number 150 | May 2012

bulletin 150

→ space for europe

European Space Agency

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

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

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

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

The ESA headquarters are in Paris.

The major establishments of ESA are:

ESTEC, Noordwijk, Netherlands.

ESOC, Darmstadt, Germany.

ESRIN, Frascati, Italy.

ESAC, Madrid, Spain.

Chairman of the Council: D. Williams

Director General: J.-J. Dordain

←

On cover:
Celebrating *Bulletin* 150, here are a selection of covers, showing how the *Bulletin* has evolved from 1975 to present.

bulletin

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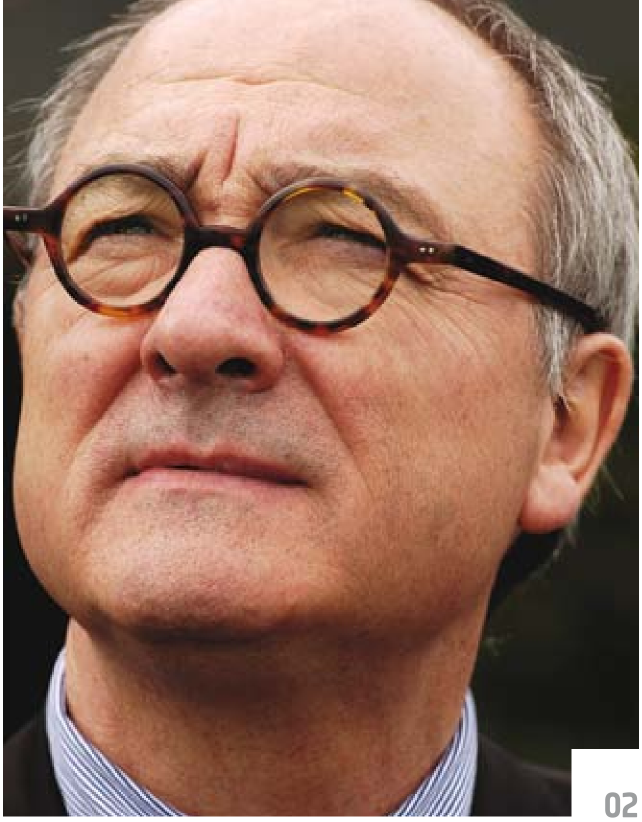

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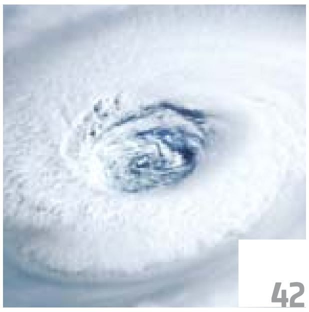

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Jean-Jacques Dordain
(I. Heine)

→ ESA BULLETIN: A WINDOW ON THE UNIVERSE

An introduction to the 150th issue

Jean-Jacques Dordain
ESA Director General, Paris, France

The 150th edition of the ESA *Bulletin* promises to be something special and it indeed deserves a special tribute.

The *Bulletin*, now published four times a year, is a window on the Universe: it portrays our activities almost day by day, and it lives because of the ESA specialists whose written contributions reach out to the international space community of decision-makers, industry, academics, students and the space-interested general public.

As well as a wide range of in-depth articles on various disciplines, from space science to telecommunications, from satellite navigation to Earth observation, from launchers to human spaceflight, from operations to technology, every issue provides an overview of ESA's ongoing programmes – a useful tool to keep abreast of the status of major space projects in our agency.

The *Bulletin* faithfully reports the many achievements that have crowned the history of European space activities in

If you wish to anticipate the world of 2024, read the *Bulletin*

the last 40 years, as well as a few of the obstacles we have encountered in an ever-changing world.

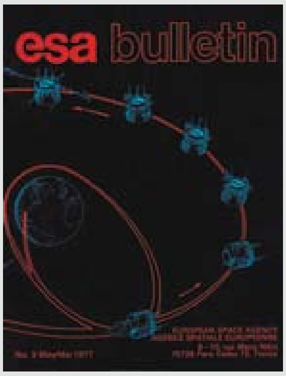
Through the *Bulletin*, ESA tells its great story, a history of pioneering success and technical excellence; the story of its staff and contractors who ‘make’ ESA, the story of a community of European scientists and engineers engaged in outstanding research, and the story of decision-makers and politicians struggling to make the best use of the resources allocated to space activities in Europe.

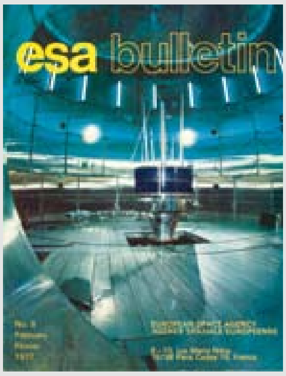
We are one of the few space agencies worldwide that operate across the entire field of play in space, making scientific discoveries, performing technical development and boosting industrial competitiveness, at the same time as enabling operational services that improve the lives of European citizens.

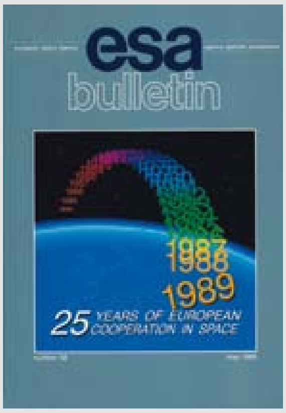
Since its issue No. 1 in 1975, the *Bulletin* has marked the most exciting milestones and has kept its readership informed of ESA’s developments.

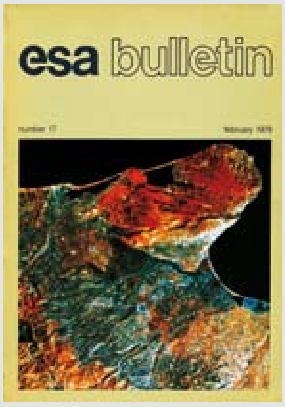
The circulation of the publication, which is free of charge, has increased from the original handful of copies to today’s 9900 copies, without forgetting that many more readers see the *Bulletin* on the Internet.

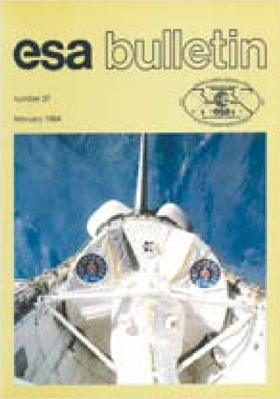
I will not be Director of ESA when the 200th issue is published in 2024, but I am sure that the ESA of 2024 will not be the same ESA we know today. Preparing the world of 2024 is what we are doing today at ESA, and I am sure that the world of 2024 will be different also thanks to what we are reporting today in the *Bulletin*. If you wish to anticipate the world of 2024, read the *Bulletin*.

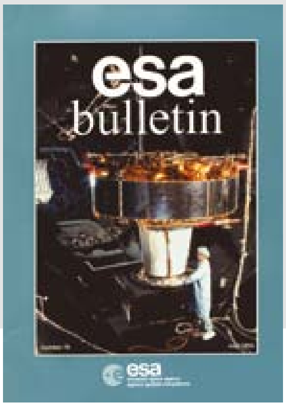






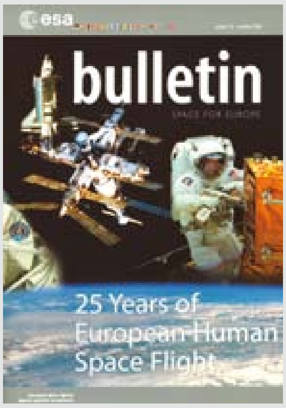






The agency of 2024 will have grown far beyond the 19 Member States that today make up its strength. By that time, space will have been recognised even more as one of the few sectors where Europe is both a world leader and a model: a leader in the commercial market, in technology and in the provision of services, and a model for using space to benefit the citizens of Europe and the world, and as a reliable partner in international cooperation.

However, I definitely count on reading that issue of the *Bulletin*. Most probably it will not be a printed document, but rather a virtual 'e-publication' that we download on our 3D holographic tablets. But no matter how it looks, I invite you not to miss any issue, because the *Bulletin* will, I am sure, continue to inspire, inform and be the lively 'reporter' of ESA life; because the *Bulletin* is a look into the future. ■



→ 150 issues online

About ESA Bulletin

The ESA Bulletin is the flagship magazine of the European Space Agency, published four times a year to report on ESA's activities and achievements. In addition to a wide range of articles, every issue provides an overview of the status of ESA's major space projects. It has been inspiring and informing the space interested public ever since it was first issued in 1975.

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To celebrate the 150th edition of the ESA *Bulletin*, we have created a special ESA App for iPhone and iPad, enabling you to browse ALL 150 issues, a treasure chest of space history at your fingertips.

The ESA *Bulletin* App is now released on the Apple Store, along with Version 4.0 of the ESA App. Download both for access to the complete range of information from ESA's online sources, making full use of the iPhone and iPad touch features.

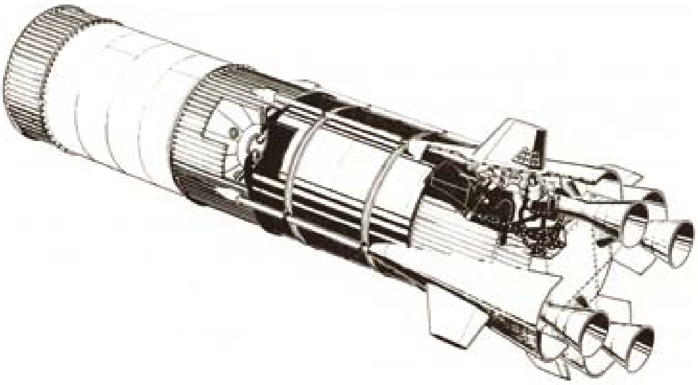
As well as watching videos or live programmes, and keeping up with events such as launches, dockings, press conferences or tweetups, Version 4.0 allows you to search the entire archive of ESA *Bulletins* directly on your mobile device... wherever you are.

The full archive of ESA *Bulletins* is also available at ESA's Publications web site, **www.esa.int/publications**.

These downloadable pdf files represent essential historical reference materials, as well as giving a fascinating look back through time!

→ FROM 1975...

ARIANE



Participating ESA Member States:
- Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland

Planned first test flight:
- Mid-1979

Etats membres participants:
- Allemagne, Belgique, Danemark, Espagne, France, Italie, Pays-Bas, Suède, Suisse

Premier vol d'essai:
- mi-1979

> “Through the *Bulletin*, ESA tells its great story”

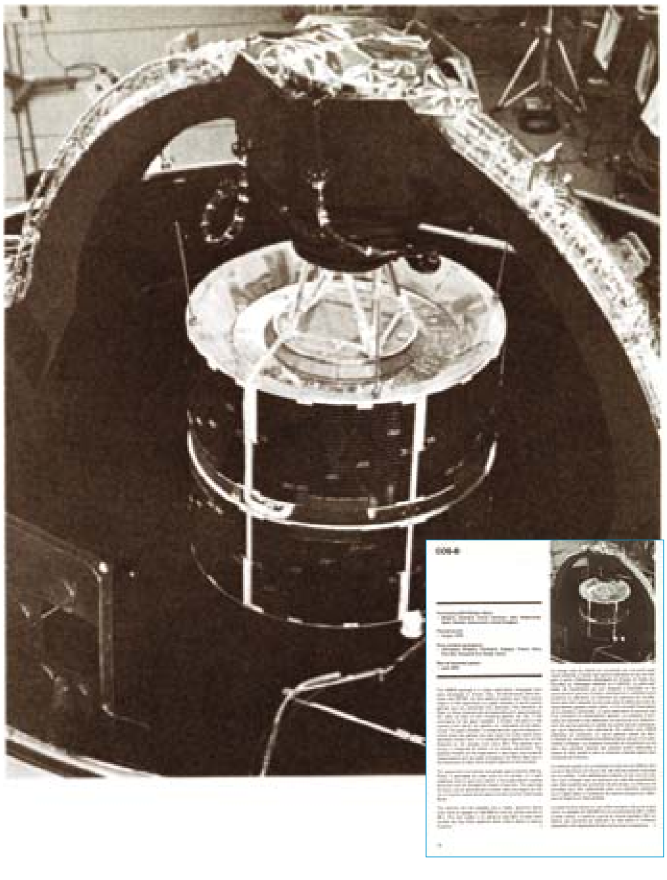
COS-B

Participating ESA Member States:
- Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland, United Kingdom

Planned launch:
- August 1975

Etats membres participants:
- Allemagne, Belgique, Danemark, Espagne, France, Italie, Pays-Bas, Royaume-Uni, Suède, Suisse

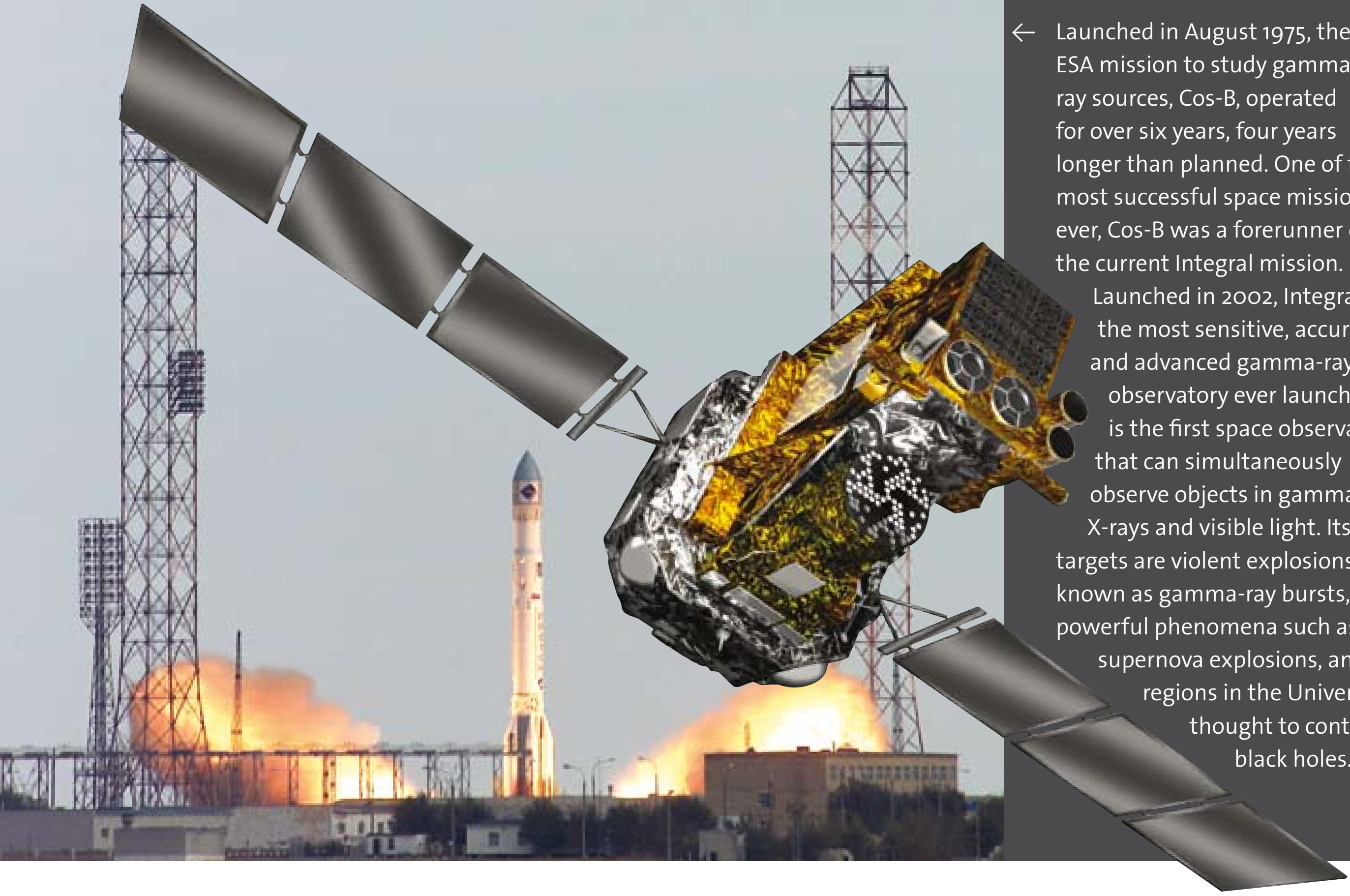
Date de lancement prévue:
- août 1975



...TO 2012 AND BEYOND

← Work on the first Ariane launcher began as early as 1974. On 24 December 1979, Ariane 1 blasted into space from Europe's Spaceport in Kourou, French Guiana. Europe's independent adventure in space had begun. Successive versions of Ariane have launched half of all the world's commercial satellites. Ariane 5 maintains this impressive record, making it one of the most reliable launchers in the world at an affordable price for Europe. ESA is preparing new launch systems to respond better to Europe's future needs and to stay at the forefront of new developments in space.

> "A history of pioneering success and technical excellence"



← Launched in August 1975, the first ESA mission to study gamma-ray sources, Cos-B, operated for over six years, four years longer than planned. One of the most successful space missions ever, Cos-B was a forerunner of the current Integral mission. Launched in 2002, Integral is the most sensitive, accurate and advanced gamma-ray observatory ever launched. It is the first space observatory that can simultaneously observe objects in gamma rays, X-rays and visible light. Its main targets are violent explosions known as gamma-ray bursts, powerful phenomena such as supernova explosions, and regions in the Universe thought to contain black holes.

→ FROM 1975...

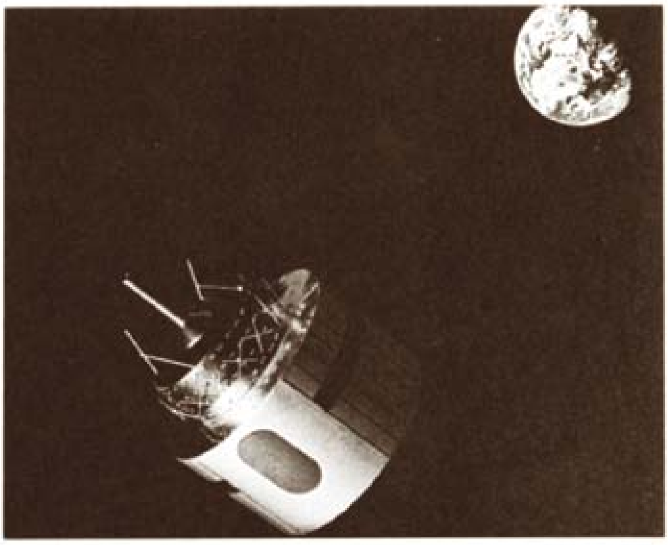
METEOSAT

Participating ESA Member States:
- Belgium, Denmark, France, Germany, Italy, Sweden, Switzerland, United Kingdom

Planned launch:
- April 1977

Etats membres participants:
- Allemagne, Belgique, Danemark, France, Italie, Royaume-Uni, Suède, Suisse

Date de lancement prévue:
- avril 1977



> **The Bulletin will continue to inspire and inform**

SPACELAB

Participating ESA States:
- Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Switzerland, United Kingdom (Member States) and Austria (Observer State)

Planned delivery to NASA:
- Mid-1979

Etats participants:
- Allemagne, Belgique, Danemark, Espagne, France, Italie, Pays-Bas, Royaume-Uni, Suisse (Etats membres); Autriche (Observateur)

Date de livraison à la NASA:
- mi-1979

...TO 2012 AND BEYOND

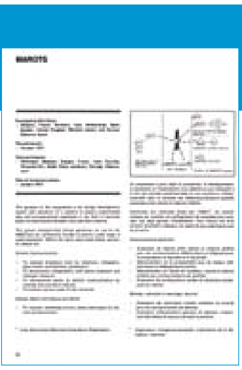
← For almost 30 years, ESA has been developing Europe's geostationary weather satellites. The success of the early Meteosats led to the creation of the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) in 1986. ESA and Eumetsat worked together on later satellites in the series, designed to deliver continuous weather images to European weather forecasters. This cooperation continues now on Meteosat Second Generation. Planned for 2015–25, Meteosat Third Generation will provide significant improvements over the current Meteosats and, together with increasing computer power, will undoubtedly take weather forecasting to the next level.

> “Marking the most exciting milestones”

← In August 1973, NASA and ESRO (now ESA) signed a Memorandum of Understanding to build a science laboratory for use on Space Shuttle flights. Called Spacelab, construction started in 1974 by German company MBB/ERNO. Spacelab components were used on 25 Shuttle flights up to 2000. The legacy of Spacelab lives on in the form of the Multipurpose Logistics Modules used to supply the International Space Station and other systems derived from it. These include the Harmony and Tranquility nodes, and particularly the European Columbus laboratory.

→ FROM 1975…

MAROTS

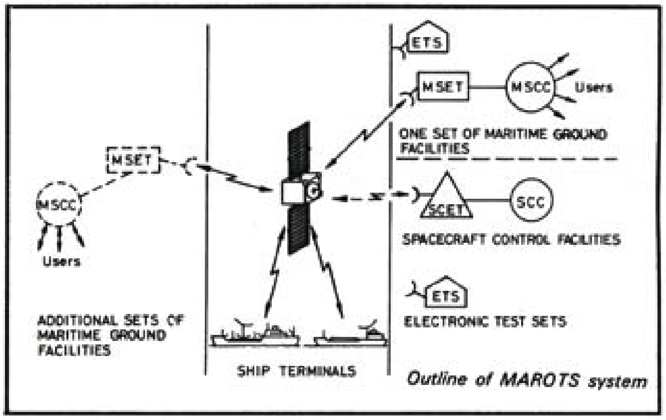


Participating ESA States:
- Belgium, France, Germany, Italy, Netherlands, Spain, Sweden, United Kingdom (Member States) and Norway (Observer State)

Planned launch:
- October 1977

Etats participants:
- Allemagne, Belgique, Espagne, France, Italie, Pays-Bas, Royaume-Uni, Suède (Etats membres); Norvège (Observateur)

Date de lancement prévue:
- octobre 1977



Outline of MAROTS system

> **The Bulletin is a look into the future**

AEROSAT

Participating ESA Member States:
- Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, United Kingdom

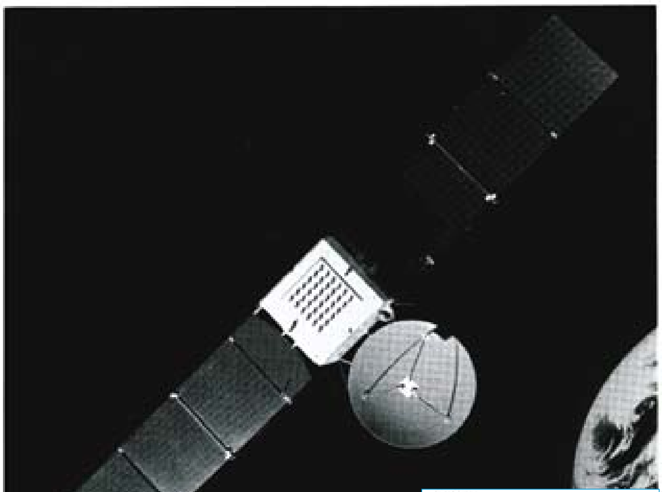
In partnership with:
- Canada, Comsat General, the US Federal Aviation Administration

Planned launches:
- First satellite : November 1978
- Second satellite : Early 1979

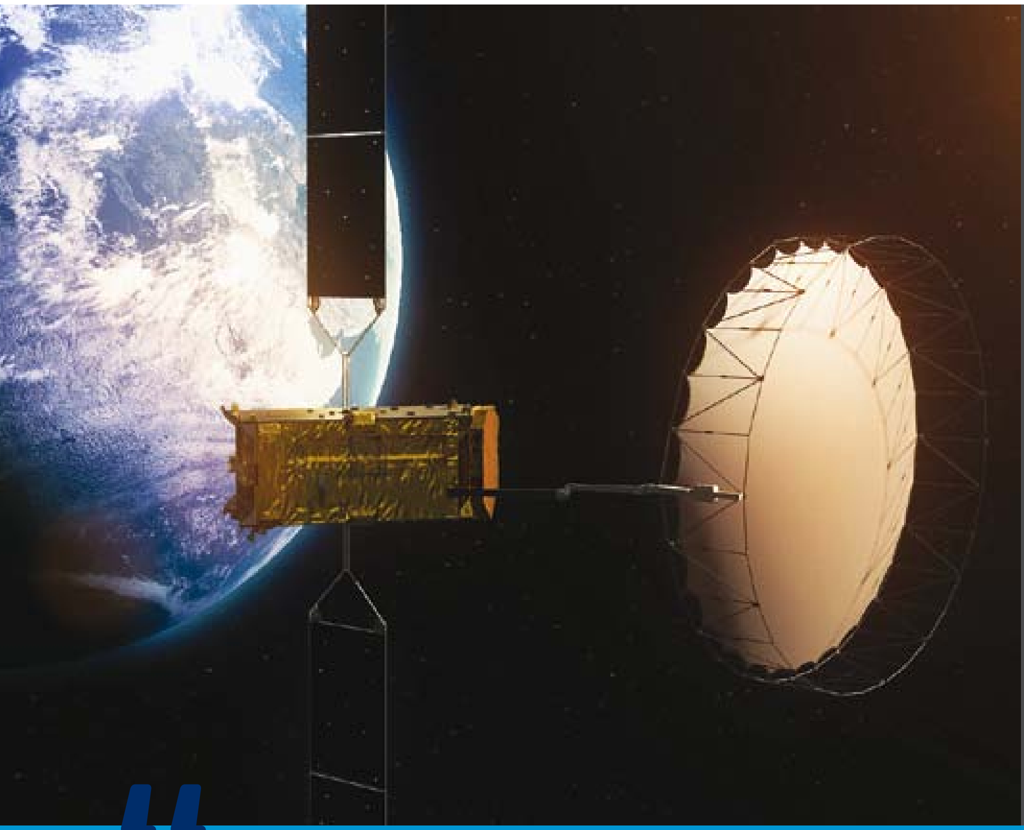
Etats membres participants:
- Allemagne, Belgique, Danemark, Espagne, France, Italie, Pays-Bas, Royaume-Uni, Suède

En coopération avec:
- Canada, Comsat General, Administration fédérale de l'Aviation (Etats-Unis)

Dates de lancement prévues:
- premier satellite : novembre 1978
- second satellite : début 1979



...TO 2012 AND BEYOND



← MAROTS (Maritime Orbital Test Satellite) was one of the ESRO programmes, along with Ariane and Spacelab, negotiated for the founding of ESA. Its design, and that of the experimental OTS satellite on which it was based, inspired the design of many subsequent satellites in Europe. Since 1975, ESA's Telecommunications Programme has contributed to a competitive European industry, through its many research and development activities. One example is Alphabus, extending Europe's telecommunication satellite range significantly beyond the capabilities of existing platforms, in response to an increased market demand for larger payloads for new broadband, broadcasting and mobile communications services.

> “What will the next 150 issues bring?”

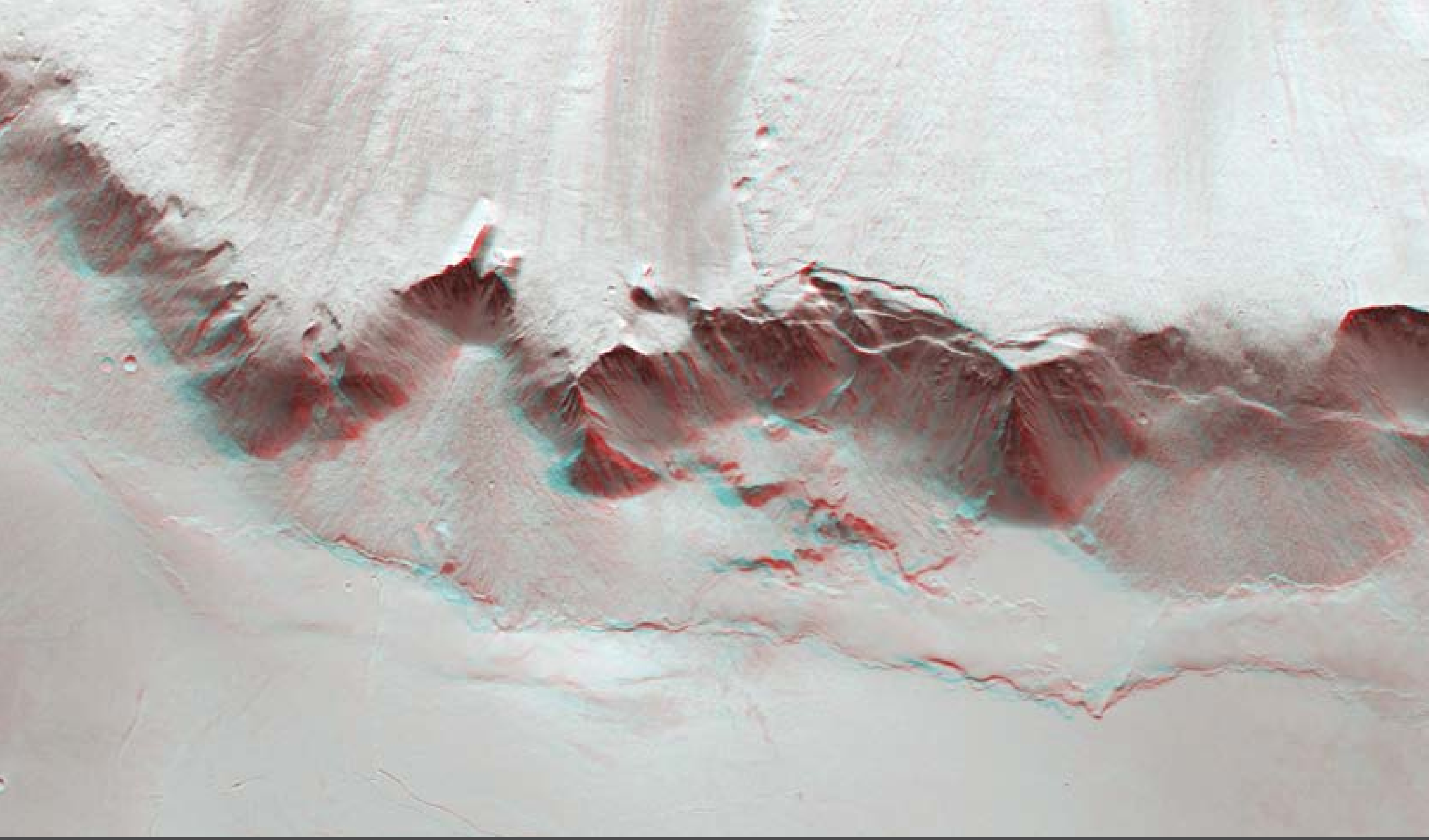
← Aerosat was first attempt to create an air traffic management system with a combination of navigation/positioning concepts and telecommunications. It was part of an agreement with the USA dating back to 1971, but economic and political problems meant the programme was eventually cancelled. Today, there is still the need for such a system. Over the last decade the aviation sector has seen tremendous growth, making Europe the densest air traffic space in the world. Iris is a new air-to-round communication system, the satellite-based solution for the Single European Sky ATM Research (SESAR) programme. By 2020 it will contribute to the modernisation of air traffic management by providing digital data links to cockpit crews in continental and oceanic airspace.

→ SPACE IN 3D

ESA’s quest for a three-dimensional – and extraterrestrial – experience

Nadjejda Vicente, Pantelis Poulakis and **Massimo Sabbatini**
Directorate of Human Spaceflight and Operations, ESTEC,
Noordwijk, the Netherlands

ESA's Columbus laboratory on the International Space Station seen in 3D (ESA/NASA)



↑ The eastern scarp of the volcano Olympus Mons on Mars, as taken by the High Resolution Stereo Camera on ESA's Mars Express in November 2004 (ESA/DLR/FU Berlin)

Bringing space down to Earth, ESA is treating your senses to a new viewing experience. Tricks of perception, advanced optics and customised software take you on a three-dimensional tour of the International Space Station.

When talking about Yuri Gagarin's flight into space, the Russian rocket designer Boris Chertok used to say that mankind had left its two-dimensional being behind forever. He considered our world restricted to length and width. Humans had reached space and, with it, a third dimension for our activities was opened.

Half a century after humankind first ventured into space, an ESA-developed camera produced the first ever live-streaming three-dimensional (3D) images in the history of space travel – showing the International Space Station like never before. Viewers on the ground felt as if they could virtually jump into space.

However, 3D photography has been around for over 150 years, from early stereoscopes to the golden era of the 1950s, and now the boom we are seeing today. In the 19th century, scientists were already working to develop methods to reproduce 3D effects in images and movies. The advent of auto-stereoscopic displays and stereo projection systems made stereo media available to larger audiences than the traditional science and engineering design communities.

The success of science fiction blockbuster Avatar has helped push 3D back towards the mainstream cinema theatres. YouTube has even launched a very powerful channel to share 3D content online. We are living in a 3D renaissance.

Capturing space in 3D

In the space business, 3D is nothing new. Stereo vision was first used in space on planetary spacecraft in the 1970s to show the rugged topography and complex textures of asteroids and moons. Helios 1 and Helios 2 were the first solar-observing spacecraft (1974–80) to gain a stereoscopic vantage point close to the Sun, showing a different face of our star. They improved scientists' knowledge of solar physics and aided in space weather forecasting.

Among the planetary bodies of the Solar System, the 'Red Planet' is without doubt the most preferred 3D object. Mars came into focus for ESA thanks to data from the Mars Express High Resolution Stereo Camera (HRSC). Although ordinary images can give a spectacular bird's-eye view, they can convey only part of the story. They miss information on the topography, or the vertical elevation of the surroundings.

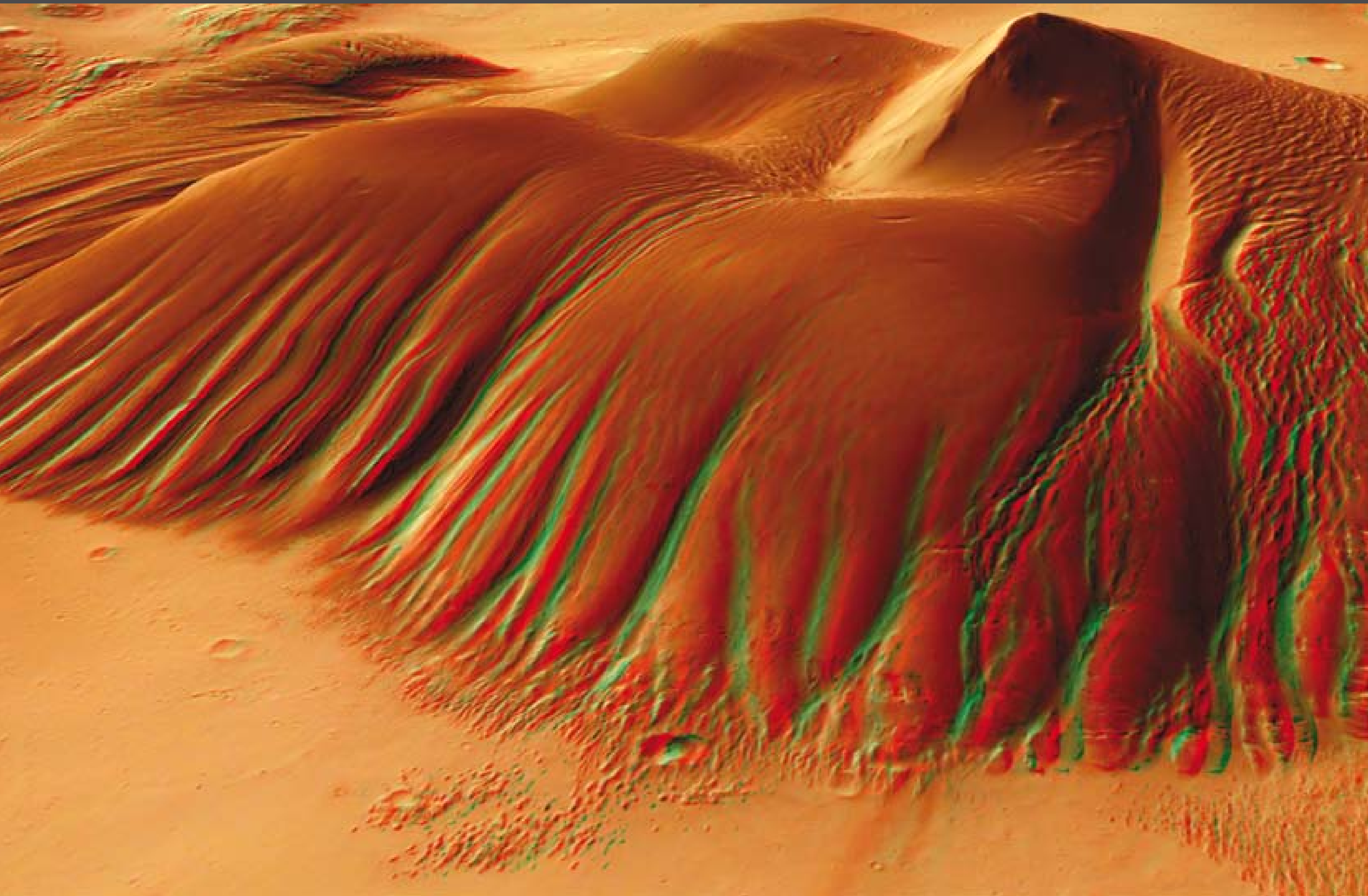
That’s where Mars Express made the difference. It produced a digital terrain model that is considered to be the most detailed topographic dataset ever released for Mars up to that date. Obtaining this kind of data requires a spacecraft to look at the same surface feature twice, each time from a different angle. The HRSC is the only experiment that can do this in one pass.

There is also a long tradition of stereoscopic still and video imaging on the International Space Station. Audiences were taken on the first cinematic journey to the orbital outpost in 2002 with a 3D IMAX film. Space Station 3D used two IMAX 3D cameras specifically designed and built for operation in microgravity. These cameras filmed the Station as it grew from a tiny outpost into a permanently inhabited scientific research station. Life in zero gravity got closer to the audiences.

“I was hugely inspired by the IMAX movie. We knew that a blockbuster in 3D would change the way we watched

↑ NASA astronaut Bill Shepherd, Expedition 1 Commander, uses an IMAX camera on the ISS in February 2001 (NASA)

↓ Another image taken by the High Resolution Stereo Camera on Mars Express, this one shows the central region of the Nicholson Crater, with its characteristic remnant hill (ESA/DLR/FU Berlin)



movies in the cinema," confesses Massimo Sabbatini, ESA's Erasmus Recording Binocular (ERB) coordinator, with the success of James Cameron's film Avatar in mind.

Since then various kinds of 3D imagery have been shot on the ISS, the Space Shuttle and the Hubble Space Telescope. For the IMAX project, astronauts and cosmonauts had to be trained as filmmakers over several months, and 20 km of film had to be flown into in space. Now that the Shuttle era is over, the transfer of cargo to the Station becomes more critical.

This is where ESA's latest 3D movie camera steals the scene. Truly a space camera, ERB-2 is technology demonstration payload that can use a direct link between space and ground. It produces high-definition stereoscopic video imagery in an unprecedented quality, and there is no need to upload any film.

How does 3D work?

The ancient Greeks already knew about stereoscopic depth perception. As described by the assumptions of the 'father of geometry', Euclid of Alexandria, we live in a three-dimensional Euclidean space.

Most of us use what is known as 'binocular vision' to perceive depth and see the world in three dimensions. The binocular system relies on the fact that we have two eyes, which are about six centimetres apart. This separation causes each eye to see the world from a slightly different perspective.

Our brain processes the divergence by fusing the two views together. In fact, it uses the difference to create our own sense of depth. This ability allows us to gauge our surroundings and relative distances between objects in our visual range.

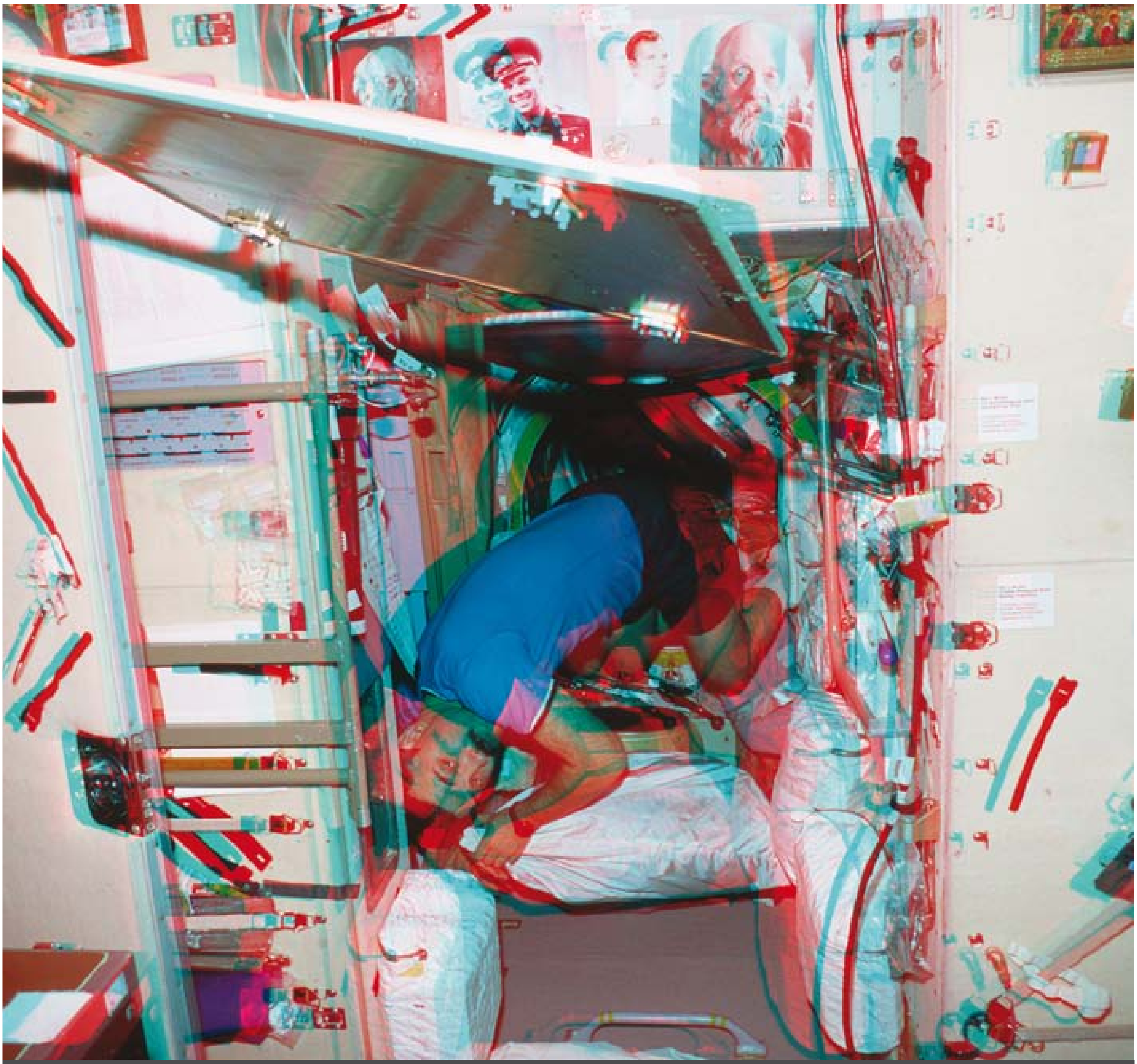
3D films enhance the illusion of depth perception. The images are recorded from two cameras aligned on the horizontal axis, and special projection hardware and eyewear are used to provide the three-dimensional illusion when viewing the film.

Colour filter glasses are one of the oldest methods of viewing 3D images or movies. They do not require a special screen and even work on printed paper: two separate images are superimposed and coded with colour filters. The audience wears red and cyan glasses that allow only one of the images to enter each eye. Your brain does the rest.

Nowadays, more modern display techniques are available to offer better quality pictures. Passive polarised glasses with dual projectors, as well as advanced colour filtering or shuttered techniques, are among the most used. The

→ Milestones in 3D

1838	Charles Wheatstone publishes first paper on stereo perception
1844	David Brewster introduces 'Stereoscope' to take stereo photographs
1851	3D photo of Queen Victoria is displayed at Great Exhibition, London
1855	Kinematoscope is one of the first devices to show movement using different photographs
1922	First anaglyphic movie – *The Power of Love* – shown in theatres
1931	Tru-Vue introduced viewer for film-based transparencies in stereo
1939	View-Master 3D viewer introduced commercially
1952	'Golden age' of 3D cinema led by *Bwana Devil*, the first US 3D movie in colour
1970	Stereovision technology invented (two images sit side-by-side on single film strip with anamorphic lens to fill the screen)
1995	First 3D reconstruction of a solar coronal mass ejection (CME) with computer- assisted tomography
1997	Mars *Sojourner* rover takes stereoscopic images on the Red Planet
2001	ESA organises first public transmission of stereoscopic images at IFA, Berlin, demonstrating operational capability for recording and transmitting space-related content
2002	*Space Station 3D*, first IMAX 3D movie filmed in space, released
2003	ESA sends first 3D analogue still camera to ISS, the RBT-X5 (Pedro Duque is first astronaut to use it)
2004	Mars rover *Spirit* delivers 3D panoramas of martian surface with unprecedented detail
2006	ESA astronaut Thomas Reiter uses ERB-1 camera during Astrolab mission
2007	First 3D images of whole Sun as two NASA spacecraft (STEREO) give first-ever view of all sides of Sun simultaneously
2008	ESA's Mars Express takes highest-resolution full image of moon Phobos
2008	HiRISE camera on NASA Mars Reconnaissance Orbiter provides 3D terrain maps of Valles Marineris
2009	James Cameron's film *Avatar*, shot with the Fusion Camera System he helped develop, hailed as best 3D film to date
2011	First 3D video of asteroid Vesta by NASA's Dawn spacecraft
2011	First live 3D video transmission from space with ESA's ERB-2 camera



↑ ESA astronaut Pedro Duque remembers taking this picture with the RBT-5X camera in particular, "The Commander was fixing something in the plumbing and he had a number of panels unscrewed and open. I caught one, let it float in front of the camera, and took the picture. This was the most impressive one for 3D effects."

latest systems are the auto-stereoscopic displays that allow viewers to enjoy the 3D experience on mobile phone screens, even with no eye-wear.

Because 3D is our natural way of seeing, it creates a sense of realism for the audience. The public no longer have to imagine the volume and relation of objects in the scene, and especially for environments with limited access, such as space, under the sea or subterranean caverns, an 'immersion experience' is guaranteed.

Developing a 3D space camera

At the end of the 1990s, the only way to give viewers a sense of presence in space was the virtual reality theatre of ESA's Erasmus Centre, at the European Space Research and Technology Centre (ESTEC) in Noordwijk, The Netherlands. Even before the ISS was built, the head of the centre at the time, Mr Dieter Isakeit, believed in the power of stereoscopic vision to open a new window to space. The ESA ESTEC Software Simulation Section gave its support by using powerful real-time computers to generate interior and exterior views of the ISS.

By then, ESA was investigating the feasibility of flying a 3D camera on the ISS to document life and work on board. The Erasmus teams began working on developing appropriate equipment and procedures on the ground that could be put to use on the Space Station.

In 2003, an analogue stereo still camera was sent to the ISS: the RBT-5X, a special mechanical combination of two Nikon film cameras. This film-based camera was completely manual in operation but capable of taking high-quality pictures. Relying on the collaboration with small European companies, ESA was able to produce 3D imagery on the ISS.

"This two-lens camera certainly had a funny look. In order to take pictures, you had to unlearn all we knew about automatic electronic cameras," says ESA astronaut Pedro Duque, who made a special effort to take all kinds of pictures with this camera as extra examples.

"I had time to prepare a dozen or so photos to show the 3D capabilities to their maximum. One or two I posed, setting the camera on a bracket. I remember especially one: the Commander was fixing something in the plumbing and he had a number of panels unscrewed and open. I caught one, let it float in front of the camera, and took the picture. This was the most impressive one for 3D effects."

ESA's Paolo Nespoli, who spent six months on the ISS on his Magisstra mission, also recognises the value of 3D in space and says, "Weightlessness forces a different use of the environment: with no up or down, objects are everywhere and tend to fill all of the available space. I believe 3D media capabilities are a unique visualisation tool, better enabling us to communicate and share the microgravity experience."

The films exposed on board by Pedro had to be taken back to Earth for processing, digitising and stereo alignment. An extensive database of 3D still images was then used to increase the value of the Erasmus Centre's virtual model of the ISS. Combining Pedro's 3D pictures with synthetic computerised images proved very effective in immersing the audience.

For ESA's small team on the ground, it was the definitive proof that 3D was the way to go. This first experiment worked beautifully, but there were long waits before receiving the film and getting the images ready. The question was now how to speed up the process: can we do this digitally?

Goodbye film, hello high-res

In 2004, the idea of recording a stereo movie in digital format was born. The father of this initiative was Gianfranco Visentin, Head of ESA's Automation & Robotics Section at ESTEC. Together with the Erasmus team, Visentin looked at the feasibility of a camera that would use a hard disk to store images instead of film. This led to ERB: the Erasmus Recording Binocular.

"Following our experience with telescience operations on sounding rockets and Foton missions, the idea of a digital stereoscopic camera was already mature in our minds," said Massimo Sabbatini.

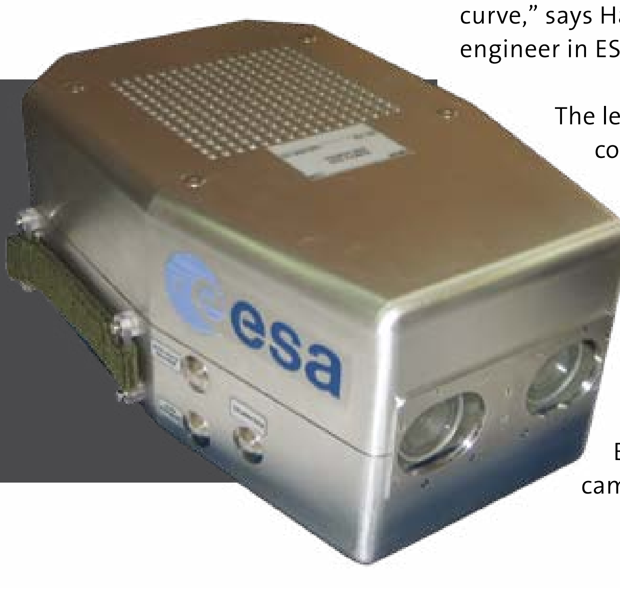
ERB-1 was the first fully digital stereo camera to be used on the ISS. It was built to be able to operate in microgravity conditions, with the design accounting for low power consumption and the particular thermal environment of the ISS.

A peculiar synergy was involved in its creation. Teams were involved not only from ESA's Human Spaceflight and Technical Directorates, but also a small company that specialised in rapid prototyping, Cosine BV from the Netherlands, joined the project.

Integration and testing was done in-house, with the unusual set-up of ESA acting as final integrator and taking on the risks of development, which reduced the costs of the overall project. "It was an interesting learning curve," says Hans Ranebo, at that time a payload engineer in ESA's Robotics Section.

The lessons learned in ERB eventually led to a commercial spin-off for Cosine. The company produced the CP-31 camera, also known as the 'White Camera', to enter to the 3D market. This camera offered 3D film directors a unique one-stop-shop for filming, monitoring, recording and playing back 3D content in high-definition quality.

But first and foremost, the ERB digital camera was designed for mapping the



→

The Erasmus Recording Binocular ERB-1 was the first fully digital stereo camera to be used on the ISS

↑ ESA astronaut Thomas Reiter uses ERB-1 on the ISS in 2006 (NASA/ESA)

Station's complex interior at 25 frames per second. Former ESA astronaut Thomas Reiter, now Director of ESA Human Spaceflight and Operations, used the digital stereoscopic camcorder extensively during his Astrolab mission of 2006.

Thomas, who has often expressed his enthusiasm for this novel media, managed to get about two hours of stereo footage in low resolution. A 20-minute video was produced and shown to the public in different events across Europe.

"During my mission to the ISS, I spent some time filming with ERB-1. Taking advantage of my long stay in space, the main goal back then was to do a 3D mapping of the Station's interior. The importance of this task was very clear to me, because such imagery could help people on the ground to get a better idea of the ISS environment and to optimise payload design and onboard operations," said Thomas.

"Back on Earth, I still remember the first time seeing the 3D video wearing the 3D glasses. I felt almost like I was back on board, and it was quite impressive to see the Station again in such depth. The immersive experience is very powerful, and I am convinced this can bring people very close to the feeling of 'weightlessness' without actually being there. I wasn't the only one to be fascinated: the same reaction happened when the film was shown to the public at various venues all over Europe after my flight," Thomas added.

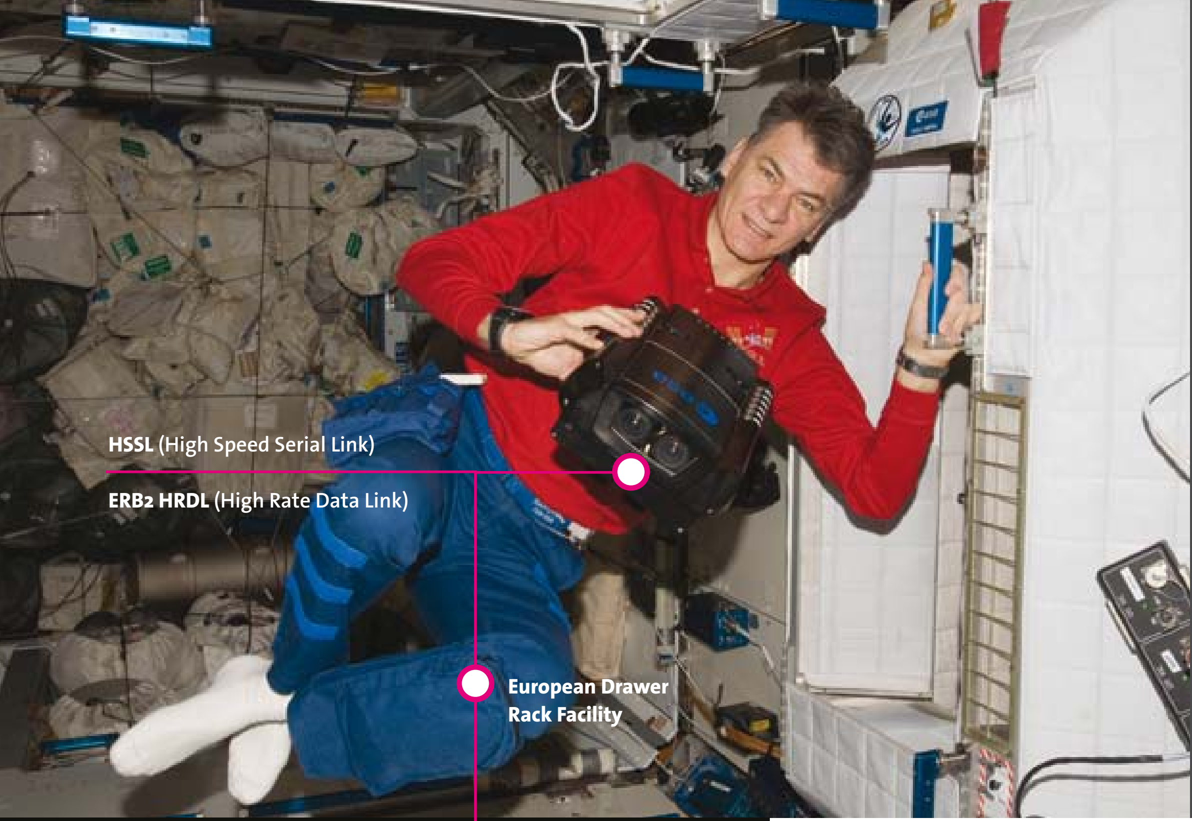
"Initial results with ERB-1 and feedback collected with various audiences were so promising that we pushed for exploiting the scientific, engineering and outreach potential of such media," explains Massimo Sabbatini.

In 2007, the demand for a second-generation of stereoscopic camera was higher: it should have high resolution and be able to transmit images to the ground in real-time, allowing the production of live programmes.

A design concept was drafted with an industrial designer to meet the requirements for use in space. The result was a futuristic-looking camera, ergonomically designed for easy assembly and maintenance. The idea of built -in stereoscopic viewfinder was kept from ERB-1. While other 3D cameras only have one screen, ERB-2's twin viewfinders allow the astronauts to dive into three dimensions.

Not much bigger than a shoebox, with high-definition optics and advanced electronics, ERB-2 counted on European industry for its development. While Cosine BV handled the overall design and the man/machine interface, ESA turned to Techno System of Naples, Italy, for the miniaturisation of the electronics and space software design. They brought expertise in digital imagery from their data handling on various microgravity platforms. "It was an ambitious project," confirms Francesco Grassini, then a system engineer for ERB-2.

In ERB-2, one computer controls the two cameras. The level of complexity is similar to any of the scientific facility racks on the ISS. Most of the tests for full space qualification took place at ESA's Test Centre at ESTEC.



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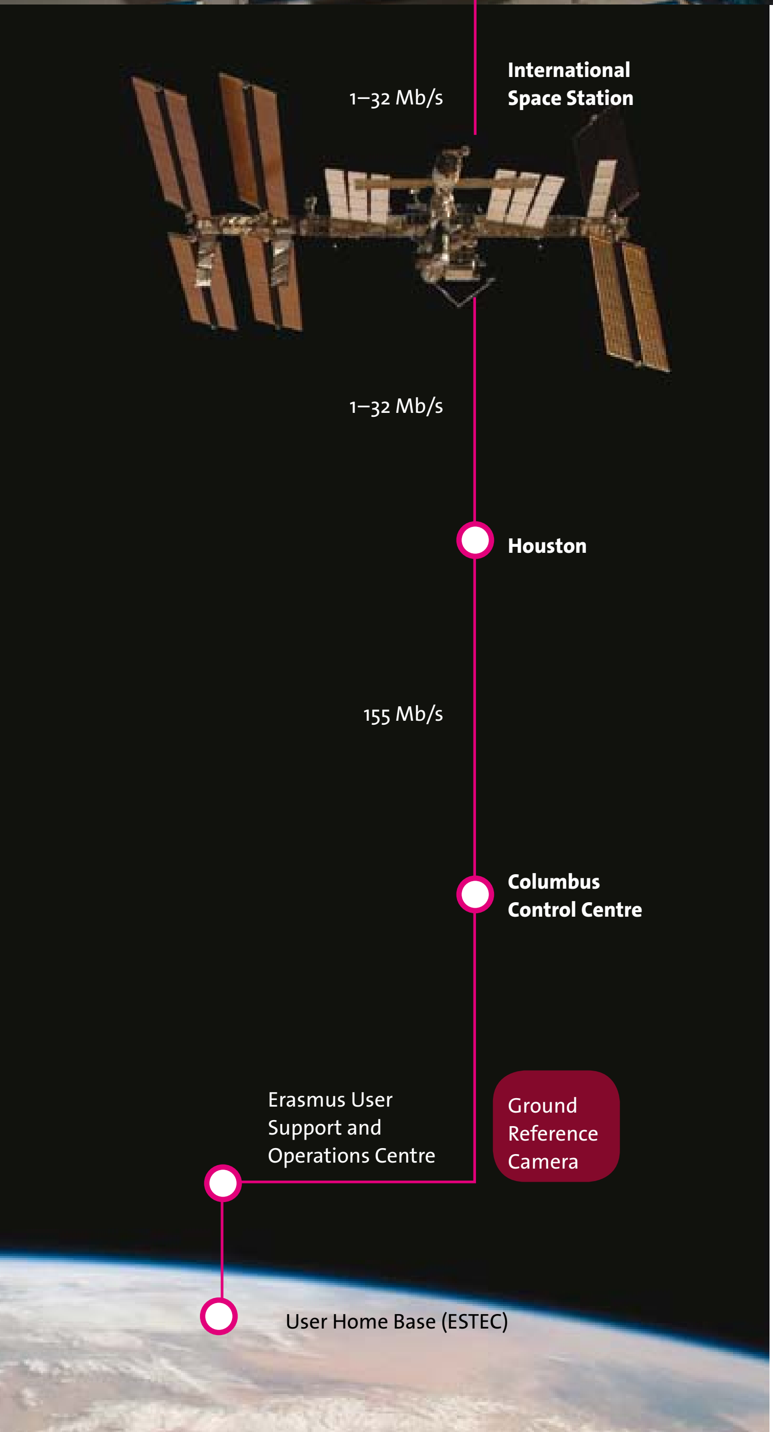
Paolo Nespoli was the first ESA astronaut to use the ERB-2 camera on the ISS in 2011 (ESA/NASA)



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Data transmission path for ERB-2 from orbit to the ground

The final product is capable of recording high-definition stereoscopic pictures, compatible with some of the emerging standards in commercial television. Compared to its predecessor, ERB-2 also offers the possibility to downlink the images to ground, saving the need to physically download the recorded sessions from its hard disk.

Like other scientific facilities on the ISS, ERB-2 does this not as a downloadable file, but as a datastream using the High Rate Data Link (HRDL) available on board. The camera can be controlled from the ground via telecommands without active participation of astronauts in space. This new version offers also improved resolution and increased sensitivity even in low-light conditions.

The first 3D video transmission from space

In 2011, NASA astronaut Ron Garan operated ERB-2 to open a new ‘real-time’ window on the ISS through stereoscopic eyes, in high-definition quality. As a Flight Engineer for Expedition 27/28, Garan set up the camera in Europe’s Columbus laboratory. While talking about the work on the ISS, he enhanced the sense of depth and presence by playing with an inflatable Earth globe.

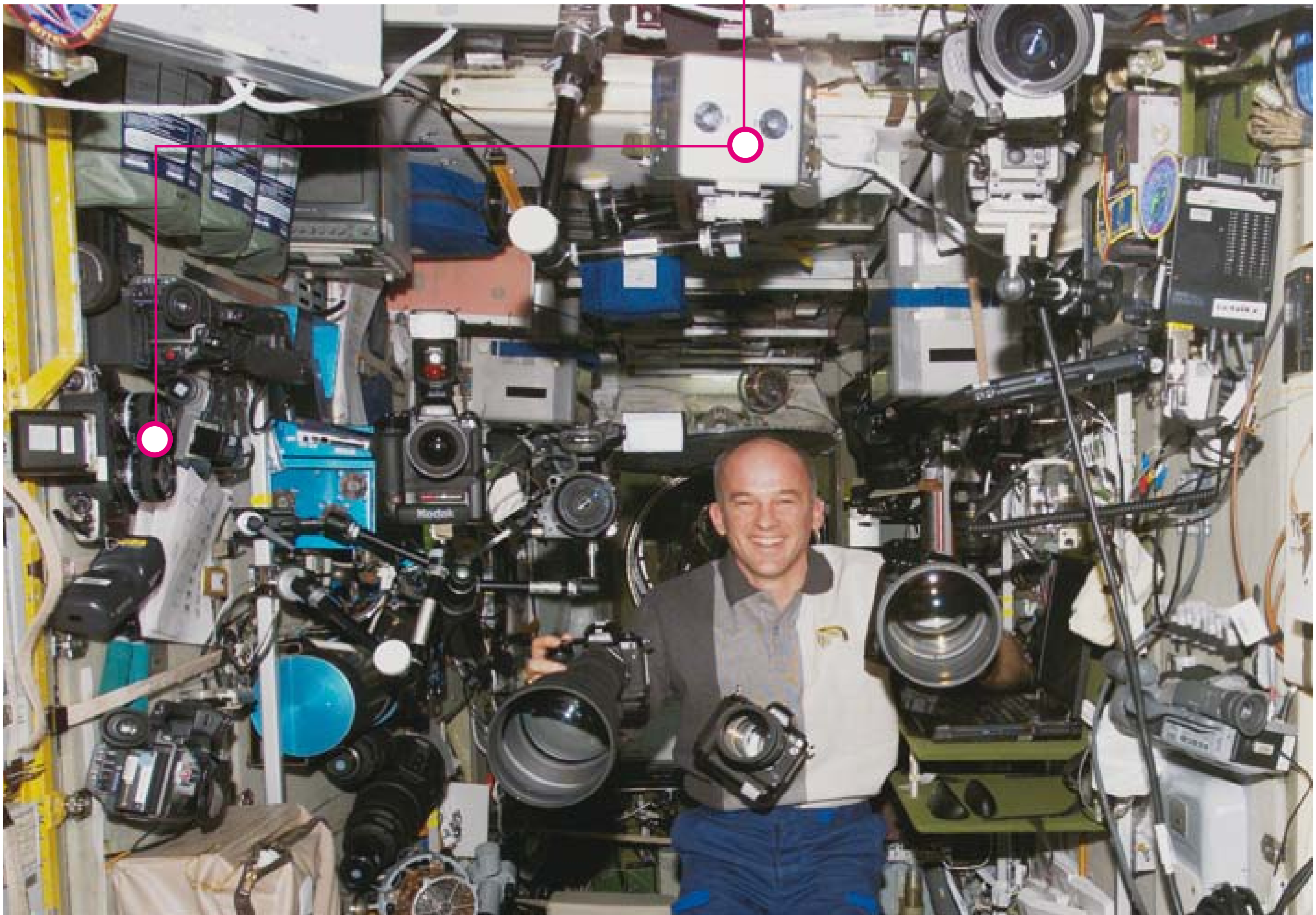
On the ground at the ESTEC, viewers wore polarised glasses similar to those used in cinemas. “This really felt like being in space with an astronaut by your side,” commented Massimo Sabbatini.

The video clip became a hit on YouTube, and this premiere was a long-awaited commissioning test of the Live Mode transmission, proving that all systems and procedures are ready to be used for future ERB-2 live-streaming events.

↑ NASA astronauts Mike Fossum and Ron Garan (centre) and Japan Aerospace Exploration Agency astronaut Satoshi Furukawa have fun with the ERB-2 camera (NASA/ESA)

After filming with it, in both free and live modes, Ron was enthusiastic about the applications of ERB-2, adding, “I think it is going to be certainly a powerful educational tool. We can use it to help people sharing the experience of living and working in space.”

↓ Smile! NASA astronaut Jeff Williams demonstrates some of the many cameras on the ISS. ERB-1 is visible at the top, and the Nikon RBT-5X 3D camera at left (NASA)



→ ERB-2 CAMERA

Operated with only 10 buttons, four of which control the basic operations of record, playback, delete and power on/off, an astronaut can use the stereo viewfinder to see what is being recorded, and even delete unwanted footage on the spot.

The system has been designed with flexibility in mind, allowing the replacement of the optic subsystem in orbit. It can be powered either by connection to the European Drawer Rack (EDR) or by standard batteries already on board for other cameras on the Station. The images and the sound are recorded directly by the camera, where they are stored in three separate compressed files: left-eye, right-eye and audio.

With ERB-2 connected to the EDR, ground controllers can initiate a direct link with the camera. On Earth, special computer software decompresses the movies and converts them to a format compatible with most stereoscopic screens and projectors.

→ ERB-2 specifications

Operating modes
1. Standalone recording
2. Playback
3. Realtime streaming to ground

Video
25 frames per second, compressed 720p HD

Standalone recording time
80 minutes

Cameras
Two high-definition cameras with motorized objectives

Mass
6.82 kg

Onboard displays
Two Super Video Graphics Array OLED (miniaturised organic light emitting diodes displays)

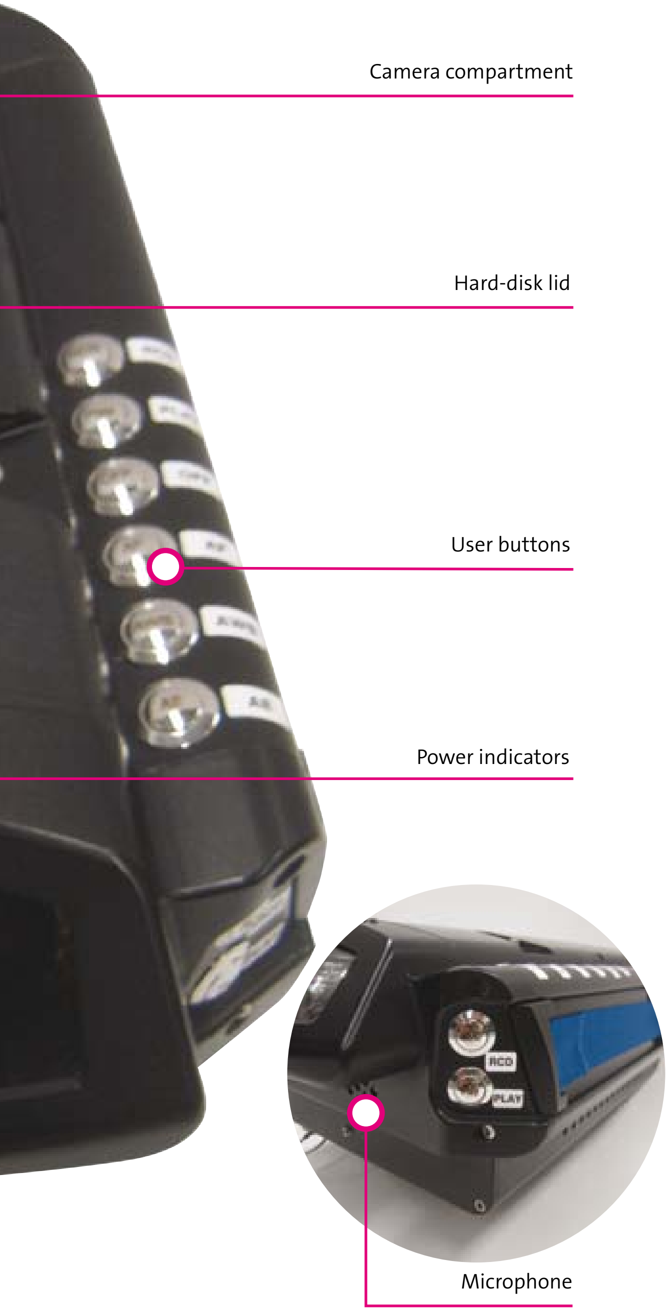
Onboard storage
120Gb hard disk (exchangeable)

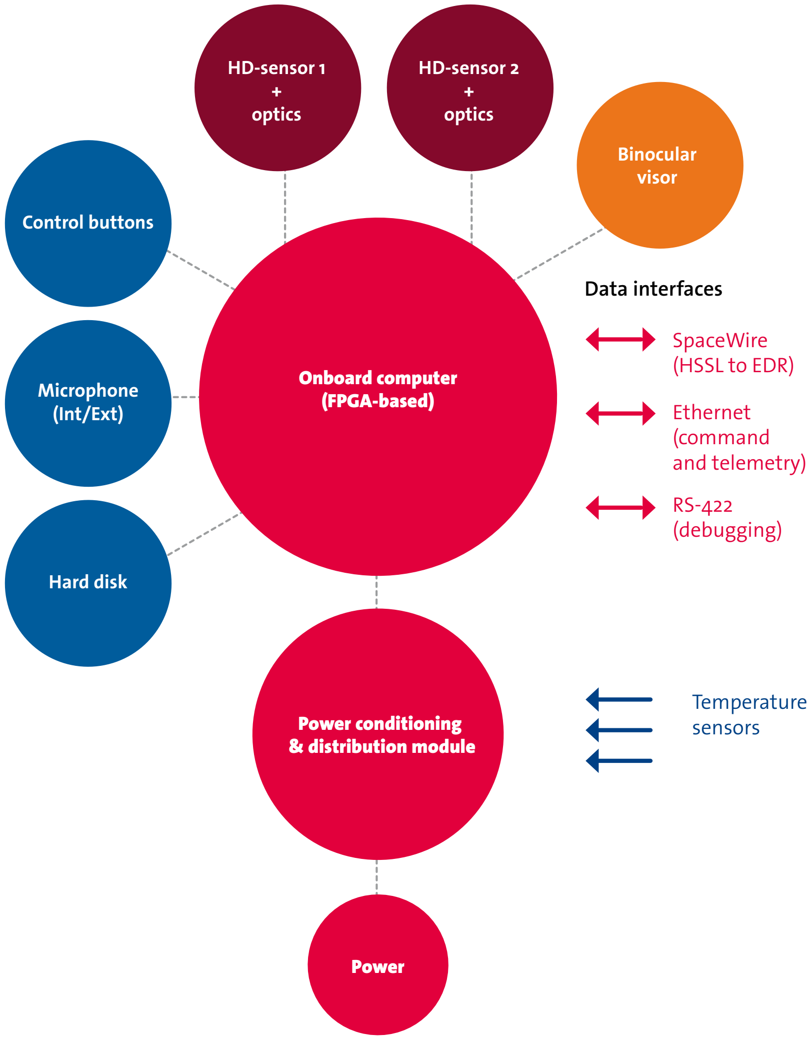
Power consumption
42W (max.)

Dimensions
397 x 186.5 x 269 mm

→ ERB milestones

2000	Inauguration of Erasmus Centre, hosting first Virtual Reality Theatre with computerised model of ISS
2003	Analogue stereo still camera RBT-5X sent to ISS
2004	Birth of ESA's ERB concept. A mix of real and simulated 3D imagery is a powerful outreach tool in the Virtual Reality Theatre
2005	Testing of ERB-1 at ESTEC
2006	ERB-1 first used on ISS
2007	First public showing of ERB-1 pictures at venues in Europe
2008	Development of ERB-2 starts. Cosine BV produces CP31 commercial camera based on ERB-1
2010	ERB-2 arrives at the ISS and first commissioned on 9 June by NASA astronaut Tracy Caldwell-Dyson
2012	Paolo Nespoli, André Kuipers and many US astronauts filming with ERB-2





↑ ERB-2 system architecture

← André Kuipers with a Nikon D2Xs digital SLR camera during Expedition 30 on the ISS (ESA/NASA)

The future

Three-dimensional mapping of the ISS and daily activities, such as lunch or physical exercises, are on the list of things to be filmed in the short term. However, ERB-2 is not the only 3D camera on the ISS. Astronauts have been also using smaller 3D cameras designed for scientific and technical research. Besides the ERB-2 and RBT-5X, there are cameras by Panasonic and Fuji.

During his Magisstra mission, Paolo Nespoli was the first to try the ERB-2, as well as a compact 3D camera already on the commercial market. “In my six months on board I missed some of the functions found today on cameras, like zoom, wide angle and a large viewing screen,” says Paolo.

The small camera turned out to be ideal for spontaneous snaps, because it allows the user to check the images immediately using the screen on the back. “I would certainly encourage ESA to developing the concept further,” says Paolo. New imagery from Europe’s current ISS astronaut André Kuipers, using the compact camera, is available online on ESA’s Flickr channel.

Today, ERB-2 is providing a vastly improved 3D view of the ISS for both educational and promotional purposes. Astronauts soon realised its potential, and these near-real 3D images are not only changing the whole viewing experience, but can also be used in supporting science operations

During an inflight call last year, NASA’s Ron Garan said, “We can use this camera to help us with robotics and some of the fine work we have to do outside. A 3D view is going to help us immensely.”

Massimo Sabbatini dreams about filming extravehicular activities to support the astronauts during spacewalks or other critical robotic operations. To make that dream come true, further developments are needed. An incremental design approach could lead to a ERB-3, the next generation of ESA stereoscopic cameras.

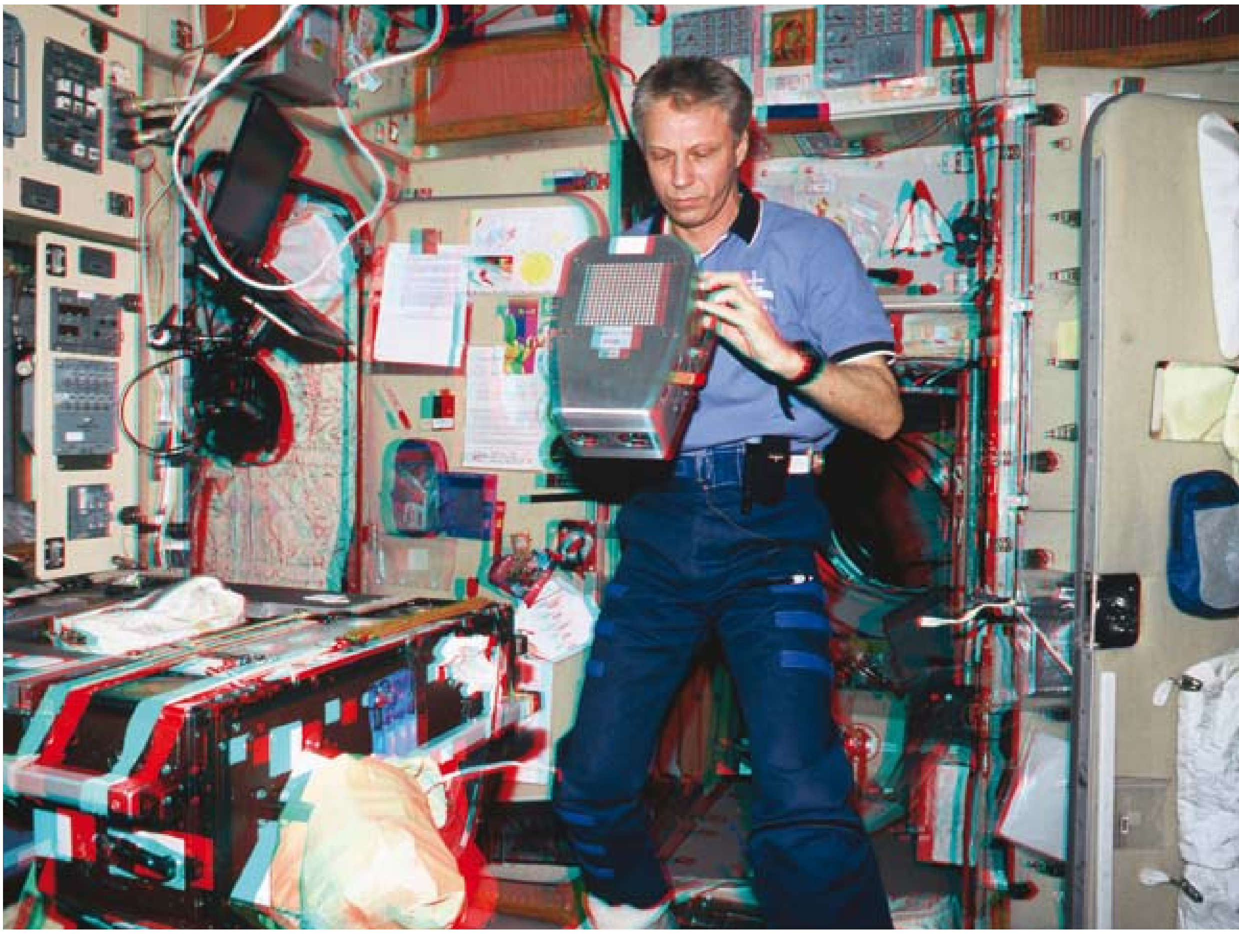
In the meantime, put on your 3D glasses and immerse yourself in the world of the space, without leaving planet Earth. See more 3D images on ESA’s YouTube 3D channel and on **www.flickr.com/ESAin3D .** ■

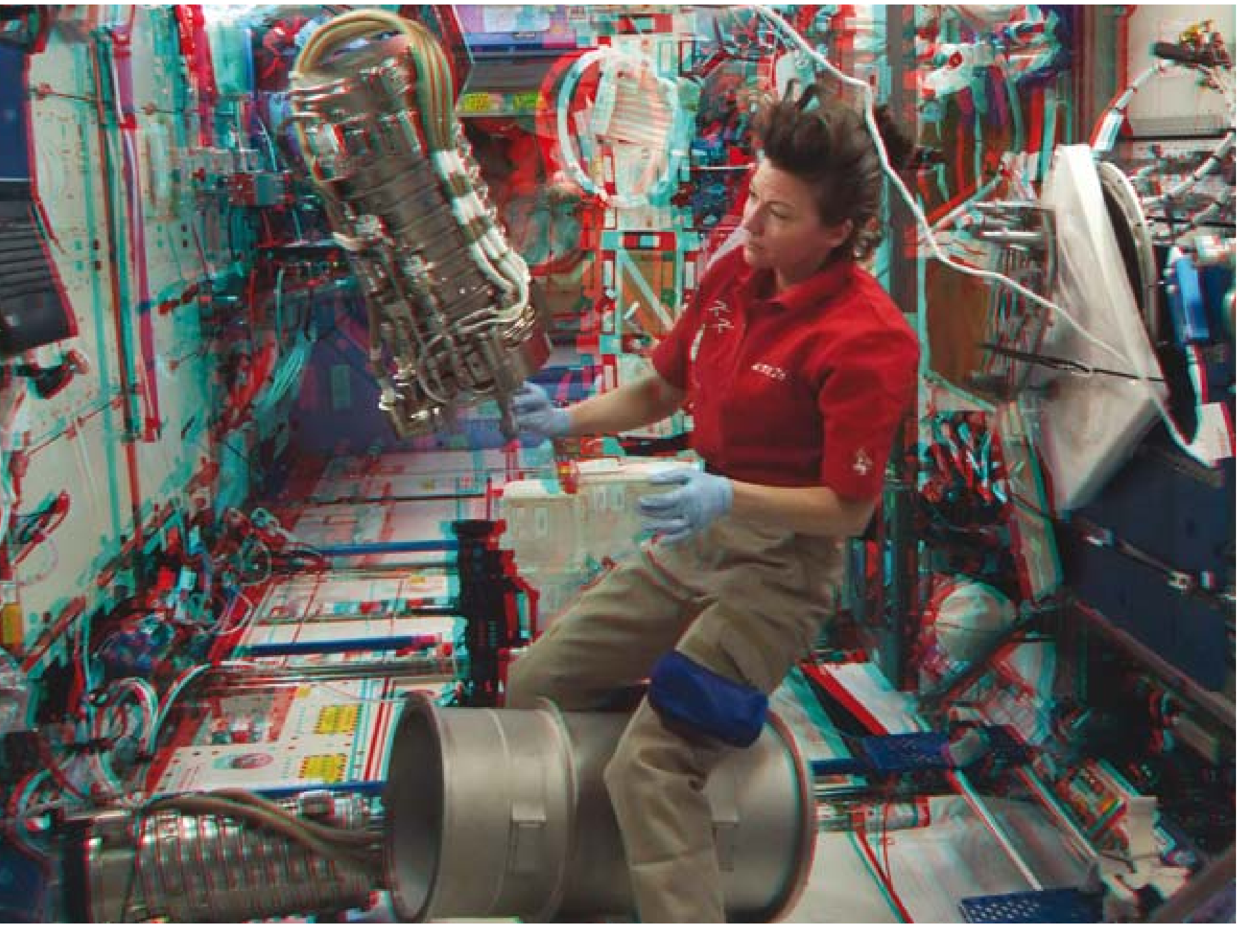
→ Paolo Nespoli in the Destiny module of the ISS during his Esperia mission in 2007 (ESA/NASA)

→ 3D GALLERY

→ Pedro Duque in the Russian Zvezda module of the ISS (ESA/NASA)

→ Thomas Reiter using ERB-1, taken with a compact 3D camera in 2006 (ESA/NASA)





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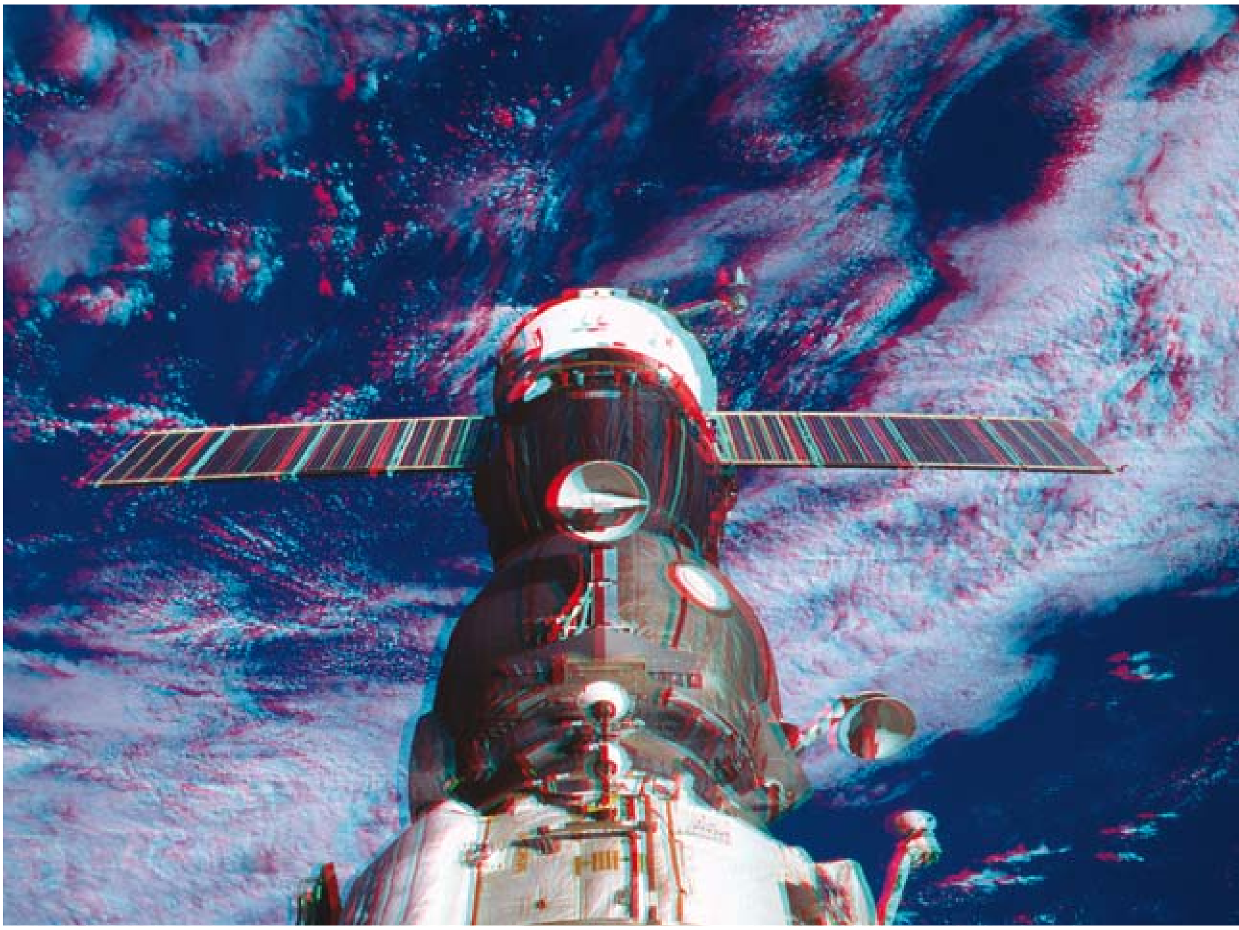
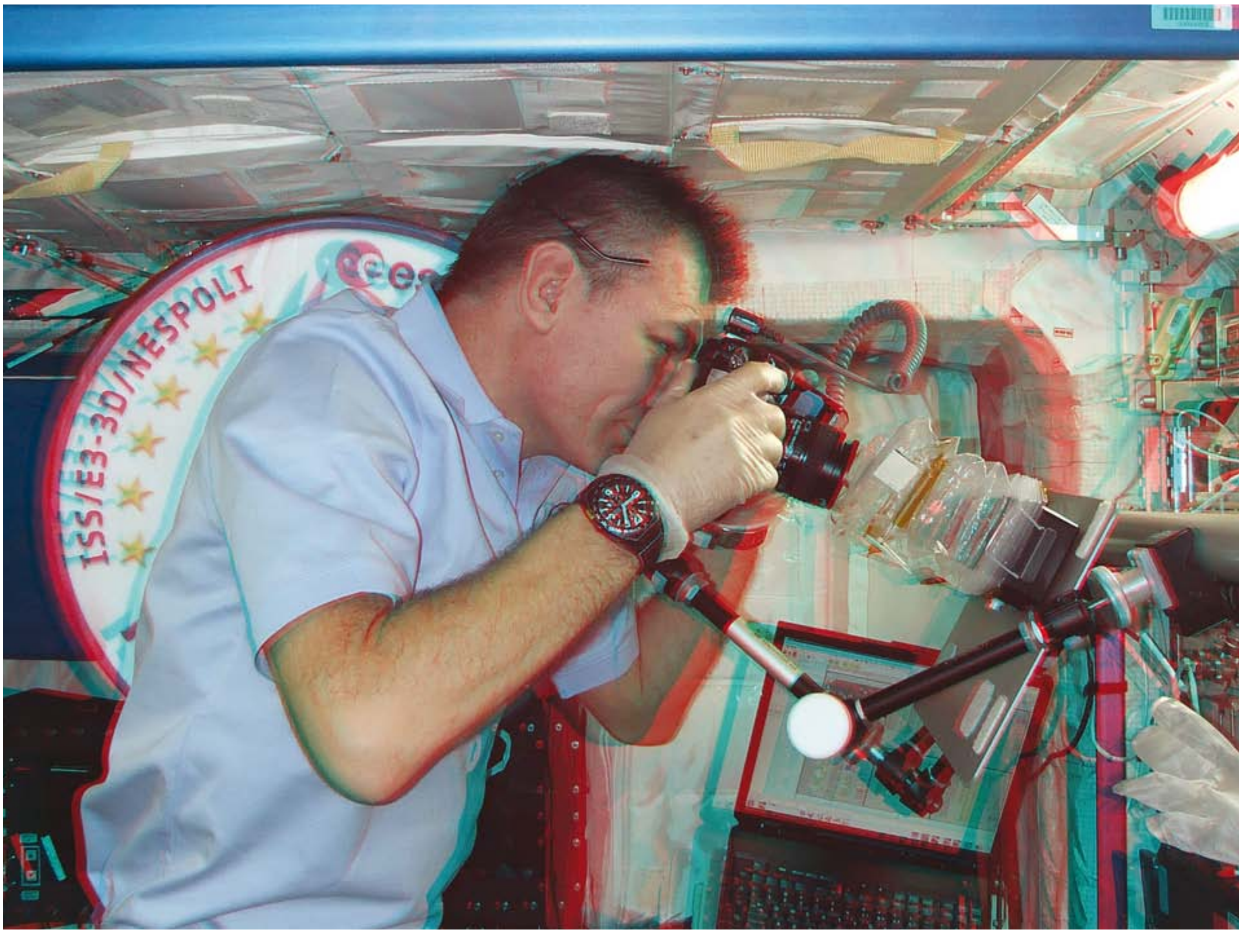
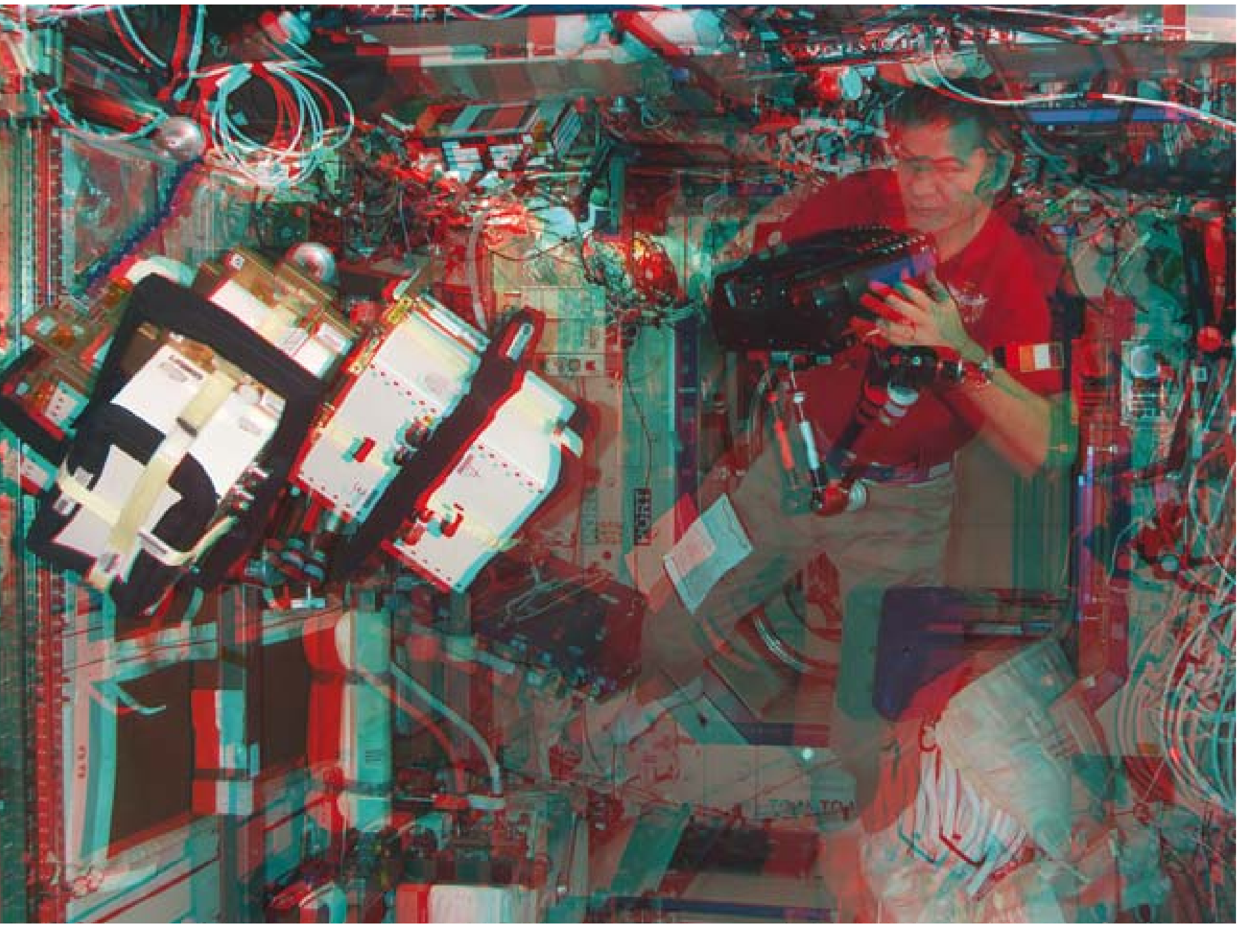
↙ Two views of NASA astronaut Cady Coleman on the ISS in 2011 (ESA/NASA)

→ A Soyuz spacecraft docked to the ISS with Earth as backdrop (ESA/NASA)



→ Paolo Nespoli takes a picture of the Greenhouse in Space educational experiment in the Columbus laboratory on the ISS (ESA/NASA)





← Paolo Nespoli uses the ERB-2 during MagISStra mission in 2011 (ESA/NASA)

← André Kuipers, Flight Engineer for ISS Expeditions 30/31, during training for spacewalk activities in Houston, 2010 (ESA/NASA)

ESA's Lunar Lander descending to the Moon's surface (ESA/AOES Medialab)

→ DESTINATION MOON

The European Lunar Lander: opening a new era for exploration

Richard Fisackerly, Bérengère Houdou, Diego De Rosa, James Carpenter,
Christian Philippe, Alain Pradier and Bruno Gardini
Directorate of Human Spaceflight and Operations, ESTEC, Noordwijk, The Netherlands

The Moon is a stepping stone on the path of human exploration beyond low Earth orbit. Taking this next step means demonstrating new technologies and learning more about this challenging environment. The European Lunar Lander intends to do just that.

A new face of our nearest neighbour is emerging from the exciting discoveries of recent and ongoing lunar missions from space agencies around the world. With over 10 orbital spacecraft and impactors making the journey to the Moon in the past decade, a wealth of new data has become available and has stimulated an exciting 'lunar revival'.

After over 30 years, the Moon is once again firmly in the spotlight as an exploration destination for both robotic missions and human explorers, especially its polar regions.

"The Moon's south polar region is a unique location in the Solar System: where Europe can demonstrate the technology and capabilities required for the future robotic and human exploration missions beyond the limits of low Earth orbit, to the Moon and ultimately to Mars," says ESA's Bruno Gardini.

A further wave of automated lander missions is planned for the next decade by various spacefaring countries, this time striving for access to the surface and performing direct measurements there. Europe has been preparing its own contribution and participation to this new phase of exploration, with work on lunar landing and associated technology development going on for several years.

Getting down to the lunar surface, however, is not as simple as it might seem. Indeed the Americans and the Russians succeeded several times during the 1960s and 1970s, but landing in today's perspective of exploration is a very different challenge from Apollo or Luna.

Landing now requires major advances in the levels of accuracy and autonomy. Such high performance is needed to target specific well-illuminated landing sites or locations of special scientific interest, and to ensure the proximity of robotic and human surface mission elements.

The European Lunar Lander has the primary objective of proving the technologies required to achieve the landing accuracy and safety needed to realise the exploration missions of the future. Once on the surface, the Lunar Lander will be the first 'explorer' to experience the conditions at the Moon's south pole region, which looks very different from the landing sites visited in the past.

It will capitalise on this achievement, deploying a suite of instruments and sensors to investigate the environment and its effects, providing key data to help inform the preparation of future exploration missions and systems.

"The Lunar Lander is a strategically important and exciting mission, not only because of its technical achievement in getting access to the lunar surface, but also because of the opportunities it provides to perform exploration at the landing site. It will take advantage of Europe's industrial and scientific expertise, and demonstrate Europe's capability as a reliable partner in a future international exploration scenario," says Bérengère Houdou, Lunar Lander Phase-B1 Project Manager.

The Lunar Lander mission is part of the activities of ESA's Directorate of Human Spaceflight and Operations, preparing the way for future human exploration. The prime contractor Astrium GmbH in Bremen, Germany, has gathered the expertise of more than 10 companies from six European countries.

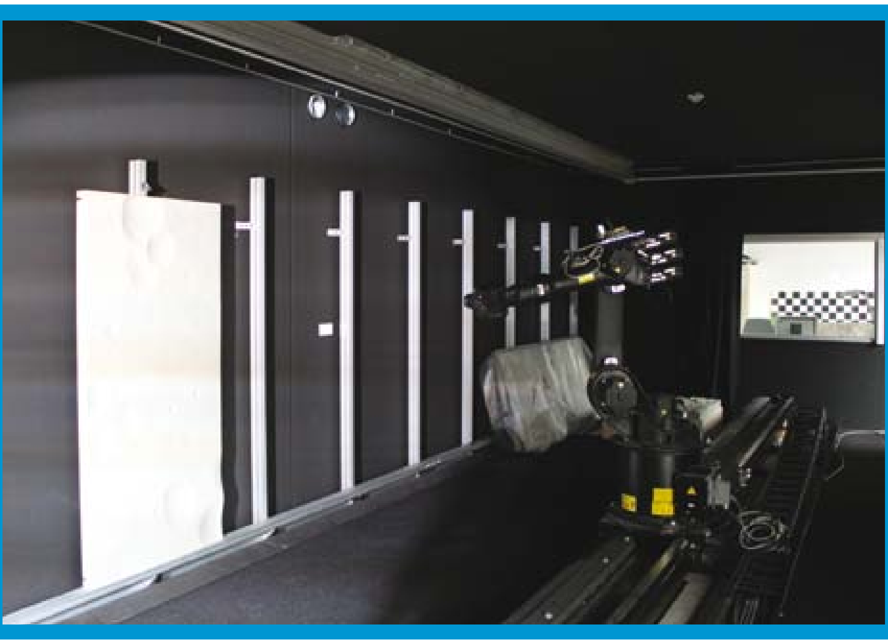
The project is currently in Phase-B1, which includes mission and system design as well as hardware 'breadboarding' and testing, all focused on building a spacecraft that can achieve an accurate and safe landing and then operate in the unique environment of the lunar poles.

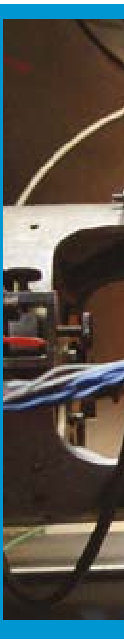
A target for exploration

The availability or absence of sunlight plays a major role in space exploration activities and in creating the environmental conditions in which those activities take place. This is especially true on the Moon's surface, which for the most part experiences around 15 days of continuous illumination followed by the same period of continuous darkness.

→ Technology

The Lunar Lander mission builds on hardware and technology that has been the focus of developments in ESA programmes such as Aurora and ATV, as well as in national programmes. Such activities include testing of navigation sensors and algorithms in DLR's TRON facility (left), hotfiring of the 200N ATV assist engine at Astrium's Lampoldshausen facility (centre) and drop testing of prototype landing legs at DLR's LAMA facility in Bremen (right)

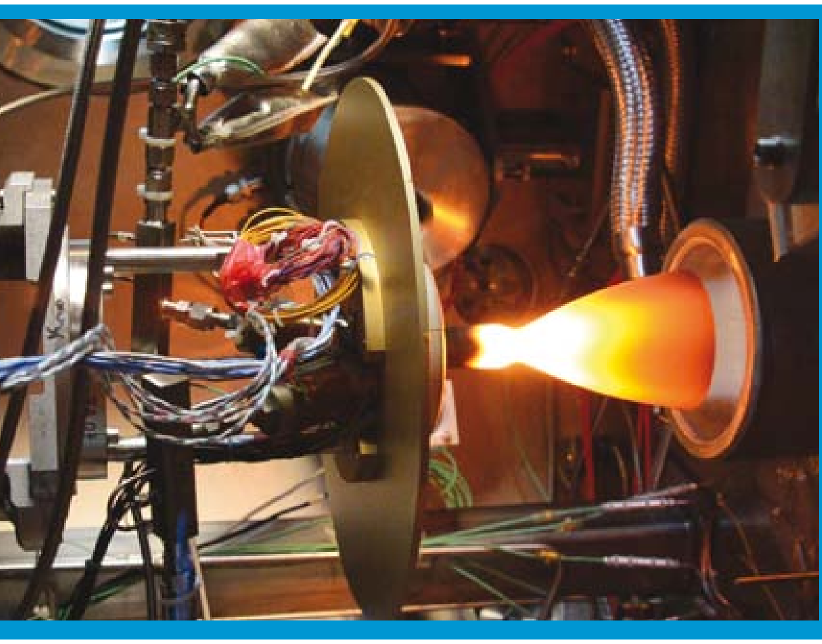




↑ The lunar south pole as seen by the Japanese 'Kayuga' spacecraft in 2007 (JAXA)

While daytime temperatures at the surface can reach around 130°C, during the long lunar 'night' they can quickly reach lows of –160°C. For landers or other surface systems relying solely on solar power, batteries and standard thermal control hardware, surviving these conditions for a full 15-day lunar night poses an extreme and currently insurmountable challenge.

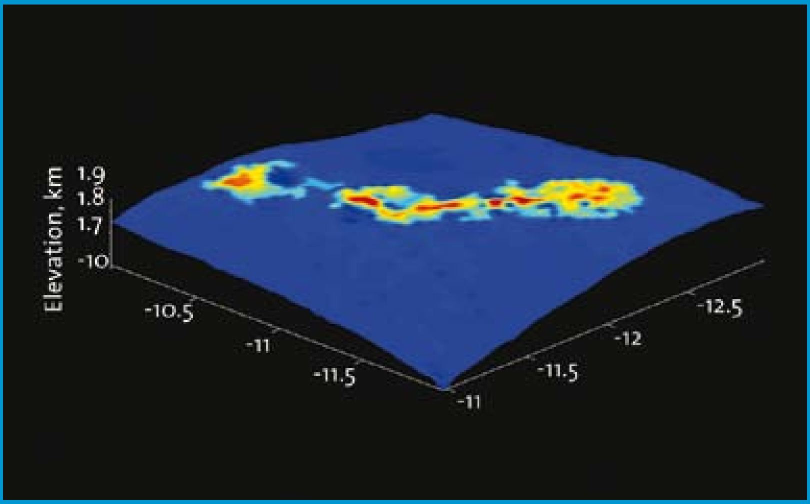
The lunar polar regions, however, offer a range of very different and unique illumination conditions. This is principally because of the combination of inclination of the Moon's rotation axis (nearly perpendicular to the ecliptic) and the large variations in altitude of the terrain in the polar regions.



(NASA)

→ Site analyses

The Sun is always very low on the horizon when seen from the lunar south pole, meaning vast portions of the surface are immersed in darkness at a given time. Only those regions which are high enough with respect to the surrounding landscape, such as this ridge (above) imaged by the NASA Lunar Reconnaissance Orbiter (LRO), experience sunlight for long periods of time. The Lunar Lander team, in cooperation with several science teams, is studying these images alongside surface topographic data obtained by the LRO Laser Altimeter to identify areas on the surface which receive the longest periods of illumination (in colour, right) and which are relatively free of hazards – and which are therefore good landing site candidates.



This results both in local peaks, which can experience several months of near continuous sunlight, as well as polar craters, which are kept in virtually permanent darkness.

Surface sites offering the possibility for long periods of sunlight and solar power are attractive for both near-term robotic missions as well as the establishment of a longer-term human lunar presence. These regions are also proving, through the results of recent orbital missions, to be rich in resources, including water, which may be utilised locally to support exploration activities. Solar wind implanted volatiles, and water ice at the lunar poles also represent an important record of the history of the inner Solar System.

It is this combination of conditions and characteristics that mark out the lunar south pole region as one of the most important destinations for future exploration. But while attractive for exploration missions operationally and scientifically, the Moon's polar environment poses a number of important challenges that the Lunar Lander mission must face.

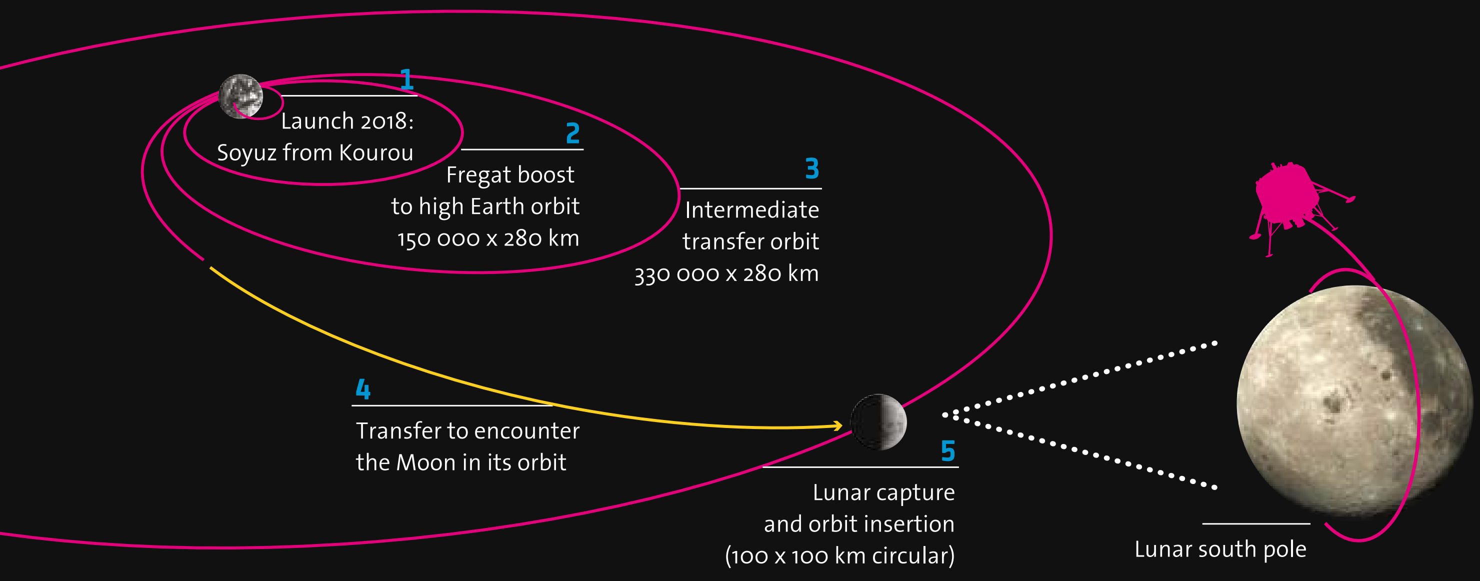
In terms of the Lunar Lander mission and its objectives, the demonstration of the technologies required to achieve a soft, safe and precise landing is paramount. However in order to offer an opportunity for surface exploration activities and investigations, the Lander targets those specific surface sites offering the possibility of several months near-continuous illumination.

The surface areas with good illumination conditions are, by their nature, limited to a few hundreds of metres. This has important impacts on the overall mission profile, and is why the landing accuracy and associated navigation technologies are so crucial.

The Lander must achieve this high performance completely autonomously, without intervention from ground.

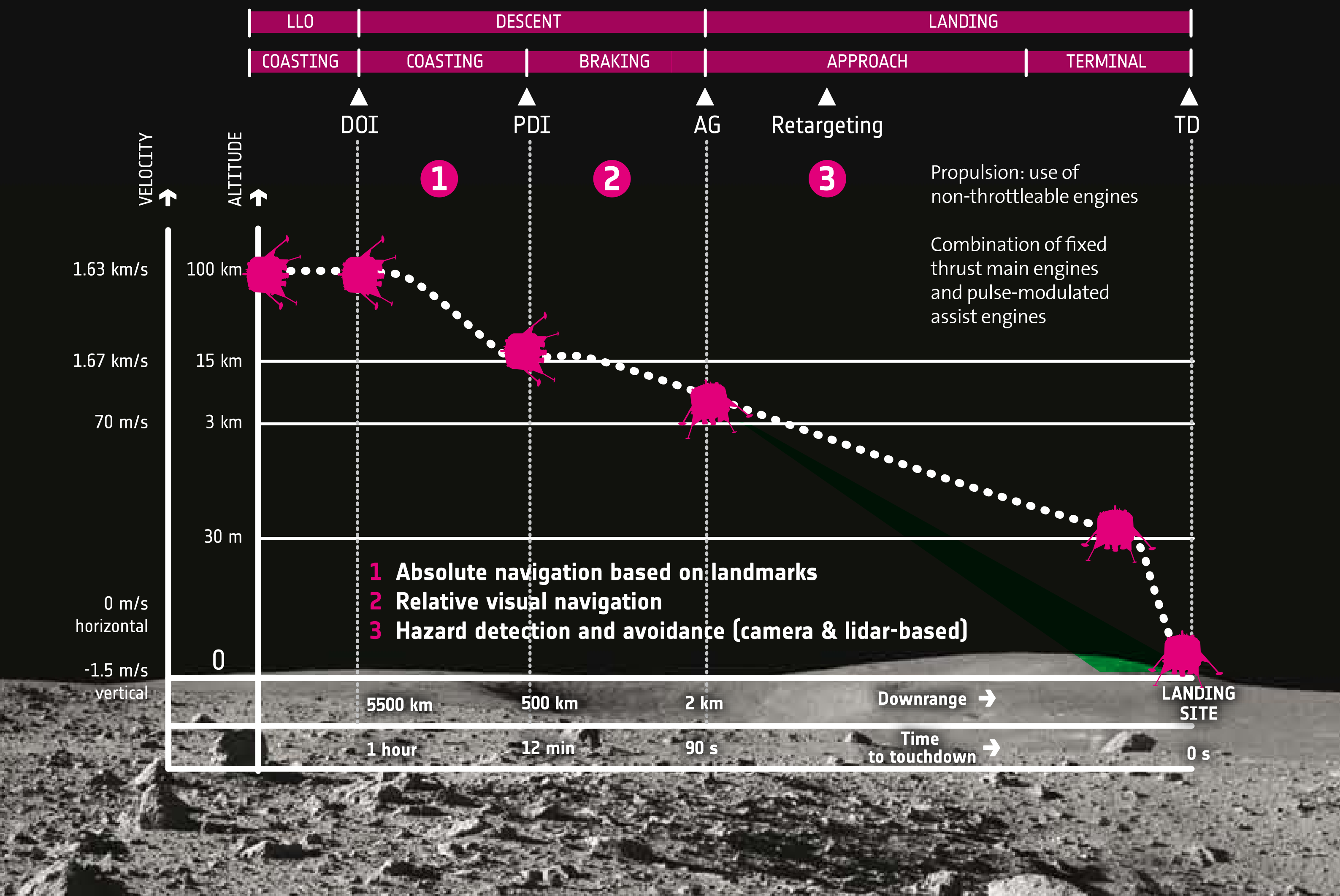
→ FROM EARTH TO THE MOON

Launch to lunar orbit



Descent and landing profile

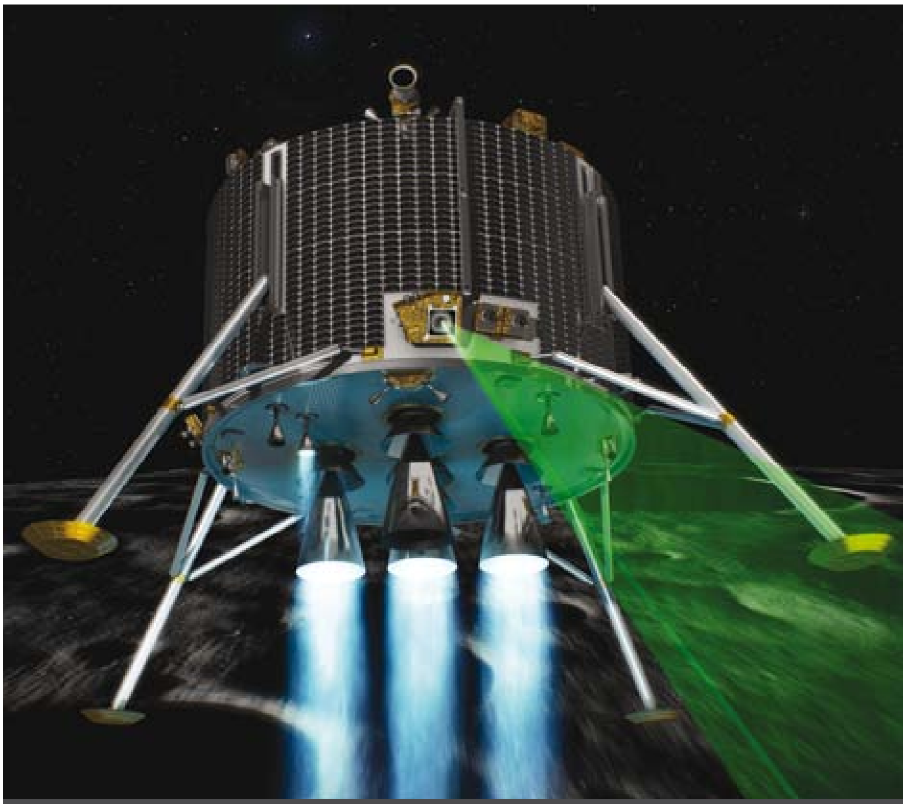
LLO	Low lunar orbit	AG	Approach Gate
DOI	Descent Orbit Initiation	TG	Terminal Gate
PDI	Propulsive Descent Initiation	TD	Touchdown



Propulsion: use of non-throttleable engines

Combination of fixed thrust main engines and pulse-modulated assist engines

1. **Absolute navigation based on landmarks**
2. **Relative visual navigation**
3. **Hazard detection and avoidance (camera & lidar-based)**



↑ Lunar Lander scanning the surface terrain for hazardous features such as slopes, boulders and shadows (ESA/AOES Medialab)

↑ Thrust is reduced for final phases of terminal descent (ESA/AOES Medialab)

Getting to the surface

Launched on a Soyuz ST-B in 2018 from Europe's Spaceport in Kourou, French Guiana, the Lunar Lander will spend several weeks travelling to the Moon in a number of highly elliptical orbits. While this takes time, this approach avoids the limitations on launch opportunity that would come from a direct injection to the Moon by the Soyuz.

Once captured in a circular low lunar orbit, at around 100 km above the surface, the Lander waits for the best alignment of its orbit with the Sun, Earth and lunar surface, to meet the requirements for communication and surface illumination.

The Lander executes a Descent Orbit Initiation burn, firing its engines over the Moon's north pole. It begins coasting for one final half-orbit, coming down from 100 km to 10 km altitude.

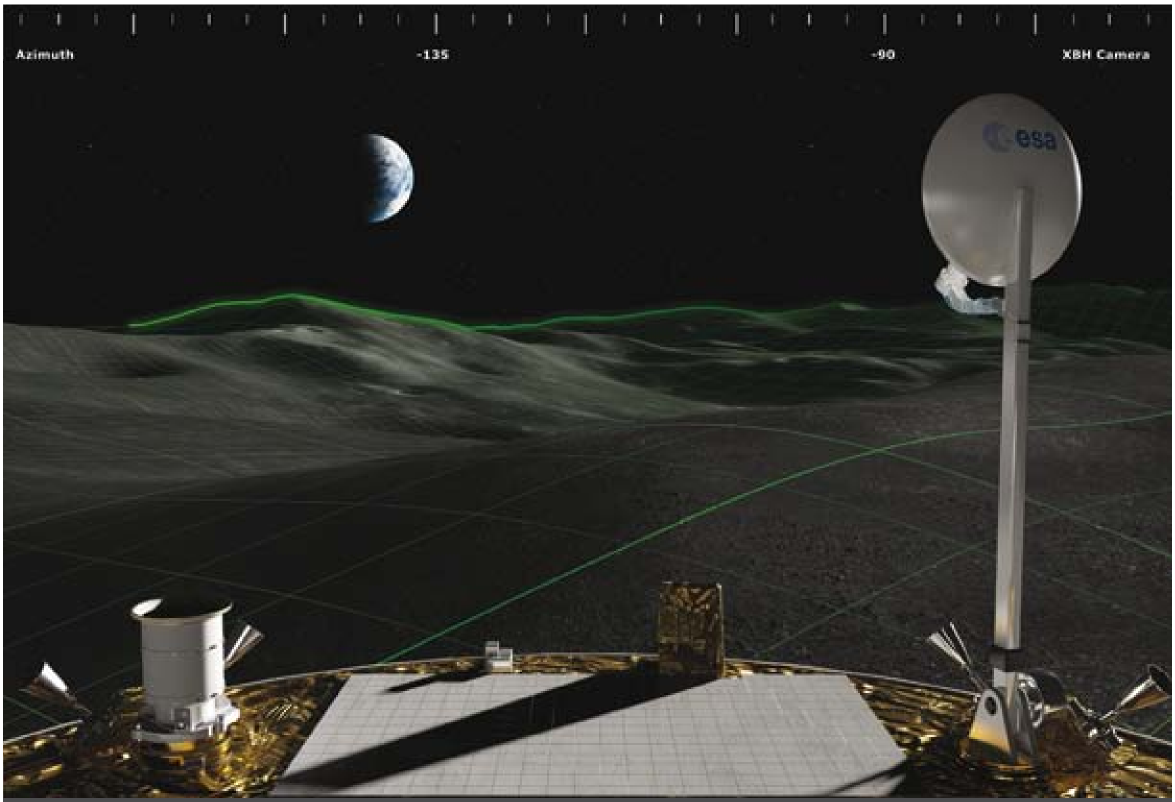
During this phase, the Lander uses Optical Absolute Navigation, an advanced technique involving the matching of landmarks (extracted from camera images acquired in real time during flight) with reference landmarks stored on board, to ensure an accurate estimation of its position autonomously.

As the Lander closes in on the south polar region, it initiates the Main Braking phase by firing all of its main engines at maximum thrust. During this braking, the Lander uses Optical Relative Navigation to track features using the onboard cameras. The Lander is able to monitor its relative velocity with respect to the surface and to ensure a precise trajectory during the final minutes of descent.

"Landing accuracy is key to the mission's objectives and to enabling future exploration, and is also strongly affected by the landscape of the sites we are targeting for illumination," says Diego De Rosa, Lunar Lander System Engineer.

On approach to the landing site, the Lander modulates the level of thrust from the engines, progressively shutting down the main engines and compensating with 'assist engines' operating in a 'pulsed mode'. The Lander is therefore able to precisely control its descent in a fuel-efficient way.

The engines on which the Lander relies reflect the drive to use European technologies and to use equipment that has already a good level of technical maturity. The five main engines are based on the European Apogee Motor (EAM)



↑ View of lunar horizon and back to Earth once on the surface (ESA/AOES Medialab)

and the six 'assist' engines are derived from thrusters used on the Automated Transfer Vehicle.

During the landing phase, the Lander has the capability to characterise the surface terrain in terms of hazardous features such as slopes, boulders and shadows, and to decide to retarget to a new hazard-free landing site if necessary.

The Lander's avionics play a central role in enabling the autonomy behind this decision-making and planning capability. Analysing sensor data, making decisions and implementing those decisions via commands to thrusters, represents a major challenge for both the Lander's hardware and software.

In the final moments, the Lander descends vertically to the surface and completes touchdown on its four landing legs. "The moment of touchdown on the Moon will represent many firsts, not only for Europe, including the demonstration of new enabling technologies, access to a key dynamic and diverse environment, and not least the beginning of a new era in exploration," says Richard Fisackerly, Lunar Lander System Engineer.

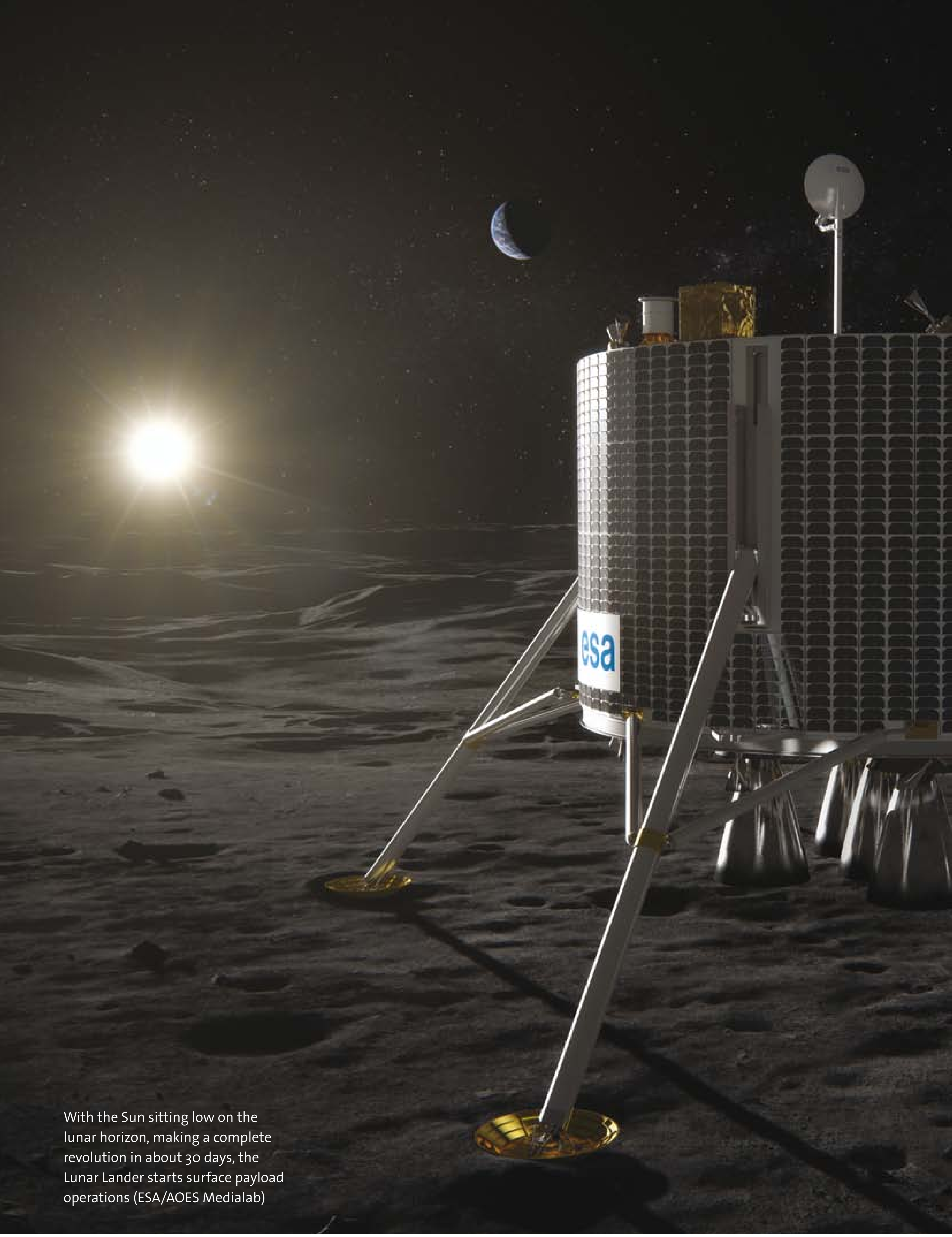
Operating in a harsh environment

When on the surface, the Lander will immediately deploy equipment such as the main antenna and the surface camera package. Only when the full data-set from the descent and landing phase has been received on Earth can the Lander turn its attention to exploring its new home at the lunar south pole.

With the Sun sitting low on the lunar horizon, making a complete revolution in about 30 days, the Lander will start surface payload operations.

Many of its instruments will characterise aspects of the lunar environment and its effects, for example, measuring and monitoring the properties of dust near the surface, local electric fields and plasma environment.

Along with the static monitoring instruments, the Lander also carries experiment packages that will analyse lunar surface samples. To acquire these samples, the Lander must deploy its robotic manipulator arm, which can be operated from the ground in near-real time because of the proximity of Earth.



With the Sun sitting low on the lunar horizon, making a complete revolution in about 30 days, the Lunar Lander starts surface payload operations (ESA/AOES Medialab)

The unique location of the lunar south pole imposes some important operational constraints. The Lander uses a direct-to-Earth link for receiving commands and sending back data, avoiding the need for a communications relay orbiter. However, the slight inclination of the Moon's orbit means that Earth appears to rise and set over the horizon on a 28-day cycle at the pole, meaning that the Lander has to be able to operate autonomously for around 14 days at a time.

"Given that we must exploit the 'season' of good illumination conditions to the utmost, the Lander must make best use of all its time on the surface, in making measurements of this important environment for exploration. This implies operating even during periods in which communication with Earth is not possible," says Richard Fisackerly.

Autonomous operations ensure that the mission continues even without communication with Earth, but the potential for darkness is a completely different challenge. The Sun sits low in the sky, grazing along only a few degrees above the horizon, so its visibility depends on the local topography and on the precise location of the landing site.

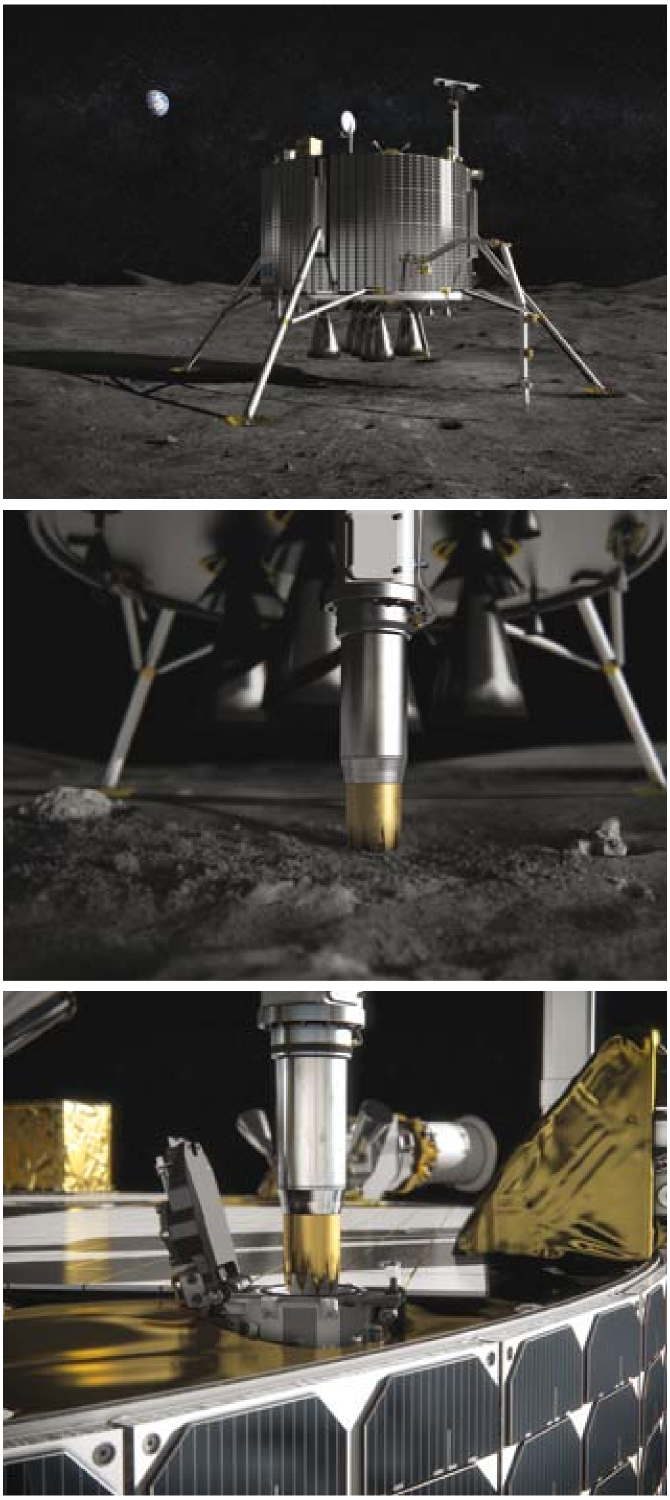
In trying to select the best possible landing sites with illumination for an extended period up to several months, mission planning places a strong emphasis on the analysis of topographic and image data. But it cannot be excluded that the Lander will experience short darkness periods, such as when the Sun passes behind a peak on the horizon or a large obstacle nearby.

"We predict these darkness periods to be in the order of tens of hours based on simulations performed before the mission. But it will only be after landing that the precise timing and duration of periods without illumination are known and can be used for planning of the operations.

The Lander must therefore be designed to maximise its robustness to darkness and low temperatures by building in a 'survival' or 'hibernation' mode," says Diego De Rosa. The Lander can be configured to endure several days of darkness, with critical temperature-sensitive equipment, such as batteries, electronics and communications systems, cocooned in the core of vehicle. This capability will allow the Lander to extend its period of surface operations for as long as possible.

Exploration enabling science

The Lander platform provides an opportunity to carry out investigations on the surface that enable future robotic and human exploration. Living and operating on the lunar surface in a sustainable way will be a major challenge, in which there are many fundamental unknowns.



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The Lander carries experiment packages that will analyse lunar surface samples. From top, the Lander deploys its robotic manipulator arm, then positions the sample collection device on the surface, and then returns it to the lander body to deposit the samples for analysis (ESA/AOES Medialab)

On-the-spot measurements provide a vital element in understanding these unknowns and a model payload has been put in place in the Phase-B1 study that addresses a range of important questions.

One major issue for exploration during the Apollo era was dust. Dust stuck to surfaces leading to thermal and mechanical problems, interfered with mechanisms, prevented proper sealing of vacuum seals and entered the crew compartments of manned spacecraft where it caused operational difficulties. More recently, the potential toxic effects of this material have also been realised.

Understanding the properties and behaviour of dust is therefore an important aspect of the Lunar Lander mission, and is supported by the sampling operations of the robotic arm coupled with microscopic investigations of dust particle properties.

Dust also plays an important role in the environment at the lunar surface, where solar ultraviolet radiation and high-energy particles, along with solar wind and magnetospheric plasmas, are incident directly on the dusty surface. This results in interactions that are complex and poorly understood, and which lead to a unique and challenging operating environment for exploration that may include strong electric fields, levitated dust and the global transport of dust particles.

The Lander's model payload includes a suite of instruments to measure the properties of this dusty plasma environment and provide insight into the underlying physics that drive it.

"From previous missions we know that lunar dust has major effects on surface systems from rovers, to life support systems, to radiators and solar panels, as well as the physiology of the astronauts themselves. However we have a poor understanding of the properties and behaviour of this dust *in situ* and its interactions with systems. In order to learn to mitigate the effects of dust and to live and work in this environment, we have to properly understand it. The Lunar Lander aims to address this," says James Carpenter, ESA's Lunar Lander project scientist.

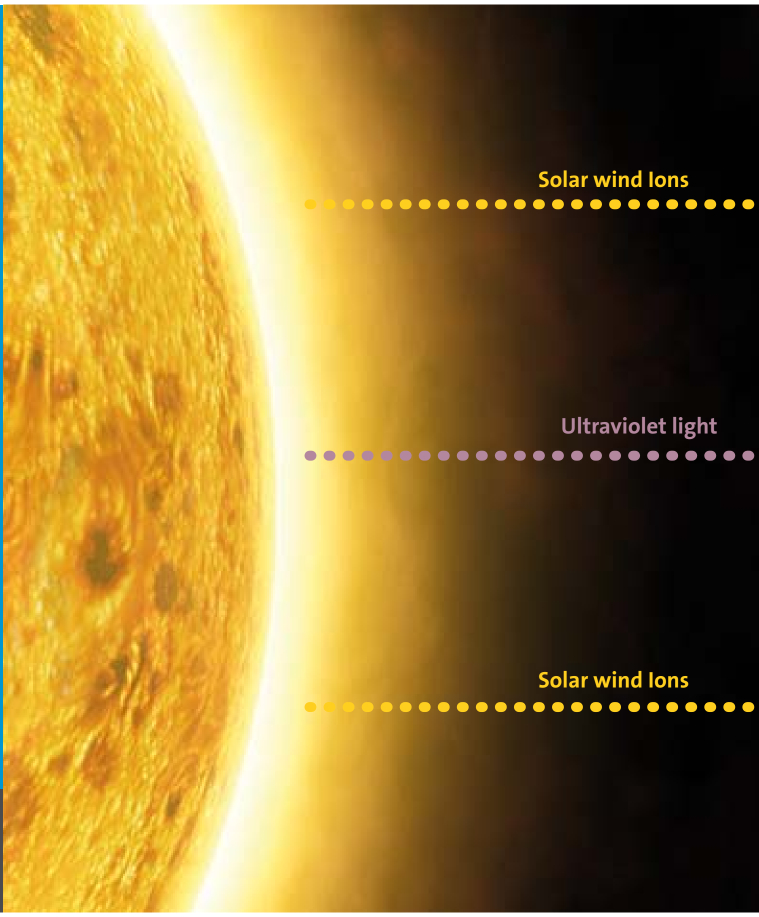
The lunar environment also offers opportunities for both science and future exploration. One example, which has become apparent in recent years following new scientific results, is the likely abundance of volatile materials, including water ice, at or near the surface.

→ Science to support exploration

The lunar surface is subject to incident ultraviolet radiation and charged particles from the Sun and Earth's magnetosphere. These particles charge the dusty lunar surface and may result in global and local transport mechanisms for charged lunar dust.

During the Apollo missions, lunar dust was found to be a big problem for operational activities. Dust stuck to surfaces and was abrasive, often preventing vacuum seals from operating correctly. Dust inside the pressurised modules could inhibit human activities and may pose a serious threat to health when inhaled.

The Lunar Dust Environment and Plasma Package (L-DEPP) is one candidate payload under study for the Lunar Lander mission. The experiment combines measurements of the complex local plasma and electromagnetic environment with investigations into the properties and behaviour of dust, and the effects of this environment on radio measurements.



→ Charging and electric fields experienced at the lunar surface

Understanding the nature of these volatiles, including their origins and the processes that affect them, is a first step in their potential use as resources for future missions. But this information will also provide insights into the history of the inner Solar System, with wide ranging implications for planetary sciences, Earth sciences and astrobiology.

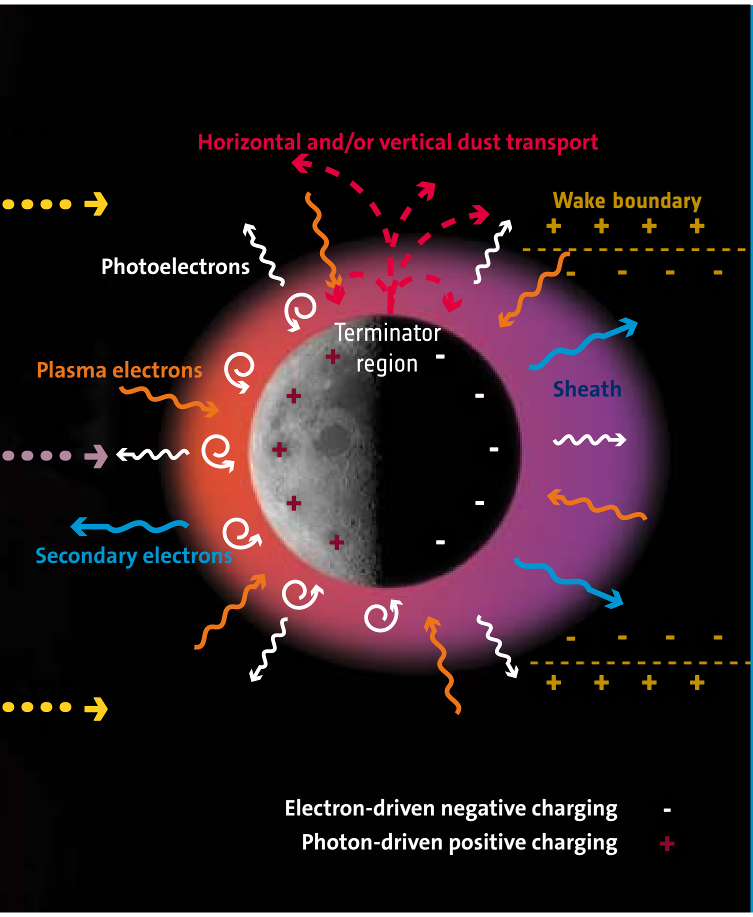
Rebirth of lunar exploration

The Lunar Lander mission prepares for the future, both technologically and in terms of enabling science. This fits within an international context that has seen a rebirth of interest in lunar exploration, a fleet of orbital missions gathering new data, and a drive to take the next step down to the surface.

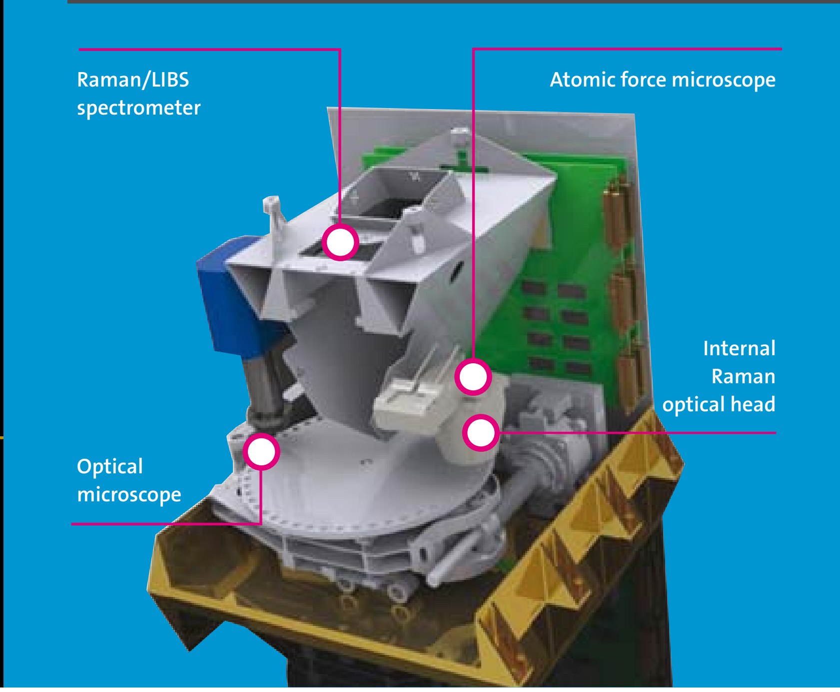
For Europe and European industry in particular, this self-standing mission is an opportunity to take the lead in the precision landing technologies needed for the future, which can open the door to cooperation on more ambitious missions in the coming decade.

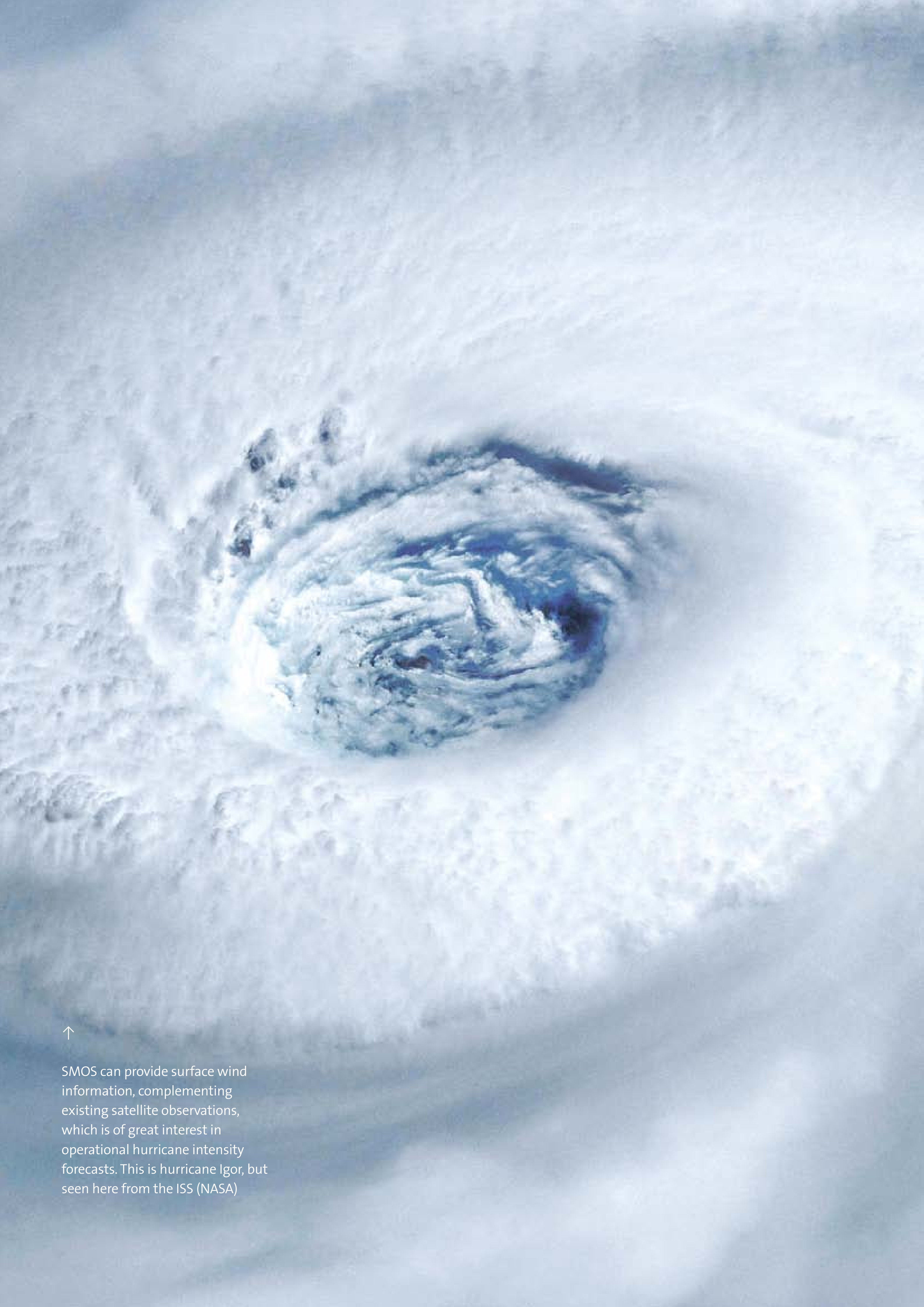
A decision on the next phase of the Lunar Lander mission will be made at the ESA Ministerial Council at the end of 2012. ■

↑ December 1972, Apollo 17 astronaut Harrison Schmitt experiences lunar dust (NASA)



↓ The Lunar Dust and Regolith Analysis Package (L-DAP) is one of several potential payloads under study for the Lunar Lander. The experiment investigates the properties and chemistry of dust and regolith grains for particles as small as tens of nanometres (SEA)





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SMOS can provide surface wind information, complementing existing satellite observations, which is of great interest in operational hurricane intensity forecasts. This is hurricane Igor, but seen here from the ISS (NASA)

→ THE SUPPORT TO SCIENCE ELEMENT

A pathfinder for innovation in Earth observation

Diego Fernández-Prieto, Michael Rast and Mark Doherty
Directorate of Earth Observation, ESRIN, Frascati, Italy

Mark Drinkwater and Pierluigi Silvestrin
Directorate of Earth Observation, ESTEC, Noordwijk, The Netherlands

Earth observation from space is entering a new era, characterised by a growing number of increasingly advanced and sophisticated satellite missions

These new missions will provide scientists and other data users with an unprecedented capacity to observe and monitor the Earth system and its dynamics, from local to global scales, with different new and complementary techniques.

For ESA, this new era has already started. With the launches of the first three Earth Explorer missions – GOCE, SMOS and CryoSat – new and unique data are already being delivered to the scientific community.

The coming Sentinel satellites for the Global Monitoring for Environment and Security (GMES) initiative will not only complement existing monitoring missions, providing operational long-term data to establish critical information services for Europe, but also represent a major source of data for scientists worldwide.

The full exploitation of this growing capacity in terms of enhanced and new observations represents both a major scientific challenge and a unique opportunity for innovation and science. It will enable huge synergies offered by this multi-mission observational potential, together with the continuous advances in Earth system models and in situ observation networks.

Anticipating this opportunity, ESA launched a new element of its Earth Observation Envelope Programme in 2008, called the Support To Science Element (STSE). Its main purpose is to provide an efficient, flexible and dynamic mechanism to support scientists and industry in Member States. It would innovate and explore opportunities and challenges in terms of novel observations, new algorithms, enhanced products and new Earth science results offered by the rapidly expanding portfolio of ESA's Earth observation missions.

To achieve this objective, the programme has been split into four themes, or 'pillars', that respond to an end-to-end approach to science. These are:

1. ***Looking for next-generation Earth science missions***
Developing and exploring novel mission concepts and observational techniques to form the basis for the next generation of European scientific satellites

2. ***Innovation in exploiting Earth observation data***
Developing advanced and innovative methods, algorithms and products that could exploit the increasing ESA Earth observation assets and open doors to new scientific results and new applications

3. ***Supporting young scientists***
Involving the next generation of young scientists in the use and scientific exploitation of ESA Earth observation missions to foster scientific excellence in Europe

4. ***Ensuring ESA's contribution to international science***
Fostering the exploitation of Earth observation by new and wider user communities, in particular, major international scientific programmes that address key open questions in Earth system science

Pillar 1: Looking for next-generation Earth science missions

Understanding the Earth system has raised interest in the international political arena. This interest has increased the demand for increasingly accurate and reliable observations to describe the dynamics of critical variables and processes in different components of the Earth system and climate. Here, the exploration and development of novel mission concepts should respond to the needs of the international scientific community.

The STSE has initiated a number or activities in innovative areas with three main priorities:

- to focus on current observational gaps, looking for new concepts that could provide answers to major scientific questions (for example, retrieving high-resolution (15 km) all-weather sea-surface temperatures and winds, exploring passive microwave concepts);
- to investigate the evolution of current Earth Explorer satellites (for example, the potential evolution of EarthCARE into a multi-wavelength high spectral resolution lidar concept);
- to advance the scientific basis of immature but promising Earth Explorer mission proposals following the recommendations of the ESA Earth Science Advisory Committee (for example, satellite-to-satellite lidar occultation concepts).

But this route also includes a new initiative: the 'Earth observation-convoy' project series, dedicated to exploring new mission constellations. These are made up of small targeted satellites flying in formation in long-term operational missions (such as the GMES Sentinels), offering new opportunities for synergies.

→ Result

Laser experiment simulating a new satellite-to-satellite observation principle

A unique experiment, involving laser beams transmitted from a mountain peak on La Palma to Tenerife, was carried out to test a novel mission concept in 2011. The concept uses an active link between two satellites orbiting Earth and is based on the technique of differential absorption spectroscopy at infrared wavelengths to acquire accurate measurements of atmospheric greenhouse gases, such as carbon dioxide and methane.

For the ground-based demonstration, equipment was set up on each island, with ESA's Optical Ground Station on Tenerife (2390 m above sea level) acting as the receiver. The transmitter was installed at the Observatorio del Roque de los Muchachos at a similar altitude on La Palma. From the tops of these volcanic mountains separated by 144 km of Atlantic Ocean, there is an unobstructed line of sight between the two facilities, making this one of the best sites in the world to conduct such experiments.

During a two-week period, the study team, including scientists from the University of Graz in Austria and the Universities of York and Manchester in the UK, recorded the first-ever data of this kind.

↑ Laser beam from the ESA Optical Ground Station on Tenerife

↑ Location of experiment sites, Canary Islands, July 2011

These activities have been also complemented by the creation of a number of software packages, including simulation tools and experimental datasets. These will give the scientific community the necessary elements to prepare the future exploitation of emerging concepts.

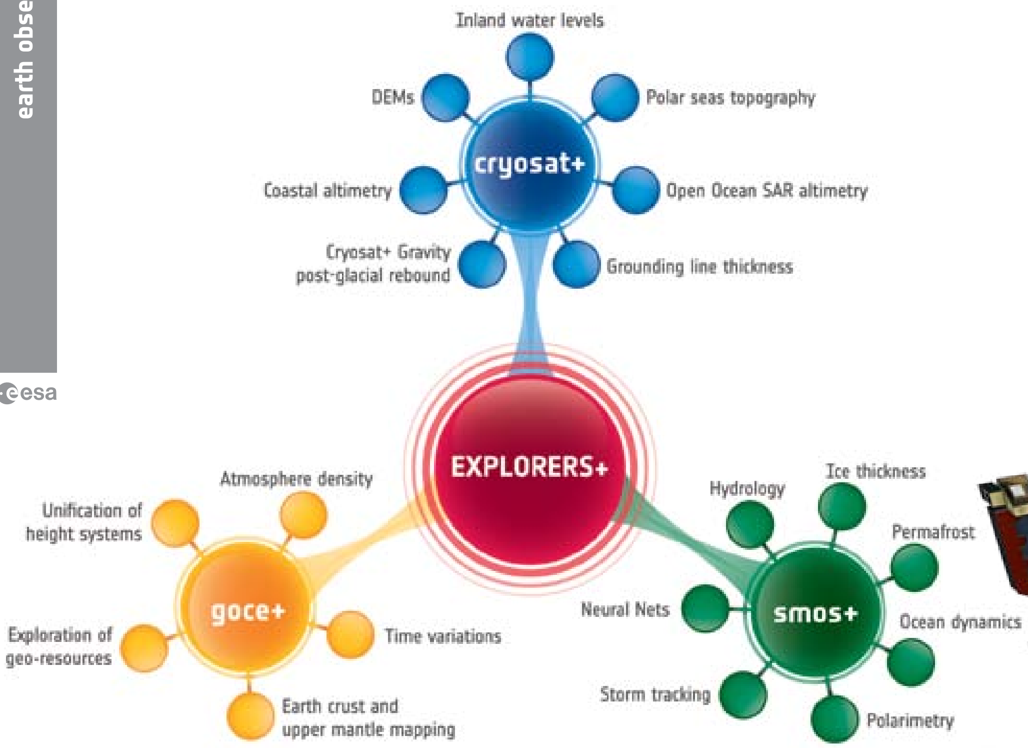
Pillar 2: Innovation in exploiting Earth observation data

In years to come, the increasing number of Earth observation missions available for scientific and operational use will provide opportunities to develop methods, algorithms and products that could open doors to new scientific results and applications.

In the last few years, almost 20 projects have been set up for maximising the scientific return of ESA missions, with special attention given to the recently launched Earth Explorer satellites and the continuously growing ESA archives.

A significant effort has been made in promoting the exploitation of the first Earth Explorer missions, as well as to exploring their full capacity beyond their primary scientific goals. The 'Explorer Plus' project series was started, which includes more than 10 studies to foster new applications of GOCE, CryoSat and SMOS data.

Through these projects, STSE leads to new applications for the Earth Explorers, such as atmospheric density mapping with GOCE, sea-ice thickness retrievals with SMOS, and innovative land applications for CryoSat. But this also enlarges the user base beyond their original science communities and promotes discoveries, demonstrating the value of these types of missions as precursors for future mission concepts.



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Major thematic areas addressed by the 'Explorer Plus' activities

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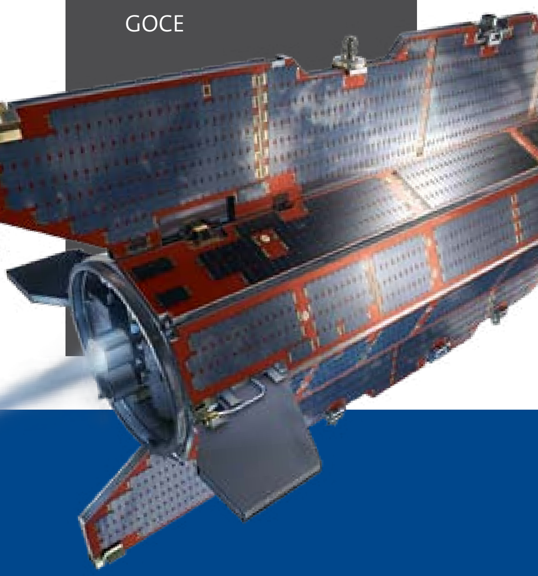
GOCE



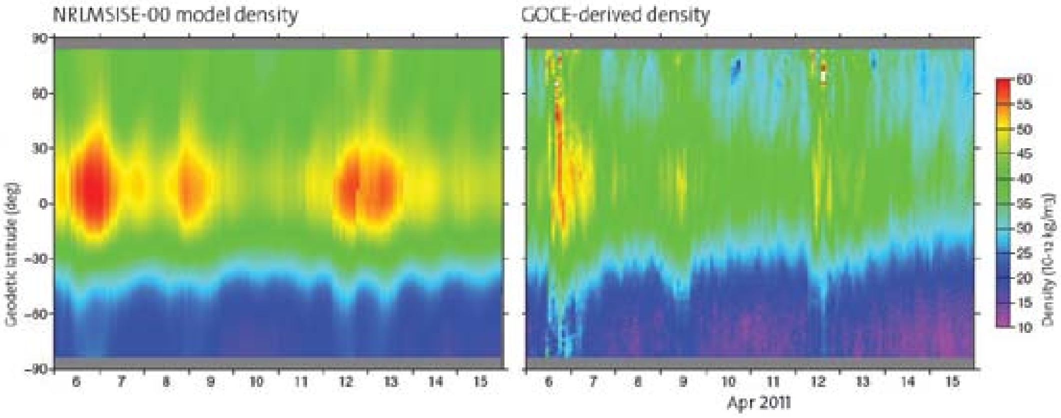
→ Result

GOCE as an atmospheric mission

The accelerometers carried by GOCE were designed primarily to provide critical information on Earth's gravity field. The GOCE+ AirDensity project, led by the Technical University of Delft, aims to exploit this information to derive highly detailed data on thermospheric density and winds.

GOCE's orbit is unique; it is Sun-synchronous and, thanks to its drag-free control system, its altitude can be kept fixed for several years at about 255 km. This leads to sampling characteristics that are ideal for studying the effect of variations of solar and magnetospheric energy input to the thermosphere. The density and wind retrieval algorithm is based on the principle that the observed and modelled aerodynamic acceleration vectors should match both in direction and length.

Results show that, even though GOCE was not primarily designed for studies of the thermosphere, its application in this area has resulted in density and wind datasets with information at unprecedented levels of coverage and precision.



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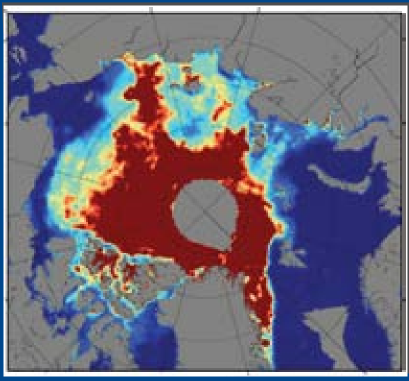
A sample of the first GOCE-derived density observations, compared with equivalent NRLMSISE-00 model observations to the left. The GOCE data shows the sharply delineated responses of the thermosphere to several moderate fluctuations in geomagnetic activity (TU Delft/CNES/HTG)

→ Result

SMOS helps CryoSat to map sea-ice thickness

Thin sea ice, less than about 0.4 m thick, is of particular interest for the energy exchange between the atmosphere and the ocean in polar regions. ESA's Soil Moisture and Ocean Salinity (SMOS) mission can be used to retrieve information about sea-ice thickness, complementing the CryoSat mission. The SMOSIce project, led by the University of Hamburg, has demonstrated the capability of SMOS to measure the thickness of thin sea ice (i.e. thinner than 0.5 m). Validation with ice thickness derived from electromagnetic induction measurements (Alfred Wegener Institute) and from thermal infrared imagery (Finnish Meteorological Institute) confirms the validity of the method.



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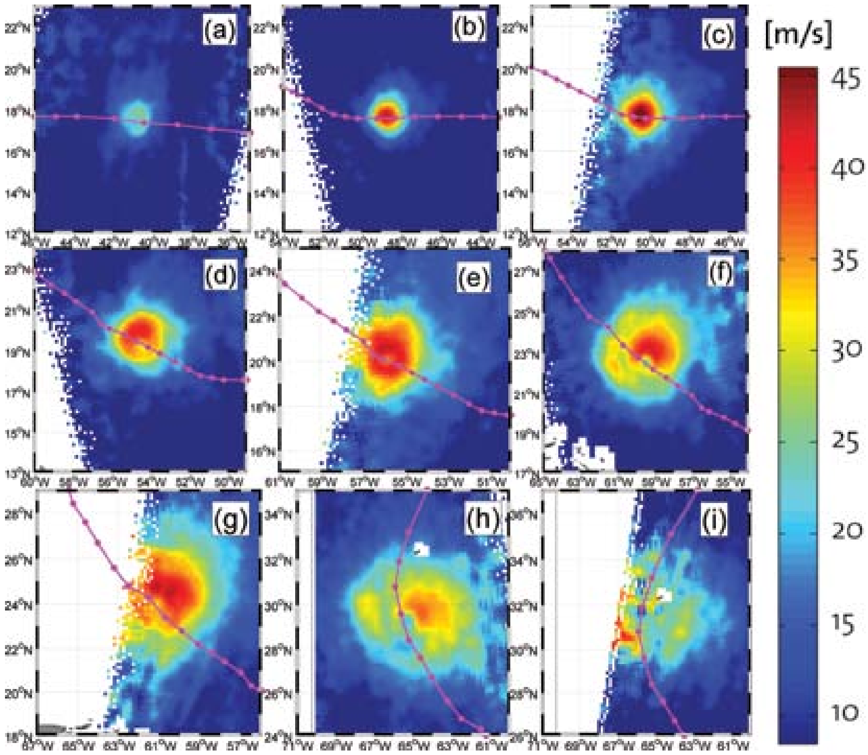
Sea-ice thickness during the Arctic freeze-up as seen by SMOS in November 2010 (KlimaCampus, Univ. Hamburg)

→ Result

SMOS for extreme storms

The SMOS mission currently provides multi-angular L-band (1.4 GHz) brightness temperature images of Earth. Because upwelling radiation at 1.4 GHz is significantly less affected by rain and atmospheric effects than at higher microwave frequencies, the new SMOS measurements offer unique opportunities to complement existing ocean satellite high wind observations, which are often erroneous in these extreme conditions.

This new capability was recently demonstrated by analysing SMOS data over hurricane Igor, a tropical storm that developed to a Saffir–Simpson category 4 hurricane in the period 11–19 September 2010. Thanks to its large spatial swath and frequent revisit time, SMOS observed the hurricane nine times during this period. Surface wind speeds were estimated from SMOS brightness temperature images using an algorithm developed by scientists from Ifremer and CLS/Brest. This shows the capacity of SMOS to provide quantitative and complementary surface wind information, which is of great interest in operational hurricane intensity forecasts.



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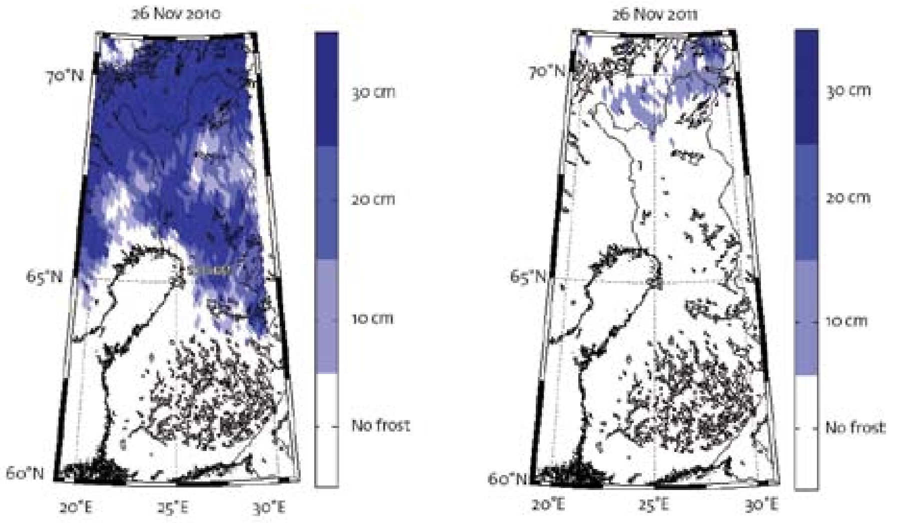
Sea-surface windspeed fields (m/s) retrieved from SMOS data over the Saffir–Simpson category 4 hurricane Igor that developed in the North Atlantic Ocean from 11 (a) to 19 (i) September 2010. The magenta curve shows the hurricane eye track (N. Reul/Ifremer & J. Tenerelli/CLS)

→ Result

SMOS measuring permafrost depth

Detecting frozen soils (and the depth to which they are frozen) from space has been an unresolved scientific problem. During the freezing process, SMOS brightness temperatures increase as the top 50 cm of the soil is frozen. Over winter, the readings remain stable, even with the presence of deep snow. Thawing in spring leads to a decrease in brightness temperature. SMOS can detect frozen soil from space, and the depth of freezing can also be inferred, as demonstrated by the SMOS+ Permafrost study carried out by the Finnish Meteorological Institute and Gamma Remote Sensing (CH).



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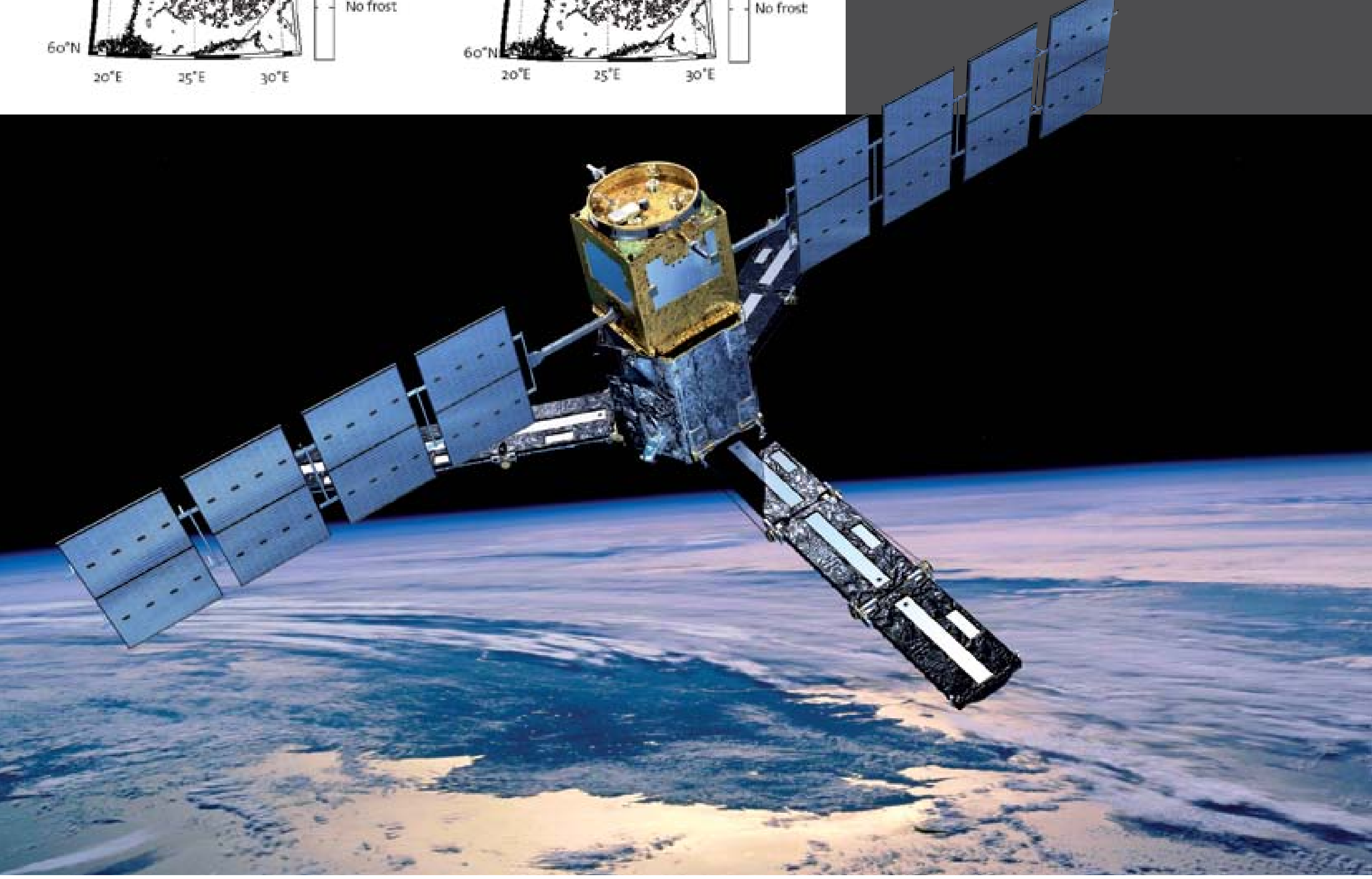
The difference in frozen soil area and depth between 26 November 2010 and 26 November 2011 in northern Finland. In 2001, the late frost is associated with Europe's mild weather last autumn (FMI/ Gamma)

↓

SMOS

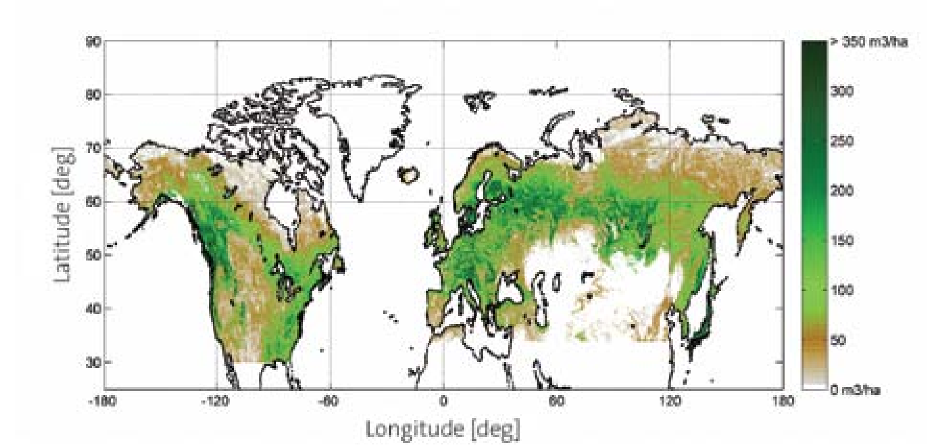


→ Result

Radar data estimating global boreal forest biomass

Having a large-scale boreal forest biomass inventory would allow scientists to understand the carbon cycle better and to predict Earth's future climate more accurately. However, obtaining these maps has been very difficult – until now. A new processing algorithm was developed by Gamma Remote Sensing (CH) and the University of Jena (DE) using images from the Advanced Synthetic Aperture Radar on ESA's Envisat satellite.

It allows for the retrieval of boreal forest biomass with an accuracy well beyond the levels that have been previously reported, i.e. up to 500 cubic metre per hectare. Using this method, the ESA archives will be exploited to generate yearly global maps of biomass (Growing Stock Volume, GSV) over the entire boreal ecozone with a resolution of 10 km and accuracies of 20%, while avoiding the problems associated with saturation usually encountered with C-band radar retrievals at high biomass densities.



← Map of forest Growing Stock Volume (GSV) for the northern hemisphere. GSV was estimated with the BIOMASAR algorithm using Envisat ASAR ScanSAR backscatter images acquired in 2005

Pillar 3: Supporting young scientists

In 2009, as part of the STSE activities, the 'Changing Earth Science Network' was launched to support young scientists at post-doctoral level in ESA Member States to undertake cutting-edge research activities addressing the 25 challenges of the ESA science strategy.

The initiative first supported a set of 10 young scientists from seven Member States. A second call in 2010 resulted in another group of 10 projects enlarging the geographical distribution of the projects to nine countries. These projects address all the different areas of Earth science including major open questions and important topics, such as the global study of CO_2 and methane dynamics, the use of Envisat data to enhance the characterisation of ocean–atmosphere fluxes, the development of new methods to monitor glacier dynamics in Greenland, the improvement of fire characterisation, and many others.

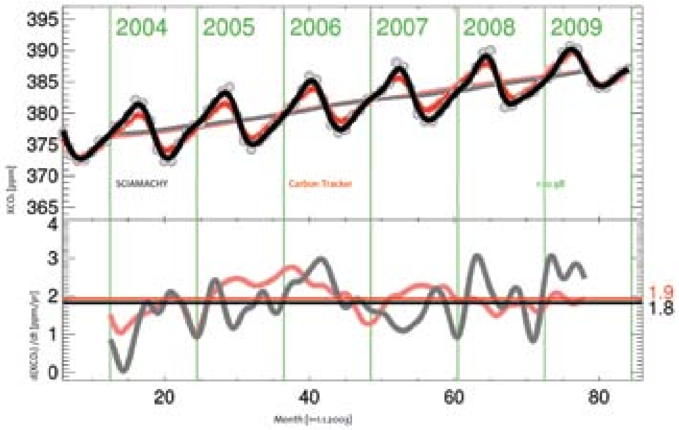
This initiative will not only maximise the scientific return of ESA missions, but also consolidate a critical mass of young scientists in Europe with a deep practical knowledge of ESA Earth observation data. At the same time it improves the interactions between ESA and the next generation of scientists. To facilitate this process, young scientists participating to the initiative also have the opportunity to carry out part of their project at an ESA establishment as a visiting scientist working with ESA experts.

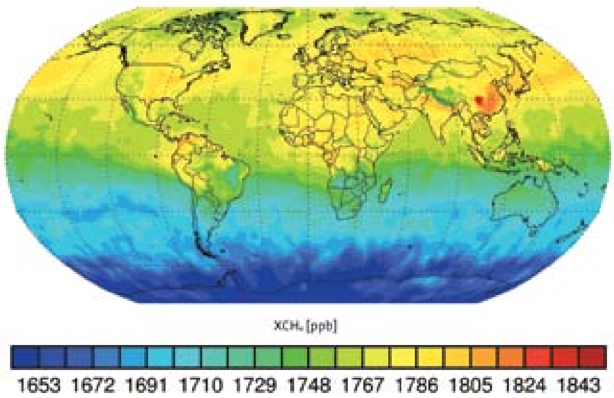
↑ Distribution of the participants at the Changing Earth Science Network

→ Result

Global evolution of CO_2 and methane

As part of the Changing Earth Science Network, Oliver Schneising from the University of Bremen has studied the global temporal evolution of two of the major greenhouse gases, CO_2 and methane, retrieved from SCIAMACHY. The results confirmed not only the pronounced seasonal cycle due to growing and decaying vegetation, but also the steady increase of atmospheric carbon dioxide primarily caused by the burning of fossil fuels. The retrieved global annual mean carbon dioxide increase amounts to about 2 ppm/yr. Major methane source regions, such as the Sichuan Basin in China, famous for rice cultivation, and the inter-hemispheric gradient, are clearly visible in the SCIAMACHY data. The retrieved methane results also show that, after years of stability, atmospheric methane has started to rise again in recent years, which is consistent with surface measurements. This new methane increase is a worldwide phenomenon with the largest increase observed in the tropics and northern mid and high latitudes amounting to about 8 ppb/yr since 2007.





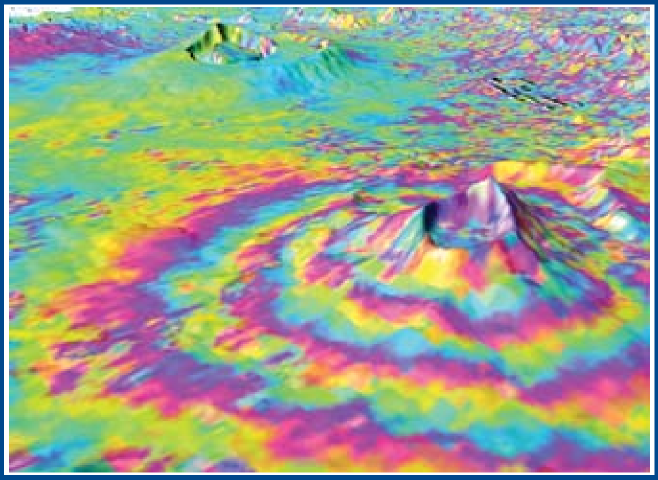
↑ Comparison of carbon dioxide column-averaged mole fractions retrieved from SCIAMACHY with NOAA's CarbonTracker assimilation system, demonstrating the seasonal cycle and the increase of CO_2 with time

↑ Seven-year mean (2003–9) of retrieved SCIAMACHY methane, with clearly visible major methane source regions and the inter-hemispheric gradient

→ Result

Understanding the formation and dynamics of the African Rift Valley

East Africa is being gradually pulled apart by the forces of plate tectonics and eventually a new ocean will form. Geologists use the lithological record to analyse the development of the rift over millions of years. Now images from satellites such as Envisat allow the monitoring of active changes over timescales ranging from days to years. The ISMER project, carried out by Juliet Biggs from the University of Bristol, has studied the processes that drive earthquake swarms at different stages of maturity along the rift, and has remotely monitored land surface displacements at the rift volcanoes. Along the way, the project discovered uplift or subsidence at eight volcanoes that were previously believed to be inactive and has identified new faults.



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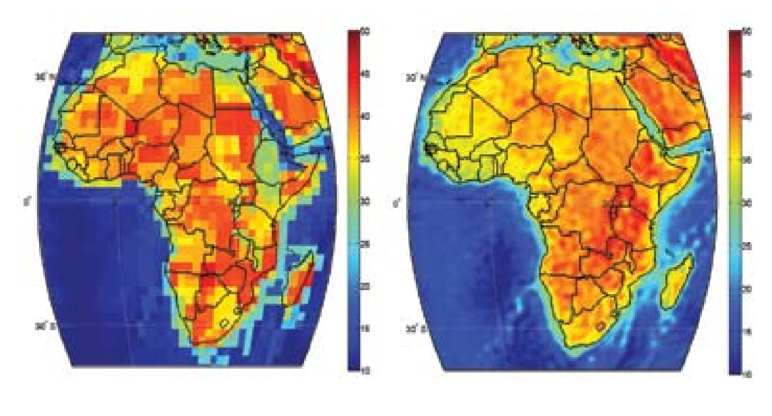
Volcanic uplift in the African Rift Valley, captured by ESA's Envisat

→ Result

First GOCE crust-mantle atla

The study of the discontinuity surface between Earth's crust and mantle – the Mohorovičić discontinuity or 'Moho' – is fundamental in Earth sciences to understand the dynamics of Earth's interior. Usually unknown anomalous subsurface density distributions are derived from ground-based gravity observations. The Moho depth is commonly estimated by means of seismic and/or gravimetric methods. However, Moho models based on seismic or gravity data are usually limited by poor data coverage. Daniele Sampietro, from the Polytechnic University in Milan, has generated the first global high-resolution map of the boundary between Earth's crust and mantle from data from ESA's GOCE satellite. The results provide the first estimate ever produced to map Moho depth almost worldwide with unprecedented resolution, and in regions where no ground data are available.



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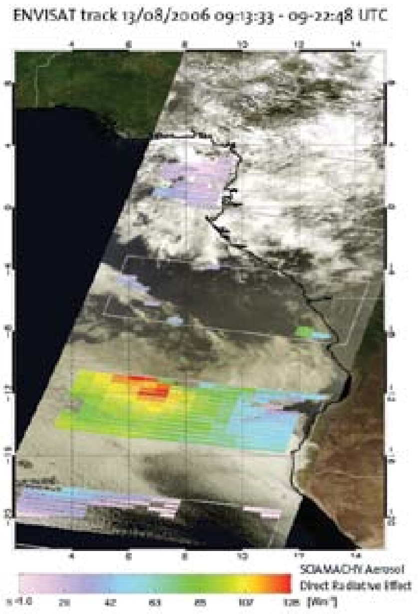
African Moho map from CRUST2 and from the inversion of GOCE data (D. Sampietro/Polytechnic Univ., Milan)

→ Result

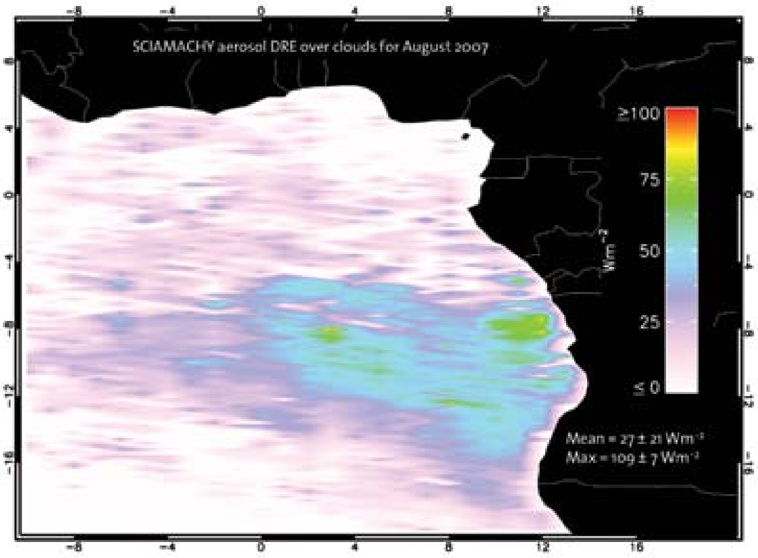
Revealing the role of aerosols in climate

Aerosols play an important role in Earth's radiation balance, by scattering and absorbing solar radiation. More importantly, aerosols can change cloud dynamics as cloud condensation nuclei by absorbing solar radiation, thereby heating the atmosphere. Unfortunately, space-based observations of aerosols in the presence of clouds are difficult and aerosol parameters are normally retrieved only after cloud screening. The CLARIFI projects, carried out by Martin de Graaf from the Royal Dutch Meteorological Institute (KNMI), provided the first aerosol Direct Radiative Effect (DRE) estimates, the amount of absorbed radiation by the aerosols, above clouds from SCIAMACHY, which had never been retrieved from satellites before.

↙ MERIS RGB composite overlaid with SCIAMACHY aerosol DRE on 13 August 2006, near the west coast of Africa, showing the horizontal distribution of clouds, and the radiation absorbed by aerosols above the clouds.



↓ Monthly averaged aerosol DRE over marine water clouds measured by SCIAMACHY in August 2007 over the South Atlantic Ocean (M. de Graaf/KNMI)



Pillar 4: Ensuring ESA's contribution to international science

International coordinated scientific efforts have always been one of the main catalysts for discoveries and progress in scientific knowledge. Major international scientific programmes and initiatives, such as the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP) or the joint projects of the Earth System Science Partnership, among others, provide a coordinated framework for international scientific collaboration in Earth system science and climate research, involving thousands of scientists worldwide.

Since 2009, STSE has initiated a number of collaborative research and development activities to face key open questions in Earth system science where data from ESA satellites can play a fundamental role. These activities bring together Earth observation experts, modellers and Earth system scientists to address current global scientific challenges jointly. These also allow a dialogue among communities to explore, facilitate and promote the integration of Earth observation-based information into advanced Earth system models.

These activities not only aim to ensure ESA data contribution to major international scientific efforts, but also try to foster the use of Earth observation data among extended Earth science communities and, in some cases, those not yet familiar with the use of such data.

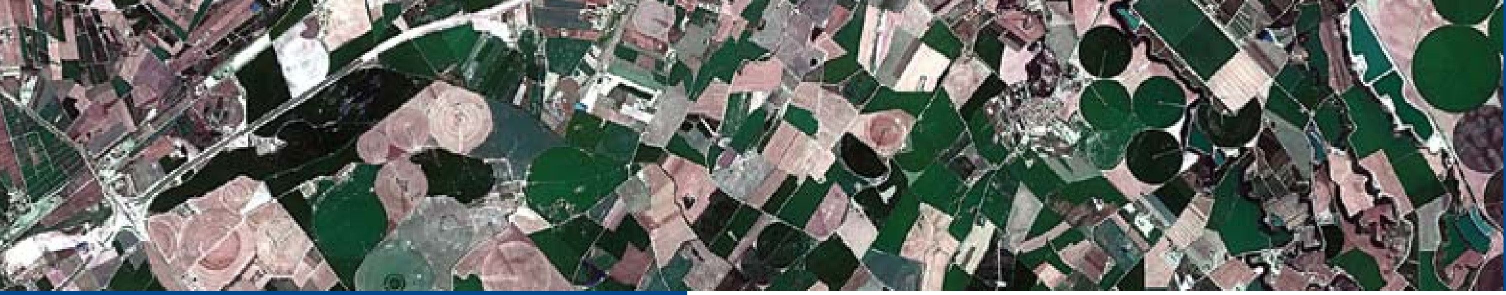
So far, active collaborations have been established with the Cryosphere, Water Cycle and Stratospheric science projects of the WCRP (CliC, GEWEX and SPARC), the Land-Atmosphere Interactions project of IGBP (iLEAPS) and the international ocean-atmosphere interactions project (SOLAS).

The partnerships are implemented through dedicated STSE research projects, joint international conferences and publications. These are effective tools to maximise scientific return of ESA missions, while ensuring the programmatic coordination and alignment of STSE initiatives with the main scientific priorities.

Preparing for the future

The years to come will offer unprecedented prospects for science, but also significant challenges to be faced. Here, STSE will create new opportunities for scientists and industry in ESA Member States to prepare for the future.

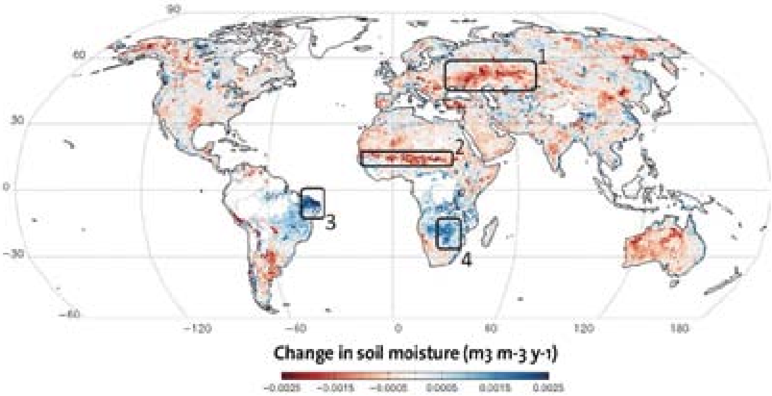
The well-established portfolio of ESA candidate and planned missions offers a window to the future in terms of the observation systems that will be available within the coming decade. There is an opportunity to identify and target major gaps and needs in observations and



→ Result

First view of 30 years of soil moisture dynamics from space

As part of ESA's WACMOS project, a harmonised soil moisture dataset with over 30 years of observations has just been developed, based on eight different satellite observation systems including Nimbus-SMMR, DMSP-SSM/I, TRMM-TMI, AMSR-E, Coriolis Windsat, ERS-1, ERS-2 and MetOp-ASCAT. The harmonised datasets have been validated extensively with *in situ* observations and describe the soil moisture of the upper centimetres with an accuracy of between 0.02 m^3/m^3 and 0.1 m^3/m^3 depending on location. The first trend analysis of this dataset revealed subtle soil moisture trends over the entire globe varying from -0.06 m^3/m^3 to 0.06 m^3/m^3 over the last 31 years. The strongest negative trends can be found in Russia, Kazakhstan and the Sahel region. Strong positive trends are found in north-eastern Brazil and southern Africa.



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Trends in annual average satellite soil moisture from 1979 to 2010. These values were derived from the WACMOS soil moisture dataset (TUW/VUA)

measurements for the future, and STSE will continue to investigate the novel mission concepts responding to these gaps and contribute to the preparation of ESA's next generations of missions.

STSE will also continue to foster full exploitation of capabilities and synergies offered by the growing number of current and future ESA missions, with special attention to the Earth Explorers and the rapidly growing ESA archives.

This increasing multi-mission capability will be instrumental in expanding the user base of ESA data to new scientific communities in all areas of Earth system science. STSE has already started establishing bridges among these communities through dedicated Earth system science projects, conferences and partnerships with major international scientific programmes.

Preparing for the future not only involves scientific and technological developments, but also postulates preparing future generations of scientists. An important priority for STSE is the support to young scientists in Member States enabling them to carry out research activities addressing the major scientific challenges of the ESA science strategy.

Science at the service of citizens will also be an important priority for STSE in the coming years. The achievements and results of the programme can contribute to educating the public, policy makers and scientists on the benefits of Earth observation data in Earth system science. New communication mechanisms and tools will be developed in order to make STSE attractive not only to scientists, but also to get Earth observation science closer to the young generations. ■

→ NEWS IN BRIEF

In this stunning photo, ATV *Edoardo Amaldi* approaches the ISS for docking on 28 March 2012. Taken by NASA astronaut Don Pettit, it shows the ATV thrusters firing under automated control as the vessel nears the Russian module of the ISS (ESA/NASA)

Third ATV arrives at Station

ESA's ATV *Edoardo Amaldi* lifted off from Europe's Spaceport in Kourou, French Guiana, on 23 March on an Ariane 5 heading towards the International Space Station.

The Automated Transfer Vehicle, the most complex spacecraft ever produced in Europe, is delivering essential supplies to the orbital outpost. It will also reboost the orbit of the ISS while it is attached for about five months. This is the third in a series of five supply ships developed in Europe to fulfil its obligation towards the exploitation costs of the Station.

ATV *Edoardo Amaldi* completed a technically perfect automated docking with the Russian Zvezda module of the ISS on 29 March. The procedure was monitored by the astronauts from inside the ISS and by the ESA/CNES mission operations team at the ATV Control Centre, Toulouse.

Docking marked the start of an intensive period of activity to open the hatch, enter ATV and confirm that all its systems were operating normally and were fully integrated with the data, electrical and other systems of the ISS.

After opening the hatch and first ingress, the crew installed an air scrubber to remove any contaminants that may have come loose inside ATV's pressurised cargo area. Early on 30 March, the crew also installed the Russian POTOK air filter unit as a measure against any bacterial contamination that may have occurred on ground before the hatch was closed for launch.

Two days later, ATV *Edoardo Amaldi* conducted its first 'test' reboost, proving that it is fully integrated with the Station and ready to perform orbit boosts and manoeuvres if necessary.

ATV's thrusters ran for 351 seconds, increasing ISS velocity by 1.0 m/s and boosting average altitude by 1.73 km. The successful test burn means that ATV is ready for a series of larger planned reboosts (the first expected on 5 April) and to conduct debris avoidance manoeuvres when necessary.

ATV is delivering 860 kg of propellant, 100 kg of oxygen and air, and 280 kg of drinking water, all to be pumped into

←

André Kuipers unloading cargo in ATV *Edoardo Amaldi*

→

ESA astronaut André Kuipers (right) and Russian cosmonaut Oleg Kononenko monitor the docking

← ATV *Edoardo Amaldi* in flight

the Station's tanks. It is also carrying 2200 kg of dry cargo such as scientific equipment, spare parts, food and clothes for the astronauts.

During the five months it will spend docked to the Station, it will act as a temporary module, providing 45 cubic metres of extra crew quarters on the orbital outpost. On previous missions, ATV was welcomed by the astronauts as 'the quietest place in the Station' and was often the preferred area for working.

At the end of its mission, scheduled for 27 August, ATV *Edoardo Amaldi* will separate from the Station, packed with waste bags. The following day, it will be directed to burn up safely in the atmosphere during reentry over the South Pacific Ocean.

Malta signs Cooperation Agreement

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Karlheinz Kreuzberg, Head of ESA Director General's Cabinet (left), signing the Cooperation Agreement with Jeffrey Pullicino Orlando MP, Chairman of the Malta Council for Science and Technology. Behind them are Nicholas Sammut, Vice Chairman & CEO of the Malta Council for Science & Technology (left), and the Hon. Lawrence Gonzi, Prime Minister of Malta (Office of PM, Malta)

Malta signed a Cooperation Agreement with ESA on 20 February. The objective of this agreement is to allow Malta and ESA to create the framework for more-intensive cooperation in ESA projects in the future.

Discussions with ESA started in 2004 through the Maltese Embassy in Paris. The Malta Council for Science and Technology (MCST), in charge of space affairs and also responsible for the National Strategy for Research and Innovation, was appointed as ESA's counterpart.

The priority areas for Malta in research are telecommunications and satellite technology, as well as high-technology engineering (for example, Micro-Electro-Mechanical Systems and nanotechnology). The Department of Physics at the University of Malta has a number of research interests in space activities.

Eight more Galileo navsats agreed

ESA has signed for a further eight Galileo satellites and modifications to Europe's Ariane 5 launcher to carry four navigation satellites at a time.

The contract to build and test the satellites was awarded to a consortium led by prime contractor OHB System AG in Bremen, Germany, and partner Surrey Satellite Technology Ltd (SSTL) in Guildford, UK.

In January 2010, this consortium was awarded the contract to build the previous 14 satellites. As before, OHB is responsible for the satellite platforms and overall integration, while SSTL is building the navigation payloads.

ESA also signed two contracts with Astrium in France, to modify the more powerful Ariane 5 ES variant of the launcher to deploy four Galileo satellites at a time into medium orbit. The Ariane 5 ES is currently used for launching ESA's Automated Transfer Vehicle to the ISS at around 380 km, but requires changes and requalification to deliver satellites to orbital altitudes of 23 222 km.

A dispenser will be developed to carry and then release a quartet of satellites into their target orbits. The requalified launcher, known as the 'Ariane 5 ES Galileo', should be available by the second half of 2014.

The Galileo constellation began to take shape on 21 October 2011, when the first two of four Galileo In-Orbit Validation satellites were launched. The remaining two will be launched at the end of this summer. These will be followed by the Full Operational Capability satellites now being built by OHB and SSTL.

→

Signing the contracts for Galileo and Ariane on 2 February, EC Vice-President responsible for Industry and Entrepreneurship Antonio Tajani, ESA Director of Galileo and Navigation-related Activities Didier Faivre and CEO of Arianespace Jean-Yves Le Gall (Arianespace)

A new generation of meteorological satellites

↑

A Meteosat Third Generation MTG-I sounding satellite

Europe's next fleet of meteorological satellites is set to debut in 2017. Meteosat Third Generation will ensure full continuity with the current Meteosat satellite family, but it will also introduce significant improvements.

The contract between ESA and Thales Alenia Space for developing the new Meteosat Third Generation (MTG) family of satellites was signed on 24 February. Following on from Meteosat Second Generation, MTG is a cooperative venture between Eumetsat and ESA, and will ensure continuity of high-resolution meteorological data to beyond 2037.

The cooperation on meteorological missions between Eumetsat and ESA is a success story that started with the first Meteosat satellite in 1977 and continues today with Meteosat Second Generation and the polar-orbiting MetOp series.

The new series will comprise six satellites: four MTG-I imaging and two MTG-S sounding satellites.

The first two prototype satellites are scheduled for launch in late 2017 and mid-2019, respectively. Both satellites will be positioned in geostationary orbit above the equator at a longitude between 10°E and 10°W.

In addition to the advanced imaging capabilities offered by the Flexible Combined Imager, the satellites will offer an all-new infrared sounding capability and imaging of global lightning that will provide early warning of severe storms.

MTG-S will also carry the Sentinel-4 payload for the Global Monitoring for Environment and Security (GMES) programme. This advanced payload will analyse atmospheric chemistry and identify concentrations of trace gases like ozone and nitrogen dioxide.

The MTG mission will also provide continued support to global search and rescue monitoring, as well as supporting the Advanced Data Collection System.

Fifth ATV named Georges Lemaître

The last Automated Transfer Vehicle, ATV-5, has been named after Belgian scientist Georges Lemaître, continuing the tradition of drawing on great European visionaries to reflect Europe's deep roots in science, technology and culture.

Lemaître was professor of physics at the Catholic University of Leuven, Belgium. He was the first person to propose the theory of the expansion of the Universe, and provided the first observational estimation of the Hubble constant, which he published in 1927, two years before Hubble's article. Lemaître also proposed what became known as the 'Big Bang' theory.

↑ Georges Lemaître

Heading for the Sun

The development and construction phase of ESA's next-generation solar explorer has started. Due for launch in 2017, Solar Orbiter will investigate how the Sun creates and controls the heliosphere.

The contract to build Solar Orbiter was signed on 26 April on the occasion of a ceremony celebrating 50 years of the United Kingdom in space, by Prof. Alvaro Giménez Cañete, ESA Director of Science and Robotic Exploration, and Miranda Mills, Astrium National Director – Earth Observation, Navigation and Science.

Astrium UK will lead a team of European companies who will supply various parts of the spacecraft. The contract carries a value of about €300 million, one of the largest ever signed between the ESA Science Programme and a UK company.

"ESA awarded a very important contract in the space science domain to Astrium's spacecraft design and build facility at Stevenage in the UK. This is testimony to the role that the UK has played in space flight since the launch of Ariel-1 in 1962 and to the important role that the UK continues to play in space science," said Prof. Giménez Cañete.

Solar Orbiter continues a long tradition of European Sun explorers, including Helios 1 and 2, Ulysses and SOHO, all in partnership with NASA, as well as ESA's Proba-2. They have all prepared the ground for Solar Orbiter to advance our understanding of how the Solar System works, one of the major scientific questions of ESA's Cosmic Vision 2015–2025 programme.

Solar Orbiter will investigate the connections and the coupling between the Sun and the heliosphere, a huge bubble in space created by the solar wind that extends far beyond our Solar System. It is through this wind that solar activity can cause auroras and disrupt satellite-based communication.

To get this close-up view, Solar Orbiter will fly to within 45 million km of the Sun, closer than Mercury. It will image the poles for the first time, helping us understand how the Sun generates its magnetic field.

"Solar Orbiter is a fantastic mission," said Prof. Giménez Cañete. "It will help us understand how the Sun, essential to almost all life on Earth, forms the heliosphere and the origin of space weather, which can have an enormous influence on our modern civilisation."

Solar Orbiter is an ESA-led mission with participation from NASA, which will contribute the launcher, one full instrument and one sensor. The current plan is for dedicated launch from the Kennedy Space Centre, Florida, on a NASA-provided Evolved Expendable Launch Vehicle (possibly an Atlas V 401, with a back-up scenario of an Ariane 5 launcher from Kourou, French Guiana).

Ten scientific instruments will be funded by ESA Member States and the United States, and developed by teams led by Principal Investigators from Belgium, France, Germany, Italy, Spain, Switzerland, the UK and the USA.

→

Solar Orbiter

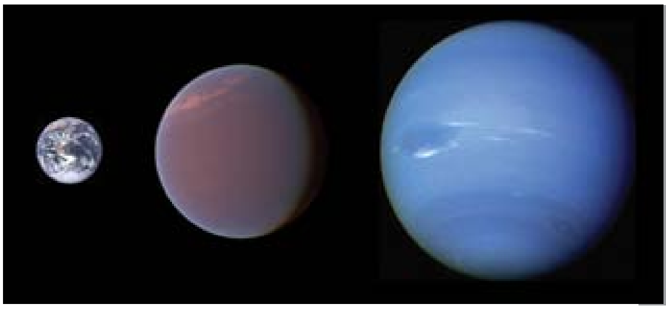
Hubble discovers new kind of planet

Astronomers using the Hubble Space Telescope have found a new class of planet, a water world enshrouded by a thick, steamy atmosphere, smaller than Uranus but larger than Earth.

Planet GJ 1214, located in the constellation of Ophiuchus and just 40 light-years from Earth, was discovered in 2009. GJ 1214b is like no planet we know: about 2.7 times Earth's diameter and weighing almost seven times as much. It orbits a red-dwarf star Gliese 1214 every 38 hours at a distance of 2 million km, giving it an estimated temperature of 230°C.

In 2010, scientists reported that they had studied the atmosphere of GJ 1214b, finding it likely that it was composed mainly of water. However, their observations could also be explained by the presence of a planet-enshrouding haze in GJ 1214b's atmosphere.

Hubble's Wide Field Camera 3 (WFC3) was used to study GJ 1214b when it crossed in front of its host star. During such a transit, the star's light is filtered through the planet's atmosphere, giving clues to the mix of gases. Hazes are more transparent to infrared than to visible light, so the Hubble observations helped to tell the difference between a steamy and a hazy atmosphere. Hubble's data are most consistent with a dense atmosphere of water vapour.



← Comparison of size, Earth, GJ 1214b and Uranus (NASA/Celestia)

Since the planet's mass and size are known, astronomers can calculate the density: only about 2 g/cm^3. Water has a density of 1 g/cm^3, while Earth's average density is 5.5 g/cm^3. This suggests that GJ 1214b has much more water than Earth and less rock. As a result, the internal structure of GJ 1214b must be very different from that of our world. The high temperatures and pressures would form exotic materials like 'hot ice' or 'superfluid water', substances that are completely alien to our everyday experience.

Europe goes to Jupiter

Jupiter's icy moons are the focus of Europe's next large science mission, to be launched in 2022 and arriving at Jupiter in 2030, to spend at least three years making detailed observations around the planet.

The Jupiter Icy Moons Explorer (or 'JUICE') is the first Large-class mission chosen as part of ESA's Cosmic Vision 2015–2025 programme.

Jupiter's diverse Galilean moons – the volcanic Io, icy Europa and rock-ice Ganymede and Callisto – make the jovian system a miniature Solar System in its own right.

With Europa, Ganymede and Callisto all thought to host internal oceans, the mission will study the moons as potential habitats for life, addressing two key themes of Cosmic Vision: what are the conditions for planet formation and the emergence of life, and how does the Solar System work?

The Jupiter spacecraft will continuously observe the planet's atmosphere and magnetosphere, and the interaction of the Galilean moons with the gas giant. It will visit Callisto, the most heavily cratered object in the Solar System, and will twice fly by Europa.

The spacecraft will also make the first measurements of the thickness of Europa's icy crust and will identify potential sites for future *in situ* exploration, before finally entering orbit around Ganymede in 2032, where it will study the icy surface and internal structure of the moon, including its subsurface ocean.

Ganymede is the only moon in the Solar System known to generate its own magnetic field, and the mission will include observations of the unique magnetic and plasma interactions with Jupiter's magnetosphere in detail.

↑ The Jupiter Icy Moons Explorer mission

→ PROGRAMMES IN PROGRESS

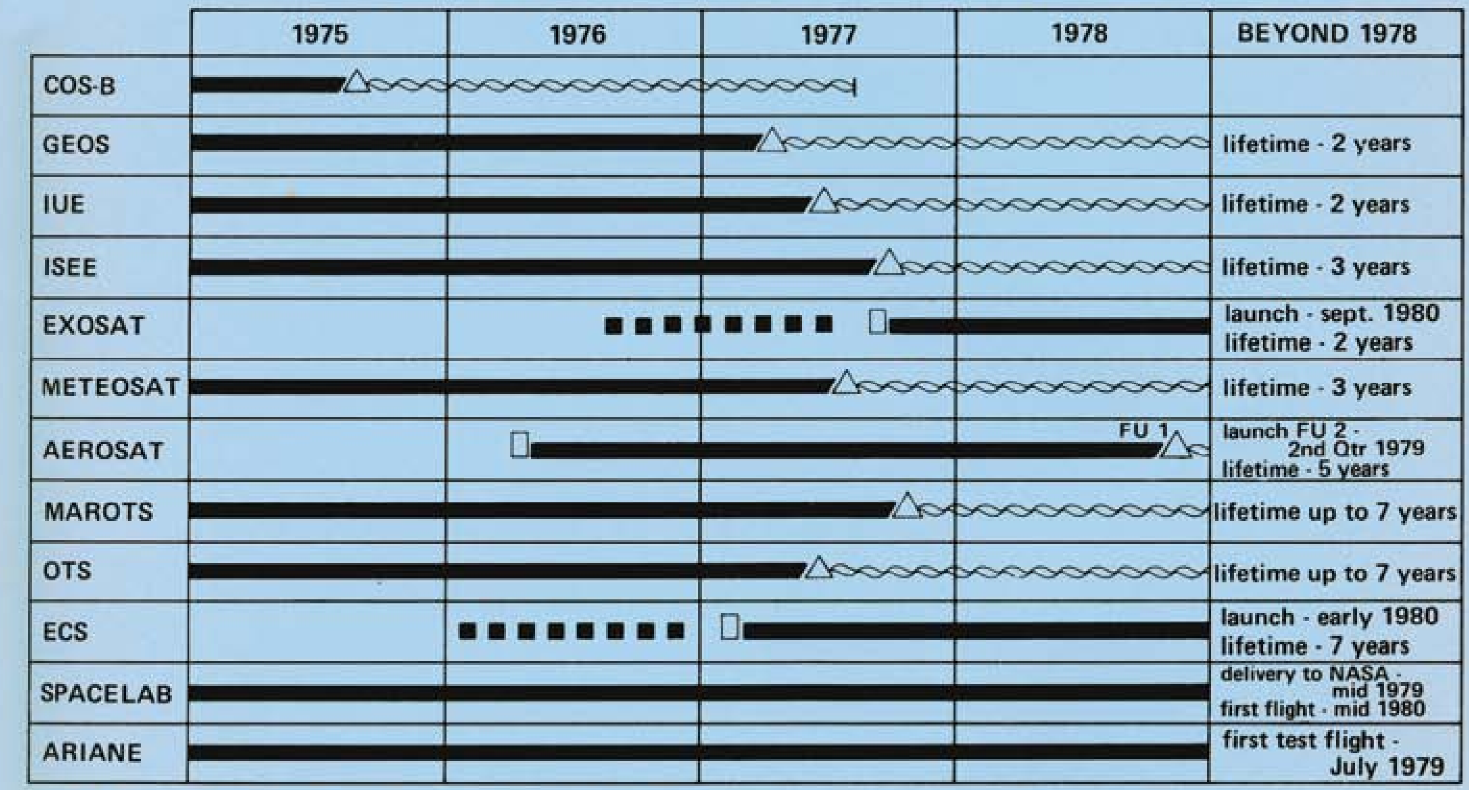
Status at end of April 2012

A stunning shot of the UK and Ireland by night, with the Aurora Borealis, provided by André Kuipers on the ISS (ESA/NASA)

Projects under Development

Projets en cours de réalisation

THE ESA DEVELOPMENT AND OPERATION PROGRAMME (as at September 1975)



■■■■■■ = phase B (design definition)
▯ = award of hardware contract
▬ = phase C/D (development)
△ = launch
〰 = operation

* In ESA Bulletin No. 1, two launch dates were quoted for the Canadian Technology Satellite (CTS). The correct date was December 1975 (this has since slipped to January 1976).

The 'Programmes in Development' page from Issue 3, October 1975

→ THE BLUE PAGES EXPLAINED

A guide to ESA programmes in progress

Many people ask what are all these acronyms, models, phases and reviews mentioned in the Bulletin's 'blue pages' or 'Programmes in Progress' section? Some also ask why is this section called the 'blue pages'?

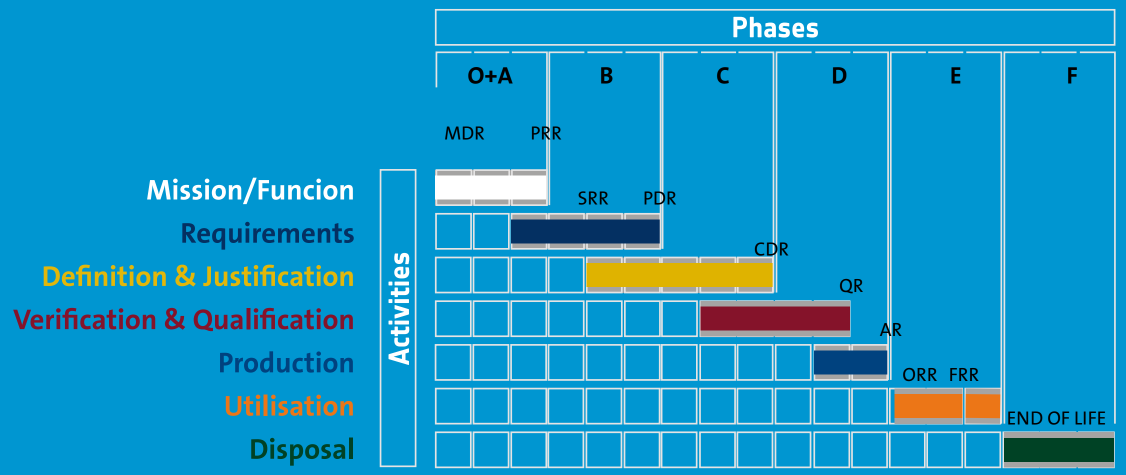
Here we'll try to answer some of these questions.

The 'blue pages'

The first Bulletin started listing ESA's Current Development Programmes as a specific section in June 1975. In Issue 3, October 1975, this section was renamed 'Programmes in Development' and first printed on light blue paper to distinguish it from the news and other items. Throughout the Bulletin's history, its editors and designers have always referred to this section as the 'blue pages', even though it changed colour again to grey in 2008.

What are 'Phases'?

All ESA space projects can be broken down into 'phases'. Each phase is designed to advance the system or product from one stage to another after successful completion of its characteristic activities. Dividing a project into phases is a major contribution to the overall risk management.



Note: AR = Acceptance Review
CDR = Critical Design Review
FRR = Flight Readiness Review
MDR= Mission Definition Review
ORR = Operation Readiness Review
PDR = Preliminary Design Review
PRR = Preliminary Requirements Review
QR = Qualification Review
SRR = System Requirements Review

↑ Usually a space project is broken down into seven main phases. During these phases, there are milestones called 'project reviews'. Each review is an examination performed by a team of experts not directly responsible for the activities covered by the review. They look at what has been achieved and decide whether or not to start the next phase.

Phase-0
This is where we identify of needs of the mission. Mission analysis includes: expected performance, dependability and safety goals, assessment of operating constraints, physical and operational environment and possible system concepts. At the end of Phase-0, a Mission Definition Review (MDR) takes place.

Phase-A
This 'feasibility phase' finalises the needs expressed in Phase-0 and proposes solutions. This is where we study the possible system concepts, estimate the technical and industrial feasibility, and identify constraints of cost, schedule, organisation, utilisation (operations, implementation, maintenance), production and disposal. A Preliminary Requirements Review (PRR) is held at the end of Phase-A.

Phase-B
Also called 'Preliminary Definition', this involves the selection of technical solutions for the concept selected in Phase-A. By this stage, we should know precise performance levels, costs and schedules. During Phase-B, a System Requirements Review (SRR) can be conducted, to identify 'Make or buy' alternatives, confirm the feasibility of recommended solutions, as well as define the operating conditions. Sometimes, Phase B is split into Phase-B1 (the mission's system definition) and Phase-B2 (the development and verification of technologies needed to make the mission possible).

Development Configuration Baseline
This is what ESA calls the basic design of a space mission. This is delivered at the end of Phase-B in the Preliminary Design Review (PDR), which confirms the chosen solution retained for development into a full space mission.

Phase-C
This is the detailed study of the design from the previous phase, as well as the start of production of parts of the

↓ Defining a mission in ESA's Concurrent Design Facility. Concurrent engineering is a way of designing a space mission with experts from several disciplines performing tasks in parallel. Fast and effective interaction ensures consistent and high-quality results in a much shorter time

spacecraft and its systems. Test and qualification conditions are defined, and the methods of production and verification are prepared. We see the start of technology assessments or qualification, as well as the start of procurement. Production begins after the Critical Design Review (CDR).

Phase-D

This is where development ends and production and ground qualification testing begin. This phase, ending with the Acceptance Review (AR), allows the preparation of the 'utilisation phase' (Phase-E) and any series production of parts or systems. Acceptance includes making an agreed set of technical tests, where the delivered product is compared against the requested design (configuration baseline). Phases-C and D are generally inseparable, because of the closely linked nature of the activities.

Assembly, Integration and Testing (AIT)

Satellite AIT activities are a logical and interrelated sequence of mechanical, electrical and environmental tasks usually occurring in Phase-D. This means assembling the various subsystems into an integrated satellite and performing functional and environmental tests on it as a system. 'Assembly' is the mechanical connection of the satellite's parts. 'Integration' is the interconnection and functional verification between the units or subsystems that make up the full satellite.

'Testing' is the sequence of checks made to verify that project requirements are satisfied and if the satellite will survive the stresses of launch and operations in orbit. Some AIT tasks, such as Quality Assurance planning, can take place in earlier phases.

Phase-E

The 'utilisation phase' comprises the launch campaign, launch and in-flight acceptance of all parts of the mission going into space and, if needed, their operation and maintenance, as well as the acquisition of feedback.

For launchers and complex satellite projects, Flight Readiness Reviews (FRR) and Operational Readiness Reviews (ORR) take place before launch.

This phase is often divided into two sub-phases: a Phase E1, which is an overall test and commissioning phase of the system, at the end of which the first In-Space Test Review is conducted. Phase-E2 is the utilisation phase itself, with the spacecraft operating in space.

Phase-F

'Disposal' covers all events from the end-of-life until final disposal of the spacecraft or system.

Why different spacecraft models?

Space engineers usually find that there is not enough time to perform all verification activities in a serial manner. Many activities have to be done in parallel in order to keep within budget and avoid an overly long programme.

Generally speaking, engineers must first qualify the spacecraft design, and then they acceptance-test the flight hardware. In testing, the hardware is subjected to conditions that are more severe than it would normally encounter, and for longer, which means that a spacecraft could be over-tested, or fatigue and wear might be a concern. This is why we actually build at least two spacecraft. A Development Model (DM) undergoes all the qualification tests, before a Flight Model (FM) is manufactured and assembled for acceptance tests and launch.

↑ A Galileo dispenser on ESTEC's QUAD electrodynamic shaker in 2010. This is a Qualification Model of the dispenser, along with a pair of Engineering Models of Galileo satellites (a Structural Model and a Structural/Thermal Model)

←

Galileo In-Orbit Validation Protoflight Model and Flight Models undergoing assembly and testing at Thales Alenia Space in Italy

Sometimes, other models might be built for testing in different ways: a Structural Model (SM), a Thermal Model (TM), a combined Structural/Thermal Model (STM) or an Electrical Model (EM). These development models might be followed by a Qualification Model (QM).

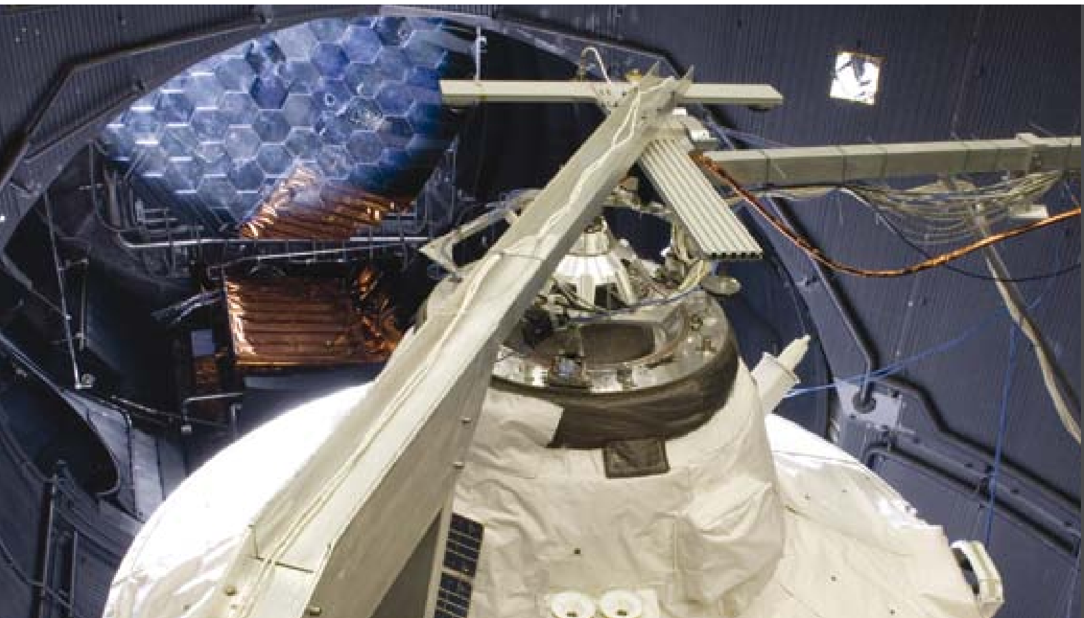
What is a Protoflight Model?
A common solution nowadays is to use a Protoflight Model (PFM) that allows qualification and acceptance to be combined – at least at the overall spacecraft level. This model is really the flight spacecraft, subjected to more severe qualification-level tests but only for acceptance durations. This approach can only be used if full qualification, in all respects, has already been achieved at the equipment level. PFMs might be used when a spacecraft is launched that is fully identical to an earlier one, or where several spacecraft have the same structure (or 'bus') that is already qualified, but carry different payloads.

What is an Electrical Functional Model?
We need to verify system function and performance early in testing, and for this we need an Electrical Model. For new or complex missions, this can be an Engineering Model, close to flight-representative, with flight structure, qualification model equipment and wiring. Redundant units are not needed.

↑ The Rosetta orbiter Electrical Qualification Model at Alenia Spazio in Turin in 2000

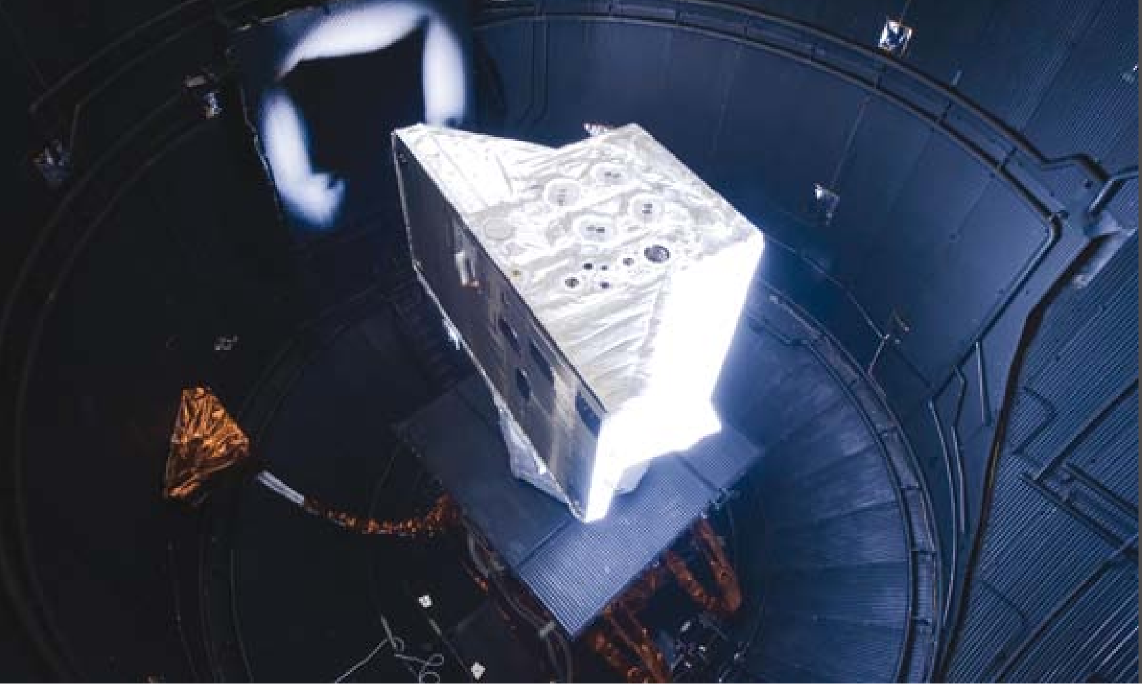
For less-demanding cases, the electrical test model could be set up on a test bench, and referred to as an Electrical Test Bed or Electrical Verification Model (EVM).

What is a Thermal Balance Test?
This simulates the mission thermal environment (solar radiation, Earth albedo, deep space views, internal dissipations) and is usually performed in a solar simulation



← ESA's Automated Transfer Vehicle, ATV *Jules Verne*, in Thermal Vacuum Testing at ESTEC in 2006

→ Structural Model of the Gaia Payload Module during vibration testing at Intespace, Toulouse, France in 2011 (Astrium)



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The Structural/Thermal Model of the BepiColombo Mercury Planetary Orbiter in the Large Space Simulator at ESTEC in 2011

←

The Radio Frequency Qualification Model (RFQM) of the Planck telescope at Thales Alenia Space for RF testing in 2007 (TAS)

chamber in a vacuum with lamps simulating the Sun, as in ESTEC's Large Space Simulator.

Hot or cold views to space can be simulated using with liquid (cold) or heated gaseous nitrogen piped around the chamber walls. These tests are usually performed on a Structural/Thermal Model spacecraft, built with equipment that is thermally representative but not fully functional.

What is a Thermal Vacuum Test?
This test is similar to the Thermal Balance Test, but verifies electrical performance at temperature extremes and so requires fully functional equipment. Thermal 'cycling', or repeated heating and cooling, induces thermal stresses that might detect component failures.

What is a Sinusoidal Test?
This vibration test demonstrates the ability of the equipment or spacecraft to withstand low-frequency excitations of the launcher. Sinusoidal vibration is the simplest form of vibratory motion, and when plotted looks like a smooth sine wave.

What is an Electromagnetic Compatibility Test?
These tests determine whether a spacecraft will be adversely affected by electromagnetic interference from external sources, or whether any of its internal components interfere with external elements, such as the launch vehicle or ground systems at the launch site.

What is Radio Frequency (RF) Compatibility Test?
Similar to EMC testing, but with particular emphasis on interference caused by radio uplinks or downlinks. ■

More information

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2008
2009
2010
2011
J F M A M J J A S O N D
SCIENCE & ROBOTIC EXPLORATION PROGRAMME
HUBBLE
SOHO
CASSINI-HUYGENS
XMM-NEWTON
CLUSTER
INTEGRAL
MARS EXPRESS
ROSETTA
VENUS EXPRESS
HERSCHEL
PLANCK
LISA PATHFINDER
MICROSCOPE
GAIA
JWST
BEPICOLOMBO
SOLAR ORBITER (M1)
EUCLID (M2)
COSMIC VISION M3
JUICE (L1)
EXOMARS
EARTH OBSERVATION PROGRAMME
MSG
MTG
METOP
CRYOSAT
GOCE
SMOS
AEOLUS
SWARM
EARTHCARE
SENTINEL-1
SENTINEL-2
SENTINEL-3
SENTINEL-5 PRECURSOR
TELECOMMS/NAVIGATION PROGRAMMES
ARTEMIS
ALPHASAT
EDRS
SMALLGEO
HYLAS
GNSS-1/EGNOS
GALILEO
TECHNOLOGY PROGRAMME
PROBA-1
PROBA-2
PROBA-3
PROBA-V
HUMAN SPACEFLIGHT PROGRAMME
COLUMBUS
NODE-2 / NODE-3 / CUPOLA
ERA
ATV
ASTRONAUT FLIGHTS
ELIPS ISS UTILISATION
ELIPS NON-ISS PAYLOADS
TRANSPORTATION & HUMAN EXPLORATION
EYHARTS
SCHLEGEL
DE WINNE
FUGLESANG
NESPOLI
VITTORI
KUIPERS
FSL, BIOLAB
EDR
GEOFLOW
MSL/MSRR
WAICO
MARES
TEXUS-44
TEXUS-45
MASER-11
TEXUS-46
MAXUS-8
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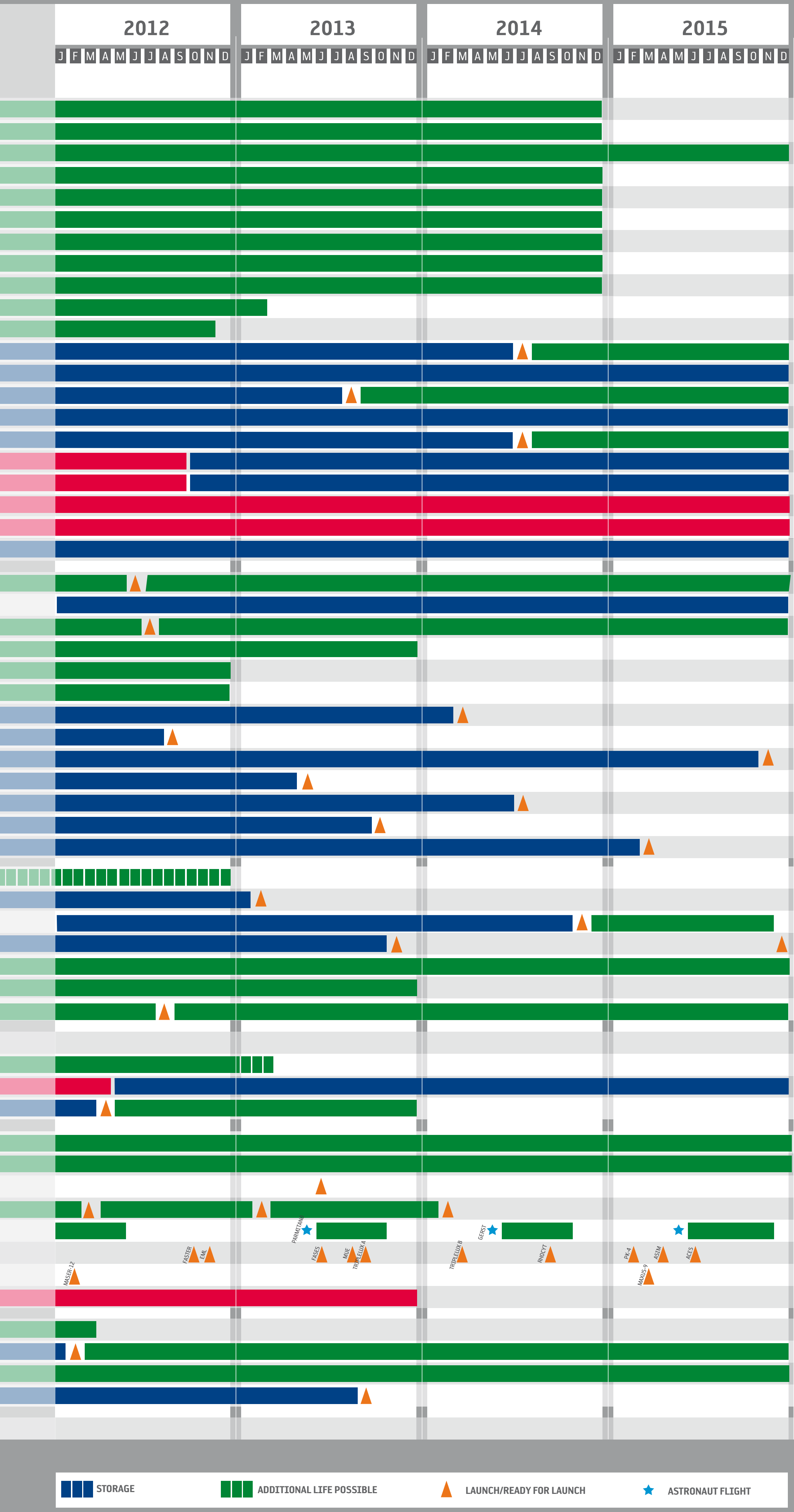
MAIN DEVELOPMENT PHASE
OPERATIONS



COMMENTS

LAUNCHED APRIL 1990 / OPS EXTENDED UNTIL 2014
LAUNCHED DEC 1995 / OPS EXTENDED UNTIL 2014
LAUNCHED OCT 1997 / OPS EXTENDED UNTIL MAY 2017
LAUNCHED DEC 1999 / OPS EXTENDED UNTIL 2014
LAUNCHED MID-2000 / OPS EXTENDED UNTIL 2014
LAUNCHED OCT 2002 / OPS EXTENDED UNTIL 2014
LAUNCHED JUNE 2003 / OPS EXTENDED UNTIL 2014
LAUNCHED MARCH 2004 / ARRIVES AT COMET 2014
LAUNCHED NOV 2005 / OPS EXTENDED UNTIL 2014
LAUNCHED 14 MAY 2009; OPS UNTIL 2013
LAUNCHED 14 MAY 2009; OPS EXTENDED UNTIL 2012
LAUNCH MID 2014
LAUNCH MID 2016
LAUNCH SEPT 2013 / NOMINAL MISSION END 2018
LAUNCH OCT 2018
LAUNCH MID 2015
LAUNCH EARLY 2017
LAUNCH END 2019
LAUNCH 2022/2023
LAUNCH 2022
LAUNCH JAN 2016 / MAY 2018

MSG-3 LAUNCH JUNE 2012, MSG-4 LAUNCH 2014
LAUNCH MTG-I-1 2018 / MTG-S-1 2019
METOP-B JULY 2012 / METOP-C OCT 2016
CRYOSAT-2 LAUNCHED 10 APR 2010
LAUNCHED 17 MARCH 2009: OPS UNTIL END 2012
LAUNCHED 2 NOV 2009
LAUNCH EARLY 2014
LAUNCH AUG/SEPT 2012
LAUNCH NOV 2015
LAUNCH MAY 2013
LAUNCH JUNE 2014
LAUNCH OCT 2013
LAUNCH MARCH 2015

LAUNCHED JULY 2001, OPERATIONS EXTENDED
LAUNCH EARLY 2013
LAUNCH EDRS-A, END 2014; EDRS-C, END 2015
LAUNCH EARLY 2014
LAUNCHED NOV 2010; OPS 15 YEARS
OPERATIONS START 2008
GIOVE-A 2005 / GIOVE-B APR 2008 / IOV OCT 2011 & AUG 2012

LAUNCHED OCT 2001
LAUNCHED 2 NOV 2009 / OPS EXTENDED UNTIL 2011/12
LAUNCH 2015/16
LAUNCH 2012

LAUNCHED FEB 2008 / OPS UNTIL END 2020
NODE-2: OCT 2007; NODE-3 WITH CUPOLA: FEB 2010
LAUNCH JUNE 2013
ATV-3 MAR 2012, ATV-4 FEB 2013, ATV-5 FEB 2014
PARMITANO: MAY 2013; GERST: MAY 2014; TBD: MAY 2015
BIOLAB, FSL, EPM, EDR (EuTEF, SOLAR) WITH COLUMBUS MAR 2008
MASER 12: FEB 2012; MAXUS-9: MAR 2015
PREPARATORY ACTIVITIES INCLUDING LUNAR LANDER WITH PRE-SRR, SEPT 2012

PHASE 1 MATURITY KEY POINT APRIL 2012
FIRST LAUNCH FEB 2012
FIRST LAUNCH 21 OCT 2011
SYSTEM ACCEPTANCE REVIEW, JULY 2013
LAUNCH READINESS REVIEW SEPT 2013

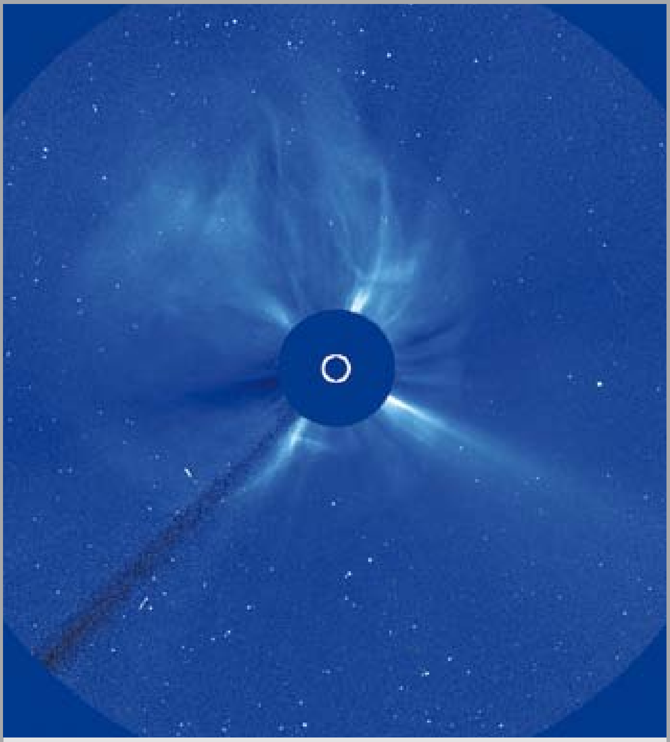
SYSTEM REQUIREMENT REVIEW, DEC 2011

KEY TO ACRONYMS

AM	Avionics Model	LEOP	Launch and Early Orbit Phase
AO	Announcement of Opportunity	MoU	Memorandum of Understanding
AIT	Assembly, integration and test	PDR	Preliminary Design Review
AU	Astronomical Unit	PFM	Proto flight Model
CDR	Critical Design Review	PLM	Payload Module
CSG	Centre Spatial Guyanais	PRR	Preliminary Requirement Review
EFM	Electrical Functional Model	QM	Qualification Model
EM	Engineering Model	SM	Structural Model
EQM	Electrical Qualification Model	SRR	System Requirement Review
FAR	Flight Acceptance Review	STM	Structural/Thermal Model
FM	Flight Model	SVM	Service Module
ITT	Invitation to Tender	TM	Thermal Model

→ SOHO

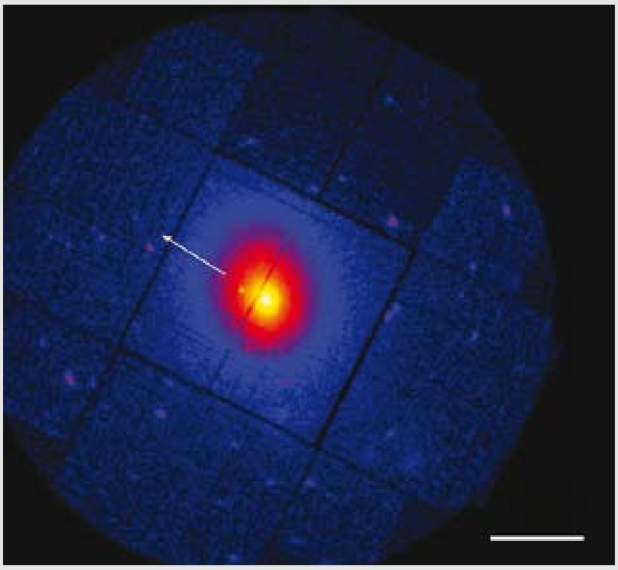
In early to mid-March the Sun showed high levels of activity, with three X-class and 15 M-class flares. All X-class events were associated with very fast and wide Earth-directed coronal mass ejections (CMEs) and major solar energetic particle events, which affected several spacecraft. The X5-class flare of 7 March was the second largest flare of this solar cycle. The related CME sparked some of the most spectacular auroras observed in recent years. SOHO/LASCO observations again played a key role for the space weather predictions of NOAA/SWPC and NASA Goddard's Space Weather Laboratory.



The Earth-directed CME and associated X5-class flare of 7 March that sparked spectacular auroras (ESA/NASA)

→ XMM-NEWTON

After more than 12 years in orbit, XMM-Newton remains as successful as ever. On 26 March, the 3000th refereed paper based on its observations was published, reporting on an observation of a cluster of galaxies. These large structures, which can be as large as 10 million light-years across, are made up of hundreds, or in some cases even thousands, of galaxies. Spectrometry of the central regions in the cluster was performed which determined the mechanical characteristics of the gas therein, in addition to its thermodynamic quantities. This kind of measurement can only be performed with XMM-Newton and was done for the first time less than two years ago.



XMM-Newton image of the galaxy cluster Abel 3112. The white bar scale at lower right corresponds to a distance of 1.3 million light-years on the cluster (G. E. Bulbul/NASA GSFC)

→ CASSINI-HUYGENS

A region on Saturn's moon Titan has been found to be similar to the Etosha Pan in Namibia, Africa. Both are partially ephemeral lakes – large, shallow depressions that are sometimes filled with liquid. Titan's lakes, however, are filled with liquid hydrocarbons (a methane-ethane mixture), rather than water. This area, named Ontario Lacus appears to not be permanently filled with liquid but alternate between drought periods and flooding. This finding appears consistent with the predictions of climatic models near Titan's polar regions describing the relative evaporation and precipitation rates.

Images from Cassini have revealed strange kilometre-sized objects punching through parts of Saturn's F ring, leaving glittering trails behind them. These trails in the rings, which scientists are calling 'mini-jets', fill in a missing link in our story of the curious behaviour of the F ring. These small objects appear to collide with the F ring at gentle speeds, about 2 m/s. The collisions drag glittering ice particles out of the F ring with them, leaving a trail typically 40 to 180 km long.

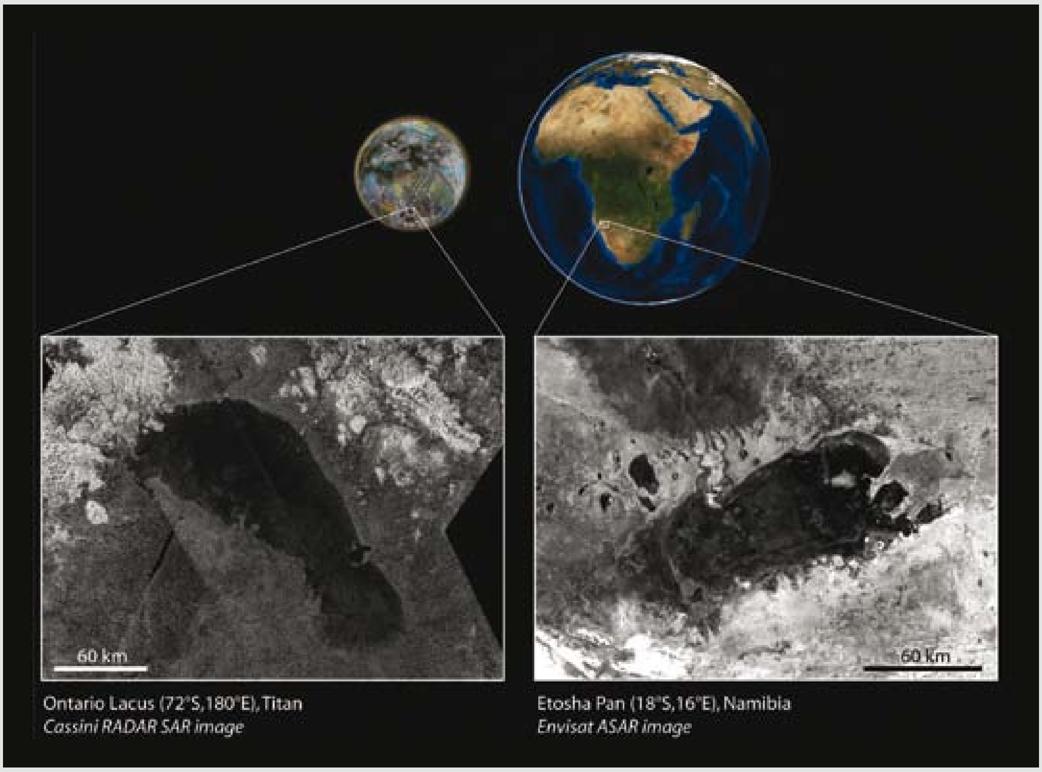
Proof of the suspected existence of low-frequency electromagnetic waves between Titan's surface and the upper atmosphere (a phenomenon known on Earth as 'Schuman resonances') has been elusive ever since Huygens's landing on Titan.

On Earth, Schumann resonances are triggered by lightning. However, the Cassini orbiter has so far not detected any lightning on Titan despite making multiple flybys. Schumann resonances were detected in the data of the Huygens Atmospheric Structure and Permittivity, Wave and Altimetry instrument. These resonances could be explained using Saturn's magnetospheric plasma sweeping past Titan's upper atmosphere as the energy source.

→ CLUSTER

The science output continues at its highest rate since launch. A recent highlight was the combination of data from Cluster and Mars Express, allowing for the first time an examination of the loss of atmospheric ions from Earth and Mars under the same conditions.

A fortuitous alignment of planets during a passing gust of the solar wind, allowed scientists to compare the protective effects of Earth's magnetic field with that of Mars' naked atmosphere. It was found that while



A Cassini radar image of Ontario Lacus, Titan's largest lake in its southern hemisphere, compared with Envisat radar image Etosha Pan in Namibia, Africa (ESA/NASA/LPGNantes) the pressure of the solar wind increased at each planet by similar amounts, the increase in the rate of loss of martian oxygen was ten times that of Earth's increase. Such a difference would have a dramatic impact over billions of years, leading to large losses of the martian atmosphere, perhaps explaining or at least contributing to its current tenuous state.

The result proves the efficacy of Earth's magnetic field in deflecting the solar wind and protecting our atmosphere.

It is hoped that the work can be extended by incorporating data from ESA's Venus Express spacecraft, which also carries a sensor that can measure the loss of its atmosphere. Venus will provide an important new perspective on the issue because, like Mars, it has no global magnetic field, yet it is similar in size to Earth and has a much thicker atmosphere. It will therefore provide unique data to help place the results from Earth and Mars in context.

Cluster will continue to play an important role in these studies because it is the only mission in near-Earth space capable of taking such measurements. In addition, scientists are keen to observe how the approaching maximum in solar activity may affect the loss of atmospheric particles from all three planets.

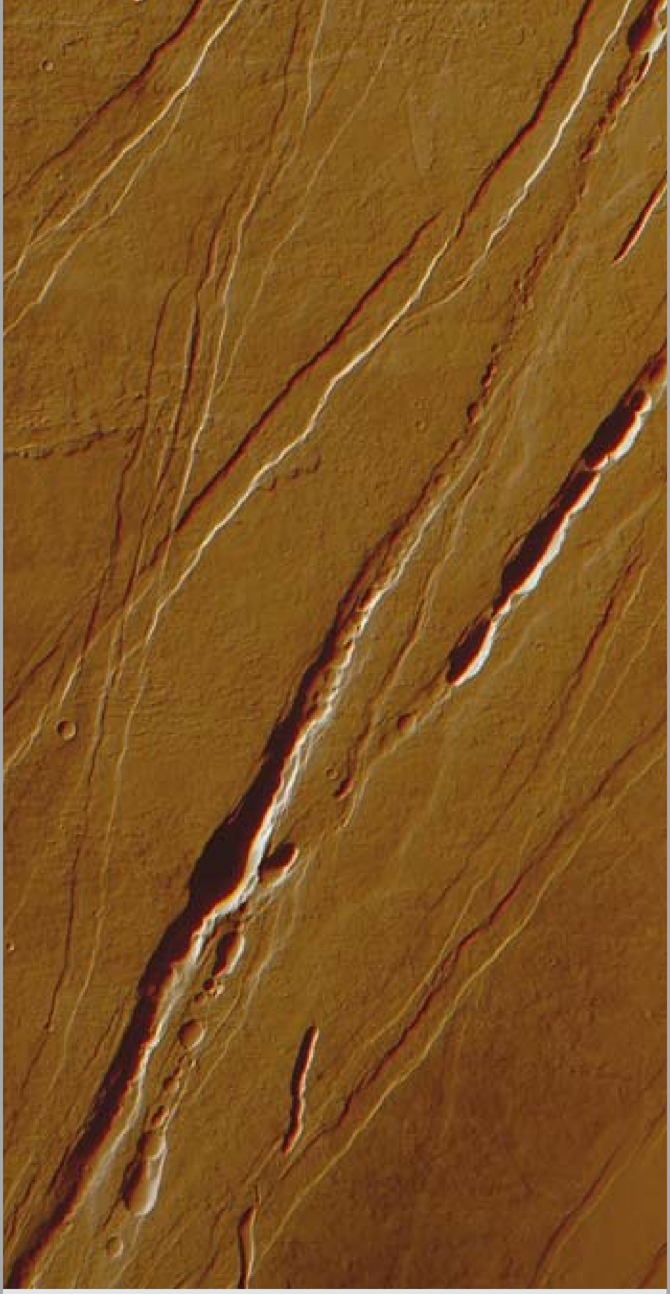
Cluster is continuing its implementation of Guest Investigator (GI) operations. The aim of the Cluster GI Programme is to identify new and compelling use of the Cluster scientific payload and spacecraft configuration by requesting proposals from the scientific community.

The geometry of small-scale turbulence with spacecraft separations of around 40 km was investigated and most recently a multi-scale configuration was implemented to examine reconnection at the magnetopause.

This autumn, the spacecraft will be separated by the largest distances so far in the mission, to examine the evolution of waves at the boundary of the magnetosphere. Distances of around 20 000 km will be achieved during the period of observation, growing by an order of magnitude during other portions of the orbit.

→ MARS EXPRESS

The spacecraft and instruments are again working normally following solution of the problem in the solid-state mass memory. An orbit-phasing manoeuvre was executed recently that will put Mars Express in the correct location to support NASA's Mars Science Laboratory, due to arrive on the surface of Mars on 6 August.



This false-colour nadir image was acquired High Resolution Stereo Camera on Mars Express during orbit 946, from an altitude of about 300 km. It shows a region called Oti Fossae, close to Arsia Mons, one of the three large volcanoes aligned in the Tharsis plateau, and is a good example of martian tectonics. Oti Fossae is a complex of extensional faults that created 'grabens', long valleys bordered by cliffs on each side, due to the movement of normal faults. This shows events of extension of the crust near Arsia Mons.

Other striking features are the long and deep pits in the middle of the image. They are followed by a series of smaller, aligned circular pits. It is believed that the largest pits were formed by the coalescence of several growing circular pits. These pits, or 'craters', are not formed by meteorite impacts, as are the many impact craters on the surface of Mars. They most likely formed by the extensional process, in which surface material has fallen into underground voids. They may still be growing today (ESA/DLR/FU Berlin)

→ ROSETTA

While Rosetta is in hibernation, preparations are being made for the approach and encounter with Comet 67P/Churyumov-Gerasimenko in 2014. Evaluation continues of the scientific data obtained during the flyby of asteroid (21) Lutetia. The latest results of this flyby have been summarised in 21 scientific papers that will appear in a Special Issue of Planetary and Space Science later in 2012. They confirm that (21) Lutetia is geologically a complex asteroid, which was heavily battered but not completely shattered in the past. Its surface is covered by a deep regolith layer, consisting of a fine-grain dust and a coarser component, which at the extreme end contains boulders of a few hundred metres diameter around some young craters. No magnetic field signature was detected that could be attributed to the asteroid, from which an upper limit for the global magnetic properties of (21) Lutetia could be derived.

Rosetta is set to wake up on 20 January 2014 for the rendezvous with its target comet.

→ VENUS EXPRESS

Venus is an odd planet – it does not internally generate a magnetic field, unlike Earth. However, it does have a number of similarities with Earth – the latest example being the evidence for magnetic 'reconnection' in its induced magnetotail: a process where opposing magnetic field lines break and reconnect with each other.

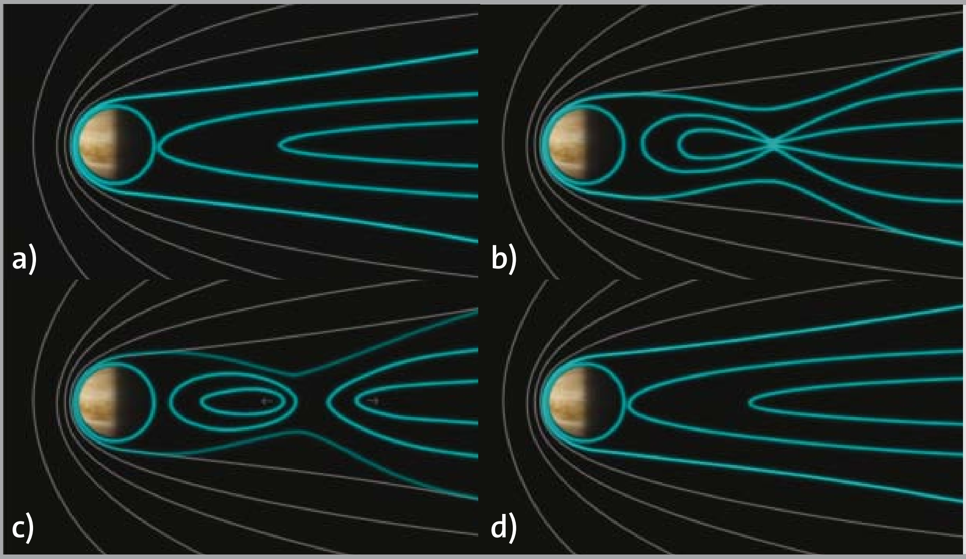
Since Venus has no intrinsic magnetic field to act as a shield against incoming charged particles, the solar wind interacts directly with the upper atmosphere. This interaction, in combination with the heliocentric magnetic field, creates an induced magnetic field that appears similar in shape to that of Earth's, but is much weaker and smaller in extension.

Reconnection is a well-known phenomenon in the magnetospheres of Earth, Mercury, Jupiter and Saturn, and is triggered by variations in the solar wind. This process is responsible for magnetic storms and polar auroras – known on Earth as the Northern and Southern Lights. In this process, plasma that is located on the planetward side of the position of the reconnection is accelerated towards the planet, and plasma that is located outside the position of the reconnection is accelerated away from the planet and is lost.

However, reconnection was not generally thought to occur on a non-magnetised planet with a weak magnetosphere like Venus. Now a detailed study of data from the Magnetometer and ASPERA instruments on Venus Express have revealed that, despite the absence of an intrinsic magnetic field at Venus, 'magnetic reconnection' does happen at Venus as well.

On 15 May 2006, Venus Express was crossing the induced magnetotail of Venus when it observed a rotational magnetic field structure over a period of about 3 minutes. Calculations based on its duration and speed imply that this was about 3400 km across. The event, which took place about 1.5 Venus radii (about 9000 km) down the tail, is thought to be evidence of a passing transient magnetic loop structure that is formed by magnetic reconnection in the magnetotail. Data on energetic particles from the ASPERA instrument also support this explanation.

Further studies of the magnetic field and energetic particles data from Venus Express revealed the signatures of many similar observations of energy exchange between the magnetic field and the plasma in the tail. Interestingly, these events typically occur at a distance ten times closer to the planet than they do on Earth. This is to be expected as the Earth's magnetosphere is about ten times larger in extension. The data show that, in many respects, the induced magnetosphere of Venus act as a scaled-down version of the Earth's magnetosphere.



Magnetic reconnection at Venus

a) The undisturbed induced magnetosphere

b) Field lines downstream of the tail connect

c) Field lines break up and a 'plasmoid' is created. This plasmoid is accelerated towards the planet and the field lines downstream of the connection point will accelerate any plasma away from the planet

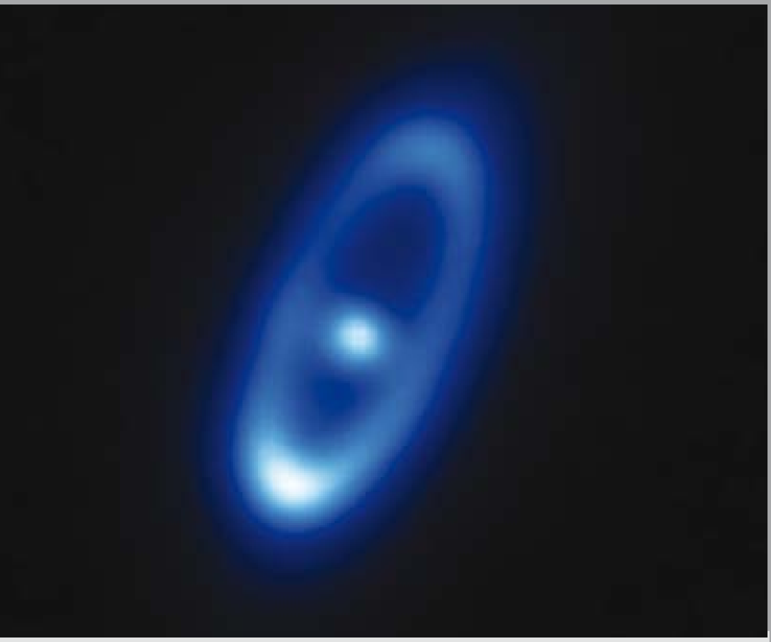
d) Back to the undisturbed situation

The discovery that plasma is lost from the tail as a result of magnetic reconnections provides a possible additional explanation for how and why gases are lost from Venus' upper atmosphere. This has implications for understanding how Venus lost its water after the planet began to experience a runaway greenhouse effect. The understanding of atmospheric loss is key to establishing the evolutionary history of planets, and the role of magnetic reconnection, even if is still poorly understood because of the scarcity of in situ observations at planets other than Earth, can now be explained in more detail.

→ HERSCHEL

Herschel is well into what is expected to be its last year of observing. In-flight operations will continue until all superfluid helium has been exhausted, which is predicted to occur around February 2013. All Key Programme observations and the vast majority of the observations selected in late 2010 in the first in-flight call for observing proposals have been performed. Current observing is dominated by programmes selected in late 2011. The spacecraft and ground segment are working well.

Herschel recently studied the dusty belt around the nearby young star Fomalhaut. It was a major surprise when it was discovered in the early 1980s by the US/UK/Dutch IRAS satellite that this seemingly perfectly normal star – and many others – were surrounded by dust.



The star Fomalhaut and its dust belt. These Herschel observations at far-infrared wavelengths show the belt glowing by its own light, and indicate the dust temperatures in the belt to be between –230°C and –170°C. However, because Fomalhaut is slightly off-centre and closer to the southern side of the belt, the southern side is warmer and brighter than the northern side (ESA/Herschel/PACS/B. Acke, KU Leuven)

Because of its proximity (25 light-years), Fomalhaut has been targeted by every infrared instrument available to astronomers ever since, including ESA's ISO, NASA's Spitzer and Hubble telescopes. Herschel's new images show the dust in the form of a well-defined belt in much more detail at far-infrared wavelengths than ever before. The narrowness of the belt is thought to be due to the gravity of one or more possible planets in orbit around the star, as suggested by earlier Hubble observations.

The Herschel data show that the dust in the belt has the thermal properties of small solid particles, with sizes of only a few microns across. But Hubble observations suggested solid grains more than ten times larger. Those observations collected starlight scattering off the grains in the belt and showed it to be very faint at Hubble's visible wavelengths, suggesting that the dust particles are relatively large.

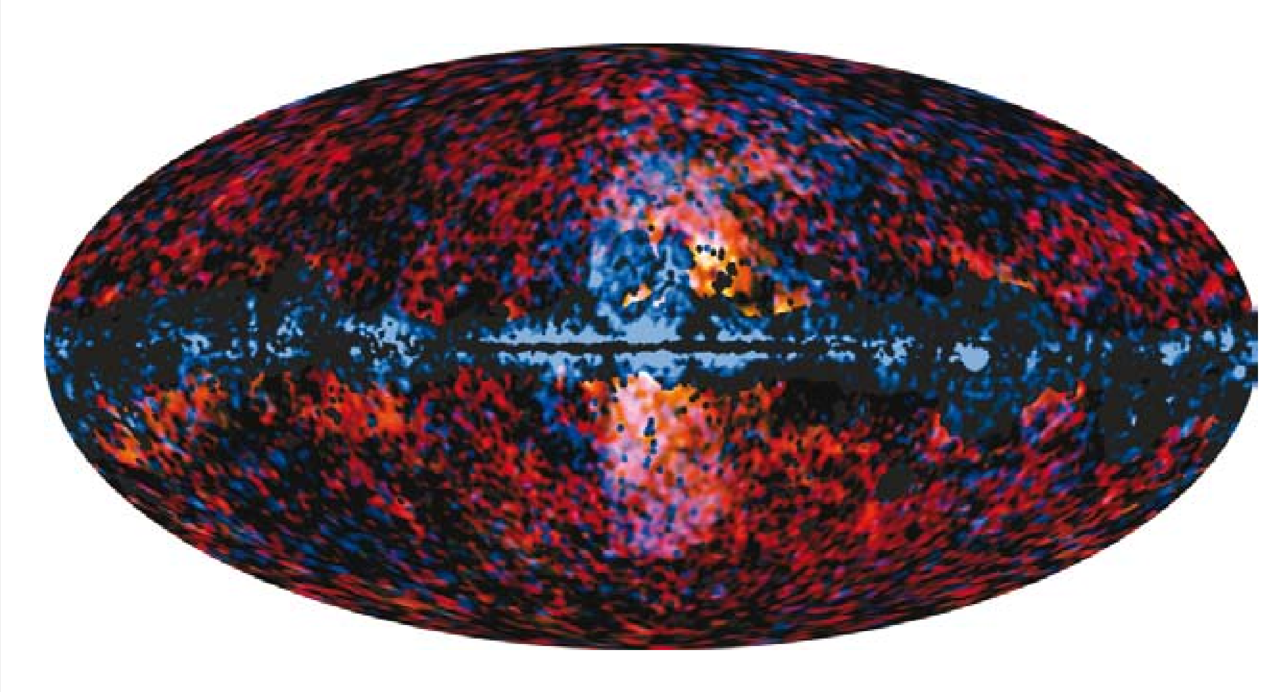
To resolve this paradox, it is suggested that the dust grains must be large fluffy aggregates, similar to dust particles released from comets in our own Solar System. These would have correct thermal and scattering properties. However, this leads to another problem: the bright starlight from Fomalhaut should blow small dust particles out of the belt very rapidly, yet such grains appear to remain abundant there.

The only way to overcome this contradiction is to resupply the belt through continuous collisions between larger objects in orbit around Fomalhaut, creating new dust. To sustain the belt, the rate of collisions must be impressive: each day, the equivalent of either two 10 km-sized comets or 2000 1 km-sized comets must be completely crushed into small, fluffy, dust particles.

→ PLANCK

Planck's Low Frequency Instrument (LFI) is currently completing its sixth survey. Optimism about the life expectancy of the sorption cooler (required to operate the LFI detectors at a low temperature) has increased, and it is now believed that it may continue to operate at least until the end of currently funded operations in January 2013. Observations of Jupiter and the Crab nebula (both important calibration sources) were carried out between January and March.

During the 'Astrophysics from the radio to the sub-millimetre' conference in February, 14 papers were presented describing new scientific results from Planck. Among these, of note were the extraction of an all-sky carbon monoxide map by Planck, and an analysis of the 'Galactic Haze' – a hard synchrotron emission localised



All-sky image of the distribution of the Galactic Haze seen by Planck at microwave frequencies superimposed over the high-energy sky as seen by NASA's Fermi Gamma-ray Space Telescope. The Planck data (red and yellow) correspond to the haze emission at frequencies of 30 and 44 GHz, extending from and around the Galactic Centre. The Fermi data (blue) correspond to observations performed at energies between 10 and 100 GeV and reveal two bubble-shaped, gamma-ray emitting structures extending from the Galactic Centre. The two emission regions seen by Planck and Fermi at opposite ends of the electromagnetic spectrum correlate spatially quite well and might indeed be a manifestation of the same population of electrons via different radiation processes (ESA/NASA)

around the Galactic Centre and linked to the 'bubbles' observed by NASA's Fermi Gamma-ray Space Telescope.

→ COROT

The process of extending the COROT mission for a second time, beyond 2013, is continuing and the detailed planning for operations during such an extension is also under way. An investigation into the possibility of uploading new software to the spacecraft, to enable part of the vetting process of exoplanetary candidates to be carried out on board, is ongoing.

Field LRa01 (first observed in 2007) was re-observed last winter. The first detected rocky planet, COROT-7b, was detected with a much higher signal-to-noise this time, since fortunately its solar-type star is about an order of magnitude less active than four years ago. Apparently this star is going into an activity minimum similar to that of our own Sun every 11 years. The planet was also detected in the simultaneous radial velocity programme carried out at ESO in Chile and it is hoped that detailed analysis of this data will confirm the suspected planets COROT-7c and 7d.

The 'official' exoplanet count of COROT is 26 but with around another 10 objects under detailed study and follow-up. A further 50 objects are on the target list for follow-up when resources become available. Because of the unique follow-up process adopted by the COROT team, including radial velocity observations with the world's largest telescopes (thanks to a cooperation with NASA), as well as diffraction-limited adaptive optics imaging, infrared observations and high-precision photometry from the ground, the reported COROT planets are among the best-studied exoplanets.

The diversity of these objects is becoming more obvious. One conclusion, however, is that with the current state-of-the-art observations, it is hard to determine the fundamental physical parameters (mass, radius and age) for the small (super-Earth and smaller) planets now being picked up. This is because these parameters depend on us knowing the same parameters for the host star. Lacking asteroseismological observations, the best precision that can be obtained is not better than 10%. It is difficult to see how this can be remedied without a spacecraft simultaneously performing asteroseismological observations of the host star and transit observations of associated planets.

→ GAIA

Integration and test of the remaining flight units on the Service Module is proceeding and the preparation for the thermal balance/thermal vacuum test this summer has started.

The first of the two telescopes has been precisely aligned and the wave front error is within the 50 nm specification. The second telescope is almost at the required alignment value and needs some final tuning. The focal length difference between the two telescopes is less than 2 mm over 35 m, as required.

Activities on the Focal Plane Assembly FM are finished and the system is ready for integration on the PLM. Tests performed included the mechanical and thermal acceptance and the functional performances in vacuum at the nominal operating temperature of the CCDs (–110°C). The performances of the Focal Plane Assembly were as predicted.

The Basic Angle Monitor (the instrument which in orbit will measure the variation of the two telescopes' lines of sight) was delivered by TNO to Astrium SAS and it will be soon integrated on the PLM.

Development of the Mission Operation Centre at ESOC and the Science Operation Centre at ESAC are progressing. Several radio frequency compatibility tests between the spacecraft and the ground station have been performed.

The Arianespace launch campaign plan, including detailed timeline and safety, is being discussed with the launch authorities. The Payload Adaptor, which mechanically and electrically connects the launcher to the spacecraft, has been delivered.

→ LISA PATHFINDER

The propulsion module has been put in storage and the spacecraft has been subjected to end-to-end functional testing of some of the science experiments. In these tests, the configuration is mostly with flight equipment, with ground segment equipment where necessary: for instance, the free-floating test mass is replaced by special checkout equipment that simulates the dynamics of the test mass and feeds the closed-loop control system.

Only the micro-propulsion thruster and the LISA Technology Package (LTP) Core Assembly (LCA) FMs were missing. A dedicated thermo-optical model substituted the LCA, including a flight interferometer bench; during the thermal balance test, the optical performance was measured within specification at picometre level.

In April and May, the Qualification Review part 1 will take place covering the system environmental testing. Currently some LTP units, needed for the completion of the LCA, are being dismounted to allow the start of the spacecraft hibernation phase. The functional verification activities are being finalised, both on the Real Time Test Bench and on the Software Verification Facility.

On the micro-propulsion system activities, the planned tests on the caesium FEEPs emitter unit, incorporating a ceramic accelerator shield and a narrower emitter channel, were stopped when the total impulse exceeded 1000 Ns. Not only was the mission requirement of 600 Ns – including margin – exceeded, but also two key quality parameters, the leak current and the specific impulse, showed excellent performance throughout the test duration.

ESA Project Scientist Paul McNamara in front of the LISA Pathfinder Science Module FM in Astrium facilities in Stevenage, UK (Astrium/ESA)

Members of the joint ESA/Astrium/IABG team after the Thermal Vacuum Test in Ottobrunn, Germany, with the LISA Pathfinder Science Module still inside the solar simulator chamber (IABG/Astrium)

Tests will now proceed at thruster assembly level, i.e. including the caesium reservoir and representative electronics. In parallel, cold-gas thrusters and long-lead items for the drive electronics have been ordered to preserve the schedule of this back-up micro-propulsion system.

It is expected that a decision will be made by October at latest on whether or not to change the baseline micro-propulsion system. The mission is fully compatible with both cold gas and FEEP.

Industrial development of the selected launch lock mechanism concept is proceeding nominally and the CDR was held in April.

The US Disturbance Reduction System payload flight hardware has undergone a number of functional tests at system level with JPL participation.

The PDR of the baseline launch vehicle, Vega, took place in April.

→ MICROSCOPE

The new tender for procurement of the ESA-provided cold-gas micro-propulsion system was released in March. The industrial contract will be started before summer.

→ JAMES WEBB SPACE TELESCOPE

Work is progressing for launch in October 2018. Several key milestones were advanced including procurement of the new detectors for the near-infrared instruments, including ESA's NIRSpec. Replacement of the flight detectors will take place in 2015 before the Integrated Science Instrument Module is integrated into the full observatory.

Investigations into the cracks in the NIRSpec optical bench concluded, and the flight optical bench has been discarded. Preparation of a new flight optical bench has been completed with a dynamic proof load test. Integration of the optical subassemblies on the new flight optical bench has started.

The MIRI Acceptance/Pre-Shipment Review is under way. The instrument has been vibrated again and alignment stability verified as recommended by the review panel. The first set of detector tests has been carried out by JPL to identify the source of the observed loss of detector sensitivity; data analysis is ongoing. The Review will take place in early May after which it is planned to ship the MIRI FM to NASA.

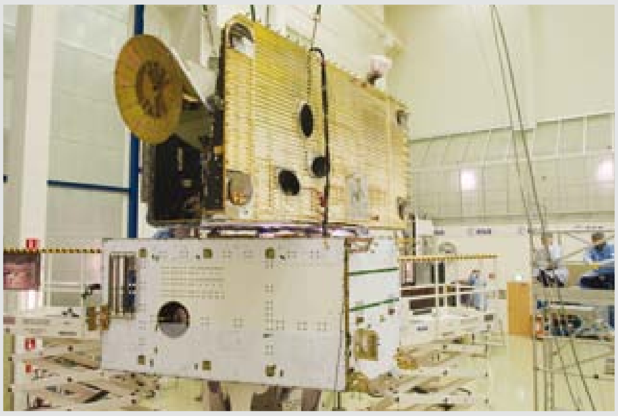
→ BEPICOLOMBO

Detailed evaluation of the Mercury Planetary Orbiter (MPO) thermal balance test revealed unexpected heat leaks through the high temperature blankets. Modifications to the blankets were defined and will be tested during the next months in order to demonstrate expected performance improvements. Similarly, interfaces to external equipment like solar arrays and antennas are being optimised to reduce heat leaks. The heat transfer capability from spacecraft equipment to the radiator will be augmented with the installation of additional newly ordered heat pipes.

Work on the spacecraft STMs, which are all in the ESTEC cleanroom, continued in preparation for mechanical tests of the composite spacecraft. A first mating of the MPO and the Mercury Transfer Module has been exercised. Equipment and subsystem-level CDRs are being conducted. All MPO payload CDRs were completed. System Functional Test preparations are ongoing on the spacecraft Engineering Test Bed with the full payload complement. The payload development schedules were optimised, in some cases identifying additional calibration time prior to FM delivery.

JAXA has completed the Mercury Magnetospheric Orbiter (MMO) FM mechanical and electrical interface checkout. The FM units are currently under environmental acceptance testing in Japan, and will be ready for final integration onto the MMO spacecraft later this summer.

The ground segment proceeded with the first delivery of Mission Control System and the installation of the hardware. The simulator software requirements review and the PDR of the Mission Planning System were completed. A test between the deep space transponder and the ground station to demonstrate system compatibility is prepared and ready to start.



First mating of Mercury Planetary Orbiter and Mercury Transfer Module Structural and Thermal Models

→ EXOMARS

Work continued on the Trace Gas Orbiter (TGO) and Entry, Descent and Landing (EDL) Demonstrator Module, to be launched in 2016, as well as study work on a Mars surface science mission, to be launched in 2018. The work was supported through an Authorisation to Proceed issued by ESA for the January to March inclusive.

In this period, the project began the task of reorienting the programme to a new international cooperation with Roscosmos. In this cooperation with Russia, two launch dates were confirmed for 2016 and 2018. Meetings were held at technical and programmatic levels between ESA and Roscosmos, to agree an overall responsibility sharing for the missions. For both missions, Roscosmos will provide a Proton launcher. For the 2016 mission, maintained as a combined orbiter and lander mission, ESA will provide a TGO and an EDL Demonstrator Module.

Two Russian instruments will fly on the TGO, along with two European instruments, and Russian instruments will be added to the EDL module surface science package (DREAMS).

A particular advantage for the 2016 mission's surface science has been gained with the addition of the Russian instruments along with the inclusion of a Russian-developed Radioisotope Thermoelectric Generator (RTG). The RTG, along with Radioisotope Heater Units (RHUs), converts the surface platform to a long-life science platform that can operate for one martian year.

For the 2018 mission, ESA and Roscosmos have agreed to perform a surface science mission together by sending a large capsule to Mars containing a 300 kg rover and a surface science platform. The two surface elements will work together on Mars and will use the communications infrastructure installed on the TGO from the 2016 mission. The 2018 spacecraft composite will consist of a Carrier Module provided by ESA, a Descent Module and Surface Module provided by Roscosmos with some contributions by ESA, and a Rover Module provided by ESA with some scientific instrument contributions from Roscosmos.

Project technical meetings with Russian counterparts responsible for Proton, the Russian instruments and the RTG and RHUs have established the feasibility of the 2016 mission in the new cooperation scenario. Furthermore, the overall mission design of the 2018 mission has been established with Roscosmos and discussions of the architecture for the 2018 mission have advanced. Preliminary design work will start with the responsible Russian teams in the next quarter.

The ESA Rover Module has now been resurrected from its hiatus after NASA's previous insistence on a single joint rover. ESA will no longer provide pieces to a rover but will return to the full rover design that passed an ESA System PDR in 2010. The rover teams have returned to the designs of that period and are working on accommodation of a full ESA Rover in the Russian Descent Module for the 2018 mission.

→ SOLAR ORBITER

The spacecraft and mission PDR was completed on 7 March Following contract negotiations with the prime contractor, Phase-B2/C/D is proceeding with subsystem-level procurement and several lower-tier procurements.

Most subsystem contractors have been selected and kicked off, with more than 43% (in value) of the subcontracts having been converted to Fixed Price. Phase-C/D will be initiated when this figure exceeds 80%, in the second half of 2012.

Updates to the technical baseline agreed as a consequence of the PDR are proceeding well. The system budgets are stable. Five out of ten instrument PDRs have already been conducted, and two more are under way.

After resolution of the technical and commercial aspects, final contractual negotiations are under way to procure a European-led SPICE instrument (still with involvement of US institutes) to replace the NASA-funded original instrument. Similarly, negotiations are underway with the University of Kiel for replacement of the Suprathermal Ion Sensor (part of the Energetic Particle Detector instrument suite led by the University of Alcalá).

The ESA Rover, resurrected for the joint ESA/Roscosmos 2018 mission (ESA/AOES Medialab)

Development of the Mission Implementation Plan has started. Mission analysis for a potential additional September 2017 launch opportunity with a US Atlas V launcher has been completed, so this can be analysed from the points of view of system engineering and scientific return.

The Solar Orbiter request for frequency assignment has been issued for inter-agency coordination. Mission planning concept definition has started, in preparation for definition of the interfaces and processes to be established between the Mission Operations Centre and the Science Operations Centre.

→ PROBA

Proba-2 continues to acquire images of the solar disc and irradiance samples of solar flux through the increasing activity of solar cycle 24. The peak of this solar cycle is currently predicted for mid-2013. Solar scientists classify flares according to their brightness observed in the range from 1 to 8 Angstroms. X-class flares belong to the strongest category associated with major coronal mass ejections and solar energetic particle events. When released towards Earth, these can cause radio blackouts or long-lasting radiation storms. Proba-2 observed an X2-class flare on 27 January and an X5.4 flare on 7 March.

LYRA, the solar irradiance instrument on Proba-2, runs flare-hunting campaigns with its back-up measurement unit. When an increased probability of strong flares is expected, the Science Operations Centre commands opening of the back-up unit for several hours. In the case of the X5.4 flare, the campaign was successful and the largest flare in this solar cycle was measured in all four wavelength channels. Surprisingly, the Lyman-Alpha channel (115–125 nm) did not show the increased signal response that is typically expected just before or at the beginning of a flaring event when non-thermal electrons bombard the chromosphere.

The activity of the solar cycle decreased afterwards, with days without any active region visible on the solar disc. Operators at the Science Centre are now standing by to prepare the next flare-hunting campaign.

→ ENVISAT

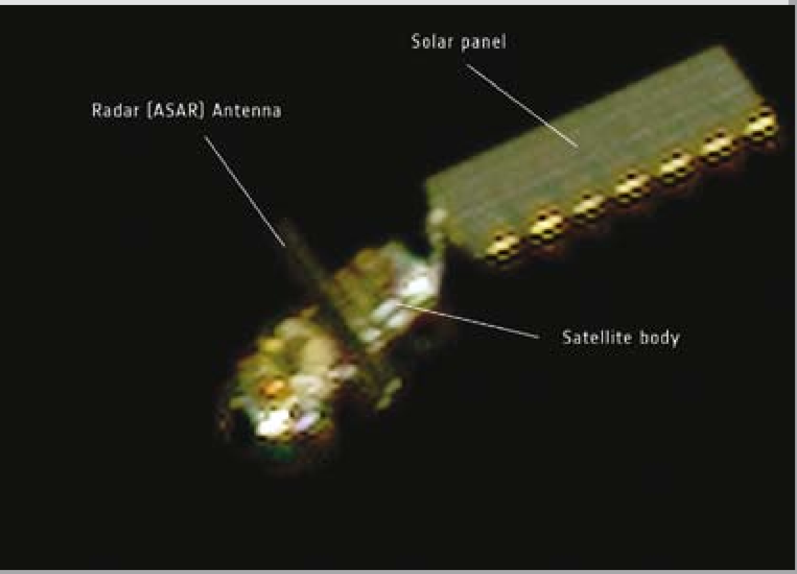
A few weeks after celebrating its 10th year in orbit (double its original five-year mission), communication links with Envisat were suddenly lost on 8 April, without any signs of platform degradation before the event. An extended network of ground stations was immediately activated by ESOC to send commands to the satellite, but all attempts have been unsuccessful so far (at date of print).

The Anomaly Review Board is gathering and analysing information on the satellite status using observations from ground radar, from the French Pleiades satellite and from laser retro-reflector data. ESA engineers are trying all possible options to recover the Envisat satellite, bearing in mind that a large data gap until the Envisat follow-on missions, the Sentinels, would be detrimental to the development of Earth observation in Europe.

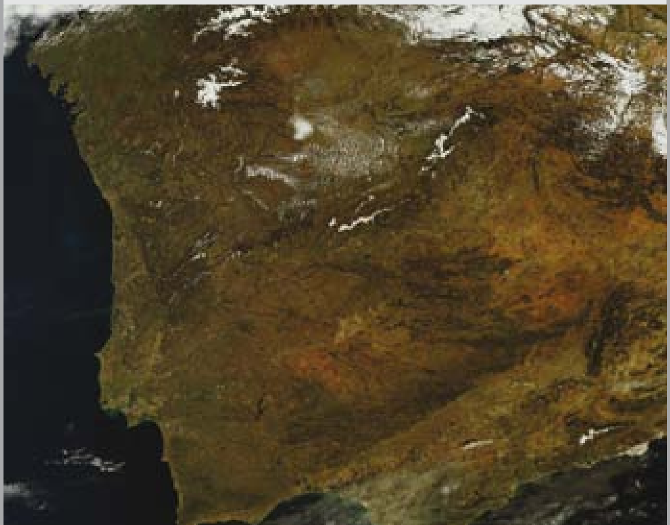
For a decade, Envisat has been keeping watch over our planet. The Envisat mission and its data have gradually built a strong presence in the Earth observation user communities, within and outside Europe.

The number and diversity of the Envisat user communities is astonishing: about 2500 peer-reviewed scientific papers have been published, covering many Earth-science fields: oceanography, cryospheric sciences, atmospheric composition, land use, tectonics, etc., and there has been large operational use for public services such as oil spill monitoring, land subsidence or air quality.

The French Pleiades Earth observation satellite captured this image of the silent Envisat on 15 April from a distance of about 100 km (CNES)



Envisat's Medium Resolution Imaging Spectrometer (MERIS) captured this image of Portugal and Spain on 8 April. The image was transcribed in Ka-band to ESRIN via Artemis, the ESA data relay satellite. It is the last Envisat data transmitted via Ka-band before the communication anomaly (ESA)



→ GOCE

The health and performance of the satellite is excellent, while running on the redundant main onboard computer. Solar activity levels are increasing steadily with the approach to solar maximum, but so far the mission operations altitude and therefore the signal-to-noise ratio of the gravity field measurements could be maintained. A reprocessing campaign of all GOCE data is ongoing, following a significant improvement of the gradiometer data-processing algorithm chain.

Release 4 of GOCE-based gravity field models is therefore expected in the last quarter of 2012. Meanwhile, ESA is preparing its plan for operations beyond 2012. Having reached all its objectives, the mission now offers the opportunity to seek ways to improve the spatial resolution of gravity field data, in a way no other mission (flying or planned) will be able to do. This would mean operating at a slightly lower flight altitude.

→ CRYOSAT

CryoSat continues to perform well. A new version of the ground processors was released in February, improving the quality of the products distributed to the scientific community, and the first reprocessing campaign is about to start.

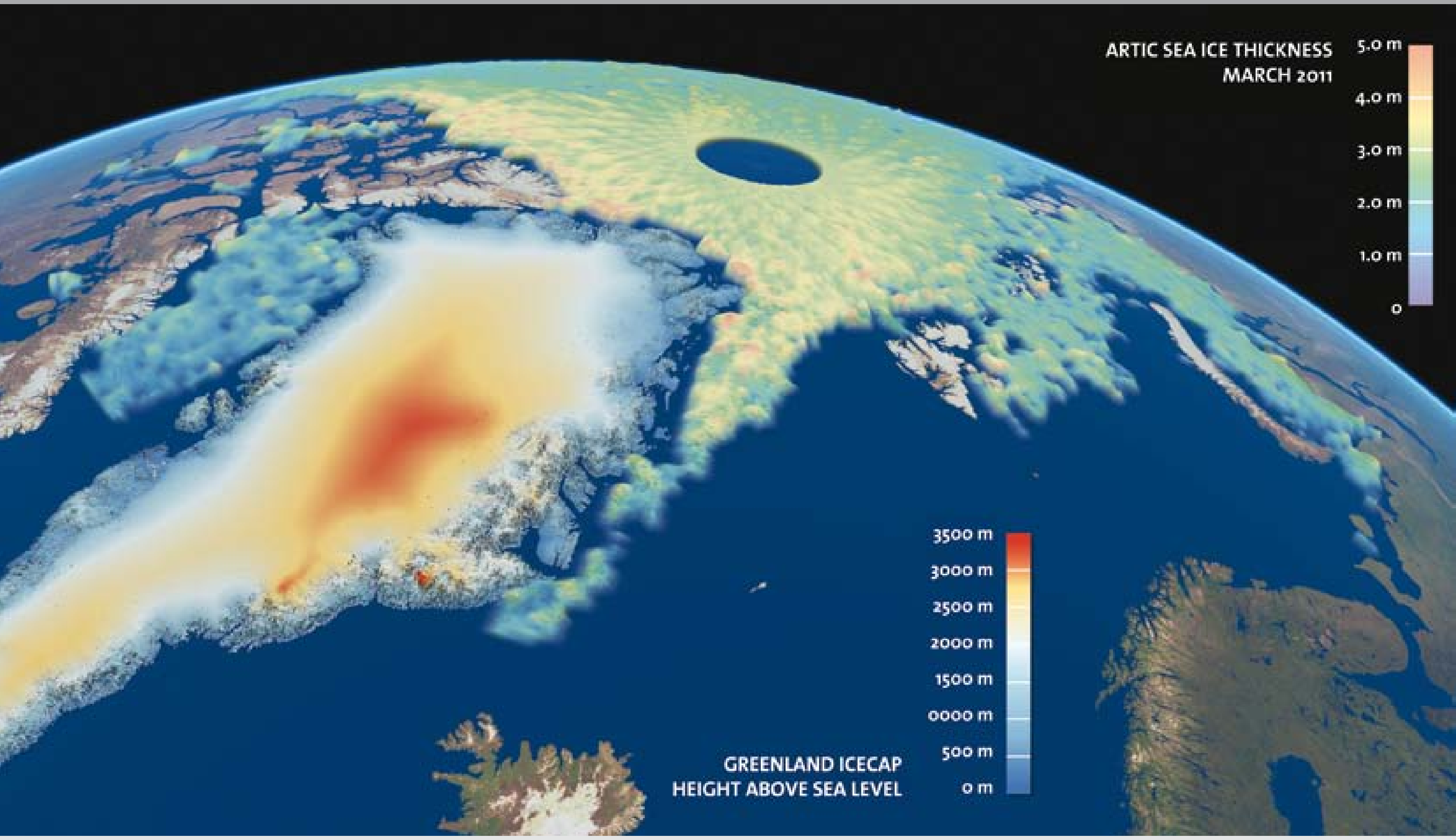
In April, the first winter sea-ice thickness variation map of the Arctic, produced from CryoSat-2 validated data, was presented at the Royal Society in London as part of the events celebrating the 50th anniversary of the UK in space. At the same time, a new digital elevation model of the Greenland ice sheet, using more than 7 million individual measurements acquired by CryoSat-2 during the first year of mission operation, was also shown.

→ AEOLUS

The first laser transmitter has completed an endurance test in near-vacuum conditions with overall positive results. Specific performance issues are being analysed and refurbishment will be carried out before formal qualification for flight.

The master oscillator of the second flight laser transmitter is aligned and tests show good performance.

Refurbishment of the transmitting and receiving optics has almost been completed and the delta-qualification of the main optical bench is now in preparation.



Produced from CryoSat-2 data, this map shows Arctic sea-ice thickness, as well as the elevation of Greenland ice sheet, for March 2011. For sea ice, green indicates thinner ice, while yellow and orange indicate thicker ice (CPOM/UCL/Leeds/ESA/PVL)

→ SWARM

All three Swarm satellites have completed their environmental tests and are nearly ready for launch.

The launcher adapter was delivered by Khrunichev. The satellite fit check and shock test with this adapter have been completed. One of the Electric Field Instruments has been calibrated on the satellite. Other calibrations are planned next month. The Swarm FAR began on 15 March. Ground segment preparation activities are proceeding according to plan.

The launch has been delayed to August/September. ESA is still awaiting the launch manifest for 2012 for the Rockot launcher from the Russian Ministry of Defence, indicating the launch date for Swarm.

→ EARTHCARE

The project is entering Phase-C/D and activities are proceeding to plan, with organisation of the System CDR for later in 2012. The satellite configuration and system budgets remain stable with adequate margins. Avionics equipment EMs are being tested, and the setup of the spacecraft EFM is under way.

The CDR for the Broad Band Radiometer instrument was held. The ATLID EQM laser pump unit Manufacturing Readiness Review was held and the operation point of the laser head has been confirmed. Testing of the Engineering Confidence Model of the Multi-Spectra Imager VNS camera started, while the TIR camera assembly is nearing completion.

The Cloud Profiling Radar (CPR) SM has been delivered and handed over to ESA. It is now available for fit checks to the spacecraft and the mechanical ground support equipment. The CPR EM is being assembled in Japan. The Overall Configuration and Interface Design Review of the ground segment has been completed in preparation for its CDR later this year.

→ METEOSAT

MSG-3

MSG-3 has completed its final test activities, including the System Validation Test that confirms compatibility with the control centres (ESOC for LEOP and Eumetsat for normal operations). Following the success of ESA and Eumetsat reviews, MSG-3 was declared fit for flight. It was put into its transport container on 30 March and shipped to Kourou on 13 April. Satellite health tests, final integration and fuelling will take place for a launch planned for 19 June. In the meantime in ESOC, simulation campaigns will be performed to prepare for LEOP.

MSG-3 installed in the transport container prior to shipment to Kourou (Thales Alenia Space)

MSG-4

Reassembly of the Scan Drive Unit has been restarted. Following the Eumetsat Council decision, planning is being consolidated to prepare for a launch in early 2015, followed by in-orbit storage.

→ MTG

The complexity of both of the MTG-I imager and MTG-S sounder missions, and the associated stringent requirements on both platform and instrument performances, continue to be major challenges.

Progress within the industrial team continues with a clear focus on the satellite PDRs scheduled for May/June. The PDR for the Flexible Combined Imager (FCI), the primary instrument for the imaging satellite, concluded in April. The PDRs for the Common Platform and the Infrared Sounding Instrument (IRS) follow in autumn.

In parallel with the technical baseline consolidation, the Best Practice Procurement process is progressing with over 60% (by value) of the subcontractors selected. Three significant procurements that have taken place in the period are for the Satellite Management Unit (SMU), the Lightning Imaging (LI) instruments and the (common) FCI and IRS Scan Assemblies (SCA). For the SMU and the LI the preferred contractor has been selected, while for the SCA evaluation of the offers is now under way, with a TEB anticipated in April.

The goal remains to complete all major subcontractor selections by autumn, to allow for the formal Phase-C/D price conversion process to commence.

→ METOP

MetOp-A

The satellite and all remaining instruments continue to perform excellently in orbit. The HRPT-data transmission continues to be operated well, but in restricted coverage area due to space radiation potential problems.

MetO p-B

After six years in storage, the PLM, SVM and SA completed their acceptance test campaigns and passed the FAR. The satellite was shipped to Baikonur in February and is already in flight configuration: all modules are assembled, health test passed and alignment activities completed.

Launch preparations were progressing well, with the satellite hydrazine filling planned for April and integration inside the fairing and with the Soyuz launcher in May.

MetOp-B is in final configuration for launch on 23 May. All functional tests and assembly activities were completed with great teamwork from Astrium, Starsem, ESA and Eumetsat

MetOp-B at Baikonur during the delicate integration and deployment of the solar array

However, on 27 April, Eumetsat and ESA were informed by the launch service provider Starsem that the launch scheduled for 23 May had to be postponed. This is due to additional measures required to ensure the availability of safe drop zones for parts of the launcher after lift-off.

Launch is expected to take place in the second half of July, after the launch of MSG-3. MetOp-B will be kept in a safe environment in the Starsem facilities at Baikonur ready to be fuelled.

MetOp-C

PLM, SVM and SA are back in storage, awaiting the launch of MetOp-B. Several instruments were dismounted for calibration and/or troubleshooting due to non-conformances. GOME-2 completed calibration at TNO and is in storage at Selex Galileo. Launch of MetOp-C is planned from French Guiana in October 2017, but needs to be ready as a back-up for MetOp-B from late 2013.

→ SENTINEL-1

Following delivery of the spacecraft structure last February, the GMES Sentinel-1 project is fully dedicated to the AIT of the different flight equipment on the spacecraft structure panels and, in turn, the complete Sentinel-1A spacecraft. Most flight units have already been delivered and the remaining units will be delivered in the coming months. The four computers on board have been tested together at spacecraft level.

At Astrium GmbH, Germany, the SAR instrument is undergoing integration of the Sentinel-1A SAR antenna remaining six in the final stages of integration and test. All antenna flight units (including the critical transmit/receive modules manufactured by Thales Alenia Space, Italy) have been delivered. The antenna centre panel passed the test campaign and the panels of the left wing are being completed. The SAR electronics EM testing and, in parallel, the production of the FM units, are progressing at Astrium, UK.

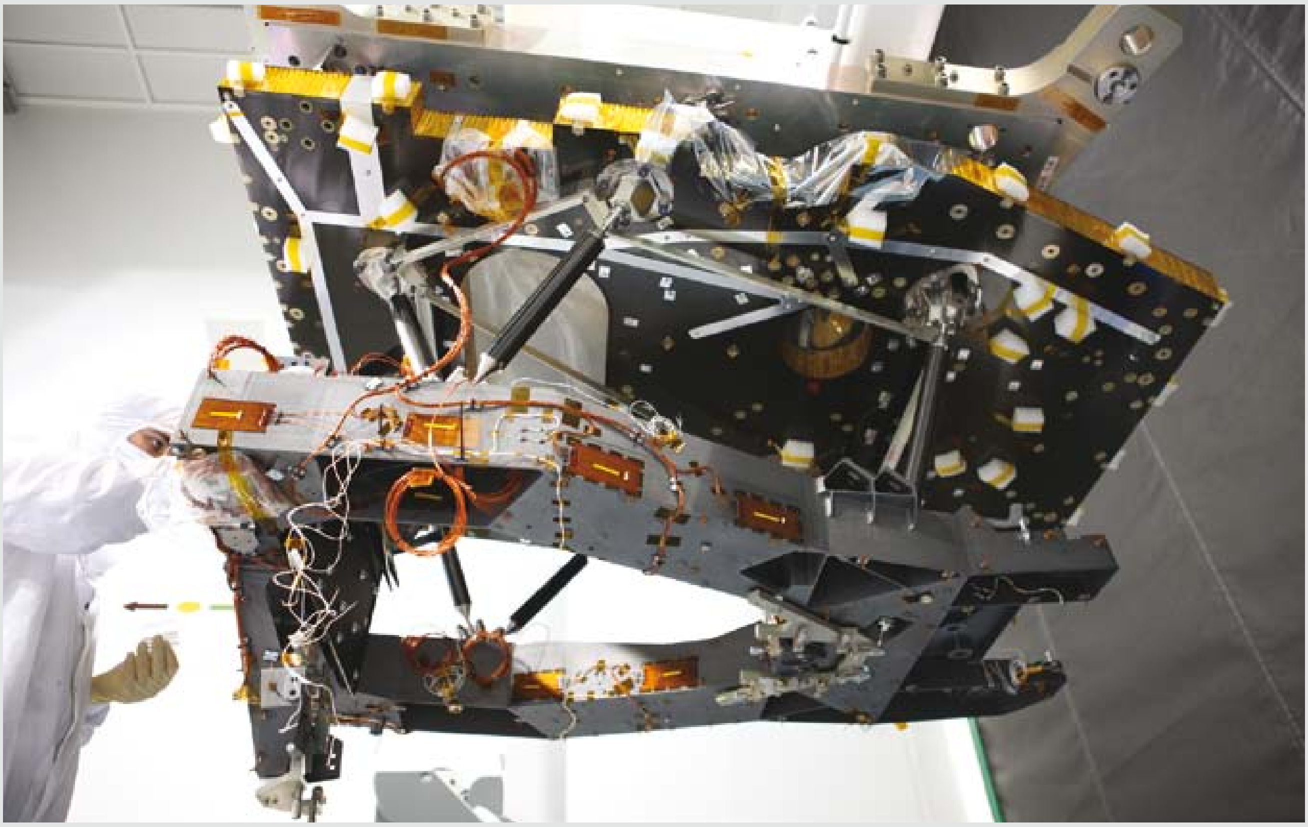
After the completion of the Preliminary Mission Analysis of the Sentinel-1A launch with a Soyuz from French Guiana, activities with launch service provider Arianespace continue for a launch date in May 2013.

→ SENTINEL-2

Payload instrument technological developments have been qualified, including the optical beam splitter. The 12 FM detectors and optical filters are being integrated and aligned on the two instrument focal planes (visible and near-infrared, shortwave infrared). In parallel, the instrument telescope silicon carbide structure has been integrated, including installation of the thermal hardware. The three mirrors are being integrated and aligned. The secondary instrument structure and the video and compression unit FMs will be delivered before summer. FM equipment for the second instrument model is also being delivered to the instrument prime contractor.

The satellite command, control, and payload data handling EFM testing is proceeding. The Remote Interface Unit EM has now been delivered to the satellite prime contractor, enabling an extension of the test programme to include all satellite command and control test cases. Correction of some identified mass memory and formatting unit anomalies related to memory management are being retrofitted. Satellite software development is progressing coherently with the needs originating from the integration and test team. The Optical Communication Payload EM has been integrated into the satellite EFM and tested. The delivery of the Power Conditioning and Distribution Unit FM will allow integration and test of the Sentinel-2 PFM.

Sentinel-2 image quality activities conducted under CNES responsibility, and including the Level-1c Ground Prototype Processor, are progressing. Availability of adequate calibration material is being reviewed in support of the preparation of the commissioning phase, and to decide on the need to conduct further calibration campaigns. The Sentinel-2 Payload Data Ground Segment underwent its PDR. The first Sentinel-2 satellite Validation Test campaign was completed in March.



Sentinel-2 Multi Spectral Imager telescope during integration (Astrium SAS)

→ SENTINEL-3

Phase-C/D development activities are proceeding, with the focus moving from the design phase to the manufacturing and AIT phase.

At spacecraft level, platform integration activities are continuing. The propulsion tanks were completed at the beginning of April with the proof test, while all thermal control items have already been integrated. Start of the avionics integration is planned early May, starting with the Power and Control Distribution Unit and followed by the Onboard Computer and the Data Handling subsystem. In parallel, Virtual EM testing is proceeding and the delivery of the first version of the Flight Software took place, in preparation for the first System Validation Test between the satellite virtual EM and the flight operations segment in June.

At instrument level, the OLCI camera EM testing is complete and attention is moving to the FM, where the Focal Plan Assembly and the Video Acquisition Module are starting their test campaign. The SRAL PFM instrument TRR is scheduled by the end of March, as soon as the Data Processing Unit PFM is available after testing, since all the remaining SRAL flight hardware has already been integrated on the satellite flight panel.

The MWR antenna PFM and FM2 RF test campaigns were concluded, while testing of the various subassemblies is ongoing. At SLSTR level, the integrated EM testing is almost complete, without any major anomaly. Because of problems discovered during the manufacturing of some infrared detectors, integration of the flight instrument will be delayed.

On the launcher side, the Eurockot SRR took place in March, marking the start of the preparation for the Preliminary Launcher Mission Analysis Review planned later this year, while the SRR with Arianespace is now planned for April.

→ SENTINEL-5 PRECURSOR

The TROPOMI PDR was concluded at the end of March, providing a complete baseline design for the whole payload. ESA Best Practice Procurement activities for Astrium Ltd continued. The system-level PDR is now confirmed for July.

→ SMALLGEO

The PFM integration campaign started with the transfer of the Repeater Module from RSSZ (Switzerland) to OHB-System in Bremen, Germany, for the integration of the harness and the Payload Management Unit. Following this step, the Repeater Module will be shipped to Tesat to finalise the integration of the payload units.

The deliveries of PFM equipment are also advancing. Astrium have completed the final qualifications tests of the solar array, and the two wings, together spanning over 12 m, have been delivered to OHB.

Two antenna reflectors built by EADS-CASA Espacio have passed critical acoustic and vibration tests at ESA. The 'Iberia' reflector will provide broadband services in Ka-band over Spain, including the Canary Islands and the Portuguese mainland. This dish is shaped to concentrate signals around these areas. The 'Europe' reflector will provide Ku-band broadband services mainly over Spain, the Canary Islands and Portugal but also all of Western Europe.

One of the reflectors has a unique feature used for the first time on a European commercial satellite. Stretching 1.8 m across, the Europe reflector is not painted the usual white colour. White paint protects the antenna reflector from the extreme temperatures in space, but it distorts radio frequencies. Instead, the bare carbon keeps frequency loss to a minimum.

During the tests at ESTEC, the Europe reflector and the 1.2 m Iberia reflector were subjected to sound pressure levels reaching 145 decibels and vibration levels similar to that to be experienced when the satellite is launched into geostationary orbit.

Both antennas are undergoing a series of radio-frequency tests at EADS CASA Espacio before being added to the satellite at the end of the year, including tests to determine the bare carbon's resilience to extreme temperatures. In parallel, the STM and EM integration are continuing.

→ ALPHABUS AND ALPHASAT

Alphasat payload test activities are ongoing in Toulouse. The optical laser terminal has been fully assembled and is in final testing stage prior to delivery to the spacecraft. Preparations for the satellite thermal vacuum test are on track for a campaign starting in the summer.

The Alphabus Extension programme is on track, to significantly enlarge the payload capabilities among other things, by making extended use of electric propulsion.

In Alphasat ESA/Inmarsat Applications, the second call for proposals has been issued for development of innovative value-added applications based on Inmarsat's Broadband Global Area Network and Global Handheld Service using the Alphasat and Inmarsat 4 satellites.

Alphasat under payload testing

→ ARIANE 5 POST-ECA

The Steering Committee of the Launch System PDR took place in December. Following this, the Ariane 5-ME Phase 1 Maturity Key point took place in April.

→ SOYUZ AT CSG

The second step of the Soyuz Launch System Qualification Commission (CQ SLS 2) was conducted in April, after the exploitation of the data of the first and second flights. The review concluded with the recommendation for the final handover of the Soyuz Launch Complex to Arianespace, in the role of launch service provider, marking the start of the exploitation phase. The Steering Board is scheduled for the beginning of June.

→ FUTURE LAUNCHERS PREPARATORY PROJECT

Intermediate eXperimental Vehicle (IXV)

The IXV Phase-D/E1A and B are progressing, including the flight segment and ground segment deliveries, and the preliminary mission analysis activities.

For short-term activities preparation, Phase-D/E1A and B activities are being implemented, ESA is continuing the elaboration of the scenarios for the implementation of the Phase-E/F (i.e. the mission into space).

Next Generation Launcher (NGL)

In System studies, after the first milestone (KP1), the second phase is now close to completion, with the analysis of six configurations (HHSC, HBHSC, HHGG, HBHGG, PPH, CH). The next milestone, KP2, is split into 2 steps: (i) a review of the design of this second loop which started mid-December and has been pursued up to early April, and (ii) a review of the concurrent activities. After the collocation session, the KP2 is now completed.

The Phase-B of SCORE-D (Stage COmbustion Rocket Engine Demonstrator) is progressing to PDR, in particular with actions associated with the development Key Point. The different sub-systems’ Feasibility Reviews are starting. The valves Feasibility Review took place in March.

In Cryogenic Upper Stage Technologies (CUST), the industrial activities are progressing with, in particular, the Final Presentation of the MT-A activities on the Sandwich Common Bulkhead, and the Test Readiness Review for the Propellant Pre-Conditioning/Propellant Management Device concept developed by Air Liquide.

In avionics and photonics, the negotiation for a set of activities in Data Handling sub-systems/photonics is now completed, to begin in April.

ESA astronaut André Kuipers pictured at a window of Cupola on the ISS, with the Canadarm robotic arm at left and Earth above (NASA/ESA)

→ HUMAN SPACEFLIGHT

ESA astronaut André Kuipers was the lead robotics crewmember of Expedition 30 on the ISS during ATV rendezvous and docking. He is continuing his activities for the European PromISSe mission, which started in December 2011 and has been extended by about six weeks, with landing tentatively scheduled for 1 July. Kuipers has undertaken many research activities in the past few months using different research facilities and hardware in ISS partner modules as well as in the European Columbus laboratory. Columbus reached the milestone of four years attached to the ISS on 11 February.

ISS highlights of the last few months also include the undocking of the Progress 45P logistics spacecraft; launch and docking of Progress 46P (with 2.6 tonnes of ISS cargo); a debris avoidance manoeuvre by the ISS in connection with debris from US and Chinese satellites; and a Russian-based spacewalk which carried out numerous tasks including relocation and installation of the Russian robotic arm.

→ SPACE INFRASTRUCTURE DEVELOPMENT/ISS EXPLOITATION

In preparation for the arrival of ESA's third Automated Transfer Vehicle, ATV *Edoardo Amaldi*, the ATV Control Panel was installed inside the Russian Service Module and docking cameras were tested. ISS Flight Engineers André Kuipers and Oleg Kononenko undertook an onboard training session (including rendezvous and docking malfunctions) on a new ATV Simulation Application, and tested the ATV's Proximity Communications and associated Equipment.

ATV *Edoardo Amaldi* was launched to the ISS on 23 March by an Ariane 5 from Europe's Spaceport in Kourou, French Guiana, and docked with the ISS automatically on 29 March. The ATV carried 100 kg of oxygen, 285 kg of water, 4 tonnes of propellant, and 2.25 tonnes of dry cargo to the ISS. Activities are also ongoing for the next ATVs. ATV-4, named ATV *Albert Einstein*, is undergoing integration activities for a scheduled launch in March 2013. ATV-5 is now named ATV *Georges Lemaître*.

André Kuipers floats inside the newly arrived ATV *Edoardo Amaldi* (NASA/ESA)

ATV *Edoardo Amaldi* seen before docking with the ISS on 28 March (NASA/ESA)

ATV *Edoardo Amaldi* is launched on 23 March by an Ariane 5 from Europe's Spaceport in Kourou, French Guiana (ESA/CNES/Arianespace/PhotoOptique Vidéo du CSG)

→ UTILISATION

European research in the Columbus Laboratory
André Kuipers' PromISSe mission is in full swing with the ESA astronaut more than halfway through his mission at the end of March. He has been a focal point for much of the European research as well as undertaking or supporting numerous experiments for ESA's ISS partners.

→ HUMAN RESEARCH

Human physiology has again been a principal focus of the European research programme in the past few months. Kuipers carried out two sessions of the Neurospat experiment in January and February. Neurospat investigates the ways in which the crews' three-dimensional perception is affected by long-duration stays in weightlessness, and uses the European Physiology Modules facility for EEG measurement. Kuipers is supplying valuable additional information to the science team through questionnaires, and was instrumental in retrieving lost data on orbit that has subsequently been downlinked for analysis.

A milestone was reached with the Passages experiment as NASA astronaut Dan Burbank had his final experiment session on 15 March, concluding all on-orbit activities for the experiment with all 10 subjects. The Passages experiment is designed to test how astronauts interpret

Wearing an electroencephalogram electrode cap, André performs a NeuroSpat science session in Columbus (NASA/ESA)

visual information in weightlessness, using virtual reality stimuli such as passing through a virtual door. This neurological experiment can improve our knowledge of neurological processes and provide an insight into the efficiency of performing certain tasks in space, which in turn can improve training techniques for astronauts.

Turning to cardiopulmonary research, Kuipers and NASA Flight Engineer Don Pettit were both subjects of ESA's Vessel Imaging experiment in January. Vessel Imaging is carried out in conjunction with NASA's Integrated Cardiovascular Experiment and consists of an echography scan together with ECG and heart rate measurements being taken to quantify the cardiovascular response to fluid shifts in the body during long-term exposure to weightlessness, with the aim of optimising countermeasures to the adverse effects of spaceflight.

There was more positive news for ISS cardiopulmonary research for the CARD experiment as Kuipers replaced the failed Photoacoustic Analyzer Module of the Pulmonary Function System in Human Research Facility 2 in Columbus at the end of January.

The Pulmonary Function System is an ESA/NASA collaboration in respiratory physiology instrumentation, which analyses exhaled gas from astronauts' lungs to provide near-instant data on the state of crew health. This replacement has enabled the continuation of the CARD experiment though this is currently still on hold as a broken hose connector will first need replacing before the activities with the Pulmonary Function System can resume fully.

Within musculoskeletal research, Kuipers and Burbank carried out their first sessions of the Sodium Loading in Microgravity (SOLO) experiment between 29 January and 9 February. This consisted of each astronaut undertaking two different six-day diet sessions, one with a lower salt content and the other with a higher salt content.

During each session the astronauts log what they have eaten, have body mass measured and provide blood and urine samples for analysis. SOLO is researching salt retention in space and related human physiology effects during long-duration spaceflight.

A final physiology experiment that Kuipers continued in the last few months is 'Space Headaches' for which he is filling in weekly questionnaires which are being analysed on the ground to help determine the incidence and characteristics of headaches occurring in orbit.

→ BIOLOGY RESEARCH

Activities are building up for restarting research in the Biolab facility. A modified gripper for the fixation syringes of Biolab's handling mechanism was launched on ATV-3 on 23 March. On the same day a ground-commanded alignment test of Biolab's two centrifuges was undertaken. These activities will be followed by launch (and installation) of Biolab's new microscope. Full functionality of Biolab will enable the start of the TripleLux experiment series which will further our understanding of the cellular mechanisms underlying the aggravation of radiation responses, and the impairment of immune function under spaceflight conditions.

→ FLUIDS RESEARCH

The Geoflow-2 experiment in the Fluid Science Laboratory (FSL) is now approaching completion. Numerous runs have been completed with different temperature and rotation profiles and associated data has been downlinked for analysis in the first quarter of 2012.

In addition, Kuipers supported several runs of another fluid physics experiment: Foam Stability (which serves both education and science). Kuipers set up the hardware, exchanged experiment cells and filmed additional imagery of himself describing the experiment. The experiment demonstrated that non-foamable aqueous liquids can build stable foams under weightless conditions (due to different in drainage effects).

→ TECHNOLOGY RESEARCH

Kuipers made extensive use of the Erasmus Recording Binocular 2, ESA's high-definition 3D video camera, filming onboard activities in all ISS locations. After filming, data was downlinked to the ground for analysis via the European Drawer Rack facility in Columbus.

ESA's SOLAR facility carried out additional data acquisition during 'Sun visibility windows' in the last few months. These windows are when the ISS is in the correct orbital profile in relation to the Sun to acquire scientific data.

Finally, ESA's Vessel Identification System (VIS) has been functioning on the ISS for 21 months, with telemetry being received by the Norwegian User Support and Operation Centre (N-USOC) in Trondheim via ESA's Columbus Control Centre in Germany. The VIS is testing the means to track global maritime traffic from space by picking up signals from standard transponders carried by all international ships over 300 tonnes, cargo vessels over 500 tonnes and all types of passenger carriers. Meanwhile various service entities have been asking to get access to the VIS data that are continuously acquired on Columbus.

→ ADDITIONAL EUROPEAN RESEARCH ON THE ISS

Human research remains a key element of the European research programme on the ISS. Kuipers, Pettit and Burbank were all subjects for ESA's 'Thermolab and Assessment of Endurance Capacity by Gas Exchange and Heart Rate Kinetics During Physical Training' (EKE) experiments in conjunction with NASA's Maximum Volume Oxygen (VO2 Max) experiment from January to March. Thermolab uses the ESA-developed Portable Pulmonary Function System to investigate thermoregulatory and cardiovascular adaptations among crewmembers, while EKE aims to develop a diagnostic tool for improved assessment of endurance capacity in orbit and the development of a physiological model-related oxygen transport.

Turning to immunology, Russian cosmonauts Anton Shkaplerov and Anatoly Ivanishin were subjects of ESA's Immuno experiment on 31 January, which determines changes in stress and immune responses, during and after a stay on the ISS. The cosmonauts provided blood and saliva samples to check for hormones associated with stress response and for carrying out white blood cell analysis, in addition to filling in stress-test questionnaires.

André prepares for Immuno blood sample draws in Columbus Following the blood draws, the samples were temporarily stored in the Minus Eighty Laboratory Freezer and later packed together with saliva samples on Soyuz TMA-22 for analysis on Earth (NASA/ESA)

André performs routine in-flight maintenance on a spacesuit, or Extravehicular Mobility Unit (EMU), in the Quest airlock (NASA/ESA)

The third and final of the three experiments that form the Selectable Optical Diagnostic Instrument (SODI) experiment series finished processing in the Microgravity Science Glovebox (MSG) in the US Laboratory. Eighteen additional runs of the SODI-Diffusion and Soret Coefficient Measurements for Improvement of Oil Recovery (DSC) experiment were undertaken in the MSG in January to complete the experiment. SODI-DSC is supporting research to determine diffusion coefficients in different petroleum field samples and refine petroleum reservoir models, to help lead to more efficient extraction of oil resources.

→ OTHER WORK ON THE ISS

Kuipers' six-week mission extension will probably allow some further experiment runs or biomedical experiment sessions, as well as possibly some facility maintenance activities. In addition to his ESA research activities, Kuipers has been involved in other activities in his role as Flight Engineer of Expeditions 30/31.

These include proficiency training on the ISS's principal robotic arm in preparation for the arrival of the SpaceX Dragon logistics vehicle; setting up the control panel for the Japanese HTV-3 logistics vehicle in the Japanese laboratory; and supporting ground-commanded testing of proximity equipment in preparation for future launch and docking of HTV and the Cygnus commercial logistics spacecraft.

Further systems activities have included maintenance on the ventilation systems in Columbus and Node-3 due to airflow degradation; installing and routeing video cabling with Dan Burbank for the High Rate Communication System in the US laboratory; standard sampling and maintenance on the Water Recovery System racks in Node-3; and installing and configuring new laptops in Columbus as part of transitioning Columbus to new

André works the controls of the Canadarm2 Space Station Remote Manipulator System in the Cupola (NASA/ESA)

André takes part in an inflight call, a live link up with school children and students on the ground (NASA/ESA)

André routes video cables in the Destiny laboratory for the High Rate Communication System (NASA/ESA)

software, in preparation for upgrading the Columbus Data Management System and then integrating Columbus into the Joint Station LAN.

For partner agencies, Kuipers has been a subject of two human research experiments for NASA, and supported four biological experiments/payloads (three for NASA and one for JAXA), one JAXA fluids research experiment, one NASA technology experiment and two NASA education activities.

He has been involved in numerous public affairs/education events in different countries, ranging from a live link with the German Chancellor Angela Merkel to open the world's largest IT show (CeBIT) in Hannover, Germany, to a ham radio session in March with children who won ESA's 'Ruimteschip Aarde' (Spaceship Earth) competition at ESTEC, the Netherlands.

Kuipers performed two experiments (on Foam Stability and Convection) as part of the Spaceship Earth educational programme. Primary and secondary school children followed lessons and watched videos, and performed the same experiments on the ground. This enabled them to compare what happens in gravity and in weightlessness.

Kuipers set up ESA's new NightPod system in the Cupola on 24 February. This 'tracking device' supports a Nikon 3DS camera in taking high-definition pictures of Earth, especially at night. In a global outreach effort, all footage has been made available to the public on the internet.

→ NON-ISS RESEARCH

The MASER-12 sounding rocket mission was launched on 13 February from the Esrange launch complex in Kiruna, Sweden. The payload module landed safely and the scientists indicate full mission success and continue detailed analysis of their experiments.

MASER-12 incorporated four experiment modules with a total of five experiments. The three physical science modules covered solidification processes in metallic alloys (XRMON), a boiling and heat transfer experiment (SOURCE-2), and a study to help improve understanding of the transport and mobility of red blood cells in blood vessels through biomimicry (BIOMICS-2).

Two life science experiments were part of the Biology in Microgravity (BIM-2) module flown on MASER-12. These involved in vitro research into early immune response, which is known to be suppressed in weightlessness.

→ CREW TRANSPORTATION

Expert

Studies are ongoing to identify alternative launchers in Russia (Kosmotras/Dnepr) and in the US (Orbital Sciences/Pegasus). A Technical Assistance Agreement with the US Department of State needs to be approved before discussion with Orbital Sciences can take place. Interest has been expressed by NASA centres in supporting the Expert launch operations and costs in exchange for the reentry data.

International Berthing and Docking Mechanism (IBDM)

Development is progressing and contractual actions have begun to ensure major progress during 2012/13. The design and manufacturing of new linear actuators with in-line load cells has started. An initial set of dynamic tests of the soft-docking system with relative spacecraft motion damping has also been completed with good results.

MASER-12 payload during final integration at Esrange (SSC)

→ SPACE SITUATIONAL AWARENESS

An important step for SSA's security environment has been taken: ESA's Council approved the amendment of the SSA Implementing Rules, making the SSA Programme Security Instruction and the Classification Guide applicable to the SSA Preparatory Programme. As a result of the ITT for development of the SSA architecture, the first contract has been finalised with Astrium GmbH. A second contract, to be run in parallel, is under final negotiation.

The breadboard monostatic radar is progressing under a contract with INDRA (Spain) and the Fraunhofer Institute for High Frequency Physics and Radar Techniques (Germany). This radar will be installed at Santorcaz near Madrid. For the breadboard bistatic radar, Phase-1 has been completed with selection of the sites (Dreux and Palaiseau in France) and allocation of the frequency. Negotiations are in progress for the second phase.

In the space weather (SWE) domain, installation of a first set of applications at Redu, Belgium, and at the Space Pole in Brussels, is being finalised, allowing validation of agreed SWE services focusing on solar weather, ionospheric weather, space radiation environment and geomagnetic conditions.

Progress has also been achieved with the University of Pisa (NEODyS) and DLR (physical properties of asteroids) to organise a federated Near-Earth Object (NEO) service through a dedicated NEO Portal.

→ HUMAN EXPLORATION

Scenario studies

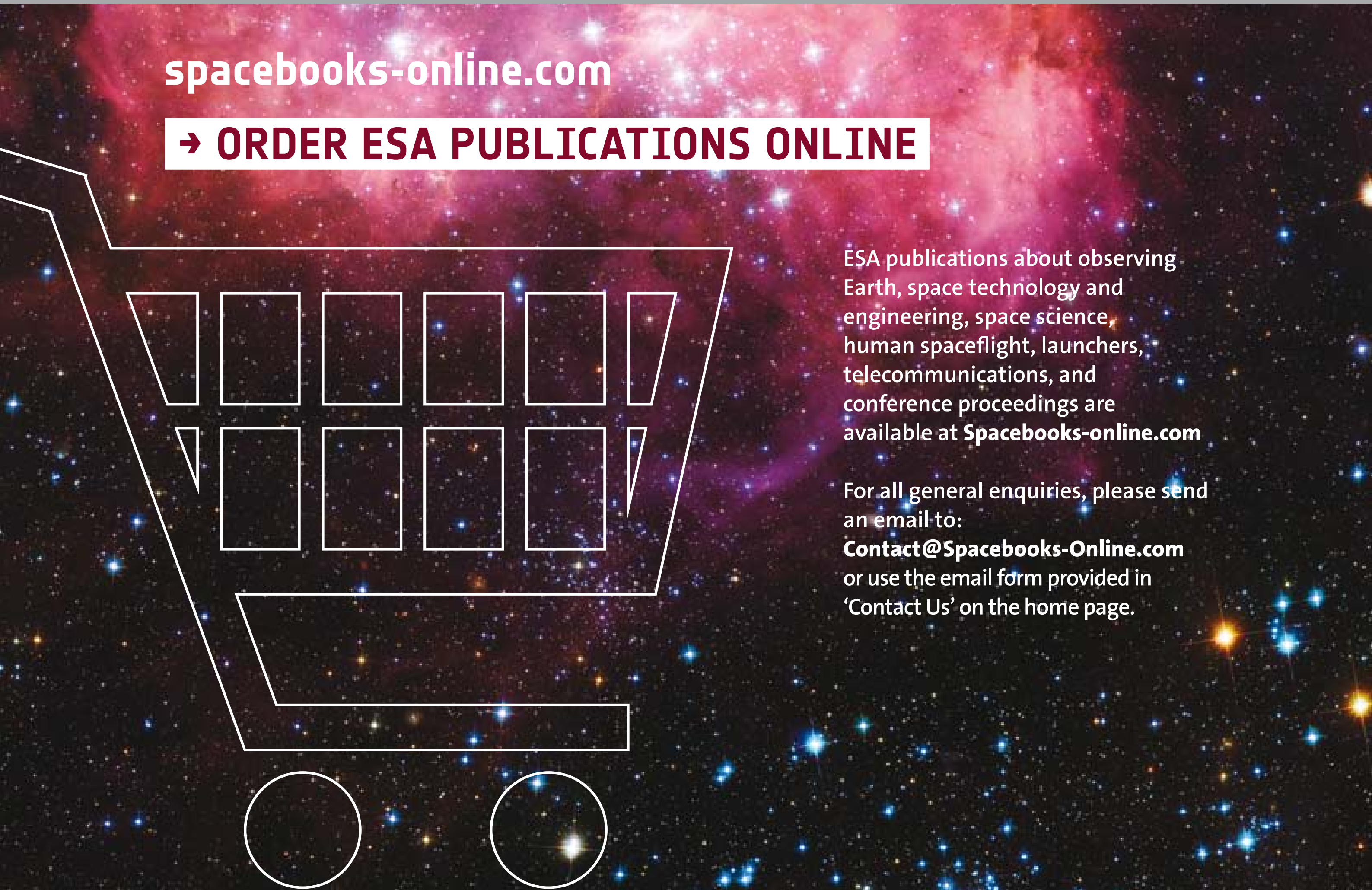
The preparation of the Final Roadmap Review is ongoing. Initial mapping of the building blocks against the ESA Directorate of Technical and Quality Management roadmap for development of exploration technologies has been completed. The European Space Policy Institute is conducting a study to assess the space exploration benefits.

Lunar Lander

The Lunar Lander Industry Day took place on the 27 January at ESTEC. A workshop on Scientific Preparations for Lunar Exploration took place in February at ESTEC to prepare for a special issue of the Journal of Planetary and Space Science.

Man-Tended Free Flyer (MTFF)

A report was produced on short and long-term scenarios for collaboration opportunities between ESA and Roscosmos on a potential small free-flyer that Roscosmos intends to launch in 2017. The outcome was also discussed at the Heads of Agencies meeting on 6 April. Investigations continue on the possibility for bilateral cooperation on a free-flyer and also on a future low-Earth orbit man-tended infrastructure after the ISS.



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