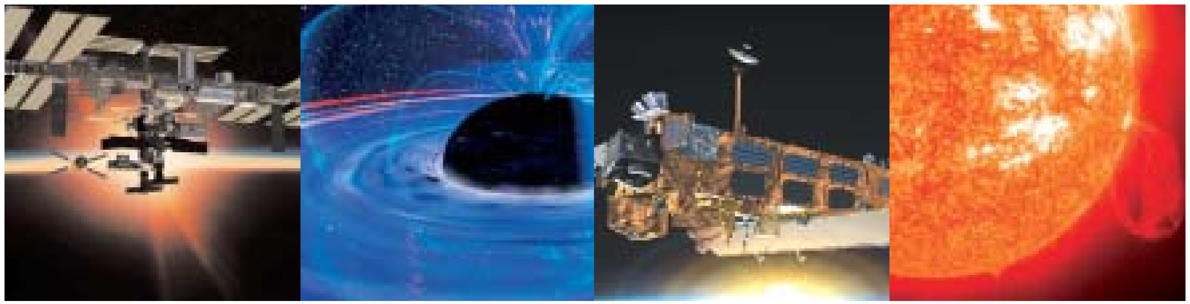
THE SPACE DIMENSION

THE EUROPEAN SPACE AGENCY



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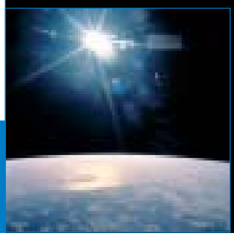
ESA's remarkable record places it in the front rank of space organisations, generating enormous benefits for its Member States and their citizens. The Agency has been responsible for developing systems that are now accepted as everyday – and profitable – parts of our lives, leading to the creation of new entities and companies responding to our needs. The Ariane rocket has long dominated the world's commercial launch market, operated by the Arianespace company. The Meteosat weather satellite system developed by ESA similarly led to the creation of Eumetsat. And the Agency's communications activities were critical for the births of Eutelsat and Inmarsat. These are all now enterprises of global importance. Likewise, ESA's science programme is second-to-none, and its Earth-observation satellites continue to return torrents of data. Europe is welcomed as one of only five Partners in the International Space Station.

This brochure highlights the broad sweep of the Agency's current and future missions up to the end of 2007. In the decades ahead, ESA will be presented with even more challenges and opportunities to enhance the lives of millions of citizens through the transformation of Europe's economic, scientific and technological capabilities.



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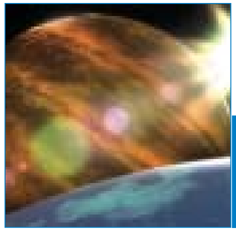


WELCOME TO ESA

Europe in Space

Space has a pivotal role in modern society and the European Space Agency (ESA) is at the forefront of the drive to explore and exploit this final frontier. As this brochure highlights, the Agency's activities are transforming almost every aspect of our lives, from weather forecasting and personal communications to navigation, medicine and agriculture.

Our future depends on the careful management of our world's resources and understanding the interactions of our ecosphere. Such global problems require a global perspective – which only space can provide. Our knowledge of global warming, climate change and the state of the ozone layer is based on unique measurements from space. The weather satellites alone save hundreds of millions of Euros each year, and the rockets that put them there have paid back triple the investment. And looking outwards, astronomers are striving to discover how the Universe began and if there are worlds just like ours out there now.

ESA's programmes for Earth observation, launchers, science, applications and human spaceflight ideally place Europe to meet the technological, political and environmental challenges of the future. In the years to come, the Agency will concentrate its efforts on four main areas: the pursuit of scientific knowledge, enhancing the quality of life, collaboration with the European Union and national agencies, and promotion of European industry.

The diversity of ESA's Member States – Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK and associate member Canada – is a source of vitality and versatility, with each country bringing its own scientific traditions, technological skills, political priorities and cultural style. Most also belong to the European Union, and, although the two bodies are independent, collaboration is increasing as they work together to create the most beneficial space policies for the citizens of Europe.

Space is already an important part of the business world, and stimulates other, non-space, industries. Europe's space industries employ 40 000 people, with a further 250 000 working in associated areas. Each new satellite is but the tip of a pyramid, the creation of thousands of men and women from factories and laboratories across the continent. As a result of their skills and efforts, ESA has become one of the great success stories, a world leader in both science and technology.

Several thousand people are also directly employed by ESA at the Agency's various establishments and ground stations in Europe or further afield. Although officials at the Paris headquarters are responsible for overall strategy, finance and administration, ESA's largest establishment is the European Space Research and Technology Centre (ESTEC) in The Netherlands, where teams of engineers and scientists oversee the development and testing of satellites.

Mission control for most ESA space projects is the European Space Operations Centre (ESOC) in Germany. Its experts track and command satellites via ground stations all over the world, including Sweden, Belgium, Spain, French Guiana and Australia. ESA's main centre for Earth observation is ESRIN, south of Rome. It manages Europe's largest archive of environmental data, coordinates more than 20 ground stations and facilities throughout Europe and cooperates with another 20 foreign ground station operators worldwide. The European Astronaut Centre in Cologne, Germany, provides training and medical support to ESA astronauts, both on the ground and during space missions. As a result of Europe's participation in the International Space Station, ESA's facilities have been opened up to astronauts from around the world.

The launch centre for European rockets and most ESA satellites is Kourou in French Guiana. Created and operated by the French space agency, the spaceport was vastly enlarged under ESA sponsorship for Ariane launches. Today, it is the most modern and efficient launch site in the world.

Decades of Achievement

At the dawn of the 21st century, ESA has evolved into a world leader in almost every field of space endeavour. At the forefront is ESA's commitment to broadening our knowledge of the blue planet on which we all depend for our survival. Following the successes of its ERS satellites, which pioneered the civil use of cloud-piercing radar, the agency recently launched Envisat, the most powerful remote sensing platform ever built. At the same time, ESA is developing smaller Earth observation satellites dedicated to specific environmental problems. Equipped with state-of-the-art instruments, these satellites will investigate particular areas of interest, such as ocean circulation and salinity, atmospheric motion, soil moisture and the thickness of Earth's ice cover.

At a time of apparent global warming, destruction of the ozone layer and rapid deforestation, broad-based observations of the atmosphere and surface are vital elements of any Earth observation effort. To this end, ESA is working with the European Union to develop a Global Monitoring for Environment and Security (GMES) programme, one aspect of which involves rapid delivery of space images and data to areas hit by man-made or natural disasters. In addition to real-time monitoring, prediction of floods and storms is essential if loss of life and property is to be minimised. For the past 25 years, the ESA-developed Meteosats have provided weather forecasters with continuous coverage of the effervescent atmosphere from the Atlantic to the Middle East. These eyes in the sky have recently been enhanced with the launch of a second-generation Meteosat, soon to be joined by Metop, Europe's first polar-orbiting meteorological satellite.

Many of ESA's satellites, including the Meteosats, are carried aloft by Europe's Ariane rockets, world leaders in performance and reliability. As the remarkably successful Ariane-4 launcher recently retired, a new-generation heavy-

ESA/CNES/Arianespace/CSG

lift vehicle, the Ariane-5, has taken its place to maintain European domination of the commercial launch market.

The newcomer is also a key component of ESA's human spaceflight and space science programmes. Ariane-5 will be responsible for delivering Automated Transfer Vehicles (ATVs) to the International Space Station. Working as a supply ship, space propulsion module and refuse disposal vehicle, ATV will play a major role in supporting astronauts from around the globe as they spend many months aboard the giant station, including Europe's Columbus general-purpose laboratory module.

Meanwhile, Ariane-5 is being upgraded and modified so that it can launch two large satellites in tandem or send scientific spacecraft to the depths of the Solar System. The first payload to take advantage of this new capability is Rosetta, ESA's unique mission to orbit and land on a comet. Rosetta is one cornerstone of an ambitious space science programme that will see European spacecraft explore the Moon and Earth's planetary neighbours in the next dozen years. One of the most exciting adventures is seeing Mars Express surveying the Red Planet for hidden water. Another planet scheduled for detailed examination is mysterious Mercury. ESA plans to send the BepiColombo mission in 2011-2012 to unveil the secrets of this little world, using solar electric propulsion technology tested by SMART-1 during a 16-month trip to the Moon.

In order to explore further afield, ESA has developed some remarkable space observatories. From their orbital viewpoints above Earth's turbulent blanket of air, these satellites can observe the Universe at infrared, X-ray and gamma-ray wavelengths, as well as in visible light.

Having contributed hardware and expertise to the Hubble Space Telescope, ESA intends to continue its highly successful collaboration with NASA by participating in the even more powerful James Webb Space Telescope. Other world-beating space observatories in the pipeline 'for the next decade' include the Herschel infrared telescope to probe the origins of stars and galaxies; Planck, to study the faint radiation left over from the creation of the Universe; Gaia, to provide the most detailed, accurate map of our Milky Way galaxy; XEUS, to probe the cosmos before stars were born; and Darwin (2014), to search for planets circling other stars. And LISA (2013) will search for Einstein's elusive gravitational waves that may shed new light on the true nature of the Universe's structure and laws.

ESA is also at the forefront of an international effort to study the Sun and understand the interaction between our nearest star and our planet. While the SOHO satellite has been unravelling the nature of the Sun's nuclear powerhouse, a quartet of Cluster satellites has been providing the first three-dimensional view of how energetic solar particles affect near-Earth space. Next, Solar Orbiter (2013-2014) will be sent for the closest look ever at the Sun. Such research also has important, down-to-Earth applications since solar storms are potent threats to power grids, satellites and human space travellers. Even high-flying aircraft are vulnerable. One particular area of interest for ESA is the impact on the health of astronauts who spend many months aboard the International Space Station.

European astronauts have already completed long-endurance missions on Russia's Mir space station and visited the ISS during its early construction. Human spaceflight will assume even more importance for Europe as the Station grows and evolves, particularly after the addition of the Columbus laboratory. As a major partner in the programme, ESA foresees a return on investment through breakthroughs in microgravity research, possibly including advanced materials and new insights into human health, disease prevention and treatment.

Efforts to commercialise the Space Station are just one aspect of a broader policy to open up space for the benefit of industry and society in general. ESA is working with the European Union to focus on practical and commercial benefits, such as improved communications and safer navigation.

The growing desire to communicate at any time from any part of the globe is being accommodated by ESA's ARTES (Advanced Research in Telecommunications Systems) programme – an effort to introduce high-speed internet, interactive TV and mobile communications to people throughout the world. One indirect benefit of this approach has been the success of European satellite manufacturers in winning contracts to build commercial communication satellites.

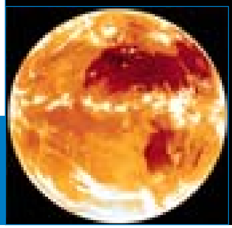
The latest ESA contribution to advanced satellite communications is Artemis, equipped with payloads to promote voice and data transmission between mobile terminals and to provide high-rate data links between orbiting satellites. One exciting outcome has been the first use of lasers to transmit information from one satellite to another.

Artemis may also become part of a new, independent, satellite navigation system. Being built by ESA and the European Union, the Galileo constellation of up to 30 satellites will provide pinpoint locational accuracy for all, including taxi drivers and itinerant business people, surveyors and airline pilots, delivery firms and emergency services. Demand for Galileo's uninterrupted signals is expected to create more than 100 000 jobs and generate some 90 billion Euros in revenue during its first 15 years of operation.

As this brochure illustrates, the first 29 years of ESA's existence have seen a succession of exciting discoveries and inspirational breakthroughs. Today, the Agency's activities extend into almost every aspect of modern life. In the decades ahead, ESA will be presented with even more challenges and opportunities to enhance the lives of millions of citizens through the transformation of Europe's economic, scientific and technological capabilities.

We are still at the dawn of the Space Age and what we can achieve is limited only by our imagination.

SENTINELS IN SPACE



Despite mankind's remarkable advances, the elemental forces of Nature remain untamed. Fortunately, although we cannot influence the wind and rain, we can make our lives much easier and safer by constantly monitoring the turbulent atmosphere, forecasting local and regional weather, and predicting future climate change.

This perpetual weather watch is possible thanks to the modern satellite technology pioneered in Europe by ESA. Today, an international flotilla of spacecraft watches the Earth and broadcasts a stream of images and information to meteorological organisations around the globe, preparing us for what tomorrow's weather will bring.

Since 1977, seven European Meteosats have climbed into geostationary orbit, 36 000 km above the equator, where they match the Earth's rotation and hover over Africa. These space sentinels have revolutionised weather forecasting for billions of people throughout Europe, Africa, Asia and the Americas. Apart from saving lives, improved weather forecasts due to the Meteosats have saved more than 200 million Euros each year. Europe's weather watchers ensure that farming, transport, construction, industry, public weather services and tourism benefit enormously from accurate forecasts that extend from a few minutes to days, weeks and even seasons.

The latest and most advanced of these eyes in the sky is the Meteosat Second Generation (MSG). The first of three flew aloft recently. Using the newest, state-of-the-art technology, it is not only a major advance in monitoring changing weather patterns over an entire hemisphere, but it is also improving storm warnings and long-term forecasts, while contributing significantly to global climate research.

Almost three times as heavy as the Meteosats, MSG sees much more sharply and frequently, revealing features like thunderstorms, encroaching storm fronts, fog banks and other hazardous weather conditions. By monitoring ozone in the upper atmosphere, MSG is improving forecasts of harmful ultraviolet light levels and the threat of skin cancer.

MSG is the first geostationary satellite to measure Earth's energy balance – how much radiation arrives from the Sun and how much returns to space – vital for understanding global climate change. Before MSG, this information was available only in brief snatches from satellites in low orbit.

MSG will be joined by MetOp, but in polar orbit at an altitude of 840 km, observing the whole globe as it circles 14 times a day. It will offer an even more comprehensive flow of weather data, as well as a reduction in Europe's reliance on US satellites. Advanced instruments will provide more accurate measurements of temperature, humidity, wind speed and wind direction, especially over the oceans. Three MetOps will be launched over a period of 14 years as Europe's contribution to a joint polar satellite system with the US.

Launches:
Meteosat-7 2 September 1997
MSG-1 28 August 2002
MetOp-1 2005

Masses:
Meteosat 700 kg
MSG 2 t
MetOp 4.5 t

Lifetimes:
5-7 years

Left: Meteosat's viewpoint is normally from above Africa, but a photo from a second hovering over the Americas has been merged in here.
Far left: what our eyes cannot see – Earth's warmth.
All images ESA/Eumetsat

TAKING THE EARTH'S PULSE

Launch:

ERS-1 17 July 1991 by Ariane-4 from Kourou

ERS-2 21 April 1995 by Ariane-4 from Kourou

Mass:

ERS-1 2384 kg; ERS-2 2516 kg

Lifetime:

3 years planned ... but ERS-2 still working

Little more than ten years ago, it was impossible for satellites to routinely monitor millimetre-sized changes in land heights. The European Remote Sensing (ERS) satellites changed that. Large areas of land, including whole cities, are now being monitored regularly for gradual subsidence or elevation. This is important not only to commercial organisations, such as mining companies, but also to authorities watching changes around volcanoes or in earthquake zones, and to scientists investigating movements between plates of the Earth's crust.

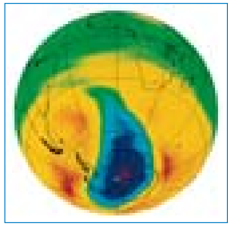
This ability to measure the surface so accurately and regularly became apparent during nine months in 1995-1996 when the ERS pair was working in tandem. They carried an identical core payload of two specialised radars and an infrared camera. Following identical orbits, one lagged 24 hours behind the other. By twice imaging the same area a day apart, it proved possible to build up surprisingly detailed and accurate 3-D land maps of the whole globe. They are now an invaluable reference for measuring subsequent land movements.

Now, only ERS-2 is beaming down information, and it is expected to continue operating into 2005. ERS-1 was held in reserve from June 1996 until it finally 'died' in March 2000 – almost tripling its planned three-year life. The two were twins except that ERS-2 also monitors ozone levels in the atmosphere.

The satellites have notched up many successes. They are the first European missions to provide detailed information on a wide range of important factors for understanding our planet and the impact we are having on it. The suite of scientific instruments operate throughout the day and night whatever the cloud-cover. As well as very detailed images and accurate height measurements, they also record wave and wind patterns over the oceans, sea, land and cloud-top temperatures, and vegetation cover.

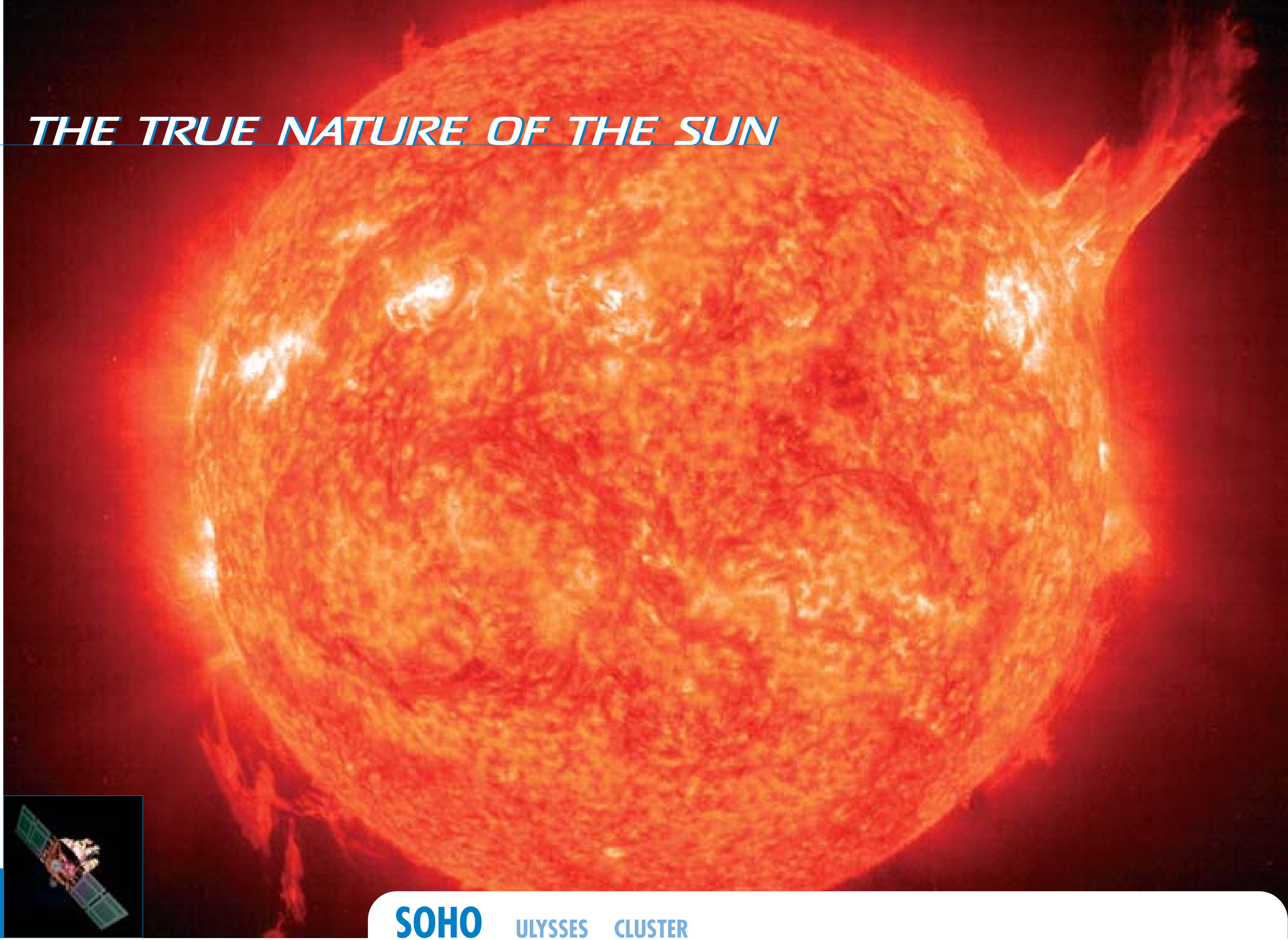
The information has found a wide range of scientific and commercial applications. Regular global measurements of the oceans and ice cover are feeding into climate studies. Ozone measurements are helping scientists to monitor the health of the ozone layer and understand how pollution affects it. Images and measurements of land surfaces are helping oil prospectors to identify new deposits, authorities to monitor changes in land use, and emergency services to monitor natural disasters. In the tropics, ERS is checking on the health of forests. The European Union is using ERS to monitor the types of crops being grown by farmers and even to estimate yields.

The ERS satellites have proved their worth many times. As ERS-2 approaches the end of its life, it is preparing to hand over comprehensive global monitoring to a new generation of Earth observation satellites – Envisat and MetOp.



Right: ERS continues to monitor damage to Earth's ozone layer.
A large hole is evident in the protective layer over the Antarctic. (ESA/DLR)

THE TRUE NATURE OF THE SUN



SOHO Launch:
2 December 1995 by Atlas-2AS from Cape Canaveral

SOHO Mass:
1864 kg (including 655 kg science instruments)

SOHO Lifetime:
~12 years

Left/right: SOHO is giving us an unprecedented view of the Sun. (SOHO/EIT consortium)

The Sun is the Earth's celestial life-giver. Its light and heat provide life on Earth with the energy to grow and prosper. Yet, from space, the Sun is revealed as a violent and unpredictable place. Gigantic eruptions of electrified gas are routinely flung into space, some colliding with Earth and damaging power and communications systems, particularly satellites. Forecasting these solar storms plays an important role in protecting our technology.

The study of the Sun is an increasingly important 'mirror' in which to reflect our analysis of the Earth's changing climate. While it is obvious that the Sun's light helps to maintain our world at a clement temperature, the Sun also communicates with the Earth via a sleet of tiny particles, known as the solar wind, that constantly buffets our planet. In addition, the Sun's magnetic field shields us from the deadly radiation of cosmic rays zipping in from the far depths of space.

The Sun's magnetic field ebbs and flows, even flipping over, on an 11-year cycle. As it does so, cosmic rays can leak into the Solar System and strike the Earth. Together with the solar wind, scientists are beginning to realise that these incoming particles may have profound effects. For example, high-flying airline passengers can receive radiation doses equivalent to several chest X-rays. And Earth's weather patterns may be significantly influenced, because cosmic rays are suspected to play a role in cloud formation.

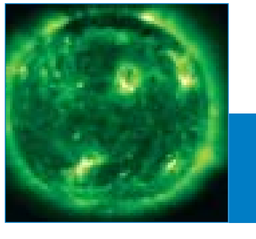
The Sun's control over our lives is immense – as is ESA's contribution to our growing understanding of the more subtle effects that the Sun has on us all.

Soho Staring at the Sun

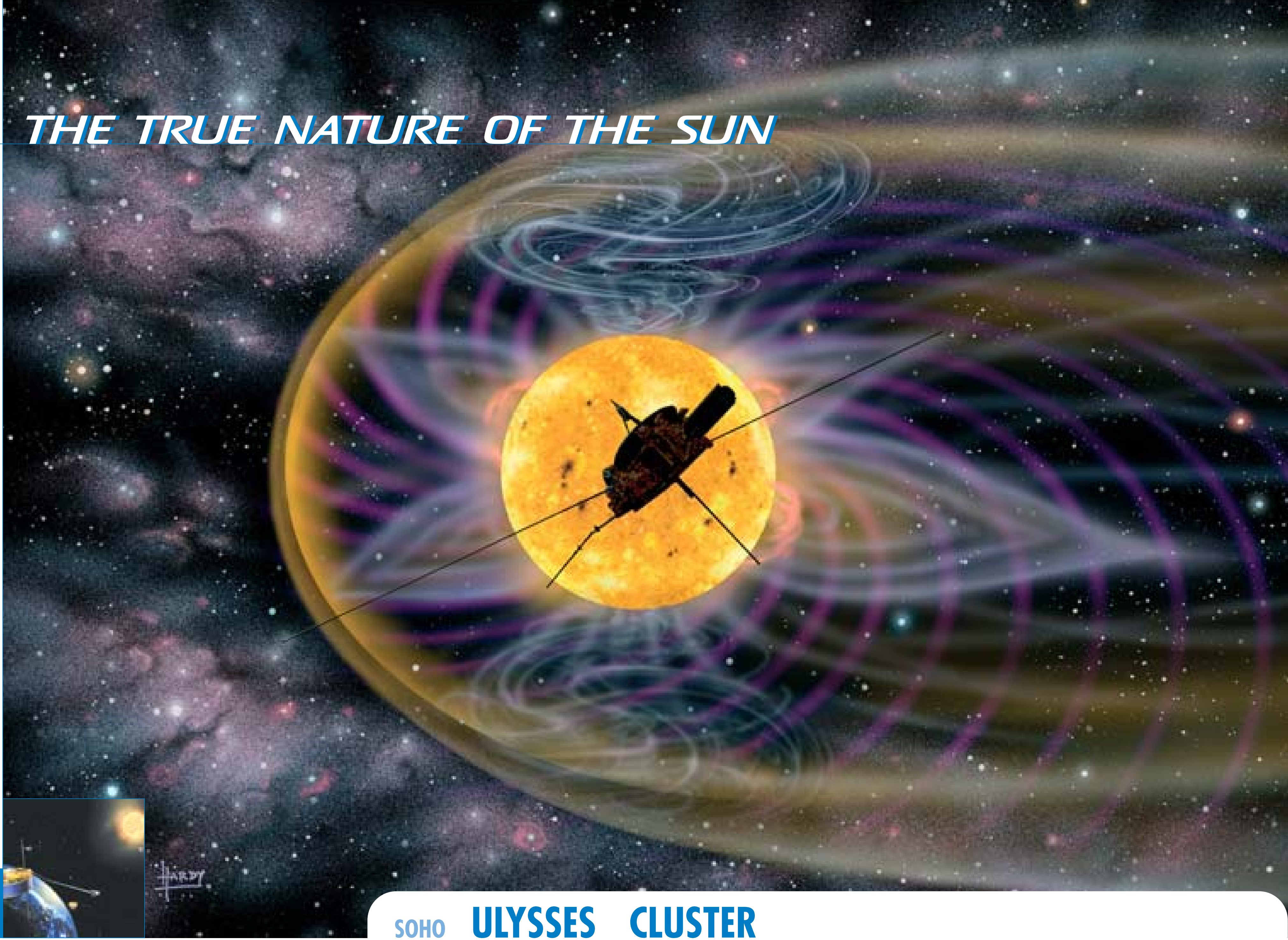
The joint European-US SOHO satellite has been staring at the Sun almost continuously for more than seven years, helping to unravel long-standing solar mysteries. One of its many major achievements has been to discover a way of forecasting which solar eruptions pose a threat. As well as turning space weather forecasting from dream to reality, SOHO may have solved why the Sun's atmosphere is a searing 2 000 000°C when its surface is 'only' 6000°C. SOHO has discovered that magnetic loops continuously bubble up, release their power and then collapse exhausted back into the surface. Another discovery is the circulation of gas inside the Sun: a river of gas 24 000 km deep flowing steadily from the equator to the poles.

Three 'helioseismology' instruments are watching surface vibrations, forming a picture of how the Sun is built, right down to its core. Five are observing the outer atmosphere and corona. One has also discovered more than 500 comets, making SOHO the most successful comet-spotter ever! Three are measuring the effects of space weather near the Earth. And one is monitoring how the heliosphere – the magnetic bubble blown out into space by the charged atomic particles streaming from the Sun – behaves in the void between the stars.

SOHO has held centre stage in solar physics for eight years and can look forward to more exciting and successful years.



THE TRUE NATURE OF THE SUN



Ulysses Launch:
6 October 1990 by Space Shuttle from Cape Canaveral

Ulysses Mass:
370 kg

Ulysses Lifetime:
14 years

Left: from high above the Sun's poles, Ulysses has provided a unique view of our star's sphere of influence. (ESA/D. Hardy)

Cluster Launches:
16 July & 9 August 2000 in pairs by Soyuz from Baikonur Cosmodrome

Cluster Mass:
1190 kg each

Cluster Lifetime:
5 years

Far left/right: the Cluster quartet dances around Earth's magnetic bubble.

Ulysses Touching the Solar Bubble

Our view of the Sun is limited by our position in space – on a planet orbiting more or less around the Sun's equator. For the past 13 years, however, we have enjoyed a different perspective on our star and its environment. Ulysses has been returning unexpected findings as it has travelled high above the Sun's poles and out as far as Jupiter. Ulysses is exploring the heliosphere in 3-D for the first time.

Much like its Greek namesake, Ulysses has had many adventures during its epic journey. It has had to withstand buffeting by a changing solar wind as the Sun has roared and then calmed during its 11-year cycle. But the experience has been rewarding. It is measuring the particles and magnetic fields pouring from the Sun and the cosmic rays, gas and dust leaking in from the Universe. And Ulysses has made remarkable findings on how they are all connected.

How the heliosphere deflects and changes cosmic rays could have a bearing on Earth's climate. Studies of old wood show that more reached Earth when the climate was colder. Ulysses also tells us that gas and dust from interstellar space is penetrating the heliosphere. Far from the Sun and high above the disc of planets, interstellar gas and dust is more common than our 'home-grown' variety. Over thousands of years, our solar system could swim through different clouds that may even affect the environment on Earth.

Cluster Dancing in Tune

Most of the solar wind slips harmlessly past Earth, deflected by our magnetic shield – the magnetosphere. But that shield is vulnerable. 'Gusts' in the wind squeeze it towards Earth and weak spots allow powerful particles through. As they collide with our upper atmosphere, they paint the aurora – beautiful shimmering curtains of light gracing the polar skies. But particularly severe sunstorms can be costly. Since 2000, we have had a new tool to study this continuous feud between Sun and Earth. The four identical Cluster satellites are flying in close formation, sometimes forming a lop-sided pyramid and sometimes in a line, building up the first 3-D picture of near-Earth space. Their separations vary between 100 km and 20 000 km, allowing them to focus on small features and then to step back for a broader view. Rumba, Salsa, Samba and Tango dance along an elongated orbit stretching a third of the way to the Moon. Sometimes they are inside the Earth's magnetic shield and sometimes outside, fully exposed to the full battering of the solar wind.

Once, as they were on the sunward side during a solar storm, the magnetosphere ballooned in and out rapidly. These were the first-ever 3-D sightings made at the same time from both sides of this ever-shifting boundary. Cluster found waves rippling along it like a wind blowing across a lake – although at 145 km/s! The quartet then rearranged itself to look at the magnetic tail that stretches for millions of kilometres from Earth's nightside.

EUROPE'S ROUTE TO SPACE

First Launches:
Ariane-1: 24 December 1979
Ariane-2/3: 4 August 1984
Ariane-4: 15 June 1988
Ariane-5: 4 June 1996

Launch Mass:
Ariane-5: ~ 750 t

Ariane-5 is launched from the Centre Spatial Guyanais at Kourou, French Guiana.
(ESA/CNES/Arianespace/CSG)

There is one family of rockets that carries half of the world's commercial satellites into space. And it is not American or Russian, but European. Over more than two decades of brilliant success, the Ariane expendable rockets have established an enviable record for reliability that has stood it in good stead during times of market uncertainty. In recent years, as communication satellites have grown ever larger, ESA has introduced the top-of-the-range Ariane-5, and even more powerful versions of the heavy-lift launcher are already under development.

With more than 200 satellites launched and a four-fold return on investment, Ariane is one of the great European space achievements. The maiden launch was successful on Christmas Eve 1979 and, four months later, the Arianespace company was created to promote and sell the launcher to commercial customers. By today's standards, the performance of this slim, three-stage rocket was fairly modest, able to deliver a 1.8-tonne satellite to an elliptical transfer orbit stretching out to 35 900 km. However, it was not long before more advanced versions of Ariane were in production.

The next important step in creating a world-beating launch vehicle came in January 1982 when ESA decided to proceed with the Ariane-4 model. Not only was the new addition to the family even more powerful than its predecessors, but it was also more adaptable.

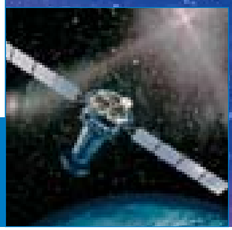
Equipped with or without liquid- or solid-propellant strap-on boosters, Ariane-4 was available in six different versions that could lift satellites ranging from 2130 kg to 4950 kg. The varying demands of the marketplace were also met by offering a range of payload fairings and satellite carriers so that it could handle mixes of one or two large satellites and six 50 kg mini-satellites on each launch.

Since its introduction in June 1988, the Ariane-4 flew well over 100 times, with only three failures, a success record of almost 98%. Although most of its passengers were communication satellites, the rocket also carried ESA's Giotto comet probe, the SOHO solar observatory, the ERS remote sensing satellites and two French Helios military satellites.

Despite this remarkable run of success, the continual growth of communication satellites retired the Ariane-4 in 2003 in favour of an even more powerful, flexible and economical launcher, the Ariane-5. After problems during early launches, the basic Ariane-5 is now well established and work on more powerful versions is under way to increase its capacity from 6 tonnes to 10 tonnes.

Not only does the Ariane-5 confirm Europe's lead in the commercial launch stakes, but it also offers new opportunities, such as launching the ATV supply ship to the International Space Station, and propelling probes such as Rosetta towards distant comets and planets.

COSMIC INSIGHTS



XMM-Newton Launch:
10 December 1999 by Ariane-5 from Kourou

XMM-Newton Mass:
3764 kg

XMM-Newton Lifetime:
>10 years

Left: XMM-Newton is finding black holes by the X-rays they generate. Right: XMM-Newton peeks through the 'Lockman Hole' window of our Galaxy into the deep Universe and sees mostly huge black holes (like left) in the centres of galaxies.

The wider Universe lies beyond the Sun and the planets, where wonder and amazement go hand-in-hand with scientific discovery. Serene beauty and unimaginable violence are found here. It is from studying the wider Universe that astronomy has produced some of the most astounding images of the modern era. The stunning Hubble Space Telescope images that thrill scientists and general public alike are a by-product of this exacting science.

The Universe is evolving, and making sense of this dynamic existence is the role of the astrophysicist. For example, exploding stars seeded the originally bland cosmos with the now-familiar chemical elements. Carbon, the essential commodity for life on Earth, is formed in the hearts of stars and subsequently spilled into space.

Like a botanist who visits a far-off land to collect samples, astronomers first map and catalogue the vast menagerie of celestial objects. Next come the chemical analysis and other investigations. Using this knowledge, we can picture how things behave and relate to one another. Finally come predictions of their behaviour. Astronomers still have a long way to go before they fully understand the celestial menagerie but, with the wide breadth of ESA space telescopes at their disposal, the job is being made easier and more productive than ever before.

Studying these far-off events is not simply a matter of academic curiosity – it is fundamental if we are to understand how our Earth fits into the rest of the Universe, whose laws rule us.

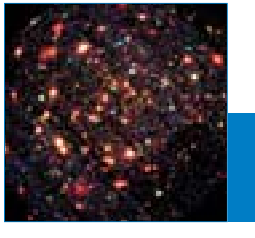
XMM-Newton A Mirror on the Universe

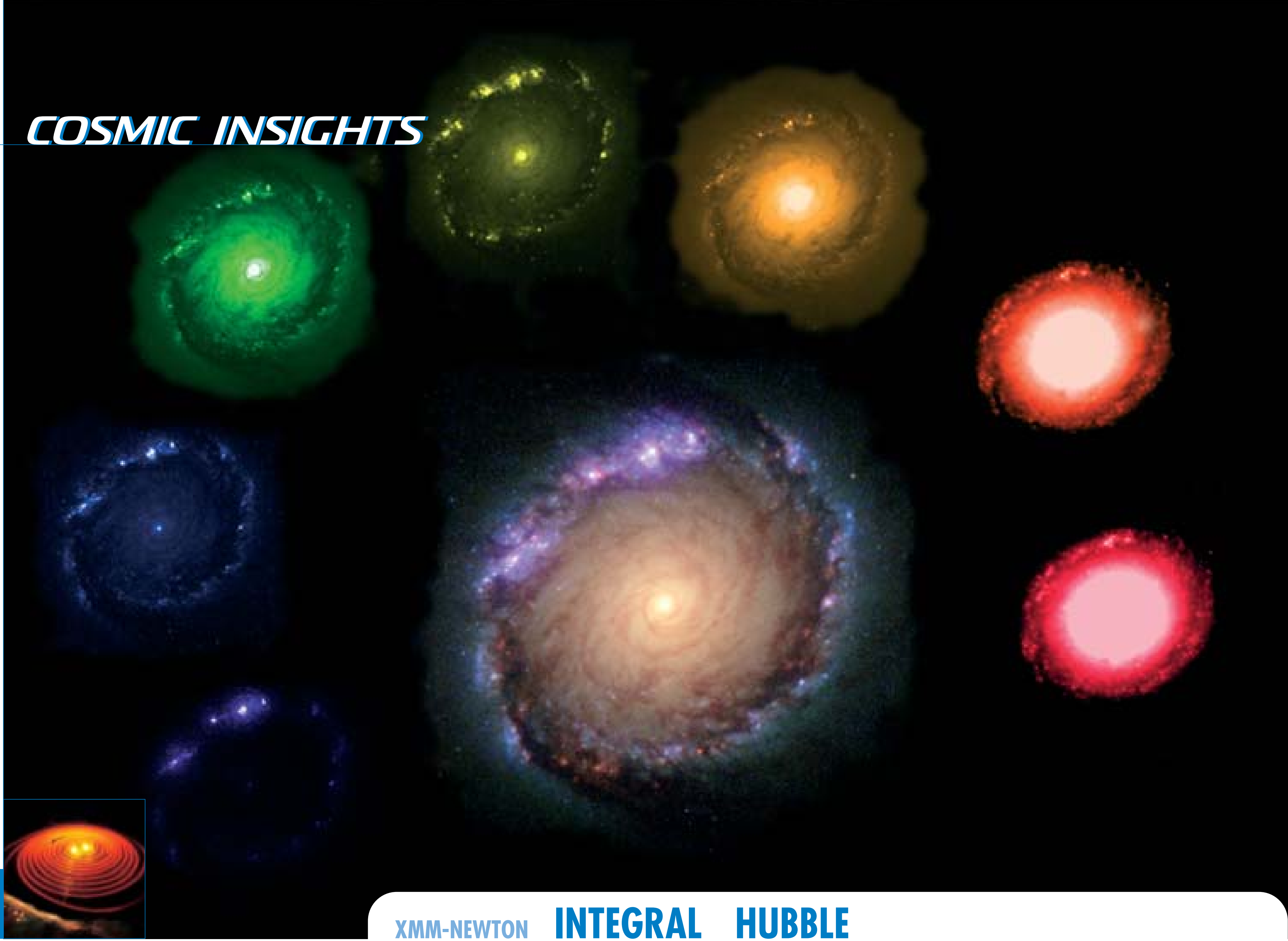
If we had X-ray eyes and could peel back the Earth's atmosphere, the night sky would look very different from the one we are used to. The background would be suffused with a soft glow, and some regions dark in normal light would shine brightly. We would be seeing the hottest parts of the Universe, from X-rays generated only when temperatures reach many millions of degrees.

XMM-Newton, ESA's state-of-the-art X-ray observatory, has been showing us tens of thousands of new X-ray sources. XMM-Newton is revealing hotspots such as the hot gas between stars, the hot atmospheres of stars, and the heating of material being sucked towards neutron stars and black holes. It is uncovering not only the whereabouts of all this hot star-stuff, but also its composition by studying the X-ray 'colours'.

One particularly interesting observation throws light on the origin and nature of gamma-ray bursts, which are the most powerful explosions in the Universe. By staring at the X-ray afterglow of a gamma-ray burst, XMM-Newton has identified the chemical elements and confirmed it as the death of a huge star in a supernova explosion.

In another discovery, XMM-Newton has found more iron than expected in an early galaxy on the edge of the Universe. As iron levels build with age, does this mean the Universe is older than we previously thought?





Integral Launch:
17 October 2002 by Proton from Baikonur Cosmodrome

Integral Mass:
4100 kg (telescopes 2 tonnes)

Integral Lifetime:
5 years

Far left: gamma-rays burst from merging neutron stars – only 40 km across but heavier than the Sun.
Right: Integral observes a jet spraying material from a galaxy's central black hole.
Illustrations ESA/Medialab/D. Ducros

Hubble Launch:
24 April 1990 by Space Shuttle from Cape Canaveral

Hubble Mass:
11 100 kg

Hubble Lifetime:
20 years

Left: Hubble's range of cameras photographed this galaxy in different colours, to produce the combined full-colour image at centre. (NASA/ESA)

Integral The Violent Universe

Although our local backwater of space is usually quiet, much of the Universe is unbelievably violent. By collecting high-energy gamma-rays, ESA's Integral satellite opens a window onto a turbulent cosmos – colliding neutron stars, exploding stars and worlds being swallowed by black holes.

A top priority is to find how the chemical elements – the building blocks of the Universe and life – are made. Stars are the chemical factories, using nuclear fusion to burn hydrogen, the lightest element, into helium. Large stars have enough raw fuel to build heavier elements such as carbon, oxygen and on up to iron. But the heaviest of all, such as gold, lead and uranium, are created only when a massive star explodes and spreads its debris through the cosmos. All of the gold on Earth began in the death-throes of stars. By looking at the gamma-rays pumped out during these supernova explosions, Integral is showing us how such cataclysmic events give birth to the chemical elements.

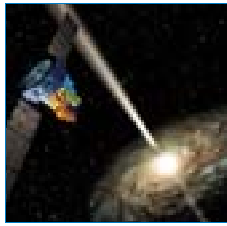
Supernovas also attract Integral's attention because the explosion collapses the core into an extremely compact object, such as a neutron star or black hole only a few kilometres across. The gravity is so strong that it pulls in anything nearby so violently that more gamma- and X-rays are generated. By observing this radiation, Integral is telling us more about these exotic objects.

Much will also be revealed about the engines powering galaxies. Gigantic black holes, the size of our Solar System but up to a billion times heavier, are thought to lie at the centres of most galaxies, where they suck in their surroundings with the release of vast amounts of energy. The most violent of all also shoot out tight jets of matter from the central black hole. Integral could provide some answers on why.

Hubble Space Telescope Probing the Universe

For more than a decade, astronomers and the general public alike have marvelled at the stream of remarkable images produced by the NASA-ESA Hubble Space Telescope (HST). Although the 2.4 m-diameter telescope is dwarfed by modern ground-based instruments, the clarity of its vision remains unequalled, thanks to its orbital vantage point 600 km above the Earth.

Europe's most important contribution to HST's success was the Faint Object Camera (FOC), which produced almost 7000 extremely sharp images of nearly every class of astronomical object during its near-12 years in space before it was replaced in 2002. FOC's unique advantage was its very high magnification. It provided the first images to show surface details on remote Pluto; the first direct images of the atmospheres of giant stars like Betelgeuse; the first image of a black hole; the discovery of white dwarfs hidden in the multitude of stars of a globular cluster; and detailed views of exploding stars. FOC's sharp eye also penetrated the inner cores of active galaxies, where black holes are lurking. FOC's results will continue to be analysed for years to come.



CONNECTING THE WORLD

Launch:

12 July 2001 by Ariane-5 from Kourou

Mass:

3105 kg

Lifetime:

10 years

Left: Artemis and Spot-4 are linked by lasers. In reality, they are 40 000 km apart. (All artwork ESA/J. Huart)

Far left: the first-ever image, showing Lanzarote, beamed between satellites by laser (CNES/Spot Image/ESA).

Artemis, ESA's Advanced Relay and Technology Mission Satellite, was launched in 2001 to pioneer new communications and space technologies before they are risked on expensive commercial satellites. Artemis is passing on data from other satellites to Earth, relaying signals from mobile handsets to ground stations, and broadcasting a navigation signal to improve the GPS system. However, it was one of the new space technologies that received a far more vigorous test than anyone had ever imagined.

Revolutionary ion engines helped to nudge Artemis gently into its correct orbit after its rocket left it stranded in too low an initial orbit. With any other satellite, the failure would have been disastrous and the mission written off. But space engineers realised that Artemis' new ion engines could push it gradually back on course.

The conventional chemical rocket thrusters mostly emptied their tanks to pull Artemis above Earth's deadly radiation belts into a circular orbit at about 31 000 km – but still too low. Then the ion engines were reprogrammed to spiral the orbit out until it reached the original target of 36 000 km. These engines shoot out jets of electrified xenon gas at high speed. The thrust is very low – no more than the weight of a postcard – but applied continuously over months or even years it can push spacecraft gradually into places they would not normally reach. Artemis doggedly climbed 15 km every day for much of 2002. It was rather like using an outboard motor to drive an ocean liner. Of course, there were unexpected problems on the way as engineers coached the engines into working in a very different way than originally intended.

Being in the wrong orbit, however, has not put Artemis off its mission. While still on its slow but steady journey, it began testing some of the new communications technologies. Images from France's Spot-4 Earth observation satellite have been relayed to a ground station on Earth using Artemis' advanced laser communications system, SILEX. The satellites illuminated each other with laser beams even though their relative speed was several km per second. After travelling 40 000 km through space, the width of each beam was no more than 300 m. Spot-4 sent its pictures to Artemis as pulses in the laser light and ESA's satellite relayed them instantly to a ground station. This is a world first. Normally, low-flying observation satellites store their images onboard until a suitable ground station comes into view. With this pioneering technique, Artemis is opening up new applications such as real-time monitoring of disaster areas.

The mobile communications payload is also being demonstrated before it is used by Eutelsat for commercial services. Artemis start broadcasting the navigation signal soon after it arrived in its final position on 31 January 2003, hovering over Africa. Artemis can now look forward to a full 10 years of fruitful operations – not bad for a spacecraft that was 'lost in space'.

SMALL IS BEAUTIFUL

Launch:
22 October 2001 by PSLV from Sriharikota, India

Mass:
94 kg

Lifetime:
2 years

Left: Proba's view of the Mauna Kea volcano, Hawaii.
Right: the field patterns of El Centro, California.

As soon as a satellite reaches orbit, attention switches from the launch pad to the people at mission control who send it messages to do whatever needs to be done. For example, change course, photograph a target or take action to avert a disaster. If satellites could be made more self-reliant, however, far less effort – and money – would have to be spent on ground control. Proba is a small low-cost satellite, testing new micro-technologies to make spacecraft more independent.

The first of its type, Proba (Project for On-Board Autonomy) is also making useful observations. Since its launch as a piggyback passenger on an Indian rocket, it has been returning spectacular images of the Earth. If successful – as early indications suggest – the new technologies it is testing will be used by larger, more costly missions.

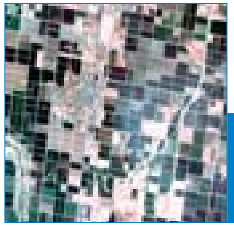
Proba carries onboard all the computing power and equipment needed to pinpoint its own position very accurately. It also has a list of targets it is required to photograph. This allows it to decide automatically when it is above a desired place and to instruct its cameras to go to work. Just as a human photographer might move around to snap a subject from different angles, Proba can rotate to take five consecutive images of the same scene. Normally, ground controllers calculate the position of a satellite and instruct it when to turn on its instruments to observe a particular scene.

Such high levels of independence required technology development in many different areas, from star trackers (for measuring angles accurately), to GPS (global positioning) systems, to new software that allows Proba to predict where it will be at a specific time in the future. Those jobs usually done on the ground have had to be redeveloped using miniaturised technology that can survive the rigours of space.

The lightweight Proba carries the highest performance computing system ever flown on an ESA spacecraft. With 50 times more processing power than SOHO, ESA's Sun watcher, it is based on processors specially developed for space under joint ESA and European Union funding. The most innovative instrument on board is CHRIS – the Compact High Resolution Imaging Spectrometer, weighing only 14 kg – which can observe the same spot on Earth from different angles and photograph an 18.6 km square area showing details as small as 18 m. The pictures are sent automatically to ESA's ground station in Redu, Belgium, and then on to scientists elsewhere via the Internet.

Proba also carries three other important scientific instruments: the SREM standard radiation environment monitor, the DEBIE debris measurement sensor, and the HRC high-resolution camera, which takes black and white images of Earth at a resolution of 8 m.

After the success of this first Proba, ESA is working on a follow-up Proba-2 in 2005 to test more autonomous systems and even smaller components and instruments.



MANAGING OUR WORLD

Launch:
1 March 2002 by Ariane-5 from Kourou

Mass:
8200 kg

Lifetime:
5 years

Left: Sicily viewed from Envisat.

Right: the collapse of the giant Larsen B ice shelf was witnessed by Envisat.

Thirty years ago, astronauts orbiting the Moon looked back longingly towards the tiny blue and white planet they had left behind, and described it as an oasis in space. For the first time, humanity could see spaceship Earth in its entirety and comprehend its fragility. Since then, our planet has been intensively monitored and studied, but many problems and mysteries remain. How and why is the Earth getting warmer? What are the effects of this global warming? Is the ozone hole growing or shrinking? How is human activity affecting the natural environment?

Envisat, the largest and most capable satellite ever launched to monitor Earth's environment, is investigating these and many other problems. Equipped with ten state-of-the-art instruments, this powerful observatory is conducting a comprehensive health check on our planet.

Envisat is circling from pole to pole every 100 minutes, recording changes in the atmosphere, oceans, land and ice cover. By comparing this new information with the results gathered over the past ten years by ESA's two ERS satellites, we can spot long-term trends and picture the complex, interwoven links of our environment. These new insights can then help us to decide how best to protect the planet.

Envisat is sending back a flood of information. Some of the first images were from its cloud-piercing radar, seeing the largest-ever single collapse of an ice shelf along the Antarctic Peninsula. The vast Larsen B ice shelf – 200 m thick and larger than Greater London – fragmented into a mosaic of icebergs.

Envisat's radar altimeter is profiling Earth's surface to measure changes in ice thickness – vital for understanding the global rise in sea level – and wave height and wind speed over the oceans. Such observations help us to understand ice changes, global warming and ocean circulation.

Another instrument is mapping the distribution of microscopic plants (phytoplankton) by measuring the 'colour' of the oceans. Since these organisms absorb huge amounts of carbon dioxide, they have a major effect on the levels of greenhouse gases in the atmosphere. Such information also helps in managing fish stocks, since the plankton provide food for shoals of fish. Dozens of other investigations will be pursued during Envisat's life – sea-surface temperatures, man-made pollution, ozone levels, soil erosion and surface subsidence, to mention just a few.

Europe now has a powerful new way of measuring key elements of the global environment and climate change. Its precise measurements of the changing Earth will assist in implementing major international environmental agreements, such as the Kyoto Protocol, under which Europe undertakes to reduce greenhouse gas emissions.

Envisat will also be the cornerstone of Europe's Global Monitoring for Environment and Security (GMES) initiative, enabling governments, researchers and companies to track pollution and react to emergencies.

PLANETARY ORIGINS AND LIFE IN SPACE

SMART-1 Launch:

27 September 2003 by Ariane-5 from Kourou

SMART-1 Mass:

370 kg

SMART-1 Lifetime:

22 months

Left: SMART-1's miniaturised instruments will scan the Moon from close up.

Far left: did the Moon result from a gigantic collision with the young Earth?

Right: SMART-1's ion engine glows during a test.

Illustrations ESA/Medialab

Earth is not an isolated world. Instead, it is just one in a system of nine planets, more than a hundred moons, and countless smaller bodies. All are unique worlds and all have their own stories to tell. Some, such as Venus and Mars, have evolved in startlingly different ways from the Earth. Others, such as our Moon and Saturn's moon Titan, have remained in the deep-freeze almost since their births. Studying these worlds helps to place our own in context: which processes are common to every planet and which are special to individual worlds? Which properties foster life on Earth, and are there any other places in the Solar System where hardy microbial life might be hanging on? New discoveries at Mars, for example, tease scientists into thinking that it might be a more inviting place for life than they previously thought. ESA will thoroughly investigate these claims.

In short, ESA is seeking to understand what makes a planet habitable. Having discovered this, what does it take to maintain that habitability? And how did life begin in the first place? The answer may be locked inside the comets. These ancient icebergs contain the chemical building blocks of life itself. During the formation of the planets, the comets seeded Earth and the other planets with at least some of the chemicals that are essential for life to form. Understanding the comets' subtle role in the origin of planets and life is of the highest importance.

ESA's exploration of the Solar System is a focused effort to understand the Earth's relationship with the other planets and an essential steppingstone for exploring the wider Universe.

SMART-1 Closest Stop: The Moon

A spacecraft needs to take with it all the fuel it needs for its journey – after all, there are no filling stations in space. ESA's small SMART-1 is testing a new type of engine planned for two major long missions: the BepiColombo mission to Mercury, and the Solar Orbiter Sun observatory. It is the first in a series of Small Missions for Advanced Research and Technology, which tests new technologies to prepare for future ambitious adventures.

SMART-1's ion engine electrifies atoms of xenon gas and ejects them at enormous speed – like a spaceship out of science fiction. The thrust is no more than the weight of a postcard but, firing continuously over months or even years, it is enough to propel a spacecraft to corners of the Solar System that conventional engines with their short, powerful bursts could never reach. SMART-1 will demonstrate this technology on a 16-month journey to the Moon, where it will take a sophisticated new look at our closest neighbour.

The scientific instruments will make a closer and more detailed study than ever before at the shape, roughness and composition of the Moon's surface. Two will search for water ice at the bottom of craters near the poles where sunlight never reaches. If there is ice, future lunar bases can use it for oxygen and rocket propellant, making space travel much easier. The Moon would become a staging post to the rest of the Solar System. The

PLANETARY ORIGINS AND LIFE IN SPACE

Rosetta Launch:
2 March 2004 by Ariane-5 from Kourou

Rosetta Mass:
~3000 kg

Rosetta Lifetime:
~10.5 years

Far left: the Rosetta lander on the comet. (ESA/Medialab)

Mars Express Launch:
2 June 2003 on Soyuz-Fregat from Baikonur Cosmodrome

Mars Express Arrival at Mars:
25 December 2003

Mars Express Mass:
1120 kg (including 65 kg lander)

Mars Express Lifetime:
minimum 1 martian year (687 Earth days) in Mars orbit

Left: Mars Express approaches its target, with the lander capsule attached. (ESA/Medialab)
Right: Mars Express has a good chance of finding any underground aquifers on Mars. (ESA/Medialab)

Moon's composition will provide clues about its history and origin. At the moment, we still do not know where the Moon came from. Perhaps it is debris thrown off when Earth was hit by a Mars-size planet. If so, it should have less iron than Earth in comparison with lighter elements like aluminium. SMART-1 could provide that vital evidence.

The Moon is a crucial witness to the early conditions of our planet. As the Earth's daughter, she holds the keys for understanding our origins and for preparing for the future exploration of the Solar System.

Rosetta   The Time Machine

Billions of primitive iceballs still linger in the depths of space, the remnants of a vast swarm that once surrounded our Sun and eventually came together to form planets. We know that these comets carry complex organic molecules rich in carbon, hydrogen, oxygen and nitrogen – intriguingly the elements that make up nucleic acids and amino acids, essential ingredients of life as we know it. Did life on Earth begin with the help of cometary seeding? What part did comets play in forming the planets? To answer these fundamental questions, Rosetta is targeted on a chunk of dirty ice orbiting the Sun every few years: Comet Churyumov-Gerasimenko.

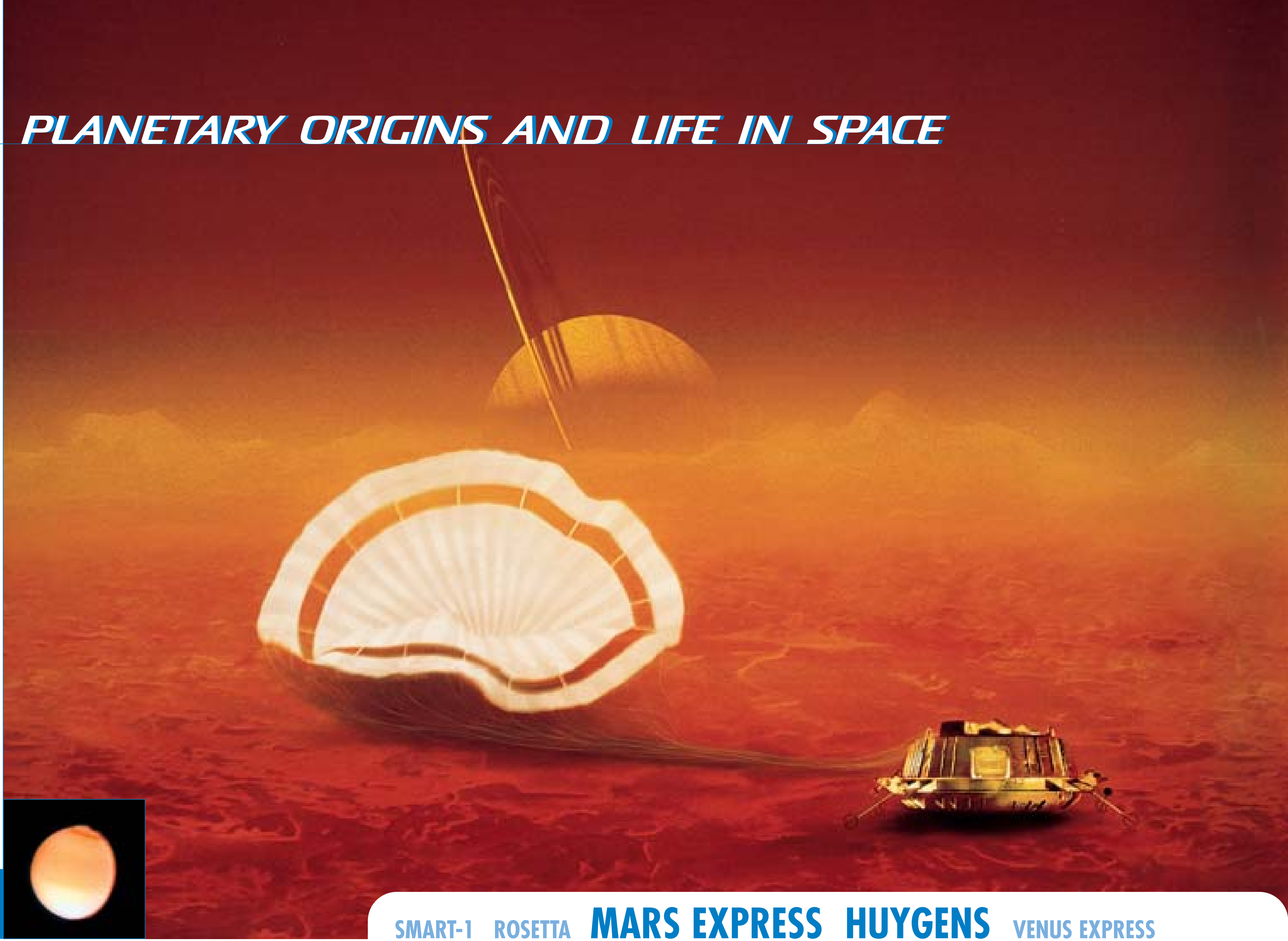
Rosetta is about the most ambitious robotic space mission ever attempted. An orbiter will observe the nucleus in unprecedented detail, and a small lander will make the first touchdown on a comet. Both must survive the hazards of travelling through deep space for more than ten years and working almost 800 million km from the Sun. As they approach the warming Sun, Rosetta will circle the comet, watching it wake from its frigid hibernation, sampling the the dancing gaseous jets and dusty halo. The trunk-sized lander will anchor itself to the nucleus. Remarkable pictures and other information on the comet's ices and black, organic crust will be beamed to Earth over several weeks or even months. By mission's end in 2015, we will have a treasure trove of new insights into the mysteries of how the planets formed and where we all come from.

Mars Express   Where Did the Water Go?

Today, Mars is a cold, dry place with a thin carbon dioxide atmosphere. But it was very different in the distant past. Large channels, carved by catastrophic floods, drain into the northern lowlands, and valleys, probably formed by running water, criss-cross the southern highlands. Mars was likely once warm and wet. Where did the water go? Mars Express, making Europe's first journey to a planet, may well find out.

Between them, the orbiter's seven experiments will produce a variety of detailed maps of the whole planet from the two years of intense observations. These maps will help to solve many of the outstanding puzzles about Mars: why is there such a remarkable difference between the young, northern lowlands and the rugged, southern highlands; why does Mars have the highest

PLANETARY ORIGINS AND LIFE IN SPACE



Huygens Launch:
15 October 1997 by Titan-4B from Cape Canaveral

Huygens Arrival at Titan:
January 2005

Huygens Mass:
~350 kg

Huygens Lifetime:
7 years (~2.5 h descent)

Left: Huygens lands on exotic Titan.

Far left: a chemical smog cloaks the secrets of Titan. (NASA)

Right: Olympus Mons, at 22 km the highest volcano in the Solar System, viewed by Mars Express. (ESA/DLR/FU Berlin, G. Neukum)

volcanoes in the Solar System; how do the martian atmosphere and climate work?

Most tantalising of all, however, is the fate of the water that once ran so copiously on the surface. Each instrument will contribute towards the solution. One will estimate how much water escaped to space as vapour from the atmosphere. Another should pick out layers of water, ice and permafrost down to depths of a few kilometres. NASA spacecraft have recently found evidence for plenty of water-ice a few metres below the surface. Mars Express plans to find out just how much is lurking deeper down. If there are substantial aquifers, Mars will suddenly become an inviting place for humans to visit.

Mars Express Are We Alone?

The more we know about life on our own planet, the more likely it seems that life could have gained a foothold on Mars. Over recent years, microorganisms have been discovered alive and well in some of the most inhospitable places on Earth. Provided there is water and energy, it seems that life will find a way of adapting to the harshest conditions.

When Mars Express arrived at the Red Planet, it released a small lander towards the surface. Unfortunately, the ambitious Beagle 2 did not survive the perilous descent. As well as studying conditions around the landing site, it was to scratch around for the tell-tale signs of past and present life. Beagle 2 was to roll to a stop on Isidis Planitia, a flat basin (and possibly a flood plain) north of the martian equator – just the type of place where life may have thrived during Mars' wet and warm past. The robot arm was to deliver samples to a tiny laboratory inside Beagle to search for evidence of this life. Earth biology favours carbon-12 over the heavier carbon-13, so any enrichment of carbon-12 will be an important clue of at least past life. If all had gone well, Beagle could have sniffed out *present* life by looking for methane gas, which is normally depleted quickly without biological sources.

Huygens Is This How Life Began?

In January 2005, ESA's Huygens probe will float down through the thick, orange atmosphere of Titan, the largest of Saturn's 30 known moons and one of the most mysterious worlds in our Solar System. The experience will be like travelling back in time to the Earth of 4 billion years ago. The chemical soup of the large moon's atmosphere is thought to be similar to the chemistry of Earth's early atmosphere before life transformed it into the air we breathe today. By studying this chemistry, Huygens will enlighten us about our own origins as well as reveal the unusual conditions on one of our neighbours.

The probe is hitching a lift aboard NASA's Cassini spacecraft, which will also study Titan from orbit around Saturn. The pair are already between Jupiter and Saturn on the final leg of their 7-year journey. The probe will take measurements during the 150-minute descent through the thick smog. If we are lucky, it will also survive for several minutes on the surface.

PLANETARY ORIGINS AND LIFE IN SPACE

Venus Express Launch:
November 2005 by Soyuz-Fregat from Baikonur

Venus Express Mass:
~1200 kg

Venus Express Lifetime:
2 years

An earthling stepping out onto Venus would be immediately crushed, poisoned and fried. (ESA/MediaLab)

Huygens will find a world only a little smaller than Mars. Titan's atmosphere is largely nitrogen, methane and hydrogen – the chief constituents of early Earth's atmosphere before life introduced oxygen. Pressure and density are also similar to Earth's. But Titan's atmosphere is a frigid –180°C and, whereas on Earth we have rain and oceans of water, Titan may have rain and lakes of liquid methane and ethane. The surface may be a treasure trove of organic chemistry. Methane in the upper atmosphere is broken up by cosmic rays from outer space and ultraviolet light from the Sun, forming new carbon-based organic chemicals that float down to the surface.

Huygens' six instruments will work throughout its spectacular descent, providing details on the chemical composition of Titan's atmosphere, its weather and clouds, and then the surface itself. Huygens may not find the exact transformation that turned complex organic compounds into living things, but it should help us to understand an important part of the chemistry that led to life.

Venus Express Unveiling Earth's Sister

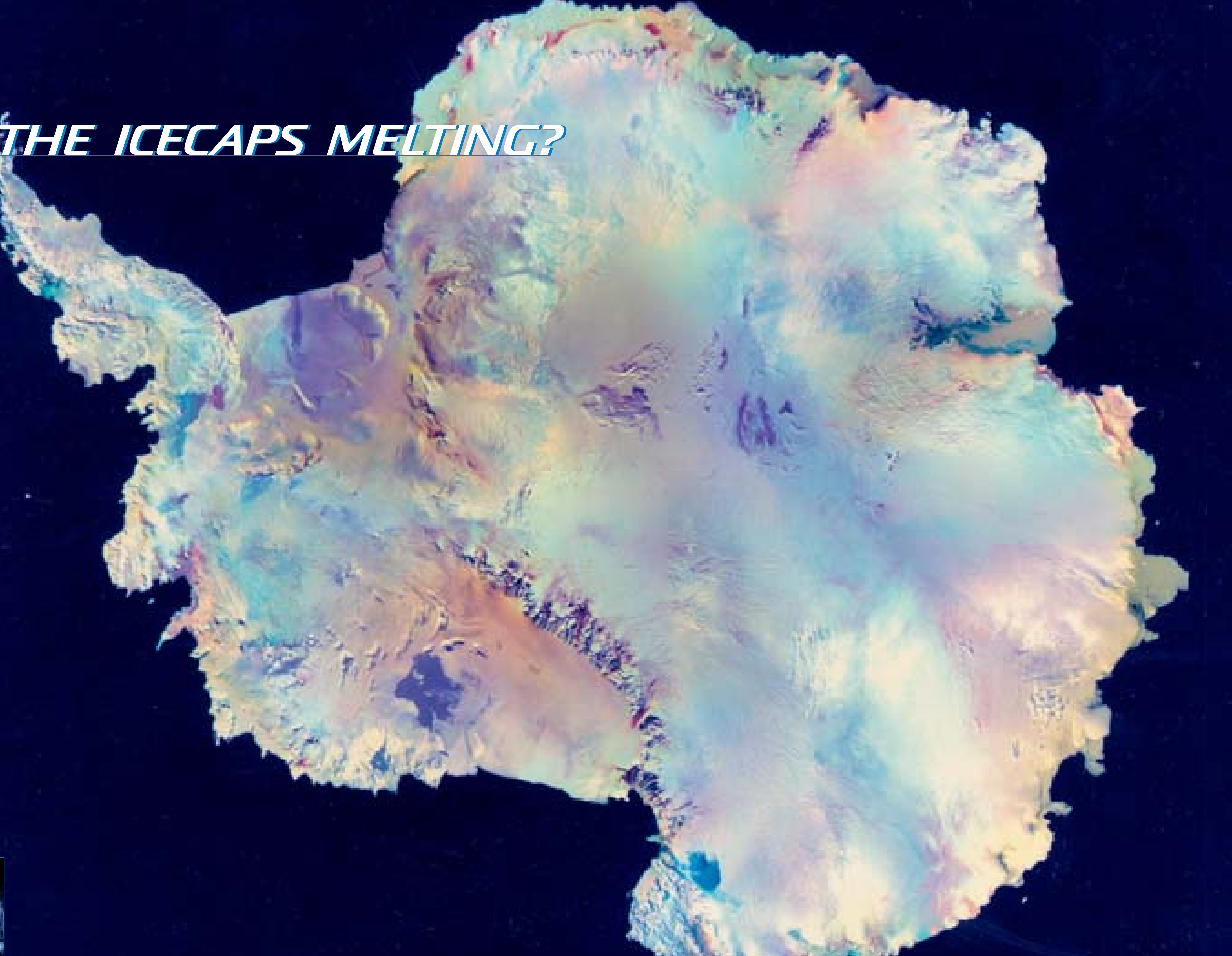
Although it comes closer to Earth than any other planet, Venus remains a mystery. After four decades of intense scrutiny by numerous Russian and American space probes, the cloud-shrouded world refuses to give up many of its secrets. Remarkably similar in size to Earth, Venus could hardly be more different in other respects – and we still have no idea why. We still do not understand the details of the greenhouse effect on Venus, which keeps the surface at a sizzling 460°C, hot enough to melt lead. The crushing atmosphere is 90 times thicker than Earth's. Most puzzling of all is how the atmosphere circulates – high-level, hurricane-force winds sweep around Venus in just four days at 360 km/h, remarkably rapid for a planet that rotates only once every 243 Earth days. Yet the surface atmosphere is a stagnant syrup.

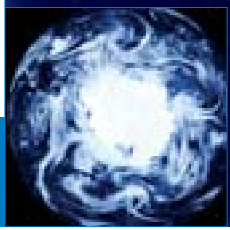
By explaining these startling differences between sister worlds, we will gain a better understanding of Earth's weather and changing climate. Despite its impressive goals, Venus Express is a low-cost spacecraft built and launched in only three years. This is made possible by basing it on Mars Express and for six of the eight instruments using spares from previous missions. Such sensors have never flown to Venus before, so the planet will be viewed through new eyes.

Some instruments, taken from Mars Express and Rosetta, will look at the atmosphere's make-up, temperature and density. One innovative instrument will picture the energetic atoms escaping from the atmosphere. Unlike Earth, Venus has no protective magnetic field so the powerful wind of electrified atomic particles streaming in from the Sun is continuously stripping away the top of the atmosphere.

When the mission was finally approved in late 2002, it meant that ESA missions will be heading for the Moon and all the planets of the inner Solar System.

ARE THE ICECAPS MELTING?





Launch:
November 2004 by Rockot from Plesetsk, Russia

Mass:
~ 740 kg

Lifetime:
3.5 years

Antarctica seen from space. (NASA/NOAA/NRSC)

Sea levels have risen by 18 cm over the past 100 years. How much of this is from the melting of the Antarctic and Greenland ice sheets? Measurements by Europe's earlier ERS satellites suggest that the centres of these sheets are holding firm, but are they melting at their edges?

So far, space techniques have been incapable of measuring changes in thickness at the edges of major ice sheets, or in smaller ice bodies, such as glaciers. All that will change in 2004, however, when ESA launches CryoSat, the first-ever mission to measure the changes in thickness of all types of ice cover. Within CryoSat's 3.5-year lifetime, it should be possible to gauge how ice thickness in the polar regions is changing, even around the edges.

CryoSat's altimeter will measure the distance from the satellite to the ice surface. Changes in these distances over the mission lifetime will mean the ice has changed thickness.

CryoSat is so sensitive that it can pick out thickness changes in large ice sheets of less than seven millimetres a year. For smaller features like glaciers or at the edges of large sheets, the altimeter will be able to detect changes of 3.3 cm per year. Such highly accurate measurements are possible only if the position of the spacecraft in its orbit is known very precisely, so onboard instruments will provide this information.

Thinning ice sheets reflect and accelerate climate change. So, too, does thinning sea ice. Although it does not contribute to the rise in sea level (because the ice is already floating in the ocean), a reduction in sea ice can have a profound effect on the Arctic climate, with consequences for neighbouring regions, especially those bordering the North Atlantic. The covering of sea ice impedes the flow of heat into the Arctic winter atmosphere from the ocean, warmed during the previous summer. Sea ice can reduce the heat flow from the open ocean by 10-100 times.

Melting sea ice also changes the amount of fresh water flowing into the ocean, affecting ocean currents and hence climate.

Previous measurements of sea-ice thickness suggest it is thinning. But they are inconclusive. Most have been obtained by drilling through ice floes or from sonar readings by submarines. CryoSat will repeatedly sample 70% of ice floes to obtain the first-ever comprehensive measurements of sea-ice thickness.

The first Earth Explorer Opportunity mission in ESA's new Living Planet programme, CryoSat is a small mission, being built relatively cheaply and quickly so that it can respond to a pressing environmental issue.

ASTRONAUTS Europe's Astronauts are Making Space History

Even as Neil Armstrong and the other Apollo astronauts enthralled the world with their exploits on the Moon, NASA was inviting Europe to participate in a post-Apollo programme. This led to Spacelab and the selection of the first ESA astronauts in 1978.

These first astronauts were German Ulf Merbold, Dutchman Wubbo Ockels and Swiss Claude Nicollier. Since Merbold's first flight in 1983, 42 space missions have been performed by 29 astronauts from ESA and its Member States, providing Europe with several years of invaluable spaceflight experience. Dozens more missions are planned for the coming decade, largely involving visits to the International Space Station (ISS).

Today, the European Astronaut Corps has 15 members, citizens of Germany, France, Belgium, the Netherlands, Sweden, Switzerland, Spain and Italy. Each has competed against thousands of applicants to join this elite band of space explorers, each bringing individual talents and expertise to the programme.

Around half the Corps are experienced pilots who began their careers in military aviation. These 'pilot' astronauts have backgrounds in aerospace science or engineering. The others have extensive scientific experience, usually in physics, and all have conducted advanced research at university level.

A few have mixed backgrounds. For example, ESA's most frequent flyer, Claude Nicollier, is both a highly experienced pilot and an astrophysicist. His four trips into orbit include two missions to refurbish the Hubble Space Telescope.

Much of the initial crew training takes place at the European Astronaut Centre in Cologne, Germany. Additional skills are acquired during lengthy training in the United States and Russia. Some astronauts have learned to operate the Space Shuttle's robotic arm which is used to manoeuvre satellites, cargo modules and human spacewalkers. Others are qualified to fly aboard and even pilot Russia's Soyuz ferry for the ISS.

Long-term habitation of the Station draws on the experience of lengthy stays aboard Russia's venerable Mir station by Thomas Reiter, Jean-Pierre Haigneré and Ulf Merbold. Some also experienced the unique challenges and excitement of extravehicular activity – working outside the spacecraft while flying around the world at 28 000 km per hour – an essential skill for exploiting the Station's capabilities to the fullest in the years to come.

As ESA is one of the five partners in the Station, there will be many opportunities for European astronauts to pursue ground-breaking scientific research in orbit, particularly after the launch of the Columbus laboratory in 2006. For at least 10 years, astronauts will work on hundreds of experiments, such as studying the effects of weightlessness on organisms and humans, and working towards new materials and medicines.

Left: Claude Nicollier working in space. (NASA)

Far left: the European Astronaut Corps.

Right: Roberto Vittori floats through the Space Station. (NASA)

EUROPE AND THE ISS

At this moment, 400 km above our heads, the International Space Station (ISS) – the largest, most ambitious space project ever undertaken – is taking shape. In an unprecedented international effort, fifteen nations are assembling the 450-tonne complex. ESA is a major partner.

Space Station assembly began in November 1998, with the first long-standing residents arriving in December 2000. Already regular visitors during the construction phase, European astronauts will serve as crewmembers once the Station is fully operational.

One of the main reasons for building the 100 m-long giant is to conduct ground-breaking scientific research. When the Station is completed, there will be up to six science laboratories, including Europe's most important single contribution: the Columbus research module. Like its 15th-century namesake, the laboratory will undertake a long journey of exploration and discovery.

The 4.2 m-diameter, 6.7 m-long cylinder will give an enormous boost to the Station's research capabilities. During its planned 10-year life, ground-based researchers – helped by the crew – will conduct thousands of experiments.

The roomy Columbus offers an entire suite of science facilities. The four walls are lined with ten standard racks, each the size of a telephone booth. Every rack can house a miniature laboratory, complete with power, cooling and video and data links to researchers back on Earth. ESA is developing a range of these science racks, all tailored to squeeze the maximum amount of research from the available space. They offer European scientists access to a weightless environment that cannot be duplicated on Earth.

Biolab, for example, allows experiments on micro-organisms, cell and tissue culture, and even small plants and animals. Another rack contains the European Physiology Modules, a set of experiments examining how the human body behaves without gravity. Such research may lead to improved treatment for age-related bone-loss and other ailments back on Earth. For smaller experiments requiring less time in orbit, ESA is building the European Drawer Rack to handle up to eight easily exchangeable experiments at a time.

Outside its protective shell, Columbus carries platforms from which experiments can be exposed to space. These include the survivability of bacteria in the harsh conditions of space, a new type of atomic clock, and telescopes to study the Sun, stars and galaxies.

Thanks to broadband communications, hundreds and perhaps thousands of scientists will conduct research aboard Columbus as though they were actually there. Researchers all over Europe will directly control their own experiments – perhaps the next-best thing to being an astronaut!

ESA has made full use of a set

Columbus launch:
2006 (aboard Space Shuttle)

Columbus launch mass:
12 800 kg (payload 2500 kg); maximum of 19 800 kg in orbit

Columbus lifetime:
10 years

Far left: Claudie Haigneré working aboard the International Space Station. (NASA/ESA)
Left: ESA/D. Ducros; right: NASA

of agreements with other ISS partners to barter Station goods and services, allowing it to allocate additional challenging work to European industry worth more than EUR 300 million.

The barters include providing Russia with the Data Management System for the Zvezda core module, a key part of the Station's 'brain' since its July 2000 launch. Russia, in return, is supplying two docking systems for Europe's Automated Transfer Vehicle (ATV).

With the aim of providing European users with access to the Station before Columbus is available, ESA has bartered with NASA for experiment space in the US Destiny laboratory module (in orbit since early 2001), as well as flights for European astronauts.

In exchange, European industry is developing 'Laboratory Support Equipment', including the Microgravity Science Glovebox, which is now installed in Destiny for astronauts to perform a wide variety of experiments into materials, combustion, fluids and biotechnology.

Rather than paying cash to NASA to cover the costs of launching Columbus aboard the Space Shuttle, ESA agreed to develop a range of Station elements and high-tech laboratory equipment and services.

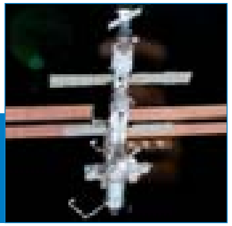
In particular, two Nodes for interconnecting ISS laboratory and habitation modules are being built using European know-how and technology. Node-2, which will connect Destiny, Columbus, the Centrifuge Accommodation Module and Japan's Kibo research module, was delivered to NASA in 2003 and Node-3 should follow in 2006.

The domed Cupola – the crew's panoramic window on space and a control room for astronauts operating Station equipment – is being supplied to NASA in exchange for the Shuttle launch and return services for five European payloads destined to be mounted outside the ISS.

In addition, ESA has supplied NASA with a Super Guppy transport aircraft, from Airbus Industries, and received in return a total experiment payload allocation of 450 kg on Shuttle flights to the Station.

ESA also has numerous cooperation agreements with the Station partners, again providing development work for European industry. For example, the European Robotic Arm (ERA) will service payloads on a later Russian external platform, and the X-38 cooperation with NASA was seen as a precursor to a Crew Return Vehicle.

These barter arrangements have significantly reduced the overall costs for the Station participants and promoted the spirit of partnership in this global programme. Above all, they are a highly practical way of cooperating closely with no exchange of money.



Why Use the ISS for Research?

The Station laboratory modules, together with the numerous research facilities, instruments and laboratory equipment, offer opportunities for fundamental and applied research in space into physics, chemistry, biology, biotechnology and medicine. The external platforms, which point towards the Earth as well as into deep space, will host space science and Earth-observation payloads, and test new technologies and products in the demanding space environment.

To understand why the ISS and its microgravity environment is attractive for research, it's useful to recall how gravity affects our lives. Gravity shapes our world: it enabled the creation and evolution of life and determined the form and composition of our bodies and the way we move. It strongly influences the gross behaviour of materials and especially of fluids, where it affects the movement of heat, mass and chemicals.

Gravity gives rise to numerous basic phenomena such as sedimentation and buoyancy, convection in liquids and gases, and hydrostatic pressure. There are many examples in nature and science. For example, plants control their direction of growth via gravity-sensitive sedimentation of high-density particles within cells.

These effects, practically absent in the weightless Space Station, play an important (often undesirable) role in physical, biological and physiological processes on Earth. They particularly influence the 'bricks' of living systems and the weak forces that bind large molecules. ISS centrifuges will allow scientists to 'control' gravity to help understand these fundamental effects, and for creating new products, technologies and improved production processes. Research opportunities include large steady flames, which can exist only in the absence of gravity-driven convection flows; the influence of gravity on the division of cells, and the development of tissues in an embryo or plant; processing of free-floating liquids and melts, thereby preventing their contamination by impurities from container walls.

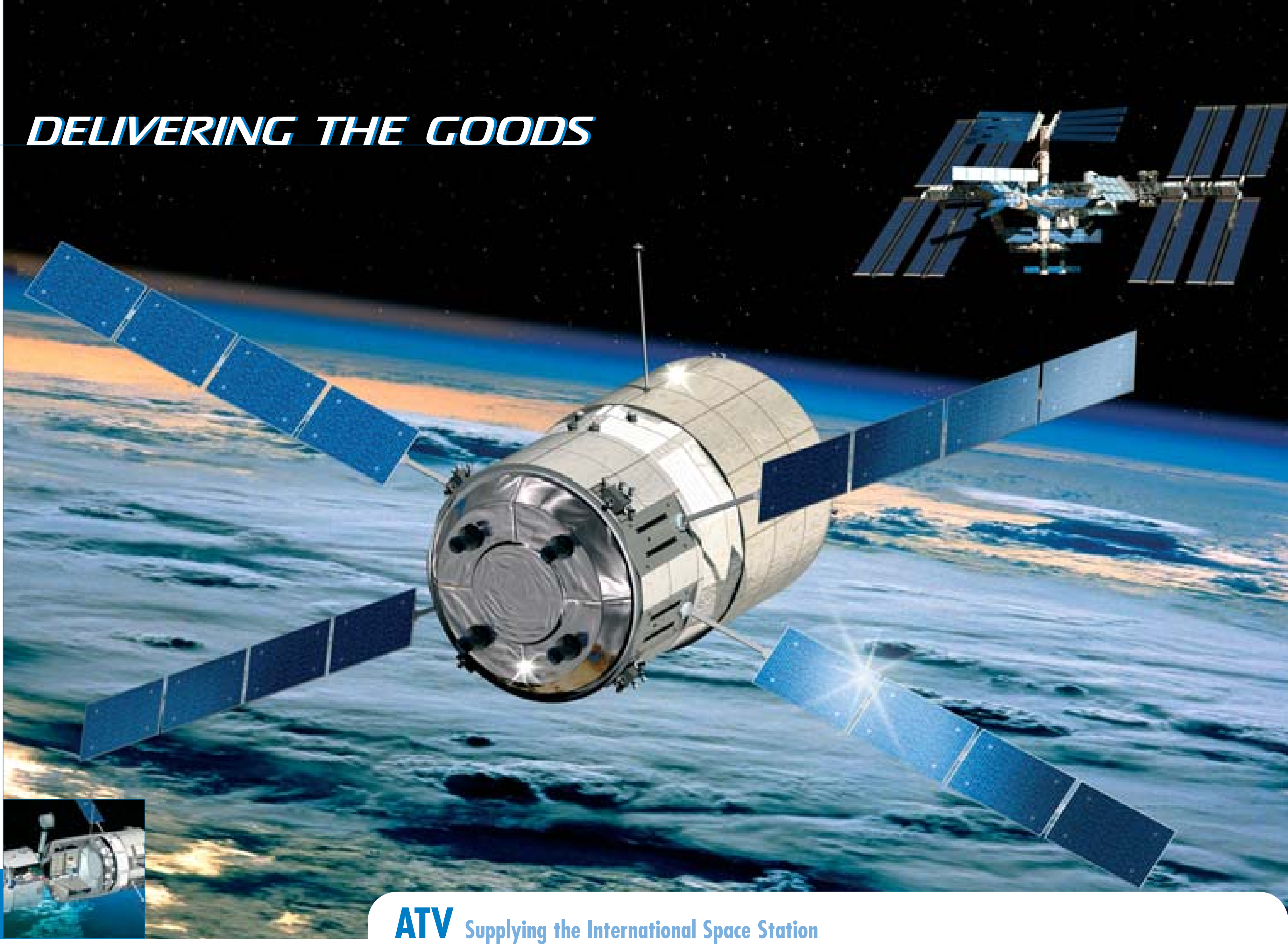
Experiments will be performed in various multi-user facilities, equipped with standardised connections and services. Europe offers, in particular, access to the Fluid Science Laboratory, Biolab, European Physiology Modules, Material Science Laboratory and European Drawer Rack (EDR). EDR will house self-standing experiment modules from any field.

The ISS is also ideally suited as an Education Platform in space, building on its wide range of scientific activities, its high public visibility and Astronauts who can act as teachers.

The Brand ISS, which represents high-quality science and innovation at the service of Mankind, offers opportunities for sponsorship, merchandising, advertisement and product placement.

Left & right: NASA

DELIVERING THE GOODS



The International Space Station (ISS) is like an island in space. Everything the giant structure and its inhabitants require has to be shipped in – air, food, water, fuel, spare parts and scientific equipment. Since it is continuously circling the Earth 400 km high, deliveries are far from simple. Specialised spacecraft capable of carrying tonnes of different cargoes have to be built and launched every few months.

At present, almost all of the Station's needs are satisfied by Russia's small automated Progress freighters or reusable modules toted inside the US Space Shuttle. However, as the Station crew grows from three to six or seven, and the time devoted to scientific research increases, more and more equipment and supplies will be required. This is where ESA's robotic Automated Transfer Vehicle (ATV) will play a key role.

ATV's main purpose is to transport up to 7.5 tonnes of cargo each time to the ISS. Launched by Europe's own Ariane-5 rocket from Kourou in French Guiana, it first flies into an orbit 300 km above Earth. After Ariane-5 has let go, ATV's four X-shaped solar wings fold out to provide electricity and the sophisticated onboard navigation system begins to steer it towards the Station. After three days, ATV edges towards its target at walking pace guided by lasers and automatically docks. If ATV's computer or the watching astronauts see any problems during the final approach, they can command it to back away. After all, connecting two space vehicles totalling several hundred tonnes and travelling at 28 000 km/h is not to be taken lightly!

The manifest will vary with each mission. It may include up to 5.5 tonnes of dry cargo stored in racks inside the pressurised compartment. Astronauts will simply float inside to unload the precious supplies, including parcels of fresh food, mail and family videotapes. Other essentials include water (up to 840 kg), air (up to 100 kg) and propellant. Some fuel is pumped into the Station's tanks for attitude and orbit control. But most of it – up to 4.7 tonnes – is burned by ATV's own rocket engines to raise the Station's orbit to combat atmospheric drag. The air is very thin at that height but still thick enough to pull the Station down by 2 km every week.

After about 6 months, ATV is turned into a waste disposal vehicle for the ISS. Loaded with up to 6.5 tonnes of rubbish, ATV separates and fire its engines to head back down and be incinerated by its fiery passage into the atmosphere.

Depending on the Station's operational lifetime, ESA will build about seven ATVs. The first, named 'Jules Verne' in honour of the 19th-century visionary author, will fly in 2005. Others will follow every year or so.

First Launch:
2005 on Ariane-5 from Kourou

Mass:
20 750 kg (7500 kg cargo)

Lifetime:
up to 6 months

Far left: unloading the precious supplies.
Right: its job done, ATV burns up in the atmosphere.
All illustrations ESA/D. Ducros

FINDING OUR WAY

Launch:
30 satellites 2005-2008

Mass:
650 kg

Lifetime:
15 years each satellite

Illustrations ESA/J. Huart

The world's aircraft and ships already rely heavily on satellite navigation. Yet there is still only one satellite navigation system available for civilian use. That will change, however, as Europe's independent Galileo system comes on line. More accurate and reliable than America's current military Global Positioning System (GPS), Galileo will open up a host of new commercial services, including traffic management, improved land usage and greater security – to name but a few. The commercial benefits for Europe could be enormous, amounting to an estimated 10 billion Euros in equipment and services every year, plus the creation of 100 000 highly skilled jobs.

Galileo will consist of 30 satellites spread evenly around three circular orbits at a height of 24 000 km, and a worldwide network of ground stations. Launches will begin in 2005 for the system to be fully operational in 2008. Anyone with a small handheld receiver anywhere on Earth will receive signals from at least three satellites to find their position to within a few metres. Users will also be able to synchronise their watches with the atomic clocks – some of the most accurate in the world – on the satellites. Certified time-stamping of the billions of banking transactions performed electronically ever day will reduce illegal activity.

The satellite constellation and ground network is being designed for greater positioning accuracy than GPS, including areas such as northern Europe where GPS coverage is patchy. Galileo's reliability and accuracy will be good enough even for 'safety-of-life' applications, such as aircraft landing and navigation in crowded shipping lanes, where there is no margin for error. GPS is built for and run by the US military, but Galileo's civil control means that it can be turned off only in the direst emergency.

Galileo's several levels of service will cater to different customers. The 'open service' will be free to all of us, whereas the 'commercial service' will be encrypted for paid access. It is expected that commercial providers will develop numerous new applications. For example, we could ask our car receiver to direct us to the nearest cinema showing a specific film. Police and other emergency services need to know where their deployed forces are at all times in order to respond more efficiently during crises. Rescue beacons triggered anywhere on Earth will be pinpointed almost immediately to within a few metres, and the authorities automatically alerted.

Galileo's cost compares with that of building 150 km of semi-urban motorway. For every Euro spent on Galileo, we expect a return of more than four Euros over the next 20 years. So great are the potential benefits that ESA and the European Union completed formal approval of the project in 2002. A Joint Undertaking is encouraging public-private participation, with the private sector funding most of the satellites and then operating the system once it is complete.

By 2010, satellite navigation could be having as great an impact on our lives as mobile phones or the internet.

FEELING THE EARTH'S BUMPS

The height of a mountain is usually measured as its height above sea level. But 'sea level' is not the same everywhere or at all times. So how can we be sure that heights measured at different places and times are comparable? We cannot monitor changes on the Earth if we have no standard starting point.

ESA will launch GOCE, the Gravity Field and Steady-State Ocean Circulation Explorer Mission, to address this problem. GOCE will measure Earth's gravity to unprecedented accuracy, on every 100 square kilometres of the surface. And because local gravity depends on the shape and make-up of the Earth's crust and mantle, the measurements will reveal a wealth of new information about how our planet is built under our feet.

And that's not all. If the whole Earth were covered by one calm, still ocean, the surface would not be perfectly smooth and regular. The lumpy gravity would create valleys and hills, with the deepest trough being nearly 200 m below the highest peak. The surface shape of this imaginary ocean is called the 'geoid' and it provides a much more accurate reference for height measurements than the ever-changing real sea level. This idea in itself is not new, but GOCE will measure the shape of the geoid to within 1 cm. Measuring sea-level changes, ocean circulation and ice movement, for example, needs this accurate geoid as a starting point.

To take such accurate measurements, GOCE needs to be acutely aware of its own position and movements in space. To cut down its own wobbles, it is symmetrical and contains no moving parts. GOCE will measure its own position in space accurately by taking readings from the GPS global positioning satellites and reflecting a laser beam back to a ground station. But how does it actually measure the gravity? GOCE has three sets of balances – like old-fashioned scales – each with weights on the ends of the 50 cm-long arms. If gravity is the same everywhere, it pulls equally on the weights. If not, it tips the balance and GOCE measures the tiny difference very carefully.

Most importantly, GOCE will reveal how the oceans circulate deep down. By comparing the height of the real oceans with the geoid, we can work out where deep waters are moving. Circulating warm and cold water in the oceans is the main highway for heat moving around the world, driving our weather and climate.

GOCE will also uncover the shape of the Earth's surface under the polar ice sheets and hence tell us the thickness and shape of the ice itself. And with the most-accurate geoid ever, we can measure the global changes in sea level, one of the most startling signs of climate change.

GOCE is the first Earth Explorer Core mission in ESA's Living Planet programme, which will establish Europe as a major authority on global environmental issues. These core missions are responding directly to specific areas of public concern and are selected after widespread consultation. GOCE is clearly a top priority for Europe's environmental and space scientists.

Launch:
February 2006

Mass:
1200 kg

Lifetime:
20 months

Far left: magnified view of the lumps and bumps in Earth's gravity.
Other illustrations ESA/P. Carril

A NEW PATH TO SPACE

VEGA A Small Package with a Powerful Punch

Launch:
first flight 2006 from Kourou

Mass:
132 t at liftoff

All artwork ESA/J. Huart

On the whole, satellites are becoming bigger and heavier – and, as a consequence, so are the rockets needed to get them into space. But there is also an opposite trend. Satellites doing some types of jobs, especially Earth observation and scientific missions, have been shrinking. This is mainly because of advances in technology allowing smaller scientific instruments and satellite systems, and the need to cut costs.

Launching a small satellite on a heavy launcher, such as Ariane-5, can be a problem: a solo launch is too expensive, so it must wait for a piggyback ride with a suitable large satellite or several other small ones with the same destinations. Alternatively, it can be lofted by a small rocket. At present, however, Europe does not have one of its own. To fill this gap, ESA is developing Vega, a small launcher capable of sending individual satellites weighing as little as 300 kg and no more than 2500 kg into a variety of orbits.

Italy first proposed a small European launcher in 1998. Now seven countries are contributing to its development under the ESA umbrella. To save costs and maximise efficiency, Vega is reusing existing Ariane-5 technology wherever possible. However, a new high-performance motor using solid propellant is under development specifically for Vega. In turn, this new motor is expected to help an improved Ariane-5 take even larger satellites into space.

Vega will carry satellites for a wide variety of applications into orbits at altitudes of 300-1500 km, blasting off from Europe's launch site near the equator in Kourou, French Guiana. A typical Earth-observation satellite weighing 1500 kg may need an orbit 700 km high and flying over Earth's poles. Vega can oblige. It will also launch small SMART satellites that ESA is building to test new technologies before they are flown on expensive science missions.

For communications, constellations of small satellites in low orbit dedicated to data transmission or 'store and forward' services typically weigh no more than a few hundred kilogrammes per satellite. Vega could deliver two or three at a time. Even constellations of telecom satellites may call on Vega to launch single replacements quickly.

Initially, Vega is expected to launch three or four satellites a year, rising to five or six once the service is established. Like the Ariane family, Vega will be marketed by a commercial organisation such as Arianespace when it begins routine production. The plan is to attract customers by being at least 15% cheaper than competitors.

TASTING THE DAMP, SALTY EARTH

Launch:
February 2007

Mass:
600 kg (300 kg payload)

Lifetime:
3 years

Our climate and weather depend largely on the movement of water and heat between the land, oceans and atmosphere. Clouds drop rain on the land, where it is used by plants and animals, runs into rivers and oceans, and eventually evaporates back to the atmosphere. The amount of moisture in the soil is a key ingredient, yet it has never been measured over most of the world.

All that will change, however, with the launch of SMOS – the Soil Moisture and Ocean Salinity satellite. SMOS will provide much-needed new data to feed into climate calculations and will contribute greatly to understanding climate change.

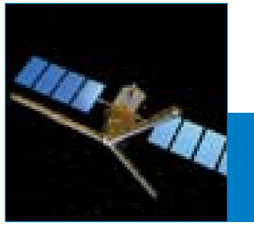
SMOS will measure the natural microwaves coming from the Earth's surface. A mixture of soil and water radiates particular microwaves very strongly, so SMOS can measure the moisture content of the top few centimetres of soil.

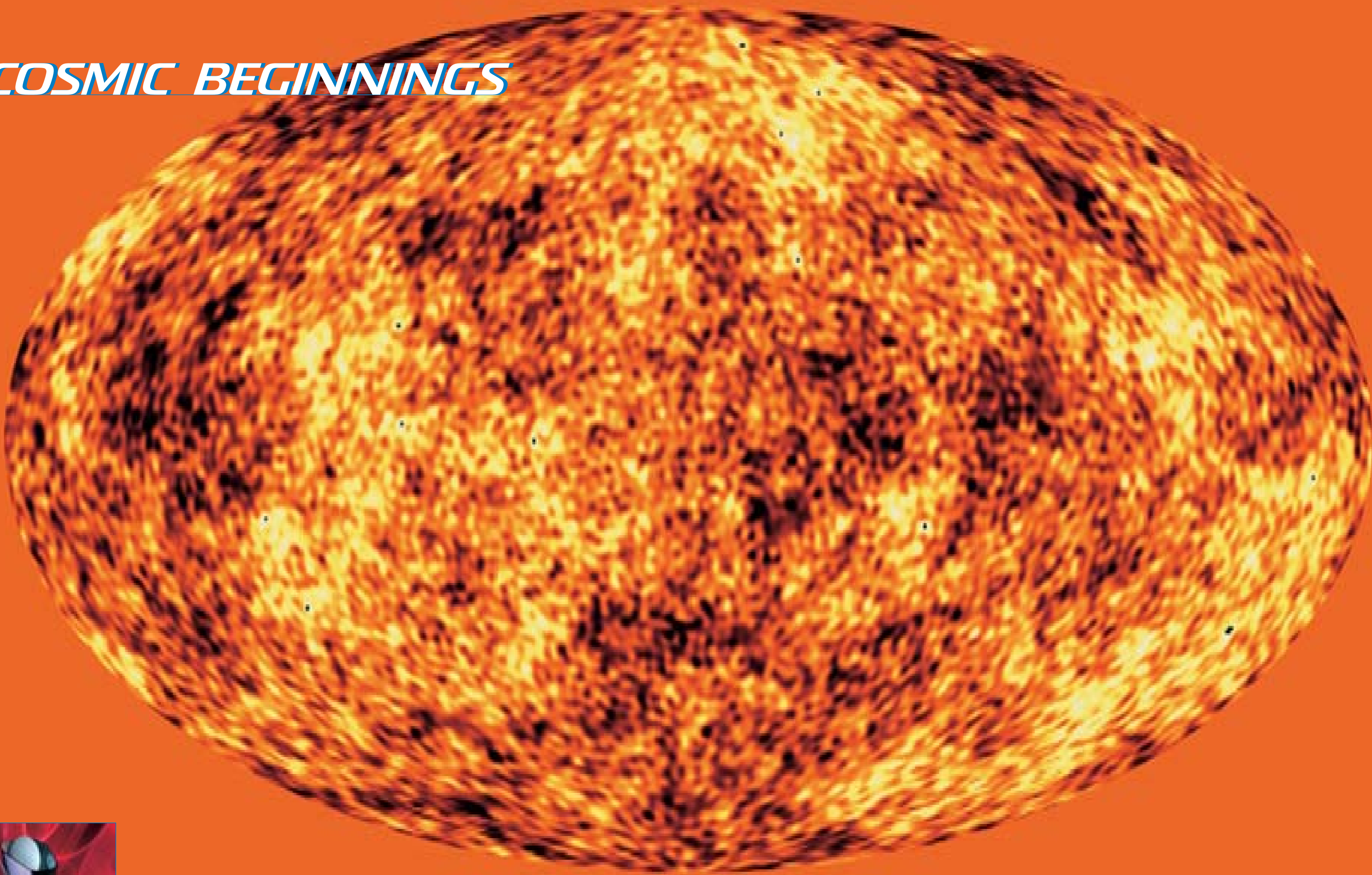
Over water, the same measurements will reveal how salty the sea is, which is just as important for understanding climate and weather. For example, the saltiness of surface water increases when moisture evaporates into the atmosphere, but falls when fresher water flows in, perhaps from rain, ocean currents or rivers. Saltier water is heavier, so salinity affects how water moves from the surface to the deep ocean. It is a major force behind ocean currents, which transport not only water but also heat across the globe. The Gulf Stream keeps Europe warm during the winter by transporting warm surface water from the Caribbean. As it moves north, the water cools and becomes saltier through evaporation. When it becomes heavy enough it sinks and travels back in the deep ocean to the equator where it re-warms, becomes less salty and rises again.

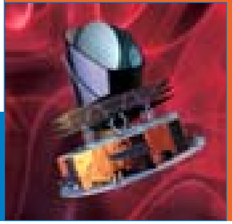
Salinity also affects the oceans' capacity to absorb carbon dioxide, a greenhouse gas. Because we know little of the ocean's saltiness, our computer calculations are poor at predicting El Niño, an extreme weather event in the Pacific triggered when warm waters move in to overlie cold waters off the coast of Peru. El Niño brings devastating floods to the Americas but droughts on the other side of the Pacific.

SMOS will measure the soil moisture in 50x50 km blocks with high accuracy over the whole world every three days. Salinity changes more slowly, so that will be measured in 200x200 km blocks at least once a month.

As the second Earth Explorer Opportunity mission in ESA's Living Planet programme, SMOS is a relatively small, low-cost satellite that will nonetheless use advanced technology, based on techniques originally developed for radio astronomy, to measure Earth's microwave radiation. Like other Earth Explorer Opportunity missions, it is being developed quickly in response to an area of immediate environmental concern.







Planck Launch:
February 2007 (with Herschel) on Ariane-5 from Kourou

Planck Mass:
~1500 kg

Planck Lifetime:
5 years

Left: a taste of how the sky will look to Planck.

Where does the study of the Universe lead? Usually to the biggest questions of all: how did it all begin and how will it all end? To answer these questions, we must track down the origins of not only celestial objects but of the Universe itself.

Almost all stars are housed in vast collections known as galaxies. Yet how stars and galaxies form is not yet fully understood. Certainly, astronomers have narrowed down the sites in our own Galaxy where stars form, but seeing the detail is the next step. Wrapped up in this detail is how planets form around stars. If astronomers could see this taking place, perhaps the mysteries of our own Earth's formation could be partly revealed.

The first stars themselves are, as yet, an undiscovered population, as are the very first galaxies. But, at ESA, the search is on for these elusive celestial ancestors.

What about the origin of the Universe itself? If human eyes could see microwaves, the night sky would glow with the very first light ever released into space. It was given out by the Big Bang – the seething fireball in which the Universe was created. Collecting this first light reveals not only the origin of the Universe but, amazingly, the answers about how it will end.

From the beginning of time, the fate of the Universe was pre-ordained by the amount of matter and energy it contained. Reading the fingerprints this has left on the very first light will tell us whether the Universe will expand forever or collapse in on itself, tens of billions of years from now.

Ironically, studying the Universe on its largest scales provides some of the deepest insight into physics on the smallest scale. At the beginning of the 21st century, ESA is providing access to the biggest science laboratory ever: the Universe!

Planck How Did it All Begin?

Telescopes show us that the Universe is expanding wherever we look. So will it grow forever until our sky empties of stars? And was there a time before the 'Big Bang' when everything was scrunched up into a tiny speck? If we could look through a window in time to the new-born Universe, then perhaps we could find the answers. ESA's Planck satellite plans to do just that.

We are used to a cold, dark Universe but for the first 300 000 years it was so hot and dense that light could not break free of matter. Then, when it had cooled to 3000°C, the first atoms formed and light was free to travel throughout the Universe for the first time. That 'first light' is still detectable today as a faint background glow – it was discovered in 1964. Of course, it has cooled in the last 15 billion years, from 3000°C to –270°C: a mere 2.7°C above 'absolute zero', the lowest temperature possible.

This Cosmic Microwave Background lights up the whole sky, but there are tiny differences from place to place – as small as one part in a million. These variations are a gold mine of

Herschel Launch:
February 2007 (with Planck)
on Ariane-5 from Kourou

Herschel Mass:
~3000 kg

Herschel Operational Lifetime:
3 years

Left: the Orion nebula star-nursery. Infrared light unveils stars hidden by the dust seen in normal light. (NASA/ESA/HST/NICMOS)
Right: thick clouds of cool dust may harbour forming stars. (ESA/ISOCAM)

information. They are nothing less than the fingerprints left by matter as it let go of light. At that time, when the Universe was 50 times younger, it already carried the seeds that eventually formed the huge structures – galaxies and clusters of galaxies – that we see today.

Planck's maps of this background will help to show what triggered the Big Bang and exactly how long ago it happened. They will tell us how dense the Universe is and if it is full of otherwise invisible 'dark matter' that may one day cause everything to collapse again. Planck's detectors have to be very cold so that their own warmth does not swamp the frigid signal from the sky. All will be cooled to –253°C or less – and some will reach an amazing one-tenth of a degree above absolute zero.

Herschel Before the Galaxies

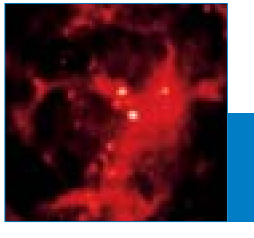
Beyond the realm of visible galaxies, at the distant edges of the known Universe, lie clouds of gas and dust with a story to tell about the early history of the Universe before galaxies were born. At some point, the clouds condensed, probably to form stars first and galaxies with intense starbursts later. Herschel will be the first space mission to see these starbursts in action.

The starbursts have not been observed in detail before because no telescope has been able to gather enough light of the type emitted by the gas and dust. Herschel will see both with unprecedented sensitivity. No Earth-bound telescope could ever do this because Earth's own atmosphere blocks most of the signals, and its own radiation swamps those that do penetrate.

With a diameter of 3.5 m, Herschel's mirror will focus the light on to three scientific instruments kept very cold inside a giant thermos bottle of liquid helium so that their own heat does not mask the very signals they are trying to measure. Some astronomical objects are so cold that they are close to absolute zero, emitting very weak signals. Herschel will open up a view of dusty regions of the Universe invisible to other telescopes because infrared light travels through dust, while other light is blocked. This window through the dust and the ability to see the dust itself equips Herschel to witness stars, planets and galaxies forming.

Herschel will see dust illuminated by the first big starbursts in the history of the Universe – the first frenetic periods of stars being created. It should also pick out the moment of star birth itself, whether in dust and gas clouds at the edge of the Universe or in galaxies closer to home. Stars are born as clouds of dust and gas collapse under their own gravity, a process that by its nature is shrouded in dust. After the birth, planets begin to condense out of the remnants of the cloud. When a new solar system is fully formed, little is left of the original planetary nebula except perhaps some rings of dust and comets, primitive bodies that never condensed fully to form planets and hence retain the purest fingerprints of the original nebula.

With its unique eye in the sky, Herschel is equipped to study all of this in action.



MAPPING THE WINDS OF CHANGE

AEOLUS ‘Seeing’ the Whole Planet’s Winds Will Improve Weather Forecasting

Predicting the weather is a basic need for the whole world. Weather forecasting will improve around the globe when Europe's Aeolus satellite goes into orbit. For the first time, weather forecasters and climate scientists will 'see' the winds throughout the entire atmosphere. Accurate wind speeds are essential for computing short- and medium-term weather forecasts, and for predicting climate change over timescales from a few years to centuries.

At present, satellites measure wind speeds indirectly from cloud movements or by probing the atmosphere's temperatures at different heights. Accurate, direct measurements are made by weather stations on the ground or by balloons that take instruments high into the atmosphere and radio back their data. Even though these radiosondes set off several times a day from more than 500 sites worldwide, they are a poor substitute for the global coverage from a satellite. Remote regions far from other stations are poorly served, and the ground methods cannot measure wind speeds at different heights.

Aeolus will shine a narrow laser beam at the atmosphere and, like conventional radar, measure the changes in the light reflected back by particles and molecules carried along by the winds in the different layers of air. Blocks of atmosphere a few hundred metres across and up to a kilometre deep will be illuminated at any one time. Over 12 hours, Aeolus will paint a picture of wind speeds throughout the entire atmosphere from the ground up to heights of more than 20 km.

The measurements will be fed into the computer models to predict what will happen after a few days. A substantial improvement in weather forecasting is expected, especially in the southern hemisphere and tropics where today's monitoring is particularly patchy. Scientists also expect to understand climate change better, because winds influence the swapping of water (hence energy) between the oceans and atmosphere. Learning how this happens should unveil the forces behind climate change.

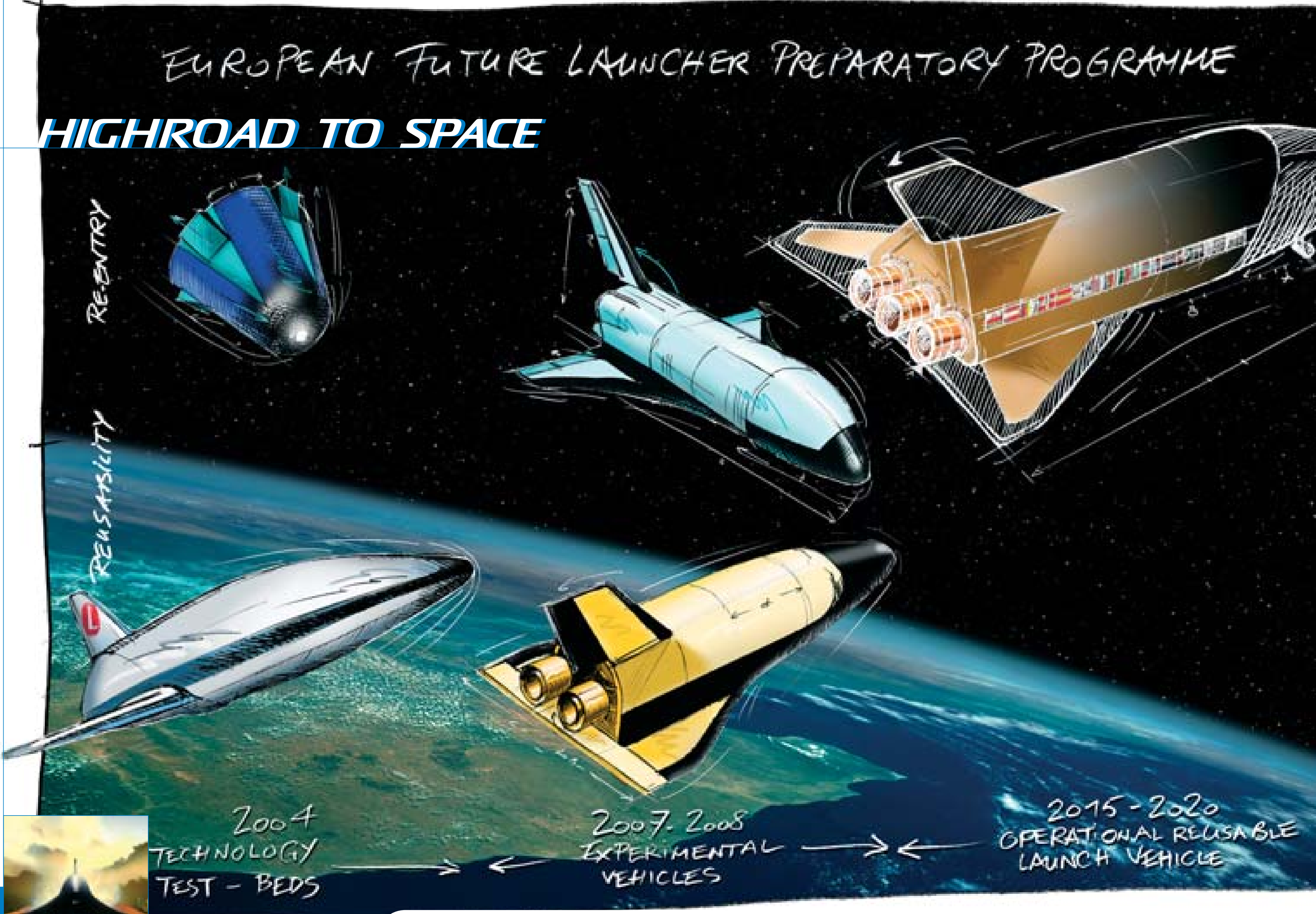
In particular, climatologists are eager to see what Aeolus can tell us about the dramatic El Niño weather event. Some years, shortly after Christmas, prevailing winds over the tropics in the Pacific change direction and warm waters move in to overlie the cold waters normally found off the coast of Peru. El Niño brings floods to the western coast of South America, which is normally dry, and drought to Indonesia and Australia, which are normally wet. The change in wind direction high in the tropical atmosphere can also trigger weather extremes much further afield. Until now, such winds have been sketchily measured, but Aeolus will detect the changes in wind speed that herald El Niño.

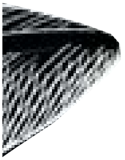
Aeolus is the second Earth Explorer Core mission in ESA's Living Planet programme, which will establish Europe as a major authority on global environmental issues. These core missions are responding directly to specific areas of public concern and are selected after widespread consultation. Aeolus is a high priority for Europe's environmental and space scientists.

Launch:
October 2007

Mass:
~1500 kg

Lifetime:
3 years


EUROPEAN FUTURE LAUNCHER PREPARATORY PROGRAMME
HIGHROAD TO SPACE
RE-ENTRY
REUSABILITY
2004
TECHNOLOGY
TEST - BEDS
2007. 2008
EXPERIMENTAL
VEHICLES
2015 - 2020
OPERATIONAL REUSABLE
LAUNCH VEHICLE



Getting into space is not easy – or cheap. A major stumbling block to space tourism and commercial spaceflight is the high price of getting off the ground. Today, carrying a single kilogram into orbit typically costs around 20 000 Euros. With people aboard, the cost literally rockets because of the need for complex life support and back-up safety systems. These are major barriers to opening up the final frontier.

To make space travel affordable in the same way that air travel is available to millions of people, we need a major effort to slash costs while increasing safety and reliability.

ESA has been working alongside national agencies and Europe's aerospace industry for many years to pinpoint and develop the technologies needed for 21st century space transportation. From 1994 to 2000, the Agency supported the Future European Space Transportation Investigations Programme (FESTIP), which led to the design of several reusable launch vehicle (RLV) concepts. This enabled engineers to study the difficult technical problems and the hardware required to turn them into reality.

Meanwhile, ESA gathered valuable data from the 1998 flight of its Atmospheric Reentry Demonstrator and collaborated with Germany to assist NASA in developing the X-38 prototype of the Crew Return Vehicle for the International Space Station. The Hermes spaceplane project in the early 1990s added considerable expertise.

Building on that FESTIP experience and on results from national programmes, ESA plans to begin its new Future Launcher Preparatory Programme (FLPP) in 2004. Under it, Europe is continuing to look at different launcher concepts, developing key technologies and carrying out test flights with experimental vehicles. Particular emphasis in the early stages is on reusable propulsion and advanced structures. Progress in these areas will allow ESA to down-select the preferred reusable launch vehicle system concept by 2006 and to complete comparative system studies of expendable and reusable concepts for the next-generation launcher by 2008.

Two-stage or multi-stage semi-reusable vehicles are within our current grasp, and they may be a step on the road to building fully reusable successors. A Two-Stage-To-Orbit design would typically involve a reusable, large spaceplane releasing a second, smaller reusable vehicle at high altitude to make its own way to orbit. The first stage would return to base for a fast turnaround, like an aircraft, before its next trip.

After further detailed studies of the most promising concepts and demonstration flights of experimental vehicles by the FLPP, a decision to proceed with the full development of the next-generation launcher could be taken around 2012. However, major advances will have to be made in many areas, including engines, guidance and navigation, and lightweight reusable structures, before this becomes a reality.

Cheap and reliable transport is the answer if we are ever to open up the Solar System.

USING SPACE ON EARTH

Ask anyone to think of profitable products generated from space exploration and the most likely response is 'the non-stick frying pan', followed by silence. In fact, Teflon was not invented as part of the space programme, but thousands of valuable space spinoffs are improving our lives.

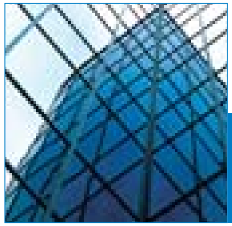
Each year, ESA invests around 250 million Euros in research and development. In order to encourage the wider use of technology developed within the European and Canadian space communities, ESA's Technology Transfer Programme (TTP) helps to usher innovative technology, systems and know-how into the wider, non-space world. Over a period of 12 years, remarkable results have been achieved. With the aid of the Spacelink Group of technology brokers, ESA has promoted more than 600 technologies developed by European space companies and universities. The companies have generated additional turnover totalling more than 200 million Euros. In addition, almost 2500 new jobs have been created and more than 25 new companies have been formed. As a result, many sectors, including health care, cars and transport, environmental protection and energy have profited from space technologies.

In medicine and health care, complex sensors and instruments developed to probe the Universe are being adapted to assist doctors and biomedical researchers. Advanced data-processing methods are helping to analyse the increasing amounts of information processed by biological researchers. European space observatories such as XMM-Newton are pioneering the exploration of the high-energy Universe, but advances in X-ray astronomy also offer powerful new weapons in the fight against cancer.

Engineers at ESA's science, technology and research centre (ESTEC) in The Netherlands have developed a new X-ray camera that could allow on-the-spot diagnoses and pinpoint cancerous areas for surgeons. After injecting a patient with a tracer that emits X-rays, a microchip in the small camera can photograph cancerous tissue. By relaying the live images to a TV screen, the camera is an invaluable tool for surgeons during operations.

Software developed to detect weak X-ray signals against background noise is also helping doctors to diagnose skin cancer at an early stage. Using the software package, a computer can spot fine differences in the colour of a highly magnified section of skin, leading to recognition of the irregular cell growth associated with skin melanoma.

Shape-memory alloys developed by ESA for lightweight, temperature-controlled actuators are finding many applications. Like elastic bands, these extraordinary metals can be stretched and bent but eventually return to their original shape. In the early 1990s, Tony Anson, then a researcher at Brunel University in the UK, realised that they could help to repair broken bones. After obtaining support from ESA's TTP to help develop commercial products, Anson set up a company specialising in using these alloys in medicine. The company developed many new products, including an orthodontic spring to control the movement of teeth and devices that can be implanted in the body using a catheter and a minimum of invasion. In 2001, Anson Medical was acquired by a major UK company for 27 million Euros.




F-Cell
S-FC 4410

Space-suit technology also has down-to-earth applications. Sensors to monitor an astronaut's movements are now being adapted to prevent cot deaths. The Mamagoose pyjamas, developed by the Belgian company Verhaert Design and Development in conjunction with the University of Brussels, have five sensors built into the cloth. By monitoring the heart beat and breathing, the pyjamas provide a new sense of security to the parents of sleeping babies.

Another type of space sensor, the electronic nose, is finding numerous applications in everyday life. Developed to detect gas leaks on spacecraft, it recognises a huge range of smells and odours, providing early warning of danger or infection. Its ability to detect pathogenic bacteria, fungi and moulds means it is being introduced into the medical, environmental control and food industries to seek out disease and test the freshness of what we eat.

Although cars might not travel as fast as spacecraft, ESA technology is having a major effect on the car industry. For example, fuel cells developed for spacecraft are seen by many as the power source of the future for road vehicles. Able to generate electricity from the simple chemical reaction of hydrogen and oxygen, fuel cells have no moving parts and their only waste product is water. When German aerospace company Dornier became part of DaimlerChrysler, its fuel-cell technology became available for cars, and from then on progress was rapid. In late 2000, two new fuel-cell vehicles were announced, the Mercedes-Benz A-class and the Jeep Commander 2. Both are quiet and environmentally friendly, with methanol-based fuel-cell systems occupying no more space than a conventional engine. Such is the promise of this technology that DaimlerChrysler intends to invest over one billion Euros to develop it for mass production.

A host of other technologies developed for space have also spun-off to vehicles. Examples include windscreens used as antennas; transparent heating systems for windscreens; navigation satellites to provide route directions; and micro-coating of metals for headlamps. Special composite materials, plastic panelling, resins and carbon fibres used on spacecraft are now available for car bodies. Fabrics and pyrotechnic devices from space are being used in airbags and safety belts. Even technologies developed for rocket propulsion are adapted by the car industry – seals for fuel pumps, engine cooling tubes, shape-memory alloys to optimise the performance of catalytic converters, microfibre/ceramic insulation material for exhaust silencers, and vibration-damping devices.

The adventure of space offers entrepreneurs expanding opportunities to create new and innovative businesses. ESA, supported by the European Commission, is setting up an independent European Network of Business Incubators to reduce the time taken in transferring space technologies to the marketplace. The European Space Incubator near ESTEC will provide operational services and expertise, including finance, hands-on assistance and engineering support.

The TTP future looks bright!

Left: this Mercedes-Benz A-class car is powered by a fuel cell. (DaimlerChrysler)

What is ESA?

The European Space Agency is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the people of Europe.

ESA has 15 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Canada has special status and participates in some projects under a cooperation agreement. By coordinating the financial and intellectual resources of its members, ESA can undertake programmes and activities far beyond the scope of any single European country. ESA is an entirely independent organisation, although it maintains close ties with the European Union, with whom it shares a joint space strategy.

ESA's job is to draw up the European space plan and carry it through. The Agency's projects are designed to find out more about the Earth, its immediate space environment, the Solar System and the Universe, as well as to develop satellite-based technologies and promote European industries. ESA also works closely with space organisations outside Europe to share the benefits of space with the whole of mankind.

ESA has its headquarters in Paris and it is here that future projects are decided upon. However, ESA also has centres throughout Europe, each with different responsibilities:

- ESTEC, the European Space Research and Technology Centre, is the design hub for most ESA spacecraft. It is situated in Noordwijk, the Netherlands.
- ESOC, the European Space Operations Centre, is responsible for controlling ESA satellites in orbit, from Darmstadt, Germany.
- EAC, the European Astronaut Centre, trains astronauts for missions, in Cologne, Germany.
- ESRIN, the European Space Research Institute, is situated in Frascati, near Rome in Italy. Its responsibilities include collecting, storing and distributing satellite data to ESA's partners and acting as the Agency's information technology centre.

In addition, ESA has liaison offices in the USA, Russia and Belgium, a launch base in French Guiana, and ground and tracking stations around the world, including Villafranca in Spain, Redu in Belgium, and Kiruna in Sweden.

ESA's mandatory activities (Science Programme and he general budget) are funded by a financial contribution from all the Member States, calculated in accordance with each country's gross national product. In addition, ESA conducts a number of optional programmes. Each country decides in which optional programme it wishes to participate and the amount of its contribution.

THE SPACE DIMENSION

THE EUROPEAN SPACE AGENCY

BR-190 November 2003

ISBN 92-9092-746-1
ISSN 0250-1589

Written by: Judy Redfearn, Peter Bond, Andrew Wilson

Edited by: Andrew Wilson, ESA Publications Division

Published by: ESA Publications Division, ESTEC, Noordwijk, The Netherlands

Designed by: Leigh Edwards

Price: €10

Illustrations provided principally by ESA and NASA