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bulletin

SPACE FOR EUROPE

European Space Agency
Agence spatiale européenne

european space agency

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(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

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ESRIN, Frascati, Italy.

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agence spatiale européenne

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

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Directeur général: J.-J. Dordain

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

Editors
Bruce Battrick
Barbara Warmbein

Design & Layout
Isabel Kenny

Advertising
Barbara Warmbein

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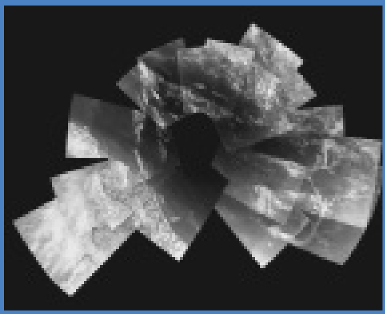
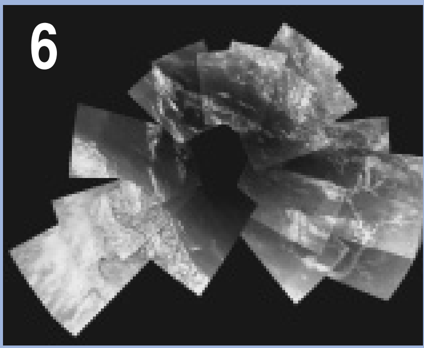
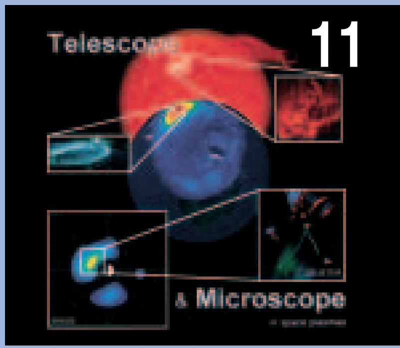


Cover: The surface of Titan, as seen for the first time by ESA's Huygens probe. See article on page 6.

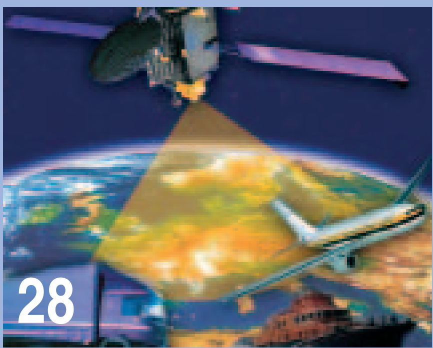


Europe Arrives at the New Frontier
– The Huygens landing on Titan



Cluster –
A microscope and a telescope for studying space plasmas

AmerHis: The First Switchboard in Space



Satellite Navigation, Wireless Networks and the Internet

Frequency Management for ESA's Missions

'Maxwell'
– A New State-of-the-Art EMC Test Facility

esa bulletin 121 - february 2005

Contents

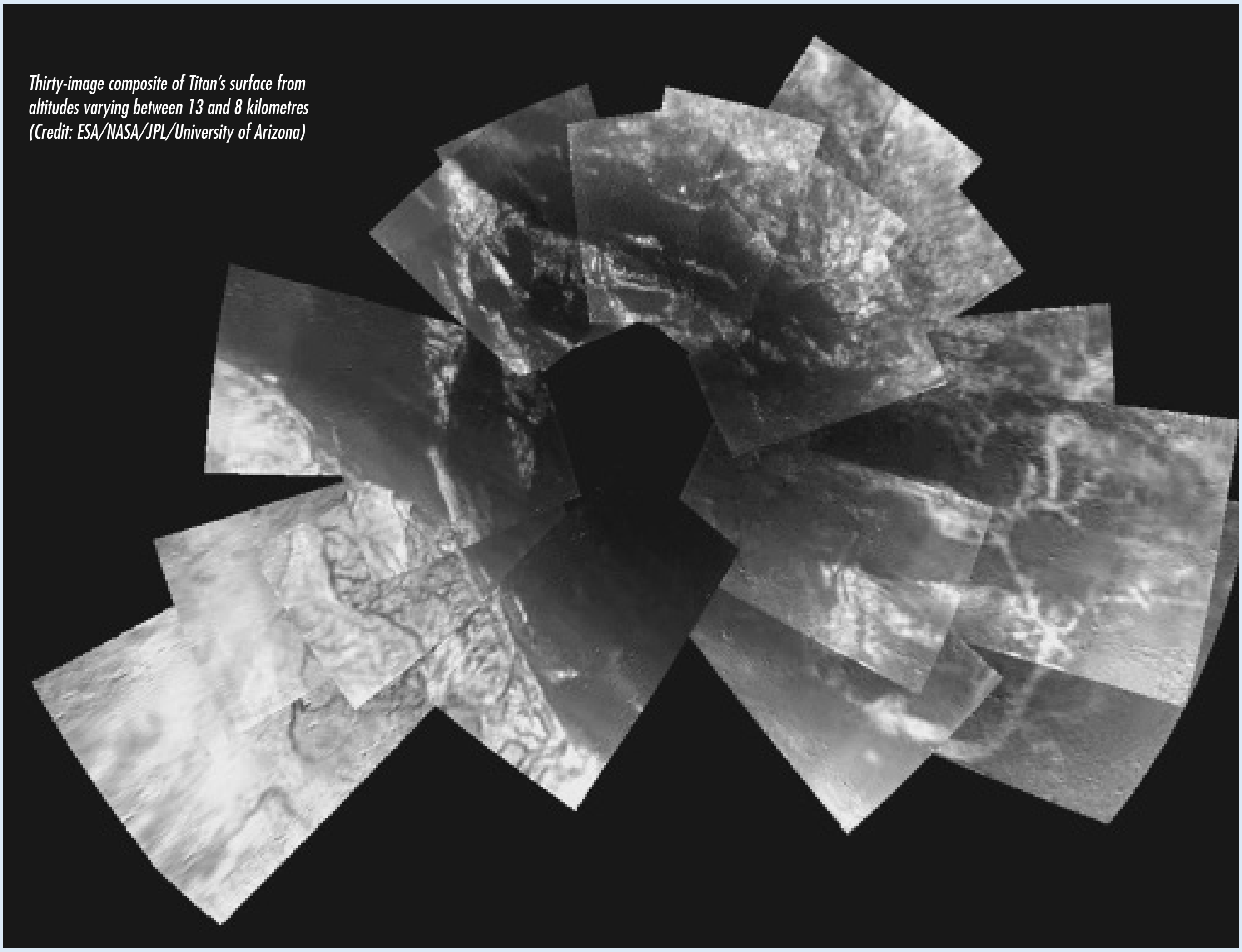
Europe Arrives at the New Frontier

– The Huygens Landing on Titan

On 14 January 2005, after a marathon seven-year journey through the Solar System aboard the Cassini spacecraft, ESA's Huygens probe successfully descended through the atmosphere of Titan, Saturn's largest moon, and landed safely on its surface. It was mankind's first successful attempt to land a probe on another world in the outer Solar System.

Following its release from the Cassini mothership on 25 December, Huygens reached Titan's outer atmosphere after 20 days and a 4 million kilometre cruise. The probe started its descent through Titan's hazy cloud layers from an altitude of about 1270 km at 09:06 UTC. During the following three minutes, Huygens had to decelerate from 18 000 to 1400 km per hour.

A sequence of parachutes then slowed it to less than 300 km per hour. At a height of about 160 km, the probe's scientific instruments were exposed to Titan's atmosphere for the first time and Huygens started to transmit its radio signal to Cassini at 09:12 UTC (spacecraft event time). The Huygens radio signals also arrived on Earth, but 67 min later as a faint tone that was detectable by large radio telescopes. At about 120 km altitude, the main parachute was jettisoned and replaced by a smaller one to complete the descent. The Huygens radio signal was detected on Earth at about 11:20 CET by the 110-m Robert Byrd Green Bank Telescope in West Virginia. About 2 hours later, the probe's signal was picked-up by telescopes in Australia, which indicated that Huygens had landed and continued to transmit after landing. Cassini listened to Huygens for 4h 36 min and then transmitted the Huygens data to Earth via NASA's Deep Space Network once the Huygens mission was over. The first scientific data arrived at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany at 17:19 CET, having also taken 67 min to travel across space. An hour later, the data indicated that Huygens had landed safely at 12:39 CET and had transmitted data for 72 min from Titan's surface.



Thirty-image composite of Titan's surface from altitudes varying between 13 and 8 kilometres (Credit: ESA/NASA/JPL/University of Arizona)

The Descent

Huygens was expected to provide the first direct and detailed sampling of Titan's atmospheric chemistry and the first photographs of its hidden surface, and to supply a detailed 'weather report'. One of the main reasons for sending Huygens to Titan was that its nitrogen atmosphere, rich in methane, and its surface may contain many chemicals of the kind that existed on the young Earth. Combined with the Cassini observations, Huygens could therefore deliver an unprecedented view of Saturn's mysterious moon.

The view from thirteen kilometres high

The picture on the previous page is a composite of 30 images taken by Huygens from an altitude varying from 13 kilometres down to 8 kilometres as the probe was descending towards its landing site. At that stage of its descent, Huygens was dropping almost vertically at a speed of about 5 metres per second and drifting horizontally at about 1.5 metres per second, just a leisurely walking pace. The composite image covers an area extending out about 30 kilometres around the probe.

The final descent and the landing site

As soon as Huygens had touched down on Titan's surface, some 15 scientists in the Descent Trajectory Working Group were hard at work to determine the location of the landing site. Apart from being needed to understand where exactly the probe had landed and to provide a reference trajectory to analyse and interpret the Huygens data set, having such a profile available for a probe entering the atmosphere of another Solar System body is extremely important for future space missions.

"This is a great achievement for Europe and its US partners in this ambitious international endeavour to explore the Saturnian system," said Jean-Jacques Dordain, ESA's Director General. *"The teamwork in Europe and the USA, between scientists, industry and agencies has been extraordinary and has set the foundation for this enormous success".*

"Titan was always the target in the Saturn system where the need for 'ground truth' from a probe was critical. It is a fascinating world and we are now eagerly awaiting the scientific results," said Professor David Southwood, Director of ESA's Scientific Programme.

"The Huygens scientists are all delighted. This was worth the long wait," said Dr Jean-Pierre Lebreton, ESA Huygens Mission Manager and Project Scientist.

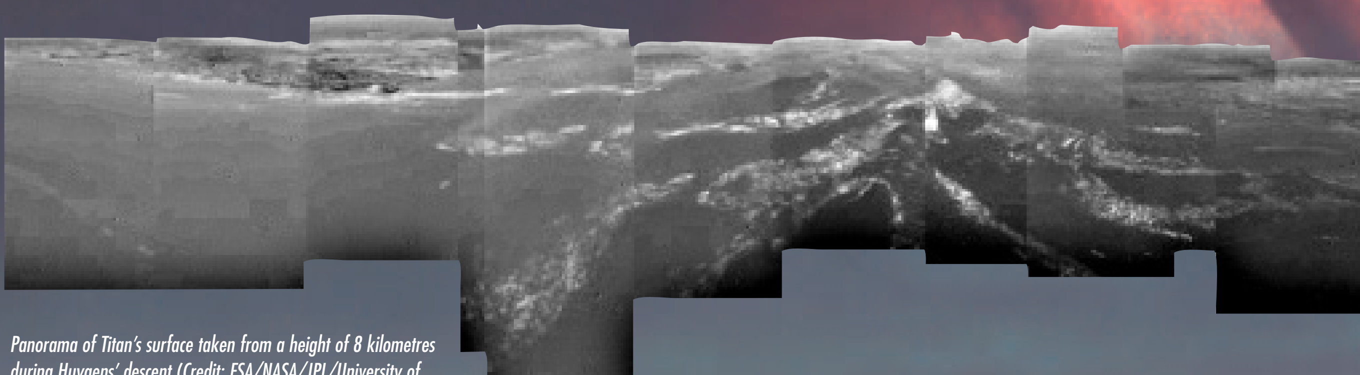
"Descending through Titan was a once-in-a-lifetime opportunity and today's achievement proves that our partnership with ESA was an excellent one," said Alphonso Diaz, NASA Associate Administrator of Science.

"The ride was bumpier than we thought it would be," said Martin Tomasko, Principal Investigator for the Descent Imager/ Spectral Radiometer (DISR), the instrument that provided Huygens' stunning, images among other data. The probe rocked more than expected in the upper atmosphere. During its descent through high-altitude haze, it tilted at least 10 to 20 degrees, while once below the haze layer it was more stable, tilting less than 3 degrees. The Huygens scientists are investigating the probe's atmospheric environment during its descent in order to explain the bumpy ride.

The bumpy ride was not the only surprise during the descent. Scientists had theorised that the probe would drop out of the haze at between 70 and 50 kilometres altitude. In fact, Huygens began to emerge from the haze when only 30 kilometres above the surface.

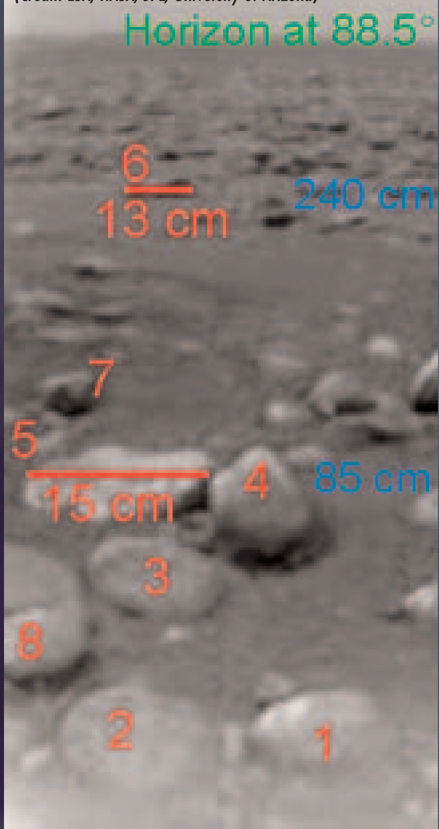
When the probe landed, it was not with a thud or a splash, but a 'splat' – it had landed in Titanian 'mud'. *"I think the biggest surprise is that we survived landing and that we lasted so long,"* said DISR team member Charles See. *"There wasn't even a glitch at impact. That landing was a lot friendlier than we anticipated."*

When the mission was designed, it was decided that the DISR's 20-Watt landing lamp should turn on 700 metres above the surface and illuminate the landing site for as long as 15 minutes after touchdown. *"In fact, not only did the landing lamp turn on at exactly 700 metres, but also it was still shining more than an hour later, when Cassini moved beyond Titan's horizon for its ongoing exploratory tour of the giant moon and the Saturnian system,"* said Martin Tomasko.



Panorama of Titan's surface taken from a height of 8 kilometres during Huygens' descent (Credit: ESA/NASA/JPL/University of Arizona)

The first colour image of Titan's surface, with centimetre scales superimposed to characterise surface features (Credit: ESA/NASA/JPL/University of Arizona)



The First Scientific Results

More than 474 megabits of data were received in 3 hours 44 minutes from Huygens, including some 350 pictures collected during the descent and on the ground, which revealed a landscape apparently modelled by erosion, with drainage channels, shoreline-like features, and even pebble-shaped objects on the surface.

The atmosphere was probed and sampled for analysis at altitudes from 160 km to ground level, revealing a uniform mix of methane with nitrogen in the stratosphere. The methane concentration increased steadily in the troposphere and down to the surface. Clouds of methane were detected at about 20 km altitude, and methane or ethane fog near the surface. During the descent, sounds were recorded in order to detect possible distant thunder from lightning, providing an exciting acoustic backdrop to Huygens' descent.

As the probe touched down, its instruments provided a large amount of data on the texture of the surface, which resembles wet sand or clay with a thin solid crust, its composition, mainly a mix of dirty water ice and hydrocarbon ice, resulting in a darker 'soil' than expected. The temperature measured at ground level was about minus 180 degrees Celsius.

Spectacular images captured by the DISR reveal that Titan has extraordinarily Earth-like meteorology and geology. Images have shown a complex network of narrow drainage channels running from brighter highlands to lower, flatter, dark regions. These channels merge into river systems running into lakebeds featuring offshore 'islands' and 'shoals' remarkably similar to those on Earth.

"We now have the key to understanding what shapes Titan's landscape," said Dr Tomasko, adding: *"Geological evidence for precipitation, erosion, mechanical abrasion and other fluvial activity says that the physical processes shaping Titan are much the same as those shaping Earth."*

Data provided in part by the Gas Chromatograph and Mass Spectrometer (GCMS) and Surface Science Package (SSP) support Dr Tomasko's conclusions. Huygens' data show strong evidence for liquids flowing on Titan. However, the fluid involved is methane, a simple organic compound that can exist as a liquid or gas at Titan's very cold temperatures, rather than water as on Earth. Titan's rivers and lakes appear dry at the moment, but rain may have occurred not long ago.

Deceleration and penetration data provided by the SSP indicate that the material beneath the surface's crust has the consistency of loose sand, possibly the result of methane rain falling on the surface over eons, or the wicking of liquids from below towards the surface.

Heat generated by Huygens warmed the soil beneath the probe and both the GCMS and SSP instruments detected bursts of methane gas boiled out of surface material, reinforcing the evidence for methane's principal role in Titan's geology and meteorology.

In addition, DISR surface images show small rounded pebbles in a dry riverbed. Spectra measurements (colour) are consistent with a composition of dirty water ice rather than silicate rocks. However, these form a rock-like solid at Titan's temperatures.

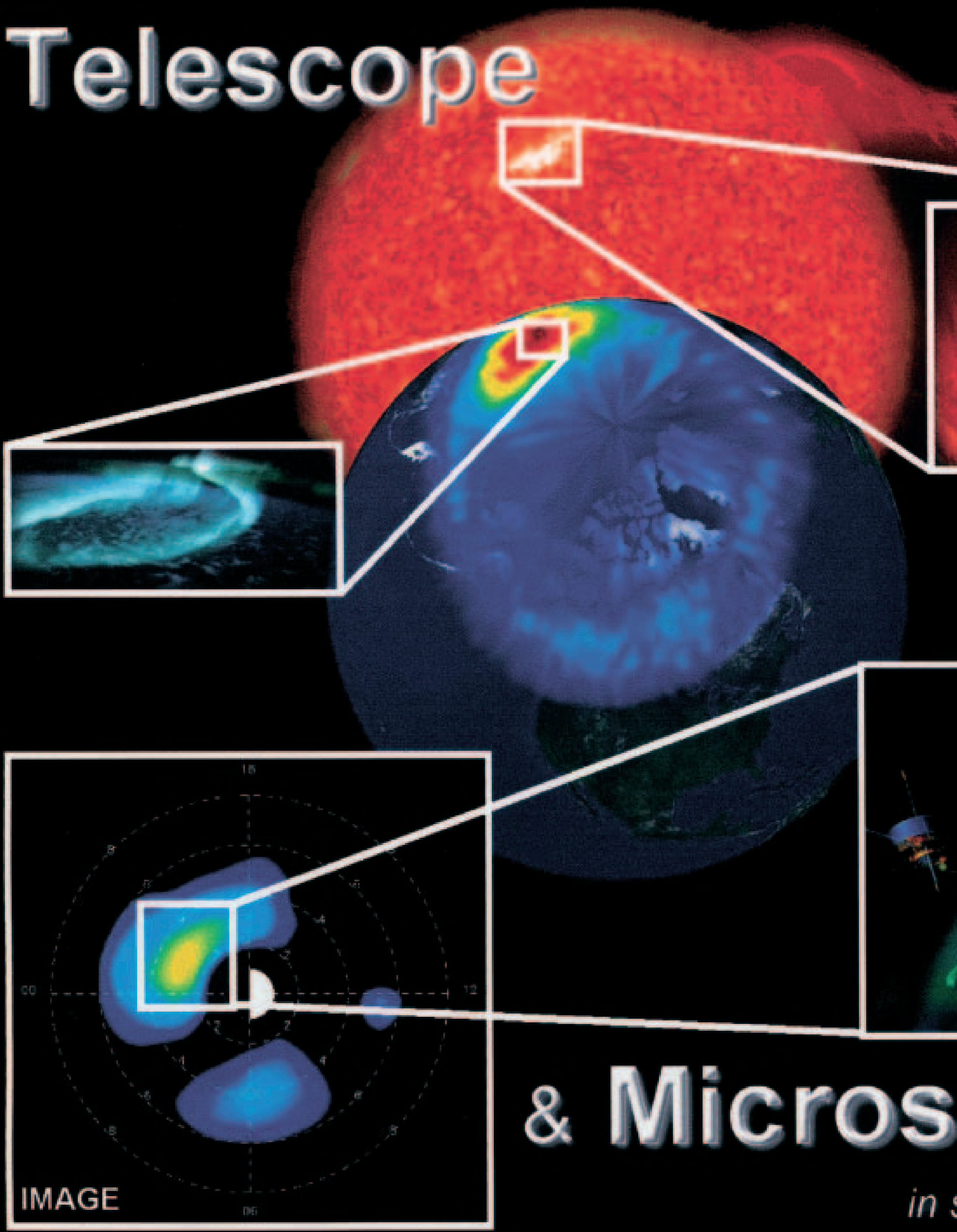
Titan's soil appears to consist at least in part of precipitated deposits of the organic haze that shrouds the planet. This dark material settles out of the atmosphere. When washed off high elevations by methane rain, it concentrates at the bottom of the drainage channels and riverbeds contributing to the dark areas seen in DISR images.

Stunning new evidence based on finding atmospheric argon 40 strongly suggests that Titan has experienced volcanic activity generating not lava, as on Earth, but water ice and ammonia.

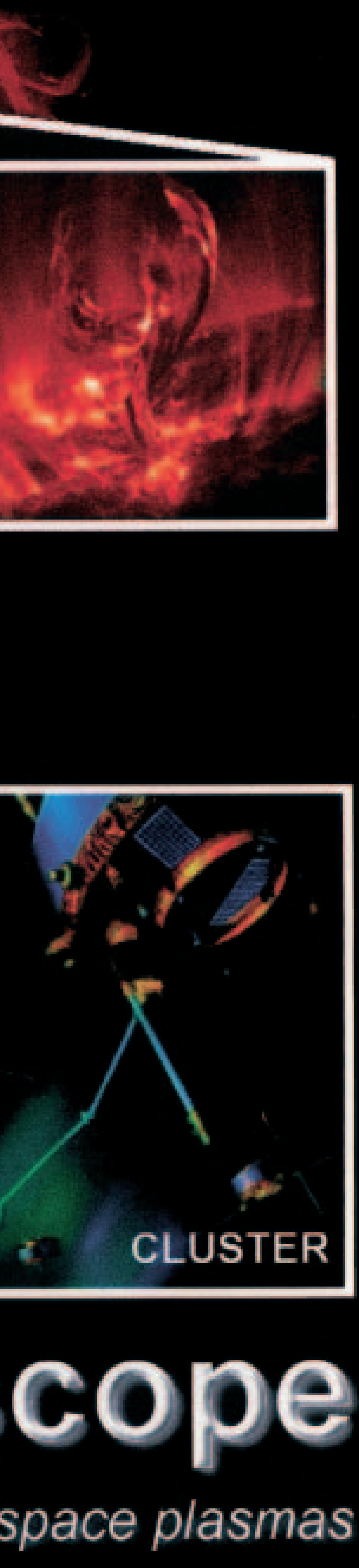
Thus, while many of Earth's familiar geophysical processes occur on Titan, the chemistry involved is quite different. Instead of liquid water, Titan has liquid methane. Instead of silicate rocks, Titan has frozen water ice. Instead of dirt, Titan has hydrocarbon particles settling out of the atmosphere, and instead of lava, Titanian volcanoes spew very cold ice. Titan is therefore an extraordinary world, having Earth-like geophysical processes operating on exotic materials in very alien conditions.

"This is only the beginning; these data will live for many years to come and they will keep the scientists very very busy", says Jean-Pierre Lebreton, ESA's Huygens Project Scientist and Mission Manager.

The Cassini-Huygens mission is a cooperative endeavour by NASA, ESA and ASI, the Italian space agency. The Jet Propulsion Laboratory (JPL), a division of the California Institute of Technology in Pasadena, designed, developed, assembled and is operating the Cassini orbiter, while ESA was responsible for the Huygens atmospheric probe.



Courtesy of AGU/D.N. Baker, Univ. of Colorado



Cluster

– A microscope and a telescope for studying space plasmas

Harri Laakso, Philippe Escoubet, Hermann Opgenoorth
Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Juergen Volpp, Siegmar Pallaschke
Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

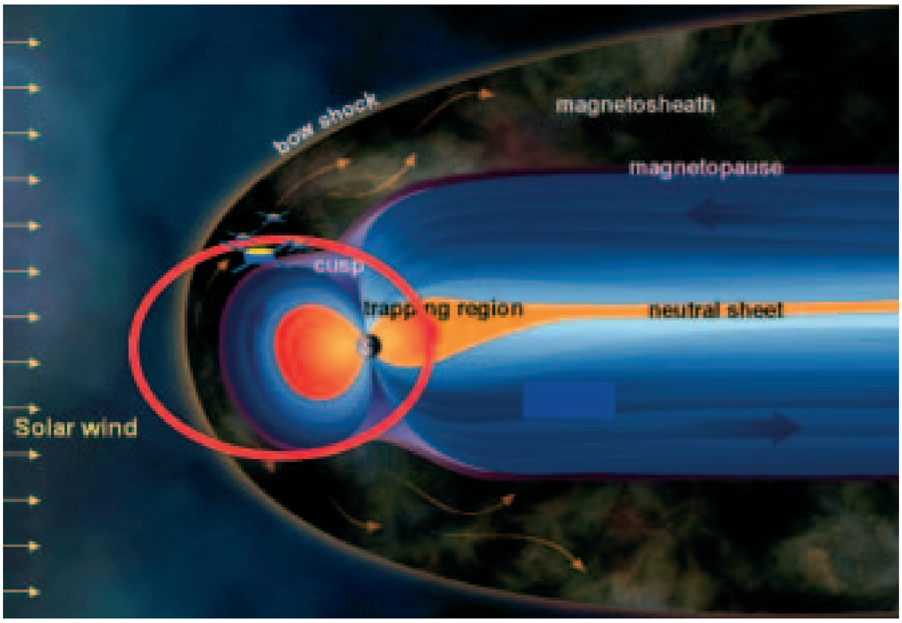
Mike Hapgood
Rutherford Appleton Laboratory, Didcot, United Kingdom

The four-satellite Cluster mission serves as both a 'microscope' and a 'telescope' for magnetospheric scientists. Using its suite of state-of-the-art instruments, it is providing a close-up view of complex small-scale physical processes occurring around the Earth. These processes are often reflections of other, sometimes violent processes that are taking place much further away from our spacecraft, which means that Cluster also serves as a 'telescope' for observing those more distant processes.

Introduction

We have been investigating the Earth's magnetosphere with space probes for nearly 50 years, allowing us to draw a general picture of the space environment that surrounds our planet. The origin of the magnetosphere lies in the Earth's internal magnetic dynamo, and without the solar wind the picture would be quite simple. However, with the solar wind – a magnetised supersonic stream of electrons and ions continuously escaping from the Sun, which interacts with the Earth's magnetic field – the picture becomes highly complex. Under the solar wind's influence, the shape of the Earth's natural magnetic field lines is transformed from a dipolar form into a large tail-like structure which is called ‘the magnetosphere’ (see adjacent sketch).

At the same time as the solar wind is distorting the magnetosphere’s outer boundaries, the ultraviolet and X-rays emanating from the Sun are ionising the Earth’s upper atmosphere, making it highly electrically conductive. This region, known as ‘the ionosphere’, is coupled to the magnetosphere via the Earth’s magnetic field lines. Above 1000 km altitude from the ground, the neutral and plasma particle densities are sufficiently low for the medium to be fully conductive. At higher altitudes in the magnetosphere, the resistance in the plasma can suddenly increase in certain localised regions, giving rise to some of the most fascinating processes that occur in space.



A sketch of the Earth’s magnetosphere; the Sun is to the left. The distance of the magnetopause on the dayside is approximately 10 R_e (where R_e is the Earth’s radius, equal to 6370 km), while the bow shock is at 14 R_e. The long tail of the magnetosphere in the nightside can continue for more than 100 R_e. Cluster orbits the Earth at between 4 and 20 R_e distance, during which the four satellites encounter most of the key magnetospheric regions. The orbit shown in red is for February-March, and half a year later the apogee is in the magnetotail

The Sun-Earth Connection

Many details of how our terrestrial environment responds to variations in solar radiation and solar wind, and their implications for humans and man-made technologies in space and on the ground, remain unresolved. Understanding and predicting such conditions in space requires multi-point measurements at critical locations in the magnetosphere and solar wind.

Basically all of the unresolved Sun-Earth connection issues can be grouped under three fundamental questions:

(i) How and why does the Sun vary?
(ii) How does the Earth’s environment respond to such variations?
(iii) What are the consequences for humanity?

The Cluster mission objectives belong primarily to the second category.

The four Cluster satellites have been orbiting the Earth since August 2000, and their observations have improved and often even fundamentally changed our previous understanding of near-Earth space. The primary aim of the mission is to characterise and model the near-Earth plasma regions and boundaries, as well as to understand the physical processes taking place there. Cluster cannot solve all of the mysteries of the Sun-Earth connection, but it is providing us with the first real 3-D measurements in space that allow us to separate the temporal and spatial features. Some of the key issues are related to the existence and characteristics of magnetic reconnection, plasma turbulence, and charged-particle acceleration. These are the main processes that control the transfer of energy, momentum and particles from one region of space to another – for instance, between the solar wind and the magnetosphere, or between the magneto-sphere and the Earth’s atmosphere.

Electric Currents

One of the most difficult measurements in space is the determination of the electric currents that extend over vast distances in three dimensions. The magnitudes of the currents are very large, typically in the range of 1-10 million Amperes, but as the cross-sections of the current systems are also large, Cluster needs to be able to detect very weak current densities, typically not more than a few 100 nano Amperes per square metre.

In principle, the currents can be estimated by calculating the fluxes of electrons and ions, but in fact the only reliable method in space is to use Ampere’s Law. This technique is based on accurate magnetic-field measurements at four points, from which one can calculate the electric current crossing the Cluster constellation. The Cluster spacecraft carry very stable and sensitive magnetometers that can provide the required measurements. Unfortunately, this does not always work in practice, either because the physics turns out to be more complex than described by Ampere’s Law, or because the separations between the four spacecraft are not optimal with respect to the size of the current region being studied. By varying the spacecraft separations during the mission, we have been able to determine the strengths and directions of the electric currents in many regions, and these data are of fundamental importance for magnetospheric modelling.

Electric Fields

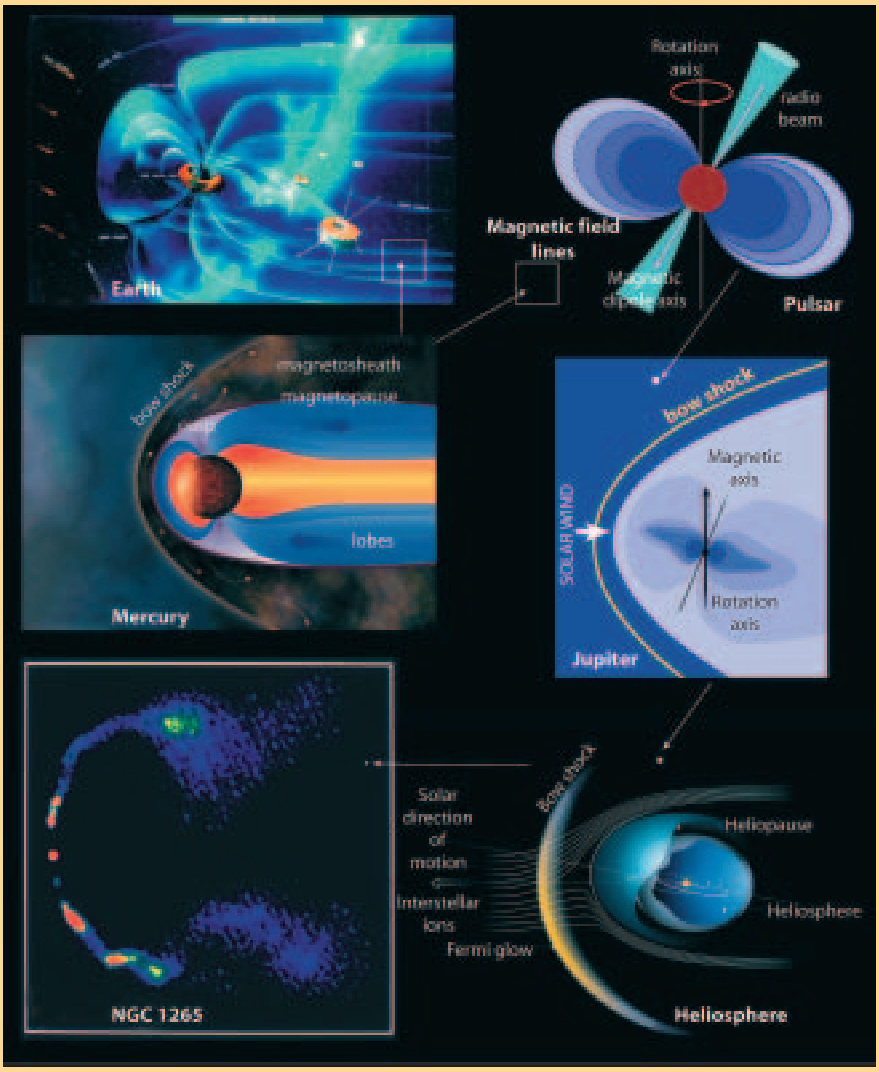
Another difficult task is the measurement of electric fields, which are needed to understand how the charged particles flow

Comparative Magnetospheres

By understanding how the Earth's magnetosphere functions and how it is driven by the energy from the solar wind, we can also better model other magnetosphere-like systems that are common not only in our own Solar System but throughout the Universe in stars, galaxies, etc. More than 99% of material in space appears as plasma, or an electrically charged gaseous medium. There are a multitude of complex physical processes occurring in such a medium, and our geospace is the only place where we can monitor and investigate them in-situ. The observational problem, however, is that the processes occur in spatially limited regions, their locations are constantly moving, and they occur for only short periods. One therefore has to be in the right place at the right time, which is very difficult, and so one needs to collect large data sets over various time and spatial scales in many locations in order to fully understand, model and predict the occurrence of the processes.

Having some knowledge of how the Earth's magnetosphere behaves, it is fascinating to visit other magnetospheres to observe similarities or dissimilarities between them and the Earth. Venus and Mars (and perhaps Pluto) are the only planets in the Solar System that have no magnetosphere due to the lack of an internal magnetic dipole. In such cases, the solar wind interacts directly with the atmosphere. Single space probes have been used to get a view of the magnetospheres of the other planets, and the interpretation of such data is made much easier by observing the processes in detail first at the Earth, especially using multiple satellites like Cluster.

The Sun also has its own magnetosphere, called the 'heliosphere'. The solar wind expands to very large distances of the order of 100–1000 AU in the Solar System (1 AU is the distance between the Sun and the Earth), and this expansion is eventually stopped by the pressure of the interstellar plasma. Currently a few satellites launched in the early 1970's are approaching the edge of the heliosphere and will soon be able to study the coupling between it and the interstellar wind, which is somewhat similar to the interaction between the Earth's magnetosphere and the solar wind.

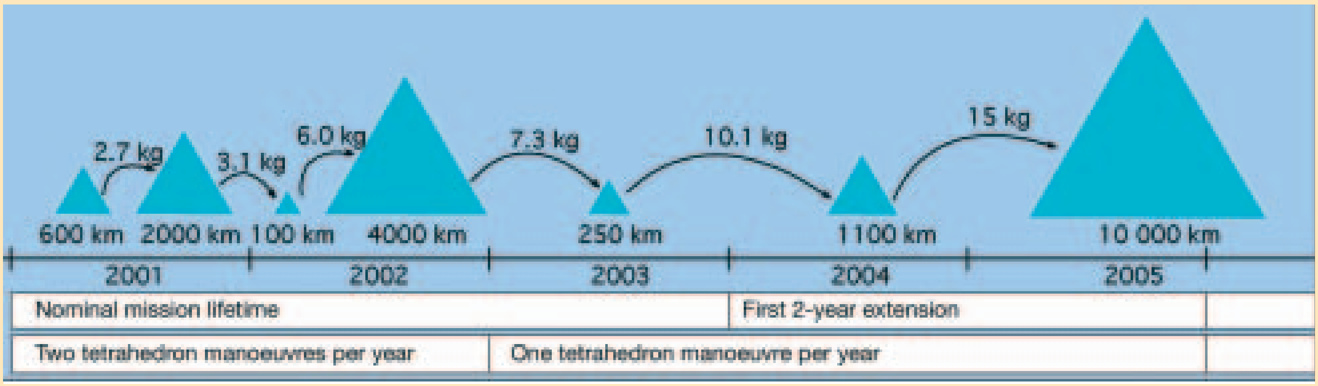


Magnetospheres, or magnetized plasma regions, are common in our Universe. These examples show simple models for Mercury, Earth, pulsar, and Jupiter, whose sizes are within a few orders of magnitude. However, similar systems also occur on larger scales, such as the heliosphere formed by the solar magnetic field as well as the galaxy NGC 1265 (courtesy of C. O'Dea & F. Owen, NRAO/AUI).

The Cluster Mission and Its Instruments

Cluster is the first space physics mission to be made up of several identical spacecraft. Each of them carries a complete suite of instruments to measure particles, magnetic fields, electric fields, and electromagnetic waves. In addition a unique spacecraft potential-control instrument (which keeps the electrical potential of the spacecraft themselves at typically 5-7 Volts) allows the scientists to monitor low-energy electrons and ions in the plasma, which would otherwise not be possible.

In any region of the magnetosphere the spatial scales (i.e. the distances over which the plasma characteristics change) appear to be highly variable. This complexity is increased by varying time scales, which makes sound interpretations highly challenging. Having Cluster measurements at four different points is fundamentally important here, although ideally many more than four satellites are needed to measure different scales simultaneously. So, having only four satellites, it is essential to change their separations regularly, because the most important scale length for one region can be completely wrong for another. For changing the side lengths of the tetrahedron-shaped formation in which the Cluster satellites fly, each satellite originally had 63 kg of fuel onboard to perform the necessary manoeuvres; at the moment, approximately half of that fuel is left. A change of constellation from one tetrahedron to another requires a complicated set of over 40 individual manoeuvres that last approximately 6 weeks. During the first two years of the mission, two constellation changes were performed annually. Since 2003, only one constellation change per year has been made.

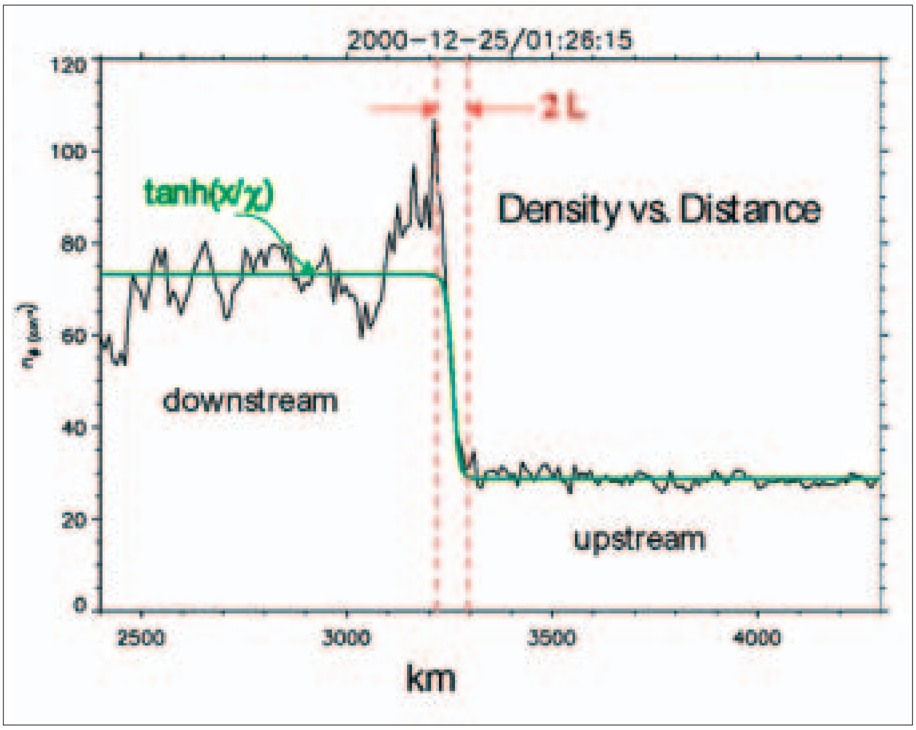


The triangles show schematically the size of separation distances of the four Cluster satellites, with the actual separation distances in kilometres given below the triangles. The masses show how much fuel was consumed during the manoeuvres conducted for each new tetrahedron constellation (Courtesy of D. Sieg, ESOC)

The Eleven Instruments on Each of the Four Cluster Spacecraft

Instrument		Principal Investigator
ASPOC	Spacecraft potential control	K. Torkar (IWF, A)
CIS	Ion composition, $0<E<40$ keV	H. Rème (CESR, F)
DWP	Wave processor and particle correlator	H. Alleyne (Univ. Sheffield, UK)
EDI	Plasma drift velocity	G. Paschmann (MPE, D)
EFW	Electric field and waves	M. André (IRFU, S)
FGM	Magnetometer	A. Balogh (IC, UK)
PEACE	Electrons, $0<E<30$ keV	A. Fazakerley (MSSL, UK)
RAPID	High-energy electrons and ions, $20<E_e<400$ keV, $10<E_i<1500$ keV	P. Daly (MPAe, D)
STAFF	Magnetic and electric fluctuations	N. Cornilleau (CETP, F)
WBD	Wideband detector	D. Gurnett (Iowa, USA)
WHISPER	Electron density and waves	P. Décréau (LPCE, F)

within the magnetosphere and how they are accelerated. Although electric potential differences across many regions can be of the order of 10 - 100 kilovolts, the actual electric fields appear to be small – just 0.1-10 millivolts – as the regions are very wide. Their detection therefore requires highly sophisticated instruments. Each of the Cluster satellites carry two state-of-art instruments that can monitor such weak fields. One measures potential differences between electric sensors located at the tips of 44 metre-long booms, and each satellite carries four such booms. The other instrument measures the drift of a weak beam of 1 keV electrons emitted by the instrument, from which the electric fields can be determined.



Density transition from downstream to upstream across the Earth's bow shock in the solar wind. The green line is a theoretical fit; the red vertical lines show the thickness of the shock (Courtesy of S. Bale, University of California at Berkeley)

Scientific Highlights

Bow shock

Shocks are a common and important phenomenon in the Universe as they accelerate particles to very high speeds. Close to the Earth, shocks appear, for instance, at the fronts of massive coronal mass ejections released by the Sun. These events cause magnetic storms at the Earth and produce plenty of high-energy particles, which are eventually trapped in the radiation belts that surround it. At a distance of approximately 14 Earth radii from our planet towards the Sun, there is a permanent shock region, known as the 'bow shock'. It is formed by the interaction of the Earth's magnetosphere with the streaming supersonic solar wind. At the bow shock, the solar wind is rapidly decelerated and the interplanetary magnetic field is compressed.

For a detailed understanding of the physics of shocks, one must have measurements on both sides of the shock as well as in the shock itself. The Cluster mission is therefore helping us to model shocks not only in front of the Earth's magnetosphere, but also elsewhere in the Universe. The position of the bow shock is subject to a continuous back-and-forth motion due to pressure variations in the solar wind, which helps Cluster in its task because it means that the spacecraft usually make several crossings once they approach the shock. As the four satellites are far apart, one gets simultaneous observations from all sides of the shock.

Cluster has been able to measure the speed and thickness of the Earth's bow shock for the first time. Based on about 100 bow-shock crossings, it has been possible to show that the shock front's thickness is proportional to the gyro-radius of solar wind ions*. At the shock, the electrons and ions get separated, setting up strong electric currents. Again for the first time, Cluster has observed such currents, which are typically of the order of one million Amperes.

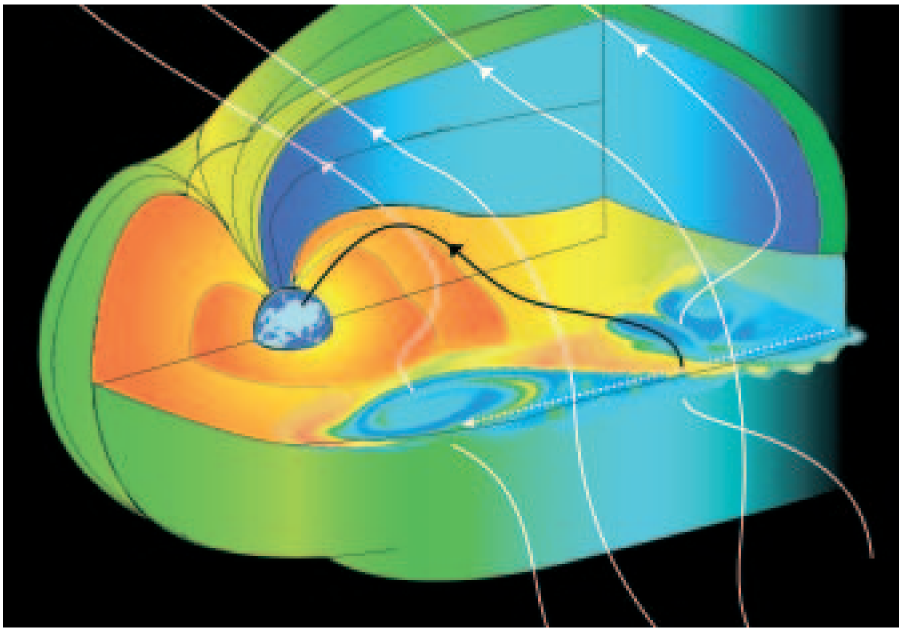
Cusps

The polar cusps are the two magnetic 'funnels' over the Earth's north and south magnetic poles, where particles from the solar wind actually penetrate the magnetosphere and reach the Earth's atmosphere. Cluster has observed so-called 'magnetic reconnection' in the neighbourhood of a polar cusp.

Magnetic reconnection occurs when two regions of oppositely directed magnetic fields interact and eventually become interconnected. It is a fundamental process in space and astrophysical plasmas through which plasmas of different origins are able to mix and become accelerated into energetic jets. It allows the transfer of charged particles between two different magnetised regions of space, for instance the solar wind and the Earth's magnetosphere. This process accelerates ions in both directions, so that the precipitating population in the cusp produces a 'bright spot' near noon, which can be observed on Earth at high latitudes (66 - 70 deg) in the form of the spectacular 'northern lights'.

On 18 March 2002, NASA's IMAGE spacecraft detected such a 'bright spot' in the northern polar cusp at the same time as Cluster detected the typical characteristics of polar-cusp reconnection. This was the first time that the reconnection process had been observed in-situ together with its effect on the Earth's ionosphere and atmosphere.

** Charged particles gyrate about magnetic field lines with a period that depends on the size of the magnetic field and the mass of the particle. The radius of the gyro motion depends on the gyro period and velocity of the gyrating particle.*



In this three-dimensional view of the Earth's magnetosphere, the curly features sketched on the boundary layer are the Kelvin-Helmholtz vortices discovered by Cluster. They originate where two adjacent flows travel with different speeds. The arrows show the direction of the magnetic field (Courtesy of H. Hasegawa, Dartmouth College)

Kelvin-Helmholtz waves

When two adjacent media flow at different speeds, waves build up at their interface and a phenomenon known as a 'Kelvin-Helmholtz instability' occurs. The wind blowing across the surface of the ocean causes waves due to this instability. Similarly in space, waves appear at the interface between two plasma media when the difference in velocity is large enough, for instance at the Earth's magnetopause.

The Cluster satellites have observed Kelvin-Helmholtz waves several times, but just recently they have discovered vortices in the Earth's magnetosphere caused by the instability. Normally, Kelvin-Helmholtz waves only distort the boundary and cannot cause particles to be transported across it. It has been suggested that the vortices let solar-wind particles enter the magnetosphere. Cluster's discovery strengthens the likelihood of this scenario, but does not yet show the precise mechanism. This is an exciting result because, with the interplanetary magnetic field and the Earth's magnetic field being aligned, the magnetopause is presently assumed to be an impenetrable barrier to the flow of solar wind, which is merely diverted around the magnetopause.

Reconnection in the magnetotail

The tail of the magnetosphere, called 'the magnetotail', appears to be an explosive region due magnetic reconnection and a source of highly energetic particles, some of which can have energies of more than 10 MeV*. There are many unsolved mysteries associated with the reconnection process in the tail, such as the actual trigger for the process and the formation of a thin current sheet that Cluster has observed to occur before the reconnection can take place.

The four Cluster spacecraft have surrounded the reconnection region in the central magnetotail several times, exploring the core region where ions and electrons get decoupled. A change of magnetic curvature across the reconnection site has also been detected. In addition, strong electric fields are observed near the site, which could explain the particle acceleration usually observed at greater distances from the site.

One of the precursor processes to reconnection is the thinning of the current sheet in the centre of the tail where the reconnection process is later going to take place. Recently, Cluster made its first measurements of such an event, showing that just before reconnection occurred the maximum current intensity was about 30 times its usual value, and that the half-thickness of the current sheet was only about 300 km, instead of the usual few 1000 km. When the current sheet becomes this thin, the motion of the ions is no longer governed by the magnetic field, and therefore they cannot be described as a fluid. The electrons, however, do still behave as a fluid and are believed to carry the main current in such a situation.

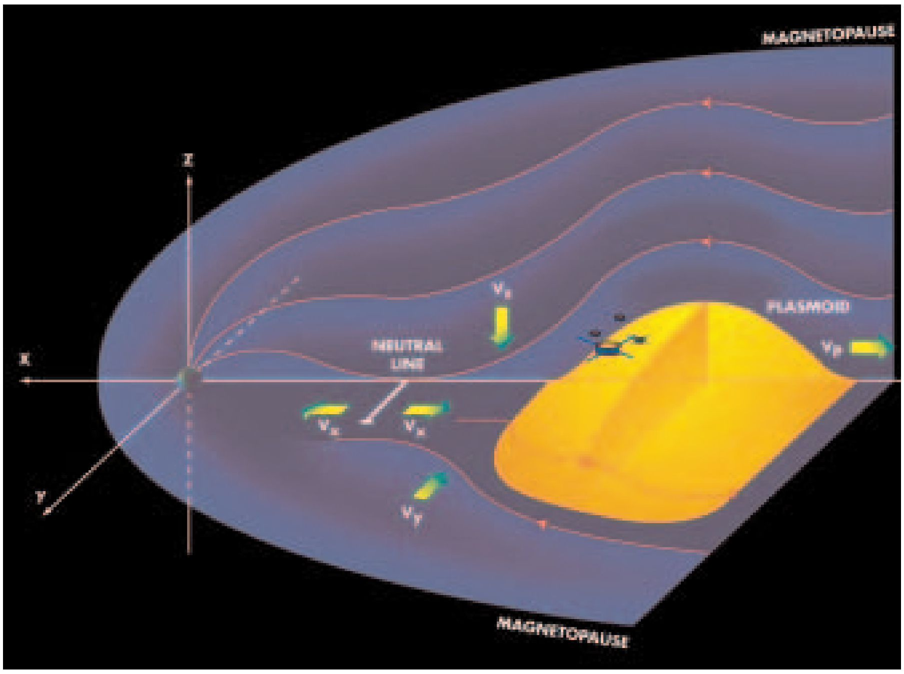
Once the reconnection process starts in the middle of the tail, a large number of charged particles are energized and sent towards the Earth. Magnetic field lines guide them to precipitate into the polar atmospheres, causing intense auroral displays. At the same time, a huge volume of tail plasma appears as an isolated 'plasmoid', which is ejected down the tail from the Earth into the solar wind. Cluster has already observed the formation of such plasmoids several times.

The consequences of reconnection are also observed in the Sun's atmosphere. Solar flares, caused by reconnection, are the most energetic explosions in the Solar System. Energetic particles accelerated in the flares escape into interplanetary space and pose a danger to astronauts, the crews of high-flying aircraft, and electronic instruments operated in space. Similar energy-release processes take place in other cosmic objects, such as stars, pulsars, black holes, quasars, and galactic accretion discs.

Remote sensing and interferometry

The magnetosphere is a strong source of a wide range of electromagnetic emissions. Some of the waves are trapped within the Earth's magnetosphere, but some, such as the non-thermal continuum radiation (NTC) and auroral kilometric radiation (AKR), can travel large distances. There are many unsolved issues concerning the generation of such waves and Cluster is also playing an important role here. The radio waves

** 1 electron volt (eV) corresponds to a temperature of approximately 10 000 Kelvin. In the Sun's atmosphere, the particles have energies of 10 - 100 eV. In the Earth's upper atmosphere particle energies are of the order of 0.1 eV. In the magnetosphere, typical energies for protons and electrons are in the range 0.1 - 10 keV. In the radiation belts, some particles are relativistic, so that the electron energies are 0.1 - 1 MeV and higher and the proton energies 10 - 100 MeV and higher.*



Magnetic reconnection occurs frequently in the magnetotail, creating a magnetically neutral region called the neutral line. As a result, on over-stretched field lines earthward of the neutral line, a large amount of plasma is accelerated towards the Earth, causing fantastic auroral displays in the polar regions. Simultaneously, on the other side of the neutral line a vast plasmoid is ejected down the tail into the solar wind (Courtesy of J. Slavin, NASA Goddard Space Flight Center)

recorded by Cluster and other satellites in the Solar System have been converted into sound waves and can be played at http://www-pw.physics.uiowa.edu/space-audio/.

The AKR (20kHz – 2MHz) is the strongest signal generated around the Earth and can easily be detected from very large distances, for instance by an alien society. The Earth's magnetosphere is the only place where we can study it in detail and Cluster's orbit is ideally placed to look for its source. The wavelength of AKR is of the order of a kilometre, hence the name. The power of emission is of the order of a billion Watts, which greatly exceeds the power of any radio station. However, the waves cannot propagate through the Earth's ionosphere and are therefore not detectable on the ground, and hence cannot disturb our radio transmissions.

By using simultaneous four-point Cluster wave measurements, the exact location of AKR's source has been identified. Similar emissions are detected at all magnetised bodies in the Solar System, such as Jupiter and Saturn where they appear with different wavelengths. For instance, Jupiter's emission is called Jovian hectometric radiation. Measurements of such emissions can also be used to detect extra-solar planets.

Future Plans

Currently the Cluster mission is in a first extension phase that will end in December 2005. The spacecraft are still working perfectly and their payloads are in good health, with 41 of the total of 44 instruments still working, and expected to continue to do so until 2010. The science community is therefore looking forward to the possibility of a second extension covering the years 2005–2009, for which there is substantial scientific justification, not least to: (i) achieve full coverage of the dayside magnetosphere at large scales, (ii) start a new phase of multi-scale observations, (iii) visit new magnetospheric regions, (iv) collaborate with new missions, and (v) collect data from a large part of a solar cycle.

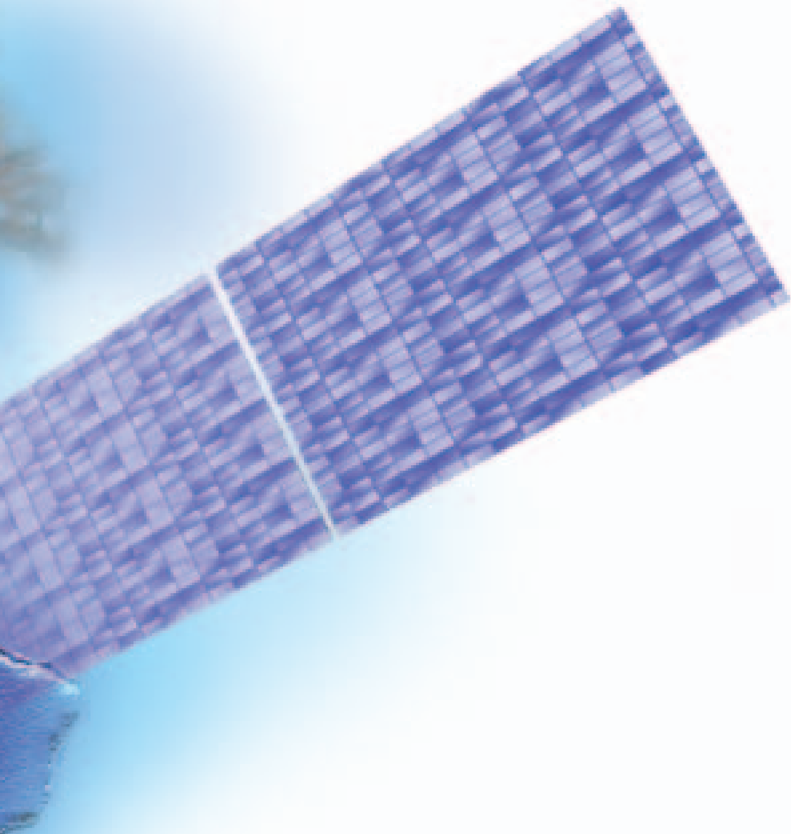
The first point is obviously of fundamental importance to complete the Cluster mission, because observations have not yet been collected with spacecraft separations of 10 000 km or more. The second objective is intended to collect observations on both small and large scales at the same time, by moving two spacecraft close to one another while keeping the separations between three of the satellites at 10 000 km. Such measurements are scientifically very exciting.

Due to solar perturbations, the apogee of the Cluster orbit drifts slowly towards the southern hemisphere. So far this has been corrected with special spacecraft manoeuvres, but in the future this drift will be allowed to continue, taking the satellites to encounters with new magnetospheric regions that have previously only been studied with single satellites. Plenty of exciting scientific discoveries can therefore be expected during this phase.

Collaboration with other missions is also fundamentally important to Cluster as the magnetosphere makes up a vast volume of space. In 2004, the two satellites that make up the China-ESA Double Star mission were put into favourable orbits with respect to the Cluster mission and carry similar or complementary instrumentation. In October 2006, NASA's five-satellite Themis mission will be launched to study magnetospheric substorm phenomena. The Cluster and Themis apogees will be on opposite sides of the Earth, so that when Cluster is monitoring the solar wind or the dayside magnetosphere, Themis will in the magnetotail, and vice versa.

To celebrate the 40th anniversary of the International Geophysical Year, the International Polar Year will be organized in 2007–2008 and the International Heliospheric Year in 2007. During these years, spacecraft, ground-based observatories and theoretical modelling will be brought together in a determined attempt to fully understand the Sun's effects on the Earth's environment. Cluster can make significant contributions to that effort!

AmerHis: The First Switchboard in Space



Manfred Wittig, Felix Petz, Frank Zeppenfeldt, Stephane Pirio, Ian Davis, Jean-Pierre Balley & Jose Maria Casas
Telecommunications Department, Directorate of EU and Industrial Programmes, ESTEC, Noordwijk, The Netherlands

Satellite telecommunications has now reached an advanced stage of maturity with nearly 40 satellite operators controlling around 250 satellites in geostationary orbit. The services that those operators provide range from backbone trunk networks in the telephony and data fields, to the distribution and broadcasting of thousands of TV channels to hundreds of millions of viewers around the World.

Successful as they are today, satellite systems are on the brink of yet another major revolution that will doubtless also have a significant impact on our daily lives in the near future. This revolution will be brought about by the provision of a new generation of cost-effective broadband interactive services, initially to larger corporations, later to small and medium-sized enterprises, and eventually to private homes.

Introduction

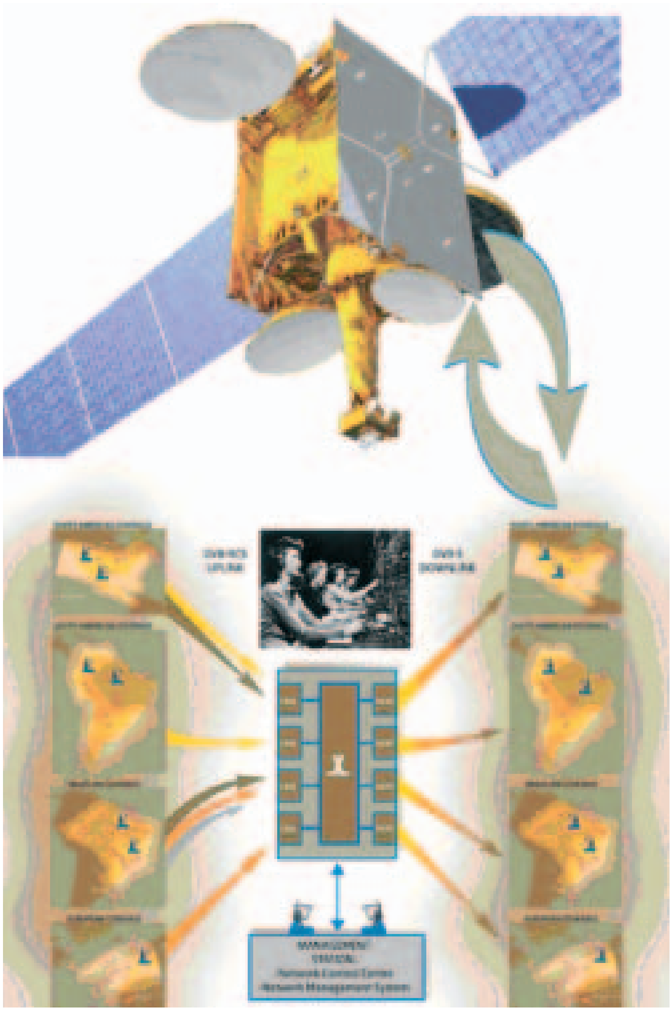
The basis for the introduction of these new services lies firstly in the availability of precisely targetted multiple spot-beam coverage from satellites, allowing greater optimisation of the use of the satellite's resources in terms of power and frequency spectrum, and secondly in the consolidation of open standards based on the successful DVB-S/DVB-RCS suite. Designing around such open standards guarantees that the receiving

Good wishes to Amazonas, on the fairing of the Proton launcher

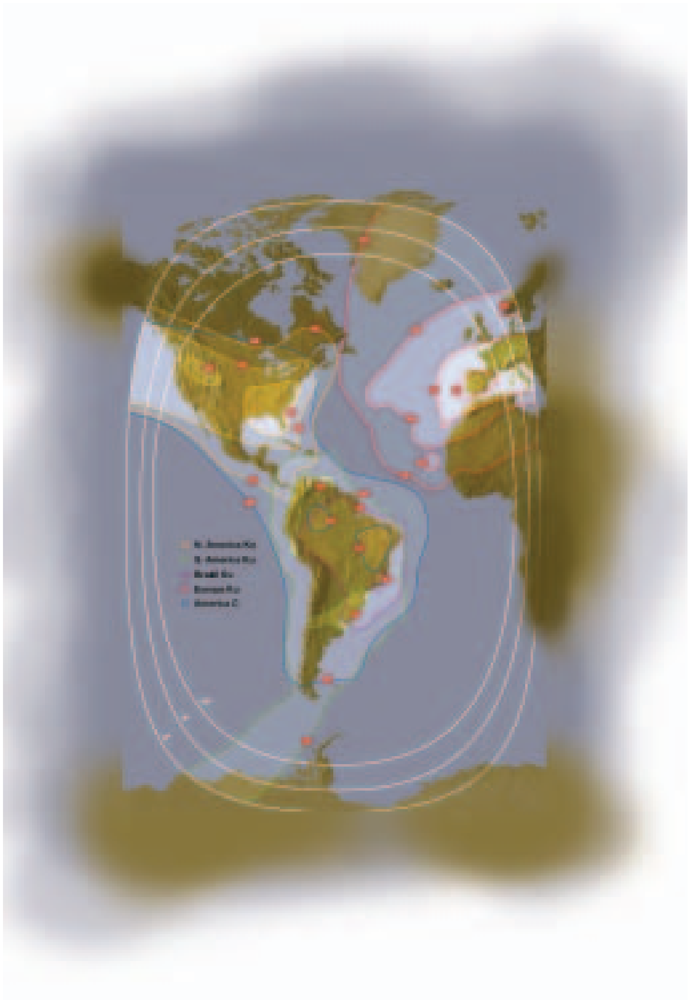
Good wishes to Amazonas, on the fairing of the Proton launcher

terminals and services will be available from many vendors, which is fundamental to the creation of an open competitive market and the delivery of economies of scale.

The consolidation of the DVB-based open-standard approach has paved the way for the introduction of a new satellite payload and system architecture, whereby a number of transmitting/receiving transponders on the same satellite can be interconnected via an onboard digital switch. In this way, the network topology becomes star-like in form, centred on the node constituted by the satellite and its



The AmerHis switchboard in space



The Amazonas coverage zones

transponders. This new architecture allows optimisation of the resources assigned to each individual transponder in terms of coverage, power and bandwidth.

The ESA Telecommunications Long-Term Plan foresees greater cooperation with telecommunications operators in order to foster the introduction of new payload technologies and services. As part of this process, ESA entered into an agreement with the Spanish company Hispasat, with the cooperation of Spain's CDTI (Centro para el Desarrollo Tecnológico Industrial), for the implementation of a regenerative multimedia system, known as the 'AmerHis System', onboard Hispasat's 'Amazonas' satellite, which was launched on 5 August 2004.

The AmerHis System

AmerHis is an advanced satellite communication system based around Alcatel's 9343 DVB On-Board Processor. This processor has the demodulation, decoding, switching, encoding and modulation capabilities needed for the four transponders on Amazonas. Each transponder covers one of the four geographical regions served by the satellite - namely Europe, Brazil, North and South America.

The complete AmerHis system consists of:

– The regenerative payload onboard Amazonas.
– A network management system, containing the Network Control Centre (NCC) and associated management control, responsible for managing the onboard resources and the user terminals.
– User terminals (Return-Channel Satellite Terminals, or RCSTs) oriented towards the commercial demonstration of new services.
– Gateways (RCST Satellite Gateways, or RSGWs) that provide the system with access to terrestrial networks.

With AmerHis, the satellite operator is able to offer broadband connectivity via a single hop to users anywhere within the four geographical areas covered by Amazonas. This is a great improvement compared with existing satellite-based networks, which require a double hop via a ground-based hub. The AmerHis concept puts that hub onboard the satellite, saving the delay of about 250 milliseconds caused by the additional second hop. The regenerative payload thereby enables real-time broadband connections between small user terminals.

AmerHis provides connectivity between spot-beam coverage areas without the need for double hops between ground and spacecraft

This unique combination of onboard processing and full compatibility with the open standards of DVB-S (downlink) and DVB-RCS (uplink) gives an AmerHis-equipped telecommunications satellite unprecedented potential compared with its rivals relying on conventional system architectures.

In summary, the key advantages of AmerHis for the user are:

– Provision of direct 'end-to-end' connectivity between any two users in different regions via a single satellite hop. This allows real-time voice and video services, as well as reducing bandwidth usage.
– Full flexibility both for the interconnection of coverage areas and payload-capacity management, allowing optimum exploitation of available onboard resources. Thanks to the dynamic resource-allocation process, the system supports predictable symmetric up- and downlink traffic, as well as intermittent 'bursty' traffic generated by a large number of users.
– The regenerative nature of the AmerHis payload, and the utilisation of DVB-S saturated carriers on each downlink, provide substantial improvements when using the AmerHis-enabled transponders. These improvements are reflected both in the enhanced throughput capacity and the reduced receive-antenna size requirements for the users.

These features, combined with the use of standard low-cost and high-performance broadband interactive user terminals, represent a major qualitative step forward in the successful development of interactive multimedia services via satellite.

The Services Offered by AmerHis

The great flexibility for managing and selling AmerHis capacity is such that all of the main telecommunications players will benefit from this advanced technology. Real- and non-real-time multimedia services and applications can be provided on readily available DVB-S/DVB-RCS compatible terminals. The system permits the assignment of resources to different subnetworks in a very flexible manner and allows user transmission rates ranging from 512 kbit/s to 8 Mbit/s. The system supports Internet Protocol (IP) based as well as native MPEG-based services, with efficient mechanisms for the provision of uni- and multicast services, and the possibility to define various quality-of-service levels to meet different user needs.

AmerHis supports mesh connectivity and star connectivity, in both cases with just one satellite hop. Unidirectional or bidirectional point-to-point connections are possible in both cases. These types of connections can either be established on demand by the terminals and the gateways, or by the Management System. A given connection can be assigned one of three priorities within AmerHis - low priority,

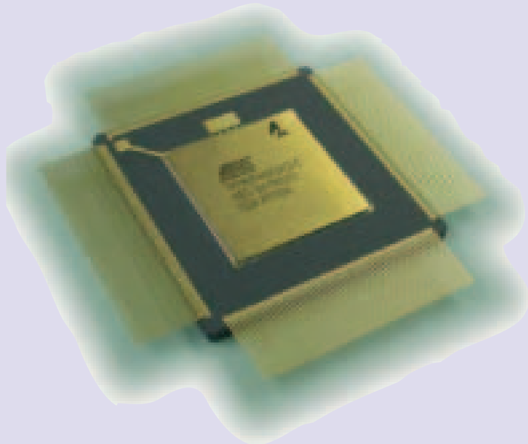
The AmerHis Elements

Space Segment – The regenerative payload

The AmerHis payload is made up of a novel set of On-Board Processing (OBP) technologies, which are being flown for the first time on the Amazonas satellite. The key feature of AmerHis is that the payload is regenerative and provides unique connectivity possibilities via its 'switchboard in the sky' functionality.

The uplink format to the OBP is MF-TDMA according to the DVB-RCS standard (MPEG-2 option), with up to 64 carriers per transponder. Data rates of 512 kbit/s, 1, 2, 4 and 8 Mbit/s can be combined in the same transponder. The downlink format is according to the DVB-S standard, with a maximum data rate of 55 Mbit/s per transponder. The OBP, which relies on complex digital signal-processing functions implemented in ASICs, offers full routing flexibility between uplink and downlink channels using dynamic capacity management.

The AmerHis payload installed on Amazonas consists of eight boxes: the down converter, the onboard processor, four modulators and two Ku-band filters.



One of the AmerHis ASICs

Ground Segment

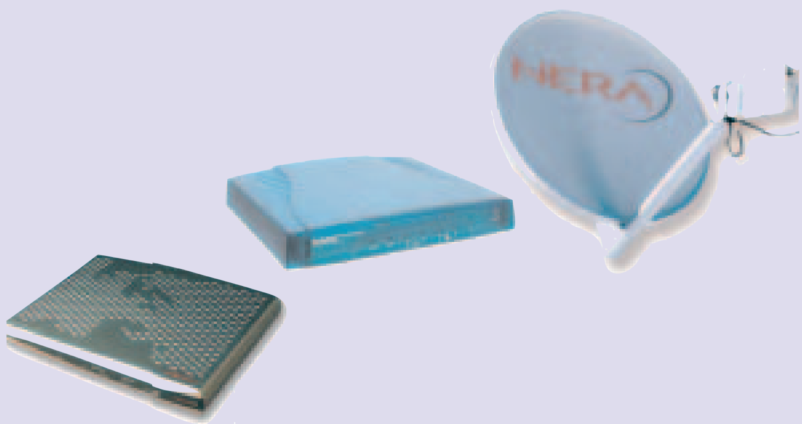
The AmerHis ground segment consists of user terminals to access the system, gateways interfacing to terrestrial services and a management system to configure and manage the network.

User Terminals

A Return Channel Satellite Terminal (RCST) provides access to other users, as well as external access to terrestrial networks and Service Providers. The peak uplink data raw bit rates for different terminal classes are:
- 512 kbit/s for Class-1
- 1.036 Mbit/s for Class-2
- 2.073 Mbit/s for Class-3
- 4.417 Mbit/s for Class-4.

The antenna and Solid-State Power Amplifier (SSPA) sizes vary from 1.2 to 3 metres and 2 to 8 Watts, respectively, depending upon the class type and coverage area.

An RCST can support both guaranteed rate and delay and best-effort classes of service. The network quality-of-service mechanism in the RCST performs prioritisation of IP flows and selects the most suitable transmission parameters for the application in question. This provides priority to mission-critical data transactions or video or voice transmissions, which require faster turnaround, while providing lower priority to less-time-sensitive traffic such as e-mail and web surfing.



AmerHis user terminals (RCSTs) manufactured by NERA (Norway) and EMS Technologies (Canada)

These terminals are based on standard DVB-RCS products and are already available from two companies. The point-to-point connectivity provided by the AmerHis regenerative payloads requires a call-handling protocol, which is now being considered for DVB-RCS standardisation. The AmerHis RCSTs from different vendors are interoperable, i.e. both terminals can work with the same hub, and have a call-handling procedure implemented.

Gateways

An RCST Satellite Gateway (RSGW) provides AmerHis users with internetworking capabilities to external networks (PSTN, ISDN, Internet). In effect, the RSGW is the hub in an access network with a star topology. It incorporates a standard low-cost and slightly modified RCST, which is an attractive solution for medium to small service providers. It has been designed to share its satellite and terrestrial bandwidth resources with a large number of simultaneous active subscribers.

An AmerHis gateway

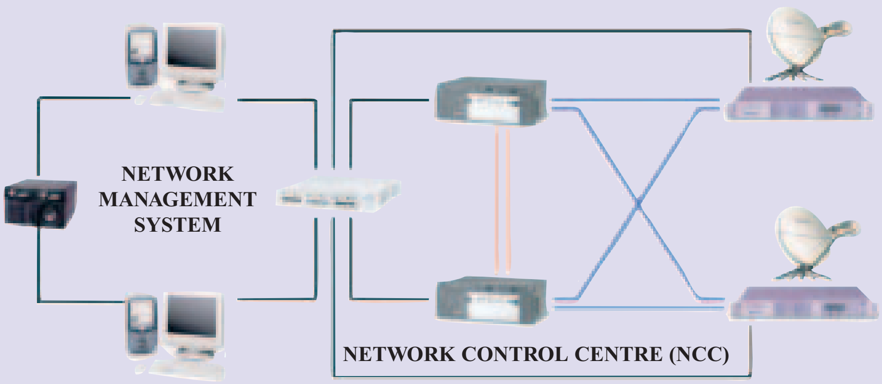
The gateway support commonly used interfaces to the terrestrial networks such as ISDN, Ethernet and ATM. To support the delivery of business-class data services, the RSGW is able to provide service guarantees to subscribers based on different quality-of-service criteria for the different subscription levels.

The peak uplink transmission raw bit rate of the RSGW is at least 8 Mbits/s (2 x 4 Mbit/s terminals). The RSGW maximum downlink throughput at IP level is at least 8 Mbit/s. In order to offer low-cost RSGWs targeted specifically at small Internet Service Providers (ISPs), a standard RSGW can be simplified by not offering voice/video services and reducing the peak uplink rate to 2 Mbit/s.

Management System

The Management System consists of a Network Control Centre (NCC) and a Network Management Centre (NMC). The NCC controls the interactive network, services satellite access requests from users and manages the OBP configuration. An NCC Return-Channel Satellite Terminal (RCST) provides terminal access to the satellite. The NMC handles the system configuration and manages the AmerHis network elements, supporting remote configuration and monitoring of the NCC, user terminals, gateways and OBP, as well as providing fault, configuration, performance and security features for all elements.

Connection-control management functions both support permanent connection set-ups and handle on-demand connection requests, such as call establishment, call modification and call release.



The AmerHis management system

high priority or high priority jitter-sensitive - each of which is associated with a specific set of traffic parameters. An admission-control function ensures optimal use of the available capacity and provision of the best possible service for the different types of application.

The physical capacity of AmerHis is distributed over Virtual Private Networks (VPNs). Each VPN can be allocated a dedicated set of logical capacity, reflecting the service provider's needs, or it can share a set with other VPNs. Any VPN can also take advantage of the AmerHis broadcast capability.

AmerHis is therefore creating a new era for relationships between Internet Network Access Providers (INAPs), service providers and customers by offering much greater flexibility than any other satellite-based system so far. Being a connection-oriented system, it allows full control over the applications crossing the network and the amount of resources allocated to those applications. In this way, over-provisioning can be avoided and billing is triggered only when applications are really using the network. This opens the door for new business models, reflected in turn in the Service-Level Agreement (SLA) between the INAP and service provider or service provider and customer.

The following are some typical AmerHis application scenarios:

Internet Service Providers

In this scenario, the Internet Service Providers (ISP) manage their own low-cost gateway and provide reliable Internet access to subscribers. Value-added services, such as Voice over IP (VoIP) or video conferencing based on the ITU H.323 standard, can be provided to individual customers via a simple configuration. ISPs can choose to offer their own SLAs, be they flat-rate, volume-based or based on a certain quality-of-service profile.

The AmerHis gateways are intended to be low-cost and have minimum infrastructure requirements. The ISPs therefore have the flexibility to locate their gateways in different AmerHis coverage regions and thereby offer more reliable Internet access and/or more attractive tariffs.

The AmerHis in-orbit testing (IOT) station, antenna and shelter and (right) the ground-support equipment used for IOT

A novel feature of AmerHis is the support it provides for multicast services, allowing streaming contents to be delivered to a large number of subscribers simultaneously. The AmerHis gateways support all of the necessary functionality for implementing these services according to the latest IETF (Internet Engineering Task Force) standards. The AmerHis network can support all of the various deployement methods currently used by ISPs, such as private and public IP addressing support, NAT (Network Address Translation), authentication and billing support.

Corporate Services

Companies with multiple branch offices in Europe, Brazil, North and South America can easily set up their own Virtual Private Networks (VPN) and share their allocated capacity between all offices.

An important feature of the AmerHis system for corporate communications is the high quality of service that can be offered for business-grade video and voice conferencing and the possibility of always reaching each branch office with a single satellite hop. In addition, access to the ISDN and POTS terrestrial networks is provided via the AmerHis gateways.

The AmerHis system allows the scheduling of specific connectivity requirements, such as the daily distribution of newspaper copy to printing facilities in different geographical regions.

Video Services

The AmerHis payload offers multiplexing and de-multiplexing of MPEG-2 transport streams and is therefore not only capable of offering IP services over MPEG-2, but also allows the routing of video. Contributions can be made from different uplink stations and, depending on the onboard switch configuration, duplicated and sent to multiple destinations if necessary, using the DVB-S standard for direct-to-Home (DTH) services. Business television services, occasional-use services and video contributions from smaller terminals can all be supported more easily by exploiting these capabilities.

Early AmerHis Operations

The Amazonas satellite was launched on 5 August 2004 from Baikonur in Kazakhstan by a Proton launch vehicle. One of the first tasks in the Amazonas in-orbit testing (IOT), which started on the 11 August, was to upload the initial settings for the onboard processor via the telecommand link. The AmerHis payload's performance was verified from Hispasat's Arganda ground station, southeast of Madrid, and a signal emitted by a station in Brazil was received. After extensive testing it was concluded that the AmerHis regenerative payload had survived the launch and was performing as expected.

All of the network elements required for the first AmerHis pilot operations are currently available. The intention is thus to verify the whole AmerHis network's operation and performance starting in 2005 and to provide the Amazonas satellite operator Hispasat with a pilot network for early commercial customers.

In addition to this commercial use of AmerHis capacity, ESA is also planning several projects geared to further technology and application development, including:

– Technology projects to look into the characteristics of the current system, propose and perform additional tests, and address further enhancements of the ground segment.
– Application projects are expected to use typical AmerHis features such as quality-of-service, multicasting and demonstrate that applications will benefit from these. Such trials will exploit AmerHis's functionality to convince service providers of the added value of onboard processing and an advanced ground segment.

One potential pilot project is to provide communications capabilities to hospitals in the Amazon rainforest region. An EU-sponsored telemedicine network is being established and some of the hospitals are several thousand kilometres away from well-populated areas in Brazil. Only satellite links can provide reliable communication capabilities. The important feature of AmerHis is being able to provide a single-hop link, for example to a hospital in Portugal for medical-specialist consultation in the event of an emergency occurring at a hospital in the rainforest.

Conclusion

The onboard part of AmerHis has been proven to function as expected in orbit, with a first videoconference between three sites in Europe taking place in early February 2005. The technology offered by AmerHis provides the means to help to bridge the digital divide in developing regions of the World, with a special emphasis on institutional applications such as telemedicine.

In addition, the regenerative onboard payload concept is also well-suited to serving communications scenarios for security, civil protection and emergency applications, which typically have demanding requirements in the areas of mesh connectivity and quality of service.

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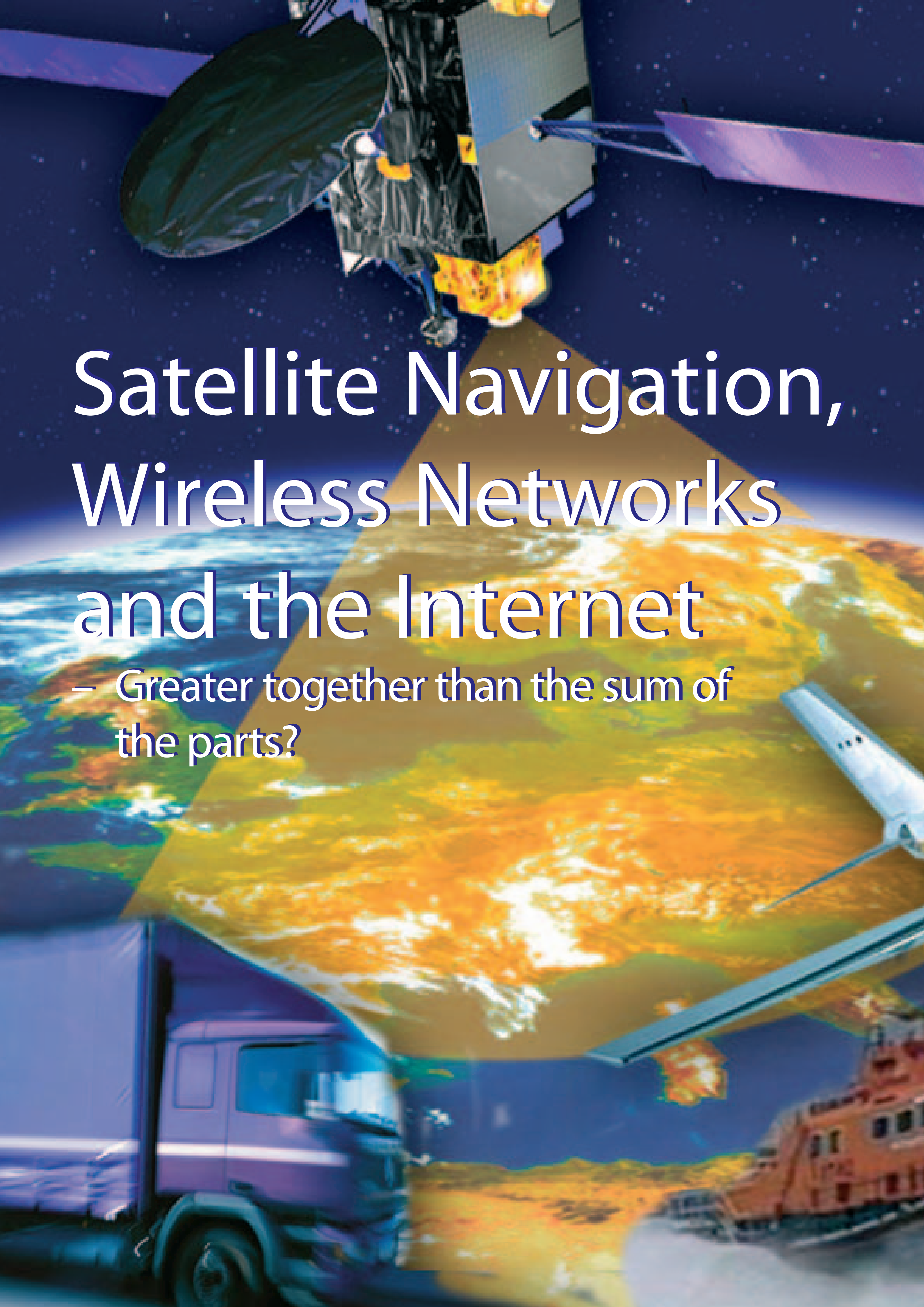
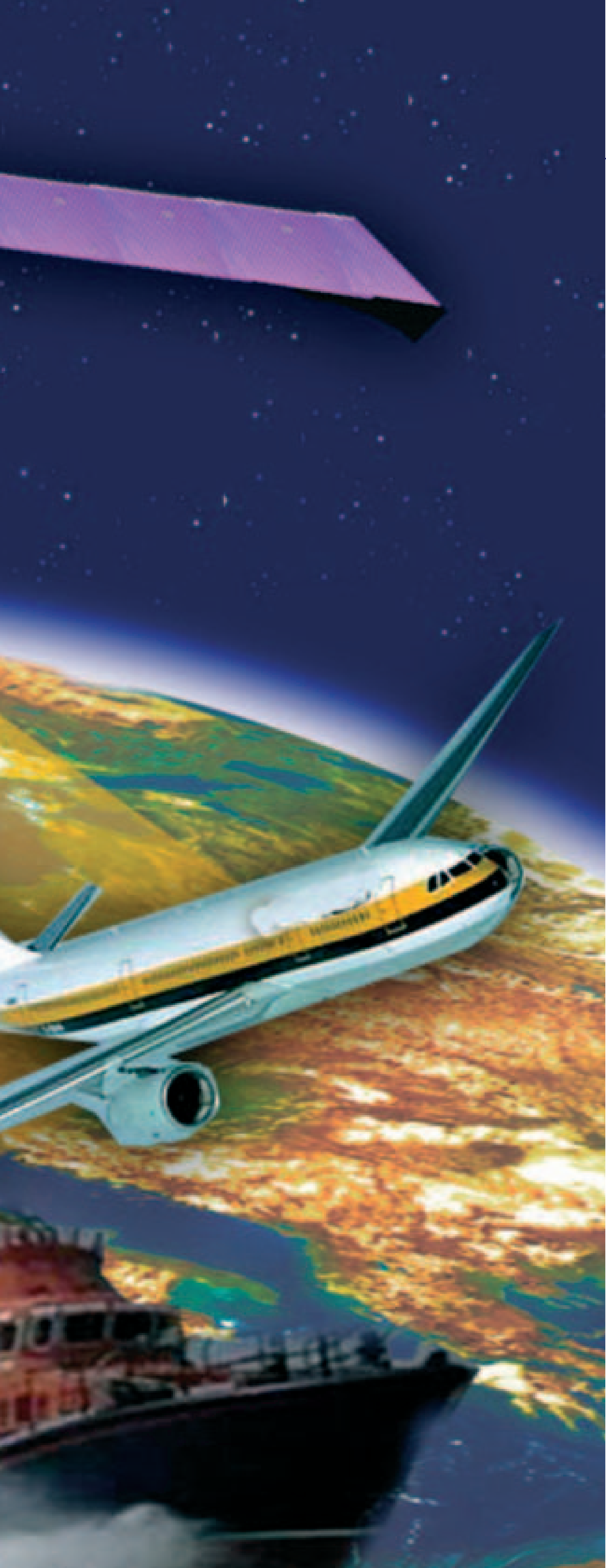
Satellite Navigation, Wireless Networks and the Internet

– Greater together than the sum of the parts?



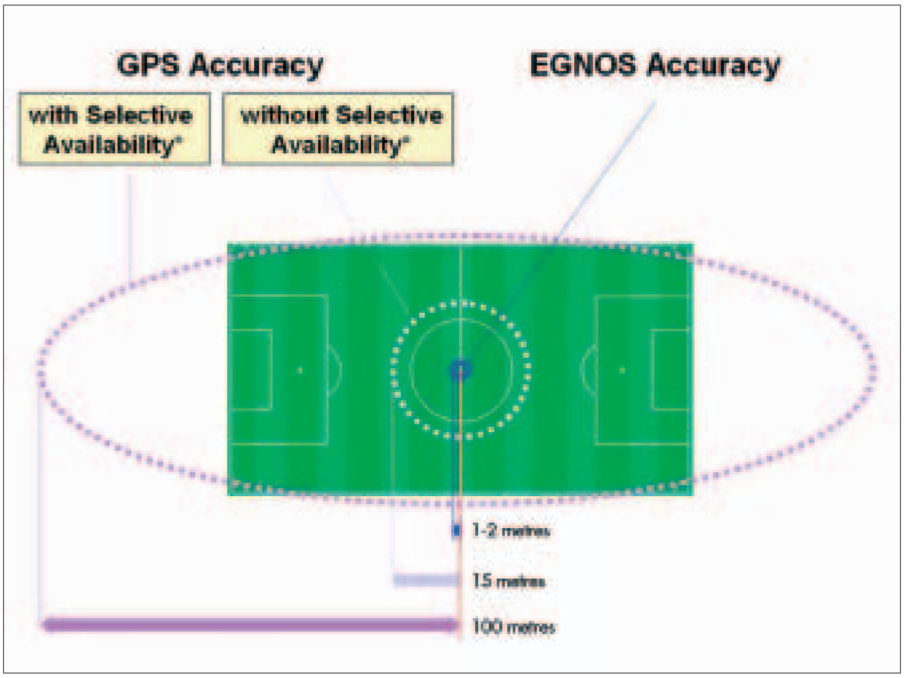


Felix Toran, Javier Ventura-Traveset, Alberto Garcia, Jean-Luc Gerner, Simon Johns & Juan De Mateo
Navigation Department, ESA Directorate of European Union and Industrial Programmes, Toulouse, France

Over the last 20 years, major developments have taken place in parallel in the key technology areas of wireless communications and satellite navigation. Both are gradually becoming indispensable tools in the professional and consumer worlds. Nowadays, major synergies are developing in terms of wireless mobile terminals with a navigation capability, or navigation terminals with wireless communications capabilities. ESA is undertaking a series of activities to support the exploitation of such synergies for the benefit of Europe's citizens through the provision of new and upgraded services from space.

Introduction

For the time being, satellite navigation is only known to the public via consumer applications of the US Global Positioning System (GPS). The implementation of a wide range of other potentially very useful GPS-based applications is still hampered by various institutional and technical difficulties. The lack of guaranteed integrity of today's GPS data is a handicap for a wide range of critical applications, not only those involving the safeguarding of human lives. The limited accuracy and coverage of today's GPS systems in towns and cities – due to what is known as the 'urban canyon' effect – is currently tending to restrict applications to somewhat basic guidance services.



The impact of EGNOS on GPS in terms of improved accuracy. 'Selective availability' is the ability of the GPS service provider to intentionally degrade system performance

The European Geostationary Navigation Overlay Service (EGNOS) system, the first pan-European Global Navigation Satellite System (GNSS) infrastructure that will begin operating in 2005, is a step forward in reducing such GPS limitations. EGNOS permanently monitors the GPS satellite constellation and provides the users with real-time integrity and correction data for the GPS satellites, thereby enabling guaranteed high-accuracy positioning. EGNOS messages are broadcast over Europe via geostationary satellites, including ESA's Artemis satellite, and this is an excellent broadcast medium for many applications (e.g. civil aviation or maritime).

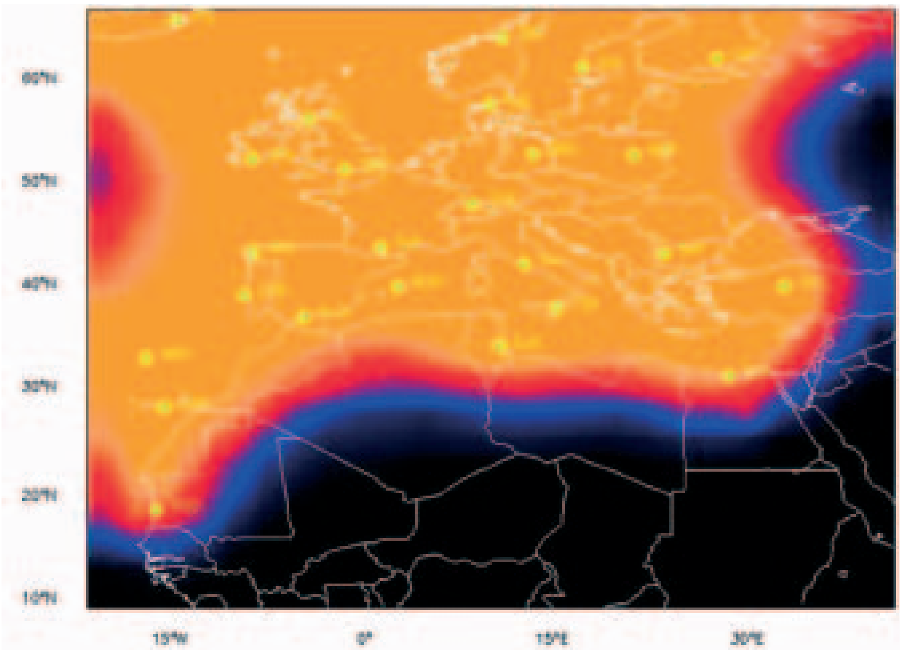
For other applications such as navigation in urban areas, in 2001 ESA developed the SISNeT technology, which improves urban penetration by providing the EGNOS data to the user through the Internet, thereby making them accessible to any wireless mobile terminal. Today many users are already using this by now well-proven technology, which has already contributed to the emergence of a large number of innovative applications. SISNeT is just one of the many services that combining satellite navigation systems and wireless networks can offer. More generally, ESA is also developing an EGNOS product-dissemination concept based on the EGNOS Data Access System (EDAS), which will be operational at the end of 2005, making full synergy between mobile and navigation services possible.

The EGNOS system is being developed by the ESA EGNOS Project Office located in Toulouse (F), with support from the ESA Directorate of Technical and Quality Management at ESTEC in Noordwijk (NL), which has put a team of experts in place and has set up a European Navigation Laboratory. There is also close coordination with the Galileo Joint Undertaking – responsible for the European Commission's navigation research programme and the establishment of the Galileo Concessionaire – and with the ESA Navigation Applications and User Services Office, which coordinates all ESA navigation-related application technologies.

Satellite Navigation and Communications – Technology and Services

Technology synergies

The integration of the communication and satellite navigation functions has major benefits at the user level. The satellite navigation function can benefit from the support data provided through the communications channel for better access to the wide-area differential and integrity GPS corrections provided by EGNOS. This avoids the problems of decreasing



EGNOS service area corresponding to the current baseline, with 34 monitoring stations (Courtesy of Alcatel Space)

GNSS performance due to 'shadowing' of the EGNOS geostationary satellites, or in some indoor environments. Such links also enable the user terminal to access the latest satellite ephemeris and SBAS messages on request, which dramatically decreases the receiver's Time To First Fix (TTFF), i.e. the time needed to start providing position. Such synergies are particularly beneficial for users at high latitudes, who may easily experience a low satellite visibility, and users in suburban and urban 'canyons'.

On the other side, the communications function benefits from the position information, allowing power adjustment based on distance and network resource optimization, in addition to the primary user benefit of access to localisation-based services for which huge range of applications are being developed.

The ESA SISNeT Technology

EGNOS will primarily broadcast wide-area/integrity GPS corrections through geostationary satellites. To provide complementary transmission links, ESA has launched specific activities to assess and demonstrate the feasibility of broadcasting the EGNOS signal by other means, such as standard FM radio signals or GSM mobile phones.

As early as 2001, ESA provided access to the EGNOS Test Bed messages via the Internet. A new product was thereby born called SISNeT (Signal in Space through the Internet), which proved to be full of potential. In February 2002, the prototype SISNeT service was made accessible worldwide via the Internet, offering immediate advantages to the GPS land-user community. Numerous users equipped with a GPS receiver and wireless Internet access have exploited the SISNeT service and benefitted from the EGNOS Test Bed augmentation signals, even in situations where the geostationary EGNOS satellites were not visible.

Extensive market studies have confirmed the value of the future convergence and merging of satellite navigation and wireless networks into compact mobile devices (e.g. mobile phones including a GNSS receiver) to offer GNSS-based Location Based Services (LBS). Such studies serve to underline the great potential of SISNeT technology, which is already being applied in many industrial developments under ESA contract.

The EGNOS Data Access System (EDAS)

In addition to providing the Internet SISNeT service since 2002, ESA has also performed a number of other feasibility studies on dissemination of the EGNOS messages via other non-space means, such as DAB (Digital Audio Broadcasting) or RDS (Radio Data Service). The high degree of success achieved in those studies has motivated the Agency to design a professional evolution of the SISNeT service to match the needs of a broad spectrum of dissemination technologies. This evolution, called the EGNOS Data Access System (EDAS), will constitute the main interface point for multimodal Service Providers supplying the EGNOS products in real-time, within guaranteed delay, security, and safety performance boundaries. Application Service Providers will then exploit these EGNOS products to offer a variety of superior services to end users.

EDAS will be developed as part of the GNSS Support Programme Step 1, with a view to having an EDAS system operational before the end of 2005, thus opening the way for its commercial exploitation by the EGNOS Commercial Operator.

The extensive suite of services that could be spawned from EDAS includes the provision of:

– SISNeT services
– EGNOS pseudolites
– EGNOS services via the Radio Data System (RDS)
– EGNOS services via Digital Audio Broadcasting (DAB)
– Wide Area Real-Time Kinematics (WARTK) services, allowing decimetre level positioning accuracies at continental scales
– Accurate ionospheric monitoring
– EGNOS performance information in real-time
– Archiving of EGNOS messages
– EGNOS corrections in standard RTCM SC104 format, ready for use by DGPS receivers.

Demonstration Activities

A PDA-based SISNeT Receiver

To verify the feasibility of the SISNeT concept, ESA placed a contract with the Finnish Geodetic Institute to develop the World's first SISNeT receiver. Based on a conventional Personal Digital Assistant (PDA) pocket-PC device, it includes both a low-cost GPS card and Internet access via a standard GSM/GPRS wireless modem. Special software combines the GPS measurements with EGNOS corrections obtained from SISNeT via the Internet. Almost any commercial GPS software can be enhanced with SISNeT positioning in this way.

SISNeT handheld receiver based on the Siemens SX45 mobile phone/Personal Digital Assistant (PDA), developed by the Finnish Geodetic Institute (FGI) under ESA contract. This was the first device to demonstrate the enormous potential of integrating EGNOS, Wireless Networks and the Internet in a single unit

During field testing in Finland, the new receiver delivered horizontal positioning accuracies of 1-2 metres and vertical accuracies of 2-3 metres. In a further step, the device has been integrated into a Siemens SX45 mobile phone.

TORMES: A personal navigator for the blind, enhanced with SISNeT capabilities, developed by GMV Sistemas (Spain) and ONCE (the Spanish Organisation for the Blind). This device has highlighted the immense benefits that the synergy between Satellite Navigation and Communications can bring to visually impaired people

SISNeT-based Navigation for the Blind

This demonstration activity assessed the benefits of using the SISNeT concept to help blind people in a city environment. The project was based on an existing personal navigator for the blind, known as TORMES, developed by the Spanish company GMV Sistemas and the Spanish organisation for the blind (ONCE). It includes a Braille keyboard, a voice synthesizer, a cartography database and navigation software. The positioning is based on a conventional GPS receiver, and hence suffers the typical signal-shadowing problems in urban areas.

The improvement provided by the integration of EGNOS data via SISNeT was tested in the outskirts and downtown areas of Valladolid in Spain. The results were excellent, with a significant improvement in both accuracy and service availability, which will allow blind pedestrians to be forewarned of obstacles in the street. Being connected to the Internet could also give TORMES important added-value, allowing users to not only receive information but also send relevant data back to the system, e.g. notification of a blocked street or pavement.

SISNeT-based Bus-Fleet Management

This activity was designed to demonstrate the improvements that EGNOS can provide for an urban bus operator. A handheld SISNeT receiver combining a GSM/GPRS modem and a GPS receiver, developed by the French company Navocap under ESA contract, was tested on a bus operating in the French city of Toulouse. The route included both residential and downtown areas, allowing the robustness of the unit to be tested for different degrees of satellite visibility. The results were quite promising, indicating that SISNeT could be a very adequate complement to (or even a replacement for) the differential GPS systems currently employed, which need a costly infra-structure.

ShPIDER: A Professional High-Performance SISNeT Receiver

An integrated professional device called ShPIDER, which includes a GPS receiver and a GPRS modem, has been developed by GMV (Spain) under ESA contract. Its navigation algorithms allow significantly improved positioning accuracy and

SISNeT receiver based on a PDA device, integrating a GPS receiver and a wireless link to the Internet in a single box. It has demonstrated the benefits of the ESA EGNOS-SISNeT technologies for urban bus-fleet management systems. This receiver has been developed by Navocap (France) under ESA contract

ShPIDER, a professional high-performance SISNeT-powered EGNOS receiver, developed by GMV (Spain). It integrates a GPRS wireless link to the Internet and a GPS receiver and has been tested in the context of both bus-fleet management in Spain and the EGNOS TRAN Project in Italy

availability compared with GPS-only solutions. The benefits are even more pronounced for low-visibility conditions, such as in cities. The ShPIDER receiver has also been tested in the framework of the bus-fleet management trial in Valladolid and the ESA EGNOS TRAN project (see below) in Rome, showing promising results in both cases.

EGNOS Dissemination through Terrestrial Networks - The EGNOS TRAN Project

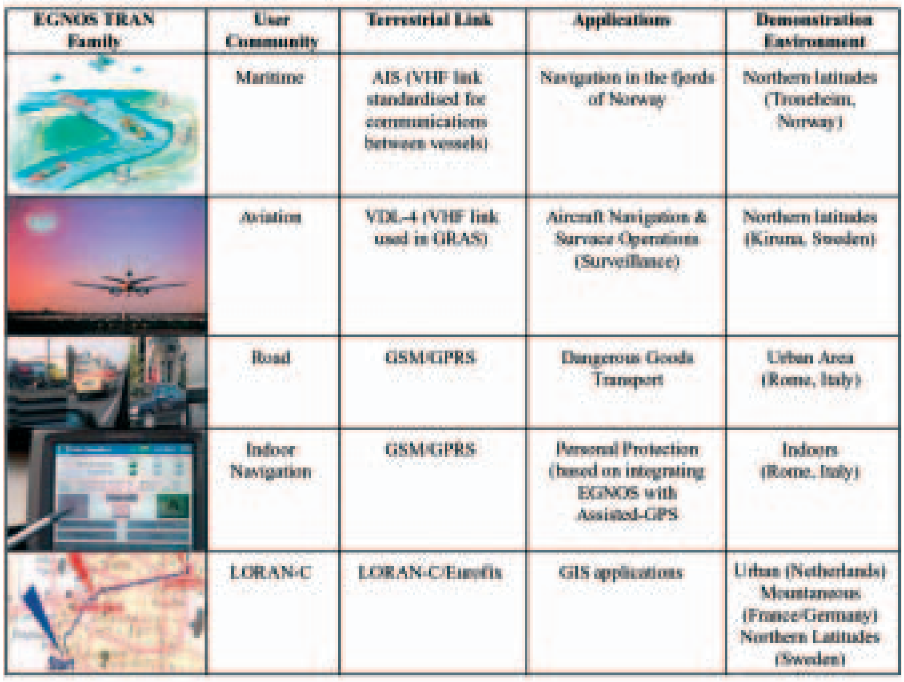
In the framework of its Advanced Research in Telecommunications Programme (ARTES), ESA launched a number of activities focussing on EGNOS signal broadcasts for areas with weak space-signal reception. Several solutions were tested through the EGNOS TRAN project (EGNOS Terrestrial Regional Augmentations Networks), all of them relying on the use of terrestrial networks as EGNOS augmentations.

Since most applications addressed were safety-critical, the use of the terrestrial link has multiple benefits. For example, the communications link could be used to resend the EGNOS information encapsulated in the appropriate format (RTCA original, GBAS, RTCM) in a manner transparent to the end user. In other cases, the communication link was used to help the end user to improve their positioning accuracy and integrity by means of an TRAN service centre that has access to EGNOS either by direct line-of-sight or a SISNeT connection, and is able to re-compute and send back the end-user navigation solution.

Several demonstrations have shown the EGNOS performance via TRAN to be very close to that when using geostationary-satellite data, despite the extra delay introduced by the communication link. The Project has confirmed EGNOS as a very cost-efficient alternative to a number of existing local-area GPS augmentation systems.

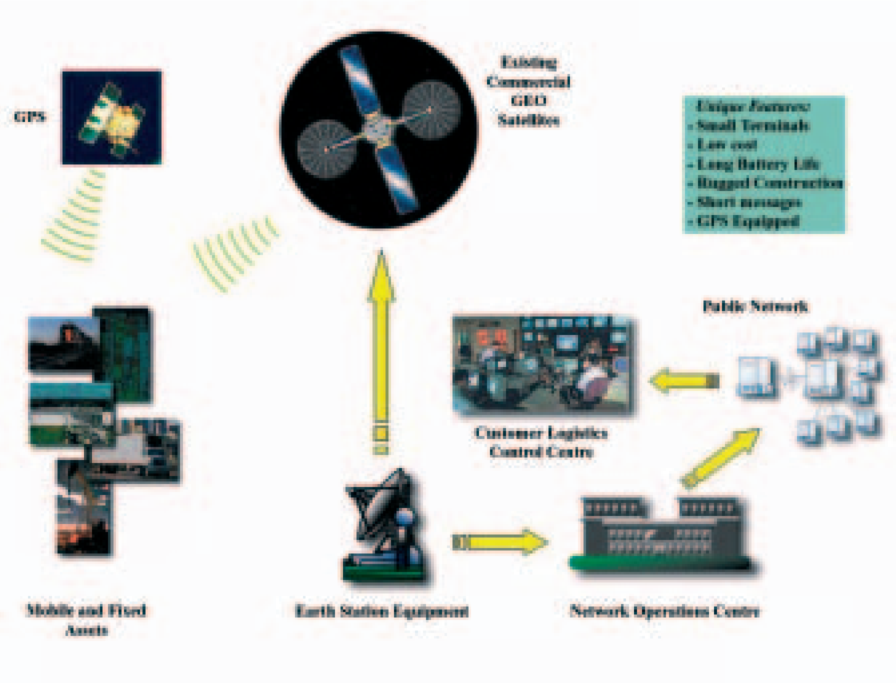
EGNOS Dissemination over RDS

ESA has also studied the feasibility of EGNOS dissemination using FM Radio Data System (RDS) signals, through a contract with TDF (France). A laboratory chain was set up in which EGNOS messages from the ESA SISNeT service were broadcast via RDS signals. A key challenge was the need to reduce the amount of information to be broadcast in order to fit the RDS bandwidth available. This was solved by developing selective filtering algorithms able to extract only the information relevant to the user, depending



EGNOS TRAN Family	User Community	Terrestrial Link	Applications	Demonstration Environment
	Maritime	AIS (VHF link standardised for communications between vessels)	Navigation in the fjords of Norway	Northern latitudes (Trondheim, Norway)
	Aviation	VDL-4 (VHF link used in GRAS)	Aircraft Navigation & Service Operations (Surveillance)	Northern latitudes (Kiruna, Sweden)
	Road	GSM/GPRS	Dangerous Goods Transport	Urban Area (Rome, Italy)
	Indoor Navigation	GSM/GPRS	Personal Protection (based on integrating EGNOS with Assisted-GPS	Indoors (Rome, Italy)
	LORAN-C	LORAN-C/Eurofix	GIS applications	Urban (Netherlands) Mountainous (France/Germany) Northern Latitudes (Sweden)

Summary of applications developed in the context of the EGNOS TRAN Project



The GlobalWave system architecture

on his/her position. The results showed typical horizontal accuracies of 1-3 metres, demonstrating both the feasibility and potential of RDS EGNOS broadcasting.

EGNOS Dissemination over DAB

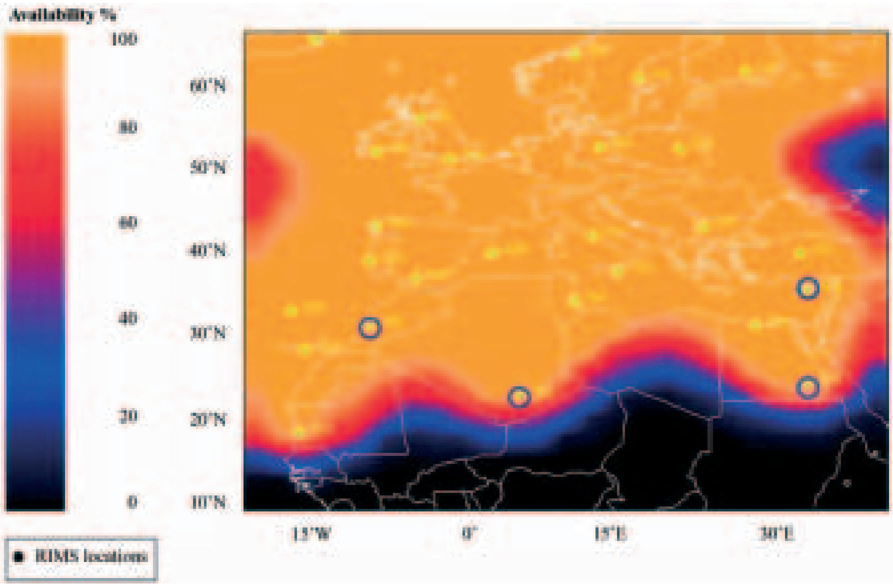
The results with RDS encouraged ESA to think about other possible means of EGNOS transmission. The focus was on Digital Audio Broadcasting (DAB), a technology that allows the listener to receive CD-quality radio programmes without signal distortion or interference. Moreover, DAB is able to carry not only audio signals, but also text, pictures, data and even videos to the receiving set, and is being implemented and exploited worldwide.

The concept was tested in Germany, through an activity performed by Bosch-Blaupunkt (Germany) under ESA contract. The EGNOS message was obtained via the SISNeT service and transmitted over DAB. A DAB car radio system received the signals and extracted the EGNOS data, which was decoded and applied to a GPS receiver through an integrated hardware-software platform. A tour through peripheral, residential and downtown areas revealed a significant improvement in terms of positioning accuracy with respect to GPS-only applications.

Integrated Receiver Technologies

ESA is also supporting several projects in the receiver-technology domain. One of the first is to develop and demonstrate a small, low-cost EGNOS/Inmarsat terminal that is capable of computing safe positions and communicating them to the web for a variety of safety, navigation and other applications in the maritime domain. The terminal is being developed by TransCore-GlobalWave (Canada) based on a commercially available product. It receives GPS/EGNOS navigation signals and computes position which, together with other sensor and message information, is communicated back to the base station using the Inmarsat-3 satellites, and to the customer via the Internet. The terminal's position is monitored through the GlobalWave application server, located at the end-user's premises. The integrated terminal thereby provides a two-way communications function between the mobile terminal and the web, with the service area determined by Inmarsat-3 satellite coverage.

Another project is the development and demonstration of an Integrated Navigation/Mobile Communication User Terminal based on the TETRAPOL system. TETRAPOL is a fully secure, digital mobile communications network (GPRS-like), designed to meet the growing needs and expectations of highly-demanding Professional Mobile Radio (PMR) users, such as public safety services, transport, or industry. The terminal supplies the actual EGNOS-based position information via the TETRAPOL communication network to an Automatic



EGNOS service-coverage expansion to the MEDA region, thanks to the addition of four monitoring stations to the EGNOS baseline. This enhancement is planned for 2006 (Courtesy of Alcatel Space)

EGNOS V2.1 (in 2006)	EGNOS V2.2 (in 2007/8)	EGNOS V2.3 (in 2008/9)
Provision of operational non-SoL services (MT0/MT2)	Provision of EGNOS time service	Broadcasting of EGNOS messages in L5
Provision of EGNOS products through non-GEO means (INSPIRE and EDAS)	MT28 provision	Upgrading RIMS L1/E5 to be able to also process Galileo IPPs to improve IONO measurements (TBC)
Expansion of EGNOS services in MEDA region (North Africa and Middle East, Mediterranean countries)	Expansion of EGNOS services in Africa	
	Expansion of EGNOS services to EU accessing countries	
	Avail. improvement by modern RIMS RX (L2C)	
	SAR return link & I/F COSPAS/SARSAT (TBC)	
STEP 1	**STEP 2**	

Vehicle Localization (AVL) server. The end-user is able to track and guide several terminals on an AVL display and communicate with them via the voice and data channels of the TETRAPOL system. The navigation module is able to acquire assisted GPS and assisted EGNOS information via the communication system whenever the clear view of the satellites is obstructed. The main applications are the tracing and tracking of mobile targets, and security and emergency location determination. A demonstration phase has verified the system's performance.

The communication part of the project is under the responsibility of EADS Telecom, whereas the navigation part is being implemented by IMST, Fraunhofer and IFEN. TeleConsult is responsible for the demonstration phase.

Future Developments and Evolution

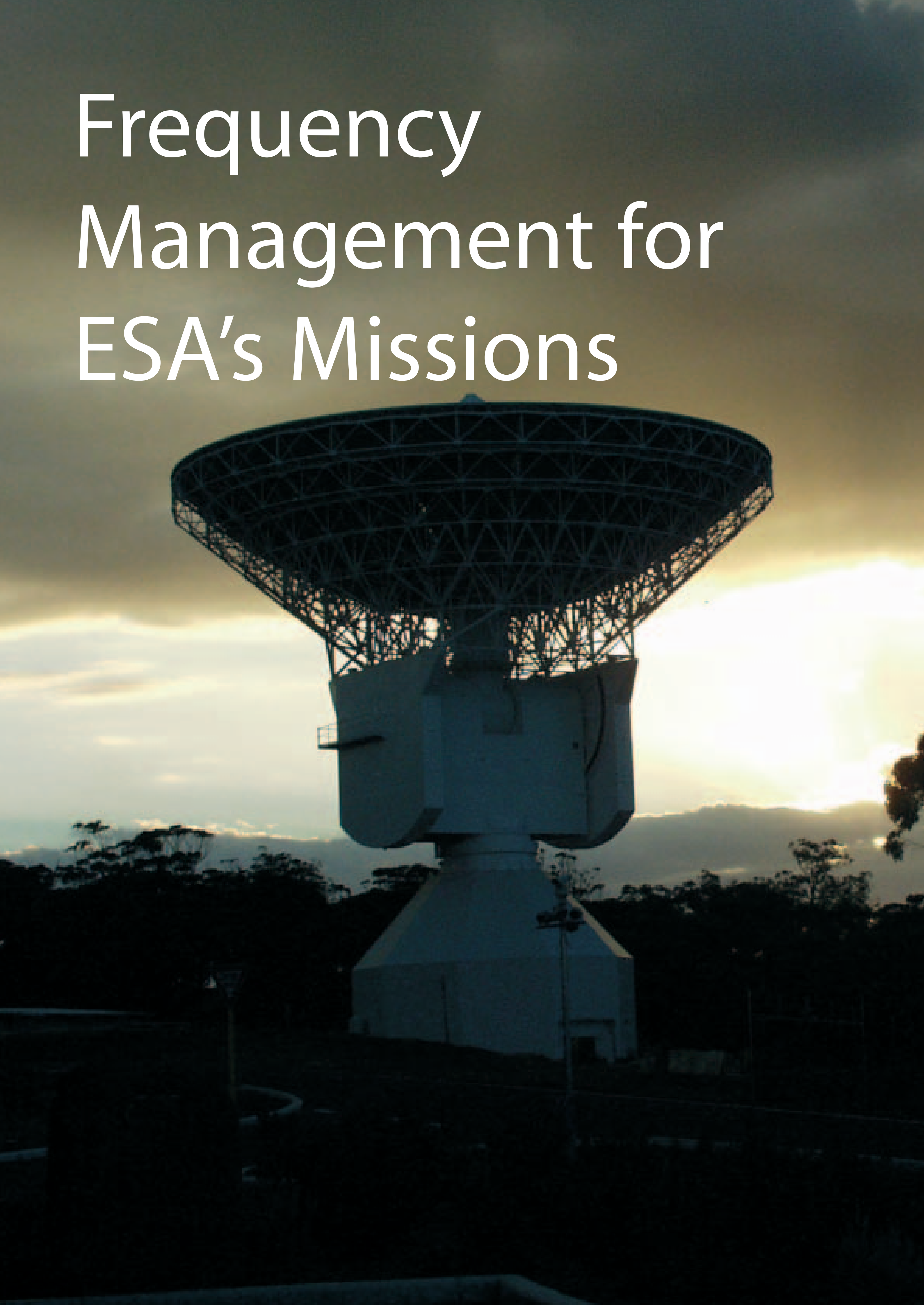
At the time of writing (October 2004), the deployment of the EGNOS infrastructure is quasi-complete, with all four Master Control Centres (MCC) and all six Navigation Land Earth Stations (NLES) already in place. 31 of the 34 RIMS Ranging and Integrity Monitoring Stations) are now installed, and all three EGNOS geostationary satellites are already successfully transmitting EGNOS test signals. The test transmissions started in December 2003, and the qualification tests are now approaching completion with the EGNOS Operational Readiness Review, which will open the way for initial system operations, scheduled for early 2005.

In parallel with the start of operations, EGNOS already plans to respond positively to today's dynamic GNSS environment. Since 1998, when the original EGNOS mission requirements were set, the launch of the Galileo Programme and the planned modernisation of the GPS and WAAS systems have brought further opportunities for EGNOS. In this global strategic race to promote and benefit from future GNSS applications, the Council of the European Union confirmed in June 2003 that, as an integral part of the European Satellite Navigation policy, EGNOS services should be extended within a long-term perspective to other parts of the World. In response to that mandate, a GNSS Support Programme was defined by ESA and the European Commission – Step 1 covering the 2005-2006 timeframe and Step 2 the 2006-2008 timeframe – to further maximise the potential benefits of GNSS for Europe's citizens, and in particular to define and implement the most appropriate evolutions of the EGNOS system to best prepare for the Galileo services to be available from 2009 onwards.

Conclusions

Since 2000 and the implementation of the EGNOS Test Bed, ESA has been playing a leading role in demonstrations of the potential benefits that European citizens can expect from these technologies. Special attention will continue to be devoted to the future EGNOS Data Access System (EDAS), which will already be operational at the end of 2005, facilitating full synergy between mobile and navigation services. These advanced GNSS services are likely to become essential assets on a day-to-day basis for many Europeans from 2005 onwards, first with EGNOS and later on a worldwide basis with the Galileo system.

Frequency Management for ESA's Missions



Edoardo Marelli
Directorate of European Union and Industrial Programmes, ESTEC, Noordwijk, The Netherlands

Enrico Vassallo
Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

People not familiar with the subject sometimes see the frequency management for a satellite as an activity whereby the 'good' frequency is selected by applying some mysterious formula. In reality, as this article will try to explain, there is much more to it. Frequency management is a rather broad discipline in which international regulations, technical discussions and negotiations play a key role. The radio-frequency spectrum is becoming an increasingly scarce resource and more and more users of all kinds are competing with each other for their share. In a nutshell, frequency management involves minimising the implications of this problem for the satellite users.

International Regulations

The frequency bands available for use by the different radio-frequency services, the technical/operational conditions under which it is possible to operate, and the relevant protection criteria are specified in the Radio Regulations of the International Telecommunication Union (ITU), a UN international treaty signed by 190 nations. These regulations are particularly important for satellite services, because their radio-frequency emissions go well beyond national boundaries.

The Radio Regulations can be changed only by a Word Radiocommunication Conference (WRC), a formal meeting of the Delegates from all nations participating to the ITU, which typically takes place in Geneva (CH) every three years and lasts a whole month. While decisions are taken at the WRC, during the intervening three years each item on the WRC agenda is assigned to the appropriate Study Group (SG) to carry out the preparatory technical work. This work enables the ITU delegates to take an informed decision on the proposed changes. The structure of the study group (see accompanying panels) follows the ITU definition of radio services, with the space research service, terrestrial service, mobile-satellite service, etc. As a consequence, ESA is mainly active in SG7, where all space-science services belong, in SG8 (radio navigation satellite service and mobile satellite service) and in SG3 (propagation).

The ITU works to achieve a consensus on all WRC agenda items through intense negotiations and diplomacy. It is normal practice for nations to form common proposals to the Conference via regional agreements prior to the WRC. This is why ESA also participates in the meetings of the European Communication Commission (ECC/CEPT), with the goal of achieving common European proposals for the WRC.

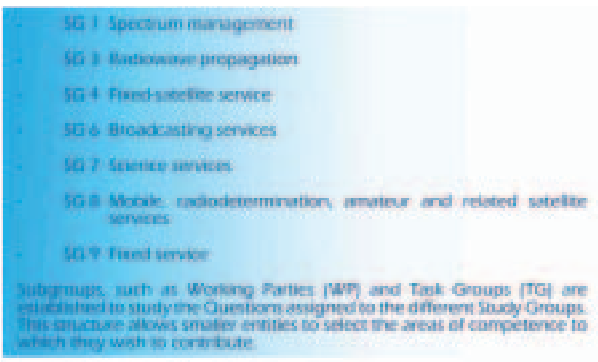
Satellite Network Filing

In order to properly register an ESA satellite and its ground stations with the ITU, a number of steps have to be followed (in accordance with administrative note ESA/ADMIN/IPOL-PROC(2004)2). At the beginning of a satellite mission's design, it is necessary to prepare a so-called 'Request for Frequency Assignment', containing preliminary data on the satellite's telecommunication systems, the preferred frequency bands, the station network to be used, and the orbital characteristics of the mission.

This request is thoroughly checked to assess compliance with the ITU radio regulations and international radio frequency and modulation standards of the Consultative Committee for Space Data Systems (CCSDS) and of the European Cooperation for Space Standardization (ECSS). Compliance is also checked with the interagency agreements of the Space Frequency Coordination Group (SFCG) (see coloured panel). If needed, changes are requested to the project. The amended document then forms the basis for conducting

The ITU sectors and their roles

The ITU-R study groups



The Space Frequency Coordination Group (SFCG)

The SFCG was created 24 years ago as an ESA and NASA initiative. It is an informal group composed of frequency managers from all of the main civil space agencies in the World. Its main objectives are to:

- adopt agreements that allow space agencies to make best use of the allocated bands and to avoid interference between members' space systems
- agree common policies and identify long-term targets related to potential changes to the international regulations.

To achieve these objectives, the SFCG members develop and adopt common resolutions and recommendations to be applied within their own organisations. These cover a variety of subjects, including for example: spectrum masks, deep-space channel plans, inter-agency frequency co-ordination procedures, interference criteria, standard transponder turn-around frequency ratios, use of specific bands, common objectives with respect to the next WRC, etc.

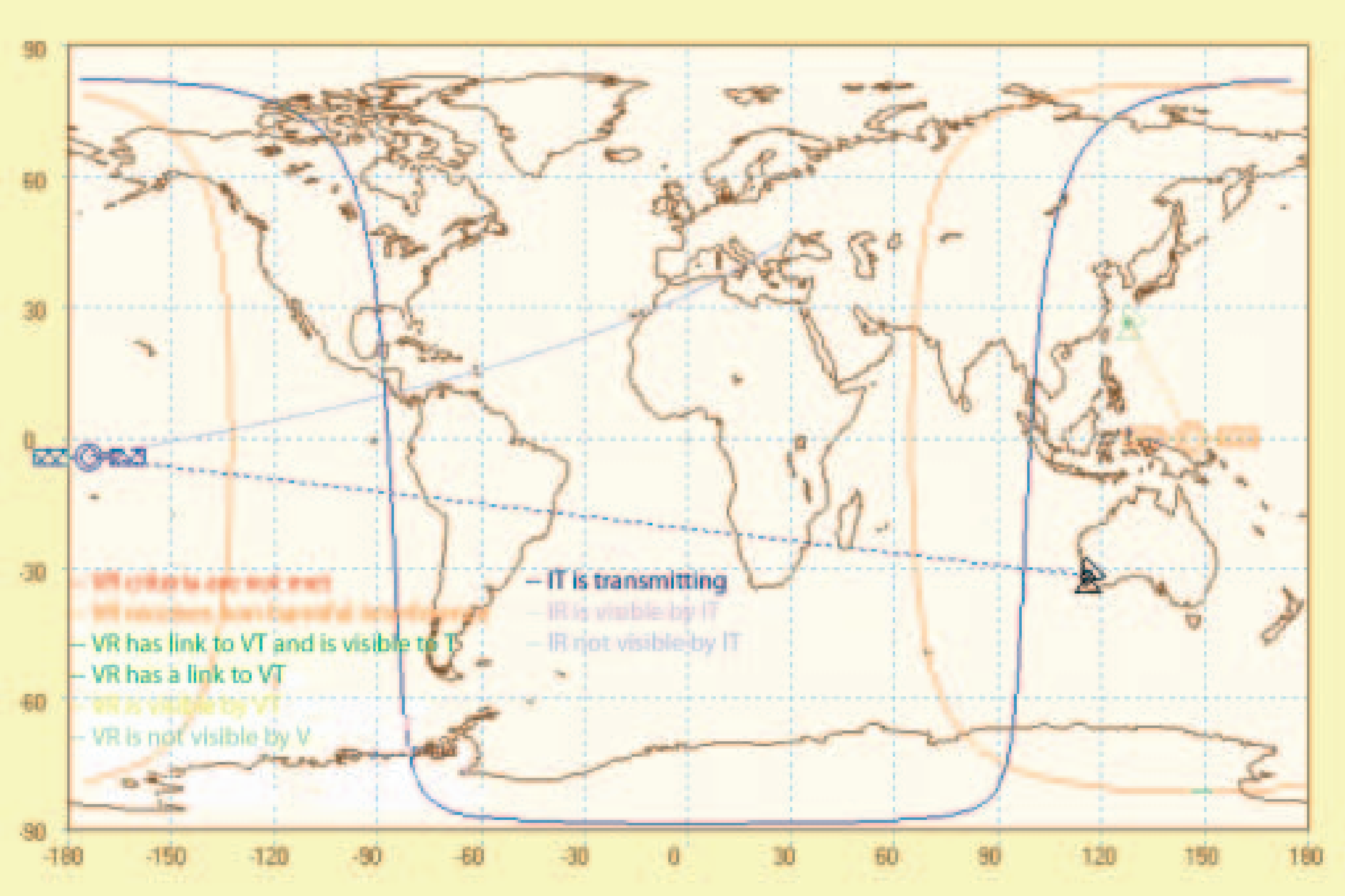
The current SFCG member agencies are: ASI (Italy), BNSC (UK), CAST (China), CMA (China), CNES (France), CONAE (Argentina), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA, EUMETSAT, INPE (Brazil), INSA (Spain), ISRO (India), JAXA (Japan), KARI (Korea), NASA (USA), NIVR (Netherlands), NOAA (USA), NSA (Malaysia), NSAU (Ukraine), NSPO (Taiwan), SSC (Sweden), RFSA (Russia). WMO, IUCAF, ITWG, CCSDS and ITU-R are observers.

The Head of the ESA Frequency Management Office has the task of permanent SFCG Executive Secretary.

Further information on the SFCG can be found at:

http://www.sfcgonline.org/.

inter-agency coordination and an evaluation of potential radio-frequency interference between the ESA mission and missions by other space agencies (NASA, JAXA, etc). These bilateral negotiations are supported by an ESA-developed software tool, which assesses the potential publication (API) filing and notification (Article 11) filing. This is carried out by using an ITU software suite. Such a filing is first circulated among ESA's Member States for association and then submitted to the ITU via ESA's notifying national administration (France). the informal coordination with other space agencies beforehand, no major problems are usually encountered at ITU level. The procedure at ITU level is much more complex in the case of geostationary satellites, but luckily very few ESA satellites fall into this category.



The radio-frequency interference scenario for ESA's Cluster and JAXA's ETS-VII satellites

mutual radio-frequency interference (RFI) by taking into account orbital characteristics, Doppler shifts, modulation formats and operating modes.

Examples of the capabilities of such a tool can be seen in the accompanying figure, which depicts the RFI scenario for the case of the Cluster satellite interfering with JAXA's ETS-VIII spacecraft.

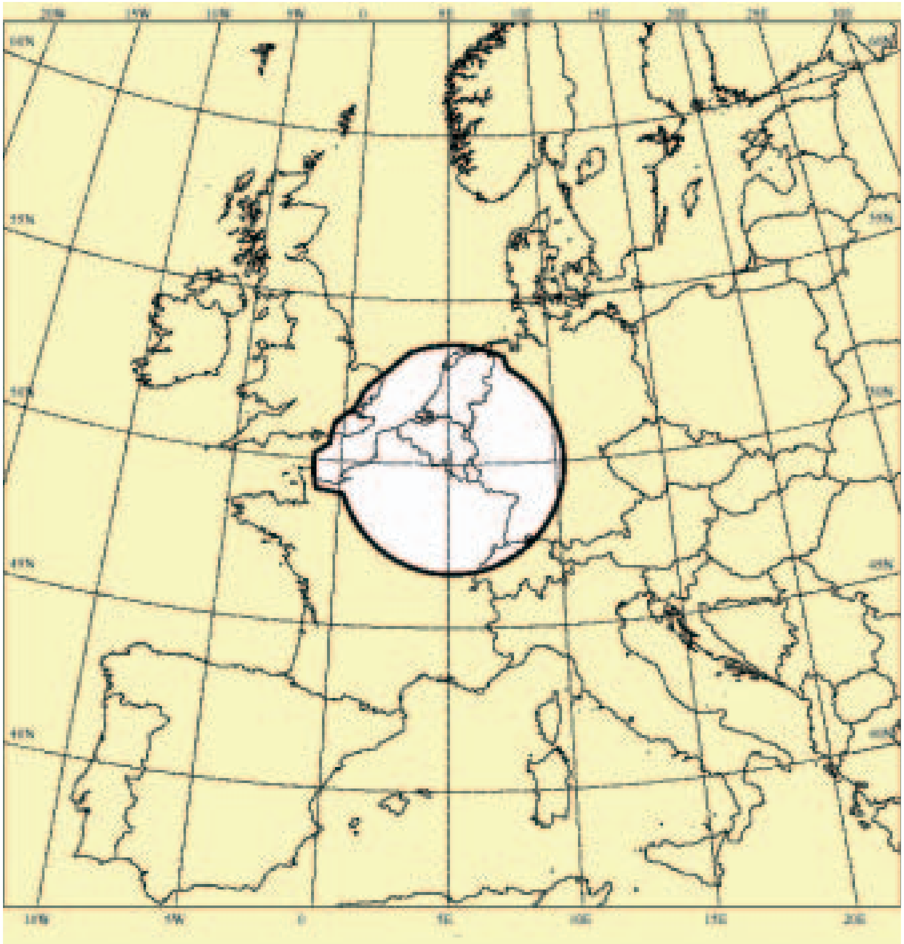
The final goal of such pre-ITU coordination is to find a reasonable frequency assignment that avoids the need for operational coordination in the future.

Having completed this task, the next step is the preparation of the ITU advance

In compliance with ITU regulations, the submission of API and Article 11 files is typically done three years prior to the nominal satellite launch date. This ensures that stable satellite and station performance figures are already available and that a normal launch delay would not invalidate the ITU filing. The maximum time allowed by ITU regulations between the API submission and the launch is 7 years.

Comments on the filing by any National Administration with the ITU will have to be answered to achieve the satellite notification. Having conducted

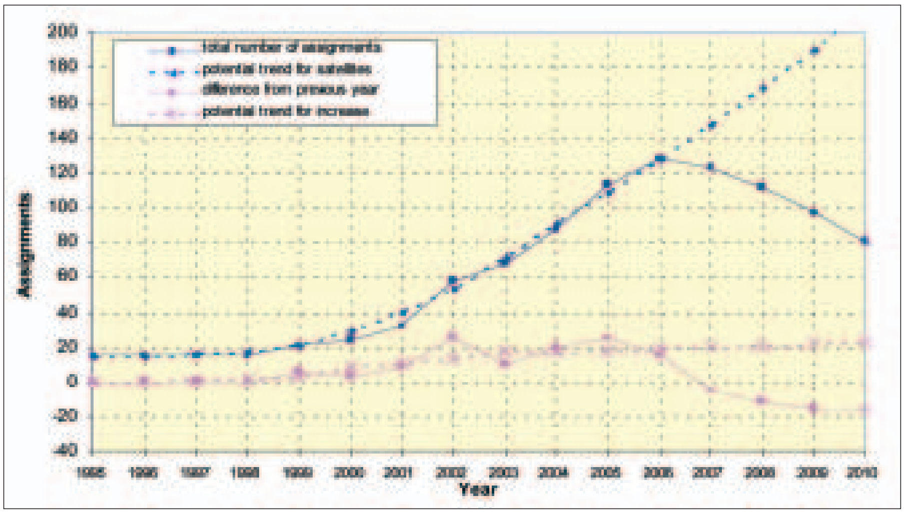
In order to operate the ESA ground stations (or a third-party station supporting an ESA mission), it is mandatory to have a transmit-and-receive licence issued by the Administration on whose territory the station is located. To ease this procedure, ESA has concluded agreements on radio-frequency use and protection requirements with all of the nations on whose territory an ESA station is located. Such agreements are based on simulations of RFI between the ESA station(s) and domestic terrestrial stations in its area of influence. These simulations, aimed at demonstrating that the protection criteria



A typical coordination contour, in this case for SMART-1 mission support from ESA's Redu station in Belgium

for both terrestrial and space services are met, utilise ITU software that takes due account of line-of-sight propagation, diffraction, anomalous propagation and rain scatter.

Having concluded such agreements does not absolve ESA from requesting individual licences for each satellite that has to be supported by the station. For European stations where cross-boundary coordination may be an issue, and therefore ITU notification of the station is also needed, the request for station licences has to be accompanied by the station coordination contours and the associated data file computed with the prescribed ITU software. The accompanying figure is an example of the coordination area for the Agency's Redu station in Belgium, in case it would need to support the SMART-1 mission in the 8.4 GHz band. It shows that international coordination with the Netherlands, Luxembourg, Germany, France, Switzerland and the United Kingdom would be required.



Number of satellites filed with the ITU for operation in the 8025-8400 MHz band

The host country Administration starts coordination on behalf of ESA, which however is required to answer questions from the interested Administrations and conduct ad-hoc RFI assessments with the tools described previously. As soon as the coordination is positively concluded (not all such coordinations to date have been successful), an ITU form similar to the satellite notification has to be prepared and submitted to the ITU. If the station coordination area is entirely within one Administration's territory, a domestic licence is sufficient. This lengthy process is concluded as soon as all stations licences (or notifications) are available.

It goes without saying that the terms and conditions of the satellite and station notifications cannot be violated during the mission operations.

Interference Events and Operational Coordination

Sometimes, the early coordination effort with other agencies like NASA and JAXA reveals a frequency-sharing problem between two missions, but programmatic considerations do not allow the selection of a different frequency. At other times, a non-coordinated satellite interfering with an ESA flying mission is suddenly detected. In these cases, the solution to minimise data loss is operational coordination between these two satellites. This coordination starts by using the satellite RFI prediction tool to assess the level and percentage of interference at both reception ends and results in a set of constraints on both missions to try and reduce the data loss to a minimum whilst not creating a huge operational burden on either mission. Such sets of constraints (typically a no-transmission cone angle) become part of an inter-agency agreement signed by both parties and are enforced by adding them to the mission rules.

To date, fewer than 20 operational coordination procedures have been established, mainly in the 2 GHz bands where there are 1600 ITU notifications. The only coordination procedure established in the 8 GHz bands concerns the Mars-Express and Mars Global Surveyor missions.

Data loss has so far only been experienced with two ESA missions: Integral being interfered with by a military satellite at Goldstone, and SOHO being interfered with by Meteosat Second Generation. While the first incident was due to a change in domestic priorities in the USA, the second is a seasonal problem due to the selection of frequencies that did not take into account an extended lifetime for the SOHO project; it is being resolved by three-party operational coordination, involving ESA, NASA and Eumetsat.

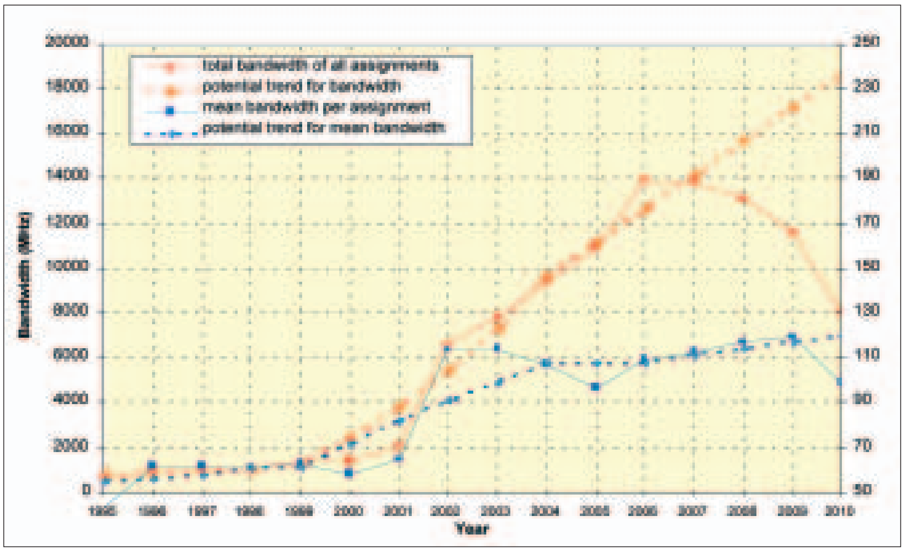
Given the fact that most ESA missions operate in the 2 GHz bands, which are already heavily congested, the very small loss of data experienced so far would indicate that the Agency's internal procedures for frequency management are sound. Nevertheless, as they say in the booklets promoting investment funds, past performance does not constitute a guarantee for the future!

Potential Problems Ahead

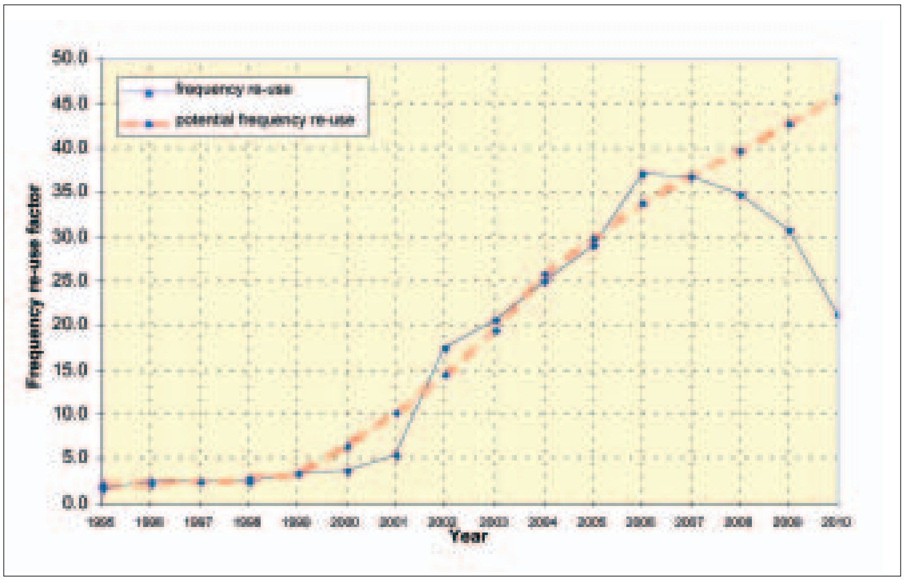
The growing difficulties in frequency management fall into two categories: competition for spectrum within the space-science services, and competition for spectrum from other services.

Competition for spectrum within the space-science services

As already mentioned above, the spectrum demand in the bands typically used by ESA satellites for tracking, telemetry and command (TTC) and for payload data transmission is increasing rapidly. New players are joining, mainly from Asian countries and commercial entities, while simultaneously new satellite projects need to transmit ever-increasing volumes of data.



Total bandwidth used by all satellites, and the mean bandwidth per satellite, for the 8025-8400 MHz spectrum range



Estimated frequency re-use for the 8025-8400 MHz band

To provide a feeling for the situation, we can take the results of a study made by ESA for the SFCG on the situation with the ITU filings in the 8 GHz band for Earth Exploration satellite downlinks. The three accompanying graphs show the historical evolution in the use of this band, and the expected trend for the coming years. The apparent reduction in the problem after 2006 is an artefact due to the fact that many satellites to be flown after 2006 have not yet been filed with the ITU, and the more meaningful curves are the dotted ones giving the trends. Even discounting the fact that some of the planned satellites will not be flown or will fail, the idea that we already have a mean frequency reuse factor larger than 10 and that this may double within a few years is rather scary!

There is obviously no room for choosing 'free' frequencies. The probability of having interference occur on the downlinks will increase exponentially, especially around the high-latitude stations. Suitable orbit selection, downlink strategies, ground-station selection, spectrum-efficient coding and modulation, and error-correction coding may alleviate the problem. They may not, however, be sufficient to make it disappear, even if we find a way to have everybody agreeing to some strict self-imposed regulations in these areas. The space-science community may even end up one day having to migrate the more bandwidth-hungry missions to higher frequency bands, with the associated cost of designing and developing new onboard equipment and ground infrastructures.

This is just one example. The S-band at 2 GHz is, in terms of users, even worse.

In other words, space agencies have to prepare themselves for a future when more and more missions will have to coordinate their operations with others and accept the associated costs in terms of extra manpower and intermittent data losses or delays. Not a comforting thought!

Competition for spectrum from other services

In addition to the 'internal problem' outlined above, space-science services have to face another, even more severe challenge. Other spectrum users, particularly those from the commercial terrestrial telecommunication sector, are putting an increasing amount of pressure on the bands used by our satellites. This may take the form of proposing that regulations less favourable to our services be introduced in the bands that we share with them, or proposing that new commercial systems be allowed to operate in these bands. ESA and the other space agencies have fought in all international forums against these attempts, so far with success. The SFCG has been very instrumental in winning these battles, but the pressure is on.

Below are just a couple of examples of problems faced in recent the past and the associated consequences:

Example 1: 3rd generation mobile telephones

Most of the 2 GHz range used by our satellites for TTC was targeted in the late 1990's for allocation to the terrestrial mobile service systems implementing the new 3rd-generation mobile telephones (UMTS) that are now appearing on the market. Luckily they were kept out of the larger portions of the TTC bands, which can still be used for space science after in-depth negotiations lasting for two conferences (WRC-95 and WRC-97). The only band assigned to UMTS within the space-science bands is 2110-2120 MHz, which overlaps with the space research deep-space uplink band and was assigned to the predecessor of UMTS in 1992.

In 1992, the first-generation mobile-phone system had only a few thousand subscribers in the World and was not

ESA's new ground station at New Norcia, photographed from the 35-metre antenna considered a threat to space science. In this band, satellite ground stations transmit signals that can have powers of up to a 400 kW in order to reach the most distant satellites. Consequently, UMTS telephones within a few hundreds kilometres of the antenna could be interfered with. If one thinks of the huge amount of money that the telecommunications companies have spent at auctions to 'buy' these UMTS frequencies, it is clear that they are not happy at the idea of suffering interference over large geographical areas. From this has come the pressure on our stations to relocate to the most remote locations. It started in Australia, where ESA had to build a new station in the outback at New Norcia, because the existing one at Gnangara was deemed to be too close to the city of Perth. Later, our Villafranca station in Spain came under similar pressure and the decision was taken to build the new deep-space antenna at the more remote location of Cebreros. Every time ESA reaches the phase of renewing a ground-station agreement with the relevant national authority, this problem is raised and has to be renegotiated.

Example 2. Wi-Fi systems
The next-generation Wi-Fi systems for terrestrial broadband wireless local networks will operate in a band overlapping with the one used by the C-band SAR imager on ESA's Envisat satellite. In Europe ESA was instrumental in defining regulations limiting the use to indoor Wi-Fi systems only, as the building's shielding effect will avoid any interference with SAR measurements. National regulations in North America, however, do not include this limitation, and so there is the possibility that in a few years time Envisat SAR images over its urban areas may experience some degradation.

Example 3. Car collision-avoidance radars
From next year, the car industry will offer the possibility of mounting short-range collision-avoidance radars on new cars. Unfortunately, these radars will initially operate around 24 GHz for a number of years, before moving to their nominal higher frequency at 79 GHz, for which the technology is still under development. Studies made by ESA and other meteorological agencies have demonstrated that a certain density of cars equipped with these devices would interfere with atmospheric water-vapour measurements made by microwave sounders like the one on the MetOp satellites. This resulted in the decision to limit the use of the 24 GHz band by these car radars to just the first few years, during which it is assumed the market penetration of these new devices will still be limited. This compromise was reached after more than two years of difficult discussions with representatives of the car industry.

The mobile-phone industry, the Wi-Fi industry, and the car industry – clearly the economic and political weight of some of our competitors for spectrum is already impressive, and there are more of them lining up! So far, ESA has managed to balance that through some well-coordinated international actions, accurate technical studies to support the space-science position, participation in all the key meetings at which decisions are taken, a good working relationship with all national and international authorities, and a responsible and reasoned approach. Will that be sufficient also for the future?

Conclusions

This article has hopefully provided an interesting overview of the work associated with frequency management for the ESA missions. It has identified the various steps in the process, the tools used and the final result. It has also described the growing complexity in coordinating the use of the bands with space missions from other agencies, as well as the risks stemming from the presence of new radio-frequency systems competing for the use of the scarce spectrum resource available. These challenges can be met only by reinforcing international coordination and by exploiting structures like the SFCG to define common long-term strategies among all the space agencies. Nevertheless, it is not unlikely that the increasing competition for spectrum may result in some limitations on the design and operation of future ESA missions!

Columbus: Ready for the International Space Station

Bernado Patti, Robert Chesson, Martin Zell & Alan Thirkettle
Columbus Project, Directorate of Human Spaceflight, Microgravity and Exploration, ESTEC, Noordwijk, The Netherlands

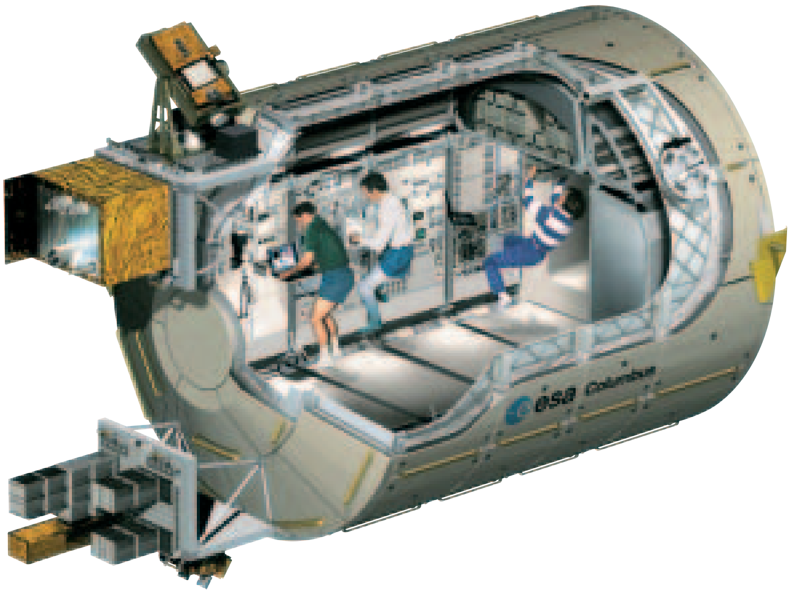
One of the key contributions to the development and operation of the International Space Station (ISS) is ESA's Columbus Laboratory Module. It will be transported to the ISS, together with its payload complement, on Space Shuttle Assembly Flight 1E in 2006. Columbus's readiness for launch requires the availability not only of the Module itself, but also three other major elements being provided by ESA, namely: the Ground Segment, consisting of the Columbus Control Centre and the User Support and Operations Centres (USOCs), the Operations products, and the Crew Training.

Status of the Four ESA Elements

The ESA-provided elements required for Flight 1E readiness fall into four categories:

The Flight Segment

The flight segment consists of the Columbus Laboratory Module and its associated Payload Complement. The Laboratory Module has been developed for ESA under the Prime Contractorship of EADS-ST in Bremen, Germany, with a major contribution from Alenia Spazio of Turin, Italy. The Module has already successfully completed its Qualification Reviews 1 and 2, and is currently undergoing testing to support the Review 2 close-out activities, which are planned to be completed in March 2005.



The Columbus Laboratory Module

The Columbus Payload Complement is composed of four pressurised payload racks (so-called 'ISPRs'), namely: the Biolab, the European Physiology Module (EPM), the Fluid-Science Laboratory (FLS), the European Drawer Rack (EDR), and two unpressurised external payloads, EuTEF and SOLAR. While the four pressurised payload racks will already be integrated into the Columbus Laboratory Module prior to launch, the unpressurised external payloads will be accommodated on a dedicated cargo carrier provided by NASA.

The Ground Segment

The Ground Segment is made up of two distinct elements, the Columbus Control Centre and the User Support and Operation Centres (USOCs).

The Columbus Control Centre, developed under the Prime Contractorship of DLR in Oberpfaffenhofen (D), was inaugurated in October 2004 and is already supporting mission preparation and mission simulations from its control rooms.

The European USOCs will carry out the majority of tasks related to the preparation for flight and in-flight operation of the Columbus payloads. Based at existing national centres specifically equipped by ESA for ISS activities, these USOCs will act as the link between the user community and ESA's ISS utilisation organisation. They will interact with the scientists at their User Home Bases by disseminating experiment data to them, and receiving and processing requests for experiment scheduling.

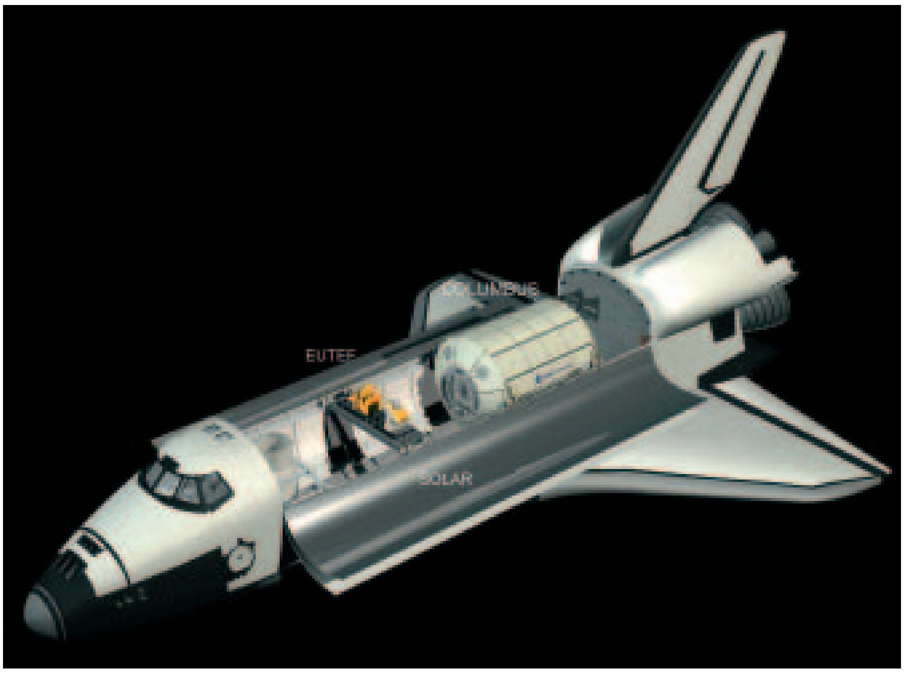
There are three basic levels of responsibility within the USOCs:

– Facility Responsible Centres (FRC) are delegated overall responsibility for a rack-level payload.
– Facility Support Centres (FSC) are delegated responsibility for a particular sub-rack payload, such as a facility insert, experiment container, drawer payload, or bioreactor.
– Experiment Support Centres (ESC) are delegated responsibility for single experiments.

The USOCs' current major activities involve the completion of infrastructure build-up and operations preparations. The former is almost complete, with the remaining part being mainly related to the installation of the common equipment supplied by ESA. Some of the USOCs have already started preparations for experiments in the framework of the early ISS activities before Flight 1E, in order to gain early experience of ISS operations.

The Operations Preparations

Onboard and ground Operations Products such as procedures and displays are close to finalisation. The verification of procedures began in September 2004, and



Columbus in the Space Shuttle's cargo bay (artist's impression)

The Space Shuttle's Return to Flight

The tragic loss of 'Columbia' in February 2003 caused a major perturbation in the planned Shuttle mission schedule. The causes of the accident have been identified by the Columbia Accident Investigation Board (CAIB), whose report listed 15 recommendations that had to be implemented before the Space Shuttle's return to flight.

NASA then established an Implementation Plan that addressed each of these recommendations in turn, as well as an additional 24 recommendations not related to the return to flight, coming either from the CAIB or from internal considerations. At the time of writing (December 2004) five of the 15 recommendations are formally closed out. A further five are in the final paperwork verification stage, and the final five are still being in work, albeit at an advanced stage.

The first return-to-flight Shuttle mission is currently planned for mid-May to mid-June 2005, subject to successful completion of the modifications to the thermal-protection insulation on the Large External Tank, debris from which caused the critical damage to the leading edge of Columbia's wing.

some of them have been used for system validation. The flight operations teams from ESA, DLR and NASA have already conducted simulations of the assembly procedures for the Flight 1E mission.

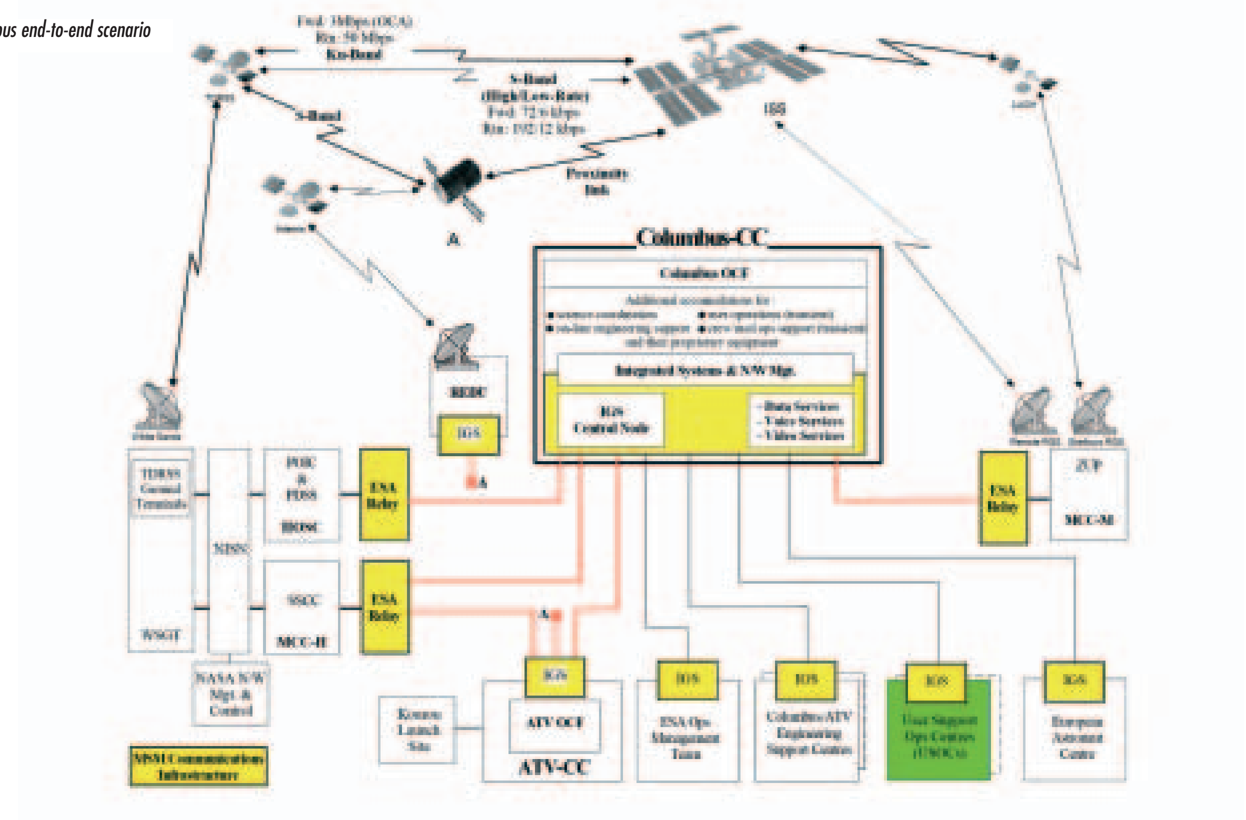
The Crew Training

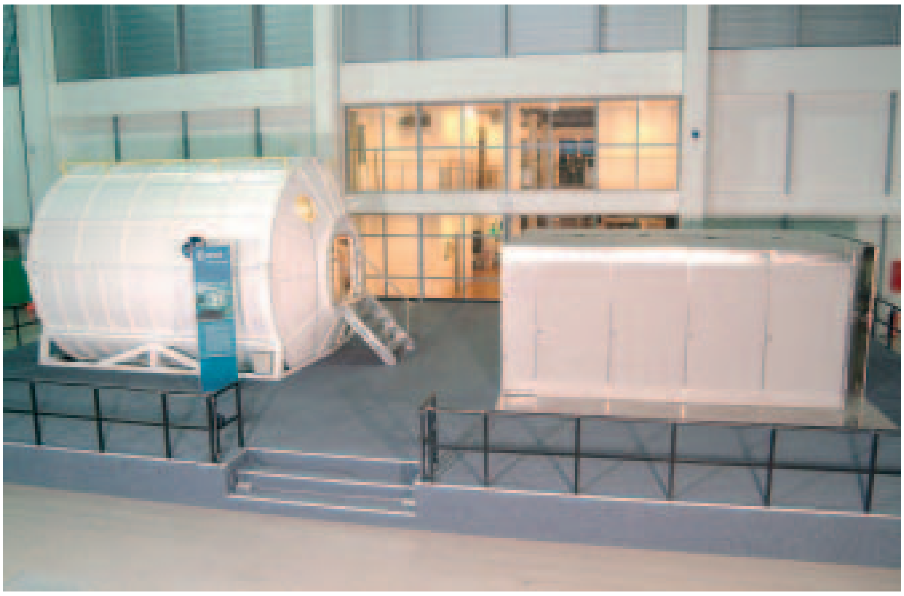
The development of the training for astronauts working with the Columbus systems was completed in 2004. The payload training itself will be concluded in spring 2005. A Columbus training simulator running the Data Management System (DMS) flight software and a Columbus Mock-up for hands-on training activities are ready for use. Stand-alone training facilities for the EPM, EDR, Biolab and FSL are ready to support generic payload training.

During the past three years an industrial instructor team has been trained and certified for crew training, and about 350 hours of astronaut training have been developed. The instructor team became fully operational in 2004 and has already conducted two courses for advanced astronaut training for six astronauts, and five training courses for a total of sixty ESA and NASA flight controllers and operations personnel.

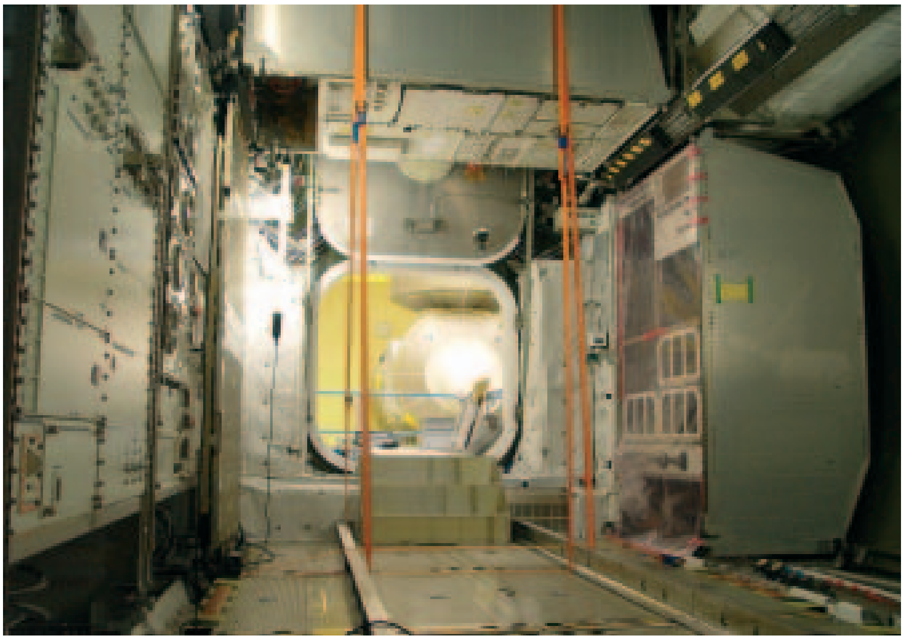
The Columbus Simulator and the Columbus Mock-up located at the European Astronaut Centre (EAC) in Cologne-Porz (D) constitute the two main facilities for the training of astronauts on Columbus systems.

The Columbus end-to-end scenario





The Columbus Mock-up (left) and the Columbus Simulator (right) at the European Astronaut Centre (EAC)



The interior of the Columbus flight model

The Integration for Flight 1E

The declaration of Flight 1E readiness requires the integration of, and the verification of the interfaces between, the various ESA-provided elements described above. The originally planned October 2004 launch date, prior to the 'Columbia' tragedy, would have ensured a smooth transition from the Columbus development stage to the operations phase. The Shuttle's grounding and the resulting two-year delay for Flight 1E have required a total reworking of the planning. Instead of slowing down the development programme, it was decided to complete the baselined set of activities according to the original planning, which involved in particular the completion of the Flight and Ground Segment Development together with the testing of their interfaces (see accompanying figure). This has minimised the impact on the development contracts and allowed the early identification of potential interface issues well before the new Flight 1E launch date. This in turn will reduce the remaining technical risks in the programme.

The payload integration and testing has therefore been followed by the System Validation Tests 1 and 2, to verify the interfaces between the space and ground segments.

Payload Integration

Payload integration took place between April and June 2004. During this period, the interface compatibility between Columbus and its pressurised payloads has been verified on the Columbus flight model. This test campaign involved the execution of individual tests for each Payload Facility, followed by an Integrated System Test.

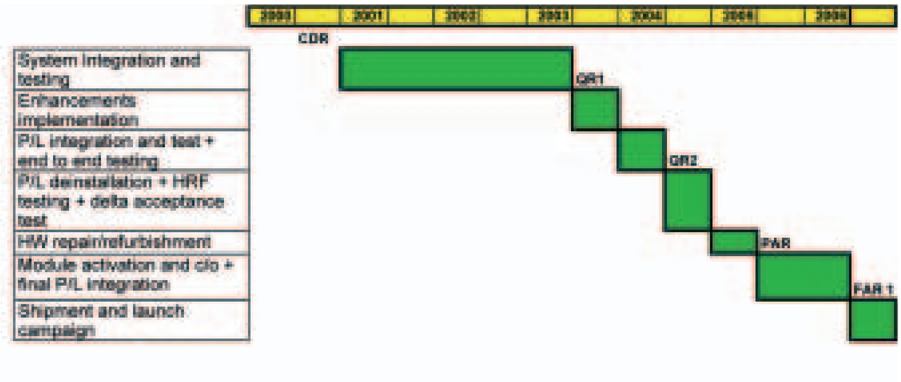
System Validation Testing

Following payload integration, the interfaces between the flight and ground segments have been tested by so-called System Validation Tests (SVT): SVT 1 used the Columbus Electrical Test Model (ETM) together with the Columbus Ground Segment, and SVT 2 the Columbus Proto-flight Model (PFM) outfitted with the pressurised payloads, in combination with the Columbus Control Centre and the USOCs.

SVT 2 was the first time that all of the major programme elements had been tested together. The functional configuration for the test was therefore extremely complex and its execution was very challenging due to the many interfaces involved. Its successful completion therefore represented a major milestone in the progress of the overall programme.

The Shipment of Columbus to KSC

Following the completion of the System Validation Tests, the items making up the European payload complement have been shipped back to their respective industrial contractors for refurbishment and enhancement. The Columbus Module itself



The Flight 1E Columbus integration and launch-preparation programme

will also undergo some refurbishment. In order to reduce the programme risks still further, some extra testing is being planned, which will include end-to-end testing of the external payload elements and extended software endurance testing.

Thirteen months prior to launch, the Columbus Module and its Payload will undergo a second round of integration and testing, in preparation for their shipment to Kennedy Space Centre (KSC). The integration phase, together with the packing activities, will be timed to allow the Columbus Laboratory to undergo a seven-month launch campaign at KSC.

Conclusion

With the completion of the Payload Integration and Test and end-to-end Test Campaigns (SVT1/SVT2), Columbus has successfully passed its Qualifications Reviews (QR1/QR2), thereby officially completing the development phase. Activities in 2005 will focus on completion of the remaining integration work, on some extra testing aimed at further reducing the mission risks, and on the final launch preparations. Current planning by ESA and EADS-ST foresees the packing and shipment activities to start in Europe in the December 2005/January 2006 time frame, in order to allow the shipment to Florida of the Columbus Module, with the Payload Racks already installed, in the first quarter of 2006 in good time for the final launch preparations.

Software Engineering: Are we getting better at it?

Michael Jones
Mission Data Systems Division, ESA Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

All modern businesses throughout the World depend on software and for many of them it is mission-critical. Software therefore accounts for a significant proportion of global GDP. It follows that software engineering, which enables efficient development of quality software, is of great importance and not just a niche specialisation. Of course, in ESA and in the space business generally, we are critically dependent on software and associated Information Technology (IT) systems, which pervade all our space systems, both onboard the spacecraft and on the ground.

Why Software Engineering is Important

Surveys have shown that the average corporation pays 3-7% of its annual revenues for hardware and software for corporate data processing, and another 2-5% for maintenance: that is 5-10% of the economy in the developed World! Information technology is critical for many businesses in that they rely on the efficiency and integrity of their IT systems for their day-to-day operations. This is especially the case for ESA and the European space industry, where software is all-pervasive in onboard avionics and payloads, in ground segments and also in the associated commercial business processes.

An epigram by the philosopher George Santayana carved over the entrance to the US Archive in Washington DC reads: *"Those who cannot remember the past are doomed to repeat it."* A variation of this could be: *"Those who cannot remember the past, may not be able to repeat their successes"*. So you need to remember the past in order to avoid mistakes and to repeat successes.

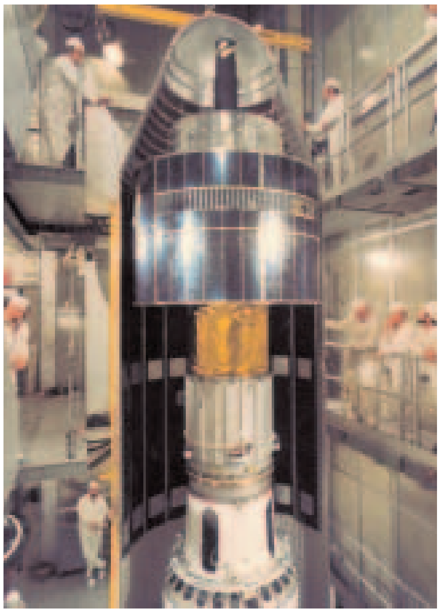
The need to take account of 'lessons learnt' is well-recognised in ESA and measures to ensure the feedback of experience into improved working practices are being actively pursued. In the case of software-engineering, the Agency has been doing this for over 25 years. In fact, software engineering is basically about recording experience in developing and maintaining software and documenting it in the form of best practices.

Software Engineering Advances at ESA

Advance 1: The importance of requirements

Software engineering in ESA started in the mid-1970s. The initial impetus came from the experience of Dr. Carlo Mazza during the Meteosat Ground Computer System (MGCS) project, which was responsible for the data-processing system for the first of ESA's meteorological spacecraft. The MGCS covered mission control, payload data processing, dissemination of meteorological products generated from the payload data, interactive product quality control and data archiving. The system aimed at a high degree of automation, particularly for repetitive but complex tasks such as the extraction of wind directions from sequences of satellite images, which was unusual at the time.

It became apparent about a year before Meteosat's launch that the MGCS project was in difficulties. The problem as Carlo Mazza saw it was that the requirements that the system was supposed to meet were not documented. Carlo therefore took the decision to stop work on development (i.e. design and coding) and document the requirements – a decision that required both vision and courage – so that management could then make informed decisions on development priorities.



The first Meteosat spacecraft, being readied for its launch from Eastern Test Range in Florida on 22 November 1997

Console at the XMM-Newton Science Operations Centre at Villafranca, near Madrid

The lesson learned was never to undertake such a project without first drawing up well-defined requirements, and it subsequently resulted in the formation within ESA of the Board for Software Standardisation and Control (BSSC), with Carlo Mazza as its first Chairman. Its terms of reference included the provision of a software engineering standard, which was eventually published as ESA Procedures, Standards and Specifications document PSS-05-0. It clearly highlighted the distinction between user requirements and software requirements, which was far from being well recognised at that time. In fact, a key message from the authors of that standard was the need to analyse and negotiate user requirements to produce an unambiguous baseline for the software developers, which can be implemented with the technology available and within the budget provided.

Advance 2: Customer/supplier equilibrium and firm-fixed-price contracts

In the 1980s and early 1990s, most software development at ESOC was done under Fixed Unit Price (FUP) conditions. That meant that the Centre bought man-hours of effort from a contractor and took full responsibility (i.e. fully 'owned the risk') for the software requirements and their implementation. As the software contractor team took no such responsibility, they were under no obligation to scrutinise requirements critically. In fact, the situation was quite the reverse – the more requirements that were accepted, the more work the software contractor got, but without ever having to take responsibility for the end product.

The problem with this lack of a suitable customer/supplier equilibrium, or division of responsibilities, came to a head with ESOC's SCOS II project, where, for the first time, an ambitious attempt was made to write comprehensive user requirements for a reusable spacecraft-control system. The resulting User Requirements

Artist's impression of the Envisat spacecraft

Document was impressive, with over 7500 requirements, but they were neither layered nor prioritised for staged implementation. There was no resistance from the supplier's side because under the FUP approach, which was then the norm, the supplier did not have to make any committing cost estimate.

In 1995, the concept of Firm Fixed Price (FFP) contracts for the development of spacecraft control systems and simulators was systematically introduced at ESOC for software development. This was motivated at the time not by issues of risk ownership, but rather by the need to move contract staff off-site to their own companies' premises to relieve site overcrowding, something that was much more practicable under an FFP regime whereby the contactor is providing either a service or a product. This idea very much influenced the new 'frame contracts' that were issued around that time (in fact, late 1996). The result was:

- Far more rigorous scrutiny of requirements by frame contractors.
- Equitable risk sharing between ESA and its suppliers.
- Formal change control (Contract Change Notices, or CCNs) for changes in requirements. A consequence was that end-users became more careful about defining their requirements.

Projects that immediately benefited from the new regime included:

- the development of the XMM-Newton Science Operations Centre (SOC)
- the development of the Envisat Mission Control System (MCS)
- the consolidation of the SCOS II command chain.

The XMM-Newton SOC is a particularly good example because the software was developed in London and Rome, integrated in Darmstadt, Germany, and finally installed and accepted at ESA's Villafranca ground station in Spain. The team consisted of over 50 software developers at its peak. Although XMM-Newton was launched ahead of the original schedule, both the control system and the SOC were ready in time.

Advance 3: Devising a good software engineering standard

Software engineering standards are used by many people and so they have to be easily understandable and practical to apply. To take one example, ESA PSS-05-0 covered:

- software engineering processes, and
- supporting processes (software project management, software configuration management, software quality assurance, and software verification and validation).

It was a compact volume of about 100 pages, covering:

- about 200 practices
- five major output documents
- four plans.

This was a remarkable achievement by the BSSC because it is concise, comprehensible and contains the right balance: providing sufficient detail, but not too much, and leaving leeway for the application of local practices. It is not over-prescriptive and focusses on important reviews and outputs.

It is easy to get this balance wrong, as illustrated by the example of the SCOS II Development Standard. One of the early and, as it turns out, correct decisions taken on the SCOS II Mission Control System project was to use Object-Oriented development methods, which, it was thought, demanded iteration during the development. The SCOS II development team prepared a development standard based on PSS-05, but explicitly spelling out the iterations within the phases. This turned out to be totally impractical, since the iteration involved repeated reviews and associated document deliveries, which, if followed, would have led to review overload. Thus it destroyed the PSS-05 equilibrium by taking a highly prescriptive approach to iteration.

As anyone who has been involved with architectural design will know, the design described in an Architectural Design Document does not spring fully formed from the minds of the designers. There is always iteration and re-design, even if it is not explicitly spelled out. This, however, is not the main lesson!

Apart from this fundamental methodological flaw, the SCOS II Development Standard was rather difficult to read, perhaps as a result of being written with limited resources by people without the necessary standards-writing skills or experience. So the main lesson is don't try to rewrite software engineering standards as part of your project. Writing such standards is time-consuming and requires special expertise, apart from the fact that most project funding does not include allowances for rewriting standards.

Advance 4: Sustaining expertise via frame contracts

Frame contracts were first introduced at ESOC in the early 1980s. The initial idea was based on the observation that following the full classical ESA procurement approach for all software developments was slow and inefficient, with a high administrative overhead. The basic idea of the frame contract is to use the full ESA contracting procedure to select a limited number of competing contractors that would be awarded all the software development work in a given domain over a 3 to 5 year period. Work packages are awarded competitively either in the initial tendering or later during the contract's duration. A streamlined competition procedure is used for each new work package.

These frame contracts were an important advance because:

- they encouraged competition
- they developed pools of expertise
- the expertise thus developed became a competitive advantage, not just for ESOC, but also for the frame contractors themselves who, on the basis of experience at ESOC, were able to get work elsewhere in the space industry.

Advance 5: Increased software productivity through reuse

A quite remarkable feature of the original terms of reference of the BSSC is the inclusion of responsibilities relating to software intellectual property rights, and software libraries. We now take the re-use of software, particularly on our desktop PCs, for granted. In 1977, however, when the

BSSC's terms of reference were written, software re-use was not such an obvious productivity winner as it now. It almost certainly stemmed from the environment at ESOC, where re-use started early and seriously with the Multi-Satellite Support System (MSSS) in the early 1970s.

There are various strategies for increasing computer programming productivity, but software re-use is arguably the most effective. At ESOC the results have been very apparent for mission control systems, where the ease of use and functional richness of the SCOS-2000 reusable mission control infrastructure has reduced development costs by a factor of 3-5 over the past six years or so (see Tables 1 to 3).

The XMM-Newton and SMART-1 missions are both very successful examples of software reuse. The gains are lower in the case of XMM SOC because there were many requirements for which reusable software did not exist, but 50% is nevertheless a still-impressive doubling of productivity. For SMART-1, only about 7% was new code, giving a very substantial leverage effect: apparently for an investment of 7% you get 100%. This is a bit over simplistic, because one also has to take into account the costs of integrating the reused software and testing the whole system. The fact remains, however, that a very sophisticated control system was developed at a low cost.

Software reuse works best when the software has been specifically developed with reuse in mind, which usually means a considerably larger initial investment, and that the end users must commit to the software's reuse.

Subsystem	LOC
XMM Science Ops. Centre	30,000
Payload Monitoring	27,000
Proposal Handling	17,000
Sequence Generation	22,000
Archive Management	42,000
File Transfer	13,000
Payload Calibration	40,000
Quick-Look Analysis	32,000
Observation Data Handling	14,000
Infrastructure/Libraries	13,000
Subtotal XSCS w/o SCOS-1	250,000
SCOS-1A/B	250,000
Total	**500,000**

Table 1: XMM-Newton software reuse in terms of lines of code (LOC)

Software Engineering Issues Today

Software failures

Software failures are still a serious concern for everyone in the space business, as the accompanying table shows. ESOC is no exception and there have recently been several potentially mission threatening software failures, including:

- MCS failure during the MSG launch and early operations phase (LEOP) 20 minutes after launch.
- Detection of a problem with handling the leap year (again in the MCS) a few days before the Rosetta launch.

How can such problems be avoided? There is no easy answer to this, but first we should look into the background. As explained above, ESOC now outsources the development of software, but remains responsible for the definition of requirements and acceptance testing. The delivered system is therefore acceptance-tested against the requirements, for which good tools have been developed at ESOC. The problem is that this is 'black box' testing, in the sense that it is done without taking into account the system's design or structure, i.e. the box is opaque! As such, it is not exhaustive, and many parts of the software product will not be executed if only explicit requirements are addressed. Testing against requirements therefore has to be complemented by extensive structural or 'white box' testing, which should ideally cover all the logic paths through the software. This is in effect outsourced to the software developers. Another factor is that error removal usually occurs at the end of the development project's life cycle and in the event of a schedule crunch is the most likely task to get neglected.

The obvious conclusion is that error-free software is an impossible goal. A more realistic goal is that of producing software without high-severity errors. We therefore need systematic ways of detecting the latter!

ECSS Software Engineering Standards – The Problem of Tailoring

The judicious equilibrium of the original PSS-05 in terms of prescriptiveness versus freedom has already been mentioned. What of the latest standard currently in use in ESA, namely ECSS-E-40? Like the solid international standard ISO 12207 on which it is modelled, ECSS-E-40 is based on the twin concepts of:

– comprehensiveness: it covers all types of projects, including highly critical ones, and
– tailoring to adapt to individual projects.

In the particular case of E-40, tailoring is essential, since if it were applied in full it

Software Origin	Source	Header	Total	%
SCOS-2000 R2.2.1	953	929	1882	76.4
Rosetta	139	160	299	12.1
Integral	63	55	118	4.8
Meteosat Second Generation	2	3	5	0.2
SMART-1	73	85	158	6.4
Total	**1230**	**1232**	**2465**	

Table 2. SMART-1 MCS reuse figures in units of number of modules (files) from each contributing project

Project	% Reuse	Productivity gain
XMM-Newton Science Ops. Centre	50	2
SMART-1 Misson Control Centre	93.6	16

Table 3. Productivity gains from software reuse

would be too heavy and prescriptive and would result in too many output documents, many of which have to be delivered several times. However, the sensible tailoring of a complex standard like ECSS-E-40 requires a detailed understanding of the whole standard, which the average software developer or project manager does not possess. Two approaches have therefore been identified:

– *Use of a tailoring tool*: The latter allows the developer to answer a set of questions about the project and the tool tailors out requirements in a consistent way, according to the answers. The tool can then print a table of retained requirements and output documents required.
– *Organizational tailoring:* For an organization such as ESOC many of the projects are similar, and so it could be expected that the same tailored standard could be used for all of them. Alternatively, a limited number of tailored versions could be considered, corresponding to different categories of projects in the organization, e.g. safety-critical and other (i.e. non-safety-critical) projects.
The second approach is the one we to apply at ESOC.

Conclusion

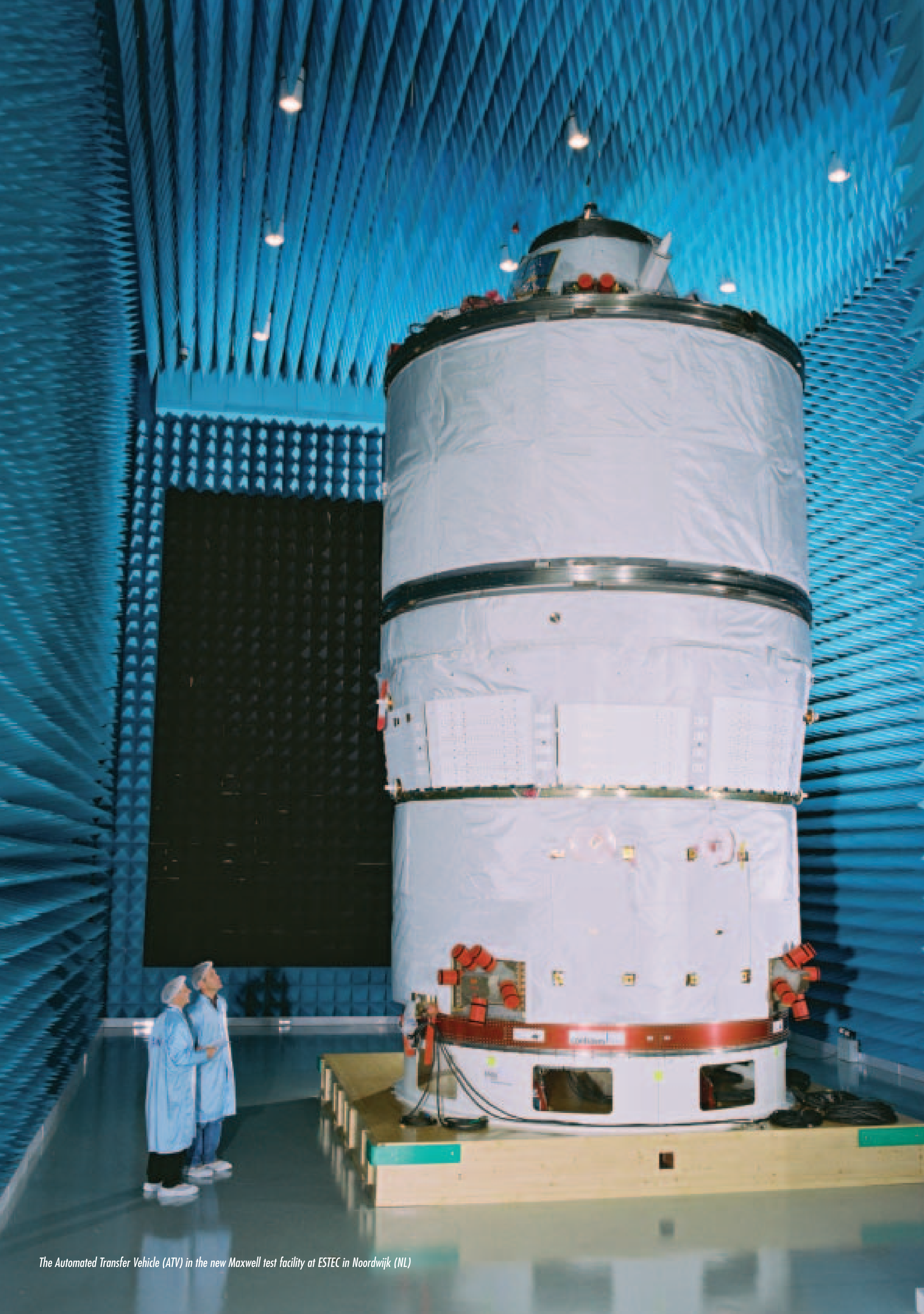
It is time to return to the question posed in the title of this paper, namely 'Software Engineering: are we getting better at it?' The reader will hopefully agree that, with the major advances described here, we have come a long way in the last 25 years, and that ESA as an organization is in a much better position than when the BSSC was first set up to establish software engineering standards for the Agency.

Firstly, this article has looked at software engineering as a branch of the empirical discipline of computing and asked if laws or rules exist to describe the practices or processes concerned. The conclusion is that while there is no 'unified field theory' of software engineering, there is a useful body of rules and hypotheses.

Secondly, it has highlighted a number of practical advances in the application of software engineering at ESOC that have demonstrably contributed to sustainable success in developing software, and in some cases have helped to reduce costs by remarkable amounts. The conclusion here is that we have indeed got much better at software engineering, and advances have also been made in the management and contractual approaches. However, the need for vigilance is eternal: with highly complex space systems there is always a danger of something going wrong, no matter how careful we think we have been about software development and validation.

Project	Incident	Root cause
Ariane 501, June 1996	Launch failure, loss of 4 Cluster spacecraft	Lack of proper software and system validation
Mars Climate Orbiter, September 1998	Loss of Orbiter	Confusion between imperial and metric units. Lack of proper software/system validation
Mars Polar Lander, December 1998	Loss of Lander	Software error forced premature shutdown of landing engine: lack of proper software validation
Titan-4B, April 1999	Failure to put USAF Milstar spacecraft into useful orbit	Centaur upper stage failed to ignite. Decimal-point error in the guidance system. Lack of proper software validation
Delta-3, April 1999	Launch aborted	Failure of on-board software to ignite main engine. Lack of proper software validation
PAS-9, Arch 2000	Loss of ICO Global Communication F-1 spacecraft	Error in an update to ground software. Lack of proper software validation

Table 4. Software-related mission failures



The Automated Transfer Vehicle (ATV) in the new Maxwell test facility at ESTEC in Noordwijk (NL)

'Maxwell'
– A New State-of-the-Art EMC Test Facility

Jean-Luc Suchail, Alexandre Popovitch & Philippe Laget
Testing and Electromagnetics Divisions, ESA Directorate of Technical and Quality Management, ESTEC, Noordwijk, The Netherlands

Christened "Maxwell', after James Clerk Maxwell (1831-1879) who unified the physical laws of electricity and magnetism with equations known as 'Maxwell's Equations', the new EMC chamber that has recently come on stream at ESTEC is the perfect facility for testing the electrical and magnetic characteristics of Europe's largest and most advanced spacecraft payloads. The chamber's spacious internal dimensions of 14.5 metres x 10.7 metres x 11 metres mean that it can handle the largest satellites compatible with Ariane-5 single-passenger launches.

What is EMC?

Electromagnetic Compatibility (EMC) is defined as: 'the ability of equipment to operate safely within a defined electromagnetic environment without causing or suffering unacceptable degradation as a result of electromagnetic interference'. EMC testing is therefore an integral part of any spacecraft's pre-launch qualification and verification programme, along with mechanical and thermal testing, and similarly requires dedicated facilities to achieve the appropriate levels of accuracy.

The EMC verification process can be separated into two broad categories of activities:
- Electromagnetic immunity and radiated susceptibility testing: to verify the ability of a device to tolerate disturbances.
- Radiated emissions testing: to characterise the level of disturbance generated by the device.

The Causes and Effects of Electromagnetic Interference

Electromagnetic Interference (EMI) can be either mission-dependent or intrinsically related to undesirable interaction between the various systems onboard the spacecraft, and therefore include, for example:
– electrical static discharge due to space-environment interactions
– intra-system common mode phenomena
– transients due to the switching on and off heavy electrical loads
– spurious radio frequencies in receiver bandwidths (so-called 'intermodulation').

The consequences of EMI-related disturbances are generally nuisances affecting the mission or reducing the efficiency of some spacecraft functions. They may also translate into irreversible loss of operational capability, with an impact on scientific and programmatic yields. The main effects are:
– temporary or permanent telemetry interruption/corruption
– noisy scientific data, or channel outages on telecommunications satellites
– accidental tripping of safety devices, spurious commands, electronic resets (e.g. clocks), spacecraft switching into safe mode
– damage to or loss of power supplies.

The most extreme consequence is total loss of the spacecraft.

The new Maxwell test chamber

Spacecraft EMC Testing

Spacecraft EMC tests are performed throughout the successive phases of the project to verify that the requirements applicable from equipment level all the way up to system level have been properly implemented. The testing is carried out inside a dedicated facility known as an EMC chamber, sometimes referred to as an 'anechoic' (i.e. reflection-free) chamber. It shields the spacecraft's receivers from outside transmitters, such as local TV broadcast stations and mobile telephones.

Reciprocally, the chamber allows the satellite's transmitters (e.g. the communications system) to transmit their signals just as they would in space. This verification covers both normal and critical mission phases to ensure that the satellite electronics will function exactly as they should.

The New 'Maxwell' Facility

The limited volume of the previous EMC chamber at ESTEC had meant that, for several years, it was no longer compatible with the size of current space projects. Some projects had therefore used the antenna compact payload test range instead, but this chamber required significant reconfiguration for EMC testing and was not optimised for this type of test. Some projects built dismountable anechoic corner structures to perform radio-frequency auto-compatibility measurements, but installing and dismounting them was laborious, they generated a storage problem when not in use, and were still not optimised for EMC testing.

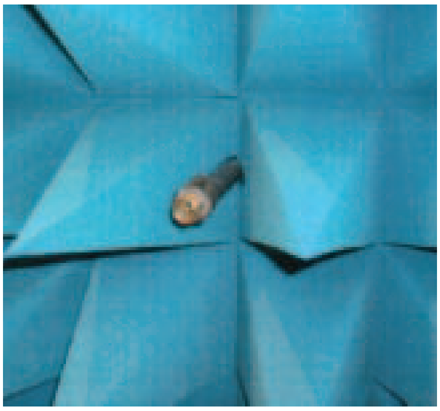
To overcome these problems, an existing verification support area in the ESTEC Test Centre has been used to erect a large EMC chamber, together with a dedicated control room, a room for customer-supplied electrical ground-support equipment, and the requisite hardware storage areas. The new facility provides an extremely clean electromagnetic environment, with outstanding shielding and attenuation of up to 40 GHz. Specially designed air-cooled high-power dissipation walls make it possible to test the latest high-power telecommunications satellites with local dissipation capabilities of up to 3 W/cm^2. An especially large door (11m high x 6m wide) provides direct access from the Test Centre's integration area to the chamber for Ariane-5 single-passenger sized satellites, transported on a non-conductive 5 m x 5 m air-cushion pallet with an SWL of 15 tonnes, which glides over an anti-static epoxy-coated floor. High-cleanliness absorbers line the ceiling, floor and doors, and state-of-the-art fire detection and suppression systems ensure a safe testing environment for the priceless flight-model satellites.

To achieve the best possible electromagnetic screening performance, the whole chamber (which is a Faraday cage) has been insulated from its supporting structure by means of high-mechanical-strength epoxy isolators and connected to a dedicated clean-earth grounding system. The latter was specially built by sinking a 150 m deep pit in the ground outside the building. A 100 m-long copper electrode was then inserted into this pit (achieving just a 0.2 ohm resistance). Last but not least, an over-voltage protection system was instwalled between the grounding facility and the building to provide lightning protection.

To provide access for signal cables between the test chamber and the integration area, EGSE (Electrical Ground Support Equipment) and control rooms, feedthrough panels have been installed in the walls. Blank panels can easily be machined and fitted with appropriate feedthrough connectors, according to customer requirements, and installed before a particular test is carried out.

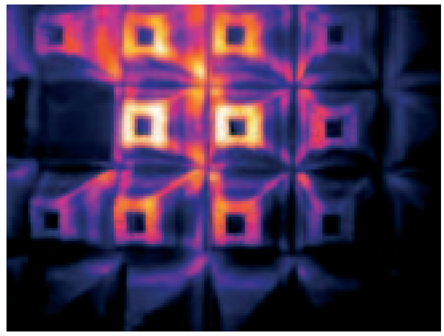
The radio-frequency absorbers on the walls of the chamber are of paramount importance in terms of the chamber's final performance, as their role is to prevent radio-frequency waves from reflecting on the Faraday screening and thereby to

Fire-resistance testing of the carbon-loaded foam pyramids at TNO in Delft (NL)


One of the many fire-extinguisher nozzles in the new chamber

simulate an infinite environment around the spacecraft. The fire-retardant, resistive carbon-loaded foam pyramids (meeting clean-room class-100 000 conditions) are mounted on supporting rails on the walls and glued to the ceiling and doors. The absorbers are manufactured using Nomex substrate honeycomb panels, providing air-circulation channels within their structure for improved cooling. When high-power tests are performed, an additional forced air-cooling system can be turned on for local areas. This system injects compressed air into the tips and edges of the absorbers to increase the dissipation capabilities of the cones.

During such high-power tests, the temperature of the walls can be monitored in real time using an infrared camera and displayed on monitors in the control and EGSE rooms. High-sensitivity detectors provide an early warning to the ESTEC central security desk should any two of the sensors reach their first alarm level. At the second threshold, the chamber's doors will close automatically, and after 30 seconds a fire-extinguishing gas (Inergen) will be released into the chamber through 15 nozzles located on the sidewalls and ceiling, reducing the oxygen level to less than 12% within 2 minutes and sustaining that level for over 20 minutes.

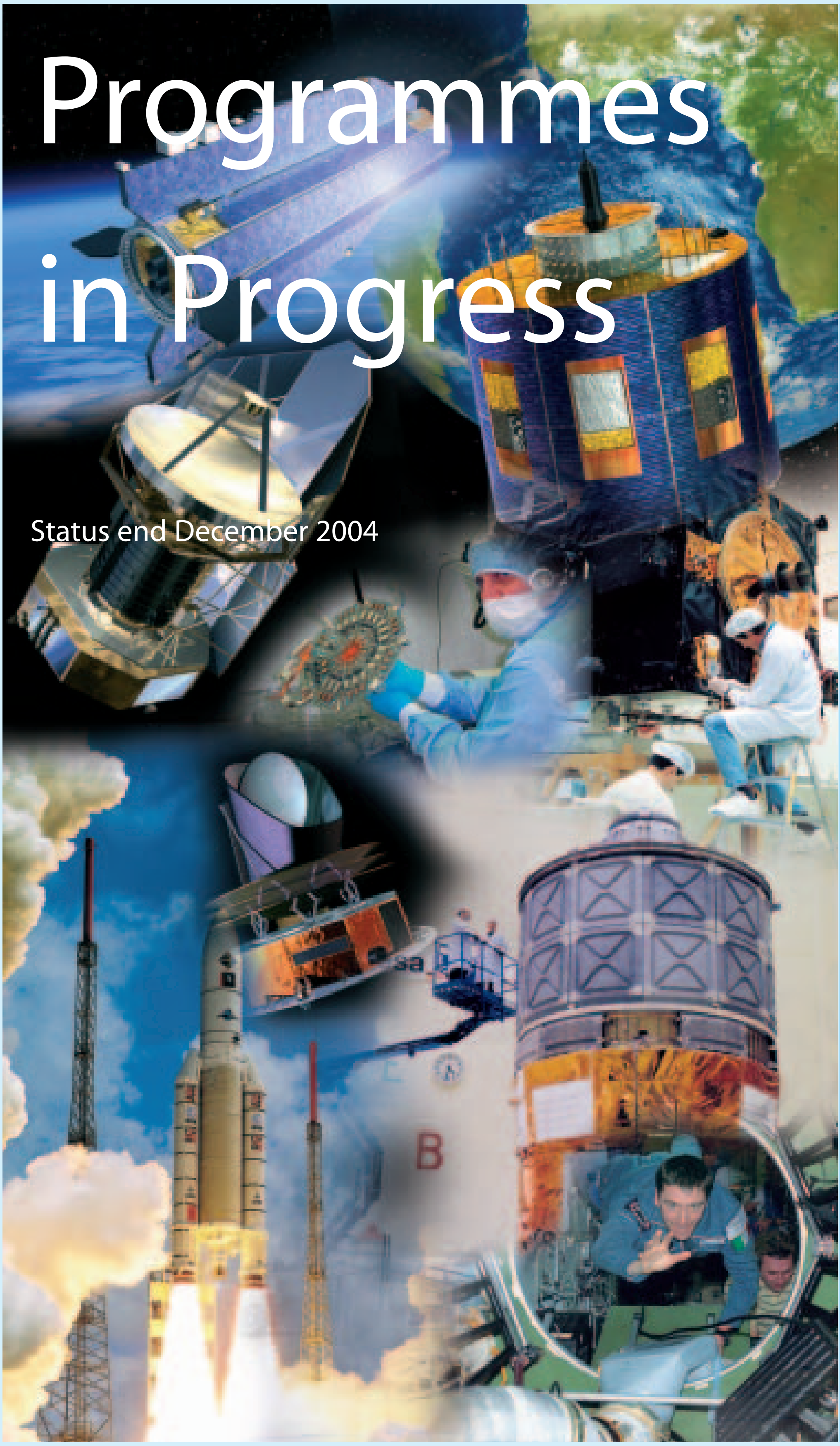

Thermal imaging of the new chamber's high-power-dissipation absorber cones during a power-dissipation test

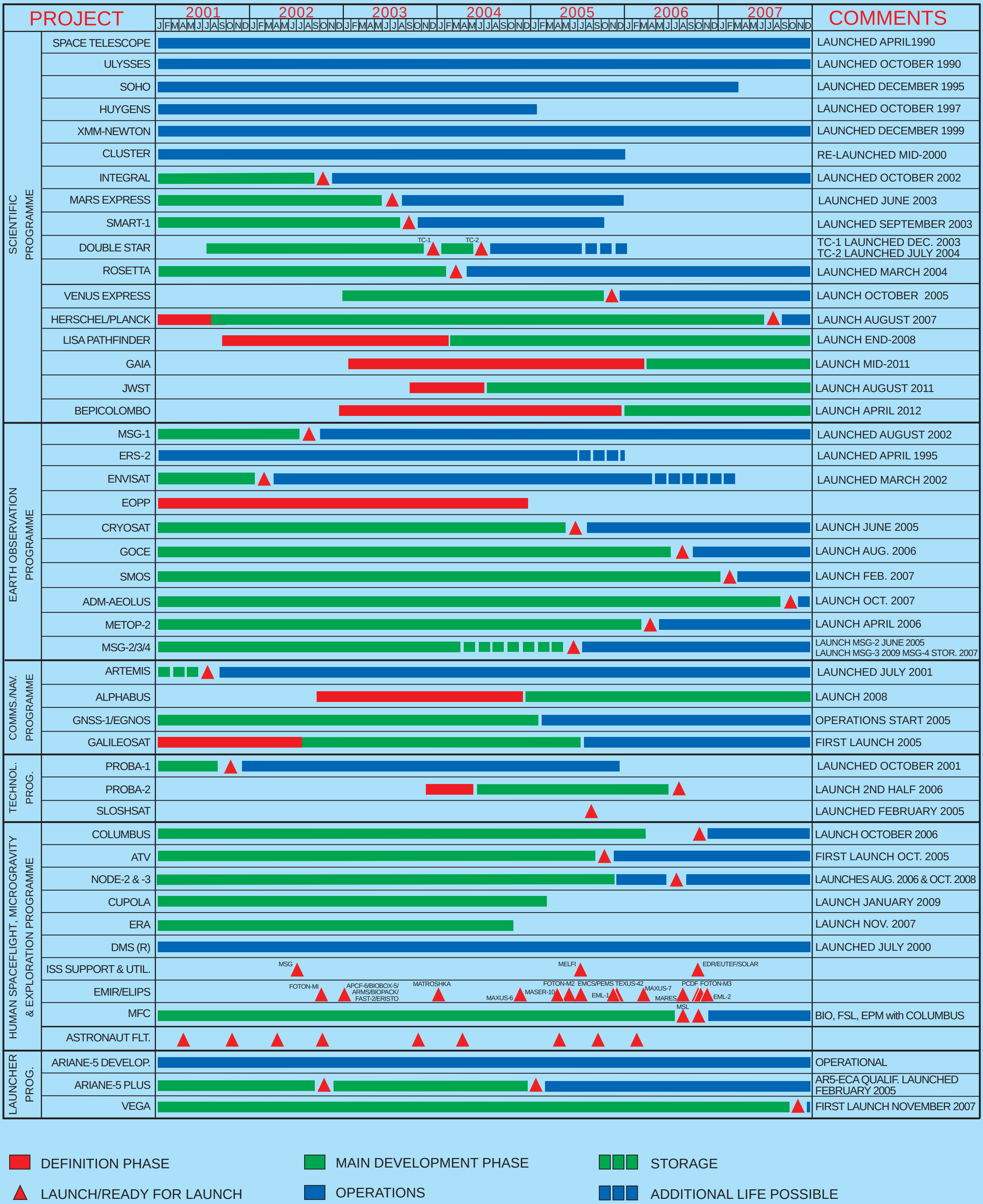
Conclusion

With the completion and inauguration of the Maxwell facility, ESA/ESTEC has complemented its unique suite of environmental test facilities – thermal vacuum (LSS), acoustic (LEAF), and mechanical vibration (Hydra) – with a state-of-the art EMC facility, thereby catering for all of the qualification test needs for Ariane-5 single-passenger-class payloads. The first major customer to use the new EMC facility, in Autumn 2004, was the first flight model of the European Automated Transfer Vehicle (ATV), called 'Jules Verne'.

Programmes in Progress

Status end December 2004




PROJECT
2001 2002 2003 2004 2005 2006 2007
J F M A M J J A S O N D
COMMENTS
SCIENTIFIC PROGRAMME
SPACE TELESCOPE LAUNCHED APRIL1990
ULYSSES LAUNCHED OCTOBER 1990
SOHO LAUNCHED DECEMBER 1995
HUYGENS LAUNCHED OCTOBER 1997
XMM-NEWTON LAUNCHED DECEMBER 1999
CLUSTER RE-LAUNCHED MID-2000
INTEGRAL LAUNCHED OCTOBER 2002
MARS EXPRESS LAUNCHED JUNE 2003
SMART-1 LAUNCHED SEPTEMBER 2003
DOUBLE STAR TC-1 TC-2 TC-1 LAUNCHED DEC. 2003 TC-2 LAUNCHED JULY 2004
ROSETTA LAUNCHED MARCH 2004
VENUS EXPRESS LAUNCH OCTOBER 2005
HERSCHEL/PLANCK LAUNCH AUGUST 2007
LISA PATHFINDER LAUNCH END-2008
GAIA LAUNCH MID-2011
JWST LAUNCH AUGUST 2011
BEPICOLOMBO LAUNCH APRIL 2012
EARTH OBSERVATION PROGRAMME
MSG-1 LAUNCHED AUGUST 2002
ERS-2 LAUNCHED APRIL 1995
ENVISAT LAUNCHED MARCH 2002
EOPP
CRYOSAT LAUNCH JUNE 2005
GOCE LAUNCH AUG. 2006
SMOS LAUNCH FEB. 2007
ADM-AEOLUS LAUNCH OCT. 2007
METOP-2 LAUNCH APRIL 2006
MSG-2/3/4 LAUNCH MSG-2 JUNE 2005 LAUNCH MSG-3 2009 MSG-4 STOR. 2007
COMMS./NAV. PROGRAMME
ARTEMIS LAUNCHED JULY 2001
ALPHABUS LAUNCH 2008
GNSS-1/EGNOS OPERATIONS START 2005
GALILEOSAT FIRST LAUNCH 2005
TECHNOL. PROG.
PROBA-1 LAUNCHED OCTOBER 2001
PROBA-2 LAUNCH 2ND HALF 2006
SLOSHSAT LAUNCHED FEBRUARY 2005
HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME
COLUMBUS LAUNCH OCTOBER 2006
ATV FIRST LAUNCH OCT. 2005
NODE-2 & -3 LAUNCHES AUG. 2006 & OCT. 2008
CUPOLA LAUNCH JANUARY 2009
ERA LAUNCH NOV. 2007
DMS (R) LAUNCHED JULY 2000
ISS SUPPORT & UTIL. MSG MELFI EDR/EUTEF/SOLAR
EMIR/ELIPS FOTON-M1 APCF-6/BIOBOX-5/ ARMS/BIOPACK/ FAST-2/ERISTO MATROSHKA MAXUS-6 MASER-10 FOTON-M2 EMCS/PEMS TEXUS-42 EML-1 MAXUS-7 MARES PCDF FOTON-M3 EML-2
MFC MSL BIO, FSL, EPM with COLUMBUS
ASTRONAUT FLT.
LAUNCHER PROG.
ARIANE-5 DEVELOP. OPERATIONAL
ARIANE-5 PLUS AR5-ECA QUALIF. LAUNCHED FEBRUARY 2005
VEGA FIRST LAUNCH NOVEMBER 2007
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
STORAGE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE

Hubble Space Telescope

From an operational point of view, the Hubble spacecraft is operating nominally, with the exception of the Space Telescope Imaging Spectrograph (STIS), one of the five onboard science instruments, which failed on 3 August 2004. However, following a focus adjustment on 22 December, analysis of data taken shortly before and after the adjustment shows a change in the point-spread function ellipticity pattern consistent with the return to nominal focus.

Operation of the Advanced Camera for Surveys (ACS) was 'suspended' on 28 December due to a reset on the main electronics board. This was the first time since ACS installation that this had happened and analysis suggested that it was due to a particle impact during HST's passage through the South-Atlantic Anomaly. The computer was reset on 30 December and the ACS returned to normal operation and resumed its planned observing schedule.

In case HST needs to be operated with only two gyros before a refurbishment mission can take place, development work on the 'two-gyro science mode' has continued. Detailed simulations show that the impact of jitter on image quality is substantially less than originally assumed, so that a 'voluntary' entry into two-gyro mode is now being discussed to preserve the lifetime of the four gyros currently operating. The first in-orbit tests without instrument involvement were carried out in November and December 2004.

The Cycle-14 Call for Proposals was issued in mid-October, with a deadline for the submission of Phase-I information by 21 January 2005.

HST's near-infrared vision is hot on the trail of a possible planetary companion to a relatively bright young brown dwarf located 225 light-years away in the southern constellation Hydra. It is thought that the companion is a planet because it is dimmer and cooler than the brown dwarf. Because a planet beyond our Solar System has never been imaged directly, this remarkable observation required Hubble's unique abilities to follow up previous observations made by astronomers with the European Southern Observatory's Very Large Telescope (VLT) in Chile. HST's observations will test and validate that the object is indeed a planet.

ISO

The third (and final) demonstration of the Astrophysical Virtual Observatory was successfully conducted at ESAC in January. The stellar science case 'The transition from AGB stars to Planetary Nebulae' made extensive use of ISO data accessible via VO-compliant tools, in cooperation with developers. The meeting marked the transition to the EURO-VO project.

ISO continues to have a significant presence in the refereed literature, with some 130 papers published during 2004, covering all areas of astronomy. Recent highlights include the detection of methylene in the interstellar medium and the mapping of dust grains in molecular clouds, showing their destruction into clusters of Polycyclic Aromatic Hydrocarbons away from the generating star.

Ulysses

The spacecraft and its scientific payload are in good health, and data return has remained excellent (average of 97% over the 14-year mission to date, and 98.2% during the last 5 years). Because of the spacecraft's great distance from the Sun and the decreasing output from the Radioisotope Thermoelectric Generator (RTG), the general onboard thermal environment is currently well below the lower limits originally foreseen for the mission. The most critical item in this respect is the hydrazine fuel of the Reaction Control Subsystem, which must be prevented from freezing if at all possible. This places additional constraints on spacecraft operations, limiting the flexibility for assigning measurement opportunities to those experiments that are not part of the core payload.

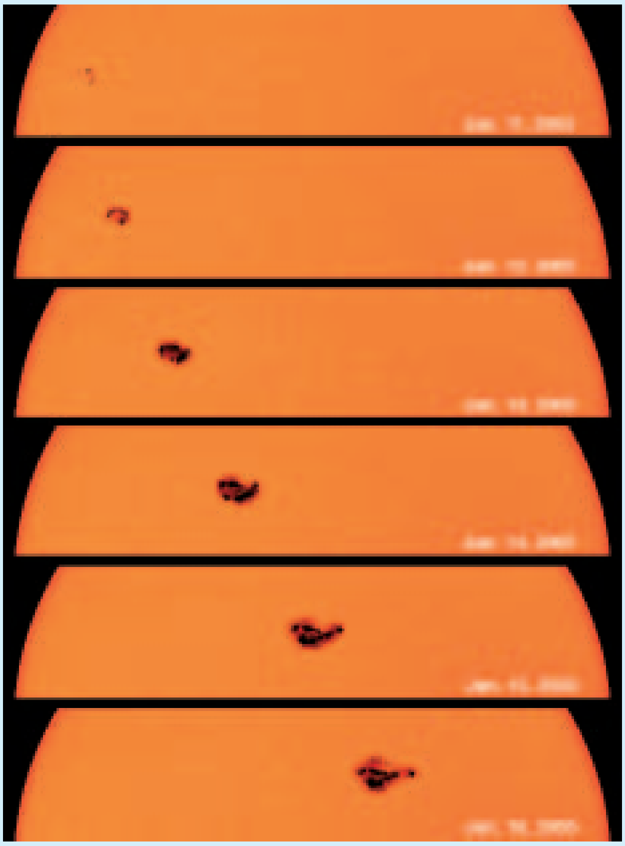
The unique perspective offered by Ulysses' orbit lends itself naturally to multi-spacecraft studies of transient solar-wind features. Good examples are the SOHO-Ulysses campaigns conducted when Ulysses is located off the limbs of the Sun as seen from Earth. Remote-sensing observations from SOHO can then be used to track disturbances leaving the Sun in the direction of Ulysses, and the in-situ measurements at Ulysses reveal the evolution of these structures as they travel outwards in the heliosphere. A prerequisite is the ability to identify the same parcel of solar-wind plasma at both locations.

During a recent SOHO-Ulysses campaign, when Ulysses was at a distance of 4.3 AU and 27 degN off the west limb of the Sun, it was possible for the first time to identify the same very hot plasma remotely at the Sun with SOHO, and in-situ at Ulysses. Four large Coronal Mass Ejections (CMEs) were observed by SOHO leaving the Sun in the general direction of Ulysses over a period of several days. By the time they reached Ulysses some 15 days later, these transients had apparently merged to form a single large solar-wind structure that drove a strong interplanetary shock. The plasma of this merged structure contained unusually large enhancements in highly ionised iron ions (charge state Fe^{16+}), indicating a high-temperature source. Such high charge states are often seen in the solar wind and have been identified with CMEs. The data from SOHO/UVCS also showed high Fe charge states, indicating very hot plasma (6-10 million degrees K) that was apparently produced high in the solar atmosphere, above 1.5 solar radii. The most likely source of such hot plasma was a reconnection event occurring in post-flare magnetic loops.

SOHO

Big bang from a very productive region

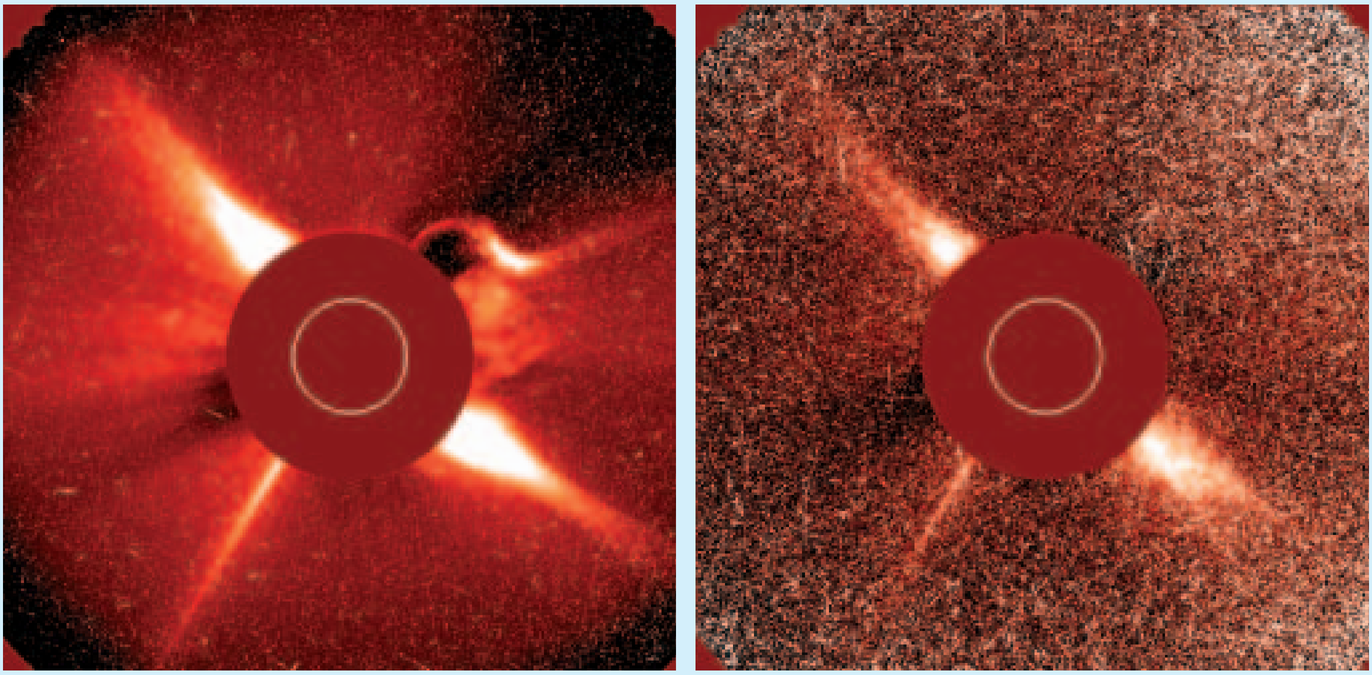
Region NOAA 10720 has turned out to be one of the most actively flaring regions of the last few years, with 15 M-class and 5 X-class events occurring since mid-January. The biggest flare so far occurred early on 20 January, an X7.1 that peaked at 7UT (2 am EST).



SOHO/MDI image of the growth of active region NOAA 10720 from 11 to 16 January 2005

Even before the flare's peak, energetic protons were pummeling SOHO as well as other spacecraft. The particles showed up as a 'snow storm' in the LASCO and EIT images as they hit the detectors and deposited part of their energy. The SOHO spacecraft experienced minor glitches that could be fixed by ground controllers, thanks to a clever software upgrade that was performed in 1999. Without this upgrade, SOHO would have been thrown into a spacecraft emergency mode due to the loss of its guide star. With the improved software, several stars are tracked at the same time and losing the primary one is therefore not a major problem, as long as there are more stars left to track. During the first few hours of the storm, four stars were lost. Two of SOHO's instruments, CDS and UVCS, were manually put into safe mode by turning down high voltages, to avoid negative effects from the bombardment.

This particular radiation storm was especially interesting because of the influx of high-energy protons (>100 MeV). In fact, according to a NOAA-SEC report it was the strongest storm since October 1989. A rare, strong Ground-Level Event (GLE) was also observed. GLEs are increases in the ground-level neutrons detected by neutron monitors and are generally associated with very-high-energy protons (>500 MeV). Elevated neutrons at ground level means there are high fluxes of energetic protons near Earth. Such high-energy radiation storms can be particularly hazardous to spacecraft, and to communication, navigation, and aviation operations at high latitudes. Scientists are still debating whether the energetic particles from such events are accelerated by the flare itself, by the shock front of an associated Coronal Mass Ejection (CME), or both.



SOHO/LASCO C2 images taken just before and just after the peak of the flare, showing a Coronal Mass Ejection (CME) associated with it. In the second image, the CME is already totally obscured by the proton shower

XMM-Newton

XMM-Newton operations continue to run smoothly. The XMM-Newton ground stations were used to support the launch of Helios, and SMART-1's orbit-insertion manoeuvres at the Moon. This involved the loss of some 40 hours of science time. The upgrading of the overall ground segment from SCOS-1b to SCOS-2000 is continuing. Recently, commands were successfully sent to the spacecraft using the new SCOS-2000 system, which is expected to be fully operational by 1 April 2005.

The status of the observing programmes is currently as follows:
- AO-2 programme: 99.8% complete
- AO-3 programme: 84.8% complete.

Completion of the above programmes is expected by March 2005, commensurate with the planned start of AO-4 observations. Currently, over 3771 observation sequences have been executed and the data for 3680 of these have already been shipped. The XMM-Newton Fourth Announcement of Opportunity (AO-4) closed on 8 October. A total of 657 valid proposals were submitted, requesting 101 747 ksec of science time, which amounts to a seven-fold oversubscription. Proposals were received from 484 different Principal Investigators from 23 countries – mostly ESA Member States, the United States and Japan. The number of countries involved increases to 35 when co-investigators are also taken into account. About 1600 individual scientists were involved in the response to AO-4.

Version 6.1.0 of the XMM-Newton Science Analysis System (SAS) was released on 24 November. The new version offers various improvements, among the most important of which are the background-modelling capability for the reflection-grating spectrometers and major changes to the OM grism data processing with the aim of making it more user-friendly. Version SAS 6.1.0 was downloaded no less than 120 times during the first week following its release.

The XMM-Newton Science Archive (XSA) has some 1300 registered users. In October 2004, a total of about 980 separate data sets were downloaded by 30 users, whilst November showed exceptionally high usage with about 5500 downloads.

A total of 719 papers based either completely or in part on XMM-Newton observations had been published in the refereed literature by the end of December 2004, 306 of them in 2004 alone.

Cluster

The four spacecraft and their instruments are operating well. An anomaly has been observed in one of the CIS (ion) detectors on spacecraft 2, and further investigations are in progress. An onboard computer on spacecraft 4 switched from main to redundant mode on 18 October, and there was a similar switchover on 31 October on spacecraft 3, probably due to computer-memory errors caused by energetic particles. Both spacecraft and their payloads were successfully reconfigured a few days later.

JSOC and ESOC operations are continuing nominally. During the September - December period, the usual automatic-gain-control fluctuations due to ionospheric disturbances were observed. When these fluctuations are too strong, the dumping of data is interrupted and the spacecraft switch to recording mode. The data return from September to December was still above 98.8%.

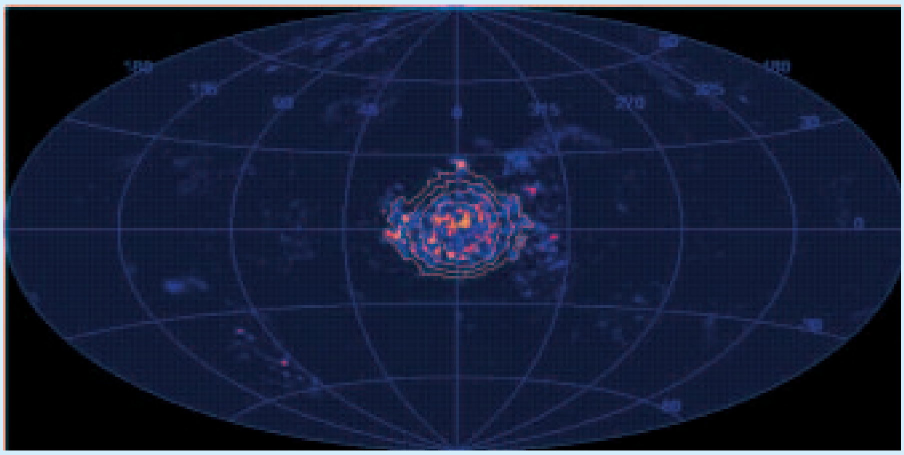
A proposal to extend the Cluster mission for four years, with a mid-term review to check the status of the spacecraft, is being prepared for the February 2005 meeting of ESA's Science Programme Committee (SPC).

Solar-wind discontinuities have been studied with Cluster. It has been shown that Minimum Variance Analysis (MVA), a widely used data-analysis technique with one spacecraft, is much less reliable than previously thought for determining the type of interplanetary discontinuities. In addition, the classification between tangential and rotational discontinuities could be revisited and gave different results from previous studies with single-spacecraft methods.

An ISSI book compiling all results obtained by Cluster on the dayside boundaries of the magnetosphere is in the final stages of editing. It contains chapters on the bow shock, magnetopause and cusp, and presents the crucial advantages of having four spacecraft operating simultaneously compared to previous single- or two-spacecraft missions.

Integral

The spectrometer (SPI) has generated its first all-sky map of the emission produced when electrons and their anti-matter equivalents, positrons, meet and annihilate one another. This process produces gamma-ray line



The SPI all-sky map of the 511 keV emission resulting from the annihilation of electrons and positrons. This map, in galactic coordinates, shows that the emission is, so far, only seen towards the centre of our Galaxy (Credit: J. Knödlseder and SPI team) emission with an energy of 511 keV. The exact energy, shape, and width of this feature provide information about the medium in which the annihilation is occurring, and the emission's distribution on the sky provides clues to the source, or sources, of the anti-matter – one of the mysteries that Integral is hoping to solve.

The latest SPI results show that the emission is, so far, only seen towards the centre of our Galaxy (the galactic bulge). J. Knödlseder and co-workers show that the sky distribution is consistent with galactic bulge or halo distributions, the combination of a bulge and a disc component, or the combination of a number of point sources. Such distributions are expected if the anti-matter is created in either X-ray binaries, novae, Type Ia supernovae or, even more excitingly, light Dark Matter. The detailed spectral shape of this feature was obtained from ultra-deep exposures of the galactic-centre region. E. Churazov and co-workers report that the line has an energy of 510.954 ± 0.075 keV and a width of 2.37 ± 0.25 keV. These are the most precise measurements of this feature ever obtained, and they indicate that the annihilation mainly occurs in an interstellar region with a temperature greater than 7000K. The next step is to combine the spectral and spatial information in order to better understand the distribution of the positron sources and how the positrons are transported in the Galaxy.

Mars Express

The last quarter of 2004 was a very productive period of science data-taking, except for a one week in early December, during which an anomaly with the solid-state mass memory prevented nominal operations, and some antenna problems towards the end of December. The memory anomaly can probably be fixed with a software patch.

Early 2005 saw a repeat, twice within a few days, of an anomaly in the Solar Array Drive Electronics (SADE), with reporting of a solar-array movement not in line with that commanded.

The planning of science observations for the 2005 eclipse season (starting in January) requires continuous trade-offs to be made between the power margins required and science observations requested. The first eclipses of the 2005 season show thermal and power behaviours fully in line with expectations.

Reports on MARSIS boom-deployment behaviour have been received from JPL and Astrium. An independent team of experts is evaluating them and a first review meeting has been planned. A decision regarding the deployment, and its possible date, should follow soon afterwards.

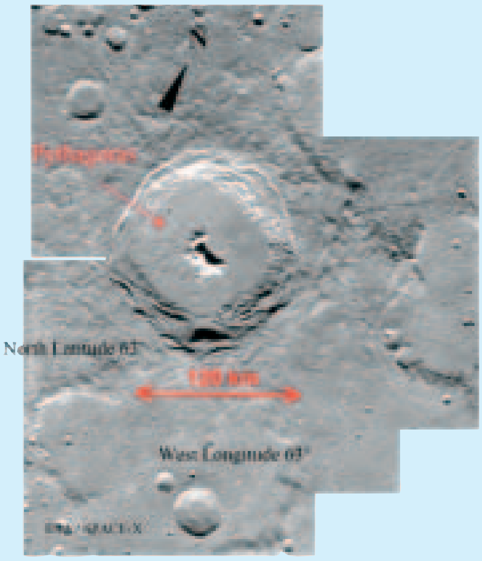
Some 300 abstracts were received in response to the call for papers for the dedicated Mars Express Science Conference, which will take place at ESTEC in the week of 21-25 February 2005.

A paper was published in Nature on a study of the time-stratigraphic relationships of volcanic and glacial structures on Mars in unprecedented detail. This provides insight into the geological evolution of Mars. It is shown that calderas on five major volcanoes on Mars have undergone repeated activation and resurfacing during the last twenty percent of Martian history, with phases of activity as young as two million years, suggesting that the volcanoes are potentially still active today. Glacial deposits at the base of the Olympus Mons escarpment show evidence for repeated phases of activity as recently as about four million years ago. Morphological evidence shows that snow and ice deposition on the Olympus construct at elevations of more than 7000 metres led to episodes of glacial activity at this height. Even today, water ice protected by an insulating layer of dust may be present at high altitude on Olympus Mons.

SMART-1

SMART-1 was inserted into lunar orbit on 15 November, after a month of free flight passing from Earth-gravity-dominated space into the Moon's sphere of influence. The Electric Propulsion (EP) system was then turned on again to lower initial lunar orbit towards the target operational polar orbit. This spiralling down was briefly interrupted for a few days at the end of 2004/beginning of 2005 to permit observation of the lunar surface.

On 11 January, when the orbit was roughly 1000 km x 5000 km, the EP thrust was again interrupted, for about three weeks, in order to make use of the very good illumination conditions and the spacecraft's already relatively low altitude to perform substantial mapping of the lunar surface on both the near and far sides. After the resumption of EP thrusting in early February, the final lunar orbit at about 300 km x 3000 km altitude is expected to be reached in about 15 days. All of the payload instruments will then be commissioned for the lunar phase and the main science phase will start. The nominal lunar science phase will end in July 2005, to be followed, if approved by the ESA Science Programme Committee (SPC), by a one-year extension.



The 120 km-diameter lunar crater 'Pythagoras' photographed by SMART-1's AMIE instrument. The two images used in this mosaic were taken from a distance of 4000 km on 29 and 30 December 2004. The crater's terraced walls are 5000 metres high (Copyright ESA/SPACE-X, Space Exploration Institute)

Double Star

During the largest geomagnetic storm of 2004, the redundant attitude-control computer failed on the TC-1 spacecraft. Now both spacecraft have non-functioning attitude computers, with the consequence that there is no attitude control. Fortunately, both spacecraft are spinning at 15 rpm and are therefore stable. A slow drifting of their spin axes is observed: about 0.9 deg per month on TC-1 and 1.5 deg per month on TC-2. This means that it should not cause any problems before the end of nominal mission lifetime (31 July 2005). In addition, initial computations from China show that the drift of TC-1 will reverse in a few months and go back towards post-launch attitude. An investigation is on-going to find the source of the problem. Memory-chip failure seems to be the most likely cause. Attitude information can be derived from the magnetometer data at perigee, and the routine processing of the latter has started.

The European instruments are operating nominally. Resets on PEACE (electron sensor) are still occurring, some of which are related to the Sun pulse not being provided at regular intervals to the instrument. Investigation continues with the Chinese. Work-around solutions are being used, such as manual resets of the instrument and switch-offs inside radiation belts. Other instruments are not sensitive to this problem and are working normally.

The European Payload Operations System (EPOS) coordinates the operations for the seven European instruments on TC-1 and TC-2, and is running smoothly. A few problems are still occurring with the ground stations, but the data return has improved, especially since avoiding periods of antenna interference on TC-2. The return in November for the TC-1 magnetometer was more than 94%.

The Double Star Workshop held on 8-10 November 2004 was a great success and the complementarity of the Cluster and Double Star missions was clearly apparent. Many new results were presented, a few highlights being:

- the magnetic reconnection observed by both Double Star TC-1 and Cluster at the magnetopause,
- flux-transfer events observed by Double Star that produce plasma injections observed simultaneously by Cluster
- deceleration of solar-wind ions at the bow shock by a charge-separation electric field, and
- oxygen ionospheric ions observed more often closer to the Earth than further down the tail.

Rosetta

With the successful completion of spacecraft and payload commissioning, the management of the Rosetta mission has been transferred from the Project Department to the Research and Scientific Support Department. The Second Mission Commissioning Results Review was successfully completed on 3 December, with the Review Board meeting at ESOC (D). All spacecraft and payload-commissioning objectives were met. One exception was the Interference Campaign, which could not be completed because the ROSINA instrument was experiencing software problems. The necessary software upgrades are being prepared and it is planned to repeat the campaign at the end of 2006, before the Mars flyby. Since 17 October, i.e. since completion of the last phase of the payload-commissioning activities, the spacecraft has been in ‘quiet cruise mode’.

The SREM (Standard Radiation Monitor) will be switched back on in mid-January 2005 and will be kept active for background-monitoring operations. All other instruments will remain inactive. However, limited payload activities will resume at the end of January with the uploading of software for OSIRIS, followed by delta-commissioning activities for ROSINA.

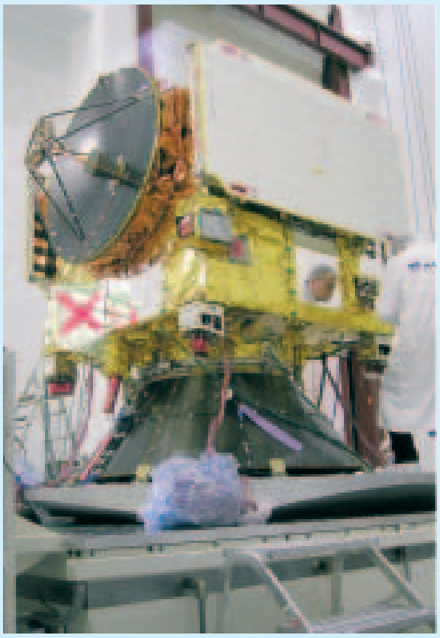
Preparations for the first Earth swingby have started, with Rosetta due to pass within 1900 km of the Earth at 22:00 UTC on 4 March 2005. The Rosetta Science Operations Centre has taken full responsibility for the first time for preparing the science operations for a specific mission scenario, namely the Pointing and Interference Scenario, involving the first joint operations of the full science-payload instrument complement.

ESA’s Planetary Science Data Archive has been fully implemented and the first data sets from the ground-based comet-observation campaigns have been ingested.

Venus Express

The project continues to progress according to plan, with the spacecraft successfully completing Integrated System Testing activities and starting the environmental test campaign in the integration facilities at Intespace in Toulouse (F). The spacecraft has also successfully passed two command and data compatibility tests with the ESOC Mission Operations Centre in Darmstadt (D), thereby demonstrating its functionality within the overall Venus Express mission system.

The Venus Express ground segment is progressing well, with all elements in full development. The new ESA station at Cebreros, Spain, which will be the Venus Express operations station, is advancing well.



The Venus Express spacecraft mounted on the vibration table at Intespace in Toulouse (F)

Mounting of the antenna dish at ESA's Cebreros deep-space ground station in Spain

The launch of Venus Express has been confirmed for 26 October 2005 from the Baikonur Cosmodrome in Kazakhstan. A 1270 kg launch mass for the combined spacecraft and adaptor has also been agreed.

Herschel/Planck

The integration and testing of the electrical (avionics) model of the Planck Service Module is making good progress. The flight model of the Service Module structure has been delivered and integration of the propulsion subsystem is ongoing. The qualification model of the Planck Payload Module, fully integrated with instrument structural models and the qualification-model Planck reflectors, has successfully completed the acoustic-noise test.

With the delivery of the last hardware elements for Herschel by the end of 2004, integration of the flight model has gained momentum, starting with the two helium tanks, the insulation shields and the cryostat outer vessel. The Critical Design Review (CDR) for the system and for the Service Module has been completed, with the Board meeting in mid-October. The overall development schedule, which takes into account the actual status of the hardware production and delivery, now shows a launch date of August 2007.

Development of the Herschel telescope is also making good progress. The primary mirror is at Opteon in Finland, where its surface polishing is nearly complete. A qualification review held in preparation for the upcoming Herschel telescope qualification testing in 2005 revealed no major issues.

The hardware development of the Planck reflectors is nearly complete, with the primary-reflector flight-model assembly and coating completed by end-2004. The optical testing of the reflectors and the telescope under the cryogenic operating conditions is still proving extremely difficult. A revised test programme has been established that will be followed for the flight model.

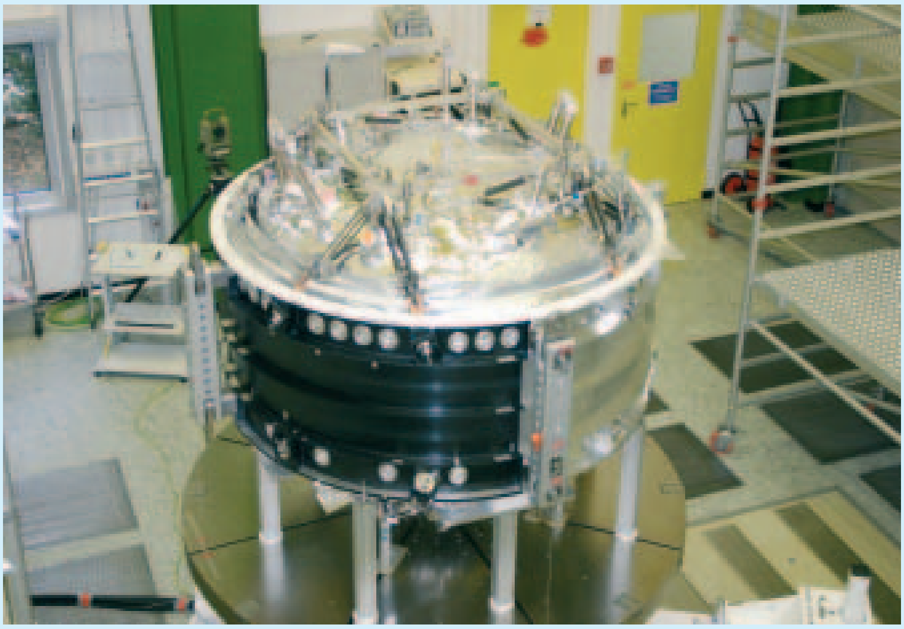
The qualification models of the Herschel scientific instruments have successfully completed their functional and performance testing and have been delivered to industry for integration into the test cryostat. Also, the Planck HFI qualification-model instrument has been delivered to Alcatel for integration with a LFI dummy and into the Planck Payload Module qualification model.

SMART-2/LISA Pathfinder

The work of the SMART-2/LISA Pathfinder Implementation Phase is in progress. However, a slowdown in activities has been required to phase them with the delayed main payload, and the LISA Technology Package (LTP) consortium start up. The main activity recently has been closure of the actions assigned by the ESA System Requirements Review. A successful Close-out Review was performed in early November. The Board concluded that, despite few remaining critical issues regarding the spacecraft architecture, such as the mass margin and the overall performance budget not being completely resolved, the project can proceed until the Preliminary Design Review (PDR), when these issues will be reviewed again.

The Review also evaluated the status of the LTP system requirements, produced by Astrium GmbH on the basis of the scientific requirements set by the Principal Investigator (Prof. Vitale from Trento University), the Co-PI (Prof. Danzmann from A. Einstein Institüt in Hannover) and ESA. They now form the basis for the contract that ESA is to award to Astrium GmbH for the ESA contribution to the LTP. A third element that was reviewed was the American equivalent of the LTP, called the Disturbance Reduction System (DRS), also accommodated on LISA Pathfinder.

The LTP development is taking longer than initially foreseen, mainly due to some critical



The proto-flight model of the Herschel Cryosat Vacuum Vessel undergoing assembly and testing at Astrium in Friedrichshafen (D) items, like the caging mechanisms of the inertial sensor assembly, which are driving the overall schedule. This implies a late start to the assembly, integration and test (AIT) activities at spacecraft level, which in turn produces an overall project slippage. The extent of this delay is currently being evaluated.

Gaia

The two competitive engineering studies continue in industry. The general work on spacecraft design has been finished and the two consortia have entered into a phase of design optimisation to ensure that the final design is compatible with the available resources.

As regards the technology-development activities, a major achievement was the handing over of the primary mirror from the production company to the contractor performing coating and polishing.

On the launcher side, a contract has been placed with Starsem to optimise the launch scenario with a view to providing an increased launch mass for Gaia.

A major Scientific Symposium on 'The Three-Dimensional Universe with Gaia' took place in Meudon, Paris (F) in early October 2004. About 240 scientists attended the event.

James Webb Space Telescope (JWST)

Several JWST key activities have been delayed three months due to NASA funding problems in 2005. This includes the overall assembly, integration and validation flow for the Payload Module Engineering Test Unit, the NIRCam and the production of primary flight mirrors. Sufficient contingency remains to avoid an impact on the launch date according to NASA. The deliveries to ESA for NIRSpec and MIRI have not been directly affected.

The remaining System Requirement Reviews were completed successfully, including those for the Ground Segment and the MIRI Dewar.

NIRSpec

Delayed agreement with NASA on main instrument interfaces (envelope and interface locations) has delayed the schedule by several months. This has been absorbed by a later need date for the Engineering Test Model. An assessment of schedule recovery for the flight model is in progress. The procurement process for the subsystems has started. Invitation to Tender (ITT) packages for the first three procurements are ready and under review by ESA.

MIRI

The MIRI Optical Module Preliminary Design Review (PDR) has been successfully completed. Some analyses and internal assembly specifications need to be consolidated. A course of action has been agreed to close-out all open issues in advance of the MIRI System PDR in March 2005. The MIRI Dewar System Requirements Review (SRR) was successfully concluded between JPL and Lockheed Martin (Dewar prime contractor), thereby consolidating the overall Dewar schedule. The Dewar has been allocated an additional 92 kg and is now compatible with the MIRI lifetime requirement of 5 years. The first hybridized detector assemblies are now being tested for integrity at JPL.

Artemis

The satellite continues to provide its planned data-relay, land-mobile and navigation services with high quality.

Envisat makes use of up to 15 Ka-band communication links per day via Artemis and relies on it for over 50% of its data acquisition. This heavy-duty scenario has been in operation for more than six months and has proved the value of data relay for providing a high volume of data and real-time scene acquisition. Spot-4 also uses up to two Artemis optical data links per day, and both users have expressed satisfaction with the service. Since the start of Artemis operations in 2003, Envisat has accumulated over 4900 links or a total of 2300 hours, and Spot-4 has achieved some 750 links or 135 hours in total.

Several hundred additional optical and RF links have been made via Artemis in connection with the evlauation of system performance and interface characteristics for future users.

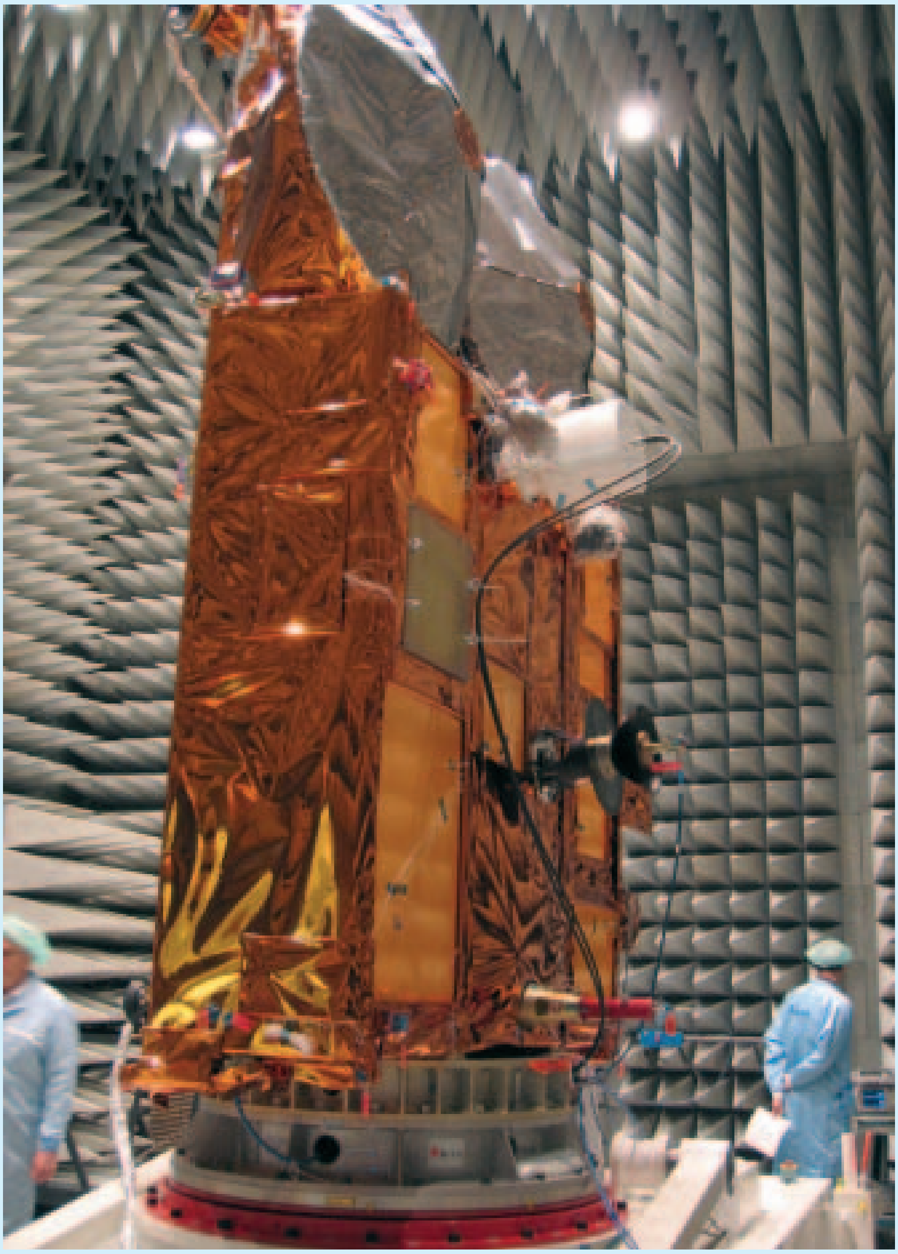
Land-mobile applications have exhibited a steady growth of applications, and a small increase in bandwidth was requested by ESA for 2005 at the annual mobile operators' meeting in December. This submission was successful and the payload has now been reconfigured to accommodate the new users. Service provision to Telespazio and Eutelsat has continued without interruption.

EGNOS has made regular use of the Artemis navigation payload via its two earth stations, at Scanzano and Torrejon, in preparation for the operational phase.

System validation tests in preparation for Artemis support to the ATV mission have been successfully executed and pre-launch compatibility tests with JAXA's OICETS are underway. These missions will be followed by EADS-Astrium's LOLA (a demonstration mission for optical communication between a UAV and Artemis) and CIRA's USV (the first flight of an unmanned re-entry vehicle). User scenarios with three optical users and five RF users are then possible, which represents a significant utilisation of the overall Artemis data-relay capacity.

CryoSat

The testing activities being performed by the prime contractor, EADS Astrium GmbH (D), on the CryoSat spacecraft have made significant progress at IABG (Ottobrunn). The repair actions related to some deficient electronic components have taken longer than anticipated however, causing delays in the programme. The spacecraft is now fully re-integrated and nominal testing has resumed.



The CryoSat satellite ready for the start of electromagnetic-compatability testing at the IABG facility in Ottobrunn (D)

On the payload side, after its arrival at IABG, the electronics of the SIRAL altimeter developed by Alcatel (F) have been mated with the double antenna manufactured by Saab (S), and successfully tested. The integration on the spacecraft has taken place in a timely manner and the altimeter's performance figures are nominal. Following this test, the CryoSat satellite has been moved to a dedicated IABG facility to undergo a first series of electromagnetic-compatibility tests.

Activities related to the CryoSat ground segment are progressing according to plan.

The second part of the second Satellite Validation Test (SVT-1b) was performed successfully by ESOC in November. The ground-segment validation campaign is progressing well.

Overall, significant progress in the development of the CryoSat mission has been made in the past months. Unfortunately, a few repair activities, due mainly to quality problems reported lately on some electronic parts, have hampered progress. Consequently, the launch has now been re-scheduled to late-June 2005.

GOCE

The GOCE space-segment development activities are progressing steadily, and several equipment-level Critical Design Reviews (CDRs) for platform and payload units have been carried out as planned.

For the Gradiometer, Alcatel Space has successfully completed the thermal and mechanical testing of the structural thermal model. Their activities are presently focussing on the electrical integration and testing of the engineering model. A stiffness anomaly discovered in three Accelerometer Sensor Head flight models integrated at Onera is currently under investigation by a team composed of representatives from industry and ESA.

In the platform area, the refurbishment of the satellite structural-model primary structure has been completed by CASA. The structure was delivered to Astrium GmbH in November, allowing the timely commencement of the platform flight-model integration activities, starting with the installation of the electrical harness, the propulsion pipework and the heater lines. Astrium GmbH has also completed the electrical integration of the platform engineering-model Test Bench, and functional testing of the latter has recently started. Astrium's Platform Software Test Bed activities are advancing, using a Command Data Management Unit (CDMU) breadboard and Version 1 of the applications software.

On the solar array, experience from other missions currently under development has shown a potential reverse-current stability problem with the baselined GaAs solar cells at high temperatures. This issue is now being addressed at ESA level in an ad-hoc working group. In parallel, a test is presently running using a simulated GOCE thermal environment to assess the suitability of the baseline GaAs solar cells for the GOCE application.

GOCE Gradiometer structural thermal model's core

On the ground-segment side, a major milestone was the successful completion of the Ground Segment Design Review in November, which confirmed the completeness and consistency of the overall ground segment. Negotiations with the company selected to develop the Calibration and Monitoring Facility (CMF) and the Reference and Planning Facility (RPF) have been completed. The related activities were kicked-off in October, and a System Requirements Review was successfully held in December. In parallel, a rapid CMF prototyping programme has been established in order to give appropriate focus to the interactivity and human/machine interface aspects of the facility. The European GOCE Gravity Consortium for the Level-1 to Level-2 data processing facility (HPF) successfully completed the Architectural Design and Interface Review in October and the Acceptance Review for a prototype version of the software in December.

SMOS

Most payload-subsystem engineering models have been delivered to the prime contractor, EADS CASA (Madrid, E) and are in the process of being integrated into a reduced engineering model of the overall payload. Critical Design Reviews are being conducted for those subsystems that have been delivered, in order to release the flight-unit production.

In parallel, integration of a full structural thermal model has started with the integration of the arm segments including flight-representative mechanisms. Delivery of the central hub structure is expected in January 2005.

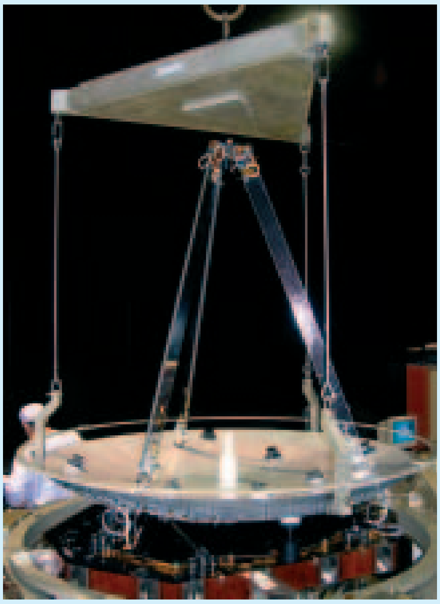
CNES and ESA, with the support of Alcatel (Cannes, F), are preparing the analyses and documentation for the satellite Preliminary Design Review (PDR) scheduled for March 2005. Formalisation of the payload-to-platform Interface Control Documents has the highest priority.

Following approval by ESA's Industrial Policy Committee (IPC), the procurement of a Russian-built Rockot launcher from Eurockot (Bremen, D) has been initiated.

The Data Processing Ground Segment design phase (Phase-B) was concluded at the end of 2004. Commencement of the implementation phase was delayed awaiting the resolution of programmatic and funding issues with the Spanish agency CDTI, which has been achieved in the meantime.

Integration of the arms for the SMOS structural model at EADS CASA

ADM-Aeolus



Optical/structural/thermal model of the ADM-Aeolus telescope being mounted on the instrument

All elements of the satellite's structural model have now been delivered, including the instrument structure, which has successfully completed vibration testing. The instrument part of the structural model will be used as an optical/structural/thermal model to verify the instrument's thermal behaviour before it is integrated with the satellite platform.

The flight models of the CCD detectors have been accepted and are being integrated into the detector front-end units. Most other flight items are making good progress.

Problems with laser pump diodes have been associated with changes to the commercial manufacturing process that were supposed to make the diodes more reliable. Flight diodes are now being manufactured using the precise methodology used for commercial diodes. They will, however, be subjected to a careful screening process after manufacture. As a back-up, assessment contracts are in place with two other prospective pump-diode suppliers.

A facility for laser-testing optical components, both clean and contaminated, in vacuum has been commissioned at DLR in Stuttgart (D), and the first results are becoming available.

The model-based Development and Verification Environment has been used to communicate, via electrical ground-support equipment, with a simulated satellite, sending both uplinked telecommands and downlinked telemetry.

The ADM-Aeolus Critical Design Review will be completed in September 2005. The current launch date of October 2007 in under threat as a result of the pump-diode problems. The project is negotiating with industry to minimise any schedule slippages.

MetOp

The integration and testing of the first MetOp satellite to be launched, MetOp-2, is well underway, with the successful completion of the mechanical test campaign (vibration, acoustic and shock) at Intespace in Toulouse (F). Notably, the second flight model of IASI – needed to replace the non-flightworthy instrument currently embarked on the MetOp-2 satellite – has been delivered on time. Activities are on track for completion of the Flight Acceptance Review in the summer. Thereafter, the satellite will be stored alongside MetOp-1, which has already been in storage from the end of 2004. MetOp-2 will then be re-activated in early 2006 for its launch campaign. Launch is now expected in the second quarter of 2006, following readiness of Eumetsat's ground segment.

Once in orbit, MetOp-2 will be termed MetOp-A, with the second satellite to be launched (nominally MetOp-1 in 2010) to be termed MetOp-B, and finally MetOp-3, nominally launched in 2014, will be termed MetOp-C.

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

Following completion of the in-orbit commissioning, the MetOp programme will nominally go into 'hibernation' until 2008, when the team will be re-activated to complete the integration of MetOp-3 and to de-store MetOp-1 and make it ready for launch.

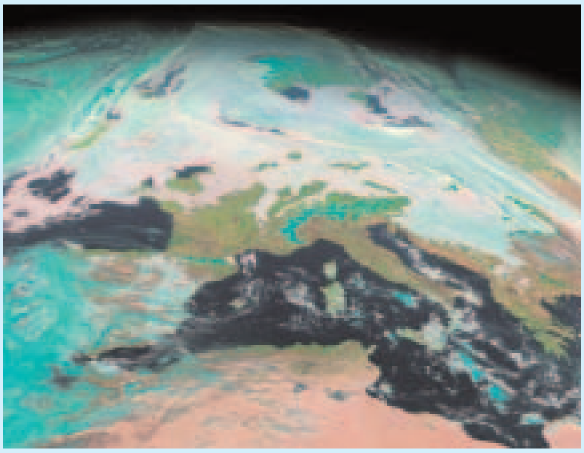
Meteosat Second Generation (MSG)

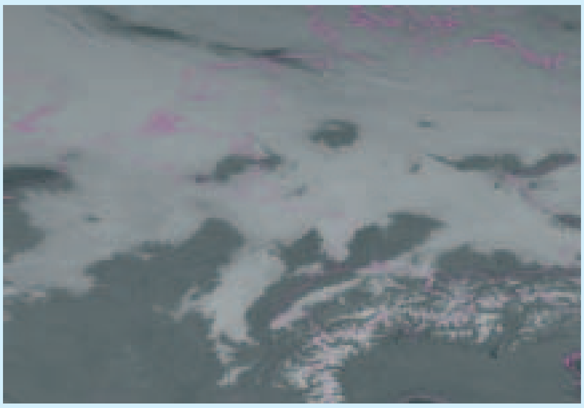
MSG-1 (Meteosat-8)
Meteosat-8 operations have been nominal, with no spacecraft behavioural anomalies. The instrument performance remains excellent, as witnessed by the beautiful images shown here and on the Eumetsat website at: www.eumetsat.de.

MSG-2
MSG-2 de-storage activities and finalisation of the open work have been completed. MSG-2 assembly, integration and test activities will resume with the preparation of the MSG-2 launch campaign, currently planned for February 2005. A launch in June 2005 with co-passenger Insat on an Ariane-5GS launcher is still to be confirmed.

MSG-3
The MSG-3 spacecraft remains in short-term-storage configuration in the Alcatel clean-room, as it will be used as 'spare box' for MSG-2 during its launch campaign. Thereafter, the MSG-3 spacecraft will be put into long-term storage, awaiting its launch date, currently foreseen in 2009.

MSG-4
Progress on the MSG-4 pre-integration activities is nominal. The UPS module has been shipped to Alcatel Space in Cannes (F), and the pre-equipped antenna platform has been delivered to Alenia Spazio. The main platform harness has been delivered, and the main platform is being finalised.





From about 4 to 14 December 2004, an anticyclonic situation over Central Europe with a strong low-level temperature inversion caused widespread fog and low-level stratus over Germany, France, the United Kingdom and many other countries. Many valleys and low-lying areas were shrouded in fog for many days, while mountain areas enjoyed sunny weather with relatively high temperatures.

The high-resolution visible (HRV) channel on Meteosat-8 is particularly useful for monitoring this kind of wintertime fog situation. It shows the presence or non-presence of fog/low stratus in the plains and valleys, the dissolution or non-dissolution of the fog during daytime, the presence of multi-layer clouds, the cloud-free mountain tops and the channelling of air flow between mountain ranges.

The RGB composite (above) shows NIR 1.6, VIS 0.8, VIS 0.6. The image over northern Europe (left) is the HRV channel (Courtesy of Eumetsat)

Human Spaceflight, Research and Applications

Highlights
Soyuz flight 9S, carrying the Expedition 10 crew, was successfully flown to the International Space Station (ISS) and docked during the night of 15-16 October. On 24 October, Soyuz 8S landed safely back on Earth, successfully concluding Increment 9. The Russian Progress flight 16P successfully docked with the ISS on 26 December, taking food and other supplies to the Station. In December, NASA confirmed that the Shuttle Return to Flight now has a planned launch window in May/June 2005.

Space infrastructure development
Columbus schedule-extension activities have been formalised with industry and disassembly of the Columbus module has started. Testing of the first NASA payload rack installed in Columbus, the Human Resource Facility, was successfully completed in October. The Test Review Board for the System Validation Test 2, and the Qualification Review 2 ESA/NASA Final Board, were successfully held in October and November, respectively.

The first mating of the Automated Transfer Vehicle (ATV-1) flight model Jules Verne has been completed at ESTEC, and the first part of the environmental test campaign, the electromagnetic-compatibility test, has been successfully completed. Functional testing continues in parallel. The System Validation Test 4B was successfully completed in December.

Manufacture and assembly activities for Node 3 are progressing. The external structure has been completed and the post-proof Non Destructive Inspection was successfully performed.

The post-shipment incoming inspection of the Cupola has been successfully performed at Kennedy Space Center (KSC).

Ownership of the European Robotic Arm (ERA) flight model was transferred to ESA in November, and the flight spares and mission preparation and training equipment are now in storage at the prime contractor's site ready for delivery to Russia. From 22 to 26 November, the Weightless Environmental Test model of ERA was tested underwater at the Gagarin Cosmonaut Training Centre.

Operations and related ground segments
The inauguration of the Columbus Control Centre (COL-CC) took place on 19 October, and its integration and final acceptance is still in progress. Acceptance reviews of several subsystems and several important interface tests with the ATV Control Centre (ATV-CC) have been conducted. A proposal for the maintenance of the Columbus ground facilities has been negotiated and agreed with Industry, and in December the COL-CC interface (part 1) to the European Astronaut Centre (EAC) was successfully tested.

Significant progress has been made in consolidating the Columbus Control Centre architecture to support both the Italian Soyuz mission, by controlling and commanding the scientific programme of the European experiments, and the Interim Utilisation Activities.

The first interface tests between the ATV-CC and the Houston Mission Control Centre, and an interface test between the ATV-CC and the Russian Service Module Simulator, have been conducted successfully.

Outfitting of the Danish and Norwegian User Support and Operations Centres (USOCs) was completed in December.

A mass-storage-device controller has failed in a ground-based DMS-R computer. The failed board has been identified and one of the two spares in the DMS-R inventory will be delivered to RSC-Energia.

The Matroshka is performing nominally and the in-orbit science operations are progressing successfully.

Utilisation planning, payload developments and peparatory missions
Preparation by the European Science Foundation of the Final Report on two Life and Physical Science User Workshops held in preparation for the ELIPS-2 programme is approaching completion.

Activities involving the European Commission (EC) continue, with the TeleMedicine Alliance-Bridge project proceeding nominally towards

The Cupola was delivered to the Kennedy Space Center on 8 October 2004 (photo NASA) the next phase. Signature of the contract for the IMPRESS Integrated Project (Material Science) took place on 22 November, the same day that the 2nd European Materials Forum, which aims at setting-up a technology platform supported by the EC, was being held at ESTEC (NL). In December, the ESA Directorates of Science, Earth Observation and Human Spaceflight, Microgravity and Exploration jointly reported on the Agency's science activities to the EC-ESA Joint Secretariat.

Out of 59 projects recommended by the Steering Committee of the International Life-Sciences Working Group in October, 20 were from Europe.

By the 12 November deadline of the Announcement of Opportunity for Life and Physical Science released in July 2004, 152 proposals had been received, 56 of which are Microgravity Application Promotion (MAP) related. The peer-selection process is under way, with the review-panel meetings planned for mid-January 2005.

Phase-2 of the last MAP continuation proposals is being implemented, and preparations for the Long Term Head-Down Tilt Bedrest study on females (WISE) are ongoing.

In October, the Test-Readiness Review for the European Drawer Rack's functional testing was successfully held, and the Science Reference Model of the Fluid-Science Laboratory was delivered to the Italian 'MARS' facility in Naples, where its Acceptance Review was completed in December.

The Cardiolab Training Model was delivered to EAC in October. In December, the Cardiolab Data Management Control Unit Ground Model 1 (GM-1) was integrated into the European Physiology Modules GM-1, whose Acceptance Review was successfully completed.

The Final Acceptance Reviews (FAR-1) for Biolab and the European Transport Carrier were successfully concluded in December.

Testing of the EuTEF external payloads and the SOLAR engineering model on the Columbus Rack Level Test Facility was successfully completed in November and December, respectively.

Agreement has been reached regarding the development of the PHARAO instrument for the Atomic Clock Ensemble in Space (ACES), up to completion of the engineering model in December 2006. The first part of the status evaluation for the Space Hydrogen Maser was completed in mid-December.

The Protein Crystallisation Diagnostics Facility flight-model Acceptance Review was started in November, and the preliminary acceptance of the engineering model was successfully completed in December.

The Muscle Atrophy Research and Exercise System (MARES) Critical Design Review (CDR) was successfully closed out at the end of November.

The Phase-B contract for the Portable Pulmonary Function System was signed in December.

Testing of the first two flight units of the MELFI –80 degC freezer at KSC has been successfully concluded. In December, flight unit 2 was accepted by ESA and JAXA and formally transferred from JAXA to NASA. The flight unit 3 activities are on hold pending resolution of the Brayton Machine problem. The Portable GloveBox development contract was signed in October and the CDR completed in December. Both the training- and flight-model deliveries are on schedule for launch with ATV-1.

The European Modular Cultivation System flight model and ground-support equipment were shipped to KSC, where the flight model's integration into EXPRESS and verification testing were completed by end-November. The 38th ESA Parabolic Flight Campaign, involving 13 experiments, was successfully performed from 18-29 October, and the 39th ESA campaign, with 12 experiments, is planned for 14-25 March 2005.

The Maxus-6 sounding-rocket flight, carrying eight experiments, was successfully launched on 22 November. Contracts for Texus-42 and Mini-Texus EML-1 were signed in December, and the Maxus-7 Phase-C/D contract is ready for signature. Maser-10 development is progressing on schedule for a launch in mid-April 2005.

FOTON-M2 payload development has been completed, and the ESA payload complement for FOTON-M3 was approved in early November.

The inauguration of a new catapult system at the ZARM Drop Tower took place in Bremen (D) on 2 December. The new system allows for vertical trajectories (rise and fall) to be performed, thereby almost doubling the free-fall time.

ISS education

On 8 December, the DELTA Researchers Schools project was officially kicked-off with signature of the Memorandum of Understanding between ESA, NASA and the Dutch Ministry of Education, Culture and Science.

A very successful ARISS radio contact between 350 Irish primary-school pupils and Expedition 10 US astronaut L. Chiao onboard the ISS, was organised in Ireland in December.

The Education products such as the DVD-1 “Newton in Space” and the ISS Education Kit, which is now available in 11 languages, are in great demand, with requests coming from numerous countries.

The third edition of the SUCCESS contest, for university-student experiments to be performed onboard the ISS, was launched on 1 December.

Commercial activities

The commercial agent selected to market the use of the European facilities and resources onboard the ISS to the biotechnology, health, food and nutrition market sectors throughout Europe, has begun work. The ISS Commercialisation review report has been finalised and the Board members approved the brand positioning of the Health Care Network.

Astronaut activities

Training for the Italian Soyuz mission at the Gagarin Cosmonaut Training Centre has continued for R. Vittori and his back-up R. Thirsk (from the Canadian Space Agency). A Payload Training Introduction for the mission was given at EAC from 29 November to 1 December, with the four astronauts/ cosmonauts Vittori, Krikalev, Turin and Thirsk attending. The Experiment Training and Baseline Data Collection Plans for the mission were agreed in December.

T. Reiter and L. Eyharts received training both at Johnson Space Center and at the Gagarin Centre for a Long-Duration Mission to the ISS by a European astronaut in late-2005/early-2006, and Christer Fuglesang continued his training for the STS-116 mission.

The COL-CC ground controllers were given ATV and Payload advanced training at EAC during October and November, and an ESA Training Academy course for about 25 ATV-CC staff was organised from 23 to 25 November in Toulouse (F).

The ATV onboard crew trainer was delivered to EAC in October.

AlphaBus

The Preliminary Design Review (PDR) in December marked the conclusion of the AlphaBus preparatory phase. In parallel, the prime contractors Astrium (F) and Alcatel (F) submitted the AlphaBus main-development-phase (Phase-C/D) proposal.

The cooperating Agencies ESA and CNES evaluated the proposal jointly, and subsequent negotiations with Industry resulted in a sound technical and contractual baseline also taking into account the recommendations of the PDR.

As a first step thereafter, an approval cycle has been commenced with the relevant bodies of ESA and CNES for the placement of a Phase-C0 contract, to provide a bridging for industrial system activities until the placement of the full Phase-C/D contract.

Within ESA, a revised ARTES-8 Programme Declaration has been approved, taking into account the separate development cycles of AlphaBus and a future AlphaSat.

The AlphaBus Phase-C/D equipment-selection process is nearing completion and consolidates the industrial consortium as well as the repartition of industrial work between the Participating States. Besides the ESA contribution, CNES is providing further national funding for the AlphaBus programme, as agreed under the terms of cooperation between the two Agencies. Approval for the full AlphaBus Phase-C/D by both Agencies is anticipated in the first quarter of 2005.

Vega

All main-development subcontracts for the Vega launch vehicle have been signed by ELV (I), the Prime Contractor, with the exception of the thrust-vector control activities contract with Sabca, signature of which is planned for end-January 2005.

A number of Critical Design Reviews of equipment and structures have already been started.

The system activities have been progressing accordingly to the planning agreed at last July’s System Design Review (SDR) Board meeting. A meeting took place in December to verify the closure status of the main recovery actions identified by the SDR. The main actions at system level are close to being concluded, with the exception of three critical points that require further analysis.

The first motor cases for the Zefiro 23 and P80 engines have been analysed after a failure was identified during the Zefiro compression test and some manufacturing defects were observed in the P80 technological model. Specific Investigation Boards have been put in place and modifications to the tooling and processes, following an established recovery plan, are being implemented and tested before resuming full-size-model manufacture and motor-validation activities.

All ground-segment contracts have been kicked-off, with the exception of some subcontracts for the control bench. Work on the Vega site in Kourou began in October and the first activities have started at the former ELA1 complex, which will be refurbished to become the Vega Launch Zone. The first two industrial Ground Segment Preliminary Design Reviews (mechanical and civil engineering) began in December.

In Brief

Ariane-5 handles the heavy stuff

The latest version of Ariane-5, designed to carry payloads of up to 10 tonnes to geostationary transfer orbit, successfully completed its qualification flight on 12 February. After a perfect lift-off from Europe's Spaceport in French Guiana, at 18:03 local time (22:03 CET), the launcher released its payload into the predicted transfer orbit.

Successful lift-off for Ariane 5 ECA Flight 164 on 12 February 2005

This success paves the way for the commercial introduction of this 'Ariane-5 ECA', which is due to replace the current configuration of Ariane-5G 'Generic'. Starting from the second flight scheduled for mid-2005, Ariane-5 ECA will become the new European workhorse for lifting heavy payloads to geostationary orbit and beyond.

The Ariane-5 ECA features upgraded twin solid boosters, each loaded with an extra 2.43 tonnes of propellant, increasing their combined thrust on lift-off by a total of 60 tonnes. The cryogenic main stage has also been upgraded to carry 15 tonnes of additional propellant and is powered by a new Vulcain 2 engine, derived from Vulcain 1, which provides 20% more thrust. The Ariane-5 ECA also introduces a new high-performance cryogenic upper stage.

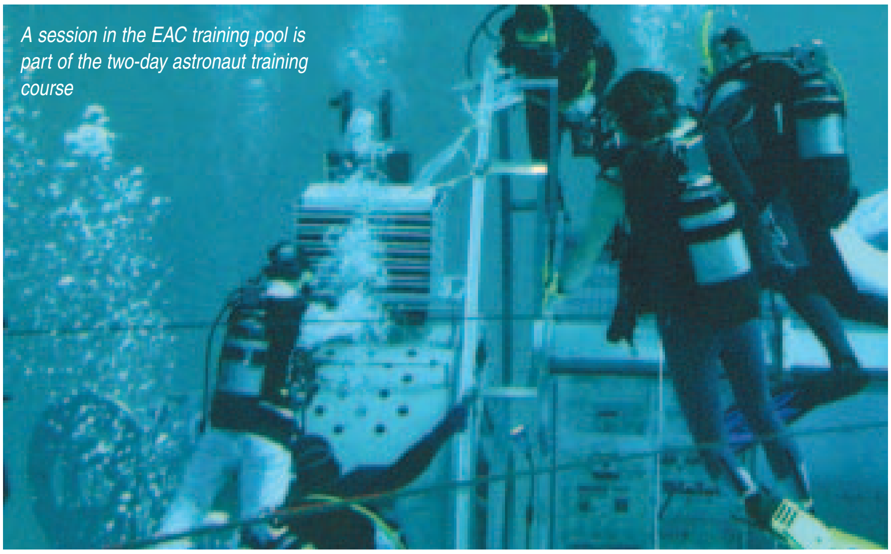
On this flight, the Ariane-5 ECA launcher carried three payloads. The first, released 26 minutes into flight, was XTAR-EUR, a 3600-kg commercial X-band communication satellite flown on behalf of XTAR LLC. This will subsequently use its onboard propulsion system to achieve circular orbit. After an initial period of in-orbit testing, it will be deployed to provide secure communications to government customers.

Next released, 31 minutes after lift-off, the Sloshsat Facility for Liquid Experimentation and Verification in Orbit (FLEVO) is a 129-kg satellite developed for ESA by the Dutch National Aerospace Laboratory (NRL). It will investigate fluid physics in microgravity to understand how propellant-tank sloshing affects spacecraft control. Its mission is planned to last 10 days.

The third passenger, Maqsat B2, will remain attached to the launcher's upper stage. This 3500-kg instrumented model was designed to simulate the dynamic behaviour of a commercial satellite inside the Ariane-5 payload fairing. An autonomous telemetry system transmitted data on the payload environment during all the flight phases, from lift-off to in-orbit injection. Fitted with a set of cameras, Maqsat B2 also provided dramatic onboard views of several key flight phases, including separation of the solid boosters and jettisoning of the Sylda upper-half payload.

Become an astronaut for two days

Have you ever wondered what it feels like to be a member of the ESA Astronaut Corps? Here is your chance: You can sign up for a two-day astronaut training course at the European Astronaut Centre EAC – complete with a dive in the EAC's pool, a twirl on the aero-trainer and a chat with real astronauts. Markus Landgraf, scientist and mission analyst at ESOC in Darmstadt, tried it out. Here is his report:



A session in the EAC training pool is part of the two-day astronaut training course

The training is organised by ProToura, an incentive firm contracted by ESA in the framework of its ISS Commercialisation activities. I took part in the course in order to learn more about the requirements of mission design and operations of missions involving humans.

On our first day all eight participants were welcomed by the ProToura and EAC team and got our blue training suits. Before the real training began, we were led to the DLR medical institute where they checked that we were fit to participate in the training. A session in a low-pressure chamber, followed by a demonstration of the effects of hypoxia, a lack of oxygen in the human brain, showed us what it means to live and work in a space environment. In addition to the testing activities, the DLR team provided insight into the physical criteria for astronaut recruitment.

'Space trainee' Markus Landgraf

A very exciting aspect of the training course was ESA astronaut Reinhold Ewald telling us about his mission to the Mir space station in 1997. His mission was dominated by medical research experiments on the effects of microgravity on the human body. The crew on board the Station needs a broad background in natural sciences and engineering in order to perform all experiments from a wide variety of disciplines. I learned that operating a manned space vehicle is quite similar to unmanned vehicles, only the mission and spacecraft design are much more driven by safety.

I was especially interested in how the experiments are performed aboard the Space Station. As I had hoped, the actual payload instructors – the people who also prepare the astronauts for their missions – trained us. Due to the large number of possibilities for payload-specialised training, we had to pick one experiment facility on which we would like to be trained. I chose the European Physiology Modules (EPM), one of the International Standard Payload Racks (ISPR) to be launched on Columbus at the end of 2006. The experiments can be performed independently on the Station, but the plan is that astronauts will interact with the Principal Investigators, located in the Columbus control centre. We trained on a variety of experiments in human physiology: the recording of an electro-myogramme, a 24-hour blood pressure monitoring experiment and the space rating of a commercial heart-rate monitor. In general, the experiments are set up very similar to a laboratory on the ground, except that the procedures during the measurements are more controlled and documented.

Physical fitness is part of every astronaut training. We spent the morning of the second day in the physical fitness facility in EAC. The training comprised walking on a treadmill, rowing, cycling, and a session in the aero-trainer, a device which allows the human body to be rotated in all directions. With fresh minds, we turned to the Columbus mock-up located in the EAC training hall and trained on the emergency hatch-closing procedure, which is important in the case of fire in the module.

In the late afternoon we prepared for an extra-vehicular activity (EVA) in the EAC neutral buoyancy facility, a large indoor pool with a submerged mock-up of the Columbus module. Here, the astronauts are prepared for more elaborate EVA training at NASA/Johnson Space Center in Houston or the Gagarin Cosmonaut Training Centre near Moscow. Because we all had different backgrounds in diving, everyone took his or her time to get acquainted with the equipment. Holding a PADI open water diver certificate, I was allowed to observe the EAC team up close as they demonstrated one of the many training procedures.

At the end Reinhold Ewald gave us our ESA astronaut trainee certificates. The team from EAC and ProToura have put together a very exciting and authentic experience. Thanks to this two-day course I now have a really good insight into what it takes to do research in such an extraordinary laboratory like the ISS.

For more information see www.protoura.com. A two-day training session costs 2950 Euro. The sessions are planned to take place three to four times a year – depending, of course, on the training times of the real ESA astronauts.

Closer ties between ESA and Russia

ESA Director General, Jean-Jacques Dordain and the Head of the Russian Federal Space Agency, Anatoly Perminov, signed an agreement for long-term cooperation and partnership in the development, implementation and use of launchers in Moscow in January.

This agreement is part of the general Agreement between ESA and the Russian Federation for Cooperation and Partnership in the Exploration and Use of Outer Space for Peaceful Purposes, and will strengthen cooperation between ESA and Russia.

The ESA-Russian partnership is based on two main pillars: the exploitation of the Russian Soyuz launcher from Europe's Spaceport in French Guiana, and cooperation without exchange of funds on research and development in preparation for future launchers.

The programme 'Soyuz at Europe's Spaceport' covers the construction of the Soyuz launch facilities in French Guiana and the adaptations that Soyuz will need to enable it to be launched from there. Work to prepare the Spaceport for Soyuz is already underway, with the first launch scheduled for 2007.

The agreement will also allow work to begin on the second pillar: preparation activities for the development of future space transport systems. Europe and the Russian Federation will collaborate in developing the technology needed for future launchers. Russian and European engineers will work together to develop reusable liquid engines, reusable liquid-stages and experimental vehicles. ESA's aim is to have a new-generation launcher ready by 2020.

The European spaceport is getting ready for the Soyuz launcher. (Artist's impression, D. Ducros)

Don't get lost in Limerick

With the opening of a new monitoring station in December, Ireland is now part of Europe's first satellite navigation system. EGNOS, which stands for European Geostationary Navigation Overlay Service, is a satellite navigation network currently being built all over Europe to provide a highly accurate signal for civil aviation. By the end of the year this network will enable everyone with an EGNOS receiver to pinpoint their position more accurately than with GPS.

The new EGNOS facility, called a Ranging and Integrity Monitoring Station (RIMS), is located at the airport of Cork on the grounds of the Irish Aviation Authority (IAA). This RIMS provides coverage for all of Ireland and a large window into the Atlantic region, one of the most heavily populated aviation routes.

EGNOS is Europe's first step into satellite navigation. Based on the correction of Global Positioning System (GPS) signals, it offers higher accuracy, integrity and continuity of services. To achieve this, a network of ground elements is needed, consisting of RIMS (34 like the one in Ireland), Master Control Centres to process the data delivered by the RIMS, and uplink stations that send the signal to three geostationary satellites. These will then relay it back to the user on the ground.

The EGNOS facility at Cork airport in Ireland

Integral rolls back history of Milky Way's super-massive black hole

The centre of our galaxy has been known for years to host a black hole, a 'super-massive' yet very quiet one. New observations with Integral, ESA's gamma-ray observatory, have now revealed that 350 years ago the black hole was much more active, releasing a million times more energy than at present. Scientists expect that it will become active again in the future.

Most galaxies harbour a super-massive black hole in their centre, weighing a million or even a thousand million times more than our Sun. The black hole in our galaxy, the Milky Way, is called Sgr A* (standing for 'Sagittarius A star') due to its position in the southern constellation Sagittarius, 'the archer'.

In spite of its enormous mass of more than a million suns, Sgr A* appears today as a quiet and harmless black hole. However, a new investigation with ESA's gamma-ray observatory Integral has revealed that in the past Sgr A* has been much more active. Data clearly show that it interacted violently with its surroundings, releasing almost a million times as much energy as it does today.

This result has been obtained by a international team of scientists led by Dr Mikhail Revnivtsev (Space Research Institute, Moscow, Russia, and Max Planck Institute for Astrophysics, Garching, Germany). As Revnivtsev explains, *"About 350 years ago, the region around Sgr A* was literally swamped in a tide of gamma rays."*

This gamma-ray radiation is a direct consequence of Sgr A's past activity, in which gas and matter trapped by the hole's gravity were crushed and heated until they radiated X-rays and gamma rays, just before disappearing below the 'event horizon' – the point of no return from which even light cannot escape.

The team were able to unveil the history of Sgr A* thanks to a cloud of molecular hydrogen gas, called Sgr B2 and located about 350 light-years away from it, which acts as a living record of the black hole's hectic past. Because of its distance from the black hole, Sgr B2 is only now being exposed to the gamma rays emitted by Sgr A* 350 years ago, during one of its 'high' states. This powerful radiation is absorbed and then re-emitted by the gas in Sgr B2, but this process leaves behind an unmistakable signature.

"We are now seeing an echo from a sort of natural mirror near the galactic centre - the giant cloud Sgr B2 simply reflects gamma rays emitted by Sgr A in the past,"* says Revnivtsev. The flash was so powerful that the cloud became fluorescent in the X-rays and was even seen with X-ray telescopes before Integral. However, by showing how high-energy radiation is reflected and reprocessed by the cloud, Integral has allowed scientists to reconstruct the hectic past of Sgr A* for the first time.

The high state or 'activity' of black holes is closely linked to the way in which they grow in size. Super-massive black holes are not born so big but, thanks to their tremendous gravitational pull, they grow over time by sucking up the gas and matter around them. When the matter is finally swallowed, a burst of X-rays and gamma rays results. The more voracious a black hole, the stronger is the radiation that erupts from it.

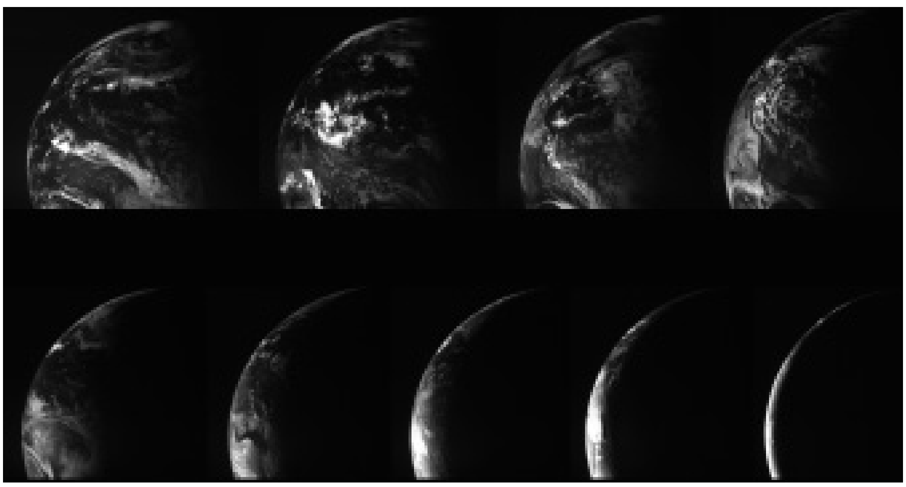
The new Integral discovery solves the mystery of the emission from super-massive but weak black holes, such as Sgr A*. Scientists already suspected that such weak black holes should be numerous in the Universe, but they were unable to tell how much and which type of energy they emit. *"Just a few years ago we could only imagine a result like this,"* Revnivtsev says. *"But thanks to Integral, we now know it!"*

SMART-1 mission extended

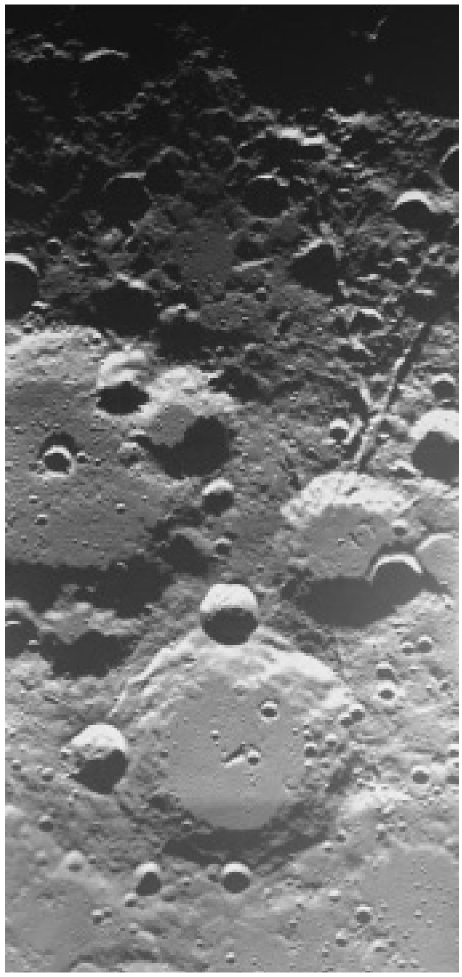
ESA's SMART-1 mission has been extended by one year, pushing back the mission end-date from August 2005 to August 2006. ESA's Science Programme Committee (SPC) unanimously endorsed the proposed one-year extension on 10 February.

The mission's extension will provide opportunities to extend the global coverage, compared with the original six-month mission, and to map both the Moon's southern and northern hemispheres at high resolution. The new orbit will also be more stable and require less fuel for maintenance.

The extension will also provide the possibility to make detailed studies of areas of interest by performing stereo measurements for deriving topography, multi-angle observations for studying the surface "regolith" texture, and mapping of potential landing sites for future missions.



SMART-1's view of a waning Earth
These pictures were taken with the AMIE camera on board SMART-1 on 1 and 2 November 2004 when SMART-1 was on course for its last close approach to Earth, before being captured by the Moon's gravity in mid-November.



An area of the lunar surface imaged by SMART-1, showing two large craters, Brianchon and Pascal (ESA/Space-X, Space Exploration Institute)

ESA astronaut to fly to the ISS on Italian Soyuz mission

Roberto Vittori

Roberto Vittori will be the next ESA astronaut to fly to the International Space Station (ISS), on the 10-day Italian Soyuz mission, scheduled to be launched on 15 April from the Baikonur Cosmodrome in Kazakhstan. The mission is called 'ENEIDE' and takes its name from the epic tale written by the Latin poet Virgil in the 1st Century BC, which tells of the journey of Aeneas from Troy to Italy, and the foundation of Rome.

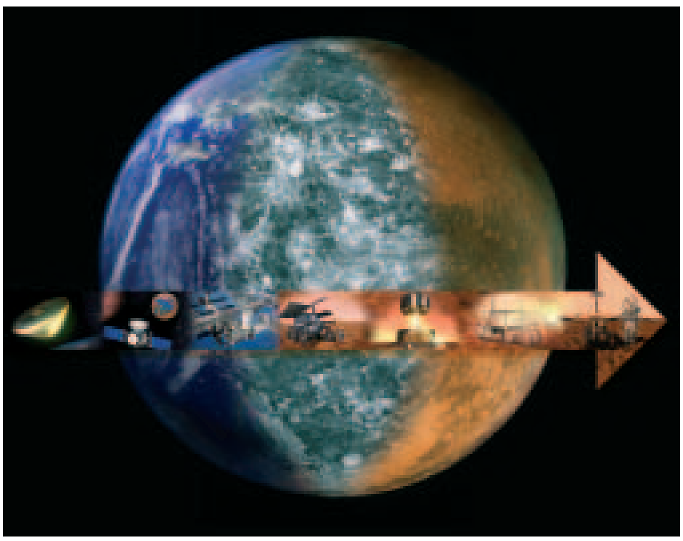
On this, his second flight to the ISS, Vittori will serve as Flight Engineer on board the Soyuz TMA-6 spacecraft, alongside the Soyuz Commander and Roskosmos cosmonaut Sergei Krikalev and NASA astronaut John Phillips. As Flight Engineer on both the outward and the return journey, Vittori will take an active role in piloting and docking the spacecraft. The main objectives of the mission are: for the ESA astronaut to perform a full experimental programme of major scientific interest onboard the ISS; to exchange the station lifeboat, Soyuz TMA-5, for Soyuz TMA-6; and to exchange the current ISS Expedition-10 crew (Leroy Chiao and Salizhan Sharipov) for the Expedition-11 crew (Krikalev and Phillips).

ENEIDE, an ESA mission, is co-sponsored by the Italian Ministry of Defence and the Lazio Region, with the support of Finmeccanica, FILAS and the Rome Chamber of Commerce (CCIAA). Many of the experiments have been developed by Italian researchers and built by Italian industry and research institutions.

"I am pleased to see this mission taking shape with such a great degree of international involvement", says Daniel Sacotte, ESA's Director of Human Spaceflight, Microgravity and Exploration Programmes; *"ENEIDE, as with all human spaceflight missions, will benefit many areas of life and further expand the experience of the European Astronaut Corps. This will help us on the road to further human exploration of our Solar System".*

ESA's 'Aurora' Exploration Programme gets further boost

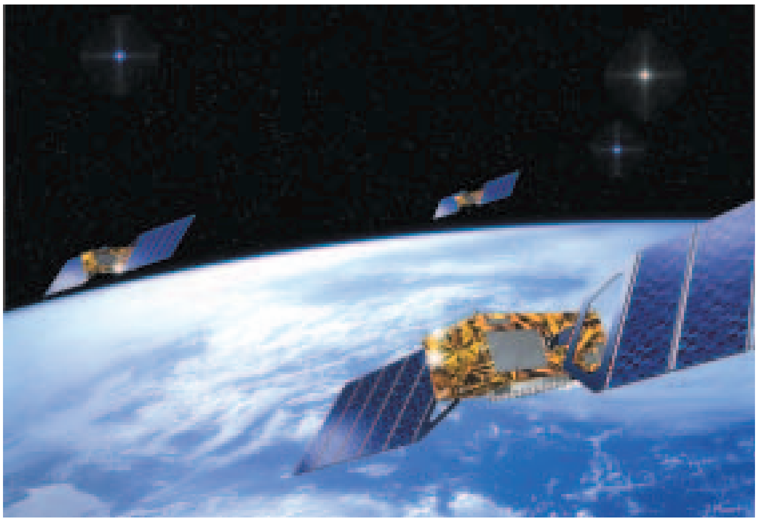
The countries participating in the Preparatory European Space Exploration Programme 'Aurora' have recently confirmed and increased their contributions for the period 2005-2006. Sweden has now joined the programme, and the subscribed envelope has nearly tripled, from the original 14.3 million Euro to around 41.5 million Euro currently. Italy has also confirmed its interest and ambitions in space exploration by further increasing its participation. The United Kingdom will also contribute additional money. France, the third-largest contributor to the programme, is followed by Belgium, Spain and The Netherlands. Other participants are Austria, Switzerland and Portugal. Canada, an ESA Cooperating State, has also confirmed an increased contribution.



On 15 December, the ESA Council approved the Agency's budgets for 2005, including that Aurora. These developments enable major industrial activities to continue and will enable the work on preparing the full programme proposal to move ahead in line with original plans. Invitations to tender for industrial contracts will be issued starting from February 2005. These include work for the ExoMars and the Mars Sample Return missions. Other activities will cover in-orbit assembly, rendezvous and docking, habitation and life-support systems, plus a broad range of technology-development work. Industry will also be called upon to contribute to the definition of a European Space Exploration strategy and architecture.

The preparatory phase of the Aurora Exploration Programme will culminate in a full programme proposal, which will be submitted to the next ESA Council Meeting at Ministerial Level, scheduled for December 2005.

A further step forward for Galileo



The Galileo project is now well and truly taking shape, with the signing on 21 December of a second contract concerning the In-Orbit Validation (IOV) phase, following that signed in July 2003 for two test satellites. The new 150 million Euro contract between ESA and Galileo Industries represents a first stage towards signing an approximately 950 million Euro contract covering the overall IOV phase.

The contract provides the basis and the technical activities necessary for in-orbit validation of the Galileo system. It gives preliminary authorisation to proceed with the whole of this work, over a six-month period. This work notably concerns the management of the programme and the choice of engineering systems and technical support required to maintain the overall credibility of the scheduling and ensure system coherence.

"This marks a further step forward for Galileo", says Giuseppe Viriglio, Director of EU and Industrial Programmes at the Agency. *"In line with the recent EU Transport Council green light for final deployment of the constellation, ESA is securing the foundations for this unique satellite locating and positioning system."*

Galileo is a joint initiative of the European Space Agency and the European Union. It will be the first-ever global satellite-navigation system designed for civilian needs that delivers guaranteed continuity of services, unlike the American GPS. The two systems will nevertheless be compatible and interoperable. esa

Heads of space agencies meet in Montreal

The Heads of space agencies from the United States, Russia, Japan, Europe and Canada met in Montreal, Canada, on 26 January to review and further advance International Space Station (ISS) cooperation. At this meeting, the Heads of Agency reviewed the status of ongoing ISS operations and NASA's plans for the Space Shuttle's return to flight. They endorsed the ISS configuration approved by the Multilateral Coordination Board. The Partners also reaffirmed their agencies' commitment to meet their ISS obligations and to complete the Station's assembly by the end of the decade, and to use and further evolve ISS in a manner that meets their research and exploration objectives.

Of particular interest to the Partners is the increased use of ISS and early opportunities for an enhanced crew of greater than three after the Shuttle returns to flight. ISS transportation needs will be met by a mix of support vehicles from across the Partnership. Planning includes support by Russian Soyuz spacecraft, the American Space Shuttle, the automated logistics re-supply capabilities provided by Russian Progress vehicles, the ATV and HTV spacecraft to be provided by Europe and Japan, respectively, as well as the capabilities from potential future commercial providers.

The Heads of Agency reaffirmed their commitment to continue the unprecedented international cooperation that has characterised the ISS Programme to date. This cooperation has enabled the Partnership to safely maintain a human presence in orbit and keep the ISS in a productive state of operations and utilisation, including the continued use of Canadarm2, during the current hiatus in Space Shuttle flights.

The ISS Heads of Agency agreed to meet again in autumn 2005. 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 Newletters

ON STATION NUMBER 18 (NOVEMBER 2004)
NEWSLETTER OF ESA's DIRECTORATE OF HUMAN SPACEFLIGHT
WILSON A. (ED.)
NO CHARGE

ECSL NEWS NO. 28 (DECEMBER 2004)
NEWSLETTER OF THE EUROPEAN CENTRE FOR SPACE LAW
MARCHINI A. & DANESY D. (EDS.)
NO CHARGE

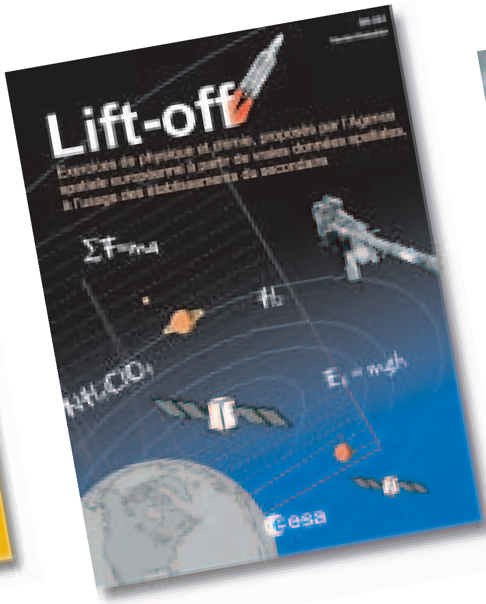
ECSL NEWS NO. 29 (FEBRUARY 2005)
NEWSLETTER OF THE EUROPEAN CENTRE FOR SPACE LAW
MARCHINI A. & DANESY D. (EDS.)
NO CHARGE

EDUNEWS NO. 6 (JULY 2004)
NEWSLETTER OF ESA's EDUCATION OFFICE
WARMBEIN B. (ED.)
NO CHARGE

CONNECT NO. 03/04 (DECEMBER 2004)
NEWSLETTER OF ESA's TELECOMMUNICATIONS DEPARTMENT
MENNING N. & BATTRICK B. (EDS.)
NO CHARGE

ESA Brochures

GALILEO – THE EUROPEAN PROGRAMME FOR GLOBAL NAVIGATION SERVICES
WILSON A. (ED.)
ESA BR-186 // 36 PAGES
(2ND EDITION; ENGLISH)
PRICE: 10 EURO



TANIA – EUROPEAN ASTRONAUT (DECEMBER 2004)
WILSON A. (ED.)
ESA BR-219 // 38 PAGES (ENGLISH EDITION)
PRICE: 5 EURO

LIFT-OFF – OEFENINGEN, VAN HET EUROPEES RUIMTEVAART AGENTSCHAP, VOOR FYSICA EN CHEMIE IN HET SECUNDAIR ONDERWIJS GEBASEERD OP ECHTE RUIMTEVAART DATA (SEPTEMBER 2004)
BUISÁN S.T. (ED. B. WARMBEIN)
ESA BR-223, NEDERLANDSE VERSIE // 72 PAGES
PRICE: 10 EURO

LIFT-OFF – EXERCICES DE PHYSIQUE ET CHIMIE, PROPOSÉ PAR L'AGENCE SPATIALE EUROPÉENNE À PARTIR DE VRAIES DONNÉES SPATIALES, À L'USAGE DES ÉTABLISSEMENTS DU SECONDAIRE (SEPTEMBRE 2004)
BUISÁN S.T. (EDS. I. DUVAUX-BÉCHON & B. WARMBEIN)
ESA BR-223, VERSION FRANÇAISE // 72 PAGES
PRICE; 10 EURO

LIFT-OFF – EJERCICIOS DE FÍSICA Y QUÍMICA PARA SECUNDARIA BASADOS EN DATOS REALES DE LA AGENCIA ESPACIAL EUROPEA (SEPTIEMBRE 2004)
BUISÁN S.T. (ED. B. WARMBEIN)
ESA BR-223, VERSIÓN EN CASTELLANO // 72 PAGES
PRICE: 10 EURO

CASSINI/HUYGENS – A PROBE TO TITAN (DECEMBER 2004)
WARMBEIN B. & WILSON A. (EDS.)
ESA BR-228 // 30 PAGES
PRICE: 5 EURO

SMART-1 – TECHNOLOGY RECORDS FROM ESA's SMALL GENIUS EN ROUTE TO THE MOON (2004)
TALEVI M. (EDS. B. BATTRICK & C. WALKER)
ESA BR-232 // 6 INSERTS
PRICE: 7 EURO

VEGA – THE EUROPEAN SMALL LAUNCHER (NOVEMBER 2004)
LEMERCIER S. (ED. B. BATTRICK)
ESA BR-233 // 6 PAGES
NO CHARGE

ESA Special Publications

PROCEEDINGS OF THE 7TH EUROPEAN CONFERENCE ON RADIATION AND ITS EFFECTS ON COMPONENTS AND SYSTEMS (RADECS 2003), 15-19 SEPTEMBER 2003, NOORDWIJK, THE NETHERLANDS (OCTOBER 2004)
FLETCHER K. (ED.)
ESA SP-536 // 681 PAGES + CD-ROM
PRICE: 70 EURO

PROCEEDINGS OF THE 4S SYMPOSIUM: SMALL SATELLITES, SYSTEMS AND SERVICES, 20-24 SEPTEMBER 2004, LA ROCHELLE, FRANCE (NOVEMBER 2004)
WARMBEIN B. (ED.)
ESA SP-571 // CD-ROM
PRICE: 30 EURO

PROCEEDINGS OF THE SOHO 15 WORKSHOP: CORONAL HEATING, 6-9 SEPTEMBER 2004, ST. ANDREWS, SCOTLAND (DECEMBER 2004)
WALSH R.W., IRELAND J., DANESY D. & FLECK B. (EDS.)
ESA SP-575 // CD-ROM
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PROCEEDINGS OF THE SYMPOSIUM THE THREE-DIMENSIONAL UNIVERSE WITH GAIA, 4-7 OCTOBER 2004, PARIS, FRANCE (JANUARY 2005)
PERRYMAN M.A.C., TURON C., O'FLAHERTY K.S. & LACOSTE H. (EDS.)
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PROCEEDINGS OF THE 5TH INTEGRAL WORKSHOP ON THE INTEGRAL UNIVERSE, 16-20 FEBRUARY 2004, MUNICH, GERMANY (OCTOBER 2004)
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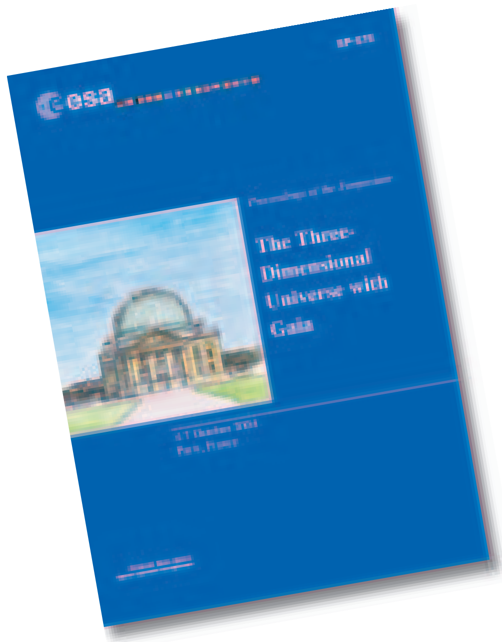
DANESY D. (ED.)
ESA SP-559 // CD-ROM
PRICE: 60 EURO

PROCEEDINGS OF THE 4TH INTERNATIONAL CONFERENCE ON SOLAR POWER FROM SPACE – SPS '04, TOGETHER WITH THE 5TH CONFERENCE ON WIRELESS POWER TRANSMISSION – WTP 5, 30 JUNE-2 JULY 2004, GRANADA, SPAIN (DECEMBER 2004)
LACOSTE H. & OUWEHAND L. (EDS.)
ESA SP-567 // 303 PAGES + CD-ROM
PRICE: 50 EURO



PROCEEDINGS OF THE SYMPOSIUM: THE DUSTY AND MOLECULAR UNIVERSE – A PRELUDE TO HERSCHEL AND ALMA, 27-29 OCTOBER 2004, PARIS, FRANCE (JANUARY 2005)
WILSON A. (ED.)
ESA SP-577 // 490 PAGES
PRICE: 70 EURO

PROCEEDINGS OF THE SECOND MSG RAO WORKSHOP, 9-10 SEPTEMBER 2004, SALZBURG, AUSTRIA (NOVEMBER 2004)
LACOSTE H. (ED.)
ESA SP-582 // 178 PAGES + CD-ROM
PRICE: 40 EURO

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE: TITAN – FROM DISCOVERY TO ENCOUNTER, 13-17 APRIL 2004, ESTEC, NOORDWIJK, THE NETHERLANDS (DECEMBER 2004)
FLETCHER K. (ED.)
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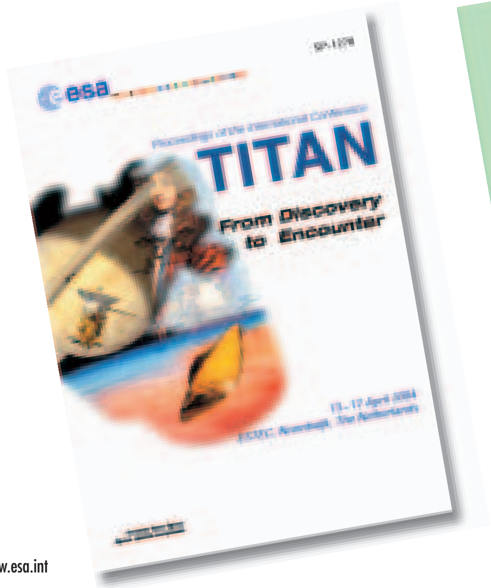

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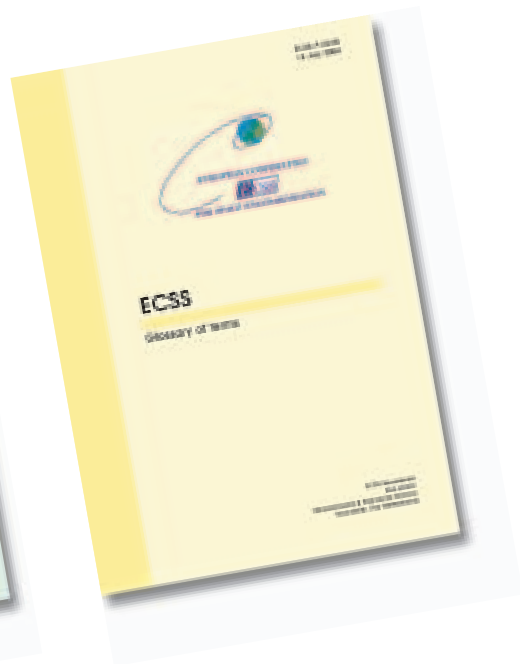

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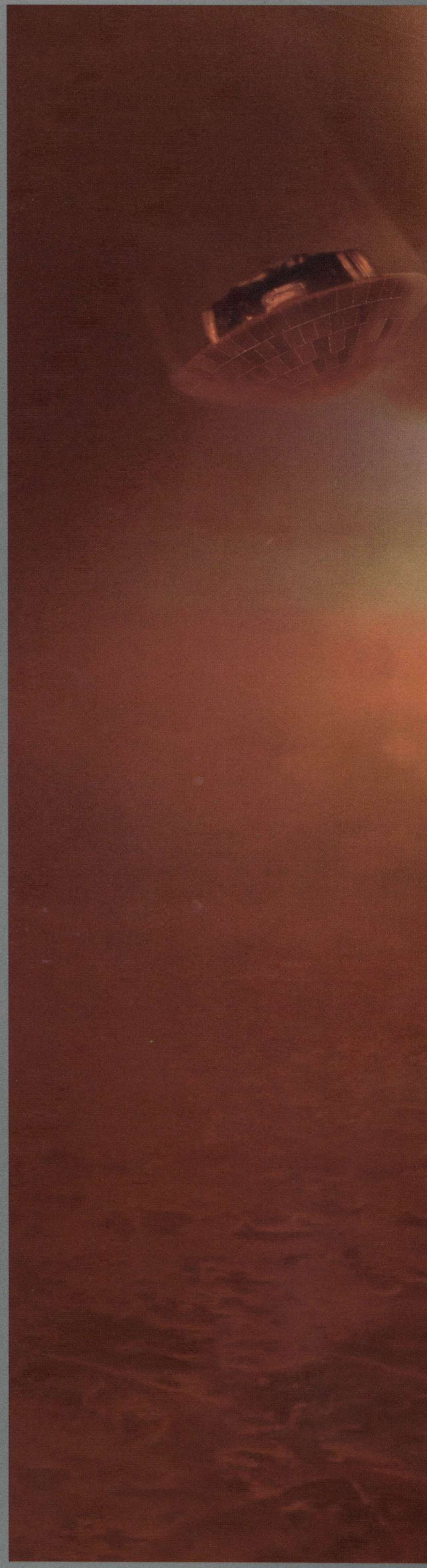

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