (GEP) of about 30 kg, on a heavy lift launcher for a 2013 launch. The Request for Quotation release for Phases-B2/C/D/E1 is expected in July, having been approved at the Industrial Policy Committee meeting at the end of June. It was agreed that there would be a Baseline Consolidation Review in the autumn and further discussions would take place at the HME Programme Board in November. It is planned that Phase-B2 will start in January 2008.

Discussions with Roskosmos continue to consolidate a broad cooperation agreement on Exploration, including both ExoMars and the Phobos-Grunt mission. A first joint meeting, held at the Russian Academy of Science in Moscow, drew enthusiastic support from both scientific communities.

A mission design review was held in April for Phase-A2 of the Mars Sample Return (MSR) study. The four MSR precursor mission studies, each lasting 6 months, were kicked off.

Preparation of the MARS-500 isolation study in conjunction with the Institute of Biomedical Problems in Moscow, is underway with the 'Call for Candidates' launched during the Paris Air Show on

Having been presented to the second meeting of the Advisory Committee for Human Spaceflight, Microgravity and Exploration Programmes, the development status of the 'European long-term strategy for Space' was presented at the 'Sky and Space Intergroup' meeting of the European Parliament, in Strasbourg, to the HME Programme Board on 23 May and to the Council of ESA.

Authorisations to Proceed were placed for both the system and the breadboarding activities for the Crew Space Transportation System (CSTS) to allow exchanges with the Russian counterpart. The short-term activities of CSTS were discussed and agreed with Roskosmos to place Russian industry under contract and allow them to work with European industry. A draft understanding is under development between JAXA and ESA to cover participation in CSTS.

## Vega

Following the System CDR board on 2 April, an action plan was set up, leading to the closure of the review by end-September.

The acceptance campaign of the Zefiro-23 QM1 structure was concluded with the completion of the compression test on

24 April. Several milestones were reached in the reporting period: the PDR of the modified interstage-1/2, acceptance of the interstage-2/3 Qualification Model (QM), and the Manufacturing Readiness Reviews of the Zefiro-23 QM case and the Zefiro-9 QM2 case. Preparation of the P80 QM firing test is under way; the nozzle has been formally accepted.

For the ground segment, the second sector of the mobile gantry was completed.

## Soyuz at CSG

The CDR for the launcher, which started in March, concluded in May. The tests of the 'Kit Sauvegarde Europe' were completed in April. After the Soyuz Launch Base was officially inaugurated on 26 February, construction continues on schedule.

The schedule of the Russian contributions is under revision by the Russian contractor, who will deliver inputs for schedule consolidation by June. The main critical aspects have been identified and might generate a delay of 3 months at most on the launch date. Efforts are in place to minimise the effects, with the goal of keeping to the launch date.

## FLPP

All activities are proceeding after the Consolidated Contract integrating all remaining activities from FLPP-1 was signed.

The proposal for the first set of activities on the High Thrust Engine was received; the Technical Assistance Agreements were drafted and approved by the Launchers Programme Board. The Preliminary Requirements Review for the Intermediate Experimental Vehicle was accomplished.

A Contract Change Notice for continuation of the first set of activities and bridging with the second set relevant to the Cryogenic Reignitable Upper Stage Engine – Expander Demonstrator was committed.





## In Brief


### 50 Science Mission Proposals

A wealth of new mission concepts was submitted by the European scientific community by 29 June, following the ESA Call for Proposals in March. The proposals cover a wide variety of scientific objectives, from the search for extrasolar planets, the study of Jupiter and its icy satellite Europa, to testing the laws of gravity.


The missions' objectives fit well with the four major themes of ESA's Cosmic Vision 2015–2025 plan: the conditions for life and planetary formation; the origin and formation of the Solar System; the fundamental laws of the cosmos; the origin, structure and evolution of the Universe.

Out of these 50 concepts, three medium missions (with cost to ESA within EUR300 million) and three large missions (costs to ESA within EUR650 million) will be selected for assessment starting in October this year.

The evaluation process will treat the scientific value and novelty of the proposal as the main criteria, together with the technological maturity and estimated cost.

At the end of the full assessment cycle in 2011, one medium and one large mission will be adopted for implementation by ESA's Science Programme Committee. Their launches are expected in 2017 and 2018, respectively. 

characterising transmission performance in the Q–V band in preparation for possible commercial exploitation of these frequencies.

The intention is to begin the programme in the third quarter of 2007, with launch in 2011. 

### ATV On Its Way

*Jules Verne*, ESA's first Automated Transfer Vehicle, arrived at the Kourou launch site in French Guiana in late July to prepare for the final leg of its journey to the International Space Station. Launch is planned for January 2008.

Only 10 days after completing its final integration and space environment tests, it left ESTEC in Noordwijk (NL) on 13 July. The 20 t ATV is the largest and most complex spacecraft ever built in Europe. The unmanned ferry will deliver cargo to the Station and help to raise its orbit.

A specialised team spent 10 weeks preparing 400 t of equipment for shipment across the Atlantic. Each item was individually documented and carefully packed into around 50 containers. "One of the major issues has been getting the

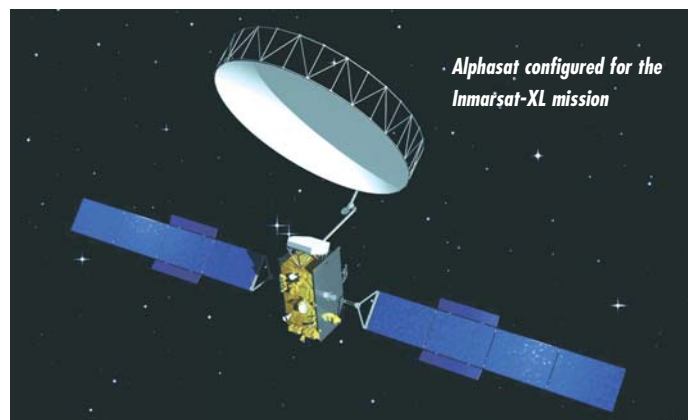
### Alphasat First Mission

ESA and Inmarsat moved closer in June to Alphasat, the first satellite based on Alphasat, the new European multi-purpose platform for the high-power communications satellite market.

Alphasat will use the Alphasat proto-flight platform, providing in-orbit validation of the platform through a commercial operator. ESA and Inmarsat have signed a Memorandum of Understanding as the first step towards confirming Inmarsat as the platform's first customer.

Inmarsat intends to fly an extended L-band payload in support of its global mobile services. The satellite will be positioned at 25°E to cover Africa, Europe, the Middle-East and parts of Asia.

This 'Geo-mobile' application requires a 90° change to the flight orientation to accommodate the large deployed reflector and its feed. In addition, Alphasat will carry three ESA technology payloads: an advanced startracker using active pixel technology, an optical laser terminal for geostationary to low-Earth orbit communication at high rates, and a dedicated payload for



Alphasat configured for the Inmarsat-XL mission



*Left: ATV is prepared for its departure from Europe. The spacecraft was shipped in three major sections*

*Right: the 5.5 kg, 40 cm-diameter YES2 capsule will be the first space payload to use a tether to begin its return to Earth*



*verification campaign, involving vibration testing, thermal-vacuum and electromagnetic testing. The team has achieved a great deal to get this far, and the students have benefited tremendously from this practical experience with a real space project."*

Following the final tests, YES2 was removed and shipped to Baikonur Cosmodrome in early July, where it met its host spacecraft again at the end of the month.

Almost 500 students from most ESA Member States, plus the United States, Japan, Canada and Australia, have worked on YES2. Although these were mainly involved in the preliminary design, some 60 students developed and built hardware and software.



*customs paperwork in order," explains Stefan Brosze, ATV Transportation Manager. "There are members of our team who know exactly where to find everything, right down to the very smallest items."*

ATV was taken by lorry and canal barge to Rotterdam harbour and loaded aboard the *MN Toucan*, a vessel normally used by Ariespace to transport Ariane rocket components on the same route across the Atlantic. 

## YES to Launch Site

After 5 years of work, the YES2 second Young Engineers Satellite experiment is ready for launch. The successful Final Acceptance Review on 20 June gave the green light for launch in September attached to the Foton-M3 spacecraft. YES2 will deploy a small recoverable capsule on a 30 km tether – the longest ever used in space – for reentry without rocket propulsion. This first descent via tether will pave the way for the low-cost return-to-Earth for future payloads.

Following 4.5 months of assembly, integration and testing

at ESTEC, the groundbreaking student experiment was shipped on 7 May to TsSKB-Progress, the Foton prime contractor, in Samara, Russia. On 14 June, the payload was installed on the exterior of Foton-M3 to begin weeks of tests.

*"Although there were tight deadlines to meet, the students worked closely in conjunction with ESA and prime contractor Delta-Utec to get it ready to launch," said Roger Walker, Project Manager for YES2, from the ESA Education Office. "It has completed an intensive*

## EGNOS and Other Satnav for Africa

ESA and the Agency for Security of Air Navigation in Africa and Madagascar signed a cooperation agreement on 22 June with the objective of using satellite navigation to improve air traffic safety over the African continent.

The agreement, which covers cooperation between ESA and the African aviation safety agency (Agence pour la Sécurité de la Navigation Aérienne en Afrique – ASECNA), focuses on the next phase of Global Navigation Satellite Systems (GNSS) deployment, which includes the extension and use of the European Geostationary Navigation Overlay Service (EGNOS) as an operational service in Africa.

The agreement envisages ESA and ASECNA providing mutual

assistance, notably with regard to extending EGNOS operational services more widely in Africa, siting European ground installations in ASECNA countries, supporting the project in international standardisation bodies and bringing Galileo services and additional elements to Africa.

ESA and ASECNA have been working together since 2003 and have organised several test campaigns that clearly demonstrated the benefits of EGNOS for Africa, where very few airports are equipped with conventional landing guidance systems.

For these campaigns, ASECNA provided its calibration aircraft and hosted and operated EGNOS stations at several African

airports. This is how the first crossing of Africa at its widest part, from Dakar to Mombasa, was achieved in May 2005, using EGNOS signals.

Composed of a network of around 40 elements distributed across Europe to record, correct and improve data from GPS, EGNOS provides modified signals relayed by geostationary satellites

to users' receivers. It offers an accuracy of better than 2 m, compared with the 15–20 m for GPS signals, with an added guarantee of signal quality.

Since the geostationary satellites that relay EGNOS also cover Africa, an extension of EGNOS may easily be envisaged with the installation of reference stations on African soil.



## Eurobot: Astronauts' Assistant

European engineers are developing increasingly sophisticated machines to work in space. ESA's 'Eurobot' recently completed trials in the giant pool at the European Astronaut Centre.

Eurobot has been under development since 2003, with the intention that the multi-jointed, three-armed assistant will eventually handle some of the more mundane tasks currently undertaken by astronauts on spacewalks. It may also be an indispensable helper on expeditions to the Moon or Mars.

In the hostile conditions of space, the tireless Eurobot will save a great deal of time and effort by taking over routine tasks. For example, the astronauts' flexible friend will be able to find its way to a worksite on the International Space Station (ISS), perform a close-up inspection and carry out preparatory work, such as transferring tools and equipment. Remotely controlled by an operator inside the ISS, Eurobot can multi-task, providing additional hands and eyes for the spacewalkers. Once the astronauts are safely inside the Station, Eurobot will clear away the tools and equipment.

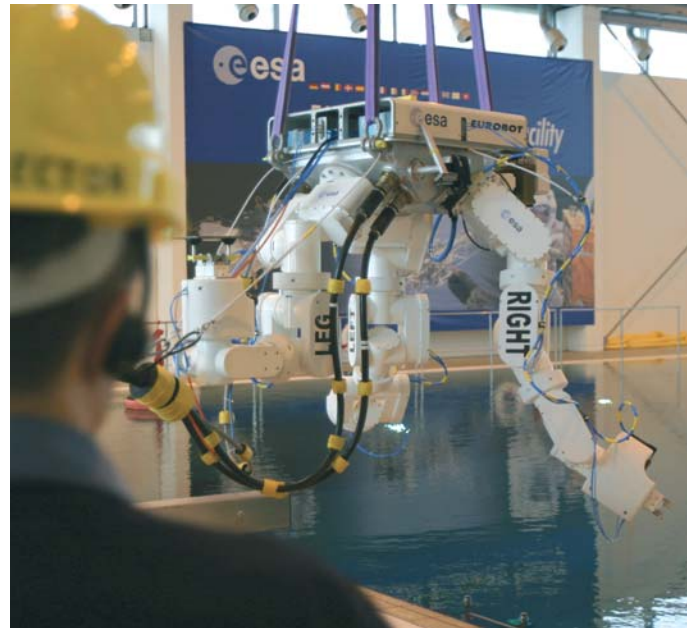
*"It could be a most useful aid,"* said Gianfranco Visentin, head of ESA's Automation and Robotics section. *"There is a shortage of crew time during all missions, so anything that improves the use of astronaut time is very desirable."*

The version of Eurobot used in July's exercises was the Weightless Environmental Test (WET) early prototype, developed for operation in a water tank where the microgravity conditions of space are simulated.

Developed for ESA by a consortium led by Thales Alenia Space, the WET model has a central body with three identical arms, each with seven joints. Although the arms' length and strength are similar to those of a human, they are much more manoeuvrable and versatile.

Each arm carries a camera and an 'end-effector' hand. The WET model has only one type of hand, which is capable of grasping EVA handrails. In contrast, the real Eurobot will have a set of three or four interchangeable hands. A head camera monitors the worksite.

During tests of its ability to move and manipulate objects, the



*Eurobot is lowered into the pool for 'weightless' testing*

project team gained experience of the robot's capabilities, trying out multi-arm control and coordination, along with visual recognition of obscured targets. Eurobot was joined in the pool by ESA astronaut Jean-François Clervoy to demonstrate the interaction between astronaut and robot.

The trials concluded the initial verification phase of the Eurobot WET model programme,

following on from preliminary dry and wet tests in Italy.

*"The tests went very well,"* said Philippe Schoonejans, ESA's Eurobot Project Manager. *"Not only has it been demonstrated that Eurobot can walk around an orbital station autonomously and safely, using no more than the existing EVA handrails, it is also becoming clear that Eurobot can really help the astronauts. And in the next phase we also plan to demonstrate its use on a planetary surface, as part of the Agency's exploration programme."*



## Launcher Contracts

ESA signed two key contracts with NGL Prime S.p.A. of Italy in June: the definition of launcher concepts for the European Next Generation Launcher, and the development of the European Intermediate eXperimental Vehicle (IXV). Both are part of ESA's Future Launchers Preparatory Programme (FLPP), which is aiming to develop and demonstrate the technologies for

a Next Generation Launcher (NGL) for Europe, expected to become operational after 2020. A secondary aim is to increase the reliability and competitiveness of European launchers, including those operational today.


The contracts have a total value of more than EUR20 million and integrate key European competences and expertise in



Two new launcher contracts were signed by ESA's Director of Launcher Programmes, Antonio Fabrizi (left), and Axel Roenneke, CEO of NGL Prime S.p.A.

launcher and reentry systems from 43 industrial and research organisations from 11 ESA member states.

The launcher systems studies will prepare key technical and programme data for the ESA Ministerial Conference in 2008, when strategic decisions about future launcher development will be made. The studies will examine the different options that Europe could adopt for the NGL.

In parallel, the IXV will demonstrate Europe's advanced reentry technologies and integrated system design capabilities. The IXV reference mission calls for launch from Kourou in 2010 aboard a Vega vehicle, followed by a fully automatic reentry, descent and landing in the Pacific Ocean. 

## Estonia Agreement

At a ceremony in Tallinn on 20 June, René Oosterlinck, ESA Director of Legal Affairs and External Relations, and Juhan Parts, Estonian Minister of Economic Affairs and Communications, signed an agreement marking closer cooperation between ESA and Estonia.

Estonia is the first of the countries that have recently joined the European Union to sign a Cooperation Agreement with ESA. Andrus Ansip, Prime Minister of Estonia, welcomed the ESA delegation and confirmed the support his government is ready to give to this new agreement.

A first meeting with an Estonian delegation took place at the beginning of 2006 at ESA's headquarters in Paris. This was followed by an invitation by the Minister of Economic Affairs and Communications to send an ESA delegation to Tallinn in November 2006, to explain in more detail

the different types of cooperation between ESA and non-ESA Member States, and to meet with potential partners.

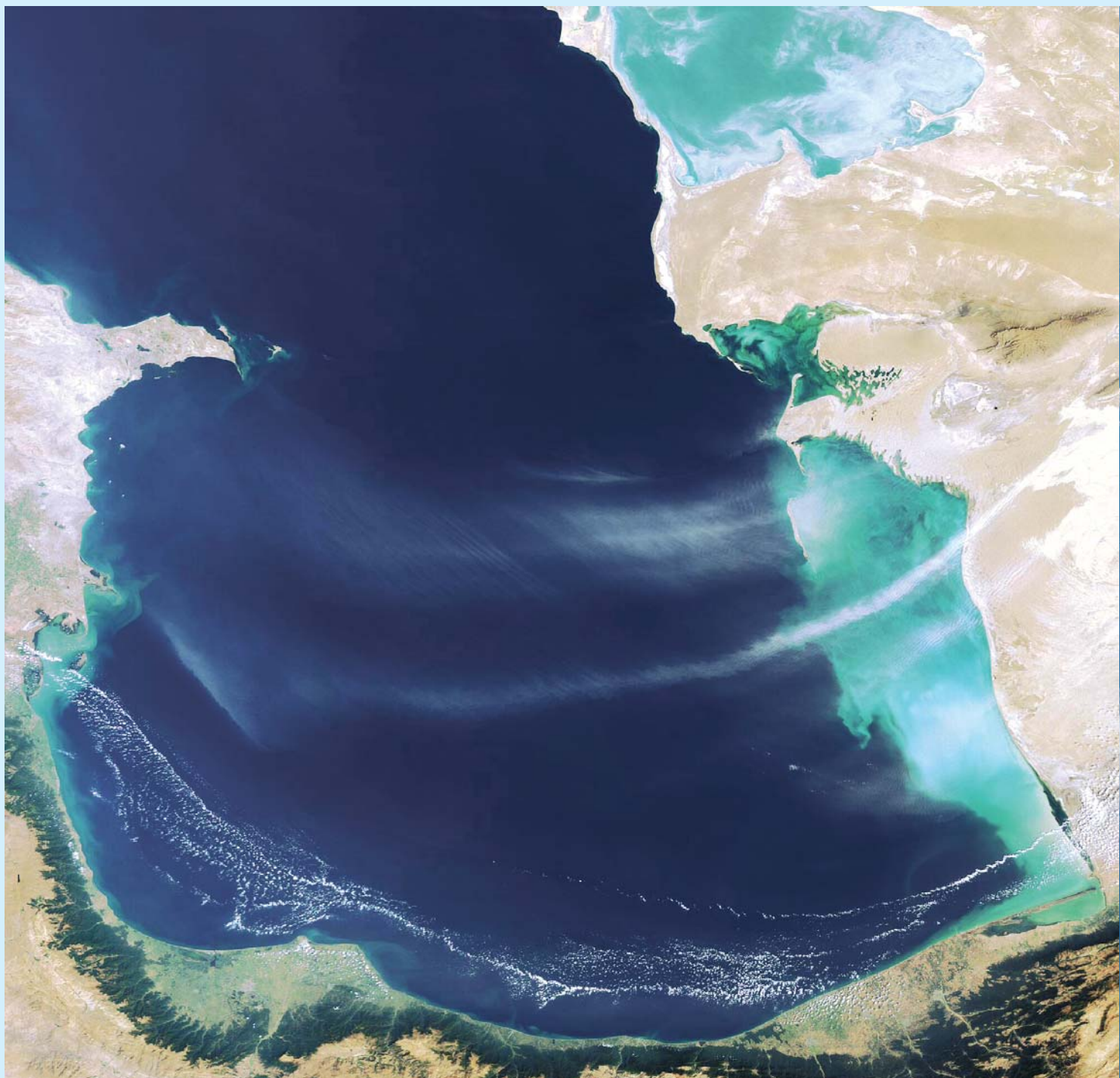
Estonia has long-standing experience in astronomy and space science. The Observatory of Tartu has worked in this field since the 19th century, and is participating in preparations for ESA's Planck and Gaia missions.

The recent adoption of the European Space Policy by ESA and the EU confirms the importance of ESA's space activities for EU Member States. New members of the EU are now approaching ESA with a view to participating in ESA's space activities.

This Cooperation Agreement is a first step. As a second step, Estonia intends to become a European Cooperating State in a few years with an increased financial contribution to space activities. 

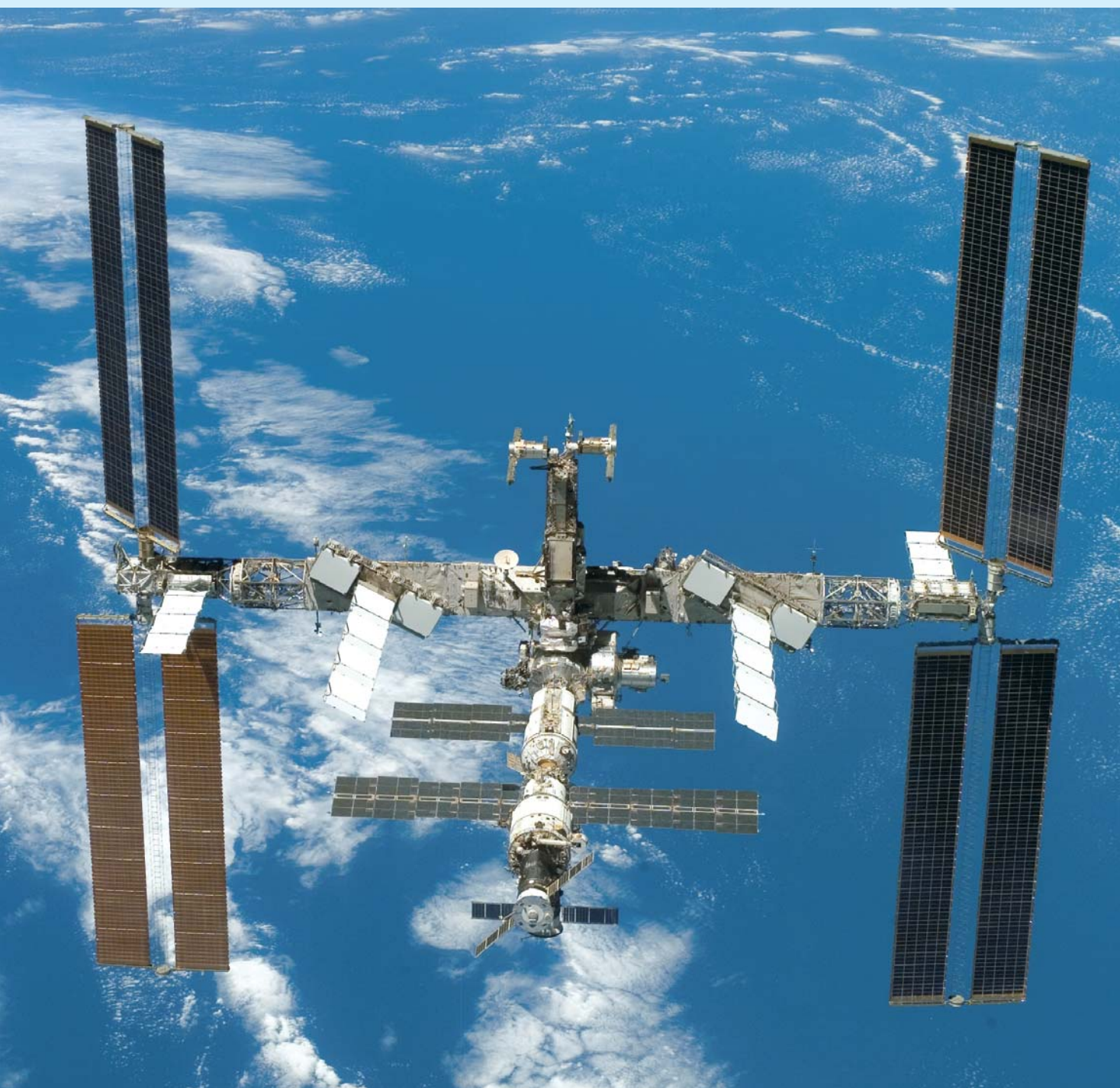


The High Resolution Stereo Camera of Mars Express imaged the Aolis Mensae region (6°S/145°E) of the Red Planet on 26 and 29 March 2007. Deep valleys are incised into the highlands with unexplained linear features on some floors. (ESA/DLR/FU Berlin, G. Neukum)



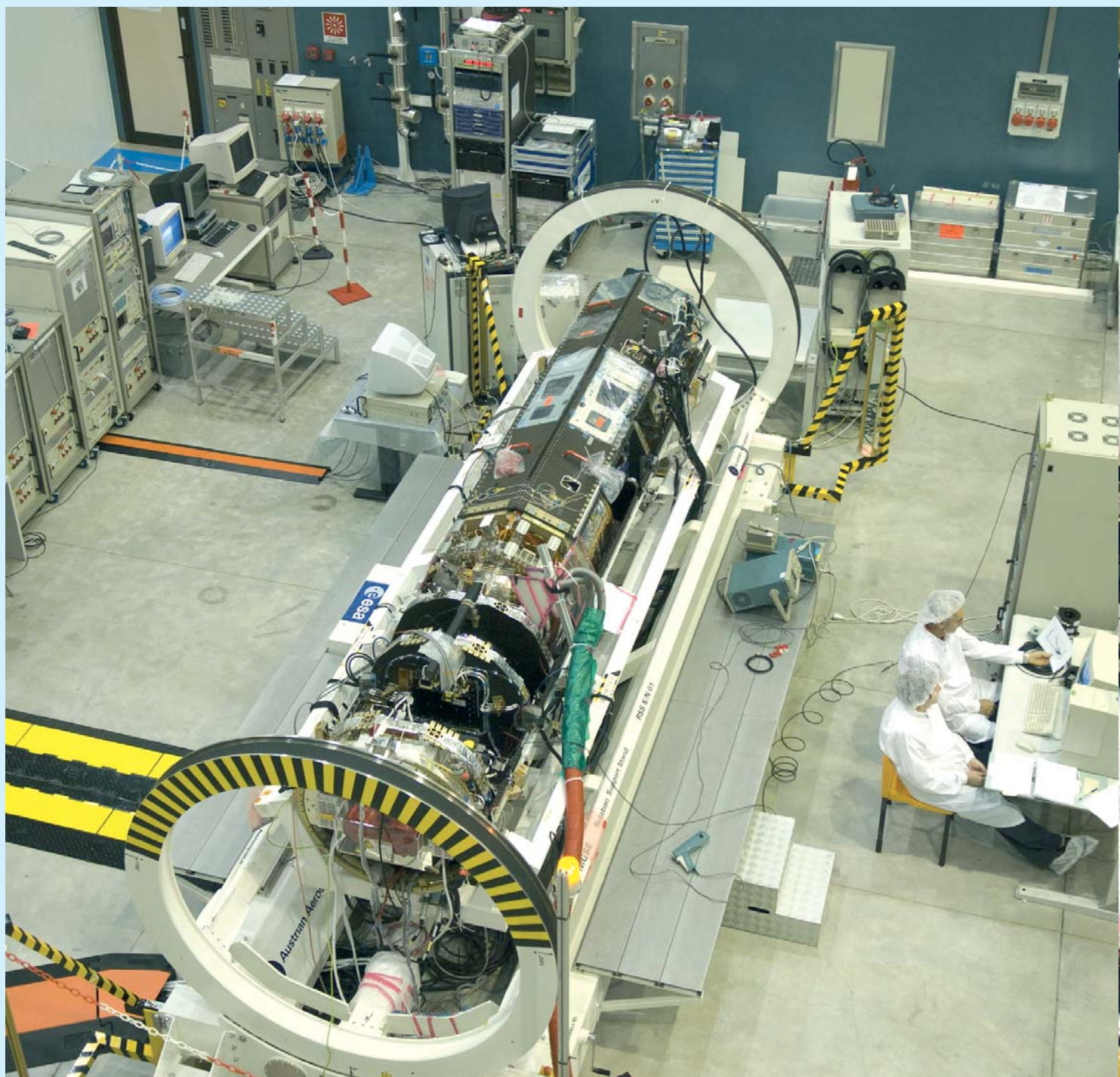
This Envisat/MERIS image of 2 September 2006 shows the southern part of the Caspian Sea, at 371 000 square km the world's largest inland body of water. The oil-rich Caspian stretches 1200 km north to south, bordered by Russia and Kazakhstan to the north, Azerbaijan to the west, Turkmenistan to the east and Iran to the south. Because the Caspian is a closed body of water, it supports a unique biodiversity but is also vulnerable to pollution from agriculture and industry –

particularly oil. The Caspian Basin is rich in oil deposits; the oil centre of Baku, capital of Azerbaijan, is on the southern side of the Apsheron Peninsula jutting out from the western shore. On the other side of the sea is Turkmenistan, dominated by the Karakum Desert. On the southern shores are Iran's green Gilan-Mazanderan lowlands and the Alborz mountain range, which hinders rain clouds moving south, explaining the contrast with the desert to the south.



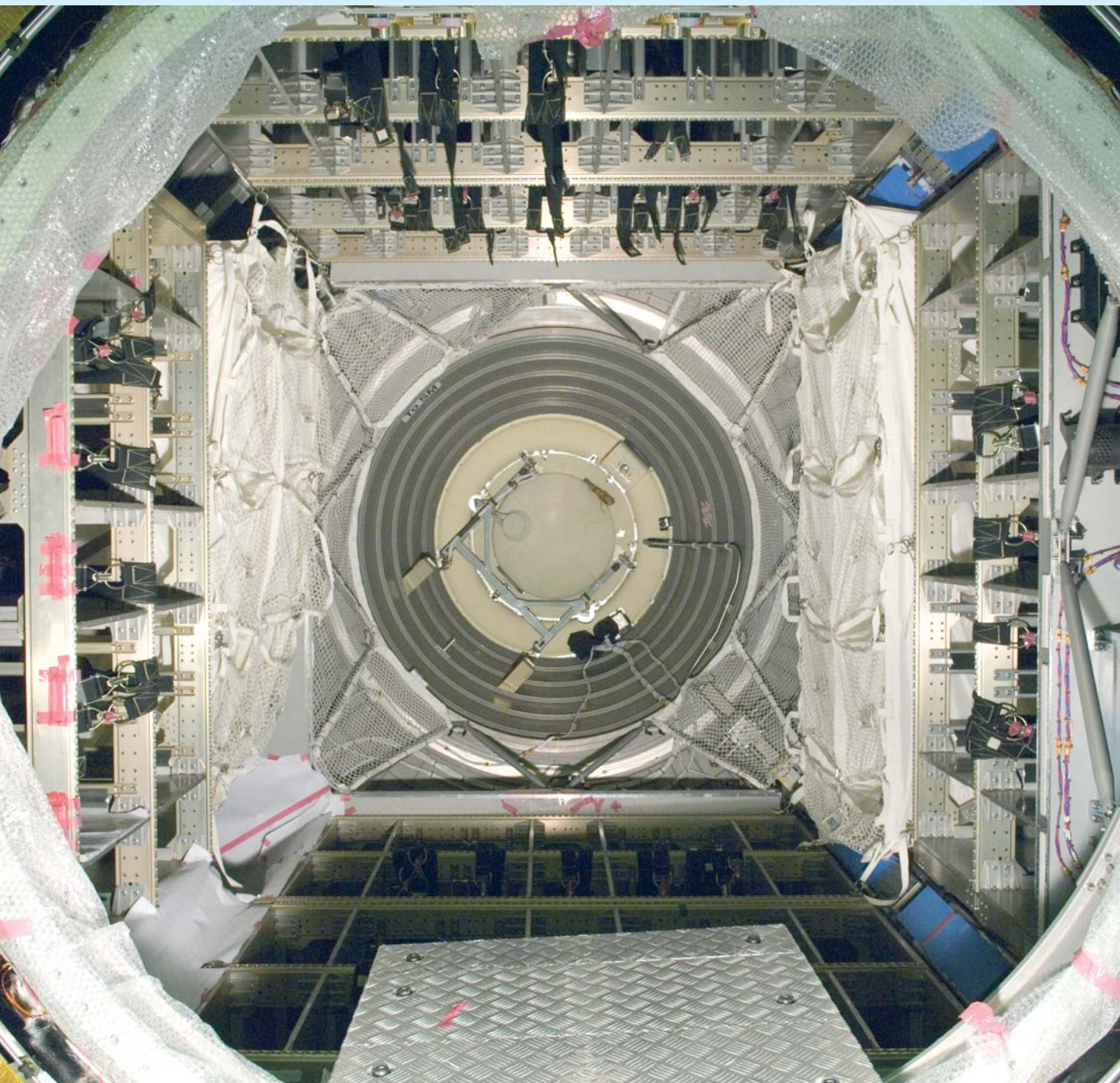
The appearance of the International Space Station as the latest Space Shuttle mission, STS-118, arrived in August. The image was captured on 17 June as STS-117 departed after attaching the S3/4 truss and solar wings at right. STS-118 will add the S5 segment at right to allow the S6 solar wings to be attached on a later mission. It will also help to prepare the way for Europe's Node-2 and Columbus modules to be added in October (STS-120) and December (STS-122) this year,

respectively. STS-120 will also move the P6 solar wings (seen here retracted on top of the Station) to their final position at far left. ESA's first Automated Transfer Vehicle is expected to arrive in January 2008, docking with the aft Zvezda module, seen here with a Russian Progress unmanned ferry attached (closest to camera). Japan's Kibo laboratory module and platform will also be installed in 2008. (NASA)



GOCE, ESA's first satellite dedicated to measuring the Earth's gravity field, is seen here at prime contractor Thales Alenia Space in Turin (I) in July before being shipped to ESTEC in August. The 'Gravity field and steady-state Ocean Circulation Explorer' will significantly advance our knowledge of how the Earth works and provide insight into ocean circulation, sea-level change, climate change,

volcanism and earthquakes. At ESTEC, GOCE will undergo final integration and environmental testing to make sure it is ready to withstand the rigours of launch and space operations. It will be launched next spring on a Rockot from the Plesetsk Cosmodrome in north-western Russia. Forty-five companies from 13 European countries have been working on the satellite since 2001. (ESA/S. Corvaja)



The interior of the Automated Transfer Vehicle (ATV) shortly before it was sealed off for the vehicle to be shipped to its Kourou launch site in July. Launch is planned for January 2008 on Ariane-5. ATV will dock with the International Space Station (the docking mechanism is protected by a red cover at the far right in the small photograph) with this pressurised section carrying an array of equipment

and consumables for the crew. Astronauts will enter via the hatch seen closed in the centre of the large image. ATV will remain attached for up to 6 months, periodically raising the Station's orbit to combat atmospheric drag, before departing filled with rubbish to burn up in the atmosphere over the Pacific Ocean. Other ATV photographs can be seen on pages 60 and 65. (ESA)





# 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 Annual Report

Annual Report 2006 (July 2007)  
 B. Battrick (Ed.)  
 ESA Annual Report // 126 pp  
 No Charge



## ESA Brochures

ESOC (April 2007)  
 D. Danesy (Ed.)  
 ESA BR-265 // 39 pp  
 Price: 10 Euro

Report by the 2006 Science Programme Review Team to the ESA Council (April 2007)  
 B. Battrick (Ed.)  
 ESA BR-267 // 48 pp  
 Price: 10 Euro



Resolution on the European Space Policy; ESA Director General's Proposal for the European Space Policy (June 2007)  
 A. Wilson (Ed.)  
 ESA BR-269 // 37 pp  
 Price: 10 Euro

## ESA Newsletter

Connect – ESA Telecommunication Newsletter (May 2007)  
 N. Menning & P. Clissold (Eds.)  
 No Charge

## ESA Special Publications

Bed-Rest Studies in the Spaceflight Era (1986–2005) – A Review  
 B. Battrick (Ed.)  
 ESA SP-1305 // 114 pp  
 Price: 30 Euro

Proceedings of the Envisat Symposium 2007, 23–27 April 2007, Montreux, Switzerland (July 2007)  
 H. Lacoste & L. Ouwehand (Eds.)  
 ESA SP-636 // CD (2 volumes)  
 Price: 80 Euro

Proceedings of DASIA 2007, DATA Systems In Aerospace, 29 May – 1 June 2007, Naples, Italy (August 2007)



L. Ouwehand (Ed.)  
 ESA SP-638 // CD  
 Price: 50 Euro

Proceedings of the 3rd International Workshop on Science and Applications of SAR Polarimetry and Interferometry, 22–26 January 2007, Frascati, Italy (March 2007)  
 H. Lacoste & L. Ouwehand (Eds.)  
 ESA SP-644 // CD  
 Price: 50 Euro

Proceedings of the 7th International Symposium 'Reducing the Costs of Spacecraft Ground Systems and Operations' (RCSGSO), 11–16 June 2007, Moscow, Russian Federation (July 2007)  
 D. Danesy (Ed.)  
 ESA SP-648 // CD  
 Price: 70 Euro

Proceedings of the 2nd IAASS Conference 'Space Safety in a Global World', 14-16 May 2007, Chicago, USA (July 2007)  
 D. Danesy (Ed.)  
 ESA SP-645 // CD  
 Price: 70 Euro

## ESA Contractor Reports

Radio Frequency Transmitter for Multimedia Ground Terminals – Final Report (May 2004)  
 ND SatCom  
 ESA CR(P)-4580 // CD  
 Price: 25 Euro

SDR Technology in Space – Final Report (June 2006)  
 Atos Origin, Spain  
 ESA CR(P)-4583 // CD  
 Price: 25 Euro



M2 – ASIC System Evolution – Executive Summary (November 2006)  
 Austrian Aerospace, Austria  
 ESA CR(P)-4581 // CD  
 Price: 25 Euro

Preparation Study of Investigations into Biological Effects of Radiation – Final Report (December 2006)  
 Univ. of Naples Federico II, Italy  
 ESA CR(P)-4585 // CD  
 Price: 25 Euro

Minimux – Final Report (October 2006)  
 Tesat, Germany  
 ESA CR(P)-4589 // CD  
 Price: 25 Euro

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LARI – Low Cost Remote Surveillance & Metering Satellite Services Feasibility Study – Final Report & Executive Summary (March 2006)  
 VitroCiset, Italy  
 ESA CR(P)-4584  
 Price: 25 Euro

Multimedia Ground Terminals & Equipment: Fast Forward – Final Report (December 2006)  
 Advantech Satellite Networks, Canada  
 ESA CR(P)-4586 // CD  
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Breadboarding of Feed Cluster for a Reflector-Based Multiple Beam SAR Antenna – Summary Report (January 2007)  
 EADS Astrium GmbH, Germany  
 ESA CR(P)-4587 // CD  
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 TNO Science and Industry, The Netherlands  
 ESA CR(P)-4588 // CD  
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Satellite Communication System Elements, Technologies and Applications: Opportunities for Start-Up Projects – Executive Summary (June 2004)  
 ComSine Ltd, UK  
 ESA CR(P)-4589 // CD  
 Price: 25 Euro