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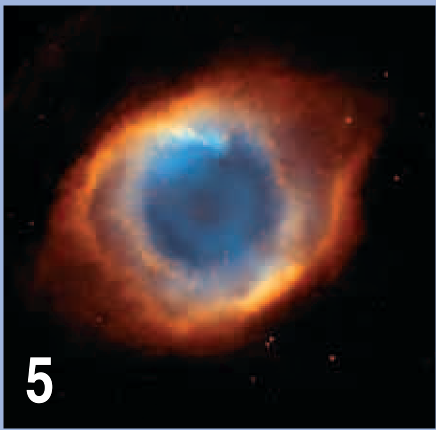
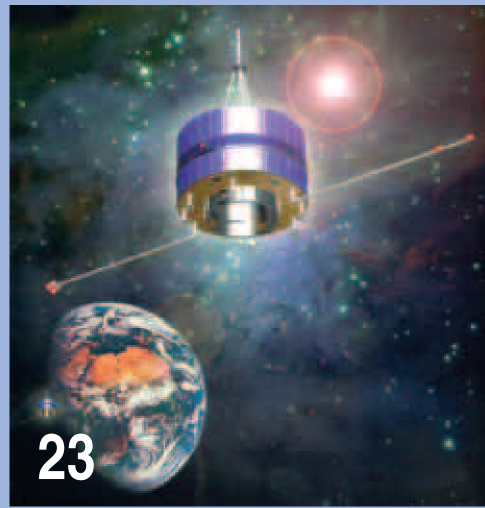
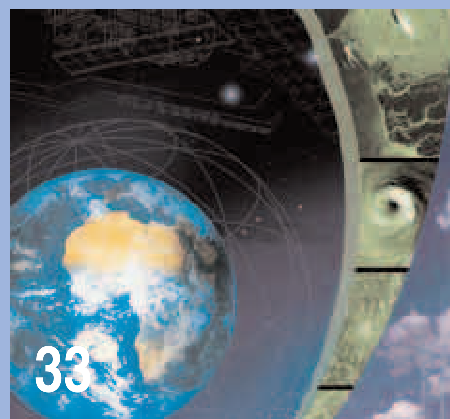


The Hubble Space Telescope



East Meets West in Near-Earth Space Data

Space Technologies for Building



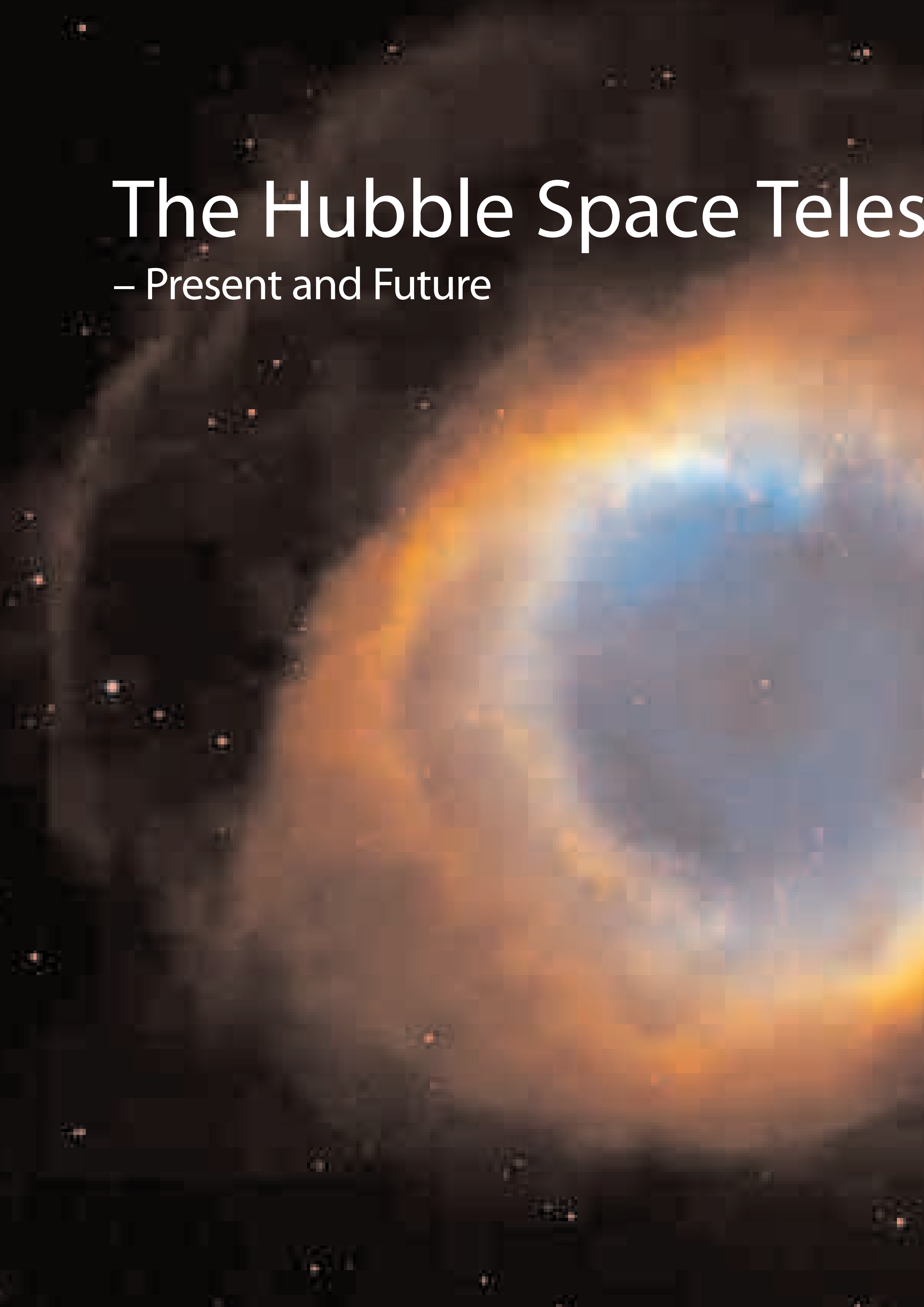
Making the Most of Earth Observation

esa bulletin 118 - may 2004

Contents

The Hubble Space Teles

– Present and Future



Nino Panagia
Space Telescope Science Institute, ESA Directorate of Scientific Programmes, Baltimore, USA

After fourteen years in orbit, the 'middle-aged' Hubble Space Telescope continues to play a major role in astronomical research, and is undoubtedly one of the most important and prolific space astronomy missions of all time. To do justice to the many important, exciting and fundamental discoveries made with Hubble, one would have to write a very thick book. This article is therefore intended to illustrate just a small selection of the telescope's results and to outline some of the observations planned for the near future.

The Hubble Space Telescope (HST) is a cooperative NASA/ESA programme conceived in order to operate a long-lived space-based observatory for the benefit of the international astronomical community. Designed and built in the 1970s and 80s, HST was planned to be a different type of mission from its forerunners, namely a long-term observatory facility in space, whose instrumentation and equipment would be serviced and exchanged in a regular three-year cycle.

HST was deployed in low-Earth orbit (about 600 km) by the crew of the Space Shuttle 'Discovery' (STS-31) on 25 April 1990. Although at the beginning the mission looked severely handicapped because of spherical aberration in HST's optics, the first maintenance mission by Space Shuttle 'Endeavour' (STS-61), in December 1993, fully restored Hubble's functionality. In fact, all of the HST servicing missions conducted so far – SM1 in December 1993, SM2 in

Launch of the Hubble Space Telescope (HST) on 23 April 1990

HST with full-Moon and Earth in the background during servicing mission SM3A (Courtesy of NASA)

February 1997, SM3A in December 1999, and SM3B in February/March 2002 – were enormous successes.

HST's current science instruments include three cameras, the Wide Field and Planetary Camera 2 (WFPC2), the new Advanced Camera for Surveys (ACS), which with its tenfold increase in efficiency and its doubled field of view relative to WFPC2 has opened up much-anticipated new capabilities for discovery, the Near Infrared Camera - Multiobject Spectrograph (NICMOS), which was revived in servicing mission 3B with the installation of a mechanical cooling system, one spectrograph, the Space Telescope Imaging Spectrograph (STIS), and the Fine Guidance Sensors (FGS, primarily used for astrometric observations).

When the new ACS was installed, it replaced the ESA Faint Object Camera (FOC), which had spent a record-breaking 4340 days – almost 12 years – in space. During its time on HST, the FOC had many celebrated successes. Its very high angular resolution, which meant it could produce extremely sharp images, was used to great effect in providing unique close-up views of nearly every class of astronomical object. Among many other firsts, the FOC revealed the first surface details on the planet Pluto, made the first direct images of the atmospheres of giant stars like Betelgeuse, took the first image of an 'exposed' black hole, and showed the circumstellar material around exploding stars like Nova Cygni 1991 and around supernovae like SN 1987A. Its sharp eye penetrated the inner enigmatic cores of active galaxies, where black holes with masses up to several billion times that of our Sun are hiding. Its special ability to detect the very faintest ultraviolet light was extensively used to make spectra of very distant quasars. This effort ultimately resulted in a breakthrough in cosmology - the first detection of singly ionised helium in the medium between the galaxies.

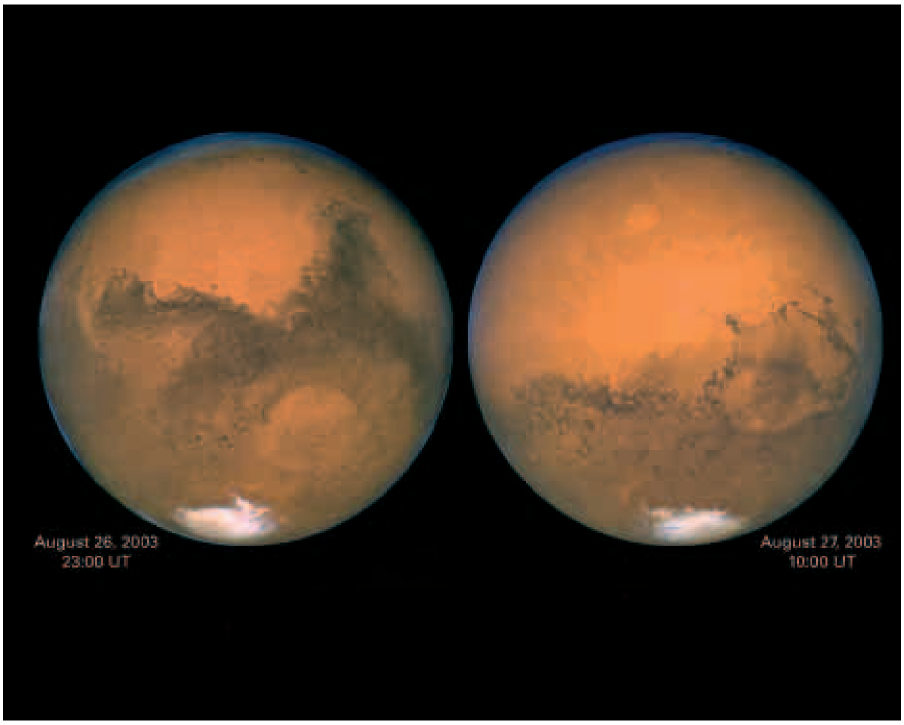
ESA/STScI representatives in front of the retrieved Faint Object Camera (FOC) in the clean room at Goddard Space Flight Center on 25 April 2002

Peter Jakobsen, the current ESA Project Scientist for the FOC, comments:

"Although the images obtained with the FOC have only rarely been as photogenic as the famous images from the Wide Field and Planetary Camera 2, the FOC has served the astronomical community well and brought home its fair share of scientific firsts."

Observations made with the HST have both solved problems that had been under debate for many years, and revealed quite unexpected and exciting new phenomena. The crop of high-impact science from Hubble includes the definitive measurement of the expansion rate of the Universe (the so-called 'Hubble constant'), the confirmation and characterisation of massive black holes at the centre of galaxies, the detection of the host galaxies of Quasi Stellar Objects (QSOs) and the exhaustive study of the properties of the intergalactic medium, telling us a great deal about the chemical evolution of the Universe.

Even more exciting are the discoveries that were totally unanticipated and that have opened new avenues to our knowledge of the cosmos, such as the discovery of the acceleration of the Universe, which implies the existence of the so-called 'dark energy' that has dominated its expansion over the last 8 billion years, the properties of extremely distant galaxies as shown by the Hubble Deep Field observations that have provided us the direct view at thousands of galaxies formed just a few billion years after the Big Bang, clues to the nature of the gamma-ray burst sources that are possibly the most energetic explosions in the Universe, the formation of planets in disks around young stars, the full characterisation of planets orbiting other stars, and the dramatic collision of fragments from comet Shoemaker-Levy 9 with Jupiter's atmosphere.



HST images (WFPC2) of Mars taken during its closest approach to the Earth (Courtesy of NASA, J. Bell (Cornell University) and M. Wolff (Space Science Institute))

Mars' Close Encounter with Earth

On 27 August 2003, the third and fourth planets from the Sun, namely the Earth and Mars, were at their closest for 60 000 years. Approximately every two years, the Earth's orbit catches up with that of Mars, aligning the Sun, Earth and Mars in a straight line, with Mars and the Sun on opposite sides of the Earth. The fact that Earth's orbit is nearly circular while that of Mars is more markedly elliptical results in Earth-Mars approaches ranging between 56 and 100 million kilometres. In late August 2003, Earth was near aphelion and Mars at perihelion, putting them a mere 55.8 million kilometres apart!

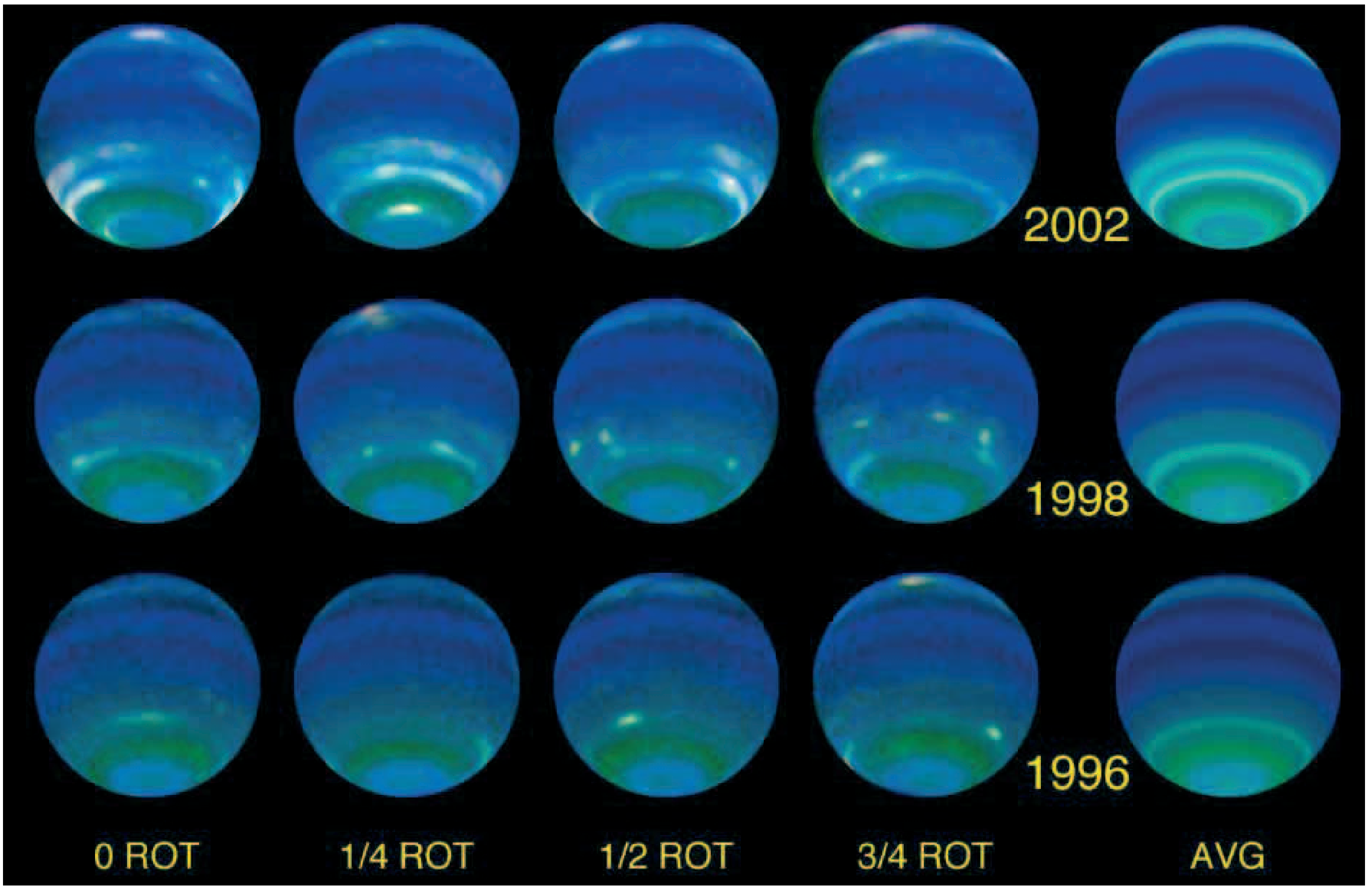
Taking advantage of such a close 'opposition' of the planets, a series of HST observations were planned to study the composition and physical state of surface materials and airborne aerosols. Timed to take full advantage of the closest approach of Mars to Earth, images and spectra were acquired at spatial scales comparable to existing spacecraft orbital spectroscopy data (about 10 km/pixel) and in wavelength regions not sampled by past or current Mars spacecraft instrumentation. These observations have therefore provided complementary scientific and calibration measurements in support of current and future NASA and ESA Mars exploration missions.

The unusually small separation of the planets also made summer 2003 the ideal time to launch scientific expeditions to Mars, as less fuel was then needed to reach the Red Planet, leaving more room onboard the spacecraft for valuable scientific instruments. Hence ESA's summer 2003 launch of its Mars Express probe, which reached the planet in December.

A Change of Seasons on Neptune

Observations of Neptune made by Hubble over a six-year period show a distinct increase in the amount and brightness of the banded cloud features located mostly in the planet's southern hemisphere. Neptune was already known for its violent weather, with winds of up to 1500 km/h, but the new HST observations are the first to suggest that this planet undergoes a change of seasons. Using Hubble, three sets of observations of Neptune were made, in 1996, 1998, and 2002, each covering a full rotation of the planet. The images showed progressively brighter bands of clouds encircling the planet's southern hemisphere.

The recent trend of increasing cloud activity on Neptune has been qualitatively confirmed at near-infrared wavelengths by Keck Telescope observations between July 2000 and June 2001 (by H. Hammel and co-workers). Additional near-infrared



Images of Neptune taken between 1996 (bottom) and 2002 (top) during different rotation phases (Courtesy of NASA)

observations were made last summer with NASA's Infrared Telescope Facility on Mauna Kea, in Hawaii, to further characterise the changes in the high-altitude cloud structure.

Neptune's rotation axis is tilted at an angle of about 29 degrees, so that the planet's northern and southern hemispheres alternate in their positions relative to the Sun. Therefore, like the Earth, Neptune should have four seasons, but unlike Earth they should last for decades rather than months. What is remarkable is that Neptune exhibits any evidence at all of seasonal change given that the Sun, as viewed from the planet, is 900 times dimmer than it is from Earth. Since the amount of solar energy intercepted is what should determine the seasons, it is still a mystery how such a small energy input can affect the dynamic nature of Neptune's atmosphere.

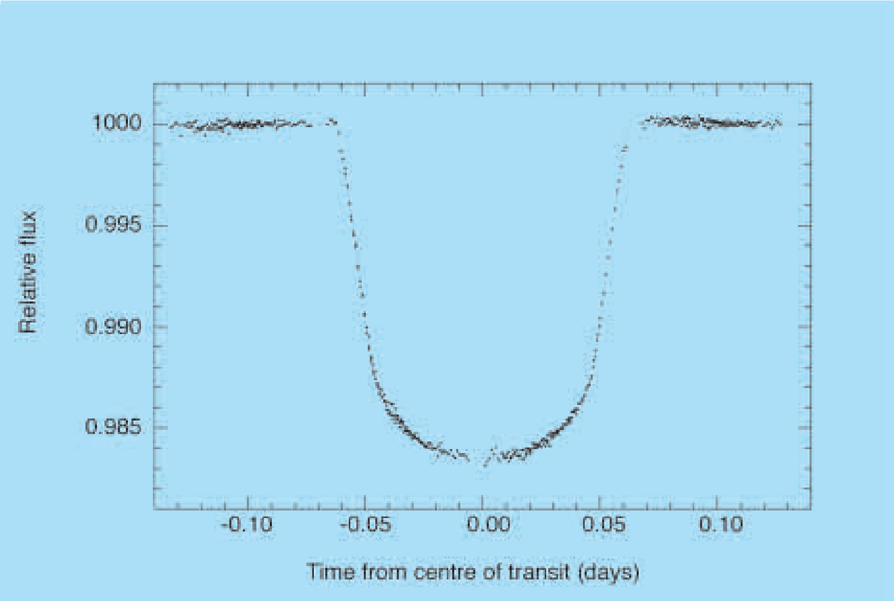
Extrasolar Planets: A Giant Planet around the Star HD209458

One of the most important questions in science and philosophy is: 'Are we alone in the Universe?' Answering it is quite hard, but we can approach the problem by first addressing other questions such as: 'Are there planets around other stars', and 'if so, are they suitable for the development of life as we know it?'

It is now almost ten years since the first unambiguous detection of an extra-solar planet, and by now we can count more than a hundred of them around stars in the solar neighbourhood. Still, characterising those planets, i.e. determining all of their properties, is a much harder task that requires special tools and techniques. Fortunately, HST is equipped with the high sensitivity and high-angular-resolution tools needed to do the job.

One of the techniques that can be used with Hubble is to study the transit of a planet in front of its parent star. As the transit occurs, a small fraction of the stellar surface is covered by the planet, producing a 'partial eclipse' and causing the observed luminosity of the star to be somewhat lower than normal, the more so the larger the planet involved. In this way, one can directly determine the size of the planet relative to the star. Since the star's radius is known from other independent measurements, one can obtain an accurate measure of the absolute size of the planet. Moreover, from measurements of the parent star's motion, which trace its 'wobble' due to the presence of the planet, one can unambiguously determine the planet's mass. Knowing the mass and the size of the orbiting planet, one can derive its average density, thereby providing stringent constraints for theoretical models of planet formation.

The low-mass companion to the star HD 209458, denoted as HD 209458b, is the



The HST-STIS light curve of HD209458 provides evidence for a planet transit (Courtesy of T. Brown et al.)

first extra-solar planet found to transit the disk of its parent. Hubble Space Telescope Imaging Spectrograph (STIS) observations of the HD 209458 system (see figure) indicated the presence of a companion planet with an orbital period of 3.52 days, a mass at least 70% of that of Jupiter, a radius about 35% larger than Jupiter's, and orbiting at a distance from its parent star of only 1/200th of the Sun – Earth distance. These properties suggest a planet rather similar to Jupiter, but orbiting closer around its star than Mercury does around the Sun. As a consequence, it is estimated that the planet's upper atmosphere is so hot that it boils hydrogen off into space

A detailed analysis of the transit light curve led to the conclusion that the planet had no rings (which would have appreciably altered the curve's shape), nor an orbiting satellite with mass greater than 3 times the mass of the Earth (whose presence would have affected the curve's symmetry).

On the other hand, spectrophotometric observations made at the times of four transits revealed that a neutral sodium absorption line was becoming detectably stronger (about 2 parts in 10 000), providing clear evidence for the presence of a sodium-rich atmosphere on the planet. This represents the first detection of an atmosphere on an extra-solar planet, marking the beginning of a new and exciting era in which such planets begin to be fully characterised, rather than just being merely detected gravitationally as point sources with mysterious properties.

Recently, an international team using the STIS, led by Alfred Vidal-Madjar (CNRS/Institut d'Astrophysique de Paris), has detected, for the first time ever, the presence of oxygen and carbon in the extra-solar planet's atmosphere's evaporating envelope. Analysis of the starlight passing through the envelope shows that it is being torn off by the extreme 'hydrodynamic drag' created by its evaporating hydrogen atmosphere. The astronomers believe that the oxygen present exists naturally, and is not being produced by any sort of life on the gaseous hot world. Nevertheless, it is a promising demonstration that the chemical composition of atmospheres on planets many light-years away can be measured, as this could someday lead to the discovery of the atmospheric biomarkers of life on such extra-solar planets.

Because the oxygen and carbon are bleeding off the gas-giant extra-solar planet, it has been dubbed 'Osiris', after the Egyptian god who lost part of his body – like HD209458b – after having been killed and cut into pieces by his brother to prevent his return to life.

The Helix Nebula: When Opportunity Knocks

The Helix Nebula, also known as NGC 7293, lies about 600 light-years away from Earth, towards the constellation of Aquarius. It has a diameter of about 2.4 light-years, thus spanning as much as 14 arcminutes in the sky. The image shown here was made by combining newly

Composite picture of the Helix Nebula produced by combining Hubble ACS images with wide-angle images from the Kitt Peak Mosaic Camera (Credit NASA, NOAO, ESA, the Hubble Helix Nebula Team, M. Meixner (STScI) and T.A. Rector (NRAO)) released images from Hubble's ACS instrument and wide-angle images from the Mosaic Camera on the NSF 0.9 m Telescope at Kitt Peak National Observatory (USA). It is one of the largest and most detailed celestial images ever made.

These Hubble observations were made possible by a fortuitous combination of events. One of the most prominent of the meteor showers is the Leonids each November. The shower in 2002 was predicted to be especially heavy, and so to minimise the risk to the telescope its aft end was pointed towards the incoming stream, whilst also minimising the cross-section presented by the solar arrays. The 'stand down' period was to last from 0 to 14 hours UT on 18 November, but in preparing for it STScI staff member Ian Jordan noticed that just outside the nominal planned safe pointing direction lay the Helix Nebula, which had been examined by Hubble many times before. This was too good an opportunity to miss and so, having secured the agreement of the HST Project at Goddard Space Flight Centre (GSFC), a small group of STScI scientists, led by Margaret Meixner, and including ESA astronomers Letizia Stanghellini and the author, created a programme that would use the nine available HST orbits to image a substantial portion of the large Helix in two colours, using both Hubble's ACS and WFPC2 instruments. The intention was to establish a first-epoch dataset suitable for later work to measure the motions of the tight knots immersed in the nebula.

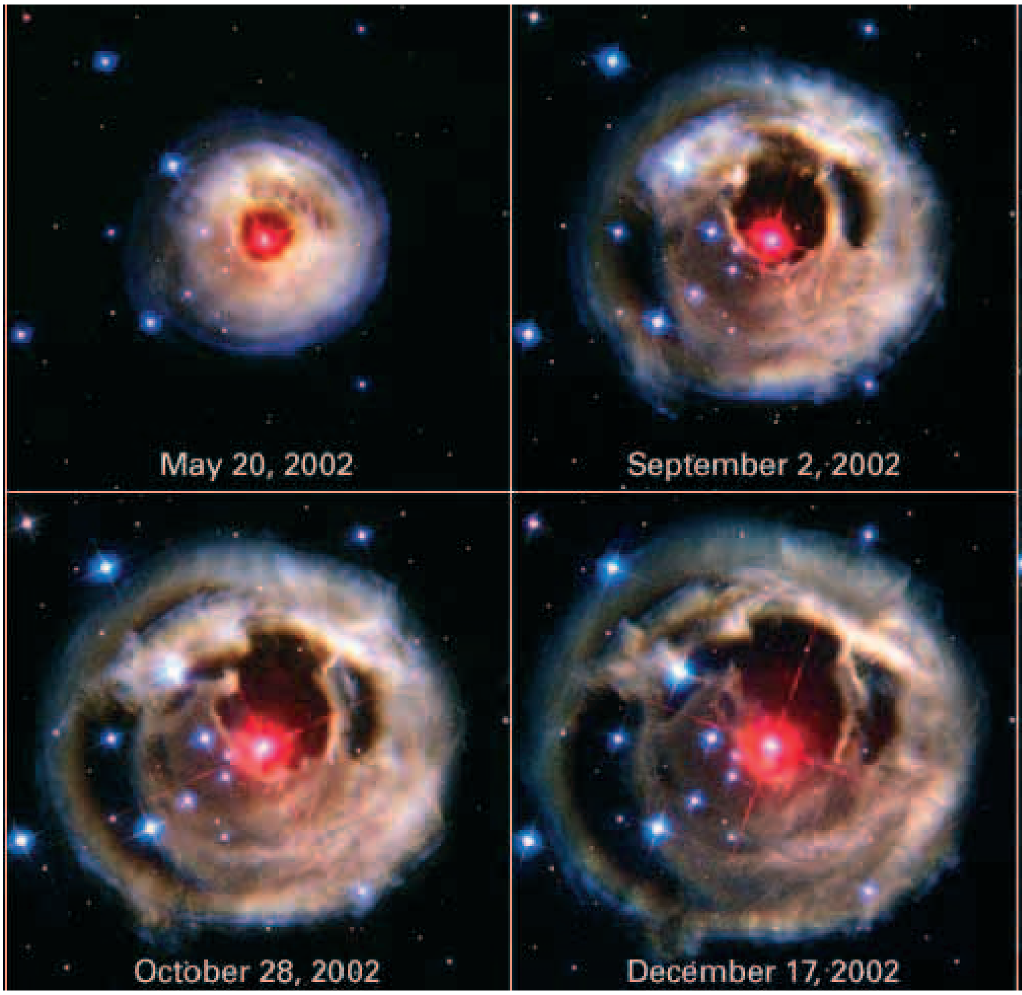
The Mysterious Outburst of the Star V838 Monocerotis

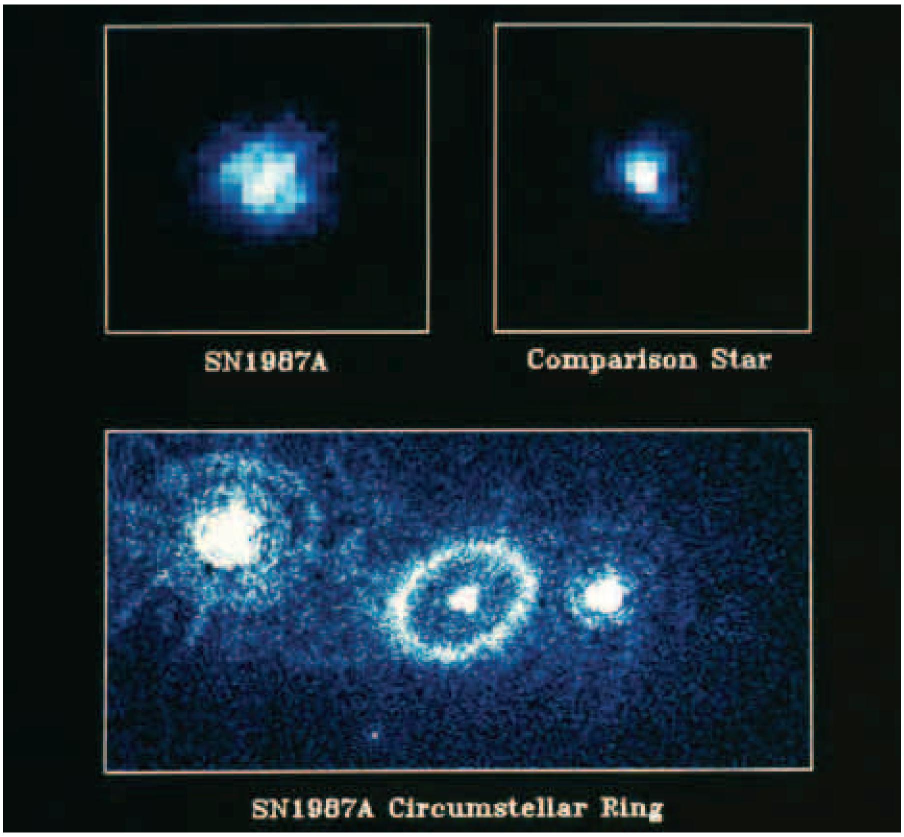
The previously unknown variable star V838 Monocerotis erupted in early 2002, brightening suddenly by a factor of almost 10 000 at visual wavelengths. Unlike a supernova or nova, V838 Mon did not explosively eject its outer layers; rather, it simply expanded to become a cool supergiant with a moderate-velocity stellar wind. A series of superluminally expanding ring-like structures appeared around the star shortly afterwards, as illumination from the outburst propagated into a surrounding, pre-existing circumstellar dust cloud (see figure). They are produced by simple reflection of light from the star by dust particles that are present in the circumstellar medium and, therefore, they are called 'light echoes'. This was the first light echo seen in the Milky Way since 1936.

The star and its surrounding medium has been studied by an international team led by Howard Bond (STScI) and including Romano Corradi (Isaac Newton Group of Telescopes, La Palma), Ulisse Munari (Observatory of Padua) and the author. They obtained a series of high-resolution images and polarimetry of the light echo with Hubble's ACS instrument.

The echo exhibits a series of circular arcs, whose angular expansion rates show that the star is more than 6000 light-years away. The polarimetric imaging would imply an even greater lower limit to the distance, as high as 19 000 light-years. Both of these limits mark the first times that these phenomena have been used to constrain an astronomical distance in the Milky Way. At maximum light, the object was extremely luminous, at least as bright as visual absolute magnitude 9.6, which is about a million times brighter than the Sun. The spectrum of the star during the outburst remained that of a cool stellar photosphere, but as the outburst subsided a composite spectrum appeared, which revealed the presence of a hot-star companion.

V838 Mon thus appears to represent a new class of stellar outburst, occurring in binary systems containing a relatively hot Main Sequence star and a companion that erupts to become a cool supergiant. A remarkably similar event was seen in the Andromeda Galaxy in the late 1980s. The presence of the circumstellar dust implies





Historic image of SN 1987A and its equatorial circumstellar ring taken on 24 August 1990 with the ESA Faint Object Camera (FOC)

that previous eruptions have occurred, and spectra show it to be a binary system. When combined with the high luminosity and unusual outburst behaviour, these characteristics indicate that V838 Mon represents a hitherto unknown type of stellar outburst, for which we have no completely satisfactory physical explanation.

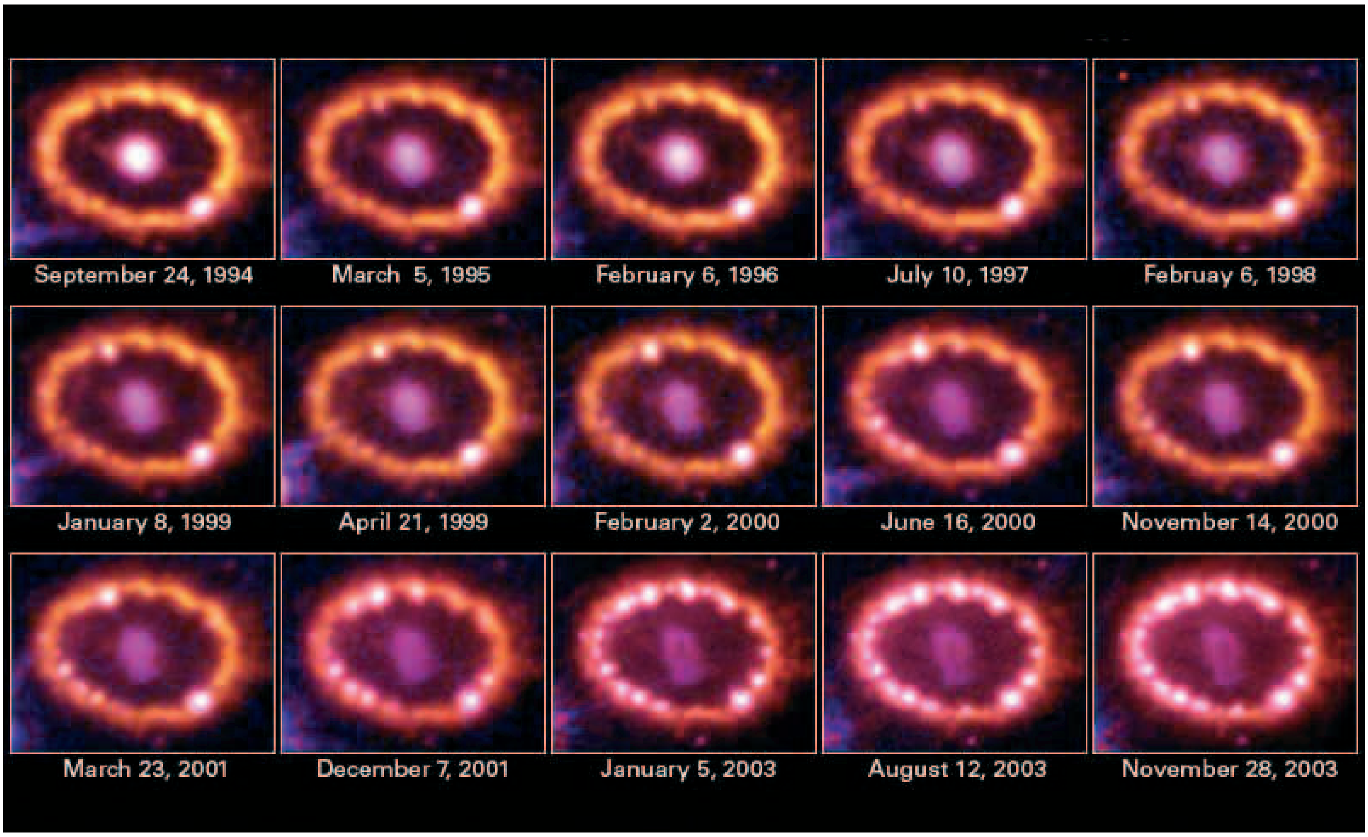
Fireworks in SN 1987A's Equatorial Ring

SN 1987A exploded on 23 February 1987 in the Large Magellanic Cloud. Hubble was not yet in orbit when this rare chance to observe a nearby supernova appeared, but it took advantage of the opportunity as soon as it became operational. ESA's Faint Object Camera took the first images on 23/24 August 1990, which revealed SN1987A to be crowned by a glorious circumstellar ring (see figure). Later, two more rings were discovered with WFPC2.

Since then, HST has kept an attentive eye on SN 1987A, and its observations have provided many fundamental results, including a direct measure of the supernova's expansion, the detailed properties of its surrounding rings, the accurate measurement of the distance to the supernova, and the origin of the stars associated with it.

Recently, Hubble has provided dramatic evidence of high-velocity material from the supernova explosion starting to overtake and crash into the slower-moving inner ring (see figure). Relatively quiescent until 1996, in 1997 the circumstellar ring started to develop bright spots, and now one can identify more than a dozen. They are the result of the fast-moving component of the ejecta, travelling at 15 000 km/s or 1/20th the speed of light, colliding with the stationary equatorial ring.

Comparison of Hubble ACS images of V838 Mon obtained between 20 May 2002 and 8 February 2004. The structure is dominated by a series of nearly circular arcs and rings, centered on the variable star, but there are cavities that become progressively more asymmetric with time
(Credit: H.E. Bond (STScI), Hubble Heritage Team, NASA, ESA)



Images of SN 1987A and its inner circumstellar ring obtained with HST's WFPC2 instrument between September 1994 and November 2003. It appears that the quiescent ring has developed at least thirty hot spots in the last five years (Courtesy of R.P. Kirshner (Harvard) & NASA)

Over the next decades, as 'slower' ejecta layers (keeping in mind that they still have velocities of several thousand km/s!) reach the ring, more and more spots will light up and the whole ring will shine as it did in the first several months after the explosion. Eventually, the bulk of the ejecta will completely sweep the ring up, clearing the circumstellar space of that remnant of the pre-supernova wind activity.

Supernovae and Cosmology: Clues to the Acceleration of the Universe

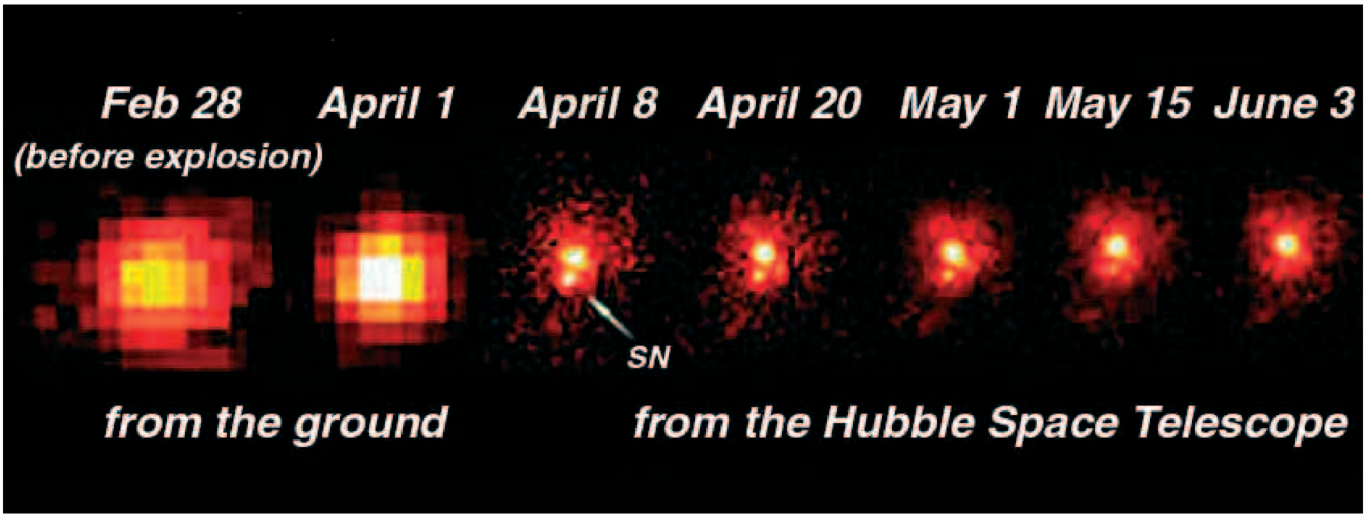
Since supernovae are very bright objects and relatively common, they are prime candidates for probing the distances to galaxies. A particular type, denoted as Type Ia supernovae (SNIa, characterised by the absence of hydrogen in their envelopes) are perhaps the best 'standard candles'. They are so similar to each other that their brightness provides a dependable gauge of their distance, and so bright that they are visible billions of light years away. However, one needs also to determine the exact value of their luminosity before using them as 'proper' standard candles and most progress in this field has been made over the last decade.

Using Hubble, an international team led by Allan Sandage, and including Gustav Tamman (Univ. of Basle), Abi Saha (STScI), and ESA's Duccio Macchetto and the author, has conducted an extensive programme to determine the absolute brightness of a selected sample of supernovae. This has allowed the placing of SNIa on an absolute scale, and the expansion rate of the Universe, the so-called 'Hubble Constant', to be determined as 63 km/s/Mpc, with a precision of 10%. This implies possible ages of the Universe in the range 11-17 billion years, depending on the acceleration/ deceleration history of the Universe itself.

When researchers initially set out to measure the Universe's expansion rate, they expected to find that distant supernovae appeared brighter than their redshifts would suggest, indicating a slowing rate of expansion with time due to the gravitational attraction of all masses in the Universe. Instead they found the opposite: at a given redshift, distant supernovae were dimmer than expected (see accompanying figure). So in fact, expansion was accelerating.

Not only did this discovery mean that the Universe would never come to an end, more fundamentally it implied that 70% or more of the Universe is made of something mysterious that we know nothing about - namely the so-called 'dark energy' that approximately 7 billion years ago overcame gravity and started pushing the Universe into an accelerated expansion.

Currently, there are two leading interpretations for the 'dark energy', as well as many more exotic possibilities. It could be an energy percolating from empty space as Einstein's theorised 'cosmological constant', an interpretation which predicts that 'dark energy' is unchanging and has a prescribed strength. An alternative possibility is that dark energy is associated with a changing energy field dubbed



Sequence of observations of supernova SN 1998ay (Courtesy of the Supernova Cosmology Project Team)

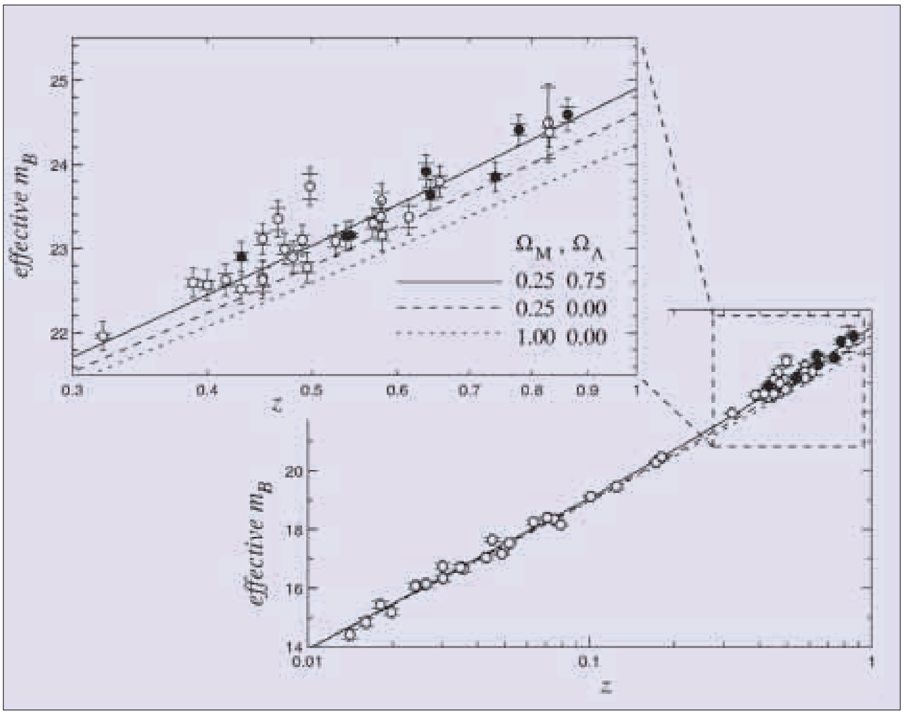
'quintessence'. This field would be causing the current acceleration, in a milder version of the inflationary episode from which the early Universe emerged.

When astronomers first realised that the Universe was accelerating, the conventional wisdom was that it would expand forever. However, until we understand the nature of 'dark energy' and its properties better, other scenarios for the fate of the Universe are possible. If the repulsion from 'dark energy' is or becomes stronger than Einstein's prediction, the Universe may be torn apart by a future 'Big Rip', during which it expands so violently that first the galaxies, then the stars, then the planets, and finally atoms come 'unglued' in a catastrophic end of time. Currently, this idea is very speculative, but one being pursued by the theorists. At the other extreme, a variable 'dark energy' might fade away and then flip in force such that it pulls the Universe back together rather then pushing it apart. This would lead to a 'Big Crunch', in which the Universe ultimately implodes.

The Hubble Ultra-Deep Field: A Journey to the Frontiers of the Universe

One of the most ambitious and successful HST projects has been the study of the so-called 'Hubble Deep Field' (HDF). For 12 consecutive days in December 1995, the telescope was pointed at an area of the sky in the constellation Ursa Major, selected for being most devoid of nearby objects, so as to probe the distant Universe, and thus the distant past.

The WFPC2 was used to image the field in four broad bands, spanning the spectrum from the near-ultraviolet to the near-infrared. The HDF images showed that nearly a third of very distant galaxies, which existed early in the history of the Universe, appear to be interacting galaxies. In particular, the Hubble Deep Field survey has uncovered quite a number of odd-shaped, disrupted-



Observed magnitudes of SNIa supernovae as a function of redshift shows that distant supernovae become dimmer than expected (Courtesy of the Supernova Cosmology Project Team)

A composite image of the Hubble Ultra-Deep field (Courtesy of S.W.S. Beckwith, the HUDF Team and NASA)

looking galaxies. They offer direct visual evidence that collisions between galaxies were more the rule than the exception in the early days of the Universe.

This analysis has led to the conclusion that the Big Bang may have been followed by a stellar 'baby boom'. The early Universe may have had an active, dynamic youth in which stars formed out of clouds of dust and gas at incredible rates. Consequently, most of the stars that the Universe will ever make may have already been formed, and so it now contains largely 'mid-life' stars.

The installation on HST in 2002 of the new Advanced Camera for Surveys (ACS), with its tenfold increase in sensitivity, opened new possibilities for exploring the Universe and so an even more ambitious project has been implemented to reach out to its ultimate frontiers, namely the Hubble Ultra-Deep Field (HUDF) project. The main science drivers are to study galaxy evolution and cosmology, including probing the epoch of re-ionisation up to redshifts of about 6.5 and characterising not only the colours, but also the morphologies of faint sources. The ACS is the primary instrument for these surveys, but WFPC2, NICMOS and STIS are also being used in parallel.

The HUDF survey is being carried out using 'Director's Discretionary Time', based on the consensus recommendation of a Scientific Advisory Committee to the STScI Director Steven Beckwith. A local Working Group, composed of STScI astronomers, led by Massimo Stiavelli, and including ESA's Massimo Robberto and the author, has assisted in the definition of the project and has been looking in detail at the implementation of the survey. The HUDF observations began on 24 September 2003, and continued until 15 January 2004. The reduced ACS images and source catalogues were released on 9 March, just seven weeks after the completion of the observations.

The composite picture that has emerged from the million-second-long HUDF exposure reveals the first galaxies to emerge from the so-called 'dark ages', the time about half billion years after the Big Bang when the first stars reheated the cold, dark Universe. The final ACS image (see figure) is studded with a wide range of galaxies of various sizes, shapes, and colours. In vibrant contrast to the image's rich harvest of classic spiral and elliptical galaxies, there is a zoo of oddball galaxies littering the field. Some look like toothpicks, others like links on a bracelet. A few appear to be interacting. Their strange shapes are a far cry from the majestic spiral and elliptical galaxies we see today. These oddball galaxies chronicle a period when the Universe was more chaotic. Order and structure were only just beginning to emerge!

The Future

Because of the extraordinary scientific results obtained so far with Hubble and the many more expected in the years to come, in late 1997 the length of the HST mission was extended by five more years with respect to the original 15-year design lifetime. The plan was to continue operating the telescope until the year 2010, with the hope of providing continuity for astronomers by then having the James Webb Space Telescope (JWST), Hubble's near/mid-infrared successor, in full operation. The next Hubble servicing mission (SM4), planned for mid-2006, was to include the installation of the Cosmic Origins Spectrograph (COS, a high-resolution ultraviolet spectrograph) and the Wide Field Camera 3 (WFC3, with imaging capabilities extending from the near-ultraviolet to the near-infrared).

This is not to be: to the dismay of most astronomers, on 16 January NASA announced that there would be no further Hubble servicing missions, with future Space Shuttle flights going exclusively to the International Space Station (ISS). The decision was based on a complex mix of factors, including crew safety, budget constraints and a commitment to complete the ISS before the Shuttle is phased out at the end of the decade, with crew safety being a primary factor following the tragic loss of 'Columbia' in February 2003. The US National Academy of Science has formed a panel to assess the viability of Space Shuttle or robotic servicing options as well as benefit and risk assessments, and we hope that plans will proceed expeditiously to save this premier scientific mission.

While these studies are underway, the present plan is to exploit the current instruments and capabilities of Hubble until it becomes impractical to continue to do so. The gyroscopes, for example, are known to have a finite lifetime, so there is a high probability that HST will have to be operated in a two-gyro mode relatively soon, which may imply substantial restrictions on the sky coverage and on the spatial resolution of the science observations. Eventually, a controlled de-orbiting of Hubble will have to take place, using a special robotic mission.

Astronomers are renowned for being creative and unconventional. Their ingenuity saved the HST mission from failure when the spherical-aberration problem with its primary mirror was discovered shortly after its launch, and was brilliantly fixed by installing corrective optics for all instruments. Now again, astronomy's best creative minds are hard at work to find ways to extend Hubble's lifetime without violating safety and budgetary constraints. Among the many innovative ideas put forward during a series of brain-storming sessions at STScI, one that has been pursued in earnest is to add a complement of gyroscopes and a power supply to the robotic device that is being designed to de-orbit HST. When that device locks onto the ailing telescope, not only could it guarantee a controlled atmospheric reentry, but it could also ensure several more years of fully functional lifetime for Hubble. The idea of an innovative servicing mission which, if successful, will allow continuity of the science from the observatory, has now been further developed and although much more work will be needed it is encouraging to know that, when presented with such difficult problems, scientists can be inventive enough to devise and pursue 'seemingly impossible' solutions that may eventually come to the rescue against all odds! esa

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ESA Directorate of Resources Management, Paris, France

Manfred Warhaut
ESA Directorate for Operations and Infrastructure, ESOC, Darmstadt, Germany

Why a Second ESA Deep-Space Ground Station?

Ground-station support for the early ESA deep-space missions Giotto and Ulysses was, and in Ulysses' case still is being, provided by the NASA Deep Space Network (DSN). To ensure independent access to its next generation of deep-space planetary exploration missions – Mars Express, Rosetta, Venus Express and Bepi Colombo – ESA, through its Technical and Operational Support (ESOC) and Science Directorates, embarked on the development of the New Norcia ground station in Western Australia. This station became operational in November 2002, and since June 2003 has been supporting the Mars Express mission on a daily basis.

With its 35 m-diameter antenna, New Norcia will not only provide tracking, data acquisition and command support to ESA's planetary exploration missions going out into deep space, which requires reliable communication at distances of up to 6.3 AU from Earth (1 AU is the distance from the Earth to the Sun), but also to the Agency's astronomy and survey missions going to the L2 Lagrangian point, namely Herschel/Planck and Gaia. Communicating with these missions will require large dish antennas in order to meet their high data-rate demands (in excess of 1.5 Mbits/sec). Consequently, in September 2001 the Technical and Operational Support and Science Directorates acknowledged that ESA needed a second deep-space ground station in order to support its future missions adequately. This opinion was strengthened by

The Cebreros site, unrenovated and still with its old antenna, about 90 km northwest of Madrid (E)

findings of the Inter-Agency Consultative Group for Space Science (IACG), comprising members from NASA, ESA, JAXA (Japan) and RASA (Russia), which show that the future demand for world-wide deep-space ground stations will greatly exceed availability. In the wider European context, therefore, the initiative to establish a European Deep-Space Network, particularly for the future planetary missions, is seen as vital.

Why Choose Cebreros?

To complement the visibility and coverage provided from New Norcia, the second station has to be located either 120 deg East or West of it. Consequently, the ESA Satellite Tracking Station (VILSPA), recently renamed the European Space Astronomy Centre (ESAC), at Villafranca near Madrid, could have been a perfect site. However, contacts with the telecommunications authorities managing the Spanish frequency spectrum (Secretaria de Estado de Telecomunicaciones y la Sociedad de la Información, SETSI) indicated that the use of deep-space frequencies from there would be problematic as third-generation mobile-telephone repeater towers were scheduled to be installed in the area in the near future and there could be interference problems. The growing number of constructions in the area was also deemed to be incompatible with a deep-space ground station.

Consequently, Cebreros in the province of Avila, about 90 km northwest of Madrid and about 60 km from ESAC, became the site of choice. In addition to complying perfectly with all of the technical selection criteria, it also enjoys particularly favorable weather conditions, which also influence station performance (rain attenuation, wind speed). For this site also, the most stringent requirement was to get the required radio-frequency clearance for data transmission and reception in the relevant frequency bands from the Spanish authorities.

The proximity of Cebreros to ESAC helps to meet the need for cost-efficient operations and maintenance, by allowing the existing contract provisions for Villafranca to be extended to include the new station. Equally importantly, the Cebreros site also has the medium/long-term potential to host the existing antenna dishes at ESAC, should the need arise due to the encroaching urbanization around that site. The operational and science operations facilities could still be maintained at ESAC.

The Cebreros site is owned by the Instituto Nacional de Técnica Aeroespacial (INTA) and formerly hosted a NASA station, which was primarily used in the sixties and seventies for tracking, data acquisition and commanding of lunar and interplanetary NASA/JPL missions. The station also provided support to ESA's Giotto mission during its fly-by of comet Halley in 1986, but since then NASA has consolidated its DSN station assets at its Robledo site.

Agreement between the Kingdom of Spain and ESA

Negotiations for an Agreement between Spain and ESA were initiated in April 2002. As the second 35 m deep-space

The Agreement between the Kingdom of Spain and ESA for the Cebreros deep-space ground station

ground station constitutes a strategic asset for its future programmes, the Agency had three prerequisites:

- ESA management authority for the site,
- an international agreement similar to that concluded with respect to the Villafranca station,
- guaranteed growth potential for the new site.

Between April 2002 and May 2003, several meetings took place between ESA and representatives of the Spanish authorities: Centro para el Desarrollo Tecnológico Industrial (CDTI), the Ministry of Foreign Affairs, the Ministry of Defence, INTA and SETSI. The negotiations, which were held in a very constructive atmosphere, focused on the guaranteed growth potential that the Agency had asked for, exemption from indirect taxes, and the radio-frequency clearances. A satisfactory consensus was reached on all of these issues, and the 'Agreement between the Kingdom of Spain and the European Space Agency for the Establishment of Ground Tracking and Data Acquisition Facilities, including a Deep Space Antenna at the Cebreros (Avila) Site' was duly signed on 22 July 2003.

The terms of the Cebreros Agreement are similar to those governing ESA's activities at Villafranca, which was signed in 1974 and still remains in force today. It has the classical structure of a Host Agreement with provisions specifying the rights and obligations of both parties, and in particular the immunities afforded to ESA with respect to the facilities to be set up and operated on the Cebreros site.

Station Completion and First Users

Industrial activities began in February 2003, with the start of work on the antenna front-end. In September, the on-site activities started with the construction of the antenna-tower access road and the

Technical Features of the Cebreros Station

The proposed antenna system will enable X-band data uplinking (7.145 – 7.235 MHz) and downlinking (8.400 – 8.500 MHz) and will provide a Ka-band receive capability (31.800 – 33.200 MHz), with the possibility of adding Ka-band transmission at a later date if needed.

The design of the antenna installation is very similar to that at New Norcia, in terms of the antenna front- and back-ends, the high-precision frequency and timing system based on hydrogen masers, and the site infrastructure. The 35 m dish sits on a full-motion turning-head pedestal incorporating a beam-waveguide feed system. The radio-frequency signals are transmitted/received by means of mirrors, cryogenically cooled X-band and Ka-band low-noise amplifiers, and X-band transmitters (20 kW, 2 kW and 400 kW).

The antenna is close to 40 m high and the structure and the equipment mounted on the pedestal weigh approximately 630 t. The smooth motion provided by the antenna servo subsystem and the stiffness of the mechanical structure under typical environmental conditions provide excellent performance ratings: namely a main reflector surface accuracy of 0.3 mm, with a tracking error as small as 0.006 deg at Ka-band.

Advanced, mostly digital technology is applied for the receivers, demodulators and ranging equipment, which is needed to determine the position/orbit of the spacecraft. As at all other ESA ground stations, the Cebreros antenna will be remotely controlled and operated from ESOC in Darmstadt (D). This avoids permanent manning of the station and limits visits by maintenance staff to occasional checks on a weekly basis.

Artist's impression of the completed 35 m Cebreros deep-space antenna

antenna pedestal. The majority of the site-preparation activities were completed by INTA (Spain) in December. The actual hand-over of the site to ESA took place in March 2004 and refurbishment of the site infrastructure and installation of a new power plant are already underway. Overall system acceptance testing is planned to start in August, with operational readiness of the new ground station foreseen for 30 September 2005.

The first user of the Cebreros station will be the Venus Express mission, in late 2005/early 2006, to be followed by Smart-2 in November 2007, Gaia in 2010, and Bepi Colombo in 2012. Possible use of Cebreros for the Herschel/Planck mission in 2007 is also being investigated. It is subsequently planned to use the station for the Rosetta mission's near-comet operations and lander delivery in 2014.

Acknowledgements

The timely and successful conclusion of the Cebreros Agreement was made possible by the support and dedication of Angel Orenes (Spanish Ministry of Defence), Juan Luis Muñoz de Laborde (Spanish Foreign Ministry), Ignacio Yurrita and José M. Leceta (CDTI), Moisés Fernández (INTA), Ricardo Alvariño and Angel Díez (SETSI), and Chris de Cooker, Marco Ferrazzani, Werner Frank, Immi Tallgren and Enrico Vassallo (ESA).

The Industrial Consortium

The industrial team for the construction of the new deep-space antenna at Cebreros includes the following companies:

– SED Systems (Canada): Prime Contractor (antenna front-end), with Vertex Antennentechnik, Germany (mechanical and servo system), MIRAD, Switzerland (radio-frequency components), ESTEYCO and NECSO, Spain (antenna tower infrastructure)
– LV Salamanca (Spain): site infrastructure and building remodelling
– S&C (Germany): power plant
– ND SatCom AG (Germany): antenna back-end and communications infrastructure
– Timetech (Germany): frequency and timing system; with Observatoire de Neuchatel (Switzerland): maser
– Alcatel Bell Space NV (Belgium): Ka-band down-converters
– IN-SNEC (France): L- and X-band converters
– BAE Systems (UK): modem and ranging system
– CS (France) : telemetry and telecommand system.

Artist's Impression of Double Star in orbit around the Earth

East Meet
Near-Eart
– Double

Bodo Gramkow, Philippe Escoubet & the Double Star Project Team
ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Peter Bond
Space Consultant, Cranleigh, United Kingdom

Karl Bergquist
Directorate of External Relations, ESA, Paris

Since their dual launches in July and August 2000, ESA's four Cluster spacecraft have been flying in formation around the Earth, sending back the first detailed, three-dimensional information about the magnetosphere and its interaction with the solar wind. This unique examination of the magnetic bubble that surrounds our planet is about to be enhanced by Double Star, a groundbreaking collaboration involving ESA and the Chinese National Space Administration (CNSA).

The Double Star programme involves the launching of two satellites - the first already placed in orbit on 29 December 2003 and the second scheduled for launch in July 2004 - each carrying experiments provided by European and Chinese institutes. This will enable scientists to analyse data sent back simultaneously from no fewer than six spacecraft, each located in different regions of near-Earth space. The simultaneous, six-point study should provide new insights into the mysterious mechanisms that trigger magnetic storms and the brilliant auroral displays in Earth's polar skies.

A History of Collaboration

Scientific collaboration between China and ESA began in 1980 with the signing of a document facilitating the exchange of information between ESA and China's Commission for Science and Technology. Twelve years later, the Chinese approached ESA with a proposal to establish a Data and Research Centre in Beijing for Europe's Cornerstone Cluster mission.

China's request to participate in an international space programme for the first time culminated in an official cooperation agreement that was signed on

ESA Director General, Antonio Rodotà, at the signing of the historic Double Star collaboration agreement with the CNSA Administrator, Luan Enjie, on 9 July 2001

25 November 1993. As a result of this agreement, a number of Chinese scientists and engineers were hosted by ESA and the institutes of the Cluster Principal Investigators (PIs), while five of their compatriots became co-investigators on Cluster.

The next step came in 1997, when Professor Liu Zhen-Xing of the Chinese Centre for Space Science and Applied Research (CSSAR) gave a presentation on the proposed Double Star programme at the Cluster Science Working Team meeting. Six Cluster PIs responded to the invitation to participate by offering to provide flight-spare models of their Cluster experiments.

In September 1999, the ESA Director General was invited by the Administrator of the Chinese National Space Administration to discuss ESA–China collaboration in space activities, and more particularly collaboration on the Double Star Programme. Shortly afterwards the Double Star Study Report (Phase-A report) was presented to ESA and to the Cluster Science Working Team. Once again, the European response was very positive.

Further progress was made in September 2000 when Double Star was given the green light by the Chinese Government. In April 2001, a European delegation composed of ESA representatives and European PIs visited CNSA in order to finalise the preparation of the agreement between the two agencies and to review the project's status. Finally, on 9 July 2001, an historic agreement to develop the joint mission was signed at ESA Headquarters in Paris by ESA's Director General, Antonio Rodotà, and the CNSA Administrator, Luan Enjie:

"This agreement marks a significant advance for international co-operation in the exploration and peaceful use of outer space," said Mr Rodotà. *"It is one of the most important landmarks in scientific collaboration since ESA and the People's Republic of China first agreed to exchange scientific information more than 20 years ago."*

"The Double Star programme will be just the first step in substantial co-operation between the Chinese National Space Administration and ESA," added Mr Luan Enjie. *"The signing of today's agreement paves the way not only for reciprocal co-operation between scientists, but for the establishment of comprehensive co-operation between the two agencies."*

Under the agreement, ESA committed to contribute 8 million Euros to the Double Star programme. This funding was to be used for the refurbishment and pre-integration of the European instruments, the acquisition of data for 4 hours per day, and the co-ordination of scientific operations. China's contribution would include the two spacecraft buses, eight scientific experiments, and the launchers and operations.

Chinese and European engineers inspecting the TC-1 spacecraft during the launch campaign

The launch of the first Double Star spacecraft, TC-1, on its Long March 2C/SM rocket on 29 December 2003

A Crossroads

Following the signing of the landmark agreement, rapid progress was made, despite the cultural and language differences and wide geographical separation.

After 18 months of intense interface-definition work, the hardware testing phase began in autumn 2002 with a successful compatibility test between European and Chinese equipment at Imperial College in London (UK).

In parallel, the assembly of the spacecraft structural-thermal model in China culminated with the successful completion of the environmental test programme in February 2003. An unforeseen obstacle, however, was the outbreak of SARS (Severe Acute Respiratory Syndrome) in April 2002, which meant that planned meetings had to be cancelled and replaced by videoconferences, remote data transfer, web cams and interactive messaging dialogues. ESA's Payload Manager for Double Star (B. Gramkow) had to obtain special permission to travel to China while the global alert issued by the World Health Organisation was still in force. Through the generous assistance of the CNSA and CSSAR, those involved could continue to work and the mission was saved. Despite the inevitable delays caused by the SARS outbreak, the payload and the CSSAR subsystems were delivered to Beijing by 10 July for integration into the TC-1 flight spacecraft (TC stands for 'Tan-Ce', which means 'Explorer'). The installation of Chinese equipment at ESA's Villafranca ground station in Spain was also successfully completed.

The launch campaign for the first Double Star satellite began in mid-November, and lasted five weeks. The launch took place as planned before the end of the year, at 19:06 UT on 29 December. The first and second stages of the Long March 2C/SM rocket fired for 7 minutes, before the solid-fuel upper stage injected the spacecraft into its operational orbit.

The TC-1 spacecraft was then in a 570 km x 78 970 km orbit with a 28.5 deg inclination. Although the apogee is about 12 000 km higher than expected, due to over-performance of the upper-stage engine, this should not affect the scientific objectives. Indeed, the higher orbit means that the spacecraft will now be able to observe the Earth's bow shock, which was not in the original science plan. Preliminary estimates indicate that the number of conjunctions with Cluster have decreased slightly, but this will be compensated by the longer time interval of the individual conjunctions.

The second satellite (TC-2) is now being assembled prior to launch in July 2004, when it will join the Cluster flotilla in a polar orbit. Meanwhile, the operational lifetime of Cluster has been extended for three years until 2005, in order to enable the unique, six-spacecraft investigation to take place.

"We have made remarkable progress, thanks to all of the scientists and engineers who have worked with such

The Double Star Scientific Payloads

Equatorial Double Star (TC-1)		Polar Double Star (TC-2)	
Instrument	*PI*	*Instrument*	*PI*
Active Spacecraft Potential Control (ASPOC)	K. Torkar, IWF, Graz, Austria	Neutral Atom Imager (NUADU)	S. McKenna-Lawlor, National Univ. of Ireland
Fluxgate Magnetometer (FGM)	C. Carr, IC, UK	Fluxgate Magnetometer (FGM)	T. Zhang, IWF, Austria
Plasma Electron and Current Exp. (PEACE)*	A. Fazakerley, MSSL, Dorking, UK	Plasma Electron and Current Exp. (PEACE)*	A. Fazakerley, MSSL, Dorking, UK
Hot Ion Analyser (HIA), sensor 2 of CIS	H. Rème, CESR, Toulouse, France	Low Energy Ion Detector (LEID)**	Q. Ren and J.B. Cao, CSSAR, China
Part of Spatio-Temporal Analysis of Field Fluct. (STAFF) + Digital Wave processor (DWP)	N. Cornilleau/ H. Alleyne, CETP, Velizy, France and Sheffield Univ., UK	Low Frequency Electromagnetic Wave Detector (LFEW)**	Z. Wang and J.B. Cao, CSSAR, China
High Energy Electron Detector (HEED)**	W. Zhang and J.B. Cao, CSSAR, China	High Energy Electron Detector (HEED)**	W. Zhang and J.B. Cao, CSSAR, China
High Energy Proton Detector (HEPD)**	J. Liang and J.B. Cao, CSSAR, China	High Energy Proton Detector (HEPD)**	J. Liang and J.B. Cao, CSSAR, China
Heavy Ion Detector (HID)**	Y. Zhai and J.B. Cao, CSSAR, China	Heavy Ion Detector (HID)**	Y. Zhai and J.B. Cao, CSSAR, China

* PEACE includes only one sensor on each spacecraft
** Instrument built by China

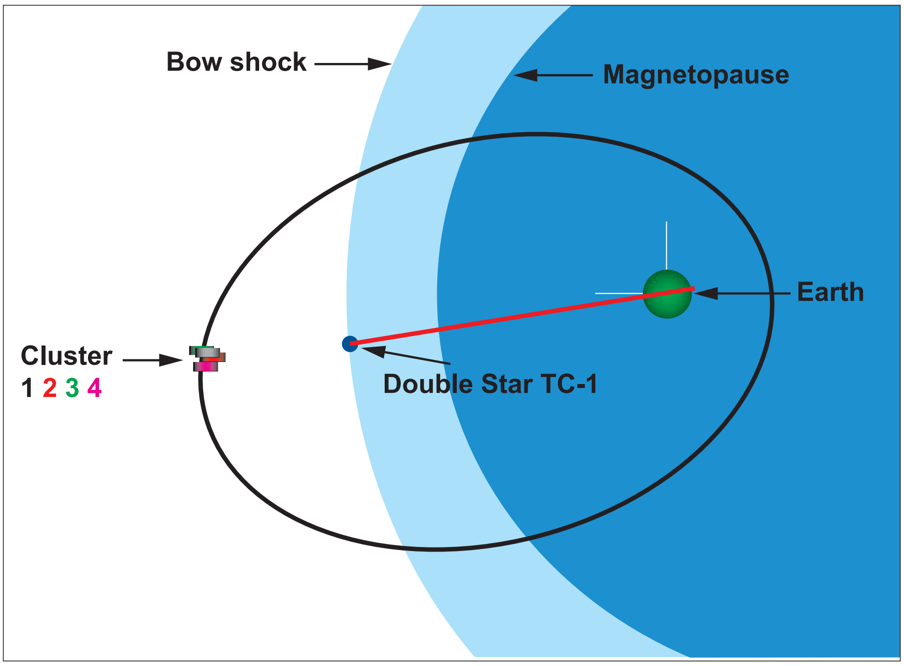
dedication on the project," says Philippe Escoubet, ESA Project Scientist for both the Double Star and Cluster missions. *"In less than three years, China has developed the two spacecraft and their instruments, while the refurbishment of the European instruments was being completed".*

Commissioning the Spacecraft

The in-orbit checkout of the TC-1 spacecraft began in early January 2004 with the successful deployment of the solid boom carrying the FGM magnetometer. However, a second boom that carries the search coil for the STAFF/DWP experiment failed to deploy. Subsequent analysis showed that the stability of the spacecraft was unaffected and its spin axis is, as expected, close to the north ecliptic pole. After an investigation by Chinese spacecraft engineers, a second deployment attempt was made on 16 February, but this too was unsuccessful.

Commissioning of the FGM instrument itself started on 8 January and its electronics were checked out successfully over a four-day period. At the time of writing, data acquisition is taking place to calibrate the instrument. Initial commissioning of the STAFF/DWP instrument has also been completed and it is functioning nominally. However, as a result of the undeployed boom, the STAFF/DWP sensor is subject to more interference and noise from the spacecraft. The Principal Investigator team responded to this challenge immediately and is adapting the data-acquisition approach in order to reduce this interference. The PEACE (electron detector) experiment underwent its first electronic tests on 20 January and is working nominally.

During this phase, the scientists had their first opportunity to conduct combined observations when increased



The Cluster and Double Star TC-1 orbits in February 2004. On this day, Cluster was in the solar wind and TC-1 at the Earth's bow shock

solar activity resulted in an M6.1 category flare on 21 January, followed by the arrival of an interplanetary shock at the Earth at around 01:35 UT the next day. The increased solar-wind pressure (more than five times higher than normal) resulted in a large compression of the magnetosphere. The bow shock was pushed towards the Earth and was detected in the PEACE data as it passed the TC-1 satellite, located at an orbital altitude of 12.6 Earth radii (80360 km). The four Cluster spacecraft, which were in the solar wind at the time, also observed the interplanetary shock. The good conjunction of spacecraft orbits will provide excellent study opportunities for similar events in the future.

Commissioning of the ASPOC (ion emitter) experiment began on 24 January, and was concluded successfully five days later with all four emitters working perfectly. This instrument will keep the spacecraft 'grounded' by compensating for its surface charging, thus enabling very good low-energy-particle detection.

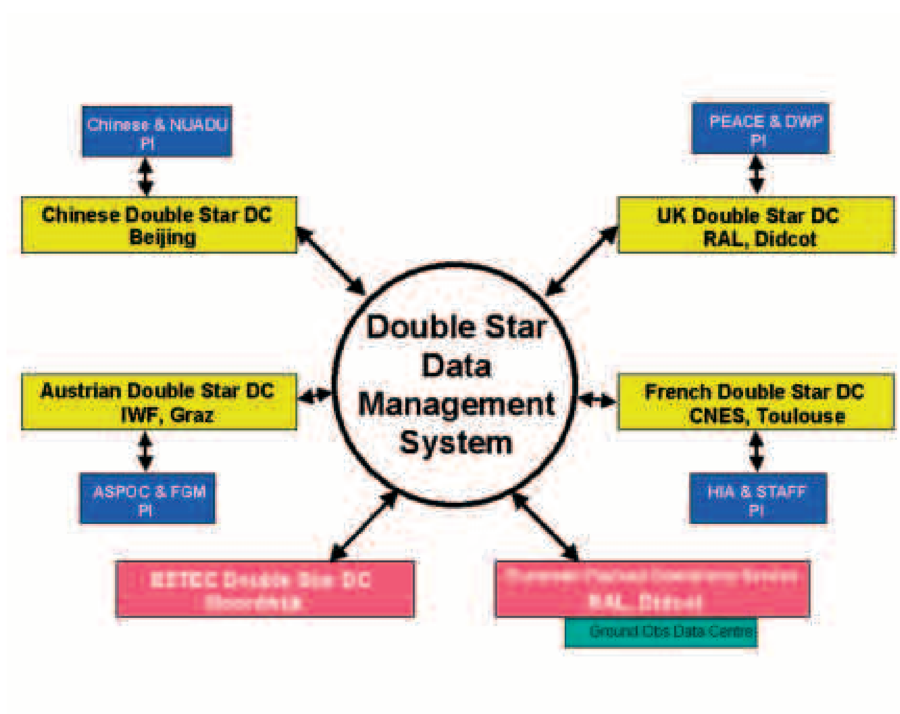
HIA, the fourth European instrument on the TC-1 spacecraft, started its first check-out on 4 February. Two days of electronics checks verified that all components were in perfect shape. The high voltages were raised slowly to around 1500 V and the first ions were detected on 9 February. In-flight calibrations continued until 13 February, when the instrument was declared fully functional by the Principal Investigator team.

In the following weeks, the TC-1 instruments were further calibrated and the data distribution system was commissioned. The Commissioning Review took place on 10 March, after which the nominal mission operations phase started.

The Cluster Legacy

Each Double Star spacecraft carries eight scientific instruments, half of which have been provided by European institutions. The key aspect of Europe's participation in Double Star was the inclusion of seven instruments identical to those flying on the Cluster spacecraft, plus one extra instrument provided by the National University of Ireland. These first European instruments to be flown on Chinese satellites are accompanied by a further eight experiments provided by Chinese institutes.

The fact that most of the European science payload was derived from Cluster 'spares' made it possible to prepare them and launch them on Double Star during the



The Double Star Science Data System

Selected Guest Investigators

Guest Investigator	Investigation
D. Boscher, Onera, F	Radiation environment research from multiple monitors using Double Star
S. Bucher, IRF-Univ., Sweden	Magnetosphere-ionosphere coupling, field-aligned currents and ion flow near the dayside cusp and auroral zone using ground-based, Double Star and Cluster data
M. Dunlop, RAL, UK	Co-ordinated Cluster-DSP measurements in the cusp and at the magnetopause
J. Jahn, SWRI, USA	Multi-spacecraft energetic neutral atom observations of magnetospheric processes
F. Pitout, ESTEC, NL	Double cusps and reconnection hypotheses
T. Pulkinen, FMI, Finland	Global understanding of storms in the inner magnetosphere
S. Schwartz, QMW, UK	Kinetic processes and conditioning in the dayside magnetosheath and equatorial geomagnetic tail
J. Wild, Leicester Univ., UK	A coordinated in-situ and remote-sensing investigation of magnetosphere-ionosphere coupling exploiting Double Star, Cluster and ground-based experiments

limited operational lifetime of ESA's quartet.

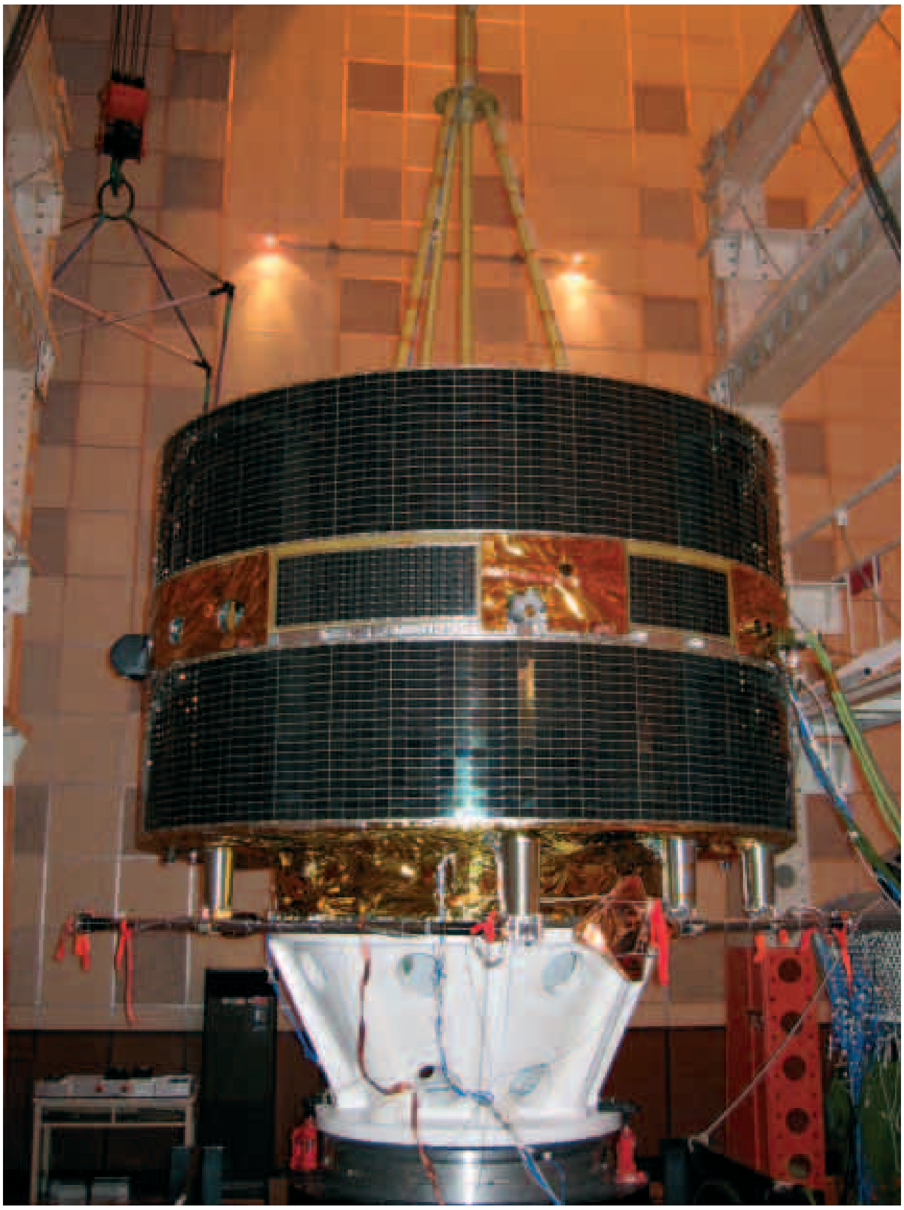
"By flying experiments identical to those on Cluster, we have been able to reduce costs and development time," explains Bodo Gramkow. *"This minimised the risks and helped us to ensure that we would be able to meet the spacecraft development schedule."*

The European-provided instruments are:

- ***Active Spacecraft Control (ASPOC) (PI: K. Torkar, IWF, Austria)***
  This instrument prevents a buildup of positive electrical charge on the spacecraft by emitting indium ions into space. (TC-1 only)
- ***Hot Ion Analyser (HIA) (PI: H. Rème, CESR, France)***
  One of the spare sensors from the CIS instrument on Cluster, this instrument analyses the distribution of ions in the surrounding space plasma during each 4 second spin of the spacecraft. (TC-1 only)
- ***Fluxgate Magnetometer (FGM) (PIs: C. Carr, IC, UK and T. Zhang, IWF, Austria)***
  Two magnetometers attached to a 3.5 metre boom measure the local magnetic field and magnetic waves. They are able to make high-resolution measurements with up to 22 samples per second. (TC-1 and 2)
- ***Neutral Atom Detection Unit (NUADU) (PI: S. McKenna-Lawlor, Nat. Univ. of Ireland)***
  Based on an instrument flying on ESA's Mars Express mission, this is an advanced particle detector designed to monitor energetic neutral atoms in the Earth's magnetosphere and perform imaging of the Earth's ring current. (TC2 only)
- ***Plasma Electron and Current Experiment (PEACE) (PI: A. Fazakerley, MSSL, UK)***
  This instrument is designed to measure the density, temperature and velocity of low-to-medium energy electrons. The spare instrument for Cluster has been split into two instruments, with one sensor flying on each Double Star spacecraft. (TC-1 and 2)
- ***Spatio-Temporal Analysis of Field Fluctuations (STAFF) (PI: N. Cornilleau-Wehrlin, CETP, France) and Digital Wave Processing Experiment (DWP) (PI: H. Alleyne, Sheffield Univ., UK)***
  A magnetometer at the end of a 3.5 metre-long boom looks at waves (rapid variations in the magnetic fields), particularly in regions where the solar wind interacts with the magnetosphere. Low-frequency data are analysed on the ground, while the magnetic components of the higher frequency waves are processed onboard. It also has a particle correlator that enables variations in the electron population around the spacecraft to be compared with the wave measurements. (TC-1 only)

The European Payload Operations Service (EPOS) at Rutherford Appleton Laboratory in the United Kingdom is co-ordinating the scientific operations of the European payload. EPOS is also developing the Double Star Data Management System (DDMS) that distributes data to the users, and the Double Star quick-look web page (DSDS web) that will display the latest data from both European and Chinese instruments. One of the EPOS tasks is to disseminate planning data about orbit and geomagnetic events in order to facilitate co-ordination with other magnetospheric missions.

Data from the Double Star experiments will be relayed to the Chinese data centre in Beijing via the ESA ground station at Villafranca in Spain and the Chinese ground stations in Beijing and Shanghai. A dedicated network line has been set up



The Double Star TC-1 satellite during mechanical testing

The first Announcement of Opportunity to select Guest Investigators for the Double Star mission was issued in June 2003, and met with a 'very positive reaction' from the European scientific community. Eight proposals were eventually selected (see panel), covering various aspects of magnetospheric physics and co-ordinating Double Star and Cluster measurements.

The Joint Mission

As its name suggests, Double Star involves two satellites – both designed, developed, launched and operated by the CNSA – flying in complementary orbits around the Earth.

Each cylindrical satellite has a mass of 280 kg and generates electrical power from solar cells which are exposed to sunlight as the spacecraft spins on its axis. Both are being launched by upgraded, three-stage Long March 2C rockets, but from different launch sites.

First to go was the 'equatorial' spacecraft (TC-1), which was launched from China's southern launch centre at Xichang on 29 December 2003. This spacecraft will investigate the Earth's huge magnetic tail (magnetotail), the region where electrically charged particles (mainly ions and electrons) are accelerated towards the planet's magnetic poles by a process known as 'reconnection'. The nominal lifetime of TC-1 is 18 months.

The 'polar' spacecraft (TC-2), which will be launched in July 2004 from Taiyuan, southwest of Beijing, will

between Villafranca and Beijing to facilitate the transfer of data. The European Space Operations Centre (ESOC) is responsible for collecting the data from Villafranca, while CSSAR is collecting the data from Beijing and Shanghai. Once they have been decompressed and prepared for use, the data will be sent to the Austrian Data Centre in Graz, where they will be made available for the European PIs. The PIs will then process their data and send the products to the Austrian, French and UK Data Centres for distribution to the scientists.

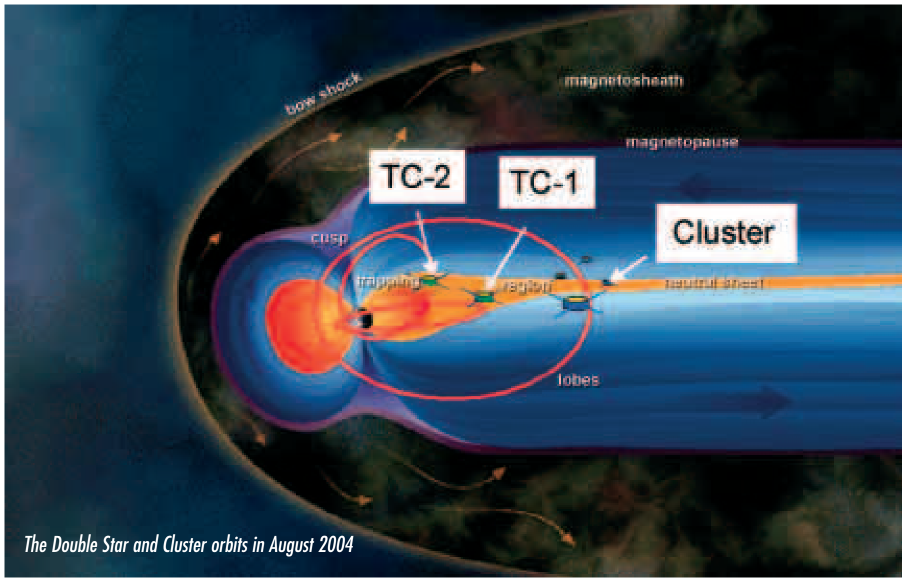
Double Star Spacecraft Characteristics

Mass:	280 kg
Design:	Cylindrical, diameter 2.1 m, height 1.2 m
Alignment:	Spin axis perpendicular to ecliptic
Power:	6.33 m^2 solar array generating 280W (BOL); nickel-cadmium batteries
Lifetime:	Equatorial (TC-1), minimum 18 months Polar (TC-2), minimum 12 months

concentrate on physical processes taking place over the magnetic poles and the development of auroras (Northern and Southern Lights). It will follow a 700 km x 39 000 km polar orbit with a 12 h period. TC-2 is expected to operate for at least 12 months.

The positions and orbits of the Double Star and Cluster spacecraft have been carefully orchestrated so that they perform a synchronised dance around the planet. While the Cluster quartet follow elongated orbits that carry them out from the Earth about one third of the distance to the Moon, Double Star will fly much closer to Earth, following very different paths.

By studying the Earth's magnetosphere from different perspectives, the six spacecraft will enable scientists to obtain simultaneous data on the changing magnetic field and populations of electrified particles in different regions of near-Earth space.



The Double Star and Cluster orbits in August 2004

Unique Insights

Planet Earth is continually subjected to a bombardment of energetic particles originating 150 million kilometres away, at the Sun. Most of the particles arrive in the solar wind, a continuous stream of protons and electrons that flows past our planet. From time to time, enormous explosions known as 'coronal mass ejections' blast billions of tonnes of material into space at such high speeds that they reach the Earth in only a few days.

Fortunately, the Earth's magnetosphere usually protects our planet from this cosmic onslaught, forcing the solar wind to flow around it like an island in a stream. However, particles can break through the defences at two known weak points, the 'polar cusps'. Particles that leak into the magnetosphere may eventually spiral down the magnetic field lines towards the Earth, generating the spectacularly beautiful, but harmless, polar auroras.

In contrast, other phenomena, such as magnetic storms caused by strong solar activity, like 'coronal mass ejections', can have serious consequences for human activities – including communication blackouts, power cuts and damaged satellites.

Although some important insights into the physical processes taking place in near-Earth space have already been provided by the Cluster quartet, the additional perspectives offered by the two Chinese satellites will significantly enhance our understanding of the interaction between the Earth's magnetosphere and the solar wind.

Whereas the Cluster spacecraft orbit at between 19 000 and 119 000 km from Earth, periodically sweeping in and out of the magnetosphere, the Double Star duo will study regions closer to home. For example, in August 2004, when Cluster will be flying far down the magnetotail, Double Star will be able to examine magnetospheric processes and activity taking place closer to the Earth. Six months later, when Cluster is flying across the bow shock, the turbulent boundary between the magnetosphere and the solar wind, Double Star will be able to study activity at the cusps and close to the magnetopause.

A typical example of how both missions will interact is in the study of the substorms that are produced when particles pick up energy and are accelerated towards the Earth's poles, creating very bright auroras. Cluster was designed to study the mechanisms that produce these substorms far away in the magnetotail. However, a few years ago, some scientists suggested that the substorms might be generated closer to the Earth, in regions that can best be studied by Double Star. The joint mission will enable both hypotheses to be tested.

Similarly, while Cluster is flying at high altitude through the polar cusps – funnel-like openings in the magnetosphere above the magnetic poles – Double Star will be able to conduct simultaneous studies at lower altitudes. This will enable scientists to study in much greater detail the 'doors' used by electrically charged particles from the solar wind to descend into the Earth's upper atmosphere.

"Space is very big, but the four Cluster satellites are very close to each other, only a few hundred kilometres apart," explains Philippe Escoubet. *"Although this enables us to observe small regions in great detail, we need more satellites to study the magnetosphere on a larger scale. By flying similar instruments simultaneously in complementary orbits onboard Double Star, we expect our understanding of the Sun-Earth connection to improve substantially.*

esa

Making the Most of Earth Observation with Data Assimilation

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Data Assimilation Research Centre, Reading, United Kingdom

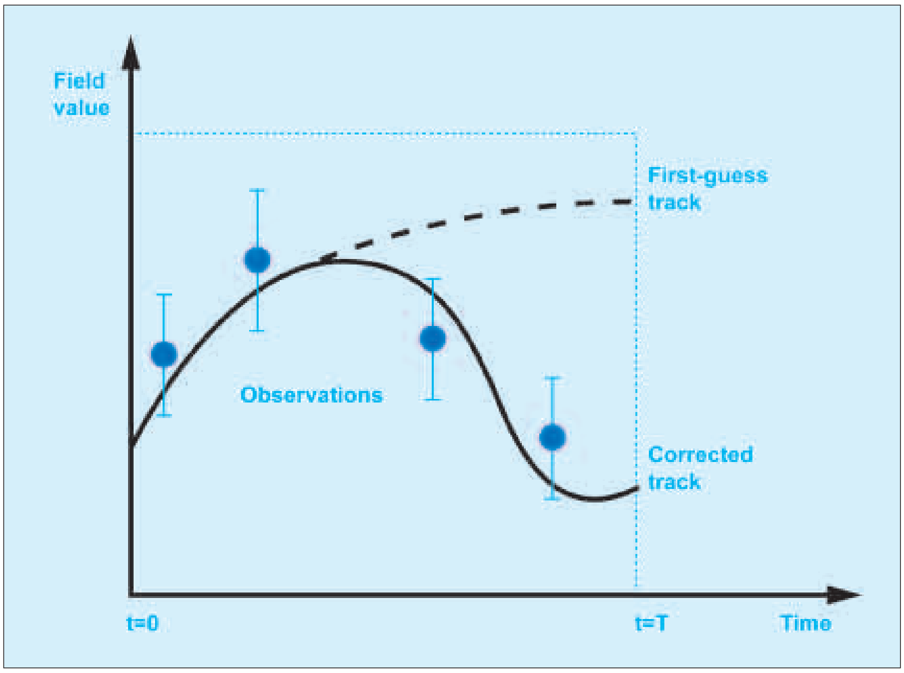
Pierre-Philippe Mathieu & Claus Zehner
Earth Observation Science and Applications Department,
ESA Directorate of Earth Observation Programmes,
ESRIN, Frascati, Italy

An international music company has invested in sophisticated recording equipment, and wishes to make a new recording of a Beethoven symphony. The Berlin Philharmonic Orchestra is hired, and sound engineers set up high-quality microphones among the players in a recording studio. The orchestra performs and each microphone produces a soundtrack. But only a part of the orchestra can be heard on each soundtrack, some soundtracks are noisy, and some are interrupted by periods of silence due to temporary faults in the equipment. Would the company market the recording as a boxed set of CDs, one CD for each soundtrack? Maybe 'yes' for the few music lovers with expert knowledge and sound equipment who could derive pleasure from such a set. But certainly 'no' for the vast majority who want a continuous, high quality, well-balanced blending of sound on a single CD.

Like the recording studio, planet Earth now has many very expensive, high-tech recording instruments deployed around it, in this case on satellites. By recording not sound, but electromagnetic signals covering a wide range of frequencies, this web of sensors is providing data of unprecedented quality and scope on the physical, chemical and biological processes occurring in the air, sea and land of the Earth System, a system of profound and far from understood complexity.

2020 Vision

It seems likely that, by the year 2020, every point on and above the Earth's surface will be viewed from space with a resolution better than 1 km in distance and 1 minute in time. Computing power, already impressive today, will be over 1000 times greater. To exploit this technological revolution, we must be able to synthesise



Schematic of a Data Assimilation System illustrating how a poor forecast (dotted line) can be corrected by assimilating noisy measurements (blue dots) into a mathematical model to provide the best estimate of the trajectory of the system (bold line), satisfying at the same time the dynamics and the observations within their error bounds (blue bar). This technique is used, for example, by automatic landing systems on aircraft in poor weather conditions. Noisy data on the aircraft's position must be combined with information on how the aircraft responds to movements of wing surfaces in order to achieve a smooth landing.

the huge amounts of data flowing from the foreseen dense halo of satellites. As in sound recording, deficiencies due to limited sampling by an individual instrument, as well as instrumental deficiencies, inconsistencies and failures, must be remedied. And as in the production of music CDs, a quality-controlled, uniformly sampled, digital version of the real world is needed.

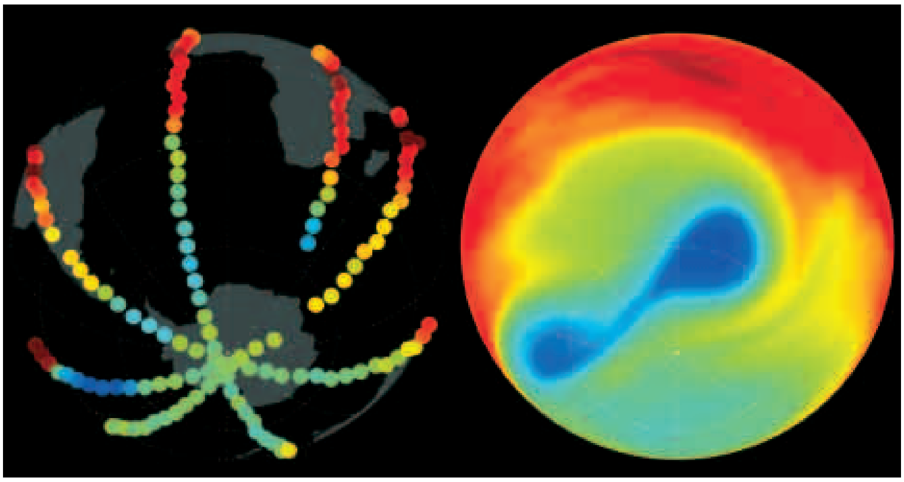
The Value of High-level Information

High-level, synthesised data products are vital in order to monitor and understand the physical, chemical and biological processes in the Earth System, and to analyse long-term trends. Serious environmental threats, of great concern for society and the sustainability of life itself, such as global change, require reliable predictions of what planet Earth will be like in the future. Skilful environmental prediction would provide guidance to policy-makers and help them in taking sound precautionary actions to protect society against the adverse impacts of climate fluctuations and weather extremes.

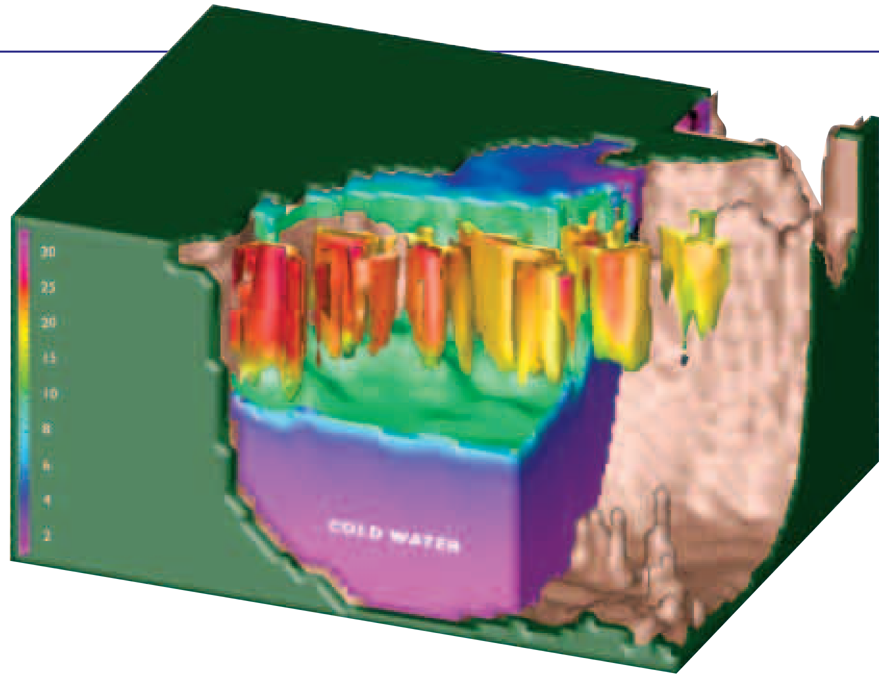
Scientifically based predictions such as weather forecasting utilise mathematical models that encapsulate our understanding of the evolution of the various components of the Earth System and of the interactions between them. The essential pre-requisite for prediction is a best estimate of the initial state of the system, encoded as numbers on a spatial grid, which may have little resemblance to the spatial pattern of available observations. For systems whose evolution exhibits sensitive dependence on initial conditions (or chaos), such as the atmosphere, the forecast can depend critically on how well the grid-based initial state is estimated from disparate observational data. In the case of satellite data, the problem is compounded by the fact that the quantity measured – spectral radiance at different frequencies – is related only indirectly to parameters represented in the model, such as winds, waves and temperatures.

What is 'Data Assimilation' and How is it Done?

How do we produce, from a mixture of sometimes conflicting observational data, a best estimate of the state of the Earth System in a convenient form for diverse applications, especially prediction? How do we ensure that a time sequence of these



Ozone distribution in September 2002 derived from Envisat's MIPAS instrument (left panel) and from the assimilation of MIPAS data into a general global atmospheric circulation model (right panel), into which all the contemporaneous ground-based and satellite measurements used in operational weather forecasting are also assimilated. The coloured dots on the left panel show positions of MIPAS observations and inferred ozone concentrations (blue denotes low values, red high values) during a 24-hour period around the time when the stratospheric polar vortex, and the ozone hole within it, split rapidly into two. At this time, real-time measurements from MIPAS were fewer in number than usual because of some (temporary) data-processing difficulties.
(Courtesy of Data Assimilation Research Centre, UK)



Three-dimensional representation of Gulf Stream eddies, obtained by assimilation of satellite data into an ocean-circulation model. The plots shows warm eddies (associated with a 0.7 m/s speed) detaching from the main current and moving above the cold water (associated with the 10°C isotherm, in green). The consistent vertical structure of warm eddies associated with sea-level anomalies indicates how data assimilation has propagated the information content from surface observations down to greater depth.
(Courtesy of CNRS/LEGI Laboratoire des Ecoulements Géophysiques et Industriels, F)

estimated states is consistent with any known equations that govern the evolution of the system? The modern method for achieving these goals is known as 'data assimilation'.

As illustrated in the accompanying figure, the term 'assimilation' should not be taken to imply a vague process of absorbing data into some computer program, but a carefully constructed procedure that brings to bear all our knowledge of the measurement process, the known errors in the measurements, the governing equations of the system, and the expected errors in those equations as approximated on a computer.

Data assimilation in its various forms has a long heritage in many different areas of science and engineering, where the term 'state estimation' is commonly used. Estimating the orbits of planets from sparse astronomical data is a classical example. Others include (noisy) signal processing in electrical engineering, for which much of the basic theory was developed, and the wide branch of applied mathematics known as control theory. In fact, data assimilation is part of everyday life. You use a kind of assimilation scheme if you sneeze whilst driving along the motorway. As your eyes close involuntarily, you retain in your mind a picture of the road ahead and of the traffic nearby, as well as a mental 'model' of how the car will behave in the short time before you re-open your eyes and make a course correction.

More formally, data assimilation is the technique whereby observational data are combined with data from forecasts by a numerical model to produce an optimal estimate of the evolving state of the system. The model brings consistency to the observational data, and interpolates or extrapolates data into data-devoid regions in space and time. The observational data correct the trajectory of the imperfect model through state space, keeping it 'on the road' in a forecast – observe – correct feedback loop (see figure).

The word 'optimal' in the above definition indicates the statistical basis of most advanced implementations of the method. The state of the system is estimated essentially as a weighted combination of observations and numerical forecasts, the weights being determined from the (supposedly known) errors in the observations and in the numerical forecasts. The great mathematician J.C.F. Gauss showed how to do this as long ago as the 18th Century: weight the data by the reciprocal of a measure of their error (the error variance).

Although simple to state, proper implementation of this rule is very challenging, and is the focus of much intense research. To give a hint of the difficulties, note that the Earth System, comprising the ocean, atmosphere, land and ice subsystems, may need a billion numbers to represent its state usefully for predictions. Characterising the likely errors in all of these variables, their inter-relationships and evolution is extremely challenging and lies at the cutting-edge of scientific computing.

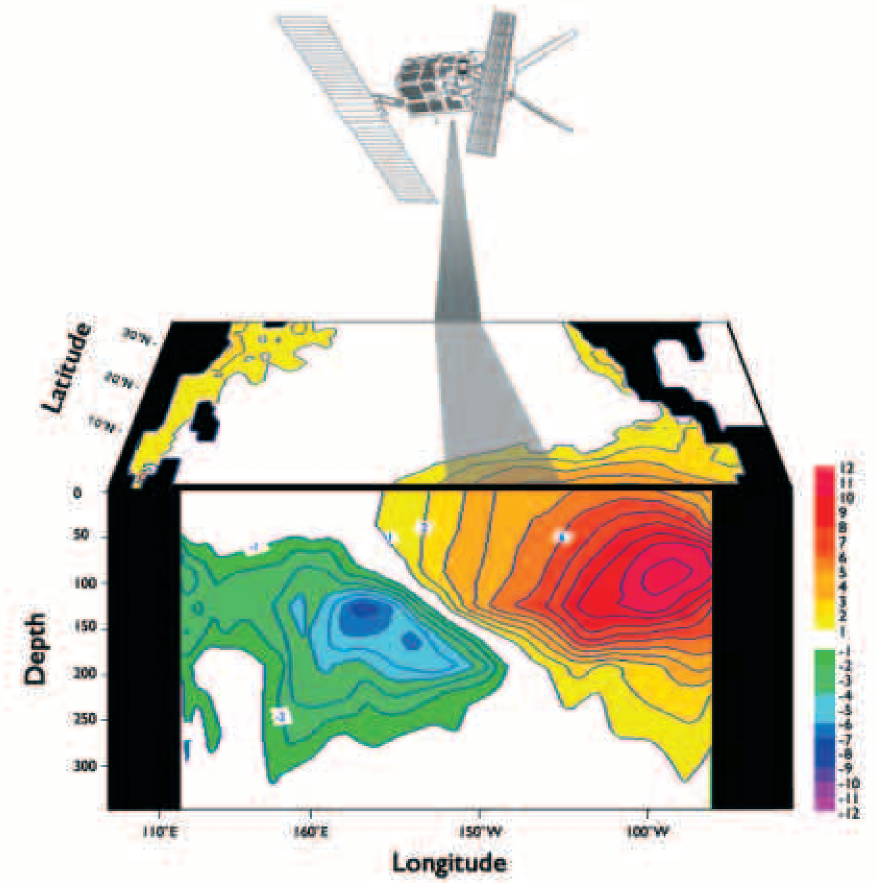
New techniques have allowed the direct assimilation of satellite observations in their 'pure' (calibrated) form as radiances, avoiding some of the pitfalls inherent in the assimilation of off-line estimates (retrievals) of geophysical parameters, such as temperature. This is an important example of how data assimilation has been a catalyst technology, enabling the full exploitation of data from remote sensing. The full benefit of satellite data in operational weather forecasting took over 25 years to materialise, because early satellite soundings were treated not as radiances, but as though they were soundings from radiosondes. The impact of the satellite measurements on forecasts was thereby diminished.

Today, direct assimilation of satellite radiances has been shown to lead to dramatic improvements in forecasting accuracy, particularly in the Southern Hemisphere where the lack of conventional data coverage makes prediction difficult. Five-day weather forecasts are now twice as accurate as in the late 1970s, and as skilful as three-day forecasts were ten years ago. This example illustrates how Earth Observation data, acquired at great expense, were under-exploited for decades because data-assimilation techniques had not been developed to make best use of the data.

What are the Benefits of Data Assimilation?

Before giving a brief description of several applications of data assimilation in Earth System sciences, we can summarise its benefits, some already alluded to, for maximising the scientific and economic value of Earth Observation data:

- *Forecasting and error tracking*. By regularly confronting numerical fore-



Anomalous Pacific temperature signal (deg C) in December 1997 simulated by the European Centre for Medium-Range Weather Forecasts ocean model assimilating in-situ and satellite data.
(Courtesy of ECMWF, UK)

casts with observations, extremely valuable error statistics can be built up, which can be used to improve the quality of the observations (e.g. by revealing biases in instrument calibration) as well as the quality of the models. This routine confrontation has led to enormous improvements in weather-forecasting models during recent decades. Data assimilation is now used to validate numerical simulations of climate.

- *Combination of data*. Different observing systems have different virtues and deficiencies. These differences can be exploited or catered for to optimise the value of the resulting data set – the single CD to play on standard home equipment, referring back to the music analogy.
- *Filling in data-poor regions*. The model provides a way to propagate information in a consistent manner from data-rich regions in space and time to data-poor regions. This capability is vital to exploit satellite observations, which due to their limited and sequential sampling provide only a fragmented picture of the Earth – like a jigsaw puzzle with missing pieces.
- *Estimating unobserved parameters*. Through relationships expressed in the governing equations of the model, parameters that are measured provide information on those that are measured inadequately or not at all. For example, temperature (or radiance) observations can be used to deduce winds, concentrations of hard-to-measure chemical species can be inferred from the observed evolution of other species, and emission rates of gases from the Earth's surfaces can be inferred from their observed concentrations in the atmosphere.
- *Designing observing systems*. When deciding whether to deploy a new satellite-borne instrument, a critical question to be asked is: What is the incremental value of the new instrument? For instance, given that the wind field in the atmosphere is closely related (outside the tropics) to the comparatively well-known temperature field, what is the value of a newly proposed wind measurement? Provided they are designed carefully, data assimilation experiments provide an objective, quantitative way to answer such questions. In addition, data assimilation can optimise the sampling pattern from an observing system, and can target observations to capture features of concern, such as a rapidly developing storm.

Data Assimilation in Practice

The parallel developments of both data assimilation and Earth Observation have received tremendous impetus from the demands of operational weather forecasting. The benefits are huge, and are felt every day as almost every aspect of our society is sensitive to weather fluctuations. Typical examples of the wider application of data assimilation to Earth sciences include forecasting the 'chemical weather', operational oceanography, seasonal climate prediction, greenhouse-gas monitoring and land modelling. Each is an example of innovative use of European satellite data by European scientists.

The first example illustrates the central role that data assimilation now plays in forecasting the chemical state of the atmosphere – the so-called 'chemical weather' – and in monitoring the impacts of man-made pollution. In September 2002, there was a completely unexpected splitting of the ozone hole over Antarctica. Ozone-poor air migrated over populated regions, giving greater exposure to damaging solar ultraviolet radiation. This unprecedented event was recorded by atmospheric instruments onboard Envisat. The left panel of the accompanying figure shows the ozone amounts inferred from measurements along the viewing tracks of Envisat's MIPAS instrument near the time of the split.

Although the spatial resolution of the measurements along the tracks is good, there are large gaps between the tracks, and only tantalising glimpses of the split are provided by the basic measurements on each day. The panel on the right shows the corresponding distribution of ozone produced by assimilating the MIPAS data into an atmospheric global-circulation model, along with all other meteorological data available for operational weather forecasting (this is a good example of the benefits of combining research-satellite data with routine measurements made by operational observing systems). Data assimilation has filled in the gaps in space and time in a manner consistent with the movement of ozone by air currents and with the changes in concentrations due to chemical reactions. Data assimilation provides a consistent sequence of global, 3D fields, which can be used to quantify the damage to the ozone layer from man-made pollutants.

Data assimilation is also at the heart of operational oceanography. The accompanying illustration is a three-dimensional rendition of the Gulf Stream eddies in the ocean off the North American coast. The Gulf Stream has a significant moderating effect on Europe's climate by carrying large amounts of heat from the warm tropics to the colder polar latitudes. The structure depicted in the figure was produced by assimilating satellite data on surface temperature and sea-level anomalies (from Topex/Poseidon and ERS-1 altimeters) into an ocean model. The model has propagated the surface information downward to reveal the 3D structure of eddies in the Gulf Stream, as though an obscuring veil were pulled away from the ocean surface. These eddies are the ocean's equivalent of storms in the atmosphere, and predicting them is useful not only for climate research, but also for ship navigation as well as exploitation and conservation of the marine environment.

Seasonal climate forecasting is a revolutionary technology in meteorology and oceanography aimed at predicting long-range fluctuations in climate (as opposed to day-to-day weather events) several months in advance. This endeavour draws heavily on a wide range of satellite observations, which are synthesised via coupled atmosphere–ocean models. The scientific basis for long-term climate prediction lies in the ocean, which acts as a 'pacemaker' by slowly nudging the atmosphere into a potentially predictable mean state. A striking example of the societal benefits of seasonal forecasting was the prediction, more than six months ahead, of the severe 1997 El Niño event. In July 1997, various satellites, including ERS-2, detected an anomalous warming of a few degrees of the ocean surface in the equatorial Eastern Pacific. A data-assimilation system fed this anomaly downwards into the ocean component of a coupled model, as shown in the adjacent figure. The coupled model in turn successfully predicted the onset of the event, and thereby allowed people to cope better with the worldwide impacts of El Niño by taking appropriate precautionary measures.

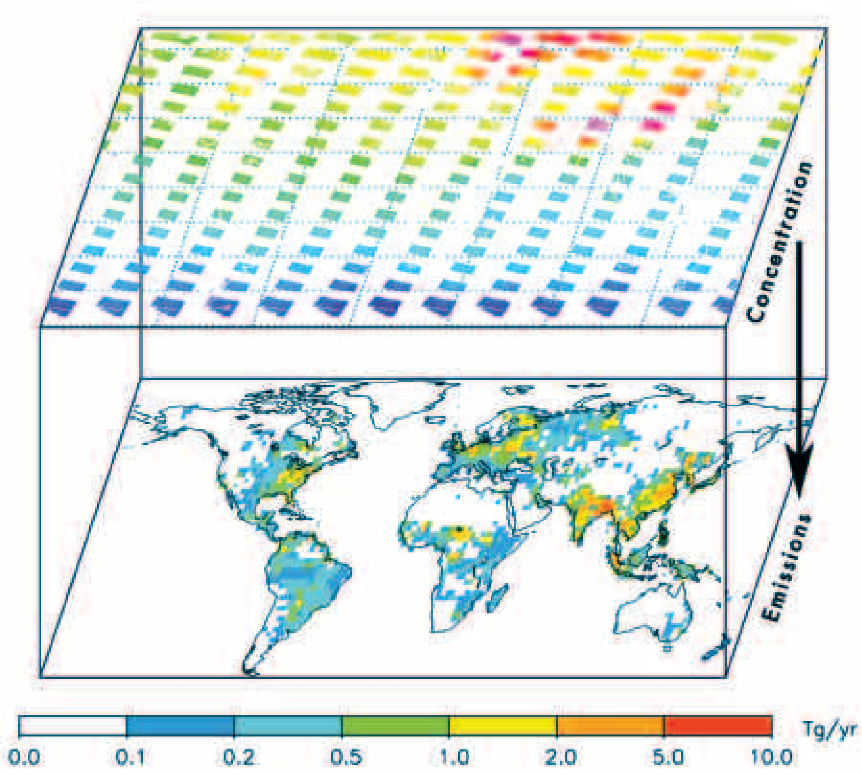
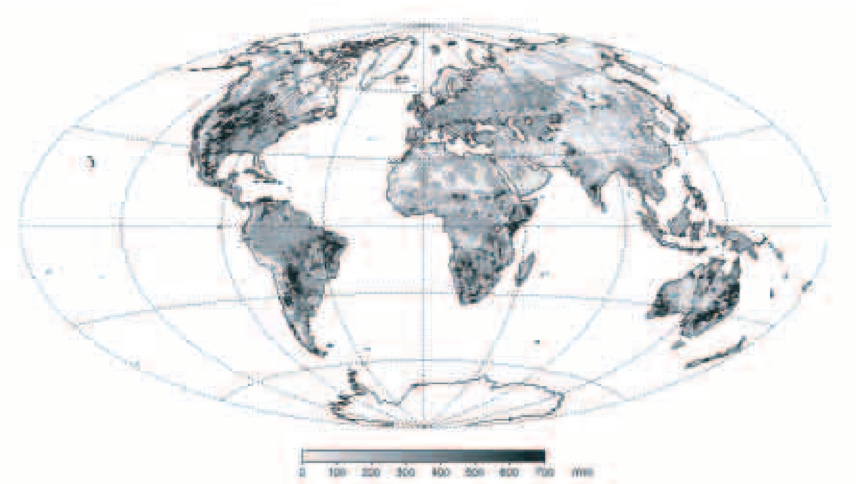


Illustration of the use of data assimilation for the retrieval of methane emissions. Assimilation of synthetic measurements of total column methane from Envisat's SCIAMACHY instrument (upper panel) into a chemistry transport model can help improve our currently poor understanding of the distribution of methane sources and sinks (lower panel in Teragram/grid cell).
(Courtesy of KNMI (NL), Evergreen Project)

Another interesting example of the use of data assimilation is to infer quantities that are not well measured (such applications are often called 'inverse modelling'). The accompanying figure shows how satellite measurements of methane in the Earth's atmosphere can help us quantify the sources and sinks of this important greenhouse gas at the surface, especially in regions where ground-based measurements are sparse (e.g. in the Southern Hemisphere or in developing countries). In this case, synthetic measurements of total column amounts of methane, made by the SCIAMACHY instrument on Envisat, are assimilated into a chemistry-transport model to reveal, for example, a strong methane source in the Amazon region of South America. Such information is crucial to understanding the cycles of greenhouse gases, and also to support the implementation of international regulations such as the Kyoto Protocol, which requires national inventories of emissions.

Applications of data assimilation now extend beyond the atmospheric and oceanographic sciences, where they are long-standing and quite mature. The method is increasingly being employed to understand the properties and evolution of the land surface using both ground-based and satellite data. For instance, knowledge of the soil moisture near the surface is obviously important for hydrological and agricultural applications, but it is also important for climate prediction, as part of the hydrological cycle in the atmosphere.



Maximum plant-available soil moisture (mm) obtained from a land-surface vegetation model after assimilation of satellite-based optical measurements of vegetation productivity.
(Courtesy of Max Planck Institute for Meteorology, D)

The accompanying figure shows an estimate of the global distribution of soil moisture derived after assimilating satellite-based estimates of vegetation productivity into a model of the land surface. As a component of a coupled system, such models are beginning to be used to make forecasts of agricultural production.

Training a New Generation of Scientists

Better understanding, monitoring and forecasting of the state of the Earth System present enormous intellectual and technological challenges. To meet them, a new generation of scientists with multi-disciplinary skills must be trained to have an end-to-end knowledge of remote sensing, modelling and data assimilation. Many of the traditional, discipline-based courses at universities do not offer such an integrated view and need to be supplemented with cross-disciplinary training.

To this end, ESA has set up a long-term Summer School training programme promoting the exploitation of Earth Observation across disciplines, and in particular through integration of measurements into forecasting models via data-assimilation techniques. The first Envisat Data Assimilation Summer School was organised from 18 to 29 August 2003 at ESA/ESRIN in Frascati and it concentrated on the assimilation of data from the three atmospheric instruments on Envisat: MIPAS, SCIAMACHY and GOMOS. The School was designed to attract first-class young scientists beginning their careers in Earth Observation, as well as those who had a desire to enter the field. Almost 60 students from 17 countries attended keynote lectures by leading scientists, and they rated the course a great success. A key feature of the training was that the material presented during lectures was reinforced by computer-based exercises (e.g. one practical involved using the latest satellite data to analyse the state of the ozone hole). All lectures, practicals and presentations are available on-line at: http://envisat.esa.int/envschool/.

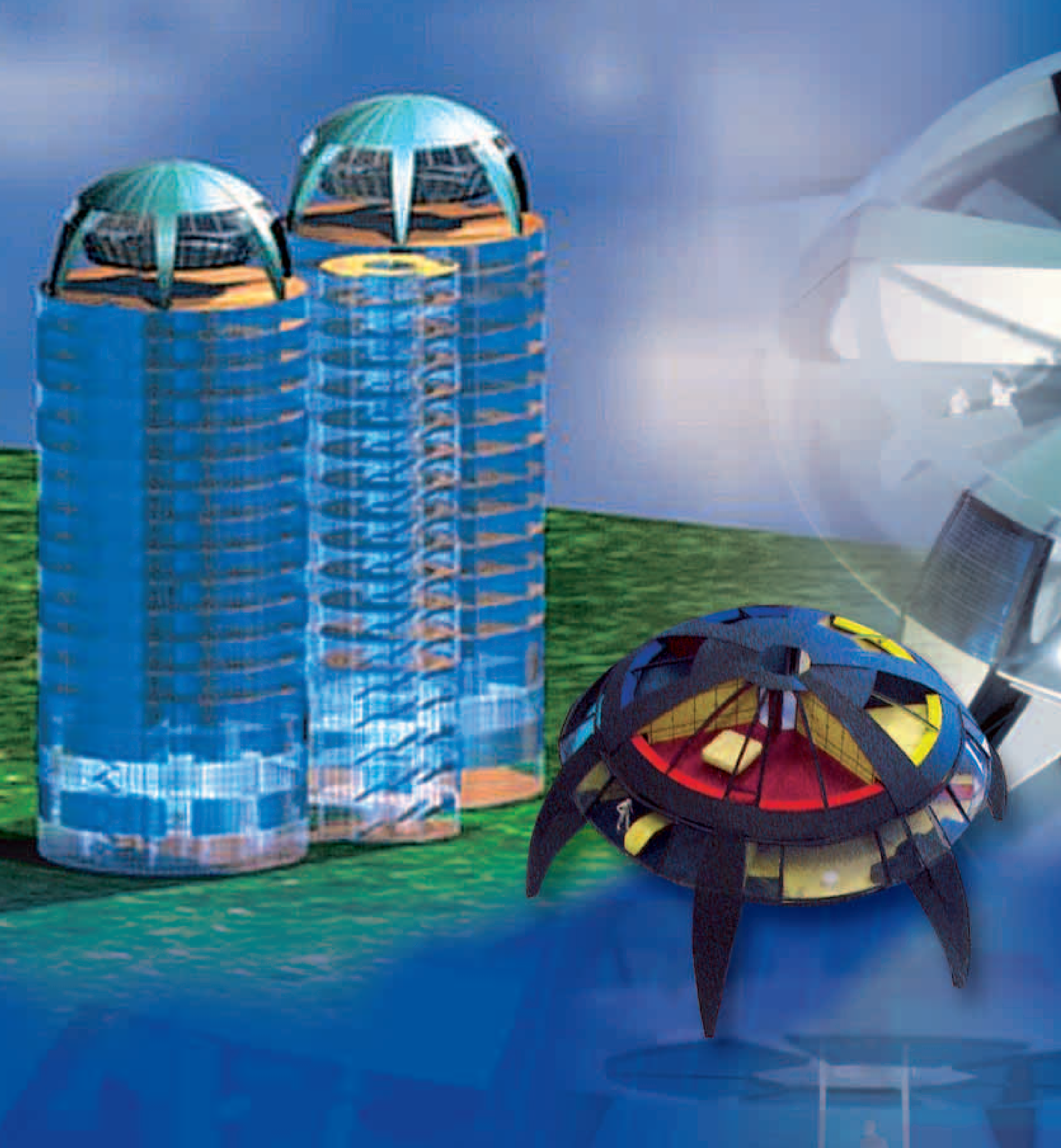
The next Envisat Data Assimilation Summer School will be held at ESRIN from 16 to 26 August 2004. It will broaden the scope of the first Summer School by providing training in the synergistic use of observations of all the components of the Earth System, for which a multi-instrumented platform like Envisat is ideally suited. The second School has already attracted 200 applications from students from 47 countries, 55% being from ESA Member States. These Schools are part of an ongoing series of ESA activities designed to help maximise the benefits of Earth Observation from space.

Conclusions

When numerical prediction models can enhance the value of measurements, data assimilation should be an essential component of the ground segment of all Earth Observation satellite missions. Data assimilation fuses disparate data streams into a coherent picture of the evolving world. By routinely confronting models with observations, it facilitates rapid advances in our ability to simulate the profoundly complex, highly non-linear, multi-component Earth System, a capability yet to be fully exploited in climate modelling. It provides the essential scientific basis for using models to forecast the evolution of the system. It also allows the incremental value of new observing systems to be judged, enabling objective decisions to be made when faced with competing opportunities.

Data assimilation is a catalyst technology to effect the transition from today's innovative, research-oriented satellite missions to the design and deployment of tomorrow's operational satellites. It is a field at the forefront of scientific computing, requiring a new generation of scientists with inter-disciplinary skills. At a time when long-term measurements of our planet's 'vital signs' are indicating rapid changes, it constitutes one of the key building blocks of a numerical laboratory of the Earth System, providing globally consistent data sets that go well beyond simple imagery (the 2D snapshots of basic satellite measurements). By meeting the geo-information needs of a wide and diverse user community, data assimilation is helping to fulfil the vision of the Global Monitoring for Environment and Security (GMES) initiative and ESA's Oxygen (O2) project.

Like the market-wise music company of our opening analogy, ESA can exploit data-assimilation techniques to deliver high-quality products in a form that can readily be used to listen to the Earth System symphony. Good listening! esa



Space Technologies for the Building Sector

Fritz Gampe
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One of the roles of the United Nations is to serve as a 'global conscience' and it has been inviting its Member States to give priority to addressing topics of global concern. One of the most debated and therefore best known initiatives is the 'Kyoto Agreement', dealing with the prevention of further man-induced global warming. Another similar UN initiative in recent years is designed to address the problems of the World's largest cities, or 'MegaCities', through a programme known as 'Habitat 21'. It is against this background that those involved in the ESA Technology Transfer Programme have been looking at how the Agency might be able to contribute to such initiatives by proposing space-derived and space-based technologies that can help to provide solutions. ESA's sponsorship of the publication in 2001 of the 'Megacities' book containing spectacular satellite remote-sensing imagery of the World's largest cities was seen as a first step in this direction.

Designing the large conurbations of the future, as well as the individual buildings that will make them up, already presents a formidable challenge, and one where the latest space technologies can help to improve the daily lives of those who will live there. Within the ESA Technology Transfer Programme, therefore, we have also begun to examine the potential contribution that space technologies can make to the building sector. The target is to be able to propose a very different style of housing surpassing current 'eco-designs' as well as offering greater protection against natural disasters and environmental threats.

Space Technologies for the Home

High-efficiency rigid solar cells
As demonstrated by the two ESA-sponsored race-winning ‘Nuna’ solar-powered cars, 25% triple-junction GaAs solar cells would be a powerful energy source for household applications. As yet, for cost reasons they are only being used for very specific applications and test systems, but their use around the house in the not-too-distant future can already be anticipated.

High-efficiency flexible solar cells
ESA is already engaged in the development of truly flexible solar cells for space applications. Based on a low-temperature ion-deposition technique onto any plastic substrate, they promise about 15% efficiency at a substantially lower cost than with today’s rigid-panel systems. They will be ideal for the SpaceHouse, being able to follow the curvatures of its outer contours. Being foldable or rollable, they can also be used as a portable energy source.

Large-scale application of Li-Ion battery cells
Where energy autonomy is required around the clock, lithium-ion batteries can be combined with solar cells using an energy-management system developed for satellites, known as a ‘power point tracker’. This was one of the leading-edge technologies that helped take the ‘Nuna’ solar-powered cars to victory in the World Solar Challenge races in 2001 and 2003.

Carbon-Fibre-Reinforced Plastics
Although CFRPs are sometimes regarded as a typical ‘technology of today', the building and construction sector so far has little knowledge of or experience with these materials. Understandably so, perhaps, when the drive in the public sector is for minimum-cost private housing, or for ‘winning the competition with the lowest bid’. However, with the introduction of new safety requirements, there is growing interest among architects, building engineers, housing associations, and insurers, etc. in trying out CFRPs. The challenge will be how to transfer the high-end manufacturing technologies of space to the manufacturing processes in the building sector. One might have to offer additional incentives such a ‘service free lifetime’ for the primary structure.

Carbon-fibre screws
ESA is currently engaged in optimising a new type of carbon-fibre screw for space applications with very stringent requirements. These screws would be ideal for the assembly of the SpaceHouse’s structure, as well as for other long-life applications with chemical-resistance and anti-oxidation requirements.

Natural-fibre composites
Alongside the development of carbon-fibre-type composites, work is also in progress on the use of ‘natural-fibre composites’. Much of the initial scientific work has been conducted in the car industry, which is still something of a niche market. Their application in the SpaceHouse would be for walls and secondary structures, using calculations made with ‘space tools.’

Fire-proof materials
To meet future fire-proofing requirements, there might be a need to change from the currently used epoxy-based to phenolic-based resins. Various aerospace laboratories are already performing application-oriented research and this know-how could be transferred to the housing market.

Flash-over protection
Not all European countries require that protection systems of this type be installed in buildings, but where they have to be applied they pose a formidable aesthetic challenge. As a result of space-technology transfer, so-called ‘Polymet’ metal-covered plastics are available which can be used non-obtrusively as a flash-over suppressant. In the SpaceHouse, for example, a very thin layer of this foil would be applied to the composite.

Water recycling
Highly efficient, space-technology-derived ‘reverse-osmosis’ concepts are being turned into commercial products in the form of two-water-loop systems. Current sanitation regulations in Europe preclude the use of this type of recycled water for drinking purposes, but it can be used for washing machines, toilets and gardens.

Air purification
It might sound far-fetched to think of using space technologies to ‘clean’ the air that we breath. However, there is an EU Directive on ‘Particulate Matters’ that calls for not more than 40 micrograms per cubic metre of particles smaller than 10 microns in that air in order to protect us from dangerous carcinogens. There is also growing concern about the rapid spread of global epidemics due to our greatly increased mobility. The relevant expert groups are therefore preparing even more stringent requirements to counter so-called ‘background dust values’ that they believe are reaching excessively high levels in some European regions.

On the International Space Station (ISS), there is already a highly efficient particle filter able to trap particles as small as 100 microns. With some additional development, this space technology could also be used here on Earth.

Medical support for the elderly
With the ever-growing percentage of elderly people in European society, the medical experience acquired from, and the equipment developed for, human spaceflight is becoming more and more interesting for ground-based exploitation.

System-engineering methodologies
Last but not least, it seems appropriate to look not just at individual space technologies that can be transferred to the building and construction sector, but also at space methodologies. Space endeavours have spawned many novel system-engineering approaches that could benefit the building sector, and the construction/building engineer’s role would be enhanced accordingly.

The Building Sector

Today, more than at any time before, buildings and other structures are incorporating a multitude of new technologies, materials and processes. There are several reasons for this, including:

- environmental and ecological issues
- safety aspects in view of increasing natural hazards
- attractiveness in terms of a building being a corporate 'icon', and
- growing pride of home owners in their properties.

There are currently about 380 million people living within the European Union (E-15), about 42% of whom are currently in work. The building and construction sector is one of the largest employers in the Union, providing some 28% of Europe's industrial jobs (11.5 million people). Its turnover amounts to some 870 billion Euros, representing nearly 10% of GDP. By comparison, the European aerospace industry has a turnover of some 80 billion Euros, and employs approximately 450 000 people. On the other hand, it could be said that the building sector is not yet one of the most technologically 'innovative' sectors, although in recent times some spectacular buildings have been put up or are currently on the drawing board. The fact that 'space habitats' have to support life in hostile environments by relying on leading-edge technologies means that the latter can also be a valuable source of innovation for the building sector back here on Earth.

Building Design and Concepts

Architects, designers, builders, environmentalists and – last but not least – consumers have already begun to embrace new technologies in areas that promise lower energy consumption and hence lower running costs. But photovoltaic, solar-thermal or geothermal energy sources are still only rarely seen in office buildings or private houses. In terms of structures, progress has been more conspicuous, with very fashionable, modern-looking designs using steel, plastics and glass extensively to provide more natural light and more efficient heating and insulation.

With the EU having now started a serious drive towards the proposed 15% reduction in carbon-dioxide emissions, 'green thinking' is no longer the domain solely of the dreamer and the enthusiast. The deregulation of Europe's energy market could also offer new opportunities to design office buildings and even individual houses in such a way that they are self-sufficient in energy or even net contributors to the energy grid.

Aside from the purely economy-related targets, there are already a number of established 'political targets' at European and global level:

(a) WHO Health Targets for Europe

- "By the year 2015, people in the region should live in a safer physical environment, with exposures to contaminants hazardous to health at levels not exceeding international agreed standards". *(European Health 21, Target 10)*
- "By the year 2015, people in the region should have a greater opportunity to live in healthy physical environments at home, at school, at the workplace and in the local community". *(European Health 21, Target 13)*

(b) Kyoto Protocol Target

- "To reduce the demand for energy by 18% by the year 2010, to contribute to meeting the EU's commitment to combat climate change, and to improve the security of energy supply".

(c) European Housing Ministers

- "The Ministers agree that the existing stock conditions (social housing) still require a considerable effort in order to meet sustainable quality norms, to be defined by each country..."*(Paragraph 4 of the Final Communique, Genval, Belgium, 2002).*

Space Technologies and Methodologies

When transferring space technologies to applications here on Earth, a careful look at their true innovative potential is needed to avoid the trap of 'wishful thinking' and to establish their true market and economic value.

Space technologies are by their very nature developed to work in extreme environments, relying on unusual combinations of materials, and to have a long intervention-free operating life. The principal design requirements for space vehicles are:

- very lightweight but nevertheless robust designs
- maintenance-free operation throughout their lifetimes, particularly as far as thermo-mechanical properties are concerned
- high degree of automation during the operational mode
- energy autonomy based, with few exceptions, on solar power only.

New Building Requirements

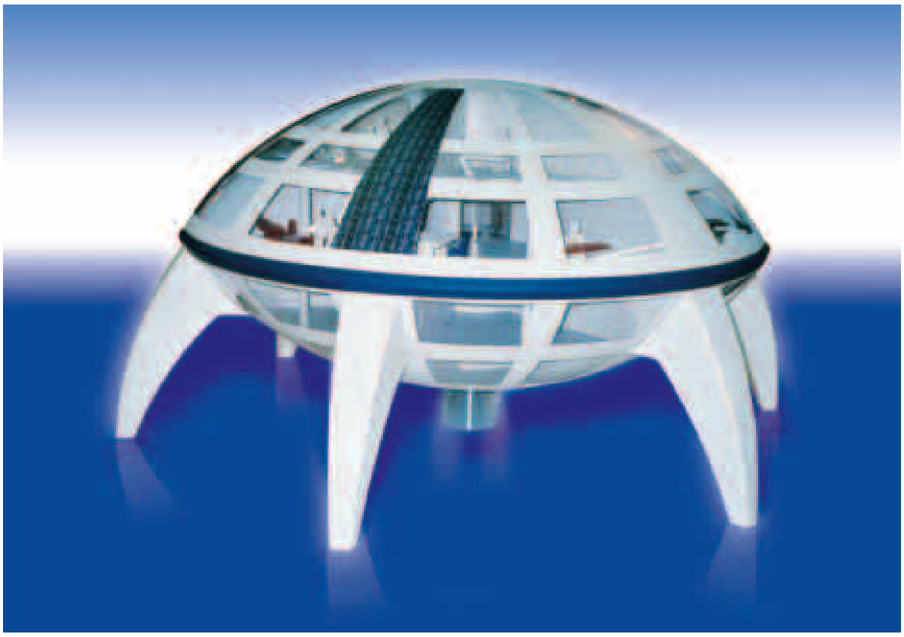
Discussions with the insurance and re-insurance sector show that they have ever greater concerns about the statistical increase in 'extreme weather' in recent years, coupled with the fact that more and more dwellings are being built in earthquake- and flood-prone zones. It is therefore proposed to adapt European building standards to these trends and to enable structures to cope with:

- wind speeds of up to 220 km/h (10-second gusts)
- flooding to depths of up to 3 m
- earthquakes of up to 7.5 on the Richter scale
- subsidence of 1.5 m during the lifetime of the building
- severe hail and exceptionally heavy rain, and
- for some areas of southern Europe, bush-fire resistance.

Europe stretches over 3500 km from north to south and 4000 km from east to west, and therefore experiences a high degree of climate variability, in terms of sunshine, winds, day/night duration, etc., even under normal weather conditions.

Can Space Technologies Help?

Discussions with city officials indicate that there is an urgent need to upgrade many inner-city areas to make them more attractive places in which to live and work. In addition, some city authorities would like to see new buildings constructed in such a



An early ESA SpaceHouse concept (Courtesy of HTS, D)

way that they do not ‘seal the ground’, and thereby avoid any further lowering of ground-water tables. A combination of today’s space materials and lightweight composites would be well-suited for such applications, and would also allow striking new structural shapes. The accompanying evolution in building techniques would be comparable to the materials revolution that has overtaken the yacht and boat industry in recent years. Faster and more up-to-date city-planning methods supported by satellite remote-sensing technologies can be an indispensable aid in this respect.

Discussions with the most progressive energy providers show that they are keener than ever to use the buildings themselves as a source of energy generation. The challenge lies in deciding how to produce the storable and transportable energy and in balancing the financial and environmental returns against the start-up costs. In addition to high-efficiency, flexible and low-cost solar panels, space technologies offer a plentiful supply of design options for the exteriors and interiors of such buildings.

Discussions with demographers indicate that the current rapid increase in the number of elderly people in European society will have an enormous impact on housing needs in terms of interior design, communication requirements, and health/sanitation provisions. Here again, space-derived technologies based on the wealth of astronaut experience accumulated in these fields, with space-derived medical monitoring methods and sensors, could be made available within the building.

Discussions with water suppliers indicate that a more optimised two-quality water standard and piping system might be economically feasible in the near future. This would alleviate the stress on natural water resources to a certain extent. Water purification systems based on the return-osmosis concept developed for space application are now at the point where they can be applied in any domestic household. In such extreme and environmentally sensitive habitats as the French/Italian ‘Concordia’ station in Antarctica, new international environmental laws already dictate the application of such technologies.

Discussions with the health sector show not only that air conditioning might be needed on a greater scale in the future, but also that the provision of ‘more healthy air’ might also be a growing necessity, particularly in inner-city areas. Today such services are only provided in hospitals to cope with allergies, infections, etc. However, here again the novel space technologies developed for cleaning the air in Europe’s Spacelab and subsequently on the Intenational Space Station, have a role to play.

Discussions with the tourism industry indicate that fully autonomous and re-locatable chalet-type buildings might be needed to conform with future norms in terms of sustainable development and the seasonal use of ecologically sensitive recreation areas. Space technologies of the sorts already mentioned above could be ‘bundled’ for this particular purpose.

Current Technology-Transfer Activities

On the basis of the various discussions outlined above, and a review of recent and expected future research and technology development activities in the space sector, efforts within the ESA Technology Transfer Programme (TTP) have been focused on three major areas of application for the available space technologies:

– safe houses/buildings with respect to the natural and human-induced environment
– healthy houses/buildings with respect to medical and mental well-being
– ecological houses/buildings with respect to sustainable energy supply, natural-resource consumption and manufac-turing processes.

The ‘SpaceHouse’

In the wake of the devastating earthquake in Turkey in 1999, the idea of attempting to design an ‘absolutely earthquake-safe building’ was born. The initial objective was to apply CFRP (Carbon-Fibre-Reinforced Plastic) composites to design a self-supporting, lightweight, shell-like structure able to withstand the forces of a Richter 8.5 earthquake. This approach would be in sharp contrast to other contemporary design solutions, which use ever more steel and concrete to withstand the induced forces.

The results of the initial feasibility studies indicated that it was a technically viable concept, but that a careful eye was needed on the cost of such a building. A 1:50 scale-model of the SpaceHouse was then built by architects from the University of Munich. It was exhibited for the first time at the

Hanover Industrial Fair in 2000, together with the flexible solar cells of Swiss origin that could provide the house's power.

The 'TranSphere'

This first engagement with the real world of the architect was based on a mutual interest in learning from each other and looking at new futuristic, but still realistic shapes. Carbon-fibre-reinforced structures gave the final concept a very 'transparent' appearance, far removed from that of any 'normal' house.

The 'Swiss Space Vitrine'

Halfway through the TranSphere activity, a new opportunity arose in the Swiss town of Yverdon-les-Bains. A large steel structure had been erected in Lake Neuenberg for the Swiss Expo 2002 fair, not far from the lake shore and in an ecologically sensitive area. This structure, known as 'The Cloud', was offered after the fair as the home for a future 'Swiss Space Vitrine', of which the existing collection of 'Maison d'Ailleurs', a world-renowned science-fiction museum in the town, would form a part. The exciting challenge was that original structure would only allow a lightweight construction to be added on top. CFRP was thus the ideal material for the 2000 square metre addition. Unfortunately, the project failed to gain sufficient public support in a local referendum.

The 'Ecospace'®

The Ecospace® initiative of TNO-Bouw (Delft, NL) is striving to 're-innovate' the building sector, as proposed within EU's 6th Framework Programme. They are exploiting the SpaceHouse approach in their attempt to foster a visible forward leap for the construction and building industry. The challenge will be to adapt the SpaceHouse concept to meet the constraints of, for example, social housing, necessitating the use of novel manu-facturing methods for the composites and a cost breakthrough in terms of exploiting solar-energy sources.

The 'Innospace' initiative

The authorities in the Basque country (Departement des Landes, La Region Acquitaine) would like to establish a highly visible 'communications platform' for the region by exploiting the SpaceHouse concept. The region would like to present itself as a centre for 'high-tech' located within an environment of great natural beauty, a region in tune with the future where sustainable development can be combined with economic growth.

Requirements for human-friendly and safe enclosed spaces (Courtesy of TNO/Ecospace, NL)

The New German Antarctic Station 'Neumayer-3'

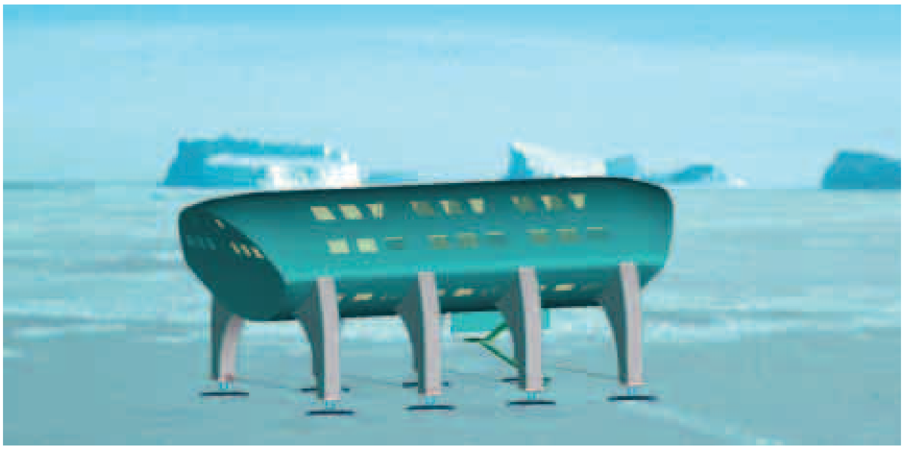
Contacts made at the Hanover Fair in 2001 have led to the ESA TTP supporting the Alfred Wegener Institute (AWI) in Bremerhaven, Germany, in the development of new station concepts. Given the more stringent environmental rules now applying to the Earth's polar regions, and the possibility of an accelerated build-up phase, AWI is assessing the merits of the SpaceHouse technologies for its future Neumayer-3 station concept.

A City Attraction: the Greifswald 'Muon Space-Weather Telescope'

Following the initial proposal for a Muon Space-Weather Telescope (MTG), financed by ESA's TTP and TRP programmes and to be developed together with the University of Greifswald, Germany, the city authorities have expressed interest in taking the next step. Concepts are therefore being developed for using the Telescope as a highly visible element in Griefswald's drive to present itself as a 'science city'. Hence, the MTG would ideally be presented in its own SpaceHouse-like habitat, alongside other science-oriented tourist attractions.

Dresden Aerospace Centre of Excellence

The Technical University of Dresden in Germany has engaged in an effort to draw its faculties together in commissioning a SpaceHouse-type building that would serve as focal point for the University and the aerospace industry of Saxony. A



Artist's impression of the Neumayer-3 Antarctic station (Courtesy of HTS, D)

working group has been formed to consolidate the various requirements and assess the suitability of several possible sites owned by the University.

The 'Safe-Eco-Space' Private Initiatives

Various expressions of interest have been received and private initiatives proposed for building one of the SpaceHouse derivatives. Currently, alternative manufacturing processes are under consideration that will on the one hand retain the novelty and flexibility in the space-technology/ methodology based concept, and on the other keep costs within the financial bounds of the potential customers.

The 'Euro-District Platform'

In the context of celebrating the 40th Anniversary of the Franco-German 'Elysee Treaty' signed in 1962, the Foreign Ministers of the two countries decided to establish common innovative projects that would serve as a communication, cultural and scientific platform for the youth. Various interested partners and authorities in the Strasbourg area have put forward the SpaceHouse as one element. The site proposed is a small island in the middle of the Rhine, forming part of the community of Neuried, and it would meet the objectives admirably.

Lessons Learnt

Based on all of the above experiences and discussions, now seems an appropriate moment to begin the pioneering activity of building the first real SpaceHouse, in which to live and work and demonstrate its wider market potential. Several space-technology suppliers have indicated their willingness to provide support in terms of knowhow and hardware, and to look at the 'advanced building sector' as a potential complement to their core businesses. Europe's boat and yacht builders already have installed capacities for the economic manufacture of industrial-standard CFRP structures of the sizes that would be needed for the house's modular elements. Some of them are also prepared to enter this new niche market for an initial, limited-investment trial period.

The reaction on the part of Europe's architects has been mixed so far. Some of them feel that they would have to redefine their role in view of using new materials with characteristics with which they are not yet familiar, while others are very enthusiastic and eager to incorporate the new materials and manufacturing methods into their repertoires. The banking sector's reaction has been neutral as regards the financing of a private SpaceHouse, as long as sufficient security is provided. Last but not least, there is the reaction of the SpaceHouse enthusiast's family to be considered, who also have to be happy to live in such a dream-home. Gauging from the public's reactions at the various exhibitions, the appreciation and the vision needed to enjoy living in such a house is equally divided between the sexes.

Artist's impression of a future space colony (Courtesy of Tim White)

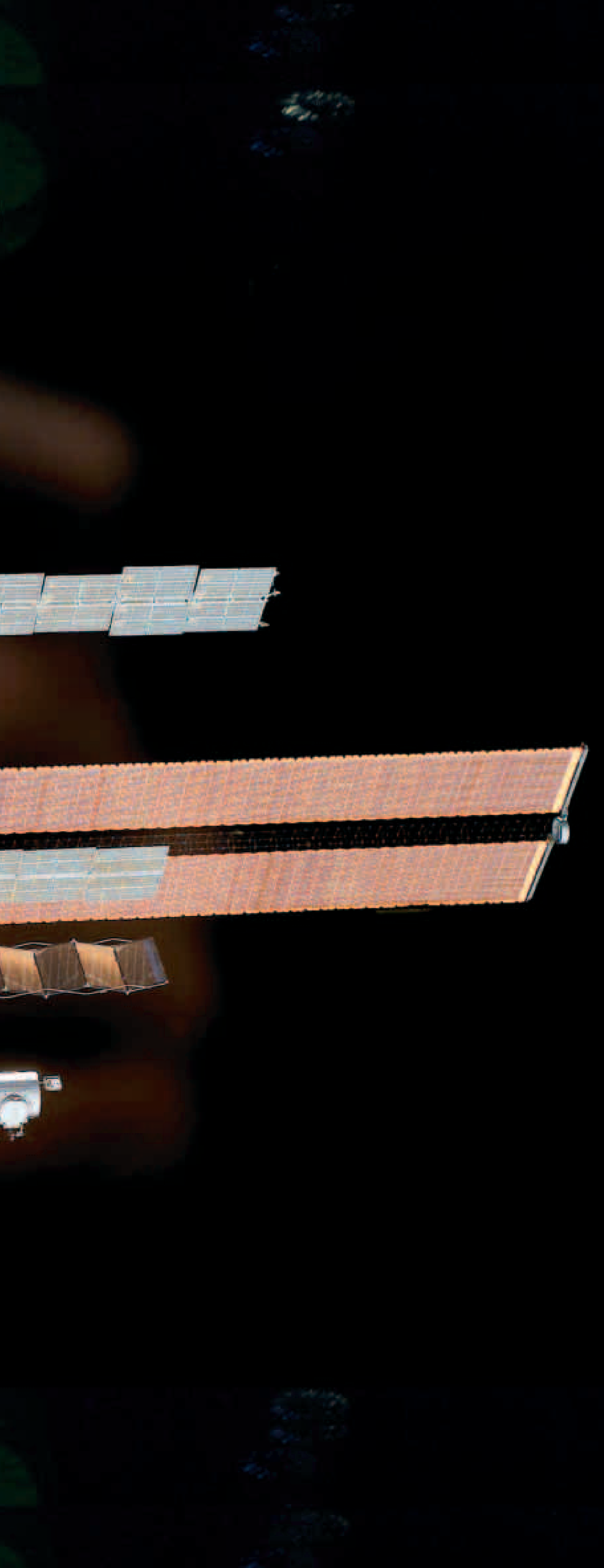
Outlook

Through its Technology Transfer Programme, the Agency has so far invested the resources needed to develop the initial SpaceHouse concept, prepare the technology base, provide the promotional platform, and foster contacts with potential investors. The TTP has recently added another tool to help make the SpaceHouse a reality, by exploiting the facilities of the European Space Incubator to develop the missing links needed to move towards a truly commercial undertaking.

ESA might also eventually build its own SpaceHouse, or rather 'SpaceOffice', on the ESTEC site, incorporating the latest space-derived technologies to make that office building as self-sufficient as possible. It would give the thousands of visitors to the ESTEC site each year the opportunity to witness first hand the advantages of 'bringing space technologies down to Earth'.

ESA’s Cooperation with International Partners
– Export-Control Issues

The current in-orbit configuration of the International Space Station



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Since ESA's creation, international cooperation has been essential to the European space effort. Without the Agency's strong commitment to join forces with its international partners, many of the ambitious projects being achieved today would not have been possible. When entering into a cooperative project, many legal issues have to be taken into account, one of the more thorny ones being export control. Though many rules and regulations with regard to export-control issues exist in public international law, these have experienced some diverging interpretations and different developments in the course of transcription into national rules. The direct addressee of the classical export-control rules is industry and not ESA as an intergovernmental organisation. Given the Agency's mandate to improve the worldwide competitiveness of European industry, ESA's functioning, and structure, these issues are nonetheless of great importance.

Applicable Law and Regulations

Situation in the ESA Member States

Because 13 of ESA's 15 Member States are also Members of the European Union, it should be emphasised that, since 1994, dual-use exports have been subject to rules established by the European Community (EC), as part of its jurisdiction over the common commercial policy pursuant to Article 113 of the EC Treaty. These rules were replaced on 22 June

Crew members onboard the International Space Station on 23 April 2004, photographed in the ISS's 'Destiny' laboratory. In the front row are astronaut C. Michael Foale (left), Expedition-8 commander and NASA ISS science officer and cosmonaut Alexander Y. Kaleri, flight engineer. In the back row (left to right) are cosmonaut Gennady I. Padalka, Expedition-9 commander; astronaut Edward M. (Mike) Fincke, NASA ISS science officer and flight engineer, and the Dutch ESA astronaut Andre Kuipers. Cosmonauts Kaleri and Padalka represent Russia's Federal Space Agency

2000 by Council Regulation 1334/2000, which set up an expanded EC regime for the control of exports of dual-use items and technologies.

Through the latter rules, a list of dual-use items has been established for which an authorisation for export is required from the relevant authorities in the EC Member State concerned. Therefore, national laws and regulations implementing such rules have been somewhat harmonised through this common list. The latter is drawn up in conformity with the obligations and commitments accepted by the EC Member States participating in the different existing international regimes, such as the Wassenaar Arrangements. However, States are also authorised to control items in addition to those contained in the above-mentioned list for security and defence purposes.

It is therefore up to the industrial entity under contract with ESA for the development or production (in the framework of a particular ESA programme or activity) of data and goods included in national export-control lists and intended for export outside the territory of the Member State concerned, to make all necessary arrangements for obtaining appropriate authorisations at national level, and subsequently abiding by all conditions prescribed in such authorisations.

ESA's rules and procedures related to export control

The starting point for ESA's rules and procedures with regard to export-control issues can be found in Article XI.5(j) of the ESA Convention. This provides that Council shall adopt, by a two-thirds majority of all Member States, rules under which authorisation will be given, bearing in mind the peaceful purposes of ESA, for the transfer outside the territories of the Member States of technology and products developed through the activities of ESA or with its assistance.

This basic provision is implemented by Chapter IV of the Rules on Information, Data and Intellectual Property, adopted by Council on 19 December 2001 (Rules). With a view to promoting the maximum exploitation of ownership rights, these Rules draw a clear distinction between technology and products that are owned by ESA, on the one hand, and those that are owned by Contractors, on the other. The transfer of technology or products owned by ESA requires the authorisation of the Agency's Technology and Product Transfer Board (ATB), whereas the transfer of technology or products owned by Contractors only needs to be recommended by the ATB. The ATB's authorisation or recommendation, which is not a substitute for the national-level authorisation process but rather an additional step, is not necessary when the transfer of technology or products is made pursuant to a cooperative agreement between ESA and a government agency of

The Russian Soyuz launcher that carried ESA astronaut Pedro Duque to the ISS on the 'Cervantes' mission in October 2003

the country of destination. In such cases, it is assumed that the ESA Council, when approving the cooperative agreement, has given an overall authorisation for the transfer of data and goods in accordance with the relevant provisions of the agreement.

In the first case – when the technology or products are owned by ESA – authorisation by a two-thirds majority of the Member States or Participating States is required. In the second – when the technology or products are owned by a Contractor – a transfer shall not be deemed to be recommended if more than one third of Member States have expressed an adverse opinion on the proposed transfer. In the case of a transfer requested by a Contractor, a Member State or an invited Participating State which is not represented at the meeting, that State shall be considered as approving the transfer.

In considering its authorisations and recommendations, the ATB takes several factors into account, including:
– the objectives of the ESA Convention and, in particular, the exclusively peaceful purposes aspect
– the competitiveness of European industry and, particularly in the case of Contractor proposals, that of the Contractor
– compliance with export controls in force in the Member States and, in particular, in the Member State under the jurisdiction of which the proposed transfer would be effected
– any reciprocity for ESA and the Member States which may be appropriate
– any requirements on re-exports; and
– any relevant technology-transferagreements.

In any case, it is important to note that ESA's rules do not prejudice the fact that export control is a national competence, governed by the national laws and regulations of the Member States and, in a number of instances, subject to those international agreements by which the Member States are bound.

Export Control in the Context of Cooperative Projects

Standard clauses

ESA has concluded numerous agreements with partners, other than agencies of its own Member States, for the purpose of carrying out activities cooperatively or on a reimbursable basis, within the framework of its programmes. The most complex cooperative framework established through a series of agreements, at various levels and of various natures, is the one set up originally in September 1988, and expanded in January 1998, for executing the International Space Station (ISS) Programme, involving the 15 Partner States and their 5 Cooperating Agencies. The ISS negotiations provided the occasion to develop a comprehensive clause on the exchange of technical data and goods, which has since regularly served as a model for agreements covering other fields of space exploration.

The ISS Partner States have agreed that: (a) each Partner's obligation to transfer technical data and goods to another Partner is confined to the data and goods necessary to fulfil the furnishing Partner's responsibilities under the applicable agreement; (b) everything must be done to facilitate transfers at every level, for example between industrial entities being contractors or sub-contractors of the cooperating agencies; and (c) to prevent unauthorised transfers to third parties, special steps must be taken to protect data and goods marked as requiring protection for proprietary-rights, export-control or confidentiality purposes. These steps take the form of a marking procedure pursuant to which the furnishing party identifies explicitly with an appropriate stamp the set of data or the goods to be protected. Such marking should trigger the application of protective measures once the data or goods arrive at the premises of the receiving party, so as to avoid unauthorised re-transfer to a third party. It is generally understood that unmarked technical data and goods received by any Partner can be freely used for any purpose.

Practical issues associated with exchanges of technical data and goods

With more than 15 years of experience in the application of technical data or goods clauses, ESA has gained first-hand experience in a number of issues, as illustrated below. Firstly, it may happen that a Partner proceeds abusively with the marking of data and goods otherwise freely available, thus hampering the efforts of the receiving Partner, because of the burden imposed by applicable protective measures, to disseminate such data or goods to all officials, contractors and sub-contractors involved in the project. This issue, referred to as 'over-marking', was discussed at length when Russia joined the partnership in the mid-1990s. That discussion led to the inclusion of the following sentence in the relevant Article:

"The transfer of technical data for the purposes of discharging the Partners' responsibilities with regard to interfacing, integration and safety shall normally be made without the restrictions set forth in this paragraph."

This sentence is more an encouragement to avoid over-marking than an outright prohibition of it.

Another problem is the potential for the extra-territorial application of the laws of a furnishing Partner State, and more probably of the relevant laws and regulations of the United States, to technical data and goods already transferred to another country. Normally, one would expect the export-control laws of the receiving country to be the only applicable legal basis for seeking remedies whenever there would be a breach of the conditions of the transfer, e.g. in case of an irregular re-transfer to a third party. However, the laws and regulations of the United States continue to apply to the technical data and goods transferred abroad, and all corresponding remedies and sanctions may come into play. This may result in certain conflicting requirements being imposed on the receiving party, i.e. conditions under United States laws and regulations that would be at variance with requirements applicable under the national law of the receiving country. It also results in formal requests being sent periodically by the US authorities to their partners to proceed with inspections 'in-situ', i.e. in the receiving country, of the conditions under which transferred data and goods are stored and used, something that may not be acceptable for policy or legal reasons.

There is also a possibility, which has materialised in the past in at least one instance, that a party receiving unmarked technical data produced by a Cooperating Agency proceeds with the 'marking' of that set of data upon receipt, thus legally limiting the furnishing party in its ability to freely transfer the data it has generated to anyone. This may also look rather abusive, although this limitation on re-transfer would be difficult to actually enforce in the State of the Partner having generated the data in the first place.

It is important to emphasise that the part of the relevant provisions referring to the direct transfer between the parties provides that such provisions do not require a party to transfer any technical data and goods in contravention of its national laws and regulations. In other words, for the direct transfer between the Cooperating Agencies, a State should not invoke the blanket application of laws and regulations pertaining to export control when proceeding with a transfer, but rather only invoke actual contraventions under its legal system, such as a regulation that would prohibit the transfer of nuclear material or military equipment. However, considering that the activities of the cooperation are carried out by the Partners primarily through numerous contractors and sub-contractors, it may be difficult to determine whether or not the interactions between contractors of different Partners in a given case constitute or generate a 'direct transfer' between two partners, the latter transfer being expressly excluded from the application of the bulk of export-control regulations, as explained above. Industrial entities involved in the transfer generally adopt a very cautious approach, to avoid any possibility of being fined for a contravention of export-control laws, and they generally require that all procedural aspects of export-control dealings, e.g. the conclusion of Technical Assistance Agreements (see below), are completed before being involved in any transfer. This not only defeats the purpose of the provisions included in agreements for facilitating direct transfers between the parties to the cooperation, but it adds significant delays, costs, and frustrations.

Since the original ISS agreements could not, for obvious reasons, have envisaged all possible utilisation scenarios, it is necessary to rely on additional agreements to spell out Partners' commitments to one another for each specific project. For utilisation activities, ESA and NASA conclude agreements in the simplified form of an exchange of letters. Even with a text in simplified form, negotiations on an exchange of letters generally take months, and such a time scale will on occasion be incompatible with technical imperatives and deadlines to be met in various projects. In some cases, the whole process has led to unaccustomed delays, pushing up costs for all interested parties. Again, a cooperating agency is under no obligation to transfer technical data or goods for a specific project until such time as a proper agreement has been concluded.

For the sake of completeness, it is worth mentioning that the ISS Code of Conduct for the Space Station crew contains provisions that oblige astronauts to protect goods and data generated by experiments conducted onboard the Station when they have received instructions to mark them. The situation in which astronauts from several nations find themselves together onboard the ISS is, therefore, treated like an export situation. This shows just how much care the ISS Partners have taken regarding the protection of sensitive data and goods.

Cooperation with the United States: Technical Assistance Agreements

Export control is a particularly sensitive topic in the USA and this is mirrored in the extensive 'International Traffic in Arms Regulations (ITAR)'. These regulations require that TAAs be in place for the export of defence articles or the performance of a defence service by a US national to or for a foreign national. TAAs need to be approved by the US State Department and usually make their way through that Department before they are even sent to the International Partner in a draft version. Any amendment has to follow the same procedure, which makes the process rather burdensome. Consequently, it seems that many times convictions and principles are sacrificed for the sake of simply advancing a given project.

TAAs compulsorily need to contain a set of required clauses, such as:

"This Agreement is subject to all United States laws and regulations relating to exports and to all administrative acts of the US Government pursuant to such laws and regulations."

and

"This TAA is an independent agreement between the Parties, the terms of which will prevail, notwithstanding any conflict or inconsistency that may be contained in other agreements between the Parties on the subject matter. The Parties agree to comply with all applicable sections of the International Traffic in Arms Regulations (ITAR) of the US Department of State."

Given ESA's status as an international organisation that enjoys certain privileges and immunities in the United States, this wording is highly inappropriate, since it seems to imply ESA's acceptance of and submission to acts of the US Administration.

Nonetheless, ESA is still recurrently asked to sign such TAAs. Such requests usually come either directly from US industry or from NASA's Jet Propulsion Laboratory, the legal status of which is not clear. For direct contacts with NASA itself, a TAA is not necessary, since it is able to transfer agency-to-agency information without a TAA by invoking an ITAR exception. Since ESA's international partner and direct counterpart is NASA, the easiest solution might therefore be to channel any export that might involve US export-control uncertainties through NASA itself. Another possible solution could be an exemption from licensing requirements in the framework of any cooperation between ESA and NASA.

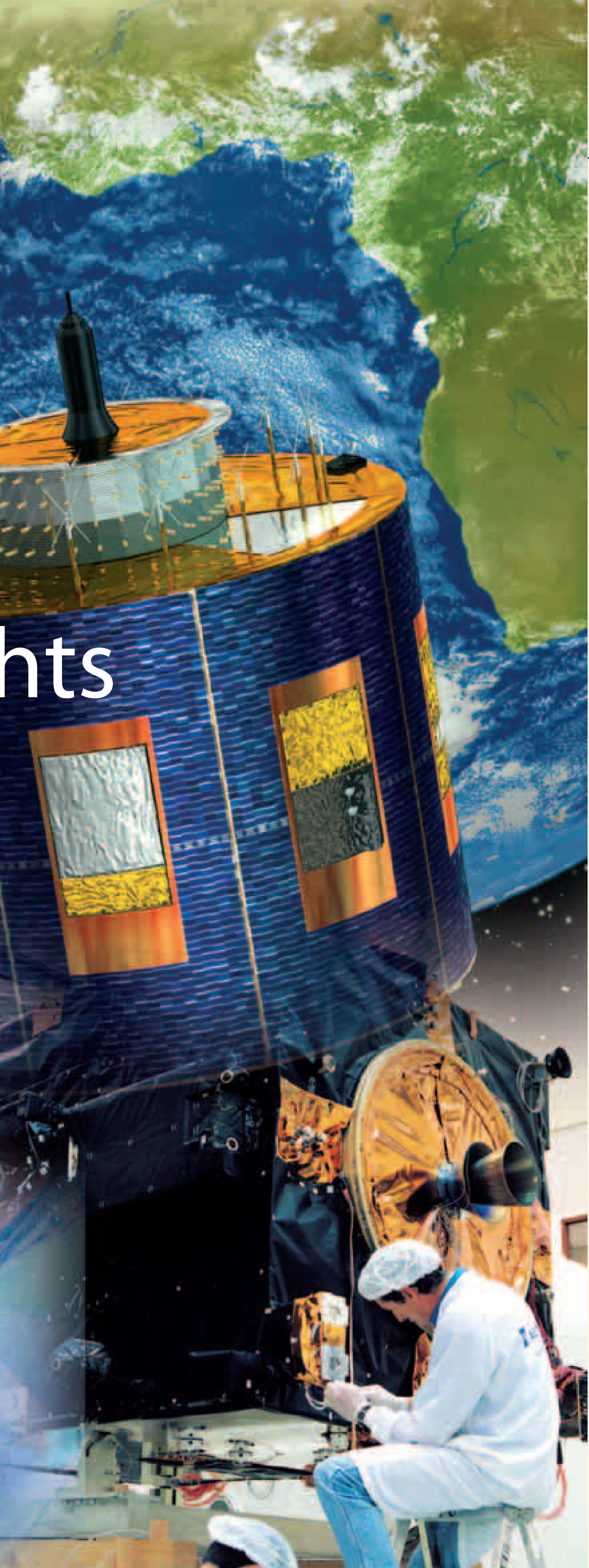
Conclusion

A good understanding of the various export-control issues facing ESA in the context of the execution of those programmes carried out in cooperation with International Partners seems to be a pre-requisite for any player involved in such activities at every level on the European side. Failure to address these issues properly, and in a timely fashion, will add costs and delays, something that could develop into a programme manager's worst nightmare!

The most compelling task ahead for ESA in following up on its existing commitments with regard to export-control matters is to develop detailed internal procedures and install appropriate mechanisms, possibly modelled on those used by the International Partners, for providing adequate protection to marked technical data and goods received pursuant to relevant clauses in cooperation agreements. This exercise, which is bound to have significant budgetary implications, would be somewhat related, although not necessarily exactly similar in every respect, to the on-going effort for implementing the various aspects of the recently-concluded Security Agreement pertaining to classified information. This is a necessary step for implementing in concrete terms existing ESA rules obliging staff members to protect the confidentiality or sensitive nature of information, and the integrity of goods, that they may receive in the course of their work.

Finally, since ESA is directly affected by the application of the export-control regulations of its Partners in the course of the various ongoing cooperative projects, it is normal that the Agency should monitor closely the development and implementation of those regulations – together with its own contractors – whenever an ESA project is involved, and should act as a lobbyist for defending European interests in that field with its Partners. This is particularly important at a time when NASA is working closely with the US State Department in trying to change the current process for issuing export-control authorisations for space-related material in the USA.


Intellectual Property Righ
– a New Regime in ESA Contracts



Karl Eisermann & Christian Grafé
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The ESA Convention contains the principles according to which the Agency enters into contracts. Article III of the Convention deals with information and data; in Paragraph 3 it states that "when placing contracts … the Agency shall, with regard to the resulting inventions and technical data, secure such rights as may be appropriate for the protection of its interests, those of the Member States participating in the relevant programme, and those of persons and bodies under their jurisdiction. These rights shall include in particular the rights of access, of disclosure, and of use." These principles were applied under the previous contract conditions (ESA/C/290, rev. 5) by the Agency agreeing that the contractor could own intellectual property rights in works developed under a contract with the Agency, but that – when required – a licence was to be granted free-of-charge to Member States and persons and bodies under their jurisdiction for their own requirements in the field of space research and technology and their space applications. The free licensing of intellectual property, which is not legally required by Article III.3 of the Convention, was aimed at encouraging the development of European space industry.

This article discusses the rationale behind the new Part II of the General Clauses and Conditions, which deals specifically with intellectual property rights (ESA/C/290, rev. 6).

Background

The Agency's old contract conditions affording free-of-charge access to the intellectual property rights of the contractor to all companies belonging to an ESA Member State proved in practice to have a number of drawbacks. Firstly, they did not encourage the registration of intellectual property rights in contract works, which facilitates protection of the works and so is in both the contractor's and the Agency's best interests. Secondly, the old conditions did not encourage the exploitation of contract works. Experience showed that contractors needed a more privileged position in order to exploit intellectual property rights, given the highly competitive situation in the global marketplace.

The objectives of the new intellectual property clauses and conditions are therefore to encourage:

(i) registration of intellectual property in contract works and so better protect the contractor's and the Agency's interests;

(ii) exploitation of intellectual property in contract works and so help generate wealth and improve the competitive position of the Agency's contractors on the worldwide market, which is one of the industrial-policy objectives of the Agency according to Article VII of the Convention.

Based on an ESA Council Resolution entitled *'Rules Concerning Information, Data and Intellectual Property'* adopted on 19 December 2001 (ESA/C/CLV/Res. 4 (Final)), the new Part II of the General Clauses and Conditions for ESA Contracts was approved by the ESA Council on 8 October 2003. The new contractual conditions are the outcome of intensive consultations between Member States, Industry and ESA. Since 1 January 2004, they have been applied to all contracts relating to research and development in the field of space technology and its applications.

Part II of the General Clauses and Conditions now makes a clear distinction between *'fully funded contracts'* and *'partly funded contracts'*. For the first category of contract, the general regime in Part II A of the General Clauses and Conditions is applicable. A contract is considered 'partly funded' where the Agency typically finances 50 percent of the development costs of the space research and development activity covered by the contract, and the contractor finances the rest. In that case, the special regime in Part II B of the General Clauses and Conditions applies.

Fully Funded Contracts

Ownership of intellectual property rights created

The Agency does not have as one of its primary objectives the ownership and exploitation of intellectual property rights. Therefore, as a general rule – as under the old regime – the contractor will own all intellectual property rights in the contract works and have the right to apply for registered intellectual property rights arising from work performed under the contract (clause 39.1). However, to encourage both the registration of intellectual property and exploitation, if the contractor fails to apply for registration, abandons or does not exploit the intellectual property, then the Agency may acquire the rights. There are some special rules that apply to 'open-source software' and 'operational software'.

Registration of intellectual property rights created

The contractor must inform the Agency as soon as possible whether the results of the contract can be protected as registered intellectual property rights, and must state whether it intends to apply for such protection (clause 40.1). At the request of the contractor, to allow for the filing of applications, the Agency must treat these results as confidential for a period of 12 months. Once the application to register the intellectual property has been made, then the contractor must supply certain information, such as the application number, filing date and whether the application is being used as a basis for applications in other countries (clause 40.2).

If the contractor does not wish to apply for, or wishes to abandon registered intellectual property rights, it must again inform the Agency. There will be a consultation process and then the Agency may seek a third party interested in protecting and exploiting the rights. If the Agency finds a suitable third party, it can require the contractor to assign the rights necessary to apply for registered intellectual property rights or grant the third party a licence on the abandoned intellectual property rights on favourable terms (clause 40.4). If a third party cannot be found, ESA may require the contractor to assign the rights to the Agency free of charge (clause 40.5).

Software is a special case. In most countries, it is currently protected in the form of copyright (which does not require registration). In addition, the European Patent Office now grants patent protection for software. It accepts patent applications for the computer programs themselves, or as recorded on a 'carrier', provided the claim for the computer so programmed would not be rejected (i.e. the computer produces a new, inventive technical effect). Although patent protection is currently available, it may not be the most commercial method of protecting and exploiting the software. If the contractor considers that it is not appropriate and demonstrates to ESA why this is the case, then the Agency may have no need to enquire whether a third party would be interested in registering patent rights to protect the software. The legal situation may soon evolve as a result of an EC Council Directive on the patentability of computer-implemented inventions, which is currently under discussion. A changed legal environment may also lead in the future to adaptation of ESA's policy in respect to the patentability of software on the basis of clause 40.

Use of intellectual property created

The contractor must make all intellectual property rights arising from work performed under the contract available under certain circumstances. The old system introduced an open licensing policy. It gave the Agency, Participating

States and persons and bodies under their jurisdiction, a free-of-charge licence to use intellectual property rights developed under a contract with the Agency for all space applications. Under the new rules, intellectual property rights arising from fully funded contracts are available:

Rule 1
– to the Agency, Participating States and any person or body under their jurisdiction on a free worldwide licence (with the right to grant sublicences) for the Agency's programmes (this rule is identical to the licence conditions under the old set of rules);

Rule 2
– to Participating States and any person or body under their jurisdiction to use, under favourable conditions, for a public programme in the field of space research and technology and their space applications (this rule is new);

Rule 3
– to academic and research institutions to use under a free licence without the right to grant sublicences for their own scientific purposes, providing the licence is not contrary to the contractor's legitimate commercial interests (this rule is new);

Rule 4
– to any third party at market conditions for purposes other than an Agency programme or a Participating State's space programme, providing the contractor agrees that the use is not contrary to its legitimate commercial interests (this rule is new).

The new licensing regime balances the interests of the Agency, Participating States, research organisations, the contractor and third parties seeking access to intellectual property rights. A key element of the licensing conditions is that the contractor can charge fees except for the use of its intellectual property rights in ESA programmes or for purely scientific purposes. The level of fees is tailored to the intended use of the rights. In addition, the licensing regime protects the contractor by enabling it to invoke its legitimate commercial interests in the case of rights licensed for purposes other than those of an Agency programme or a Participating State's space programme. This 'legitimate commercial interest' right enables the contractor to block access by a third party to its intellectual property rights and allows an exclusive exploitation position in a particular market. This rule is intended to give effective support to the competitive position of the Agency's contractors.

Encouragement to exploit
The contractor must use its reasonable endeavours to exploit all intellectual property rights arising from work performed under the contract so as to promote space research and technology (clause 44.1). This requirement responds to a major shortcoming in the old system.

If the contractor does not intend to exploit or does not effectively exploit the intellectual property rights, it must notify the Agency within a period stipulated in the contract (clause 44.2). After such notification, the Agency will consult the contractor and investigate the reasons for the failure to exploit. Following this consultation, if the Agency is convinced that effective exploitation can be made and also finds a suitable third party, it can require the contractor to grant the third party a licence, on favourable terms, to the rights not effectively exploited. If it does not find a suitable third party to exploit such rights, it can require the contractor to assign such rights to ESA (clause 44.2). The ability of the Agency to require the contractor to assign rights should encourage exploitation.

Following the Agency's acceptance of work performed under a contract, the contractor must provide written reports (and updates if required) on the exploitation of intellectual property. The timing of these reports may be specified in the contract. The most appropriate timing will depend on the technology and the commercial environment. For instance, software often quickly becomes outdated, and so the time available to demonstrate that reasonable efforts have been made to exploit it may be shorter than for other technologies. If no specific provision is made in the contract, a report has to be delivered to the Agency within 3 years and a second within 10 years of acceptance.

Software
Software may be supplied in 'object code' or 'source code' form and so requires special provisions. Software is initially created by writing a set of general functions to be carried out in a particular order. These are then expressed in a more precise format, which is a human-intelligible computer language. This human-intelligible form of the software is known as the 'source code', which is commonly used to maintain and modify the software. Source code may then be compiled or translated by special software into a machine-readable version called 'object code'. The object code gives the user little intelligible information, and so is usually a secure form for distribution to end-users.

(i) Object code
Software in object code form is available under the same conditions as any other technology. Intellectual property rights in the object code are owned by the contractor and made available as set out above in the section on 'Use of intellectual property created' (i.e. under Rule 1, 2, 3 or 4 - clause 42.1).

(ii) Source code
Source code enables the user to maintain and modify the software and is therefore a very sensitive issue. Industry therefore requested the Agency to establish a system that prevents its uncontrolled dissemination. On completion of the contract, the contractor has to deliver the source code to an 'escrow agent'. The latter keeps it confidential and secure and releases it to the Agency in the event that the contractor becomes insolvent, commits a breach of contract, or assigns the intellectual property rights protecting the software (clause 42.3). The last point is of particular relevance for the Agency since the contractor – as holder of the rights – may freely assign any intellectual property rights arising from work under the contract (clause 39.3).

If the Agency requires the source code to operate, integrate or validate software, or to maintain, update or modify software for use in an ESA programme, it may approach the contractor directly. The contractor may then choose to release the source code or require the escrow agent to release it to the Agency (clause 42.4).

(iii) Special cases: operational and open-source software

There are two special cases in which the Agency may own the intellectual property rights for software developed under a contract: these are for 'operational software' and 'open-source-code software'. In both cases, this will be clearly indicated in the Invitation to Tender.

The definition of operational software has been enlarged to take account of current practice at the Agency. It therefore covers software required for use on the ground to validate and control a space mission or to calibrate data from a space mission, and also software used in support of the general activities of the Agency, such as the ESTEC design and validation facilities or the Agency's financial-management software. It is essential for the Agency to be able to use such software in any way that it requires. This type of software will always be procured under a fully funded contract and, to ensure that it has the full freedom to use the software in the most effective way, the Agency will normally own all intellectual property rights (clause 42.8).

Open-source software according to clause 42.10 is software that the Agency wants to make freely available to members of the public even beyond the Member States. Since it is made available in the public interest and not for financial gain, it makes sense for the Agency to own all intellectual property rights. Such software will therefore be procured under a fully funded contract.

Article III.3 of the ESA Convention (read in conjunction with the other paragraphs of that article) lays down the rule that Agency-owned intellectual property rights derived from space-research activities must be freely accessible to Member States or their industry. Since free access is confined to Agency-owned intellectual property rights resulting from a space-related activity, the software tools for the Agency's management or financial services (e.g. its financial-management software) are not freely available to Member States or European firms.

Background intellectual property rights

The use of a product, application or result of a contract may rely on the use of a product or intellectual property that the contractor has created for some other purpose. Any intellectual property the contractor has created under another contract with the Agency is always made available in accordance with that other contract (i.e. it will probably be made available under Rule 1, 2, 3 or 4 as described above). However, if the contractor owns intellectual property that was not developed under a contract with the Agency and is required to complete or use any product, application or result of the contract, then it is referred to as 'background intellectual property' (this may be contrasted with intellectual property created under the contract itself, often called 'foreground intellectual property').

There is a need to ensure access to background intellectual property for use in Agency programmes. Without it, the Agency may not be able to use some of the products or applications of ESA contracts. Therefore, the Agency is granted free access to background intellectual property for the project specified in the contract, but not for any other purpose (clause 43.4). In contrast, if any third party requires background intellectual property to use or modify a product of the contract for some other ESA project, the contractor has to grant a licence on market terms. However, the contractor can restrict licensing of its background intellectual property at market rates, by relying on its legitimate commercial interest (clause 43.4). Thus, the contractor's ability to exploit its intellectual property for certain markets is protected.

Fees

In some contracts, the contractor may have to pay the Agency a fee if the results of the contract are exploited. Fees are not payable in respect of exploitation within Participating States in the field of space applications. However, fees may be due for exploitation outside Participating States, or for non-space applications (clause 46.3).

The contract states if and when fees are payable. They may only be payable on exploitation within 10 years of the date of acceptance of work arising from the contract (clause 46.1). The upper limit for fees payable cannot exceed the total sum paid by the Agency for the rights exploited.

Resupply

The Agency may require a contractor to resupply identical products, applications or results of a contract for ESA programmes. A product, application or result that deviates from the original design or technical solution provided under the contract will be treated as a normal procurement for the purposes of resupply.

The original contractor will have the know-how and technology to resupply the identical product and so should be in the most commercially competitive position to resupply. The Agency will therefore initially enter into negotiations with the contractor, and the contractor may be requested to make an offer for resupply. If the Agency does not consider the contractor's proposed price fair and reasonable, or delivery cannot be made as required, then resupply may be put out to open (or restricted) tender. If another party is selected to resupply, the original contractor may be required to give assistance and will be remunerated for the assistance provided.

Subcontractors

Where the contractor requires the services of a subcontractor, it may enter into subcontracts with approved subcontractors (unless otherwise specified in the contract - clause 36.5).

One policy objective of the new conditions is to support not only prime contractors, but also subcontractors that undertake research and development for an

ESA contract. Therefore, each subcontract must give the subcontractor the same rights and obligations in relation to the work it produces as those the contractor has agreed to under the contract. Thus, the subcontractor alone will own the intellectual property rights in the work it produces, but will make those rights available to the Agency, Participating States and any person or body under their jurisdiction on the same basis as the prime contractor.

On some occasions, the contractor and a subcontractor may jointly produce work. In such cases both parties will agree to vest the intellectual property rights in the principal contributor to the development if that party is able and willing to exploit the rights (clause 36.5 (b)). The principal contributor will then license back the rights to the other party having contributed to the development. The scope of that licence is open to negotiation. Alternatively, the principal contributor may agree with the other party on appropriate financial compensation for the exclusive right to exploit the results of their joint work.

Partly Funded Contracts

General

The objectives that underpin fully funded contracts also largely apply to partly funded contracts, so that the majority of clauses applicable to fully funded contracts are retained for partly funded contracts. To avoid repetition, only the significant variations from fully funded contracts are outlined below.

Ownership

As with fully funded contracts, the contractor will own all intellectual property rights, and has the right to apply for registered intellectual property rights arising from work performed under the contract (clause 53.1). However, since the contractor has contributed to the funding of the contract, it was not considered appropriate to give the Agency the ability to require the assignment of intellectual property if the contractor fails to register or abandons rights (cf. clause 39.2 for fully funded contracts).

Where the Agency requires operational software or open-source-code software, it will be procured through fully funded contracts, so that ownership of intellectual property rights in these products for partly funded contracts is not an issue.

Use of intellectual property

To take account of a contractor's financial contribution to the creation of intellectual property rights arising from work performed under a partly funded contract, the conditions of access and use are substantially different from those applicable under fully funded contracts. Intellectual property arising from a partly funded contract is available:

Rule 5

– to the Agency on a free, worldwide licence for Agency programmes; this is considerably narrower in scope than the licence for the Agency's own requirements in fully funded contracts, which extends to Participating States, any person or body under their jurisdiction, and includes the right to grant sublicences;

Rule 6

– to Participating States and any person or body under their jurisdiction for Agency programmes on financial conditions that should compensate the parties that paid for development of the rights being licensed according to the levels of contribution made;

Rule 7

– to any third party on market conditions to use for purposes other than for Agency programmes, providing the use is not contrary to the contractor's legitimate commercial interests.

Background intellectual property rights

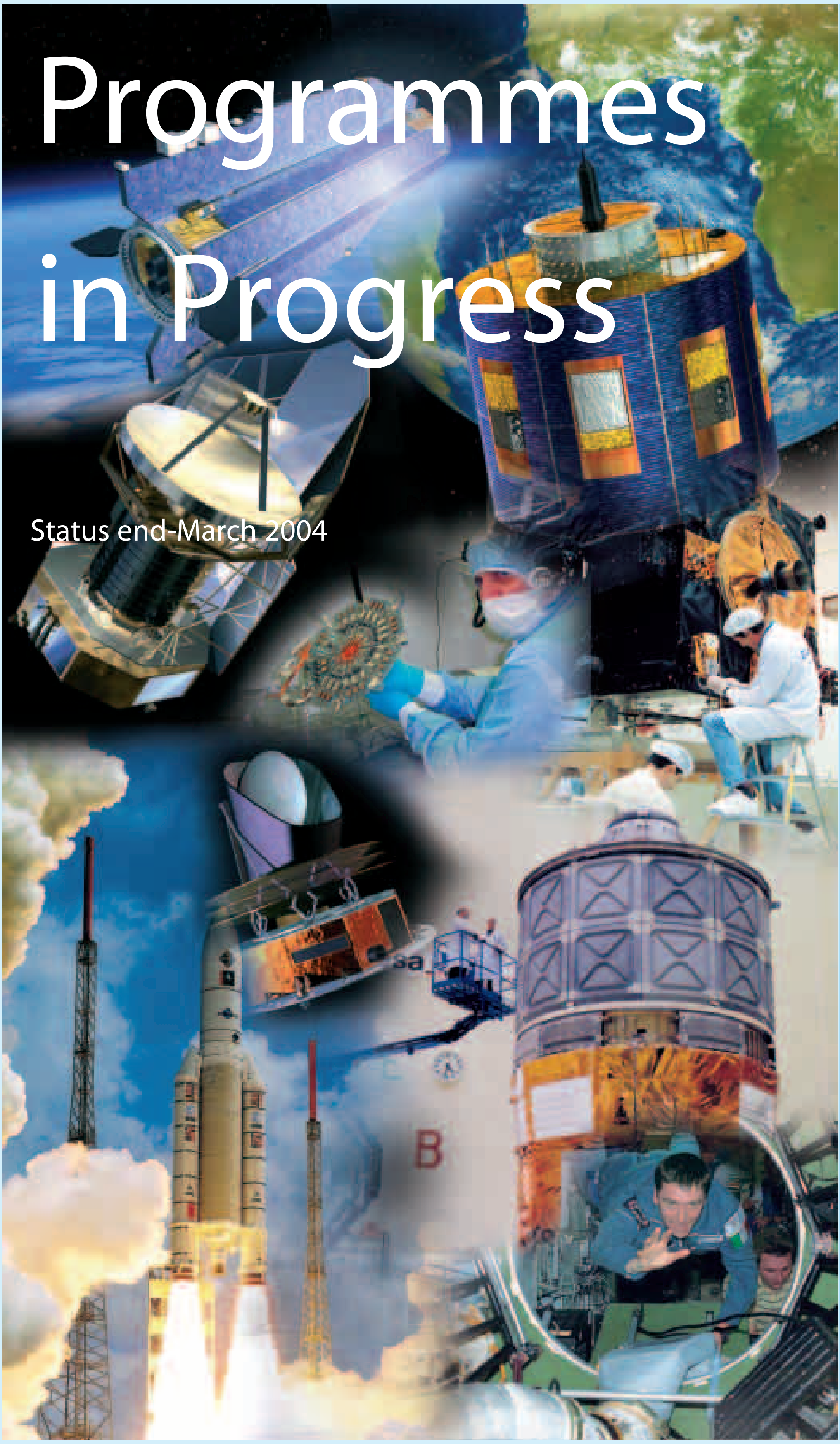
The approach to accessing background intellectual property rights owned by the contractor is different from that for fully funded contracts. If the Agency requires background intellectual property rights owned by the contractor for the project specified in the contract, the contractor must grant the Agency an irrevocable licence for the project on favourable conditions (clause 57.4). This contrasts with fully funded contracts where the licence is free.

Fees

The contractor is not required to pay a fee to the Agency if it sells or licenses results of the contract. This may be contrasted with fully funded contracts, where a fee may be payable on exploitation outside Participating States and for non-space applications for 10 years from the date of acceptance.

Conclusion

The new clauses and conditions dealing with intellectual property rights for ESA research and development contracts reflect a new policy concept. By replacing the open licensing policy and restricting third-party access to intellectual property rights developed under an Agency contract, they support the competitive position of the Agency's contractors on the world market. They further encourage the protection and exploitation of results generated by Agency-financed research and development activities. Exploitation by the contractor is highly desirable to ESA, because it can generate wealth and not only improve the contractor's competitive position, but also facilitate other companies' access to new technology on appropriate financial terms.


Programmes in Progress
Status end-March 2004

In Orbit

Programme	Project	Comments
SCIENTIFIC PROGRAMME	SPACE TELESCOPE	LAUNCHED APRIL1990
	ULYSSES	LAUNCHED OCTOBER 1990
	SOHO	LAUNCHED DECEMBER 1995
	HUYGENS	LAUNCHED OCTOBER 1997
	XMM-NEWTON	LAUNCHED DECEMBER 1999
	CLUSTER	RE-LAUNCHED MID 2000
	INTEGRAL	LAUNCHED OCTOBER 2002
	MARS EXPRESS	LAUNCHED JUNE 2003
	SMART-1	LAUNCHED SEPTEMBER 2003
	ROSETTA	LAUNCHED FEBRUARY 2004
APPLICATIONS/ TECHNOLOGY PROG.	MSG-1	LAUNCHED AUGUST 2002
	ERS-2	LAUNCHED APRIL 1995
	ENVISAT	LAUNCHED MARCH 2002
	ARTEMIS	LAUNCHED JULY 2001
	PROBA-1	LAUNCHED OCTOBER 2001

Under Development

Programme	Project	Comments
SCIENTIFIC PROGRAMME	VENUS EXPRESS	LAUNCH NOVEMBER 2005
	HERSCHEL/PLANCK	LAUNCH FEBRUARY 2007
	LISA PATHFINDER	LAUNCH EARLY 2008
	DOUBLE STAR	LAUNCH TC-1 DEC. 2003, TC-2 JULY 2004
	GAIA	LAUNCH MID-2010
	JWST	LAUNCH AUGUST 2011
COMMS./ NAV. PROG.	ALPHABUS	LAUNCH 2008
	GNSS-1/EGNOS	OPERATIONS START 2004
	GALILEOSAT	FIRST LAUNCH 2005
EARTH OBSERVATION PROGRAMME	EOPP	
	CRYOSAT	LAUNCH NOV. 2004
	GOCE	LAUNCH AUG. 2006
	SMOS	LAUNCH FEB. 2007
	ADM-AEOLUS	LAUNCH OCT. 2007
	METOP-2	LAUNCH OCT. – DEC. 2005
	MSG-2/3/4	LAUNCH MSG-2 JAN. 2005 LAUNCH MSG-3 2008 MSG-4 STOR. 2007
HUMAN SPACEFLIGHT PROGRAMME	COLUMBUS	LAUNCH OCTOBER 2006
	ATV	FIRST LAUNCH MAY 2005
	NODE-2 & -3	LAUNCHES JUN. 2006 & JUN. 2008
	CUPOLA	LAUNCH JANUARY 2009
	ERA	LAUNCH UNDER REVIEW
	DMS (R)	LAUNCHED JULY 2000
	ISS SUPPORT & UTIL.	
	EMIR/ELIPS	
	MFC	BIO, FSL, EPM with COLUMBUS
LAUNCHER PROG.	ARIANE-5 DEVELOP.	OPERATIONAL
	ARIANE-5 PLUS	AR5-ECA QUALIF. LAUNCH JUNE 2004
	VEGA	FIRST LAUNCH END 2006

- DEFINITION PHASE
- MAIN DEVELOPMENT PHASE
- LAUNCH/READY FOR LAUNCH
- OPERATIONS
- ADDITIONAL LIFE POSSIBLE
- RETRIEVAL
- STORAGE

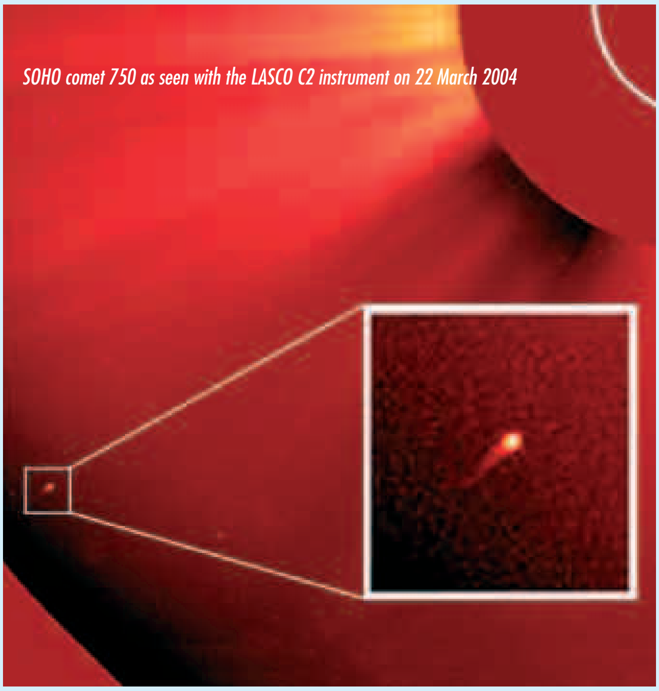
ISO

The Infrared Space Observatory Data Archive has been enhanced in content with six new sets of Highly Processed Data Products, the result of dedicated projects focused on cleaning the products of selected instrument modes of residual instrumental artifacts. ISO data were used extensively in the first scientific demonstration of the Astrophysical Virtual Observatory, on 27 January at ESO in Garching (D).

ISO continues to have a significant presence in the refereed literature, with more than 1100 papers drawing upon ISO data and covering all areas of astronomy having appeared since late 1996. Recent highlights include: tentative identifications of urea and formamide in SWS spectra of interstellar ices; detailed observations with the LWS instrument in the direction of the centre of our galaxy, towards the Sgr B2 region, where more than 70 lines from 15 molecular and atomic species have been detected at high signal-to-noise ratios; the first detection of cold dust in the extended disk of neutral hydrogen in a spiral galaxy, and in the northern shell of Centaurus A, both obtained with the ISOPHOT instrument; and the detection of dust-enshrouded star-forming activity in the infrared luminous interacting galaxies system Arp 299, obtained with the ISO camera.

Ulysses

An important milestone in the mission was reached in February, when ESA's Science Programme Committee unanimously approved the funding to continue operating Ulysses until 31 March 2008. This latest extension, the third in the mission's history, will enable Ulysses to acquire observations during a third set of polar passes. A key goal is to observe as fully as possible the influence of the recent polarity change in the Sun's magnetic field on the high-latitude heliosphere. The Jupiter Distant Encounter (JDE) campaign that commenced on 25 January was completed successfully on 8 March. The onboard tape recorder has been switched on again, marking the end of more than 40 days of 24-hour per day real-time coverage by the Deep Space Network. With the exception of the gamma-ray burst (GRB) instrument, the scientific payload was operated continuously during the JDE campaign without the need for power sharing. The spacecraft and the scientific instruments are in good health. On 30 June, Ulysses will be at its maximum distance from the Sun (5.41 AU) heading south, having crossed the heliographic equator on 20 February.


SOHO comet 750 as seen with the LASCO C2 instrument on 22 March 2004

Analysis of the data acquired during the Jupiter campaign is still in progress. Nevertheless, a number of interesting results have already emerged. The DUST instrument detected streams of dust particles flowing from Jupiter. First observed by the same instrument in 1992, the dust streams comprise grains no larger than smoke particles, and are believed to originate in the volcanoes of Jupiter's moon Io. The dust particles, which carry an electric charge, are strongly influenced by Jupiter's magnetic field. Electromagnetic forces propel the dust out of the Jovian system and into interplanetary space. The recent observations include the most distant dust stream ever recorded, at 3.3 AU from Jupiter. Another unusual feature is that the streams occurred with a period of about 28 days. This suggests that solar-wind streams that co-rotate with the Sun play an important role. The most intense peaks showed fine structure not seen in 1992.

During its second encounter, Ulysses approached Jupiter from high northern latitudes, opening a window on previously unexplored parts of the Jovian magnetosphere. This was of particular interest to scientists studying Jupiter's natural radio emission, since a distinctive type of radio signal is believed to originate in the high-latitude auroral zones of Jupiter. These signals, which have a repetitive, burst-like character, have indeed been detected throughout the campaign period. The radio and plasma-wave experiment onboard Ulysses first detected bursts of radio waves occurring approximately every 40 minutes during the Jupiter fly-by in 1992. These so-called 'quasi-periodic', or QP-40 bursts were present for several hours, then faded away and reappeared a number of hours later. More recently, NASA's Chandra X-ray observatory detected similar QP-40 pulsations in X-rays emitted in hot spots in Jupiter's northern polar regions. Although not fully understood, these phenomena also seem to be triggered by streams of high-speed solar wind hitting Jupiter's magnetosphere.

SOHO

On 22 March, SOHO discovered its 750th comet since its launch in December 1995. SOHO comet 750 was discovered in LASCO instrument images by the German amateur astronomer Sebastian Hönig, one of the most successful SOHO comet-hunters. It is part of the Kreutz family of 'Sun-grazing' comets, which usually evaporate in the hot solar atmosphere.

The LASCO coronagraph on SOHO, designed for seeing outbursts from the Sun, uses a mask to block the bright rays from the visible surface. It monitors a large volume of surrounding space and as a result has become the most prolific discoverer of comets in the history of astronomy. More than 75% of the discoveries have come from amateur comet hunters around the World watching the readily available SOHO images on the web. So, anyone with Internet access can take part in the hunt for new comets and become a 'comet discoverer'!

XMM-Newton

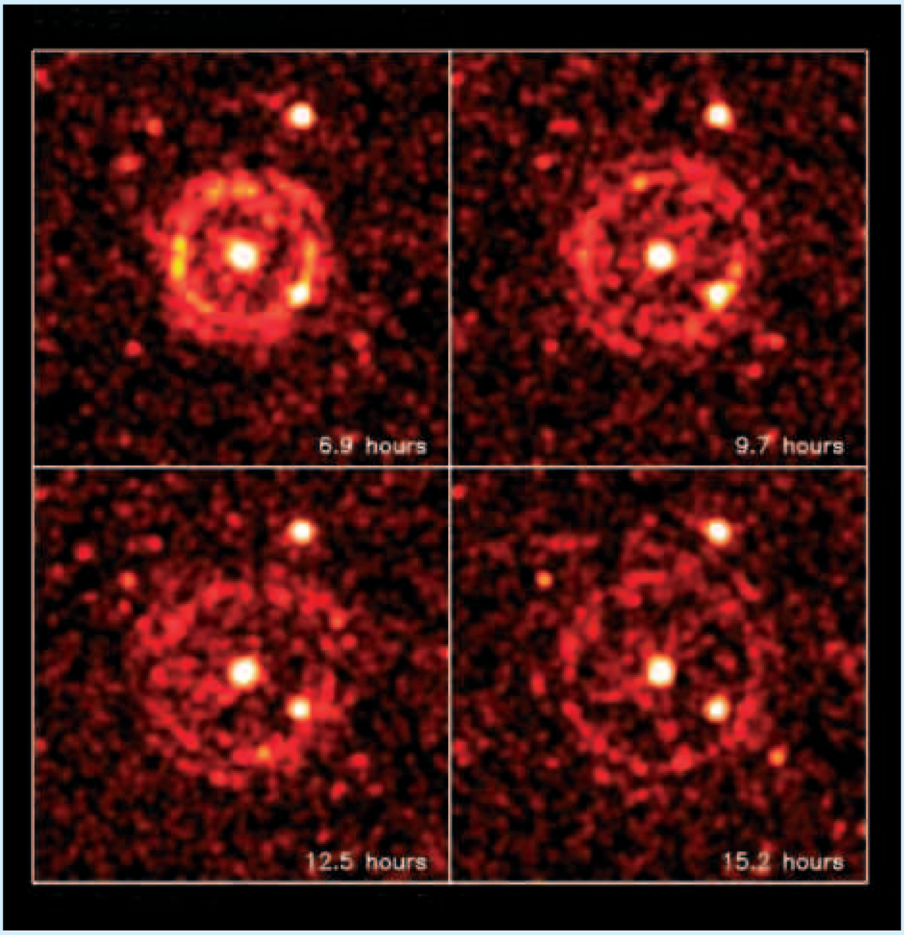
XMM-Newton operations continue to run smoothly. The spring 2004 eclipse season passed without any problems. A dedicated model of the satellite's radiation environment is being used to optimise the science observation windows in order to maximise the percentage of successful observations.

An update to the onboard software of the EPIC-MOS cameras has been tested on the flight-spare camera by the Principal Investigator team. The next step will be to verify the software, developed at VILSPA (E), by uploading it to the flight camera. This new version will allow the discarding of blemished pixels due to the expected radiation damage over the years to come.

The work on upgrading the overall ground segment to SCOS-2000 is proceeding on schedule. By October 2004, the full ground segment will run on SCOS-1b and SCOS-2000 in parallel to validate the new systems. The final switchover to SCOS-2000 will be made after a successful three-month trial period.

The data processing and data shipment is going according to plan, with over 3300 observation sequences having been executed and the data for 3100 of these having already been shipped.

The programme-completion status is as follows (13 April 2004):
- Guaranteed time: 99.0 %
- AO-1 programme: 98.0 %
- AO-2 programme: 99.6 %
- AO-3 programme: 30.1 %.



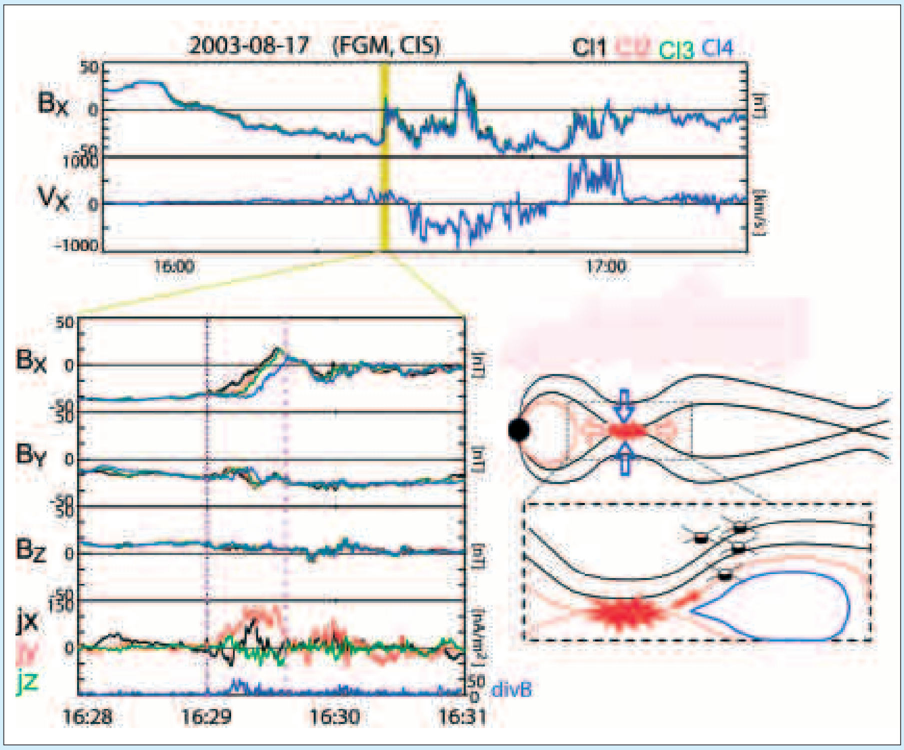
X-ray halo around the afterglow of GRB 031203 at different times after the burst had occurred. The images were taken with XMM-Newton's EPIC-pn camera (Copyright ESA/S. Vaughan, Univ. of Leicester)

XMM-Newton observed the field of the Gamma-Ray Burst GRB 031203 on 12 December 2003. The observations started only 6 hours after the alert had been received from the Integral team. The images obtained are among the most impressive taken so far with the EPIC cameras. Around the X-ray afterglow, a halo appeared as concentric ring-like structures. Their radii increased with time and can be explained by small-angle X-ray scattering. This represents the first detection of a time-dependent dust-scattered X-ray halo around a GRB.

By early-April, more than 500 papers based on XMM-Newton data had been published in, or submitted to, the refereed literature.

Cluster

Cluster, now in its fourth year of operation, is performing nominally with all instruments returning data as laid down in the Master Science Plan. Since June 2002, Cluster has collected data for 24 h per day, except during satellite constellation and attitude manoeuvres when some instruments are switched off. The fifth constellation manoeuvre will take place in May-June, when the spacecraft separation will be changed from 250 to 1000 km. Perfect tetrahedra (same distance between all spacecraft) are formed at two places along the orbit, after perigee in the Northern Hemisphere and at apogee, to be able to cover a large part of the orbit with a good three-dimensional configuration.



The top figure shows the four spacecraft measurements of the X-component of the magnetic field and the ion flow from Cluster (C1 – black, C2 – red, C3 – green, C4 – blue). The bottom left figure shows the three components of the magnetic field and the current density obtained with the curlometer technique during a selected interval including a current-sheet crossing. The bottom right figure shows a schematic of the dynamics of the Earth's magnetotail. As a result of magnetic reconnection, a large amount of energy is released towards the Earth's atmosphere and a plasmoid - a magnetic bubble - escapes from the magnetosphere back into the solar wind.

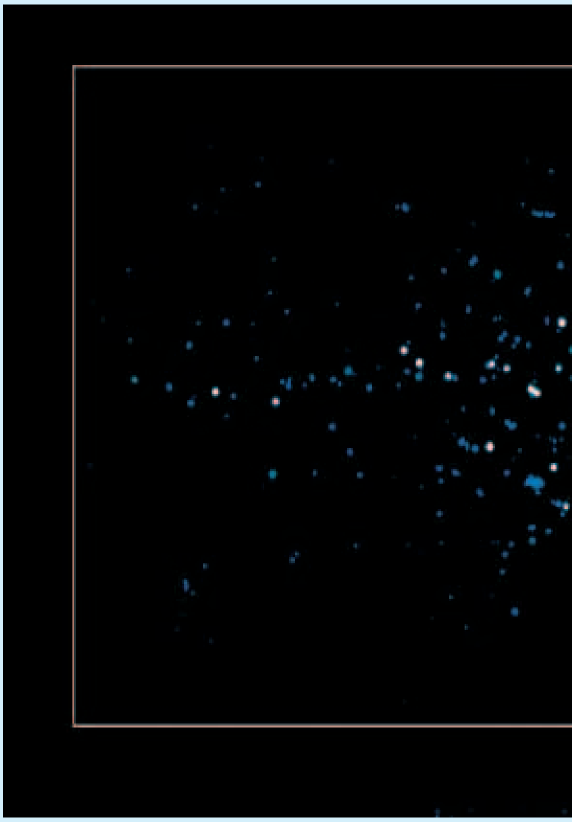
One of the fundamental physical processes in the Universe is magnetic reconnection. For scientists, somewhat fortunately, it occurs frequently in the Earth's magnetosphere. It is an explosive process, giving rise to a huge amount of energy that is drawn into the Earth's atmosphere by magnetic field lines. There are many unsolved issues involved in reconnection, such as the triggering of the process and the formation of a thin current sheet that is known to occur before reconnection takes place. It was one of the subjects of the 7th Cluster Workshop held in the first week of March. The scientific presentations and discussion focused particularly on the tail of the Earth's magnetosphere.

Between July and October 2003, the four Cluster spacecraft were in a tetrahedral formation separated by about 200 km. This was an ideal separation for resolving the structure of the thin current sheet obtained from the curlometer technique using magnetic-field data from the FGM instruments on the four spacecraft. Dr. Rumi Nakamura and her colleagues at the Space Research Institute in Graz (A) have investigated the current-sheet crossings observed on 17 August 2003. During the Workshop, a detailed comparison took place between the current density obtained by the curlometer and the average current obtained by the PEACE electron instrument on the four spacecraft. The resulting good agreement confirmed the existence of a thin current sheet in the magnetotail carried mainly by the electrons (see accompanying figure).

Integral

Integral operations continue to run smoothly. A new strategy for controlling the evolution of the spacecraft's orbit has been implemented and is having the desired effect. The orbital parameters need to be maintained in order to ensure both uninterrupted coverage of the scientifically useful part of the orbit (above 40 000 km), and suitable overlap from the two ground-stations that are used (ESA's Redu station in Belgium and NASA's Goldstone station in California).

A series of calibration observations of the Crab Nebula 'standard candle' have been performed in March. These included a series of raster scans around the source to enable the off-axis responses of the instruments to be better determined by the Integral scientists. After the Crab observations, the operating X-ray monitor (JEM-X) was swapped, and JEM-X1 will continue to be operated whilst a slow change in instrument performance is investigated.

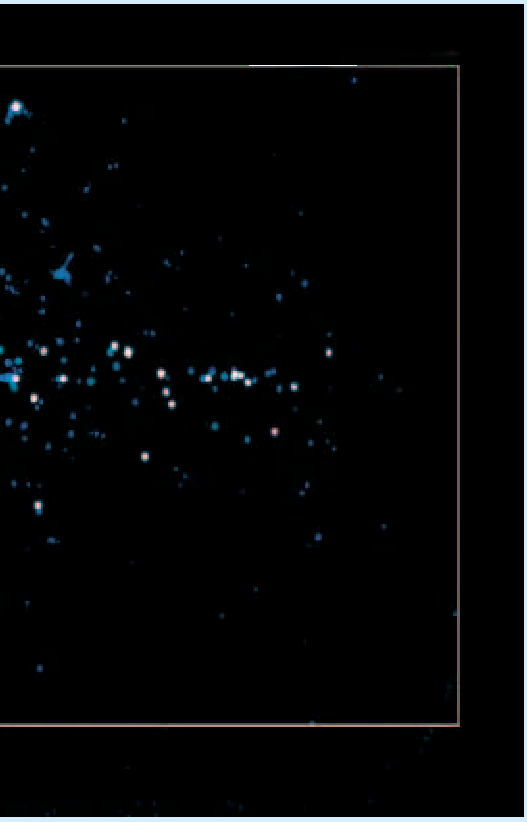


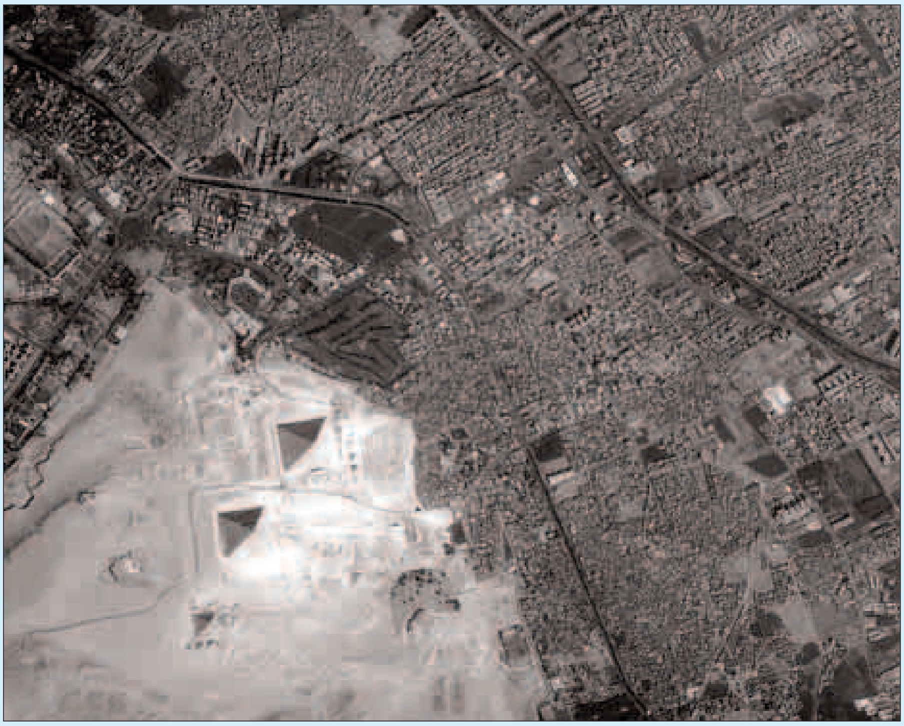
The central part of our Galaxy, as seen by Integral in gamma-rays. The brightest 91 objects in the image were classified by Integral as individual sources, while the others appear too faint to be properly characterised at this stage (Courtesy of F. Lebrun, CEA-Saclay)

Integral has solved one of the long-standing puzzles in gamma-ray astronomy – the nature of the diffuse glow of soft gamma-rays seen from our Galaxy. F. Lebrun and co-workers, reporting in the journal Nature, demonstrate that, with its superior ability to see faint details, Integral has shown that individual sources produce the soft gamma-ray background seen only as a 'diffuse glow' by previous observatories. Many of these sources are likely to be black holes or neutron stars.

SMART-1

During the first quarter, SMART-1 has continued to fly on the transfer trajectory that is gradually taking the spacecraft towards the Moon. The orbital operations entailed first a rapid expansion of the orbit in order to escape the dangerous Van Allen radiation belts around the Earth, followed by an optimised sequence of thrust and coasting arcs designed to achieve the desired transfer orbit. In March, a series of about 20 long eclipses took place, which interrupted thrusting but did not otherwise affect the spacecraft or its instruments. In the meantime, all of the scientific instruments have been commissioned. The results are still being analysed, but generally seem satisfactory. Recently, a new thrusting strategy has been resumed, entailing regular perigee thrust arcs of 10 to 15 hours. The electric-propulsion system will have accumulated some 2000 hours of operation by the end of April, producing a velocity increment of more than 1300 m/s. All subsystems are also functioning very well.





The Egyptian Pyramids as seen by PROBA's CHRIS instrument

The ground-control team is now conducting 'routine spacecraft operations'. Contact is established with the spacecraft on the basis of station availability, the baseline being twice a week for 8 hours. A detailed trajectory optimisation based on actual electric-propulsion performance was recently performed and SMART-1's arrival at and capture by the Moon is now planned for mid-November. The lunar orbit will then be adjusted and optimised to meet the scientific observational needs, with the main lunar-science phase beginning in January 2005.

PROBA

PROBA operations from ESA's Redu (B) station have continued to be shared between technological activities (mainly related to the testing of new flight software) and normal user operations related to the SREM, DEBIE, HRC and CHRIS instruments.

ESA has drafted and started implementing the 2004 acquisition plan for CHRIS/PROBA operations. In addition to supporting the continuation of past projects, the new plan makes provision for specific experiments related to ESA programmatic objectives. These include acquisitions in support of Earth Explorer candidate SPECTRA Phase-A activities, joint acquisitions between the CHRIS and German BIRD satellites in support of FuegoSat fire-monitoring activities, and acquisitions to support ESA Globewetland service development activities. A CHRIS/PROBA Workshop at ESRIN on 28-30 April will provide the opportunity to review preliminary results and fine-tune the acquisition plan.

Mars Express

Following the successful injection of Mars Express into its final orbit, the sequential switch-on of all instruments began in early January. Enough scientific data had been accumulated by 23 January to hold a very successful Press Conference, at which the first results were presented. In particular, the journalists called the first direct detection of water ice by the OMEGA instrument 'sensational'.

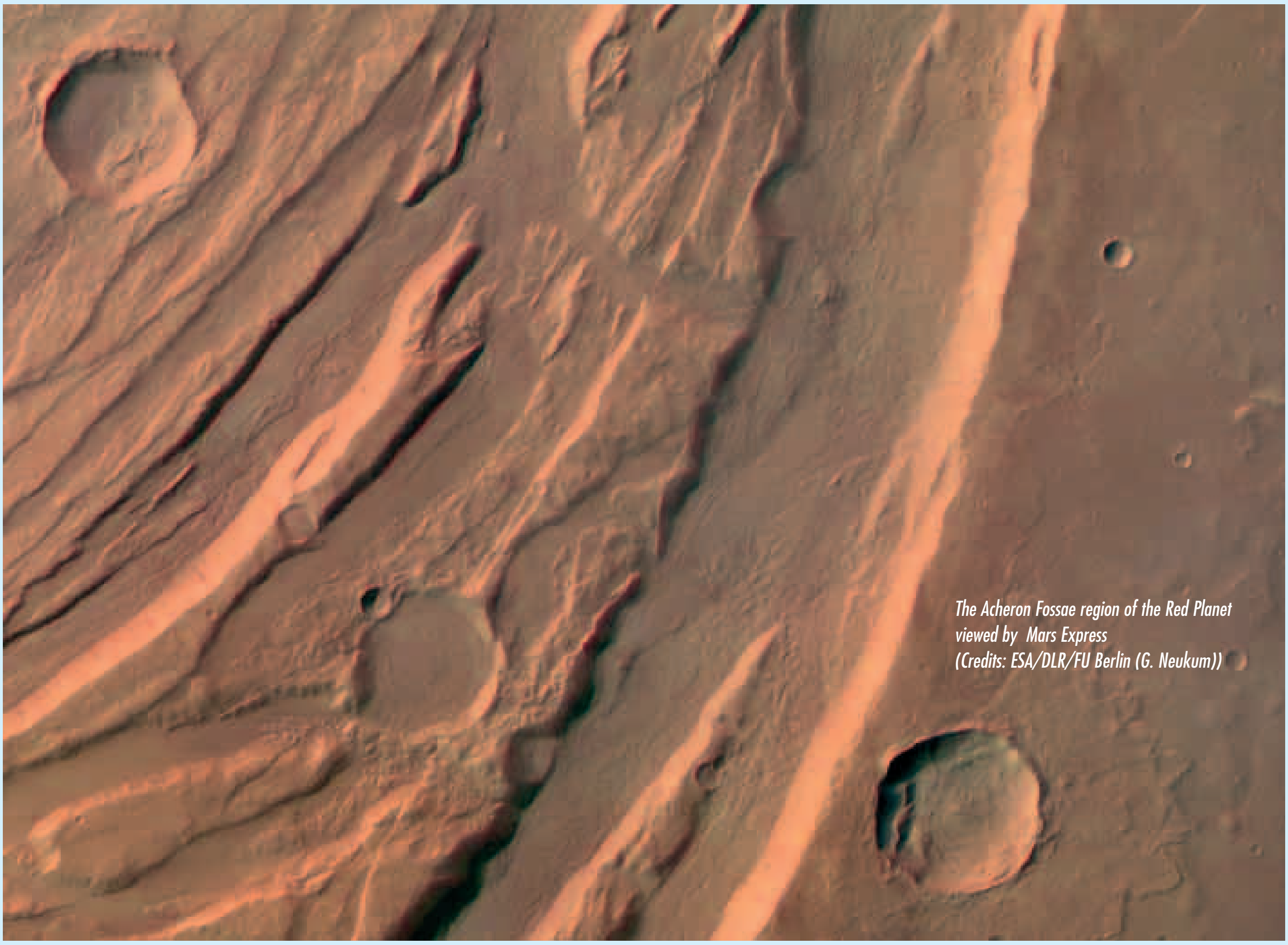
In March, the PFS instrument scientists reported traces of methane in the Martian atmosphere. As the mean lifetime of methane molecules in the planetary atmosphere is relatively short (a few hundred years only), there must be an as yet unidentified mechanism maintaining their presence.

The only remaining commissioning activity is the release of the radar booms, originally planned for May. Recent boom-deployment simulations by the radar team have raised concerns about the dynamics of the release. Further investigations are therefore needed before authorising the deployment, and so some delay is envisaged.

A further major manoeuvre has been successfully performed to establish the so-called 'e100' orbit, which reduced the apocentre from some 14 000 km to about 11 000 km. The scientific community requested this manoeuvre to provide a better data-taking balance between the scientific instruments during the mission's operational phase. The instrument operations and data production activities are already at near-operational levels, with 90 Gbit of data having already been accumulated by the scientific payload.

Double Star

The commissioning of the TC-1 equatorial satellite was completed in February, all payload and satellites are operating nominally, and the first scientific results are very promising. An attempt to deploy the STAFF boom was unfortunately not successful; the experimenter team are therefore revising their operational modes to gather the best possible scientific data with this adverse configuration. The magnetic noise was improved by an attitude adjustment, which removes boom shadowing of the solar arrays. The remaining magnetic emissions from the solar panel are being tackled by FGM with an adapted calibration method.



The Acheron Fossae region of the Red Planet viewed by Mars Express (Credits: ESA/DLR/FU Berlin (G. Neukum))

Following the Commissioning Review for TC-1 held in Villafranca (E), all space and ground-segment systems are operational. An official handover ceremony has taken place in Beijing, with both Chinese and European scientists presenting their first results to the public. TC-1 is now in full routine-operation mode in consultation with the DSP/Cluster scientific community to define coordinated observations and to provide routine data analysis.

On the second Double Star satellite (TC-2, polar), a detailed Chinese-European study revealed a design problem with the solar generator. Thanks to the rapid reaction by Chinese industry, the necessary modifications have already been implemented, resulting in a significant reduction in magnetic emissions. With the satellite's assembly and basic functional tests completed, TC-2 is now undergoing its environmental test campaign, involving mechanical vibration testing in April and thermal testing in May, followed by EMC and magnetic verification in June.

The launch campaign in Tai Yuan is expected to commence by end of June for the planned 20 July launch.

Rosetta

After two short launch postponements due to the weather and a small technical problem, Rosetta was flawlessly injected on 2 March into its Earth-escape orbit, which will take it in ten years' time to comet Churyumov-Gerasimenko. The orbital injection accuracy provided by Ariane was almost perfect, with little need for any correction manoeuvres.

After the launch, the solar arrays and high-gain antenna were deployed, the launch locks on the lander were released, and spacecraft checkout began. The launch and early-orbit phase was completed within three days and all spacecraft subsystems were reported to be working nominally.

Payload commissioning then began and ten of the twelve experiments, including the lander, have since been switched on and no major anomalies have been reported. All experiment booms have also been successfully deployed. Due to ground-station availability, payload commissioning will take place in two sessions, in May and in September/October.

The ground segment is performing well, including ESA's latest New Norcia ground station in W. Australia.

The very high accuracy of the Ariane launch means that the spacecraft has sufficient extra fuel to give scientists the freedom to choose to fly by two very interesting asteroids, between the orbits of Mars and Jupiter, during the cruise out into deep space before the comet rendezvous. The first fly-by in September 2008 will be of Steins, a fairly small asteroid with a diameter of just a few kilometres. In July 2010, Rosetta will then visit Lutetia, a much larger body with a diameter of about 100 km.

The Rosetta mission has therefore had a near-perfect start, but there is still a long journey to be made before the spacecraft eventually catches up with the comet Churyumov-Gerasimenko in 2014, which it will study at close quarters for the next two years.

Venus Express

The project is progressing according to plan, with the Critical Design Review process starting in March at the prime contractor Astrium's site in Toulouse (F). Flight-model deliveries have also commenced and, most importantly, the flight structure integrated with the entire propulsion system was shipped in early April from Stevenage (UK) to Turin (I) for the integration of the flight-model subsystems. Although the schedule is tight, the project is still on track for the 26 October 2005 launch from Baikonur.

Herschel/Planck/ Eddington

Manufacture of the structural and qualification models of the Herschel cryostat hardware and the manufacture and assembly of the engineering models for all electronic units has progressed and several units have already been delivered.

For Planck, the structural qualification testing for the two main subassemblies of the Payload Module, the telescope and the payload-module structures, has already been completed. Manufacture of the main hardware elements of the Herschel cryostat, such as the helium tanks and the cryostat vacuum vessel, have experienced some delay, but most are now close to assembly. Some final detailed-design activities are currently being completed in preparation for the Payload Module and satellite Critical Design Reviews in April/May.

The launcher Preliminary Design Review process with Arianespace is close to completion, including mission analyses and injection strategy.

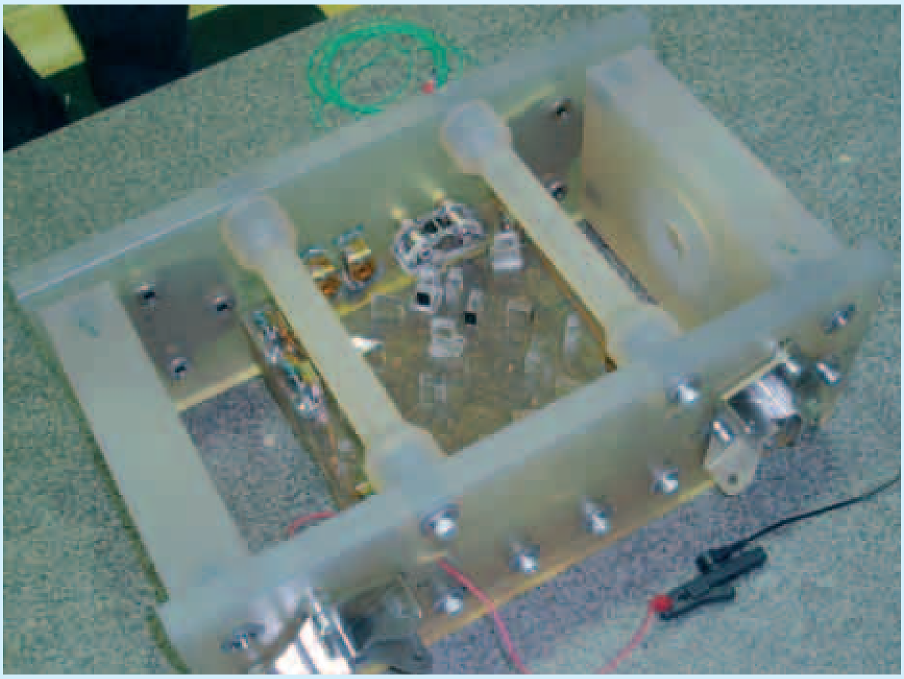
The qualification models of the Planck and Herschel scientific instruments have made good progress, with most now under test prior to their delivery to industry during the summer. The instrument teams are already concentrating their efforts on timely production of their flight models.

The Herschel telescope primary mirror has entered the next production stage, with the grinding of the front surface prior to the final polishing of the mirror. The Planck telescope's secondary-reflector qualification model is close to completing its cryogenic optical testing. The primary reflector of the qualification model has successfully passed the mechanical test phase and is also being prepared for cryogenic optical testing.

The parallel Eddington system-definition studies have been completed, with mature designs established at both industrial consortia. The contract for the development of the CCDs for the Eddington cameras is also nearing completion.

SMART-2/LISA Pathfinder

SMART-2, the second of the Small Missions for



The optical bench of the LISA Technology Package engineering model developed by Astrium GmbH (D) and tested at TNO-TPD (NL)

Advanced Research and Technology, is dedicated to demonstrating key technological aspects of the Laser Interferometer Space Antenna (LISA), a space-borne gravitational-wave detector to be flown as a cooperative ESA-NASA mission. LISA consists of three spacecraft separated by 5 million km, designed to detect the 'ripples' in space-time produced by massive objects such as black holes.

The basic idea behind SMART-2 is to shrink one LISA 'arm' from 5 million km to a few centimetres and accommodate it within a single spacecraft, also known as LISA Path-finder. The technologies to be demonstrated are the inertial sensors, consisting of two free-floating test masses contained within two vacuum cavities and an associated metrology package (the LISA Technology Package, or LTP), the proportional micro-thrusters (both field-effect-emission and cold-gas), and the so-called drag-free attitude-control system. The spacecraft also hosts an equivalent NASA/JPL-provided Drag Reduction System (DRS).

The SMART-2/LISA Pathfinder implementation contract with Astrium Ltd. (UK) was kicked-off in February, and work is already in progress on the definition of such critical subsystems as the drag-free attitude control, the micro-propulsion technologies and the avionics architecture.

The SMART-2 launch is foreseen in the first half of 2008.

James Webb Space Telescope (JWST)

The JWST has received full NASA support to ensure its timely launch in 2011, which will minimise the impact of the cancellation of the next Space Shuttle service mission to the Hubble Space Telescope, and the full teams at ESA and NASA are now in place to face this challenge. All the JWST System Requirement Reviews (SRRs) have been successfully completed and the subsystem SRRs are also partially complete.

ESA's participation in JWST consists of the Telescope's launch on an Ariane-5, the Near-Infrared Spectrograph (NIRSpec), and the Mid Infra-Red Instrument (MIRI), consisting of an imager and a spectrograph, developed by a consortium of European Institutes.

NIRSpec

All of the critical technology studies were completed with final presentations in February. The feasibility of making the mirrors and optical bench from SiC-based ceramics has been confirmed, removing a potential major hurdle. The Invitation to Tender (ITT) for the instrument's implementation phase was therefore released as planned and proposals have already been received. The tender evaluation process is currently in progress. The Announcement of Opportunity (AO) for the NIRSpec Instrument Science Team has also been issued.

MIRI

The ESA Council has endorsed the Multi-Lateral Agreement between the Agency and the different Member States participating in the MIRI instrument. It establishes the formal legal platform for participation. A Baseline Design Review has also been successfully completed, giving the green light to proceed with the structural-thermal model of the MIRI optical assembly.

Gaia

The final presentation of the Gaia technology ground-verification contract took place at ESTEC on 3 February. This successfully brought to an end a one-year industrial study by EADS Astrium of the objectives and requirements for the ground-verification activities that need to be undertaken before launch, including measurement of the optical behaviour at the operational temperature. This was an essential exercise in concluding whether the stringent payload goals can be guaranteed in orbit, and identifying the associated costs and facilities needed. Central to the plans are the use of the 'Focal' thermal-vacuum facility in Liege, Belgium.

The final presentation of results from the Gaia technology High-Stability Optical Bench contract also took place in ESTEC on 3 February. This concluded a two-year study of the basic angle-monitoring device. The work has proved the principles and processes using a laboratory prototype of a device that should ultimately have a 1 microarcsec monitoring capability in orbit. The prototype demonstrated the mounting, alignment, and thermal/vibrational stability of the prototype system manufactured from silicon carbide. The contract was undertaken by EADS Astrium Toulouse (F), supported by TNO-TPD Delft (NL) for the laboratory setup, and Boostec (F) for the silicon-carbide structure and mirrors.

On 2-3 March, separate presentations were made by Alcatel/Alenia and EADS Astrium to ESA representatives and the Gaia Science Team. Extensive presentations summarised the activities carried out under the parallel System Level Technical Assistance contracts, which have been running with these industrial teams for the past two years. As a result, Gaia was authorised to enter the Detailed Definition phase (Phase-B1) in April, and this will last for one year.

The first phase of the radial-velocity instrument design effort has come to an end with the final presentation of the work performed to date by the Radial Velocity Spectrometer Consortium. This scientific consortium, comprising Mullard Space Science Laboratory, Observatoire de Paris-Meudon, Brunel University, Leicester University, Osservatorio di Asiago, and the University of Ljubljana, worked with ESA and the industrial System Level Technical Assistance contractors under the direction of the ESA Study Manager. It has refined all aspects of the instrument design (optics, detector, mechanical, thermal, and onboard processing), providing a baseline design for Gaia's radial-velocity spectrograph. This will be further refined during the Definition Study phase.

AlphaBus

As part of the ESA-funded Phase-B activities, the prime contractors Alcatel Space (F) and EADS Astrium (F) have started the selection of equipment providers for the buildup of the industrial consortium for the AlphaBus main development phase (Phase-C/D). The Agency participates in the industrial evaluations and ensures that they are conducted fairly and

Model of the novel European 500 N spacecraft apogee motor developed for AlphaBus by EADS-ST (D)

equitably. The overall tendering and selection process will last six months. The Phase-B definition work for AlphaBus funded by CNES continues at prime contractor level and will be finalised with a Preliminary Design Review in the second half of this year. In parallel, preparations are in hand for the release of a Request for Quotation for Phase-C/D in the same period.

The AlphaBus pre-development activities are progressing well with eighteen contracts awarded by the Agency as part of the preparatory phase to secure the enabling technology needed for the AlphaBus line of products.

CryoSat

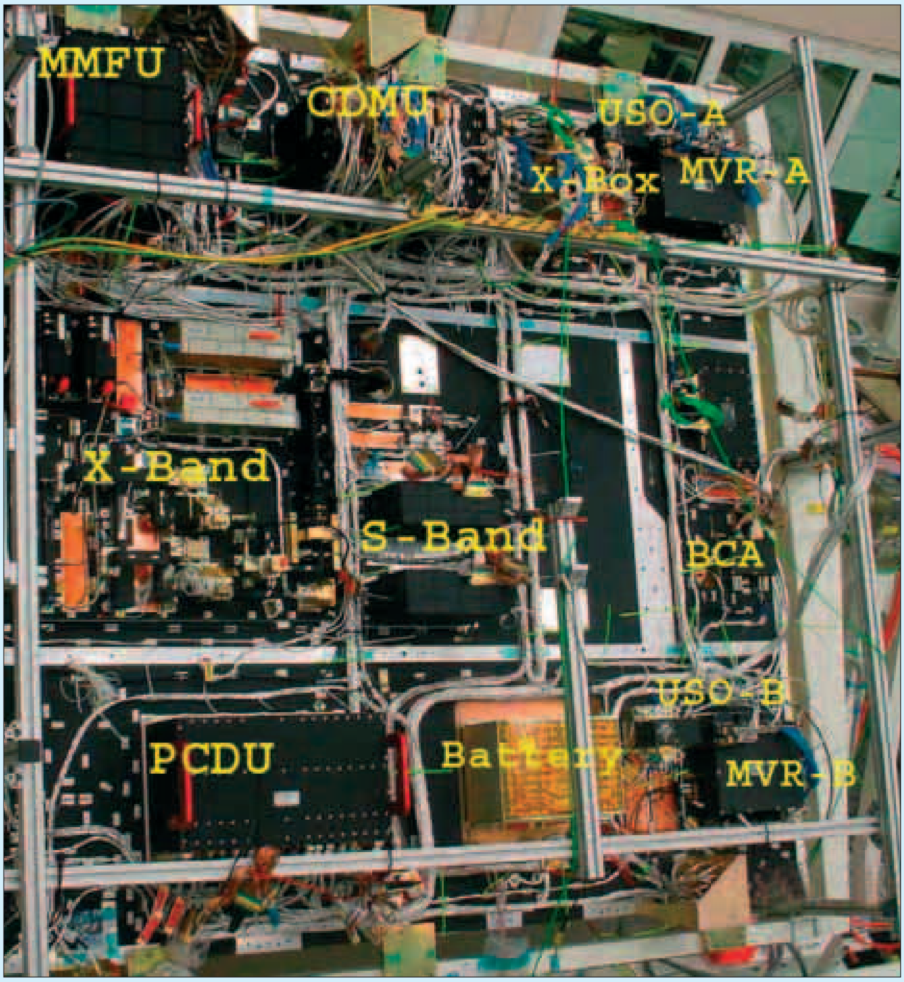
Significant progress has been made in the development of the satellite and a major milestone was reached with the completion of the Satellite Test Bed activities in late-March. EADS Astrium GmbH (D) is now integrating the electronic boxes on the mechanical structure where the cold gas subsystem and the electrical harness were previously accommodated. The next step will be the integration of the solar array that has been successfully accepted at Emcore's premises (USA).

On the payload side, manufacture of the flight model of the SIRAL altimeter has been completed. Alcatel (F) will proceed immediately with its final integration and tuning, once the extensive testing of the engineering model is completed. Excellent results have been obtained so far.

Unfortunately, a few repair activities, due to quality problems lately reported with some electronic parts, are hampering the progress of the on-going integration activities both at satellite and payload level. This is generating some uncertainties in the schedule for the satellite environmental testing foreseen at IABG (D).

Activities related to the CryoSat ground segment are progressing according to plan. The first Satellite Validation Test (SVT0) was successfully performed by ESOC in early February, confirming the efficiency of the new development approach being followed by ESOC and EADS Astrium GmbH. The Payload Data Segment facility (which includes the Instrument Processing Facility for Level-1b and Level-2 products) has been successfully installed in Kiruna by ACS (I). The long ground-segment validation campaign has been initiated and will last until September.

On the launcher side, the launch-campaign planning has been reviewed and the detailed plan for the joint operations with Eurockot/Khrunichev at Plesetsk is now consolidated. The launch should take place in late 2004.



CryoSat spacecraft nadir panel during its integration in early May at EADS Astrium GmbH

GOCE

The space-segment development activities continue to focus on the unit-level testing and the equipment-level Critical Design Reviews, and these activities will continue throughout 2004. Integration of the satellite's structural model is nearing completion at Alenia Spazio (I). Missing elements are the body-mounted solar panels and the two solar-array wings, which will be delivered by the manufacturer in April. The structural-model mechanical test campaign will subsequently be carried out in the ESTEC test facilities in early summer.

Alcatel Space has completed manufacture of the structural-thermal model of the Gradiometer instrument. In the coming months, it will be subjected to a series of mechanical and thermal tests in order to demonstrate qualification of the overall instrument design.

Electrical testing of the Accelerometer Sensor Head (ASH) demonstration model at ONERA (F) has progressed according to plan, demonstrating successful levitation of the proof-mass under 1-g conditions for the first time. The first integration tests with the ASH front-end electronics are planned to start at the end of April.

In the spacecraft platform area, preparatory activities are underway for the integration of the Engineering Model Test Bench that will be used to verify the platform's functional and electrical performance, including real-time closed-loop tests with the pre-validated flight software.

The Eurockot launch-service-contract activities are proceeding according to plan, with the system-requirements consolidation phase successfully completed in February.

On the ground-segment side, all activities are progressing normally. The Preliminary Design Review for the Payload Data Segment (PDS) was completed in March. The instrument data processors will be the subject of a separate review in May. The related Tender Evaluation Board has positively evaluated a proposal submitted by the European GOCE Gravity Consortium (EGG-C) for the Level-1 to Level-2 data-processing facility. Finally, the preparation of the documentation related to the Invitation to Tender (ITT) for the development of the Calibration and Monitoring Facility and the Reference and Planning Facility has been completed. This ITT is planned for release at the end of April.

A key event during the reporting period was the successful second International GOCE User Workshop, 'GOCE, the Geoid and Oceanography,' which took place at ESA/ESRIN on 8-10 March. More than 120 scientists from 16 different countries gathered in Frascati (I), almost double the attendance at the first Workshop in April 2001. It provided a unique forum in which to present the latest mission developments to an extensive user community and to discuss how data from the mission can best be delivered for scientific research and applications purposes.

SMOS

The payload main development effort (Phase-C/D) is in full swing, operating under an 'Authorisation to Proceed' (ATP). Manufacturing Release Reviews are being held with all subcontractors, to review and agree the baseline for engineering-model production. Parts procurement for the flight models has been initiated.

The Implementation Agreement with CNES, defining the principles of the cooperation between the two agencies within the SMOS project, has been presented to ESA's Earth-

Observation Programme Board. The Request for Quotation for Alcatel, for Phases-B/C/D of the satellite-engineering tasks, based upon use of a recurrent Proteus spacecraft bus, is in preparation by CNES and ESA. The baseline AIT flow at satellite level has been agreed between the two agencies and is now with industry for detailed assessment.

A launch site survey at Plesetsk, the site for Rockot launches, is being prepared, mainly to guarantee compatibility of the SMOS mechanical ground-support equipment with the local transportation and processing facilities. Industrial activities for the ground segment are awaiting the release of national Spanish funding.

ADM-Aeolus

The contractor teams for the spacecraft and its instrument are all now fully operational, and the last few, more difficult, subcontracts for the onboard computer, the flight software and the solar array have all been kicked-off. Many of the subsystems have successfully undergone their Preliminary Design Reviews. A number of subsystem Critical Design Reviews have also been held.

Work is progressing well towards structural-model testing and a working-model-based development and verification environment (functionally replacing an engineering-model satellite). The satellite Critical Design Review will address the results of these activities in May 2005. A full set of pump diode stacks has been delivered for the engineering-model laser. The first few flight-model stacks have been manufactured with some delay, but delivery of the flight-model lasers is not affected.

A Request for Quotation has been issued to DLR (D), which will conduct ground and airborne campaigns using a special version of the ALADIN instrument. DLR will also provide independent expertise for the algorithms to be used for engineering calibration of the data. Principle agreement has been reached with the European Centre for Medium-Range Weather Forecasts (ECMWF) on their involvement with Aeolus meteorological products. The ECMWF will (with support from MeteoFrance, KNMI, IPSL and DLR) conduct the necessary studies to define the production algorithms, produce the operational software and test it in dry runs including data validation, and use it to produce the operational products until the end of the mission. They will also report on the Aeolus data's contribution to NWP skills. ECMWF will also provide the necessary software to Meteorological Offices that wish to produce their own Level-2 products using their own temperature and pressure fields.

MetOp

The MetOp integration programme continues to progress very well, with the MetOp-1 satellite's assembly, integration and testing nearing completion and the MetOp-2 payload and service modules having completed their environmental test campaigns. The MetOp-1 satellite mechanical test results confirmed that the protoflight model exhibits higher damping compared with the structural-model tests in 2001, resulting in lower mechanical levels at identified critical locations. Based on these results, the concerns about the mechanical compatibility of the US instruments can be considered closed. The MetOp-1 satellite test campaign will conclude with onboard-software testing, AOCS sign tests and the second System Verification Test with the Eumetsat Mission Control Centre. The MetOp-1 Flight Acceptance Review, scheduled to be completed by end-June, is in preparation.

On MetOp-2, the Payload Module (PLM-2) successfully completed its thermal-vacuum testing in February in the ESTEC test facilities. The major new element for this test was the presence of a fully flight-representative IASI instrument, which required the implementation of a very complex test jig, with cryogenic panel and gas-cell/blackbody targets. All elements involved in the test performed excellently. After the test, PLM-2 was transported back to Friedrichshafen (D) for final testing prior to delivery for integration into the satellite in July.

In parallel, the MetOp-2 Service Module (SVM-2) has successfully completed its thermal-vacuum testing at Intespace (F), with only two minor anomalies recorded. In particular, modifications to the thermal design of the module and test fixtures were demonstrated successfully, thus finalising the last elements of SVM qualification.

Launch of the first MetOp satellite is still expected in the fourth quarter of 2005, the period agreed between Eumetsat and the launch-service provider Starsem

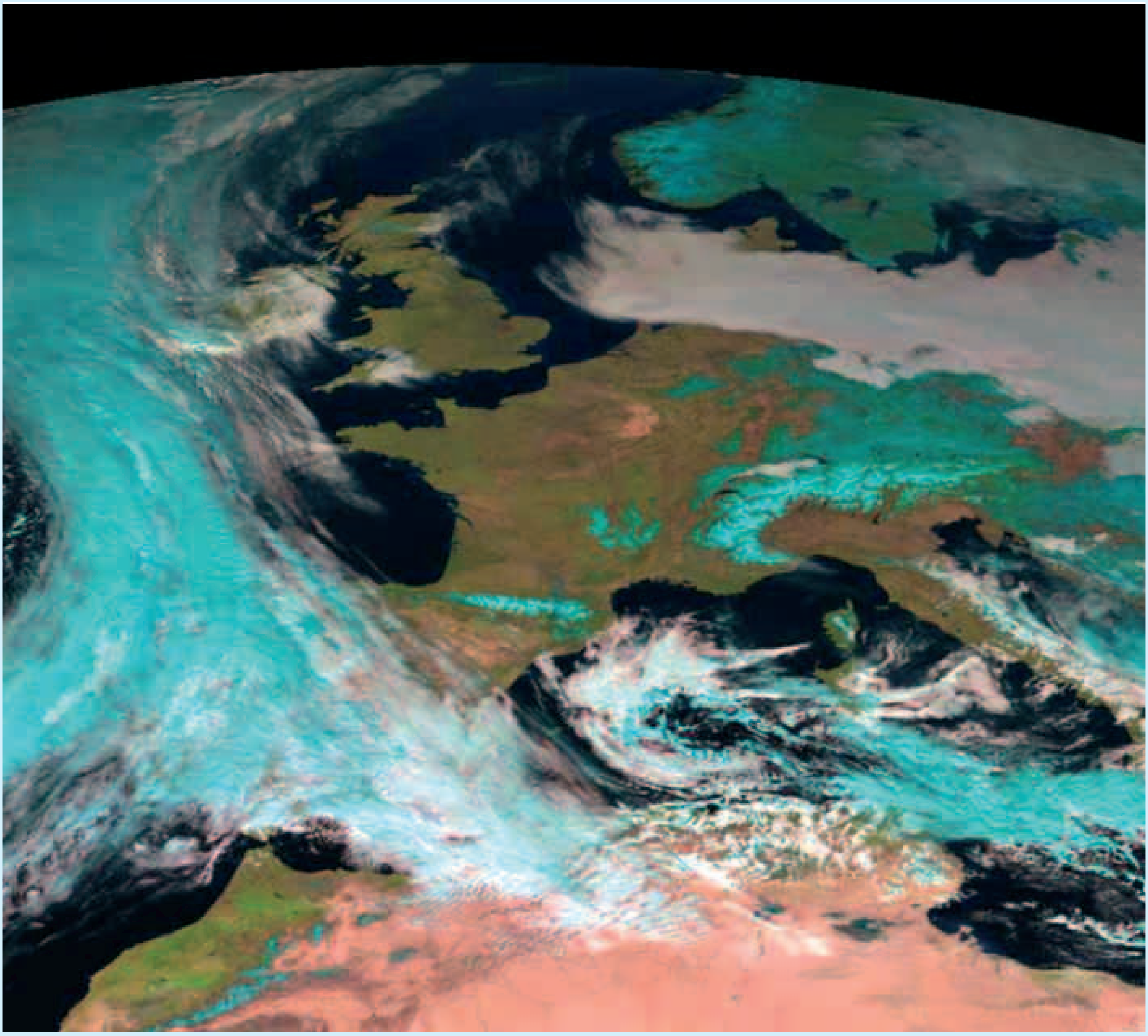
Meteosat Second Generation (MSG)

MSG-1
The first Meteosat Second Generation satellite (MSG-1) commenced routine operations on 29 January. For the operational phase, Eumetsat has designated the satellite 'Meteosat-8', providing continuity with the existing satellites operating in geostationary orbit.

MSG-2
The MSG-2 launch window has been further reduced to the three months of February-April 2005. Preparations have started for taking the satellite out of storage, where it has remained since June last year. It will then be given a 'health check', followed by a System Validation Test (SVT) and fine balancing, in preparation for the launch campaign, which is planned to start early in November.

MSG-3
The MSG-3 performance tests have been finalised. The prime contractor, Alcatel Space, is preparing the satellite for short-term storage, after which activities will focus on preparations for the MSG-2 launch. Thereafter, MSG-3 will be de-stored again and some additional work performed before the satellite is put into long-term storage (planned to last at least two and a half years).

MSG-4
All activities are going according to plan.



A Meteosat-8 composite image of visible information acquired on 18 February 2004 at 13:00 UTC: red for the 1.6 µm near infrared channel, green for the 0.8 µm visible channel, and blue for the 0.6 µm visible channel. Turquoise cloud signals the presence of ice particles, whereas white cloud is liquid moisture. Snow on the ground is turquoise. The large white patch over northeastern Europe is fog or stratocumuli, sharply contrasting with the snow-covered areas further south. Vegetation cover shows as green, due to its absorption properties in the visible range. Sandy or granitic areas are pink (Courtesy of Eumetsat)

ARTEMIS

This has been a period of routine operations with a high quality of service to the major data relay, land mobile and navigation users SPOT-4, Envisat, Telespazio and EGNOS. After one year of Artemis service operations the optical data relay link has logged over 100 hours total of operation with some 450 links, and the RF link has performed for over 560 hours with some 1800 links. The land mobile and navigation services have been continuous. Initial problems with data relay services due to spacecraft spurious upsets have now been overcome with new software and procedures, and the availability of the data-relay services is now around 99%. Increased data-relay utilisation can be expected in the near future. All spacecraft subsystems are performing well and the satellite status is nominal. The propellant lifetime is still predicted to be 10 years.

A number of enquiries have been received from new users wishing to use Artemis data relay and land mobile services. Interface tests with the Automated Transfer Vehicle are in preparation.

Vega

All launch-vehicle activities have been kicked-off by ELV (I), the prime contractor, and a number of subcontracts have been signed, including that with EADS-ST (F) for the guidance, navigation and control system. The launcher System Design Review will begin on 6 April after an intensive recovery phase during the first quarter of the year, which resulted in a comprehensive package of review documents and a number of new programmatic objectives.

The first Zefiro-9 motor case (DM00) was manufactured in February and is ready for its first pressure test.

The recent P80 first-stage activities have included preparations in March for the casting tests in Kourou on the Inert Loading Model. The large P80 filament-winding machine from Avio (I) has been installed and tested in the new Vega building in Colleferro (I), ready for manufacture of the first motor case.

Key choices regarding nozzle technologies have been agreed with SNECMA Propulsion Solide (F) after a number of trade-offs and development tests.

Evaluation of the industrial offers for the ground segment was completed in February. A number of technical updates to match developments in the interfaces between ground segment and launcher have been investigated.

Following a review of the status of all elements of the programme, the first Vega qualification flight has been rescheduled for the end of 2006.

Manufacture of the Zefiro-9 development model in progress at Colleferro (I). This solid-propellant motor is the main component of Vega's third stage (Photo courtesy of Avio)

The winding mandrel for the technological model of the P80 motor, which constitutes Vega's first stage (Photo courtesy of Avio)

International Space Station

Highlights
On 31 January, Progress flight 13P docked safely with the International Space Station (ISS). It carried among other things experiment hardware for the upcoming 'DELTA' Soyuz Mission and elements of the Automated Transfer Vehicle's (ATV) rendezvous and docking system. Progress 13P also carried 'Matroshka', a human upper-body phantom, which has become the first European external payload to be mounted on the ISS. Everything is ready for the next Soyuz flight, 8S planned for 19 April 2004, on which ESA astronaut André Kuipers will conduct his 11-day Dutch Soyuz Mission 'DELTA'.

In February, the Space Shuttle programme's management indicated that the Shuttle's Return to Flight date will be no earlier than 6 March 2005.

No critical issues regarding the status of ISS hardware and consumables have been identified. Limited science activities are ongoing with the two-man crew and the Station is in excellent order technically speaking.

Space infrastructure development
All Columbus payload facilities have completed their qualification in the Rack Level Test Facility. For Columbus itself, testing has shown that the audible noise level is well below the requirement level, making it the quietest module for the ISS.

The ATV-1 schedule currently supports launch in mid-May 2005. All integration activities will be completed at the Prime Contractor's site in Bremen (D) prior to shipment of the flight model to ESTEC. Consequently, the environmental testing at ESTEC, initially planned for mid-April, has been delayed to July. This should have no impact on the launch date. The spacecraft structure mechanical qualification tests are in progress, while functional testing has also started. Manufacture of the Russian Equipment Control System flight module has been completed and acceptance tests are about to start. The fully validated Flight Application Software V2.1 has now been delivered to the users (Functional Simulation Facility and the ATV Ground Control Simulator).

The ground operations for Node 2 have taken place at Kennedy Space Center (KSC). Node 3 machining, manufacturing and assembly work is ongoing and final preparations for the proof test, to be conducted in April 2004, are also in progress.

The Phase-0/1 Safety Review for the Cryogenic Freezer (CRYOS) took place in January and the Preliminary Design Review (PDR) Board Meeting was held successfully in March. A bridging phase, covering activities from July to October, will be introduced, and the Phase-C/D will start in October 2004.

Window integration and leak testing on the Cupola have been successfully completed and the Element Leak Test started. The Qualification/ Acceptance Review is planned for May 2004.

The European Robotic Arm (ERA) system acceptance has been accomplished, including the flight spares and the mission-preparation and training equipment. No confirmed launch date for ERA is yet available.

Operations and related ground segments
The Columbus Control Centre's development is going well with successful completion of the Site Acceptance Review for the Ground Segment Data Services System. The System Design Review 2 is ongoing and the Board is planned for April 2004.

The ATV Control Centre's development and integration is continuing on schedule with the monitoring and control system passing its Factory Acceptance Review and the first ATV System Validation Testing between ground and flight segments being successfully concluded.

The Data Management System for the User Support and Operations Centres (USOCs) has successfully completed its PDR. Installation of the Erasmus USOC at ESTEC has started. The System Requirements Review closeout for the Operations Preparation and Planning System Version 1 is ongoing. The PDR has been rescheduled to take into account the effects of the Columbus delay.

Columbus operations preparation is progressing and a second table-top simulation was successfully performed at the Columbus Control Centre.

Utilisation planning, payload development and preparatory missions
In the penultimate round for new Microgravity Application Promotion (MAP) project continuation proposals, 12 new proposals were evaluated in February. Five were recommended for direct continuation (three physical sciences, two life sciences), five were recommended for resubmission, and two for termination. By the deadline of 29 March, nine proposals had been received, of which seven were for life sciences and two for physical sciences; these will be evaluated during April.

The European Drawer Rack (EDR) flight-model interface testing with Columbus was successfully completed in February. The EDR Training Model Integration Review is planned for early April 2004.

The European Transport Carrier (ETC) Flight Acceptance Review was kicked-off in March and should be completed during April 2004. The complete set of Cargo Transfer Bags (CTBs) for the Columbus-1E launch has been delivered and the Engineering Change Request for CTB outfitting and payload stowage facility has been approved.

The flight modules of Biolab, the European Physiology Modules (EPM) and the Fluid Science Laboratory (FSL) have been delivered prior to Columbus integration, planned for April 2004. The EPM Phase-3 Flight Safety Data Package has been delivered. The FSL Training Model Acceptance Review was successfully completed at the European Astronaut Centre (EAC) and the Cardiolab Training Model was delivered to EAC.

The Pulmonary Function System flight-model 1 and 2 upgrades have been completed and tested in preparation for shipment to Johnson Space Center.

NASA has confirmed that first MELFI flight unit 1 (FU-1) will fly on flight ULF1.1, no earlier than May 2005. The system test campaign for FU-2 is almost complete, while the compatibility tests with the Japanese Experiment Module have been completed. The MELFI FU-3 rack has been integrated, with the exception of the Brayton subsystem. NASA has requested ESA to perform acceptance in Europe for and to store the Hexapod pointing system for a period still to be defined.

In February, an integrated software test with the three SOLAR (Solar Monitoring Observatory Facility) instrument software simulators, was successfully executed.

Qualification tests for EXPOSE (Exobiology Exposure Facility) have been completed and Part 1 of the Flight Acceptance Review is in progress. The EXPOSE flight model (with dummy trays) is ready for delivery to EuTEF (European Technology Exposure Facility) for system integration.

The payload PDR of the Atomic Clock Ensemble in Space (ACES) has been successfully closed, while the mission PDR is planned for mid-2004. In January a three-month delay was announced in the delivery of the Space Hydrogen Maser due to technical and design problems.

The Columbus External Payload Adaptor (CEPA) Post-Shipment Incoming Inspection in Europe was successfully completed in February, and the fit-check testing between CEPA and Columbus is ongoing.

Preparations for the Dutch Soyuz mission 'DELTA' were successfully completed. In order to be able to complete the scientific programme within the available crew time, the mission will last 11 days. Joint Integrated Simulations took place in February and March with the participation of all operations sites. The 36th Parabolic Flight Campaign, with 13 experiments, was successfully conducted in March.

A full Foton-M2 capsule payload complement has been established and development is in progress.

For the sounding-rocket campaigns, a Request for Quotation for Texus flight 42 was issued and the experiments for MiniTexus EML-1 (Electro-Magnetic Levitator) have been selected. In addition, Maxus-6 development is progressing according to schedule, a contract for advanced procurements for Maxus-7 is being prepared, and Maser-10 contract negotiations for the Phase-C/D have been completed and work has started.

The European Modular Cultivation System/Express Rack interfaces have been successfully tested at the Payload Software Interface Verification Facility at NASA's Marshall Spaceflight Center.

The Protein Crystallisation Diagnostics Facility (PCDF) engineering-model testing and flight-model assembly are in progress, and the training model was delivered to EAC in February 2004.

ISS education

The final activity and experiment preparations for the DELTA Soyuz mission education programme 'Zeg het ISS' were performed.

The European Commission Directorate General for Education and Culture has approved two ESA pre-proposals i.e. the Socrates/Minerva Action, 'Innovation in Information Communication Technology, Space for Learning' and the Socrates/Erasmus Action 'Life in Space'. The final proposals for both actions were submitted in March.

The ISS Education Kit has been published in German and an agreement has been reached for the distribution in Germany of 50% of the kits (10 000 copies). The Dutch Ministry of Education has agreed to the distribution of the Kit in Dutch to all secondary schools in The Netherlands.

Commercial activities

An Invitation to Tender for a commercial agent in the Biotechnology market segment has been issued.

In the framework of the MEDIET (Mediterranean DIET) project, food and trays have been delivered; the food certification process is ongoing in Russia.

The ISS Business Club continues to acquire members, with membership promotion activities taking place as part of the DELTA Soyuz mission-promotion activities.

Astronaut activities

The Russian Medical Commission and the Multilateral Space Medicine Board medically certified the ESA astronaut André Kuipers for flight, and the Multilateral Medical Flight Readiness Review for Increment 9 and Soyuz-8 was successfully concluded. The training for the DELTA mission was also successfully completed.

The training models of the Protein Crystallisation Diagnostics Facility, the European Physiology Modules and the European Transport Carrier were delivered to EAC.

Five European and one Canadian astronaut received the first part of their ESA Advanced Training at EAC.

The first review by ESA and NASA astronauts of the Columbus payload laptop displays has successfully taken place at EAC.

Development and successful dry runs were held in March of hands-on training procedures on Biolab and Fluid Science Laboratory for the implementation of the commercial training at EAC.

In Brief

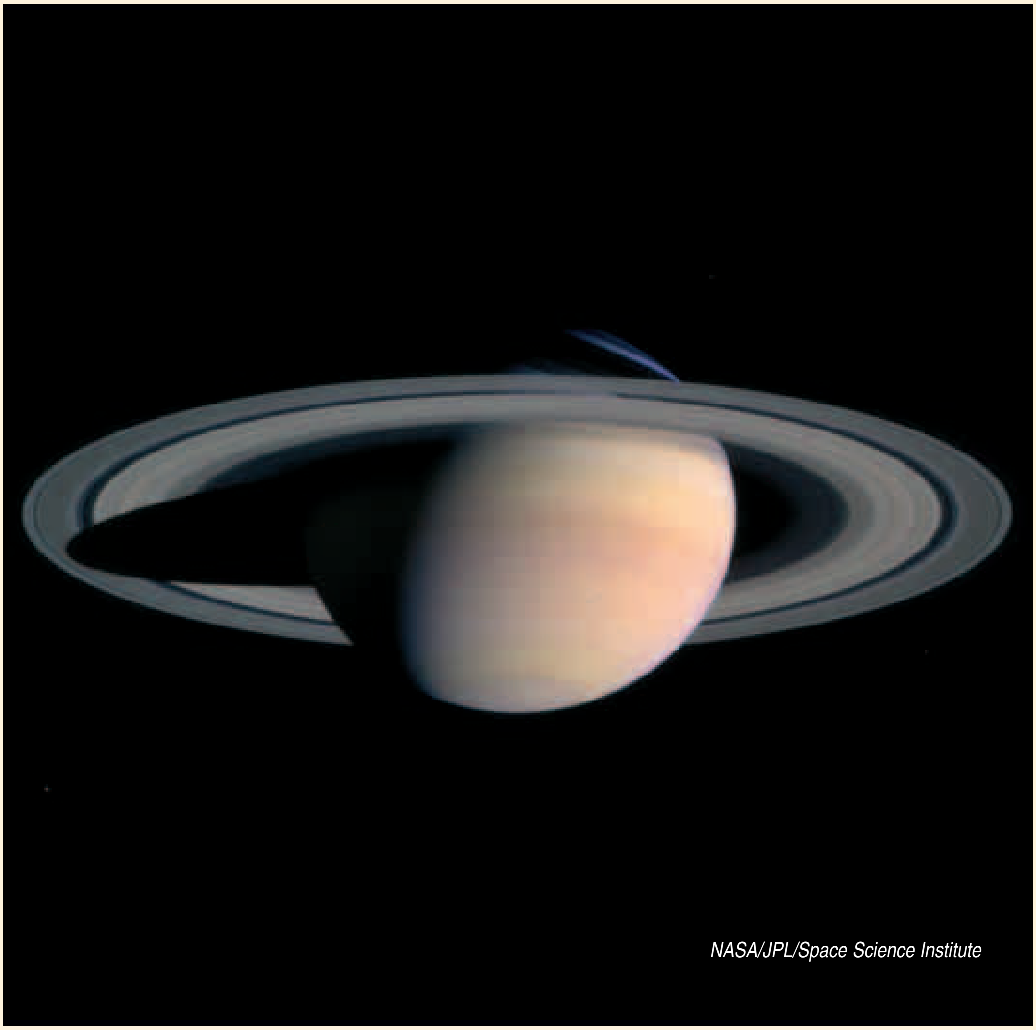
Cassini-Huygens closes in on Saturn

As the NASA/ESA Cassini-Huygens spacecraft closes in on Saturn, its view is growing sharper with time and now reveals new atmospheric features in the planet's southern hemisphere. This natural colour image was taken on 27 March by Cassini's narrow angle camera. The image is a composite of three exposures, in red, green and blue, taken when the spacecraft was 47.7 million kilometres from the planet.

Two faint dark spots are visible in the southern hemisphere – storms that are getting close and will eventually merge or squeeze past each other. Further analysis of such dynamic systems in Saturn's atmosphere will help scientists understand their origins and complex interactions.

Some of Saturn's moons are also visible in this image: Enceladus, Mimas, Tethys and Epimetheus. Brightnesses have been exaggerated to aid visibility. Its largest moon, Titan, has always fascinated scientists because it has a thick atmosphere that might resemble that of a very young Earth. Early in 2005, the Huygens probe will land on Titan's surface to collect clues about how life might have begun on Earth. At the same time, the Cassini orbiter will continue to explore Saturn and its rings.

The Cassini-Huygens mission is a cooperative project of NASA, the European Space Agency and the Italian Space Agency. Huygens will be the first probe to land on a world in the outer Solar System.



NASA/JPL/Space Science Institute

Space Girls' Day

"It is great to see that science and technology can be so much fun! And it is nice that people in these jobs are cool, too," says a 16-year-old while admiring the training pool in the European Astronaut Centre (EAC). On 22 April, EAC and the German Aerospace Centre (DLR) in Cologne and the European Space Operations Centre (ESOC) in Darmstadt, Germany, were full of teenage girls who wanted to see what it is like to work in the space sector. Girls' Day is a Germany-wide event for schoolgirls between 14 and 16. All across the nation, technology-based businesses, research institutes, laboratories, offices and organisations like ESA and DLR open their doors to inform potential future engineers and scientists about career possibilities in science and technology.

More than 160 girls visited the different centres, conducted experiments in propulsion technology, tried out computers in ESOC's control room and chatted with female professionals from all disciplines about how they became interested in space. At the end of the day, the girls left exhausted and with lots of new knowledge in their heads – the most important of which is that science isn't scary after all! esa

The girls enjoyed the hands-on activities most.

Future control room staff?

Or future space scientists?

DELTA mission concluded successfully with Soyuz landing

ESA astronaut André Kuipers performs the SUIT experiment, assisted by his Russian colleague Gennadi Padalka

The Soyuz launcher is rolled out to the launch pad in Baikonur

The 11-day DELTA mission to the International Space Station (ISS) came to a successful conclusion when the Soyuz TMA-3 command module, carrying Dutch ESA astronaut André Kuipers and the ISS Expedition 8 crew, touched down on 30 April in Kazakhstan after a return flight of just over three hours. Alexander Kaleri, the Soyuz Commander, and the second Flight Engineer, Michael Foale (NASA), were the returning Expedition 8 crew who had been stationed on the ISS since 20 October. *"It was just like a fun-fair ride,"* Kuipers said after the landing.

The DELTA mission included nine days on the International Space Station and achieved all of its major objectives. The astronauts carried out the intensive experiment programme successfully and the Soyuz TMA-3 spacecraft, stationed at the ISS for the past six months to act as the crew lifeboat, was replaced. André Kuipers' to-do list was one of the most extensive experiment programmes undertaken by a European astronaut so far on the International Space Station, spanning the fields of human physiology, biology, microbiology, physical science, Earth observation, education and technology. Many of these experiments were developed by Dutch researchers and built by Dutch industry and research institutions.

"I am very pleased with the execution of the experiment programme", said ESA's Delta Mission Scientist, Marc Heppener, also from the Netherlands. *"André has had a very busy schedule for the past 11 days. I am also extremely pleased that we have already obtained scientific results during the mission itself. The results obtained from the experiments will undoubtedly have an impact across many areas both on Earth and in space."*

Tens of thousands of schoolchildren in the Netherlands, Germany and other countries benefited from the mission, having carried out the same seed germination experiment as André Kuipers while he was on the ISS.

A view of the Soyuz spacecraft, the ISS and Earth.

The educational benefits of the mission will continue in the future through the production of educational materials to be distributed to 10 000 schools across Europe. These materials are being compiled using video footage of experiments shot on the ISS during the mission.

The DELTA mission was sponsored by the Dutch Government through the Ministry of Education, Culture and Science and the Ministry of Economic Affairs. During the mission André Kuipers had numerous contacts with the media in the Netherlands and other countries. André also had the opportunity to talk over amateur radio to schoolchildren who had won the "Zeg het ISS" competition and answer their questions.

Said Mr Jörg Feustel-Büechl, ESA Director of Human Spaceflight: *"ESA's cooperation with the Russian Federal Space Agency continues to produce excellent results. This is the fifth Soyuz mission to the ISS with an ESA astronaut, and its success heralds more Soyuz missions in the future, with two further missions under discussion for next year. The next flight by an ESA astronaut to the ISS on a Russian Soyuz will probably take place in April 2005."*

In addition to the experiment programme, the DELTA mission served to change the crew on board the ISS. The ISS Expedition 8 crew have now been replaced by the ISS Expedition 9 crew, Gennady Padalka and Edward 'Mike' Fincke (NASA), who arrived with André Kuipers at the ISS in the Soyuz TMA-4 spacecraft on 21 April and are scheduled to return next October.

André Kuipers in the ordered chaos of the Space Station.

What does a real Dutch astronaut take into space? Oranges of course!

A cup of tea and some Dutch cheese after a safe, but turbulent landing.

Tune into EuroNews for some space TV

The ESA Bulletin provides you with a regular dose of space news. If you would like to supplement these with some moving pictures, find the EuroNews channel on your TV – a special TV magazine dedicated to Space, produced by EuroNews in collaboration with ESA, is being broadcast three times a day! This Space Magazine has already covered topics like Galileo, the European Astronaut Centre and the International Space Station, with topics changing every fortnight, and is also available on the web.

Although space issues are already covered in its bulletins for breaking news, EuroNews is now dedicating a special programme to Space issues, complementing its more technically focused Hi-Tech magazine. The stories will cover all space activities: science, applications, Earth observation, launchers and human spaceflight. The aim is to help Europeans understand the benefits of the missions and activities of their space agency.

EuroNews is a key medium for delivering international information with a European point of view. Broadcast in 79 countries, EuroNews reaches 144 million households in Europe, the Middle East, Africa, Central Asia and North and Latin America via cable, digital satellite and through terrestrial channels.
This Space Magazine is produced and broadcast every two weeks in seven different languages, with a new programme starting every second Friday. Each magazine is four minutes long and is broadcast 21 times per week, including evening prime time on Fridays and Saturdays, in order to reach the largest audience.

For more information, contact Claus Habfast,ESA's Television Executive Producer: Claus.Habfast@esa.int

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ATV's videometer ready to dock

The 'videometer', a new technology device to ensure very precise automatic rendezvous operations between the 20.7 tonne *Jules Verne* Automated Transfer Vehicle and the International Space Station (ISS), has been successfully tested in March.

Based on the design of a star tracker, the Jules Verne videometer, the first automatic optical operational system ever used for spacecraft navigation, has been through extensive simulated rendezvous tests. *"For the first time, the ATV rendezvous sensors were used successfully in real conditions. And, within their operational domain, they worked exceptionally well,"* said ESA ATV engineer Stein E. Strandmoe, who supervised a critical 10-day test campaign.

For the final rendezvous manoeuvres with the ISS, the ATV will use its eye-like sensors, combined with additional parallel measurement systems, which will allow automatic docking with incredible centimetre precision while the spacecraft and the ISS are circling the Earth at 28 000 km/h.

The videometer is able to analyse images of its emitted laser beam automatically reflected by passive retroreflectors' serving as targets installed on the Station, next to the Russian docking port where the ATV will be attached.

During the last 200 metres of the orbital final approach manoeuvre, the videometer must automatically recognise the retroreflectors target patterns and then calculate the distance and direction to the docking port.

To realistically check the videometer, the tests were conducted in a hi-tech research facility at the French defence agency 'Délégation Générale pour l'Armement' (DGA), located in Val-de-Reuil, 100 km west of Paris. Inside the huge 600 metre long building, a 120 000-kg mobile platform riding on 550 metre-long rails, enabled the simulation of a continuous approach between the two space vehicles. On the platform, a set of passive retroreflectors identical to the ones to be installed on the ISS faced the videometer, which was mounted on an articulated robotic arm representing the ATV in motion.

At greater distances, *Jules Verne* will use a relative GPS reference system to get closer to the Station.

"The most surprising thing was that the sensors were almost undisturbed when we tried to fool them with other reflecting surfaces or other lights that could interfere with rendezvous targets in the ISS background," said Strandmoe. *"It's amazing how the videometer, as a totally new development, proved to be such a robust system. I was quite surprised that it worked so well the first time it was tested!"*

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Greece and Luxembourg to join ESA

Greece and Luxembourg are expected to become full members of the European Space Agency by 1 December 2005, after their national approval procedures have been completed.

The Hellenic Republic officially applied to join ESA last October, the Grand Duchy of Luxembourg in December. The ESA Council unanimously approved both applications. Greece and Luxembourg have been granted observer status to attend meetings of ESA's Council and all its subordinate bodies, to enable them to already familiarise themselves with the Agency's procedures and working practices.

Publications

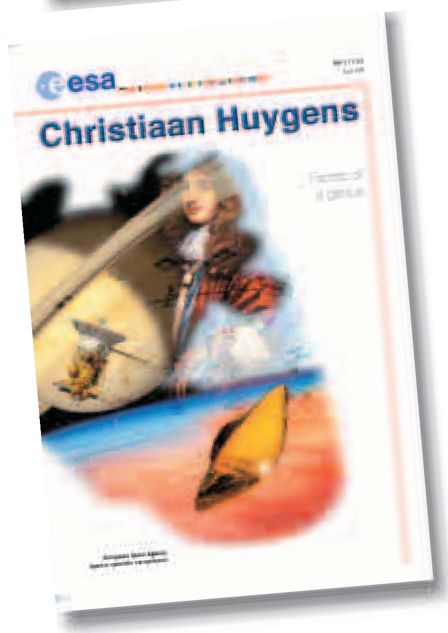
The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and Order Form inside the back cover

ESA Newsletters

ON STATION NO. 16 (MARCH 2004)
NEWSLETTER OF THE DIRECTORATE OF HUMAN SPACEFLIGHT
WILSON A. (ED.)
NO CHARGE

ESA Brochures

CHRISTIAAN HUYGENS – FACETS OF A GENIUS (APRIL 2004)
FLETCHER K. & BOUWMAN A. (EDS.)
ESA BR-211 // 31 PAGES
(ALSO AVAILABLE IN DUTCH)
PRICE: 7 EURO



ARTEMIS – PAVING THE WAY FOR EUROPE'S FUTURE DATA-RELAY LAND-MOBILE AND NAVIGATION SERVICES (FEBRUARY 2004)
A. BIRD & N. MENNING (ED. B. BATTRICK)
ESA BR-220 // 15 PAGES
PRICE: 7 EURO

THE EUROPEAN SPACE SECTOR IN A GLOBAL CONTEXT – ESA'S ANNUAL ANALYSIS 2003 (APRIL 2004)
ESA POLICY COORDINATION DEPT.
(ED. B. BATTRICK)
ESA BR-222 // 90 PAGES
PRICE: 10 EURO

ESA Special Publications

ESA's REPORT TO THE 35th COSPAR MEETING (JUNE 2004)
WILSON A. (ED.)
ESA SP-1276 // 151 PAGES
PRICE: 40 EURO

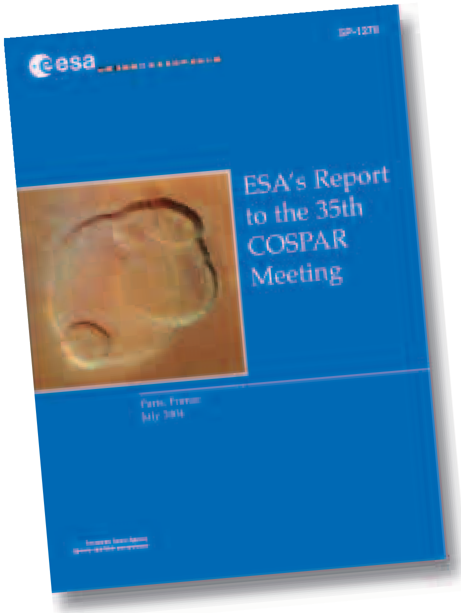
PROCEEDINGS OF THE 2ND EDDINGTON WORKSHOP – STELLAR STRUCTURE AND HABITABLE PLANET FINDING, 1-11 APRIL 2003, PALERMO, ITALY (JANUARY 2004)
FAVATA F., AIGRAIN S. & WILSON A. (EDS.)
ESA SP-538 // 457 PAGES
PRICE: 50 EURO

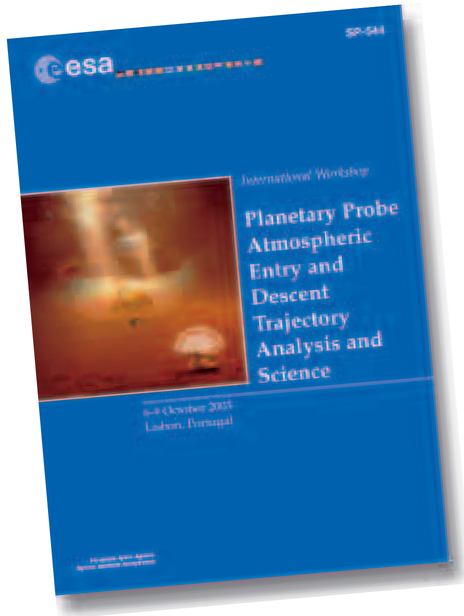
PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON PLANETARY PROBE ATMOSPHERIC ENTRY AND DESCENT TRAJECTORY ANALYSIS AND SCIENCE, 6-9 OCTOBER 2003, LISBON, PORTUGAL (FEBRUARY 2004)
WILSON A. (ED.)
ESA SP-544 // 364 PAGES
PRICE: 40 EURO

PROCEEDINGS OF THE 3RD EUROPEAN WORKSHOP ON EXO-ASTROBIOLOGY – MARS: THE SEARCH FOR LIFE, 18-20 NOVEMBER 2003, MADRID, SPAIN (MARCH 2004)
HARRIS R.A. & OUWEHAND L. (EDS.)
ESA SP-545 // 339 PAGES
PRICE: 40 EURO

PROCEEDINGS OF THE SOHO-13 CONFERENCE – WAVES, OSCILLATIONS AND SMALL-SCALE TRANSIENT EVENTS IN THE SOLAR ATMOSPHERE: A JOINT VIEW FROM SOHO AND TRACE, 29 SEPTEMBER – 3 OCTOBER 2003, PALMA DE MALLORCA, BALEARIC ISLANDS, SPAIN (JANUARY 2004)
LACOSTE H. (ED.)
ESA SP-547 // CD-ROM
PRICE: 25 EURO

PROCEEDINGS OF THE 5TH INTERNATIONAL CONFERENCE ON SPACE OPTICS, 30 MARCH – 2 APRIL 2004, TOULOUSE, FRANCE (MARCH 2004)
WARMBEIN B. (ED.)
ESA SP-554 // CD-ROM
PRICE: 25 EURO





ESA Scientific & Technical Report

LOW-DENSITY PARITY-CHECK CODES: A TUTORIAL (MAY 2004)
ROVINI M. (ED. K. FLETCHER)
ESA STR-245 // 62 PAGES
PRICE: 20 EURO

ESA Procedures, Standards & Specifications

SPACE PRODUCT ASSURANCE – DATA FOR SELECTION OF SPACE MATERIALS AND PROCESSES (FEBRUARY 2004)
ECSS SECRETARIAT
ESA ECSS-Q-70-71A // 222 PAGES
PRICE: 30 EURO