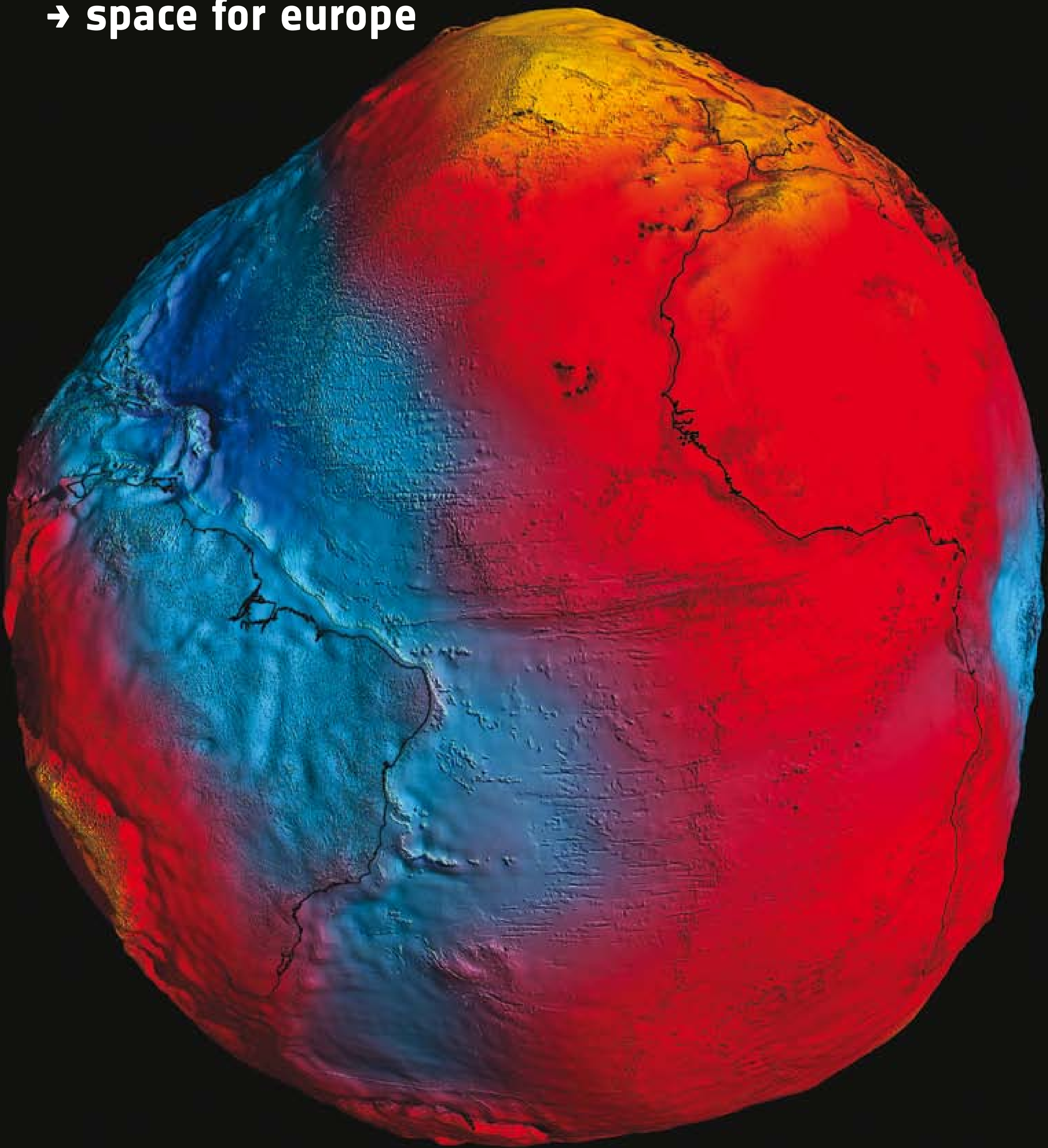
number 146 | May 2011

esa

bulletin

→ 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.

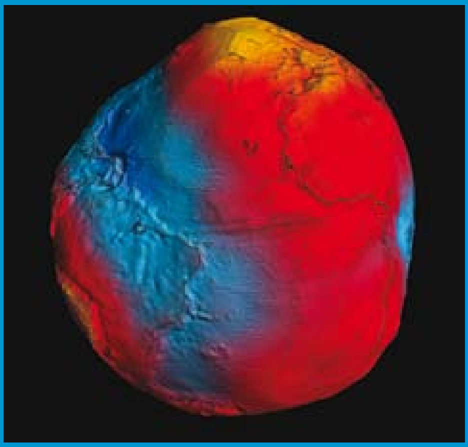
ESOC, Darmstadt, Germany.

ESRIN, Frascati, Italy.

ESAC, Madrid, Spain.

Chairman of the Council: D. Williams

Director General: J.-J. Dordain



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ESA's GOCE mission has delivered the most accurate model of the 'geoid' ever produced, which will be used to further our understanding of how Earth works. The geoid is the surface of an ideal global ocean in the absence of tides and currents, shaped only by gravity. It is a crucial reference for measuring ocean circulation, sea-level change and ice dynamics – all affected by climate change.

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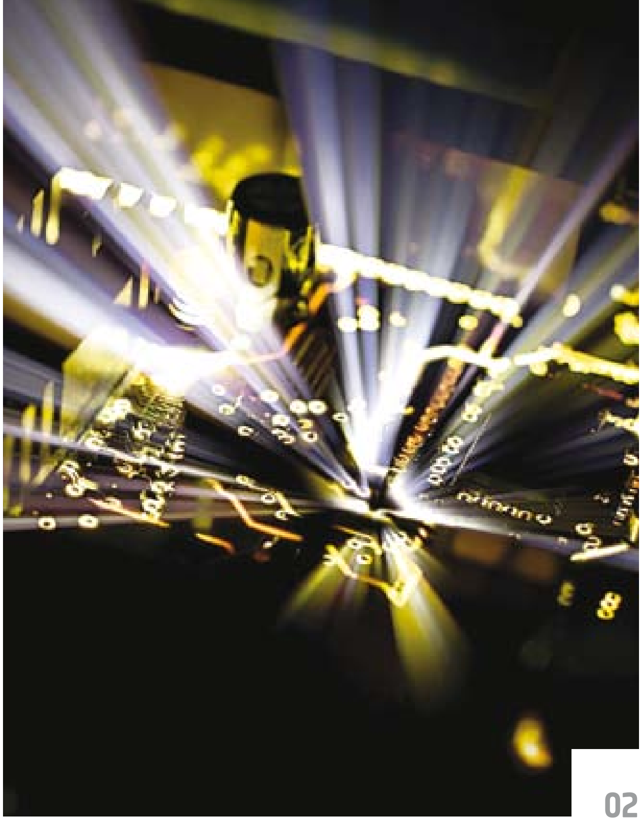
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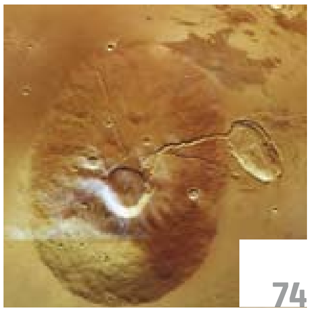
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→ BUILDING THE FUTURE

Technology development at ESA

Sean Blair with Alberto Tobias
Directorate of Technical and Quality Management, ESTEC,
Noordwijk, The Netherlands

ESA doesn't do routine. Each new ESA mission marks a significant scientific or technical step forward, whether probing further into the Universe, gathering novel data on our home planet, or pioneering new services from space.

Bringing future plans into the realms of the possible demands a steady stream of new technology. ESA spends around 8% of its budget on direct technology research and development, an activity mandated in the ESA Convention. The ESA definition of the word is precise: 'Technology is the practical application of knowledge so that something entirely new can be done, or so that something can be done in an entirely new way.'

Said in another way, try the single attribute that defines us, *Homo sapiens*, as a species: our ability to make and use new tools. Most of the human body is unremarkable when compared to other animals: it was only the tool-making ability of our brains and hands that propelled us from Africa's plains to the lunar Sea of Tranquility.

People make tools in order to do tasks they cannot otherwise accomplish; engineering is actually defined as 'the use of technology to solve specific technical problems'. This is so at ESA, and the agency runs a suite of preparatory programmes covering various technical maturity levels and domains. Much of the actual spending goes to European (and Canadian) companies and institutions: 30% of all ESA technology

→ ESA Technology Programmes

These programmes, the responsibility of ESA's Directorate of Technical and Quality Management, serve both to help define ESA's future technology needs and also eventually fulfil them:

Basic Technology Research Programme (TRP)
▪ responsible for early development stages across all service and technology domains, taking cutting-edge ideas and verifying their suitability for space applications

General Support Technology Programme (GSTP)
▪ takes previously proven ideas through successive stages of engineering, finally evolving fully-tested hardware ready for adoption by future missions

Technology Transfer Programme (TTP)
* has successfully transferred over 200 space technologies to non-space sectors

Other technology programmes undertaken by different ESA Directorates serve specific fields:

Advanced Research in Telecommunications Systems (ARTES)
▪ supports the evolution of satcom systems and services

Future Launchers Preparatory Programme (FLPP)
▪ develops new European launcher technologies and capabilities

These four programmes between them make up about three quarters of ESA technology R&D. Additional ESA programmes with a strong R&D component include:

Earth Observation Envelope Programme (EOEP)
European GNSS Evolution Programme (EGEP)
Transportation and Human Exploration (ETHE)
Science Core Technology Programme (CTP)
Mars Robotic Exploration Preparation (MREP)

contracts go to small- and medium-sized companies and 20% are with universities and research institutes.

Newly available technologies open up fresh possibilities for exploration or services – known as 'technology push'. At other times, a need is identified for new tools or techniques to make a planned space mission possible, and this is called 'mission pull'.

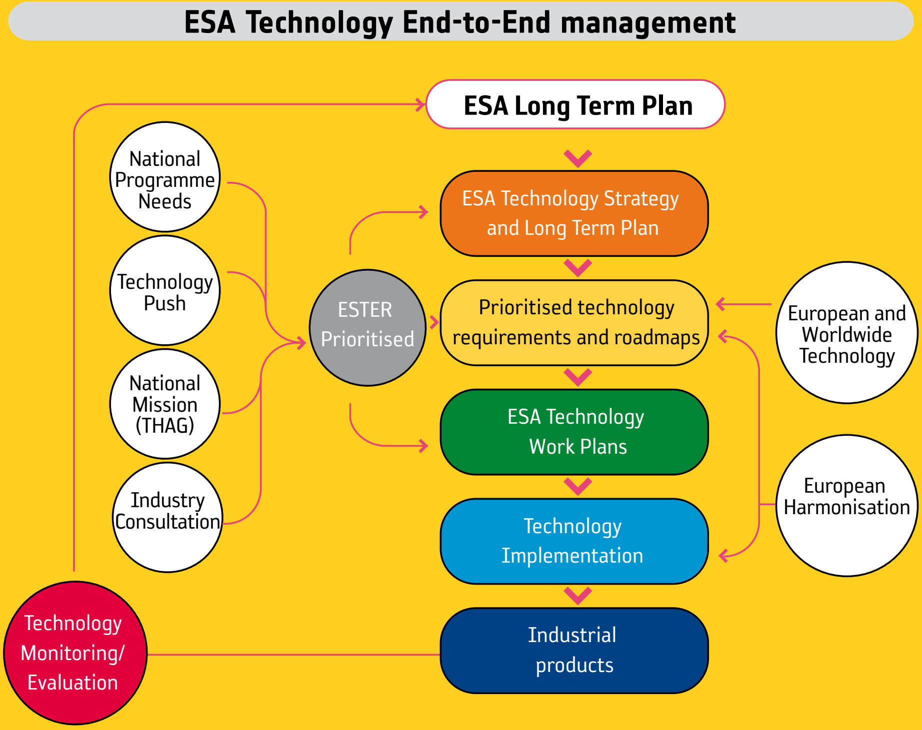
Technology for competitiveness

As well as making new missions possible, the technology programmes also maintain and expand the capabilities of Europe's space industry. Despite receiving low investment compared to its international counterparts, Europe's space sector is a significant source of high-value employment – directly providing more than 28 000 jobs – and remains highly competitive, winning in 2010 more than 30% of the world market of communication satellites.

ESA and general European institutional space activities themselves would be economically impractical if not for the continued vitality of European industry in the world market, especially in the satellite telecommunications market. But Europe finds itself competing on two fronts: with the USA in the hi-tech domain and, increasingly, with Russia, China and India in terms of low costs. In both cases, continued technological innovation is essential for success, ensuring Europe goes on being smarter when not possible to be cheaper.

End-to-End Technology Process

But how are all these different technology programmes coordinated? The answer is ESA's End-to-End Technology (E2E) Process, which establishes the principles for the overall coordination of the ESA technology programmes. The E2E process is inspired by the goals of ensuring user drive and optimisation of the use of resources. All ESA's programme directorates – Earth Observation, Science and Robotic Exploration, Human Spaceflight and Operations, Launchers, Telecommunications and Integrated Applications, Galileo and Navigation-related Activities – actively support the process. The Director's Sub-Committee on Technology supervises it.



The space sector is one of the highest value-added elements of the European economy

To maintain European competitiveness into the future, ESA leads a Europe-wide coordination of space research and development (R&D), devising technology 'road maps' to guide investment in a given field by various national and European players, including the European Commission's Framework Programme series. The annually updated European Space Technology Master Plan aims to ensure each euro spent works as effectively as possible.

In the end, the funding pays for itself: the space sector is one of the highest value-added elements of the European economy. One estimate is that every euro invested in satellite manufacturing results in tens of euro downstream. ESA's work on space makes a significant contribution to innovation on Earth and to European growth and employment.

The outcomes are indeed impressive, but in the end it all comes down to the human element. Just as tool-making is an intrinsic human trait, people are what technology is all about. Behind ESA's often remarkable technological discoveries and achievements, human curiosity and foresight remain the driving forces.

From invention to innovation

The terms are often used interchangeably, but 'invention' and 'innovation' are not the same. While an invention is a new and promising idea, an innovation is a mature idea whose early promise has been fulfilled – it has been found valuable and put to work.

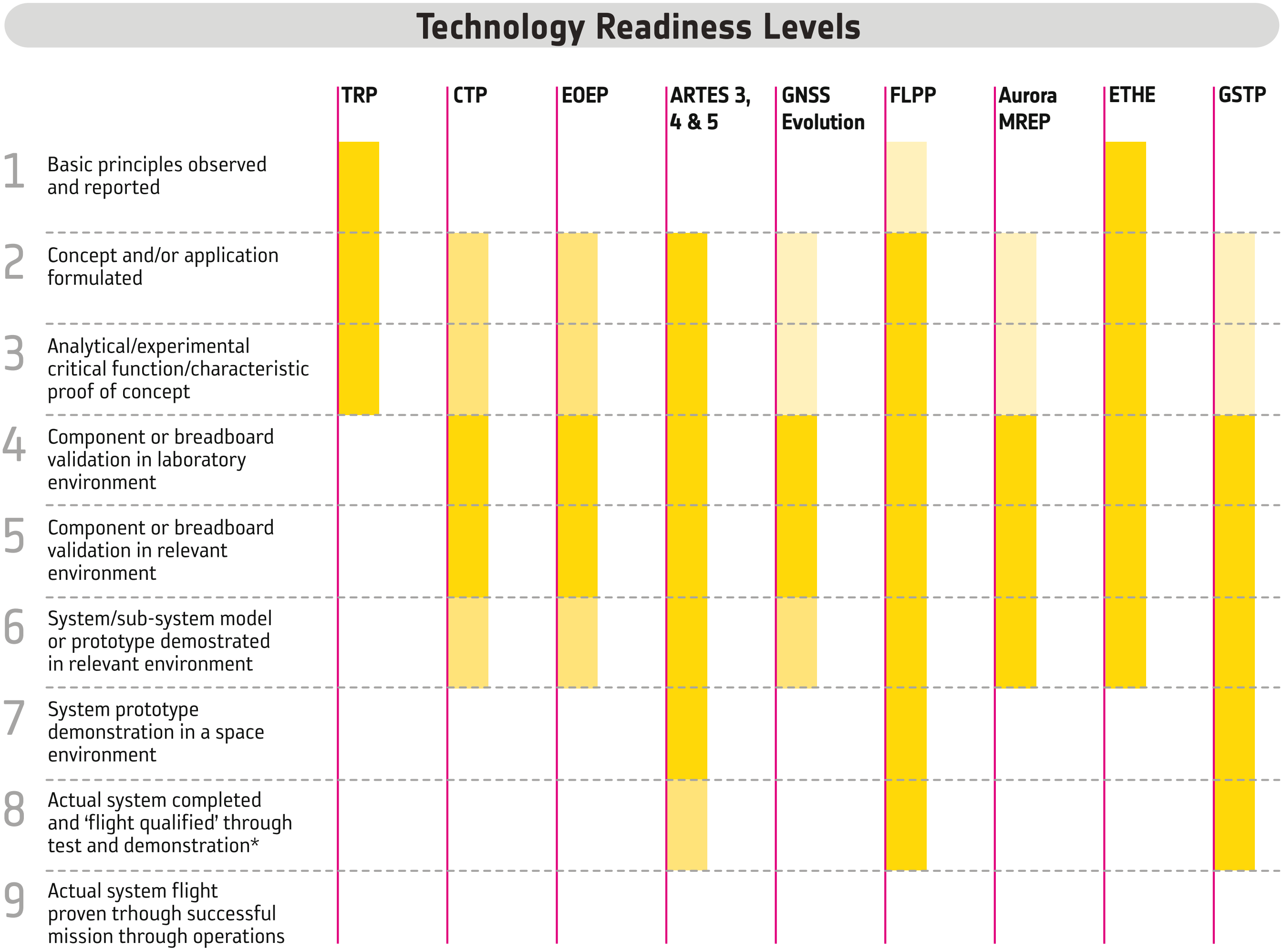
ESA relies on technological innovation to accomplish its goals: enabling novel space missions and applications of the future, boosting Europe's industrial competitiveness, preserving our non-dependence in space and benefiting the lives of European citizens. It is rare indeed when a scientific result or engineer's idea can be translated directly into a usable idea or product. Development is usually a step-by-step process. ESA's challenge is to turn inventions into innovations in a systematic way. How can progress be reliably tracked over time?

ESA, like many other research organisations, has adopted standardised yardsticks called Technology Readiness Levels (TRL). The nine-point TRL scale originated in NASA during the 1970s, where managers noted that immaturity of the technology needed to meet a project's requirements was the main cause of delays and cost overruns. For the benefit of project teams, they devised a standard way of classifying an invention's maturity: from TRL 1, corresponding to a 'demonstrated basic principle', up to TRL 9, meaning 'flight proven'.

ESA has aligned its technology programmes with this TRL scale. ESA's Basic Technology Research Programme supports R&D projects with low TRLs of 1 to 3 or 4, equivalent to identifying an application and demonstrating it in laboratory conditions. The General Support Technology Programme then takes care of the progression from TRL 3/4 to 6/7, where the technology is integrated into prototype products within a given domain and qualified at, or close to, flight standards – basically approaching the point where it is ready for adoption by a space project.

Scaling the 'technology readiness' ladder

To climb the TRL ladder demands progressively more complex and demanding R&D, as the technology becomes integrated with larger systems and tested in more realistic environments – meaning it can also get more costly. Apparently promising inventions can undergo what is sometimes termed 'Death Valley', meaning their ascent is stalled in the middle TRLs.



* Ground or space

←

ESA's Concurrent Design Facility (CDF) is not only an innovative design centre for future space mission concepts, but also a centre for the development and distribution of concurrent engineering methodology to the European space community

> **Behind ESA's often remarkable technological discoveries and achievements, human curiosity and foresight remain the driving forces**

By necessity, ESA technology programmes have tended to be domain-specific, so many basic generic technologies, such as micro-electronics, materials and photonics, have proved particularly prone to such a fate.

Because space shares the technology, and often the industrial base, with terrestrial sectors, ESA is alert to developments outside space in such generic technologies and promotes partnerships in order to advance the timely infusion of these key enabling technologies for space.

At TRL 8/9 comes the problem that flight heritage is essential for commercial market acceptance, because (understandably) mission managers are reluctant to fly an unproven technology where a flight-proven alternative is available – even if it is much less advanced.

This is why ESA has introduced the In-Orbit Demonstration Programme within the GSTP, to give new technologies the opportunity to fly on board either dedicated demonstration satellites, such as the Proba small satellite series, the Expert reentry demonstrator, or as non-mission critical guest payloads in flight opportunities, such as berths on other ESA missions (CryoSat-2 hosted a gyroscope on a chip) or ESA's Columbus laboratory on the ISS (currently home to a prototype maritime ship detection system).

The requirements of space are very demanding, but become even more extreme in the case of human spaceflight and exploration, for example, in operating far from the home base, in extreme environments and with no possibility of maintenance other than software patches. These requirements will result in very high-performance and resilient technology products, and this is what makes space a leading user and a partner of choice for common R&D. ESA promotes open innovation and common R&D with terrestrial industry sectors.

Non-dependence

Space systems are the origin of services of high strategic and economic value and are part of daily life, for example in operational meteorology, environment monitoring, communications and information, navigation, and many other, including our own safety and security.

If Europe is dependent on space systems, Europe should not be dependent when developing, deploying and exploiting such systems. Part of this non-dependence is the access to critical technologies. Non-dependence on critical technologies is essential for the technology innovation that enables the missions and provides European industry its competitive position. Non-dependence on critical space technologies is therefore an objective of ESA shared with our European partners, with Member States and industry and the subject of concerted actions.

Using technology

Ideas can develop 'top down', from the needs of a mission, or 'bottom up', from the perspectives of technology, and it is important to check them in the context of their use. In ascending the TRL ladder from an invention to an innovative product, technology will have to be assessed for performance in environment and at appropriate integration level. Infusion of new technologies may have a significant impact at high level, so it is important to understand such impact, maximise the beneficial effects and avoid negative implications. It is important to monitor the use of technologies in the context of their system utilisation.

ESA conducts assessment and feasibility studies of new mission and system concepts internally and with industry. Such studies are frequently carried out in ESA's Concurrent Design Facility. Technology development requirements are identified and 'roadmaps' drafted as part of the assessment.

Developments are conducted in interaction with or as part of the user projects. Technology readiness reviews are systematically conducted and synchronised with project phases and reviews so that the timely achievement of the right TRL for each phase of the project can be assessed.

Conversely, technology reference and impact studies are also conducted to assess the interest and impact of a new technology, e.g. wireless, system-on-chip, advanced propulsion, etc., or to identify the necessary 'leapfrogs' to speed up science or service breakthroughs (in technology, 'leapfrogging' means accelerating development by skipping inferior, less-efficient or more-expensive technologies and moving directly to more advanced ones).

→ CASE STUDIES

→ HERSCHEL IN THE SKY WITH DIAMONDS

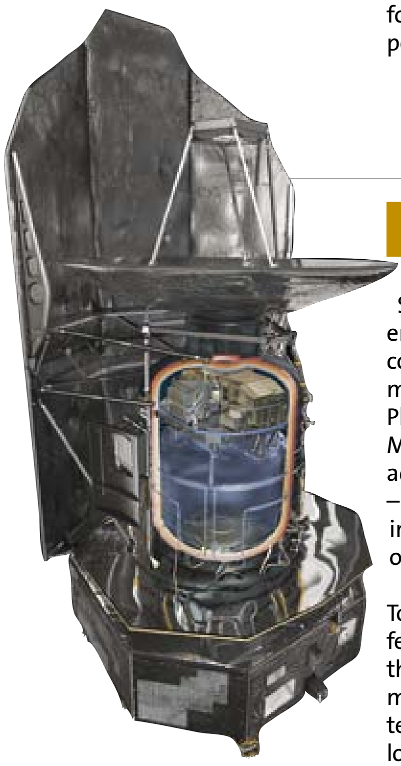
↑

Naturally occurring crystal of silicon carbide (or moissanite)

ESA's Herschel telescope surveys the cosmos with the largest mirror ever built for space: at just a third the mass of the Hubble Space Telescope's main mirror, this 3.5m-diameter reflector provides twice the collecting area while still maintaining a rigid structure and its precise shape under the cryogenic temperatures vital for infrared astronomy.

The mirror is made from silicon carbide (SiC) – a material first invented in 1893 as a diamond substitute, in widespread use today for cutting tools, high-performance brakes and even jewellery – but it took almost two decades to advance this technology up the TRL ladder. ESA partnered with French company Boostec, which originally used SiC to make ceramic bearings and seals for industrial pumps. The breakthrough came in realising that smaller pieces of SiC could be joined together at high temperatures – the final Herschel mirror was created from 12 separate SiC petal-like segments brazed precisely together, to form a single monolithic reflector substrate. This was then very accurately ground and polished to the correct shape prior to finally being coated.

Today, SiC technology is fully mature and available to other missions. Since then, the company has made telescopes for Sentinel-2, ADM-Aeolus, EarthCARE and the Near-Infrared Spectrograph for the James Webb Space Telescope, and also SiC parts for the magnetosphere-mapping Swarm constellation. In 2009, Boostec manufactured the main torus for ESA's Gaia mission, which will support dozens of ´Charge-Couple Device´ detectors to produce a 3D map of the billion stars making up our galactic neighbourhood.



→ BEST SERVED COLD

Space missions involve engineering for extreme conditions. ESA's sister missions Herschel and Planck, launched together in May 2009, both contained advancing cooling systems – the detectors on Planck, in fact, became the coldest objects ever to fly in space.

To observe the very coldest features of the Universe, the spacecraft instruments must operate at even lower temperatures, otherwise they lose all sensitivity since their own infrared emissions will be much brighter than the sky. The Herschel infrared observatory's instruments are cooled in the traditional way – placed in a tank of supercooled helium-4 like champagne in a bucket of ice – to keep them at -271.3°C, less than two degrees from absolute zero.

↖ ESA's Herschel
← and Planck

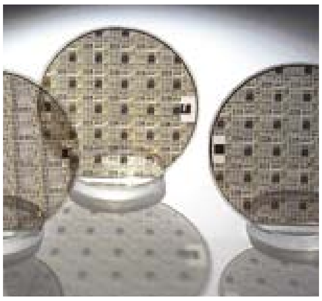
Planck's onboard detectors must measure variations in the background radiation of space left over from the Big Bang at an accuracy which is comparable to 'measuring from Earth the heat produced by a rabbit on the Moon'. No single cooling technology was capable of reaching the operating temperature needed, 0.1K from absolute zero.

Instead, four different cooling technologies were needed, each nestled in the other like Russian dolls. The spacecraft was launched 'warm', with each system bringing the temperature down in sequence before the next one could begin to operate.

The process begins with a set of three thermal shields, progressing to a US-supplied hydrogen sorption cooler, based on the repeated compression and expansion of hydrogen gas. Then there is a Joule-Thomson cooler with frictionless mechanical pumps forcing helium through a restriction, and the last stage of cooling comes from a dilution cooler originally developed with the help of ESA's TRP. This cooler can only function if all previous cooling stages function as planned, because it relies on the bizarre physics of extremely cold liquid helium, whereby the introduction of helium-3 atoms into a bath of helium-4 forces the helium-4 atoms to expand and hence trigger a cooling effect.

This technology has opened a window on the very cool Universe: Planck's first scientific results were released in January, drawn from its continuing survey of the entire sky at millimetre and submillimetre wavelengths. Its array of cooling technologies have many other potential applications in space as well, increasing the performance of future science and astronomy instruments as well as a new generation of infrared Earth observation sensors.

→ GALLIUM NITRIDE TAKING FLIGHT



Basic technology and generic products cannot always wait around for a given mission to drive their development. That is where the 'technology push' approach comes in. Take ESA's current development of gallium nitride (GaN) technology. Already in widespread use as a light-emitting diode – even lighting up Buckingham Palace among other European landmarks – GaN has been hailed as the most promising semiconductor since silicon itself. GaN operates reliably at much higher temperatures and voltages and, more importantly for space, it is inherently radiation resistant.

In 2008, ESA began its GaN Reliability Enhancement and Technology Transfer Initiative (GREAT2) to establish an independent European supply chain for GaN microwave devices, offering a fivefold increase in output power. Next year, the first results will be flown on ESA's Proba-V: the satellite will incorporate a GaN amplifier inside one of its X-band transmitters, to test the technology in orbit.

→ STARTIGER'S HUNT FOR SUN'S SECRETS

↑

Proba-3, ESA's first precision formation-flying mission

Innovation can be done in innovative ways. That's the basic idea behind ESA's StarTiger research ('Space Technology Advancements by Resourceful, Targeted and Innovative Groups of Experts and Researchers') undertaken through the TRP. Taking inspiration from industrial problem-solving 'tiger teams', StarTiger gathers together a diverse group of experts to tackle a single problem within a fixed time – typically six months or less.

Last year, a StarTiger team hosted by the Laboratoire Astrophysique d'Marseille came up with a complete system design for a two-satellite solar coronagraph: a way of flying two satellites so precisely that one can cast a sustained shadow over the other, revealing fine details of the Sun's corona that are normally kept hidden by its glare. An operational version of the system is planned to fly on Proba-3, ESA's first precision formation-flying mission.

StarTiger actions are planned twice a year: one previous campaign led to an advanced terahertz imager that has had significant spin-off success applied to security checking.

→ GEOSOUNDER FOR NEW WEATHER VIEWS

A new sensor for all-weather 'nowcasting' produced its first outdoor image during a TRP project, moving it up to TRL 4. The Geostationary Atmospheric Sounder works at millimetre wavelengths to penetrate clouds and rain. Its design relies on a principle called interferometry, with separate signals from multiple antennas correlated together to produce a picture of otherwise impossible sharpness. To further reduce the number of antennas needed, the device rotates at one degree per second, filling in further detail.

Currently only low-orbiting meteorological satellites, such as ESA's MetOp have millimetre-wave sensors, capturing only brief, narrow views as they hurtle around the world. But if you move a millimetre-wave sensor to geostationary orbit, over 36 000 km up, then continuous observations will be possible – but that is 40 times further away. A conventionally designed millimetre-wave sensor would therefore need an antenna about 10 m in diameter to deliver 30 km spatial resolution.

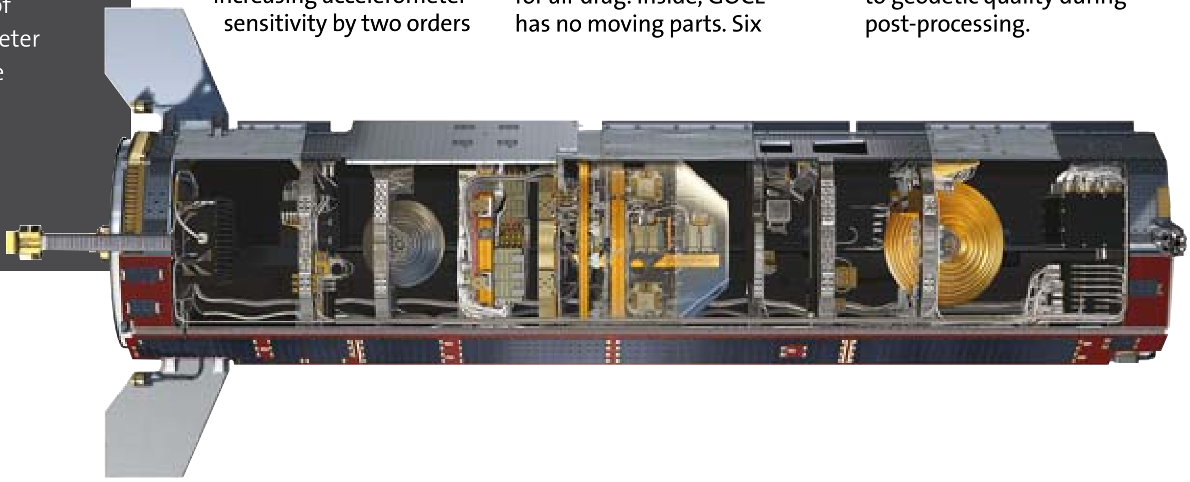
The GeoSounder design has now been proven to give equivalent performance for much lower mass and power. Showing how one mission concept gives rise to another in the space field, GeoSounder applies to higher frequencies the same interferometric technique originally proven by ESA's current SMOS mission.

→ THE PULL OF GRAVITY – AND TECHNOLOGY

ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) is an example of 'mission pull' at work. The scientific community made it clear that, to have any impact on the their specific research topics, in particular, charting the finer details of ocean and coastal currents, they required much more accurate and higher resolution mapping of Earth's gravity field.

To achieve this meant increasing accelerometer sensitivity by two orders of magnitude compared to previous missions. To reliably pick up the weak gravity signal meant the satellite had to fly at the relatively low altitude of 250 km, defying the thin remnants of the upper atmosphere to maintain a precise position in space.

The satellite itself was designed with a symmetrical low-cross section and continuously throttled ion engines to compensate for air drag. Inside, GOCE has no moving parts. Six accelerometers mounted on an ultrastable carbon-carbon composite bench make up the first space gradiometer, kept in an enclosure thermally stabilised to a thousandth of a degree. As well as all these other firsts, the satellite gravity gradiometry measurements are coordinated with a satellite-to-satellite tracking system using dual band GPS. This provides real-time precision orbit information, sharpened to geodetic quality during post-processing.



→ Cutaway view of GOCE (gradiometer enclosure in the middle)

→ RADIO TELESCOPE LOOKING BACK TO EARTH

There is a radio telescope in Earth orbit, but it is not peering out at the Universe. Instead, ESA's Soil Moisture and Ocean Salinity (SMOS) satellite is mapping the thermal emissions radiating from Earth's land and sea surfaces. The underlying technologies that make SMOS possible were developed by ESA over the last 17 years.

Producing an image of useful resolution from such faint signals would have needed a standard antenna of at least eight metres across rotating at 30 rpm – far too big and complex to fly on the launcher and satellite platform available.

Instead, SMOS's Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) instrument borrows from radio astronomy, using a technique called 'aperture synthesis' – the precise combination of radio signals from multiple antennas a fixed distance apart. This process produces an image resolution equivalent to a 'phantom' single antenna, its diameter equivalent to the maximum 'baseline' distance between the separate antennas.

Some 69 small receivers are positioned along MIRAS's three arms – radio astronomers advising ESA that a Y-shaped configuration is the single most efficient sampling shape. MIRAS builds up an image by multiplying together the signals received by all possible pairs of receivers. A cluster of nine ASICs – microprocessors tailored for a particular task – sample the signals every 18 nanoseconds to perform over 2500 complex cross-correlations every 1.2 seconds.

A major challenge was finding a way to relay these faint electrical signals from the receivers to the correlator without interference to contaminate the measurements. Another new technology was the answer: SMOS became Europe's first mission to make mission-critical use of optical fibres, an innovation that also served to cut down on payload mass and eased antenna deployment significantly.

→ ESA'S NEXT EARTH EXPLORER MISSION

Joerg Callies & **Pierluigi Silvestrin**
Directorate of Earth Observation, ESTEC, Noordwijk, The Netherlands

ESA's first six Earth Explorer missions – GOCE, SMOS, CryoSat, Swarm, ADM-Aeolus and EarthCARE – offer or will be offering unique opportunities in their corresponding science area.

Technology challenges have been encountered in all of these space projects, even before the mission selection process. For instance, SMOS, launched in 2009, is the first mission of an L-band radiometer with a synthetic aperture two-dimensional antenna. The preparation for this mission started several years before the mission was confirmed, and the technical development work for its payload, the MIRAS 2-dimensional interferometer, started in 1992. GOCE carries the first gravity gradiometer based on ultra-sensitive electrostatic accelerometers, an advanced drag compensation system with ion propulsion and a precise GPS receiver. The development of the related technologies started in the late 1980s.

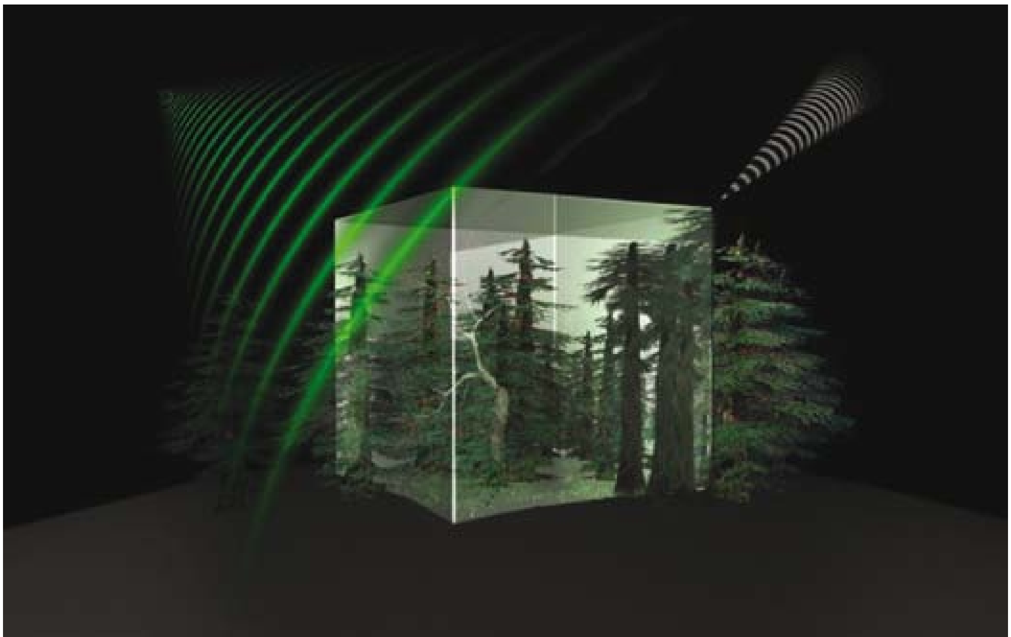
All Earth Explorers have been proposed by, and selected jointly with, the scientific community to answer key issues linked to the scientific challenges of ESA's Living Planet Programme (ESA SP-1304). For the seventh Earth Explorer, three different mission concepts are being studied (i.e. in Phase-A): BIOMASS, CoReH2O and PREMIER (see ESA *Bulletin* 131). For this core Earth Explorer mission, the preparation process started with pre-feasibility studies and technology development of the critical elements in 2007.

→ BIOMASS

BIOMASS will carry a P-band (435 MHz) polarimetric synthetic-aperture radar (SAR) to observe globally the above-ground 'biomass' (meaning the amount of carbon in plants and trees) and associated geophysical parameters.

The mission requires a very large deployable reflector antenna (diameter of about 10–15 m).

To use the large mesh reflector, a suitable feed system has to be developed.



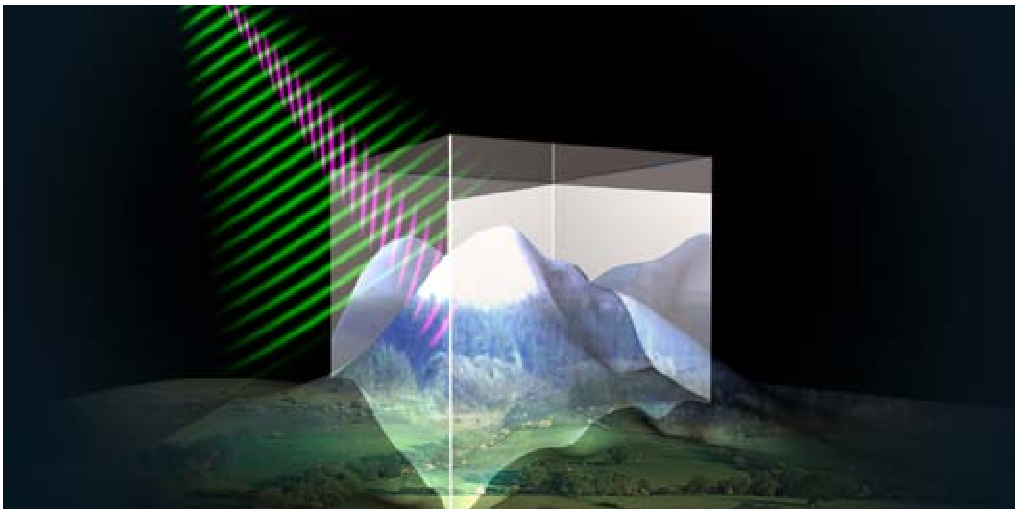
The feed breadboarding activity includes the development of four antenna doublets, one of which is fully flight representative. The feed sub-system is based on honeycomb-supported microstrip patches. The feed array has the peculiarity that it can correct the cross-polarisation induced by an offset reflector geometry.

In addition, an assessment of the P-band solid-state technology has also been part of the early 'risk-retirement' activities (meaning reducing identified risk earlier rather than later). As a result, two technologies (laterally diffused metal oxide semiconductors, LDMOS, and gallium nitride, GaN) have been selected for amplifier breadboarding and testing.

→ COREH2O

CoReH2O will provide dual-frequency (X- and Ku-band) SAR observations of snow cover, glaciers and sea ice for retrieving the snow cover extent and the snow water equivalent, as well as other important cryosphere parameters.

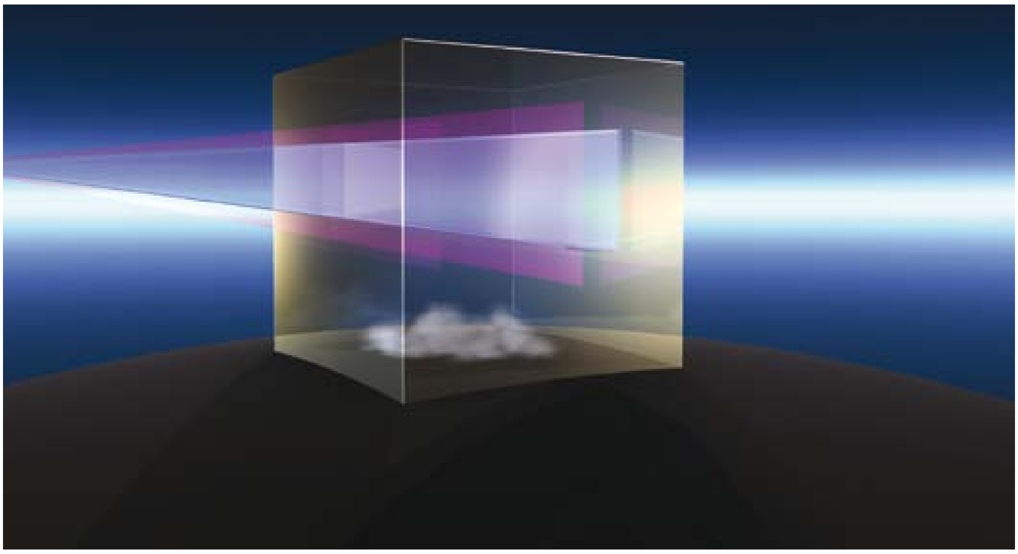
The dual-frequency SAR signals are transmitted by a single large deployable reflector antenna. In addition multiple-beam feed systems are required to provide the required swath width for both polarisations (VV and VH). The X- and Ku-band High Power Amplifiers providing the required power also require early ' risk retirement'. Two parallel developments have been initiated, addressing Travelling Wave Tube (TWT) and Extended Interaction Klystron (EIK) technologies.



→ PREMIER

PREMIER will explore the processes that control the composition of the middle and upper troposphere and lower stratosphere, to study the links between atmospheric composition and climate.

Flying in tandem with the MetOp satellite, the composition of the lower troposphere can be clearly discriminated from that of higher layers. PREMIER's instruments are an advanced infrared limb-imaging spectrometer (IRLS) and a millimetre-wave limb-sounder (STEAM-R), the latter being a Swedish national contribution to the mission.



The IRLS concept is based on an infrared Fourier-transform spectrometer, associating high spectral resolution with a limb-imaging function. The critical aspect of the instrument is the large field of view with good vertical resolution, together with a superior radiometric performance compared to existing single-pixel scanning infrared limb sounders.

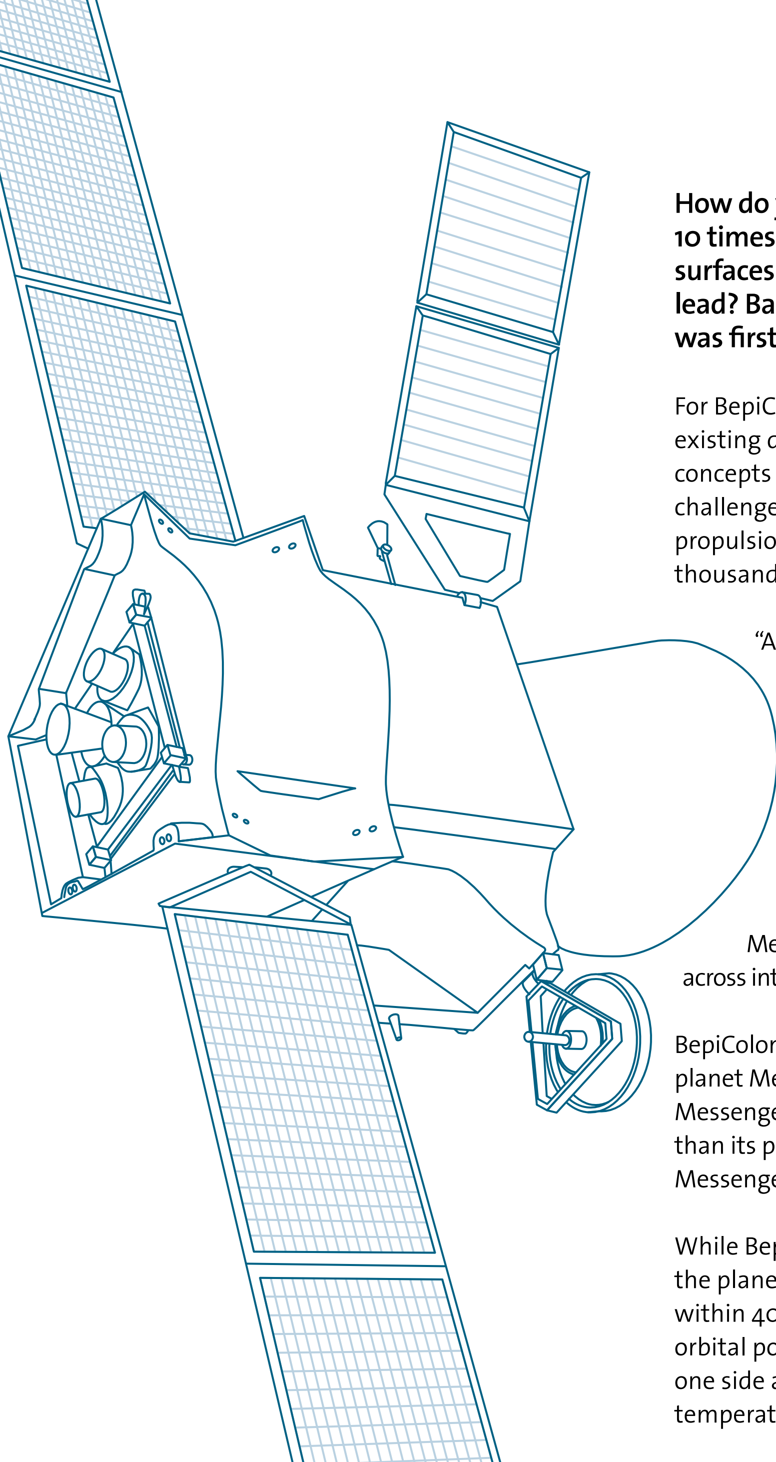
These concepts, although emerging from existing technologies, have never been applied to limb sounding so far. Breadboarding activities are taking place to demonstrate and optimise the instrument performance.

→ HOT STUFF

Seven steps in making a mission to Mercury

Sean Blair with Christopher Semprimoschnig
Directorate of Technical and Quality Management,
ESTEC, Noordwijk, The Netherlands

Jan van Casteren
Directorate of Science and Robotic Exploration,
ESTEC, Noordwijk, The Netherlands



How do you build a spacecraft that has to endure sunlight 10 times more intense than in Earth orbit, keeping its surfaces hotter than an oven – hot enough, in fact, to melt lead? Back in late 2000, when the BepiColombo mission was first selected, no one knew for sure.

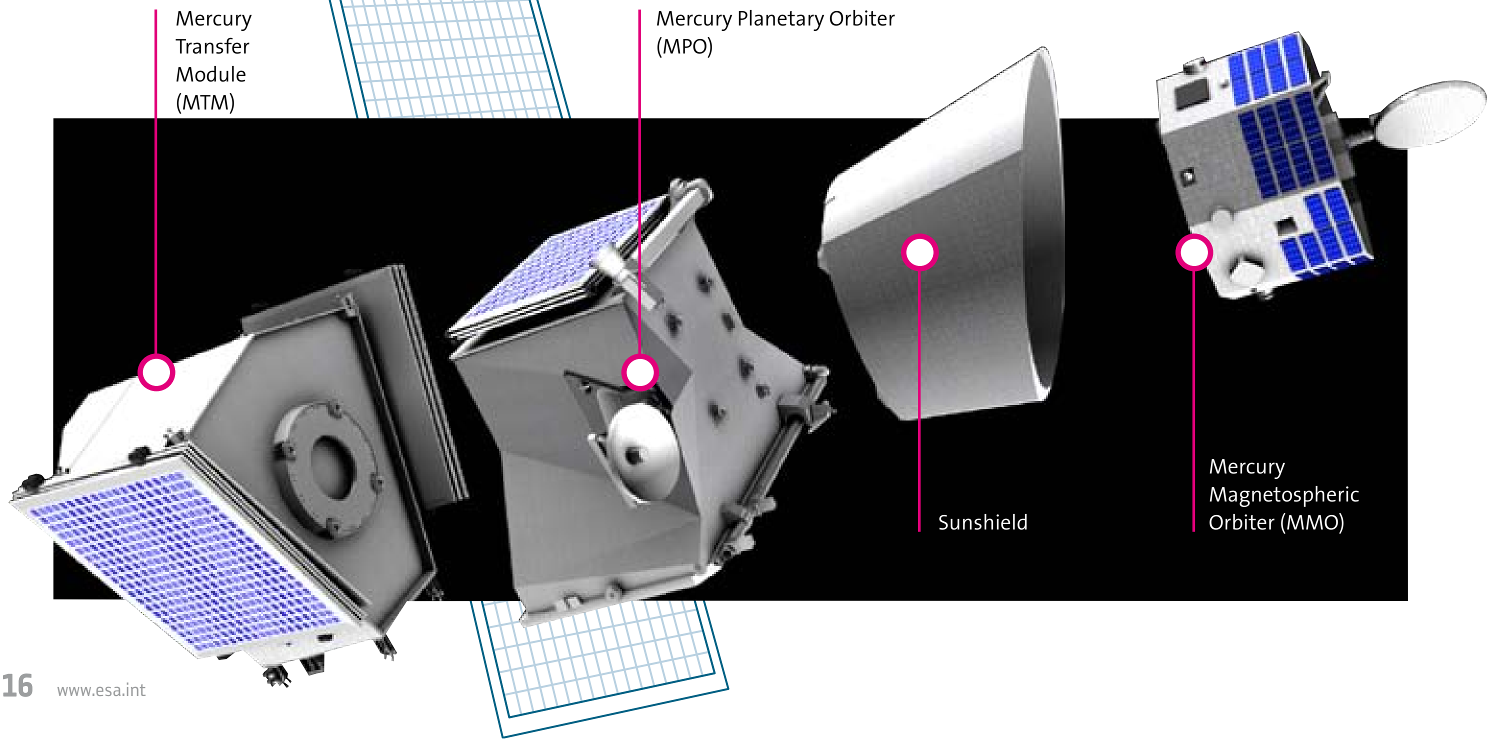
For BepiColombo, ESA not only had to extend the limits of existing design standards, but it had to develop new design concepts as well. Just reaching Mercury presents a major challenge: a new generation of highly efficient electric propulsion was required, capable of achieving the tens of thousands of hours of thrust needed to enter orbit.

"A considerable team of researchers was involved in making the mission feasible. An exceptional amount of technology development and demonstrations has been needed across a variety of fields," said Jan van Casteren, BepiColombo Project Manager.

This is really three spacecraft in one: an ESA-built Mercury Planetary Orbiter (MPO), a Japanese-built Mercury Magnetosphere Orbiter (MMO) plus ESA's additional Mercury Transfer Module (MTM) to convey the other two across interplanetary space.

BepiColombo will be the third mission to visit the innermost planet Mercury after NASA's Mariner 10 in the 1970s and its current Messenger. But BepiColombo will be taking a much closer look than its predecessors: Mariner 10 only flew past and this year Messenger went into a high elliptical orbit.

While BepiColombo's MMO will also follow an elliptical orbit, the planet-mapping MPO will orbit much more tightly, coming within 400 km of Mercury's heat-radiating surface. In certain orbital positions, when the orbiter comes between the Sun on one side and Mercury on the other, it will have to withstand temperatures as high as 450°C.



→ 1. EVERYBODY KEEP COOL

The problem of thermal management drives the spacecraft design. Slice through the MPO and you would see a complex labyrinth of heat pipes. Previously employed on a variety of missions, these sealed pipes work like a closed-loop version of human sweat glands, containing a liquid whose evaporation carries excess heat away from the MPO's sunward-side to radiating plates facing deep space. The liquid then condenses, allowing the process to begin again. The heat pipe concept helps keep MPO's interior down to about room temperature.

But what is new is the size of the radiator (about 2 m by 4 m), and the operational constraints it faces. "These radiating plates must remain cold and shaded for it to work," explains Ulrich Reininghaus, BepiColombo Spacecraft Procurement and AIT Manager.

"If they ever come into sustained contact with sunlight, or the infrared radiation emitted from Mercury's surface, then they would stop working."

The mission had to develop a unique set of specially coated louvres that prevent the radiator 'seeing' the hot planet below but allowing its own radiation to escape to cold deep space.

→ 2. MATERIAL WORLD

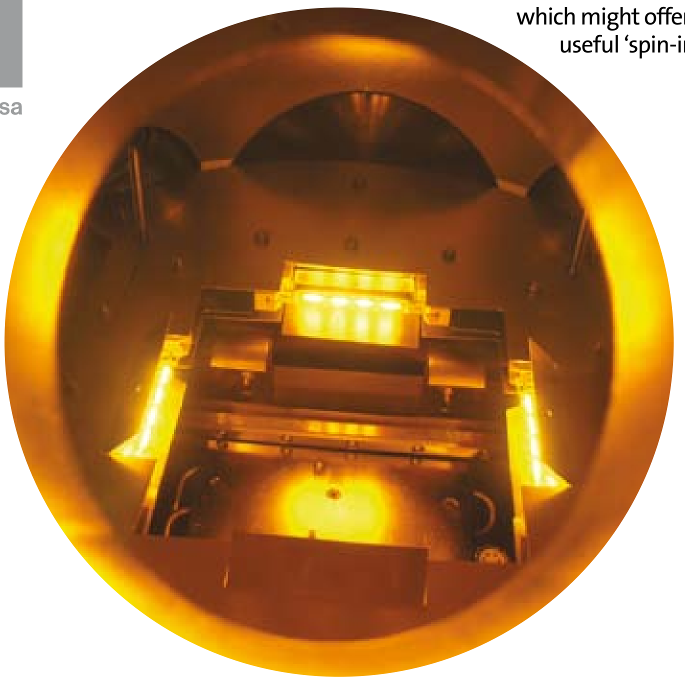
Expelling internal heat only goes so far however. Much better if it never makes it inside the spacecraft at all. The real technical challenge has been finding new materials for everything on the outside of the spacecraft in particular, which have to be able to withstand the Sun's tenfold increase in brightness and temperature extremes.

This includes antennas, the solar arrays and associated Sun-tracking sensors and mechanisms, and again the radiator and protective multilayer insulation (MLI).

ESA began a critical materials technology programme for BepiColombo at the start of 2001. The Materials Evaluation and Radiation Effects Section in ESA's Space Materials & Components Division has been busy for approaching a decade, gradually qualifying materials. This has been a huge challenge because there was no previous experience of such a harsh environment. The closest ESA ever came was with Venus Express, though that meant handling two solar constants rather than 10.

→ 3. TESTING TIMES

ESA's materials and processes engineers were involved in the mission because they had a good understanding of what materials could be candidates, as well as of related fields which might offer useful 'spin-in' technologies, such as protective coatings for jet engine turbines. However it took years to develop the laboratory facilities required for testing these new materials, adapting existing facilities wherever possible.



When you increase the light and heat intensities being operated in by 10 or 20 times that of before, then failures can happen. ESA's materials experts have had to deal with melted lamp holders, melted reflectors, and so on, but they managed to build some representative simulation chambers, such as the Synergistic Temperature Accelerated Radiation (STAR) facility.

These experts needed to predict the end-of-life conditions of all the materials in question. How might specific mission-critical properties change after years of intense solar glare? Would reflective coatings discolour, would multilayer insulation crack, would solar arrays lose electrical performance or the crucial ability to radiate away heat?

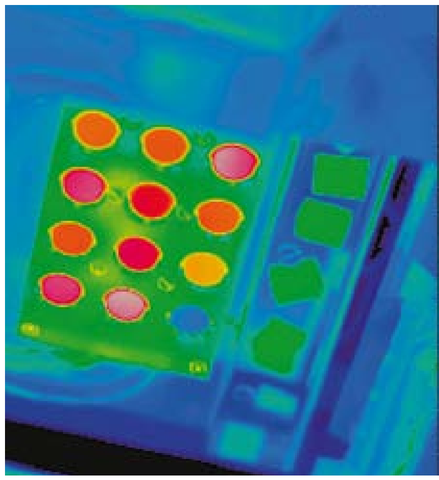
Total exposure will be something like 100 000 equivalent Sun hours. Normally, illumination levels are boosted for accelerated lifetime testing, but moving up from 11 solar constants to 30 or 40 is not so easy. The accuracy is uncertain, due to non-linear effects – the materials might unexpectedly fail for various reasons.

End-of-life estimates for Venus Express offered a starting point. The five-year-old mission remains in good health, showing the team's original estimates had been broadly accurate.

→ 4. A LIFE IN THE SUN

In such an extreme environment, everything degrades, like plastic left out in the Sun. But how critical properties degrade over time spent in orbit needs to be understood precisely. For example, it was found that when test items were removed from vacuum chamber then their subsequent exposure to air would induce chemical interactions with 'radicals' within the material itself (radicals are highly chemically reactive atoms, ions or molecules).

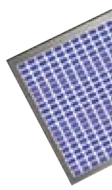
These radicals are degradation products, which alter the state of degradation. It could be that one day later, when a measurement is made, their condition would be very different. If these results are extrapolated, a performance curve would be obtained, but the real curve would end up being much worse. So a system is set up to make measurements while still in vacuum, saving time and allowing changes to be assessed more reliably.

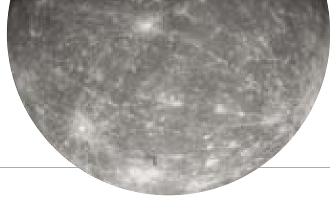


→ Infrared image of BepiColombo thermal control materials undergoing lifetime testing

→ 5. BEYOND BREAKING POINT

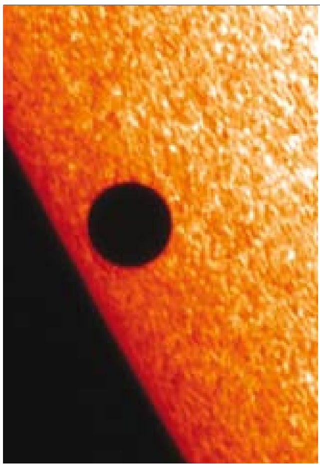
ESA needs to be sure that its chosen materials will function reliably for years on end. "We are going to the limit of a material's performance, seeing what happens when it breaks down. The result is a wealth of information that could be of interest to many other industries as well," says Christopher Semprimoschnig. The testing programme continues to qualify all the materials needed for the BepiColombo mission and is about 75% complete.





→ 6. GO FOR MLI

The multilayer insulation (MLI) covering the bulk of the spacecraft's surface is currently planned to be a woven ceramic fabric. Several layers are kept apart by spacers, designed to be as light as possible – some of the layers have a thickness of less than a tenth of a sheet of paper, just 7.5 micrometres across. "The result is much lighter than metallic foil but also more brittle. Now we need to look at processing issues – how to stack it, what shapes can it fit around and how to handle it without damage and release of particles," says Christopher Semprimoschnig.



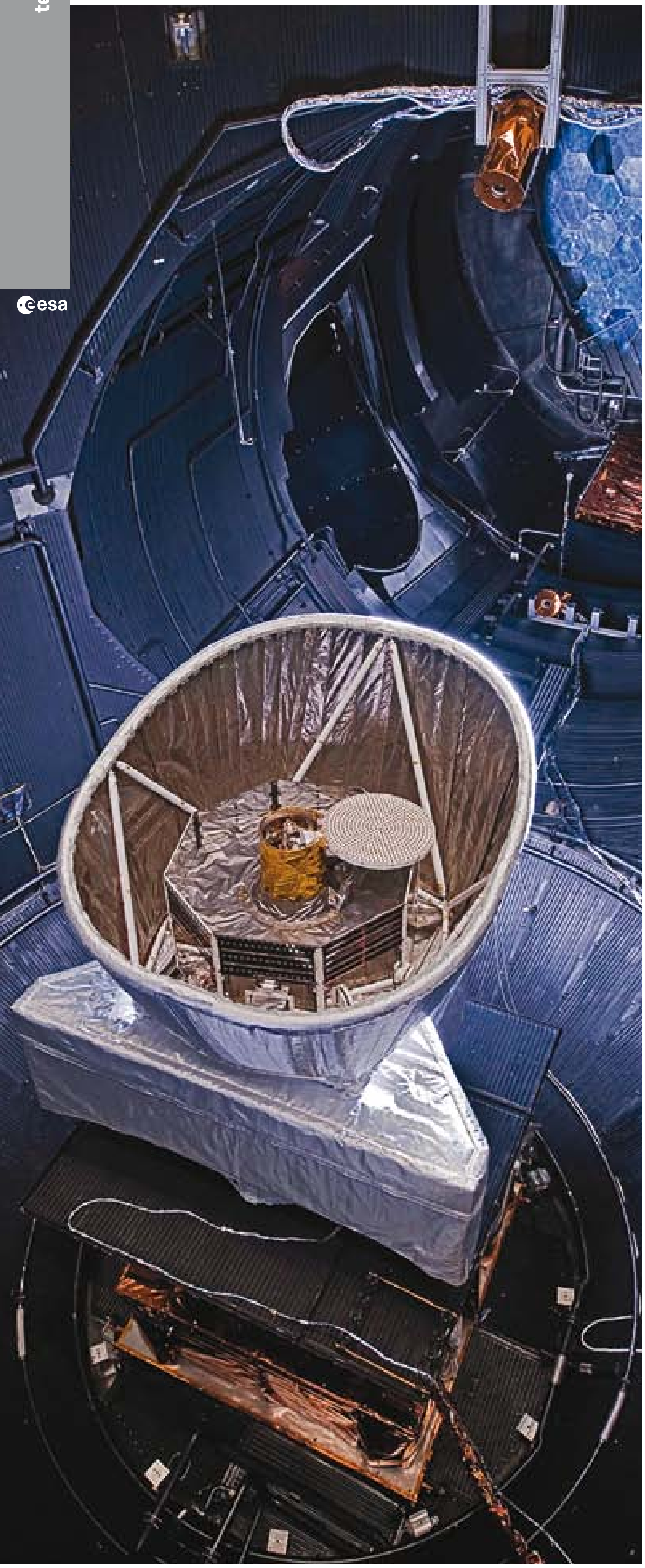
→ 7. SAVING ARRAYS

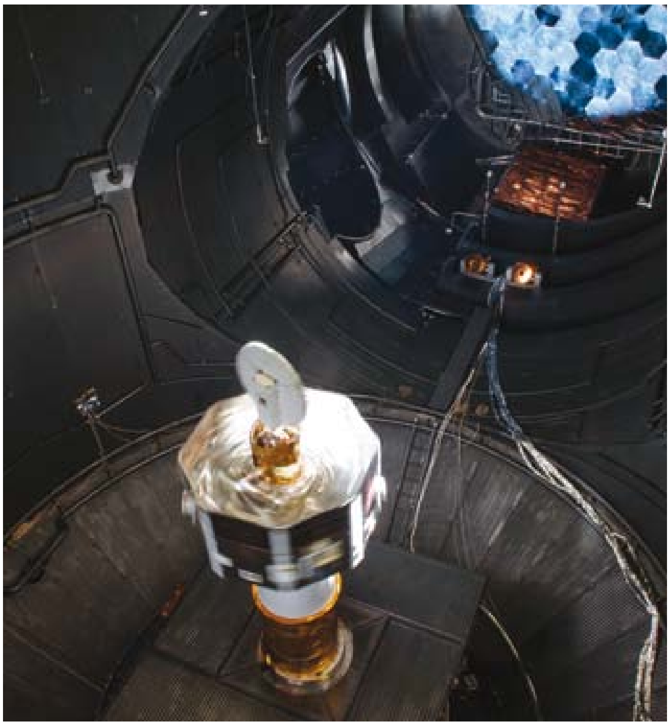
Solar cells became the single most challenging material question. Dramatic degradation in solar cell performance was detected – just one simulated month saw a 20% power loss.

This failure brought the mission almost to the brink of cancellation. The effect was due to a combination of material degradation by ultraviolet radiation and high temperatures driving down cell efficiency.

A combination of protective coatings and careful tilting of the solar arrays offered a workable solution. If the solar arrays directly face the Sun then they will heat up and fail. So instead they must stay tilted at an optimum angle – their power production stays lower, but so does the temperature.

The main antenna also requires a protective coating, though for a different reason. It is made of thin titanium for maximum performance – it needs to perform highly accurate radio science experiments to determine how 'spacetime' curves around the Sun. By itself, it would warm up like any other metal in the Sun – up to as high as 700°C. But temperature-driven deformations have to be prevented. A specially tailored coating will help to keep its temperature 300°C lower, while allowing electromagnetic signals to pass through freely.





↑ ←

The MMO under test in the Large Space Simulator, free-spinning (above) and with its ESA-built sunshield (left)

In September 2010, a test model of Japan's MMO arrived for testing in the Large Space Simulator (LSS) at the ESTEC Test Centre, in Noordwijk, the Netherlands. The LSS is the largest vacuum chamber in Europe, and its Solar Simulator was carefully adjusted to attain 10 solar constants, its light beam being brought into much tighter focus.

"To safely remove the resulting heat from the chamber walls, we installed an extra thermal shroud with a more than six times greater flow of liquid nitrogen than the existing system," explains Alexandre Popovitch, overseeing the chamber's modifications. "That required around 5000 litres of liquid nitrogen per hour of each two-week test."

There were two sets of tests, one with the MMO free-spinning – as it will operate during its active life – then one with an ESA-built sunshield which will keep it cool as it rides as a passenger to Mercury. Soon, test models of the European-built MPO spacecraft will go through the same experience.

Follow-up versions incorporating any lessons learnt must be ready for evaluation in 2012 and the launch of BepiColombo scheduled for 2014. The materials team, meanwhile, is already looking forward to the next mission, ESA's Solar Orbiter, destined to venture even closer to the Sun.

→ LIVING ON SUNSHINE

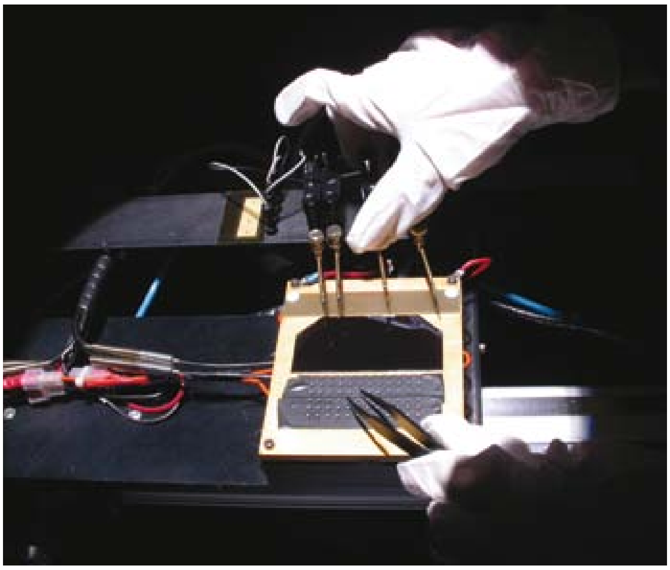
Sean Blair with Lothar Gerlach
Directorate of Technical and Quality Management,
ESTEC, Noordwijk, The Netherlands

When it comes to making future space missions feasible, solar cells are almost as essential as rocket technology. Most satellites rely on solar-generated electricity, for one obvious reason: space enjoys an endless abundance of sunshine.

By happy accident the photovoltaic cell was invented in 1954, just three years before the Space Age began with the launch of Sputnik 1. Otherwise space exploration might have been delayed for decades by spacecraft requiring bulky power supplies that would have been far too heavy to put into orbit easily.

Solar cell technology has evolved rapidly in recent years, with arrays of solar cells covering the wings and bodies of almost all satellites, and ESA has played a key role in coordinating European research and development.

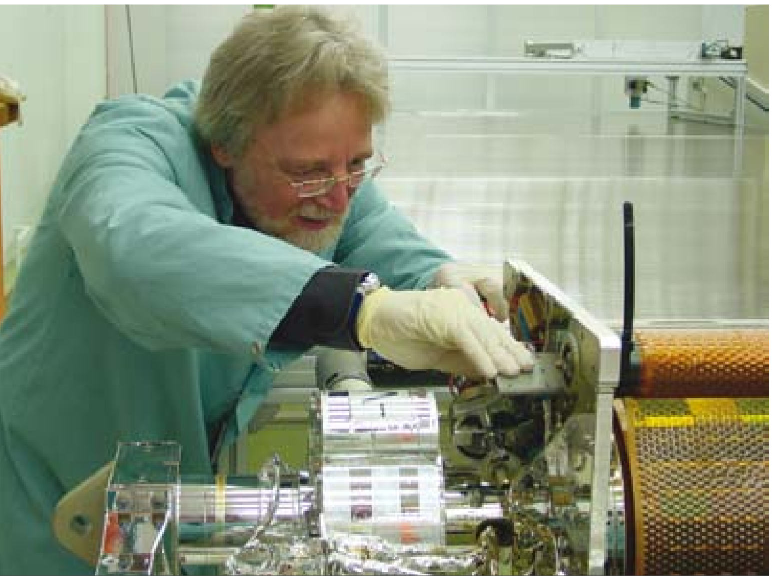
"For the last five years, ESA's workhorse solar cells have been a 28% efficient design from Azur Space Solar Power in Germany, which retains an end-of-life performance of 0.88% after on-orbit degradation," explains Lothar Gerlach, Head of ESA's Solar Generator Laboratory.



↑

Preparing to test a standard triple-junction solar cell – measuring 4 cm by 8 cm – using ESTEC's Sun Simulator

> **"Mass is not everything in spaceflight, but cost is"**



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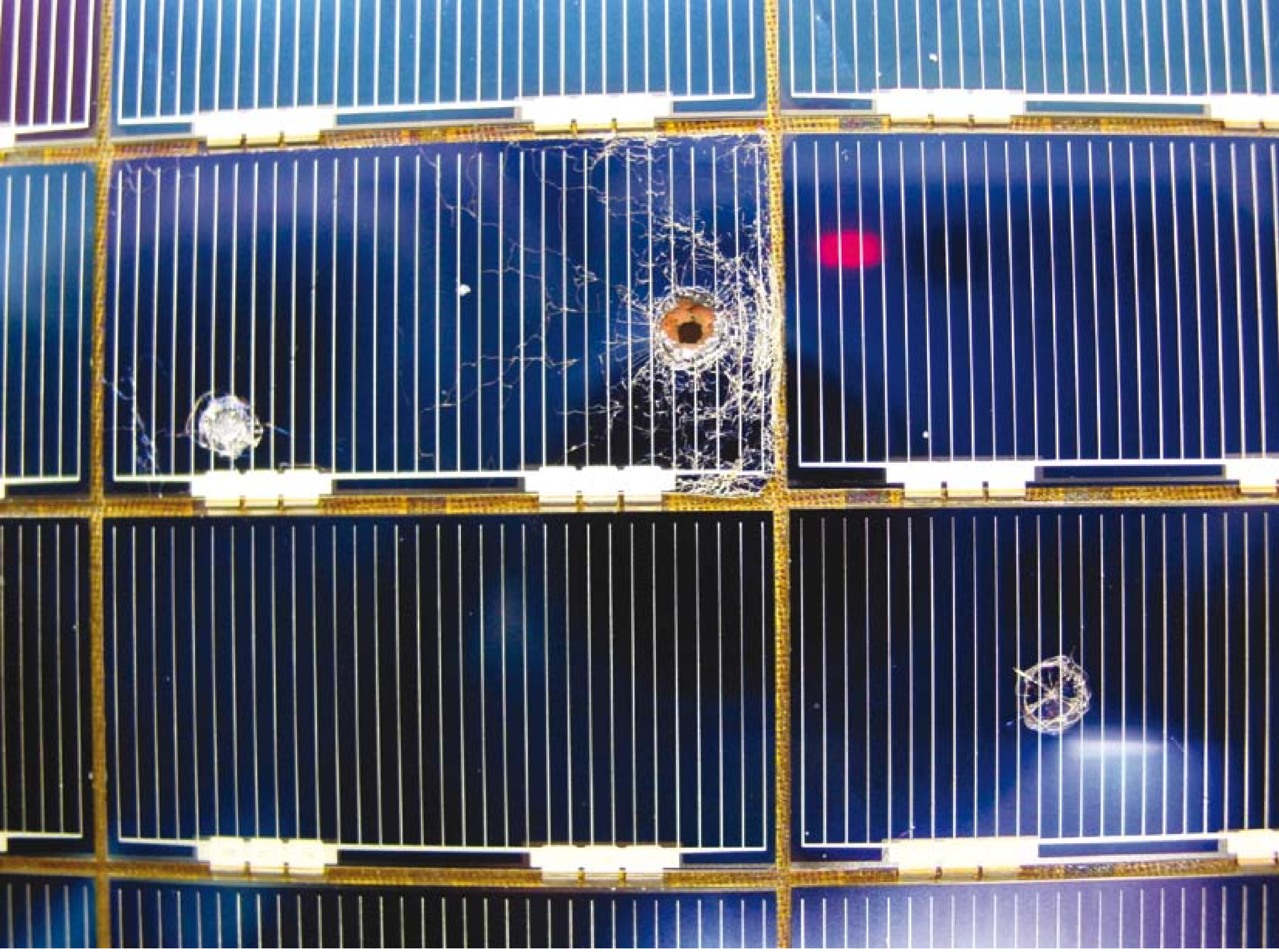
Lothar Gerlach, Head of ESA's Solar Generator Laboratory section, examines solar cells

"But industry has now qualified a 30% efficient solar cell for future space missions, its performance derived from state-of-the-art triple junction gallium arsenide (GaAs) technology. ESA plans to qualify its own slightly modified 30% efficient cells next year, using a new low-cost manufacturing approach."

Solar cells are made from the same kind of semiconductor materials as integrated circuits. Trace impurities are added to a semiconductor to alter its electrical properties – a process known as 'doping'. Different doping ingredients are used on either side of a junction to create electrical potential. Incoming sunlight generates an electrical current that flows across the junction.

Silicon used to be the semiconductor of choice but is increasingly being replaced by GaAs-based semiconductors, which can reach higher power levels. This attribute allows the stacking of multiple junctions on top of each other, all tuned to different segments of the overall light spectrum. The surface layer reacts to highest-energy blue light while letting other light through, the middle absorbs medium-energy green light and the bottom layer runs on the remaining lowest-energy red light.



The resulting efficiency leap from single to triple junction cells is of the order of 10%, although building them is tricky in practice. These layers must be carefully aligned to avoid unwanted light reflectivity and matched together based on their current flows – even though all the junctions have different current density capabilities, which change over time because space radiation degrades them at different rates.

↑

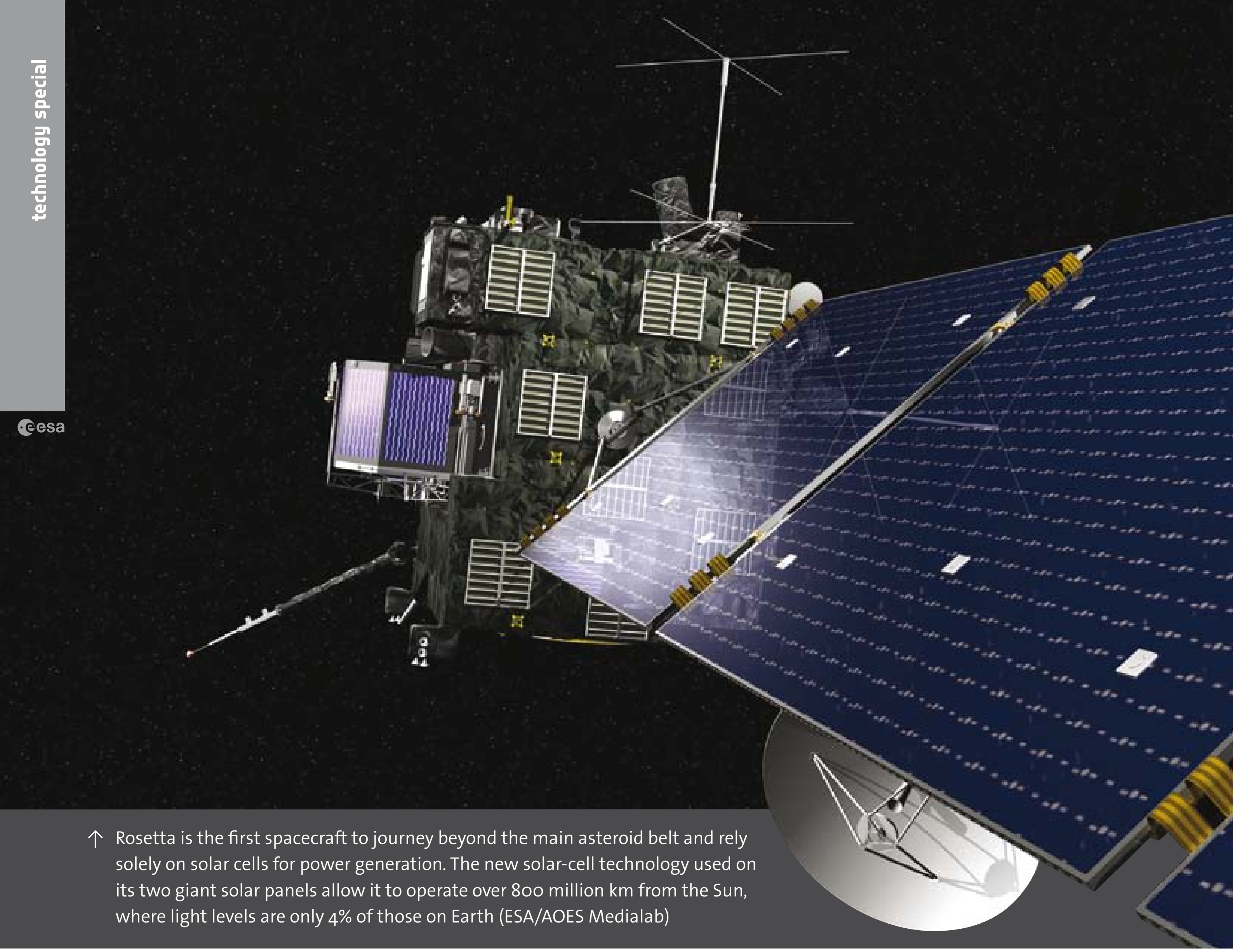
ESA-built solar cells retrieved from the Hubble Space Telescope in 2002. Solar cells in space undergo various kinds of degradation over time – meteorite impacts being the single most violent. Note two front impacts and one from the rear side seen on bottom right

"Each triple junction solar cell has about 30 individual film layers. The trick is to find the right combination of materials and doping levels to ensure all junctions are perfectly matched at the end of the satellite's life," says Lothar.

To protect against space radiation, all solar cells are covered by glass layers, typically just 0.1 mm thick. If a bare cell was exposed, it would degrade as much in days as a covered cell does in years: current geostationary satellite solar cells retain 88% of their performance after 15 years, resulting in an end-of-life efficiency of 24.6%.

GaAs-based multi-junction cells are especially vulnerable to what is called 'reverse voltage bias': if part of their solar array is covered by shadow during an eclipse or manoeuvre, then an electrical surge can occur. Bypass diodes are an essential safeguard against this threat.

Standard-triple junction cells are grown on a 0.14 mm thick germanium (Ge) foundation, called a 'substrate'. Since this layer is not needed to generate power, and Ge is a rare expensive material – amounting to about 30% of the cost per cell – researchers are working on a technique to remove and recycle this substrate. The result would be a 0.02 mm thin-film solar cell with 30% efficiency.

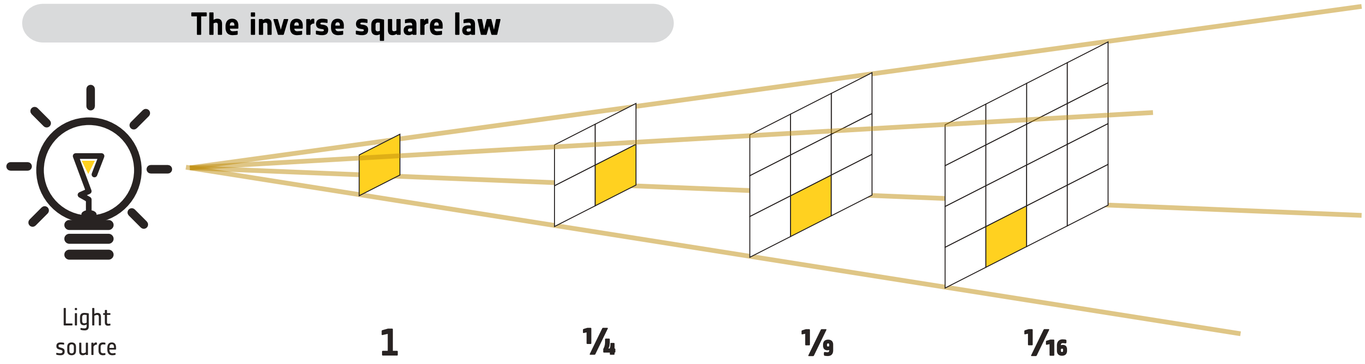


↑ Rosetta is the first spacecraft to journey beyond the main asteroid belt and rely solely on solar cells for power generation. The new solar-cell technology used on its two giant solar panels allow it to operate over 800 million km from the Sun, where light levels are only 4% of those on Earth (ESA/AOES Medialab)

> **We can confidently operate with solar power all the way out to Jupiter's orbit**

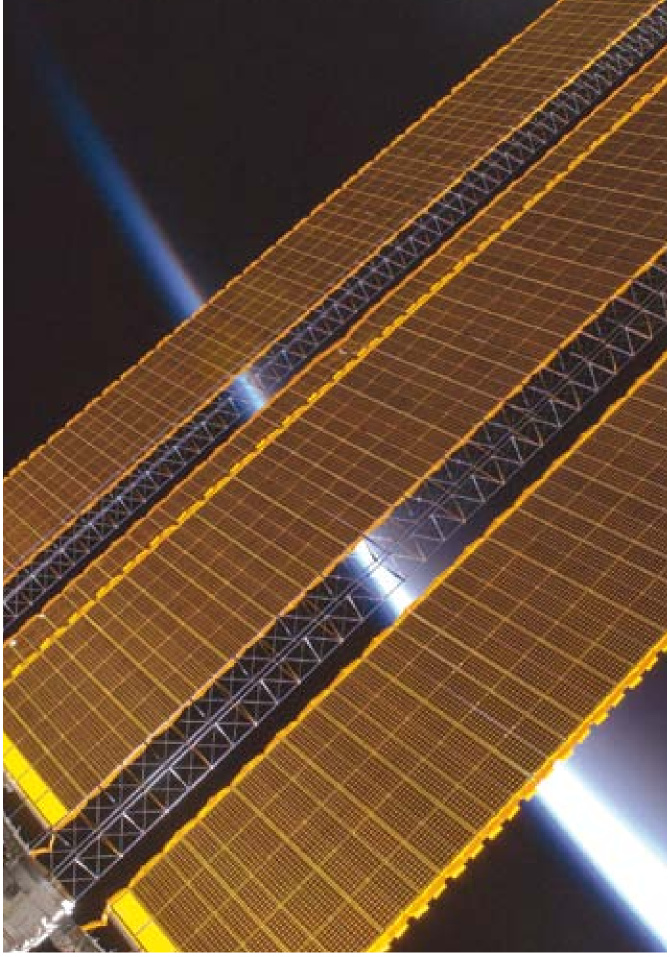
"This would reduce solar generator mass by something of the order of a kilogram per square metre," Lothar says. "Some of the really big bird telecommunication satellites have arrays of 100 square metres or more, so this would represent a significant mass saving. However this 0.2 mm cell would certainly cost more than a thick cell of the same efficiency, and the big question is whether thin cells become a commercially viable product. Mass is not everything in spaceflight, but cost is."

The inverse square law



Many experts believe that in practical terms the technology limits of the current concept has almost been reached with the 30% cell, and that efficiencies very much higher are unlikely. For any next-generation cells, the common challenge is to find a viable and reliable method to grow a 'lattice-mismatched' cell based on combining different materials. New approaches are therefore being considered for further efficiency improvements:

- Nanotechnology – offers a new degree of freedom for designers to tailor the otherwise fixed absorption properties of solar cell materials
- Nitride-based materials – their electrical properties are seen as a means of increasing current cell efficiency above 30% by adding more than three junctions
- Inverted metamorphic cell – a new type of multi-junction architecture involving cell layers grown in reverse order, delivering enhanced reliability and cost-to-power ratios



> **"ESA-led research and development will continue to drive solar cell advances"**

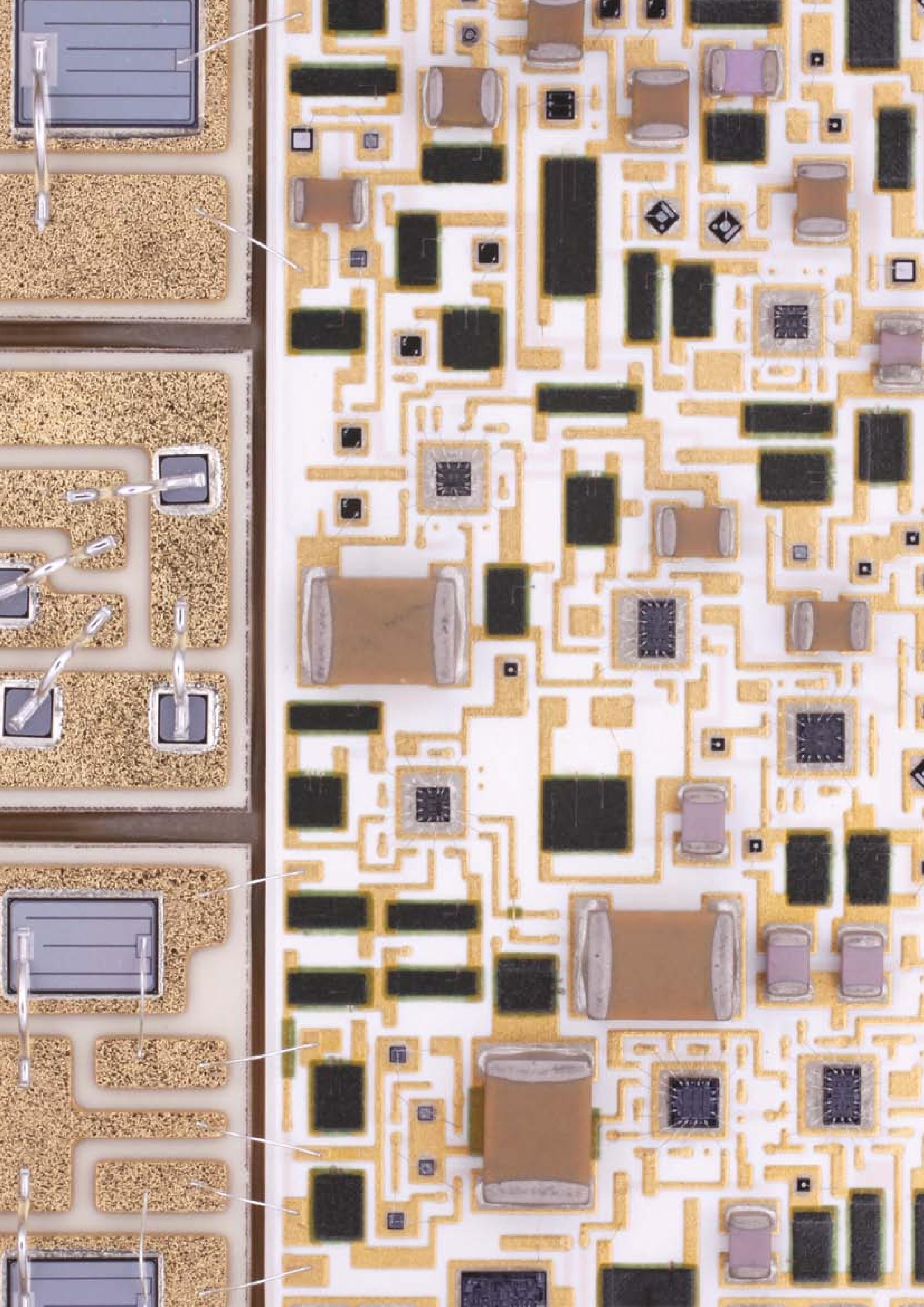
ESA-led solar cell research also aims to extend the reach of solar-powered spacecraft across the Solar System. On the one hand, robust solar cells are needed to draw close to the Sun – but moving further out throws up a separate set of problems.

Illumination reduces with distance from the Sun by what is called the inverse square law – if you go twice as far away and only a quarter the solar intensity is available, go three times as far and only one ninth of the intensity remains. This means that temperatures experienced by the spacecraft also fall with distance, though in principle this is good news for solar cell designers, since cell efficiency increases as temperature goes down.

In practice however, in low solar intensities with temperatures dropping below –100°C, standard solar arrays show worse-than-expected performance due to unpredictable degradation of individual cells. To overcome this problem, a low-intensity low-temperature (LILT) specific solar cell technology was developed. The resulting single-junction silicon cells are flying on ESA's Rosetta comet chaser, which is venturing three times further from the Sun than Earth.

"We have now applied the same design principles to our triple-junction GaAs-based solar cells," concludes Lothar. "We are confident that this LILT technology means we can confidently operate with solar power all the way out to Jupiter's orbit, though not beyond."

LILT technology has already been applied to ground applications: solar power specialist Azur Space has used it to produce security keycards that can keep topped up on indoor light alone. ESA's Solar Generator Laboratory has also been working on solar cells tailored to the red-tinged, dust-filled martian atmospheric spectrum, as a means of powering Mars rovers and other surface exploration activities beyond. More broadly, ESA-led research and development will continue to drive solar cell advances: the section's technology roadmap sees 33% efficiency as potentially reachable by 2015.



→ QUALIFYING THE PARTS THAT OTHERS CAN'T REACH

A system for space component management in Europe

Sean Blair with Mikko Nikulainen, Ralf de Marino, Wolfgang Veith, Roland Weigand, Lionel Bonora, Laurent Hili & Laurent Marchand
Directorate of Technical and Quality Management, ESTEC, Noordwijk, The Netherlands

A space mission's performance can only be as good as its component parts. To make sure a mission meets or exceeds its predicted lifespan in the hostile space environment, all components must be rigorously verified.

Spacecraft systems are composed of 'active' electronic parts such as transistors, diodes, microprocessors, memories and microwave circuits; 'passive' electrical parts that include resistors, capacitors, wires, cables and connectors; and electromechanical devices, such as thermostats and relays.

These three types are commonly referred to as Electrical, Electronic and Electro-mechanical (EEE) components. They form the fundamental building blocks of payload instruments and platform subsystems – the entire satellite, in fact.

ESA works in cooperation with other space agencies and industrial partners to ensure the ready availability of high-performance EEE parts of various kinds. This is a tougher challenge than it might at first appear: the space industry is only a small part of the worldwide consumer electronics market. For such a speciality market, it is also highly demanding.

↑ A dual-beam focused-ion beam electron microscope, used for examining components to the exacting scales required

Space components must meet strict technical requirements for radiation hardening, resistance to shock and temperature extremes, and be able to operate reliably for years at a time. Understandably, companies are not always interested in serving the space market because of high costs of entry.

In addition, non-space R&D sets the pace of technology development for components – so it is up to the space industry to 'spin in' non-space innovations to keep current, instead of the other way round. All this means that ESA has had to play an active role in the components field, investing resources to ensure quality EEE components are on hand for future missions.

Within the last decade, the proportion of European EEE components used in space missions dipped below 50%, the proportion worsening as time went on. This was unsatisfactory for various reasons: the full traceability of components – needed to ensure reliability – becomes uncertain. European non-dependence is threatened by foreign suppliers choosing to withdraw the availability of key products or limit their use through end-user agreements. The US International Traffic in Arms Regulation (ITAR) policy made this threat real.

So in 2004 ESA and other European space agencies introduced the European Components Initiative (ECI). This initiative is an open cooperative project with ESA and partner national space agencies, each participating with their own funding. Its first phase concentrated on consolidating end-user requirements for industry and implementing activities to progress components' technology levels up to space-qualified status. Its second phase, beginning in 2008, broadened its focus from the components themselves to the enabling capabilities used to construct them.

Components having been qualified for global space use are formally added to the European Space Qualified Parts List (QPL), available for the use by ESA and national agency missions and commercial users. End-user requirements are mapped from the start, helping to ensure maximum global market penetration of ECI-developed parts. This activity is performed through the European Space Component Coordination (ESCC), a harmonisation body that compiles a list of preferred and space-qualified parts, and which represents all major stakeholders from component manufacturers to prime contractors.

Members of the European space components industry and equipment manufacturers have the opportunity to propose future technologies for ECI activities through participation with the ESCC. Seven years on, the ECI has introduced a full range of new European products and this trend of dependency has been reduced. In March, ESA's Council approved a €20 million budget for the next phase of ECI until 2012, showing the strategic importance of EEE components in our ability to build innovative and competitive space systems.

> **"EEE components are strategically important for our ability to build innovative and competitive space systems"**

→ ESCC: a real player in space for Europe and beyond

Achieving a sound parts management and standardisation policy requires well-accepted practices. For over 30 years, ESA has supported a system for space components management in Europe for this purpose. Today, the European Space Components Coordination (ESCC) system supported by ESA, European national space agencies, component manufacturers and the satellite manufacturers is the centrepiece of these efforts.

EEE components are critical to ensuring the security and integrity of a spacecraft at any stage of its lifecycle. Each type of mission has unique challenges in addition to known hazards and the EEE components chosen to meet the mission objectives must be up to the task.

With the main exception of the International Space Station, once in flight, spacecraft hardware cannot be repaired or replaced. So it is essential that onboard electronics operate continuously over the mission duration.

For geostationary telecom satellites, this may mean up to 20 years of uninterrupted service. One technique that is used to minimise risk of failure is to include duplicate pieces of equipment and functions called 'redundancies'. Sometimes physical shields are also used, but both of these options increase the mass, volume and cost of the mission.

Hence it is now customary and essential practice to assess the robustness of EEE components to ensure system reliability during operational life. The ESCC System maintains a set of standards and specifications to help attain this goal. These standards and specifications have been adopted throughout the European space industry.

European space standards set requirements for the selection, procurement, and control of space components. The methodology covers the competent selection of suitable technologies and component designs, a careful choice of materials and rigorous control of the manufacturing processes, and an adequate level of testing applied on finished components that can effectively screen out all the defective and marginal parts.

The role of component reliability engineering then is to implement appropriate methods and techniques that will evaluate the behaviour of the various component types. These are defined in a series of ESCC Specifications.

Several categories of tests are used to check so-called intrinsic and extrinsic reliability. That is, component defects that are present either through their inherent construction or are built in during manufacture.

→ Categories of test

Environmental

Vibrations, acceleration, mechanical shocks, thermal cycling (fatigue effect), rapid changes of temperature.

Endurance

One of the challenges is to reproduce on the ground, and within a short period, an operational life that can exceed 15 years. Acceleration techniques are often, but not exclusively, based on elevated temperatures.

Radiation

Radiation effects include short-term disturbances, destructive events and long-term gradual degradation. These need to be simulated on Earth with particles usually similar but not identical to those present in space, but that will generate equivalent effects.

Assembly and package

Most of the integrated circuits used for space are not plastic-encapsulated as they are for terrestrial applications, but are hermetically sealed in a metal or ceramic package with an inert gas to increase their reliability. The integrity of these packages, their internal atmosphere, the absence of free particles inside and their hermeticity has to be controlled.

Many other tests dedicated to specific problems can be necessary depending on the components to be evaluated (for example, electrostatic discharge, corrosion and memory data retention.)

All of these and more are performed for all components used in a single project. This represents a very significant effort in terms of engineering resources and may extend the project schedule. Evidently there are many components that are suitable for use in different applications and projects. This is where standardisation plays a key role in avoiding 'reinventing the wheel' and providing a much higher level of efficiency and economy.

> **Standardisation plays a key role in avoiding 'reinventing the wheel', providing higher levels of efficiency and economy**

→ Benefits of EEE parts management and standardisation

Type reduction
Economical approach to the selection and preference of components, considering performance and versatility of use for many applications

Improved costs
Increasing recurrent use and thereby commercially viable production quantities at more competitive costs

Efficient and effective test methods
Consistent and reproducible data to objectively determine the compliance with space requirements

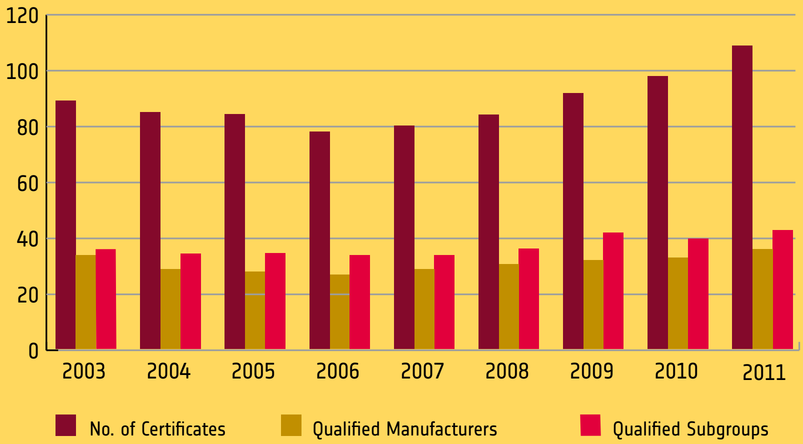
Quality management systems
Control and confidence in the consistent delivery of high reliability components

Standardisation also provides catalogues of readily available and procurable components from which users can choose without any further assessment, or in very special cases, with a limited one. These catalogues are known as the ESCC Qualified Manufacturers List (QML) and the Qualified Part List (QPL).

To date, the ESCC QML and QPL contain 36 European EEE component manufacturers. A further 10 manufacturers supply EEE components in accordance with ESCC rules. The production of European space grade components is a growth industry with an annual turnover exceeding €215 million. The rising demand for ESCC-qualified parts comes from the increase in global space systems and the recognition of quality that is provided by the EEE standardisation system.

The future of European space ambitions may depend on a stable system to provide EEE component sources that meet the needs of a fast-evolving industry.

- ATMEL
- AVX (Ceramic Capacitors)
- AVX (Tantalum Division)
- AVX/TPC
- Axon'Cable
- C&K Components
- Chelton
- Cobham MAL
- COMEPA
- Compagnie Deutsch
- Draka Fileca
- Eurofarad
- W.L. Gore & Co
- Hypertac S.A.
- Hypertac Ltd
- Infineon Technologies AG
- IRCA-RICA
- Isabellenhütte
- KVG
- Leach International Europe
- Leoni
- Meas Ireland (Betatherm)
- Microspire
- Nexans
- RAKON
- Radiall
- REL-STPI
- Schurter A.G.
- Souriau Connection Technology
- STMicroelectronics
- STPI
- Tyco Electronics
- Vishay Electronic Draloric Selb
- Vishay S.A. Division Sfernice



↑ The number of component qualifications is stable and increasing

← European manufacturers with ESCC qualification

→ SPARCs fly

Scalable Processor Architecture (SPARC) is an open standard for microprocessor design that can be applied to everything from processors in digital cameras and other compact devices up to the high-performance multiprocessor cores of mainframes and supercomputers.

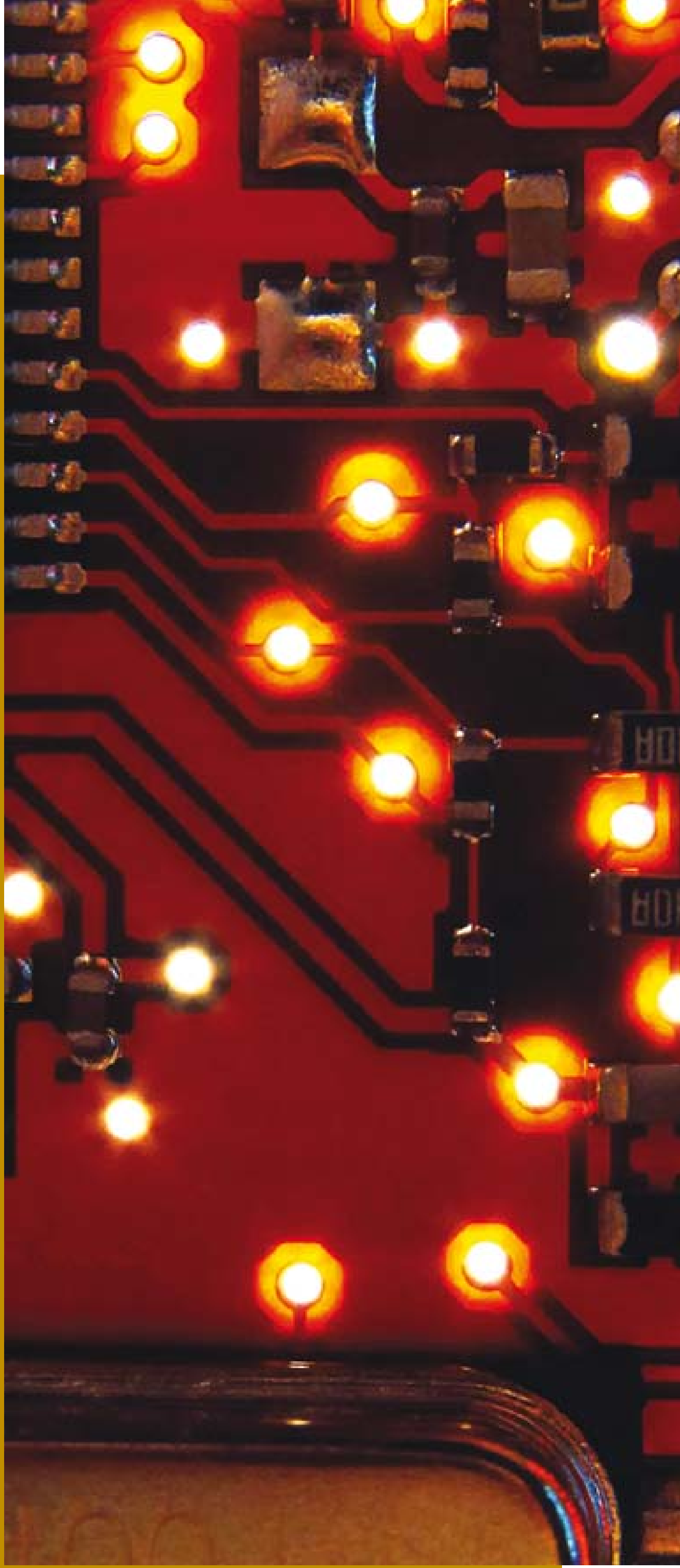
SPARC's versatility has been a great benefit to the terrestrial microprocessor industry. Software development tools are readily available, and ESA has helped Europe's space sector to tap those same advantages. A partnership between ESA and European industry extending over a number of years had led to the development of a SPARC-based family of processors for space applications, consisting of high-performance 32-bit microprocessors that have been optimised to operate in spacecraft onboard computers.

The first generation, referred to as the ERC32, commercialised by Atmel (France) as chipset TSC691-693 and as single-chip processor TSC695, act as the brains of almost all European satellites, and its usage extends to critical missions such as the International Space Station, ATV and the Ariane 5 launcher.

The following generation, known as LEON2-FT and commercialised by Atmel as the AT697 processor, is currently flying on ESA's Proba-2 and running the global ship-tracking Automatic Identification System (AIS) system being trialled on the ISS's Columbus laboratory. The AT697 has been selected for several upcoming missions, such as Proba-V, Sentinel (1, 2, 3), Gaia, Alphasat, SmallGeo and SeoSat.

'FT' stands for 'fault tolerant', meaning its design is proofed against 'Single Event Upsets' caused by space radiation. The LEON2-FT is also distributed by ESA as an IP core for space applications. It is embedded into several System-on-a-Chip (SOC) designs for various applications, such as transponders or navigation receivers.

The Next Generation Microprocessor (NGMP), based on LEON4-FT is currently under development by Aeroflex Gaisler (Sweden) under ESA contract. The specification foresees four CPU cores and a comprehensive set of peripherals, targeting also the higher needs of processing power in payload applications.



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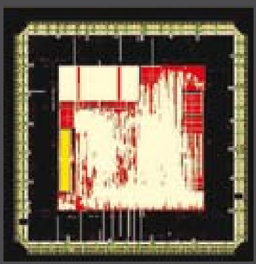
The LEON2-FT processor, currently running the global ship-tracking Automatic Identification System being trialled on the ISS (FFI)



→ Small is beautiful

Our main field of interest may be the space beyond Earth, but ESA is also currently working in inner space – the realm of the very small. ESA has teamed up with industry to design a new generation of space-worthy microchips with transistors scaled down to under 100 nanometres.

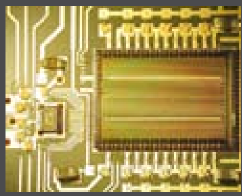
ESA's Deep Sub-Micron initiative is working with industry to transfer the current state-of-the-art technology at the heart of the world's computers, mobile phones and electronics into space systems.

Deep sub-micron technology involves etching transistor features down to 65 nanometres – only a few hundred atoms across.

First engineered half a century ago, the integrated circuit has steadily gained in computing capacity by cramming ever more transistors on a single piece of semiconductor – and designers achieve this by steadily decreasing the transistor size. The result is that computers have effectively doubled in power every 18–24 months while also dropping in price – the famous Moore's Law.

But ESA cannot simply buy standard computer chips for use on its spacecraft – they would not survive very long. Anything placed in orbit is bombarded by particles and cosmic rays that can damage electronic circuits.

ESA supports design techniques for radiation-hardened integrated circuits that are certified to operate reliably for years at a time. But the space sector never stands still: the market demands smarter satellites and more functions that still remain sufficiently compact to fit on standard rockets.



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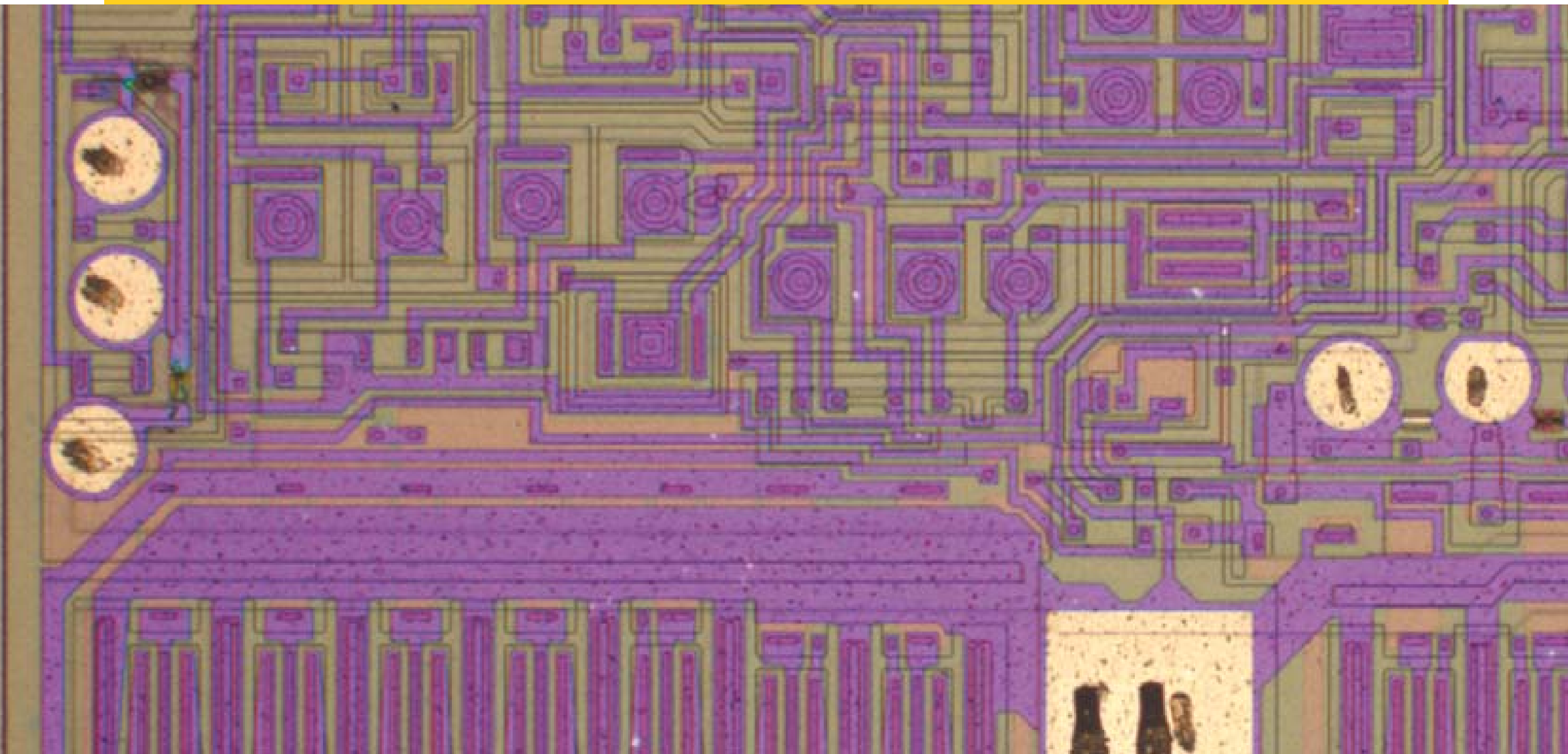
Spectrometers for several future space missions consist of fully custom-designed ASICs

While computer manufacturers make do with standardised chips, spacecraft builders need customised designs to fulfil different functions, known as Application Specific Integrated Circuits (ASICs). So for example, there are specific ASICs for data handling, telemetry, particle detection and star tracking, among many other relevant tasks. In practice, each new ASIC is not built from scratch, but is developed by reusing a set of predesigned building blocks known as 'cells' which collectively form an ASIC 'library'.

Radiation-hardening techniques are incorporated at this stage – although the deep sub-micron scale makes it more challenging, with increased sensitivity to charged particle collisions and a greater tendency for 'cross-talk' of charge between circuits. Complex 3D radiation modelling takes into account the way a typical satellite interior will influence the interaction of particles with the device in question.

A joint activity between ECI and TRP, the first phase of the Deep Sub-Micron initiative has now been completed, with trial designs being selected for manufacturing and testing in the follow-up phase.



→ Small scale, big ideas

Engineering on small scales offers a way to boost mission functionality at the same time as driving down satellite mass and volume. ESA has long been interested in harnessing micro-electro-mechanical systems (MEMS) and nanotechnology for space.

↑

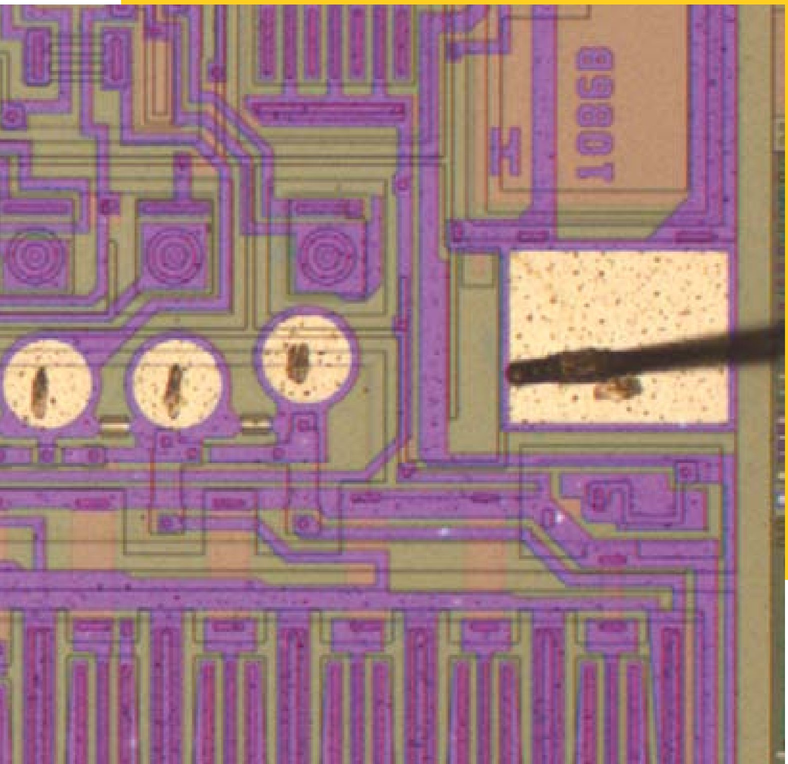
The CryoSat-2 experimental MEMS Rate Sensor

MEMS involve a single (often silicon-based) component incorporating electrical, mechanical and sometimes optical systems, built on a scale of micrometres (100 micrometres is the average width of a human hair). Although size is not the sole criteria – harnessing of production techniques from the integrated circuit industry is equally important.

ESA began researching MEMS in the mid-1990s. Today it is becoming a mature technology, found in everything from cars to washing machines, and now 'spin out' versions have made it into orbit.

European-made MEMS devices have flown on the ISS – one was used to monitor Columbus's internal environment – while CryoSat-2 incorporates an experimental MEMS Rate Sensor for attitude control.

Sweden's Prisma formation-flying mission incorporates MEMS micro-thrusters for precision control, developed by Swedish company Nanospace with ESA and Swedish National Space Board support. Each thruster is only the size of a golf ball, with 4 mm rocket nozzles. All supporting combustion chambers, valves, filters and heaters found in a standard rocket motor have been etched onto a set of coin-sized silicon discs.



More MEMS systems are on the way. One of the European contributions to the James Webb Space Telescope, the Near-Infrared Spectrometer, incorporates a micro-array made up of multiple shutters provided by NASA Goddard Spaceflight Center. Measuring 100 by 200 micrometres each, all individually controllable to let in or shut out light as required. The array will enable the first multi-object spectroscopy in orbit: current spectrometers can only study a single object at a time.

ESA's Gaia mission will carry MEMS flow sensors built in Italy to allow very tight measurement of gas flow in its micropropulsion system, for ultimate pointing accuracy, while BepiColombo could use MEMS heat sensors. A Life Marker 'lab on a chip' is also being developed which could be used on ExoMars.

Nanotechnology sees the manufacturing process shift from micro- to nano-scales (one nanometre is a millionth of a metre). ESA is now at the stage with nanomaterials where it was with MEMS back in the early 1990s. The most advanced technology candidates so far are 'Carbon Nanotubes' (CNTs). The possibilities are vast, from strengthening spacecraft structures and increasing launcher thermal resistance, to turbo-charging solar cell and battery efficiency. Although topics are unlimited, budgets are not, so ESA is identifying priorities for research.

Power flexibility has now become a reality for telecom satellites, with the first set of flexible Travelling Wave Tube Amplifiers (TWTAs) launched on Hylas-1 in 2010. Developed under ARTES with support from ESA, TWTAs are one of the key enabling technologies for telecommunications payloads

→ A KEY SOURCE FOR INNOVATION IN EUROPE

Developing technology through ESA's ARTES programme

Kate Peeren with Dietmar Schmitt
Directorate of Telecommunications and Integrated Applications, ESTEC, Noordwijk, The Netherlands

Marinella Aloisio
Directorate of Technical and Quality Management, ESTEC, Noordwijk, The Netherlands

"What happens if we do 'this', instead of doing 'that'?" So begins the thought process that leads to improving the way we live.

In the world of satellite communications, 'this' instead of 'that' has meant changes to such things as the way we receive television signals, or where we can answer our mobile phones. It has meant being able to access our email while travelling by train, or being able to determine where the traffic jams will delay our daily commute.

However, while everything usually begins with a great idea, technology is needed to make that idea a reality. Users see the end product – but what makes the end product tick? What makes 'this' work better than 'that?' How will 'this' new satcom technology improve the daily life of European citizens, and how can it be produced in an economical way to benefit European industry and consumers alike?

ESA helps to find the answers through its Advanced Research in Telecommunications Systems (ARTES) programme. ARTES has been supporting the European satcom industry since 1975, and while the term ARTES may not be familiar to the end user of satcom, industry has called ARTES the key source in Europe for innovation in satellite communications.

By facilitating research and development activities and by forging partnerships within the satcom industry, ESA's ARTES programme contributes to the development of European and Canadian industries, assisting them in the production of advanced technologies and concepts to develop world-class products and services.

Developing technology:
L/S-band 'travelling wave tube amplifiers'
Through its funding structure and various elements, ARTES has been instrumental in assisting the research and development of new technologies and improvements to current systems. One such example is the successful development of high-power L- and S-band travelling wave tube (TWT) amplifiers.

TWT amplifiers are widely used in satellite applications to provide signal power amplification at high frequencies. The development of space TWT amplifiers for telecommunication satellites started in the early 1970s in C-band and then progressively moved to Ku-band and, only more recently, to Ka-band.

At the same time, more compact Solid State Power Amplifiers (SSPA) started to be used in space in L/S-band due to the limited power required at that time in these frequency bands. However, as the power requirements started to increase, TWT amplifiers became an attractive alternative to SSPAs.

In 1996, Thales Electron Devices (TED) in Germany started with the development of high-power L-band TWT amplifiers (150 W) for digital radio services. More than 70 amplifiers were delivered for the Worldstar system. Two satellites are currently in orbit, providing digital radio programmes to large areas of the southern hemisphere.

In 1999, just after this successful step in the market, TED was asked by a customer to start the development of a high-power 250 W TWT amplifier in S-band for digital radio in North America. Shortly thereafter, the first 250 W S-band TWT amplifier was used on the first XM radio satellite.

> **ARTES is the key source in Europe for innovation in satellite communications**

The goal of the first TED developments in L/S-band was to get reliable TWT amplifiers in a very short lead-time; this goal was successfully met. Nevertheless, the overall efficiency of such tubes was low, 54% in L-band and 58% in S-band.

TWT amplifiers and ARTES
The interest in these low-frequency bands (L and S) became more strategic for the space community at the beginning of the last decade. In 2001, under the ESA ARTES 5 programme element, TED (then Thomson Tubes Electroniques GmbH) started a new development of high-power tubes in S-band. TED's goal was twofold: improve the performance of these state-of-the-art tubes and complement the existing 'conduction-cooled' (CC) design with the 'radiation-cooled (RC) version.

Under this ARTES contract, the existing S-band design was completely reworked. The target was to get a more efficient (by 5%) and lighter tube. All components such as the gun, the interaction line, the collector, the magnet focusing system, the RF transition and the housing, for both CC and RC versions, were modified and improved.

Some breadboard versions were tested for the verification of the electrical performance. This new S-band design reached an efficiency of more than 65% while maintaining the performance in all other typical parameters. The CC version had a mass of only 1500 g, while the TWT in the RC version was 2200 g, with a radiator diameter of 230 mm.

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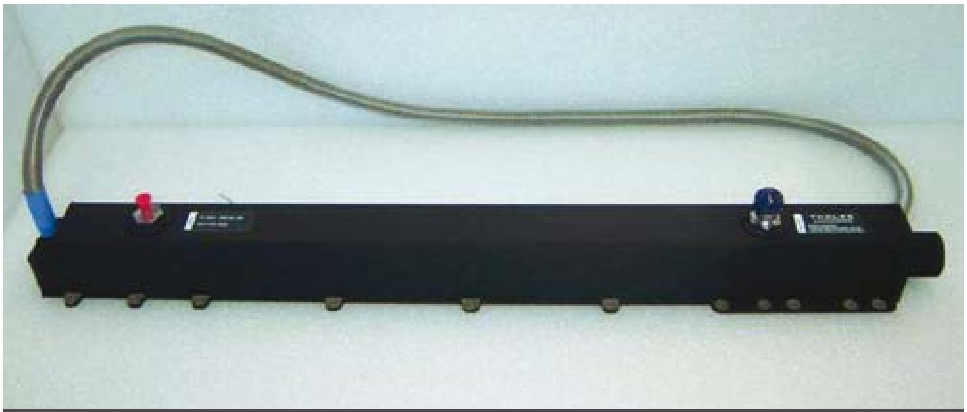
L-band TWT amplifier with an output power from 90 to 230 W in radiation-cooled design (TED)



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Conduction-cooled L-band TWT amplifier with an output power from 90 to 230 W (TED)

In 2003, the success of this ARTES 5 development was extended into an ARTES 3 activity with the goal of transferring the experience gained with the high-power S-band TWTs into the low- and medium-power range, and completing TED's L-band portfolio with high- and medium-power TWTs up to Electrical Qualification Model level.

Within two years, the excellent performances of the high-power (250 W) S-band TWTs were transferred to the medium-power (90 W and 150 W) RC and CC versions, while keeping the same efficiency as the high-power class.

In L-band, the existing 150 W design was completely reworked, leading to an efficiency improvement of 7% within the frequency range from 1.15 to 1.6 GHz and a mass reduction of 400 g. In addition, the TED L-band portfolio was extended to an RC design (150 W) and to the 250 W output power class (CC only) with comparable electrical performance and mass. L-band TWTs qualified under this activity are now successfully in orbit.

In parallel with the latter ARTES 3 activity targeting medium-power TWTs, the production started of the already-developed S-band high-power tubes, both in CC and RC versions.

At the end of 2005, TED was the only European manufacturer of space TWTs, but thanks to these ARTES activities it had gained an unrivalled portfolio in L/S-bands, fully covering the needs of most of the proposed applications and offering worldwide the first radiation-cooled version of an L/S-band TWT, not only for telecom but also navigation applications. In the same year, the very first navigation TWT amplifier ever flown was launched on the Galileo test satellite, GIOVE-A.

The future of L/S-band TWT amplifiers

S-band mobile broadcasting satellites require very high Equivalent Isotropic Radiated Power (EIRP) in order to guarantee a proper link budget to low-gain user terminals. Examples are Sirius (former CD Radio) and XM radio satellites for digital audio broadcasting over North America, as well as the Japanese-Korean MBSAT and the European S-DMB and S-MBMS for multimedia applications.

However, since the maximum radio output power reached by state-of-the-art S-band TWTs is limited to 250 W, the

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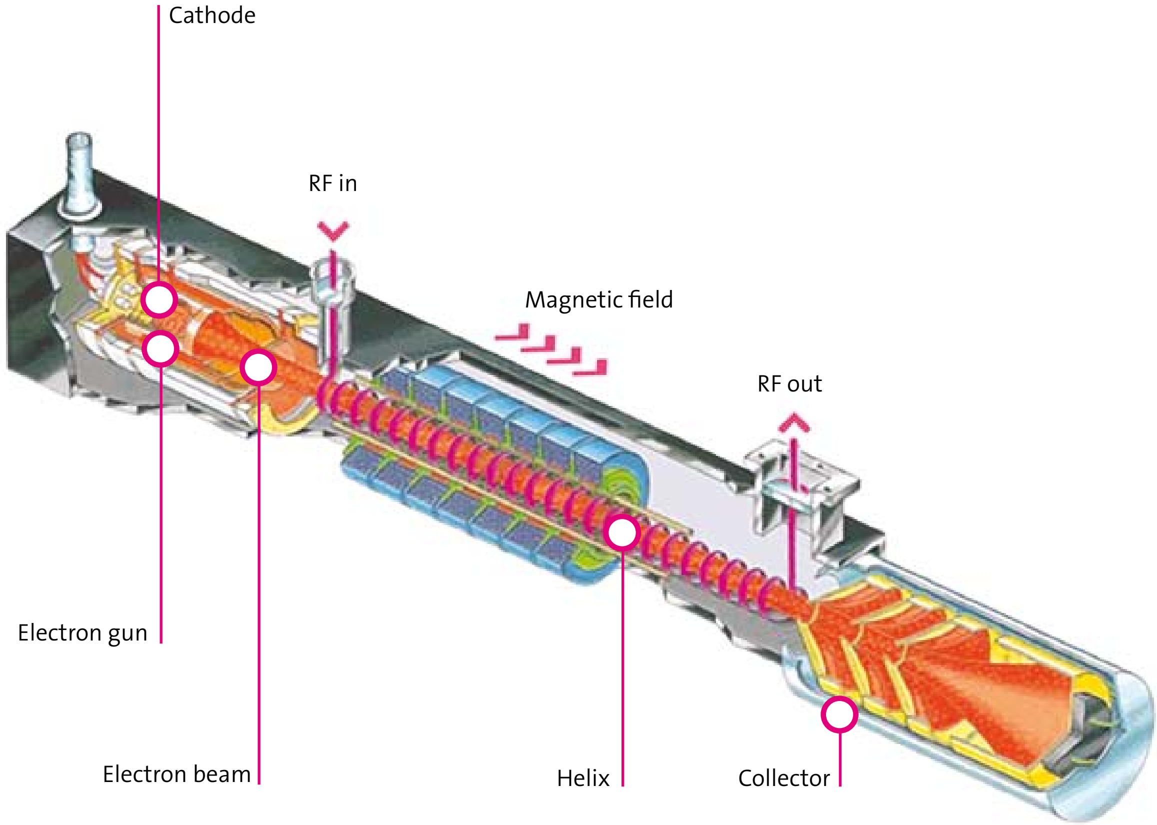
S-band TWT amplifier with an output power of 250 W in radiation-cooled design (TED)

Schematic of a TWT



↑ Travelling wave tube amplifiers (TWTAs, often pronounced 'TWEET-uhs') are commonly used as amplifiers in satellite transponders, where the input signal is very weak and the output needs to be high power. A broadband TWTA consists of a helix travelling wave tube coupled with protection circuits and regulated power supply. Its operating frequencies range from 300 MHz to 50 GHz.

solution at payload level is to power-combine a large number of TWTs, which involves highly complex, heavy and expensive technologies and leads to considerable combining losses.

Following the steady demand for very high-power TWTs in S-band, in 2007 ESA started an ARTES 5 activity with TED in order to develop the necessary technology building blocks and design, manufacture and test breadboards of a very-high-power (over 300 W) S-band TWT. The results achieved with the first breadboards were very promising and additional effort is being made to the further improve the electrical, thermal and mechanical performance in view of a planned follow-on development under ARTES 3-4.

To complement this TWT activity, another ARTES 5.1 activity was started in 2008 aiming at the development of an Engineering Model of an Electronic Power Conditioner for very-high-power S-band TWTs. This is currently running in parallel with the TWT development and is performed by TESAT Spacecom.

Another ARTES 3-4 activity was placed with TED in 2008, aimed at the qualification of a waveguide interface for S-band TWTs. In fact, TNC connectors, which are now used as standard output for high-power S-band TWTs, could cause problems (i.e. outgassing) because of the presence of a dielectric material if used in very-high-power TWTs.

Instead, a waveguide output, with no dielectric inside the interface, represents a robust solution for higher power levels. The qualification campaign of two S-band TWTs (CC and RC versions) with waveguide output interfaces was successfully completed at the beginning of 2011.

With the support of the German Aerospace Center (DLR), ESA has once again helped strengthen the position of the European satcom industry and secure its competitiveness in the worldwide market. These developments have reached new horizons for digital radio and multimedia telecommunications, as well as strategic applications such as navigation.

This was made possible by a combination of long-term research and development activities under ESA's ARTES programme element 5 and product-oriented developments and qualifications under ARTES programme element 3-4.

→ ARTES

ESA's TIA Advanced Research in Telecommunications Systems (ARTES) programme enables European and Canadian industry to explore, through research and development activities, innovative concepts to produce leading-edge satcom products and services.

ARTES offers varying degrees of support to projects with different levels of operational and commercial maturity. Its scope and plans are incorporated into the Telecommunications Long-term Plan (TLTP), the blueprint for ESA's actions over a five-year period.

Businesses in ESA Member States involved in the satcom industry, whether small or large, new or experienced, can submit proposals via the various elements of the ARTES programme. Every ARTES element includes a funding framework and follows set criteria that must be met by satcom companies wishing to participate.

ARTES 1: Preparatory

Dedicated to strategic analysis, market analysis, technology and system feasibility studies and to the support of satellite communication standards.

ARTES 3-4: Products

The development, qualification and demonstration of products. 'Product' in this case has a wide meaning; it can be a piece of equipment, either of the platform or payload of a satellite, it can also be a user terminal or a full telecom system integrating a network with its respective space segment. Telecommunication applications can also be undertaken under the terms of this element.

ARTES 5: Technology

Long-term technological development, either based on ESA's initiative, or on the initiative of the satcom industry.

ARTES 7: EDRS

The development and implementation of a European Data Relay Satellite (EDRS) system. Data relay satellites are placed in geostationary orbit to relay information to and from non-geostationary satellites, spacecraft or other vehicles and fixed Earth stations, which otherwise are not able to permanently transmit or receive data.

ARTES 8: Alphabus/Alphasat

The development and deployment of Alphasat. In partnership with Inmarsat, Alphasat will incorporate the first unit of the Alphabus Platform jointly developed by Astrium and Thales Alenia Space. Alphasat incorporates innovative onboard processing technology and will promote development of user services.

ARTES 10: Iris

A satellite-based communication system that will complement the next generation of air traffic management system currently being developed under the SESAR programme of the EU, by Eurocontrol and the European Aeronautical community.

ARTES 11: Small GEO

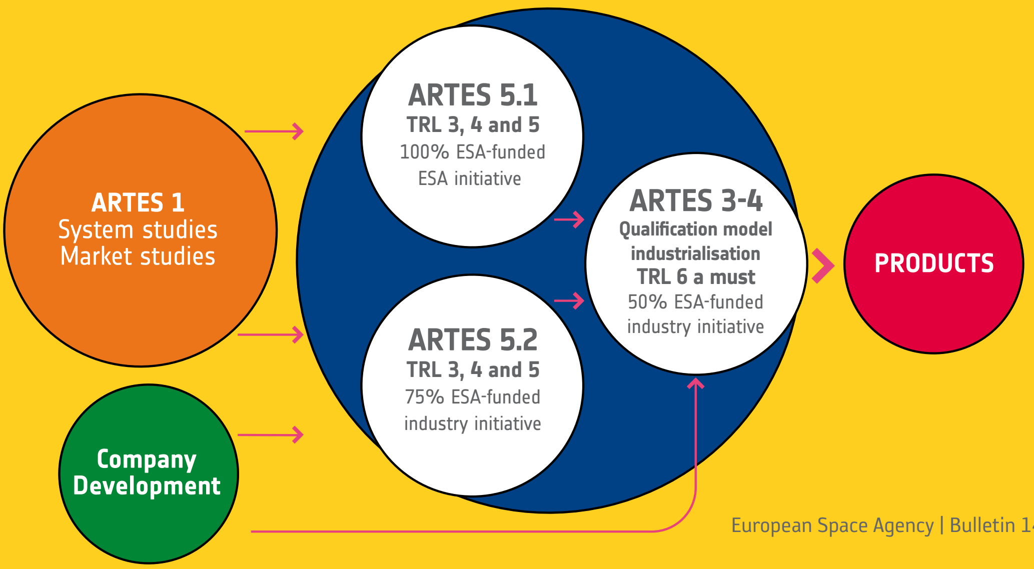
The development and implementation of Small GEO, a satellite platform developed by OHB and partners. The first satellite to use Small GEO, Hispasat Advanced Generation 1, will incorporate advanced payload technologies: the DVB S2 Processor and active antennas.

ARTES 20: IAP

The development, implementation and pilot operations of Integrated Applications. These are applications of space systems that combine different types of satellites, such as telecommunications, Earth observation and navigation. Integrated Application projects offer solutions that range from secure transport systems to developing emergency/disaster management systems.

ARTES 21: SAT-AIS

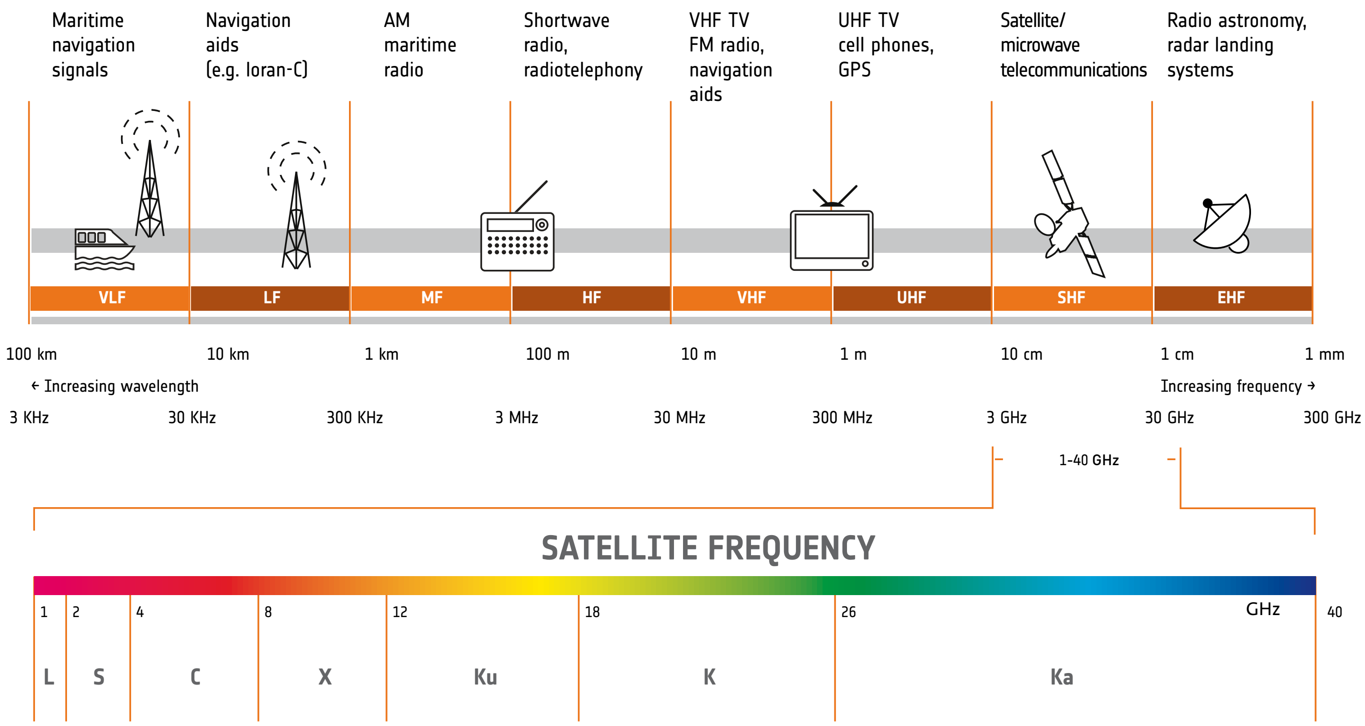
Defining the design and investigation of a sustainable space-based system that will provide Automatic Identification System (AIS) data via satellite, allowing for the detection of seafaring vessels equipped with AIS tracking devices. This European-based SAT-AIS is an initiative in partnership with the European Maritime Safety Agency and ESA.



→ Satellite frequency bands

Satellite technology is developing fast, and the applications for satellite technology are increasing all the time. Not only can satellites be used for radio communications, but they are also used for astronomy, weather forecasting, broadcasting, mapping and many more applications. With the variety of satellite frequency bands that can be used, designations have been developed so that they can be referred to easily.

The higher frequency bands typically give access to wider bandwidths, but are also more susceptible to signal degradation due to 'rain fade' (the absorption of radio signals by atmospheric rain, snow or ice). Because of satellites' increased use, number and size, congestion has become a serious issue in the lower frequency bands. New technologies are being investigated so that higher bands can be used.



L-band (1–2 GHz)
Global Positioning System (GPS) carriers and also satellite mobile phones, such as Iridium; Inmarsat providing communications at sea, land and air; WorldSpace satellite radio.

S-band (2–4 GHz)
Weather radar, surface ship radar, and some communications satellites, especially those of NASA for communication with ISS and Space Shuttle. In May 2009, Inmarsat and Solaris mobile (a joint venture between Eutelsat and Astra) were awarded each a 2×15 MHz portion of the S-band by the European Commission.

C-band (4–8 GHz)
Primarily used for satellite communications, for full-time satellite TV networks or raw satellite feeds. Commonly used in areas that are subject to tropical rainfall, since it is less susceptible to rainfade than Ku band (the original Telstar satellite had a transponder operating in this band, used to relay the first live transatlantic TV signal in 1962).

X-band (8–12 GHz)
Primarily used by the military. Used in radar applications including continuous-wave, pulsed, single-polarisation, dual-polarisation, synthetic aperture radar and phased arrays. X-band radar frequency sub-bands are used in civil, military and government institutions for weather monitoring, air traffic control, maritime vessel traffic control, defence tracking and vehicle speed detection for law enforcement.

Ku-band (12–18 GHz)
Used for satellite communications. In Europe, Ku-band downlink is used from 10.7 GHz to 12.75 GHz for direct broadcast satellite services, such as Astra.

Ka-band (26–40 GHz)
Communications satellites, uplink in either the 27.5 GHz and 31 GHz bands, and high-resolution, close-range targeting radars on military aircraft.

→ BUT WILL IT WORK?

Sean Blair with Ton de Rooij & Ali Mohammadezah
Directorate of Technical and Quality Management, ESTEC, Noordwijk, The Netherlands

When a project team selects a particular item for a space mission, they need to know it is suitable for space. And if it fails under testing, they have to know why...

Full-size satellites and systems undergo rigorous testing in simulated space conditions at the ESTEC Test Centre in Noordwijk and comparable sites elsewhere in Europe. Well before their integration into a spacecraft, component parts and materials will already have been tested in various ways by ESTEC's specialised labs, such as the Materials and Electrical Components Laboratories or the Opto-Electronics Laboratory, run by ESA's Directorate of Technical and Quality Management. These labs provide European space projects with total confidence in the materials and components they select to fly into orbit.

To achieve this, materials and components are bombarded with radiation and subjected to power, vibration or thermal stresses. They are exposed to space-like conditions for long periods. When failures occur during testing, the Materials and Electrical Components Laboratories have the in-house expertise to perform a complete in-depth failure analysis.

Unique tests, unique tools

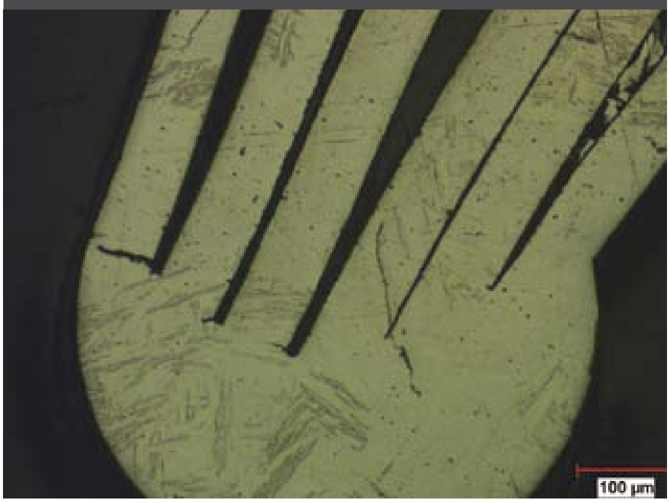
Many of the investigations performed by the Materials and Electrical Components Laboratories are extremely specialised, with few equals anywhere else in Europe. A unique array of tools is required. Tensile machines subject test items to 10 tonnes of load, while a 'nanoscratcher' assesses the resistance of the very thinnest coatings a millionth of a metre thick.

Hardware is cooked in purpose-built chambers, allowing resulting chemical vapours to be analysed by spectroscopes and gas chromatographs. Components can be bathed in radiation. Various optical, scanning electron or confocal microscopes give close-up views of tests results, with scanning probe microscopes taking resolution right down to atomic scales.

Specialised tools perform preparatory drilling or cutting. Alternatively non-invasive methods are available, such as acoustic microscopes based on ultrasound. The X-ray photoelectron spectroscope can identify a surface's chemical composition to the nanometre level, while the Electron Backscatter Diffraction camera can examine the crystallographic orientation of many materials. Coupled-thermal analysis investigates the fundamental physical properties of materials.

↓

During testing for the Planck mission, a pressure regulator of the dilution cooler control unit leaked. The leak turned out to be due to cracking of the low-pressure bellows used as the regulator. These edgewelded bellows are made of commercially pure titanium with tungsten inert gas welding. The same type of failure was subsequently found on Rosetta and ATV.



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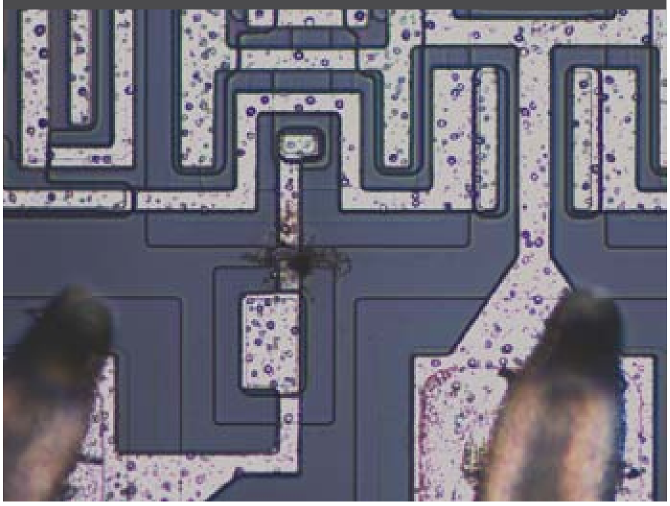
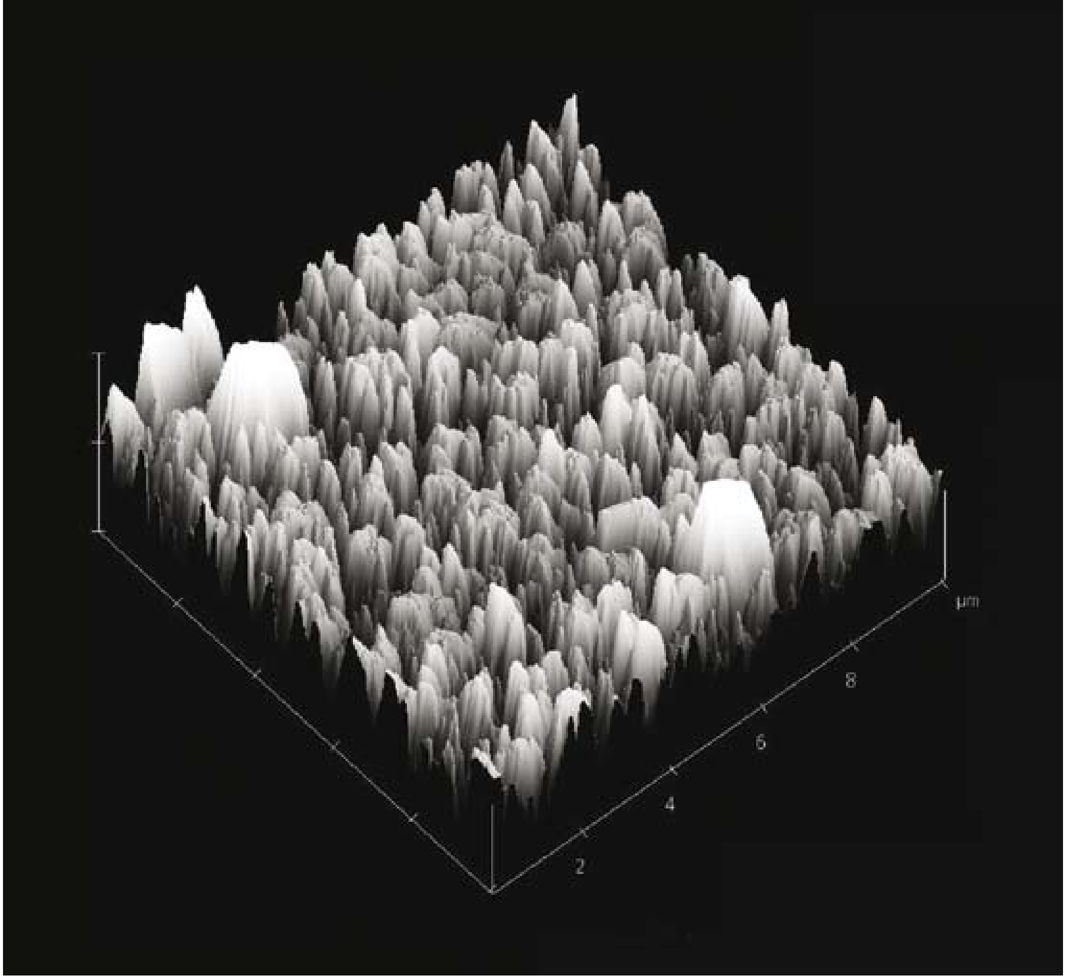
View of a component failure (melted track) through a microscope. The overstress caused a short circuit to the supply rail. This failure analysis was performed for the Alphasat project (compare this with the large image on page 41 of the same component seen through an electron microscope).





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Atomic Force Microscopy can reveal detail down to atomic level on the surface of materials

→ CORROSION AND MECHANICAL TESTING

Understanding how materials respond to different types of stress is of prime importance for ESA. The Materials and Electrical Components Laboratories can subject metallic and non-metallic materials to corrosion and mechanical strain – testing to destruction if need be. Standard qualification tests for corrosion include stress corrosion cracking (subjecting materials to a sustained 30-day strain while immersed in salt water), salt spray exposure and bimetallic corrosion (checking adjacent metals do not undergo electrolytic corrosion).

In mechanical testing – in plain words, breaking things – the labs use three types of tensile machine. Bringing a maximum of half a tonne of weight to bear, they subject samples to tension, compression, torsion and shear, optionally carried out at temperatures between –150 to +600°C. A new 3D measurement system uses high-speed cameras to capture strain as it happens.

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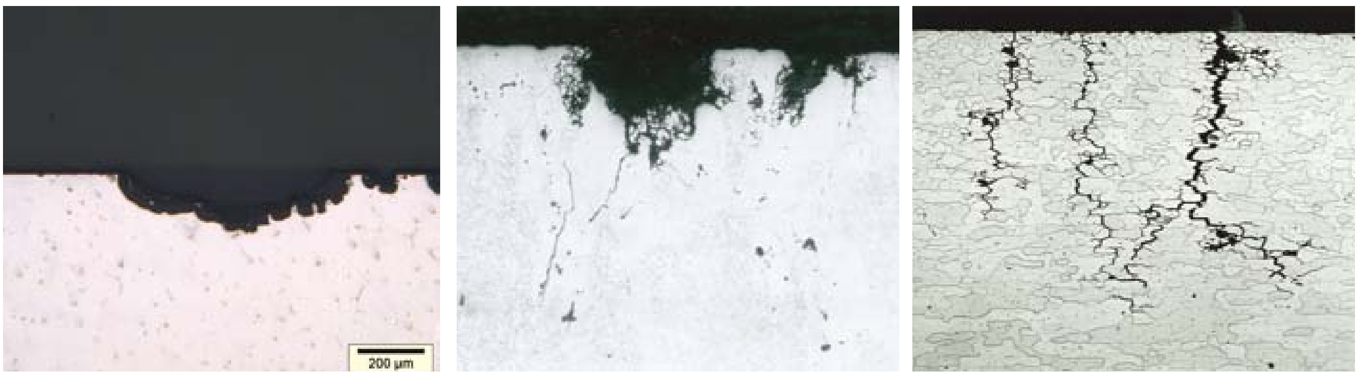
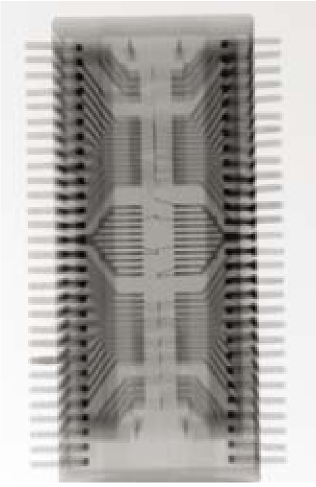
Materials displaying different stages and types of corrosion





→ TAKING A CLOSER LOOK

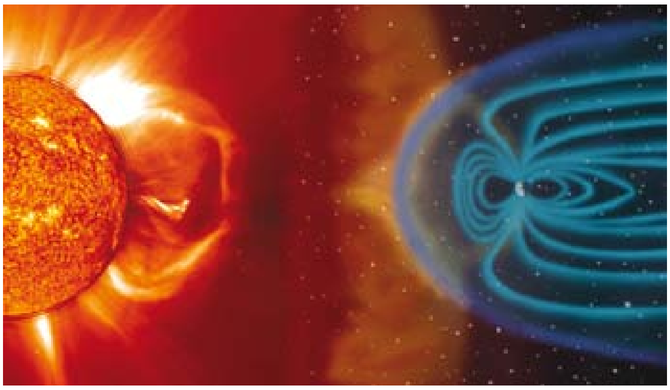
Electrical, electronic and electromechanical components are key building blocks of space missions. As they become more miniaturised, satellites are getting smarter and more capable.

← Electron and ion beam microscopes and an X-ray tomography facility are used non-destructive interior views

Current integrated circuits are designed down to the submicron level to integrate millions of transistors onto a single chip. This density means they are very difficult to evaluate and test properly. The Materials and Electronic Components Laboratories use specialised tools for examining components to the exacting scales required, including a suite of four electron and ion beam microscopes and an X-ray tomography facility for non-destructive interior views. A focused ion beam etches trenches to reveal subsurface structures; a Raman spectrometer can identify surface materials or contaminants against a 10 000-spectra database; a laser system can remove larger areas of material to expose encapsulated structures.

→ RADIATION EFFECTS

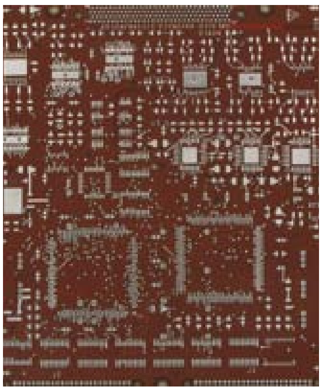
Space might be a vacuum, but it is far from empty – it is pervaded by highly energetic particles of different species and energies. These particles can affect electrical, electronic and electromechanical components in many ways, ranging from slow electrical parameter degradation and transient effects, up to catastrophic failure. To evaluate the suitability of components for ESA satellites, the Materials and Electrical Components Laboratories maintain an internal cobalt-60 gamma beam facility and a californium-252 facility.



Three highly specialised external radiation test facilities are also supported: the Paul Scherrer Insitute (PSI), Switzerland; RADEF, Finland; and UCL, Belgium. ESA supported the construction of the Proton Irradiation Facility (PIF) at PSI. Optimised for space system testing, the PIF relies on high-energy protons coming from the Institute's main cyclotron. All these facilities are employed as needed to simulate the space radiation environment with the aim of characterising components for the three main types of radiation effects: total ionising dose, displacement damage and single event effects.

→ Space is pervaded by highly energetic particles of different species and energies

→ SURFACE MOUNT TECHNOLOGY



There are hundreds of printed circuit boards (PCBs) in satellites, made of multiple electronic components mounted onto a non-conductive backing, onto which intricate metallic connections are printed. The Materials Technology Laboratory evaluates the reliability of PCBs, qualifies PCB manufacturers for space applications and verifies all surface mount technologies used on these boards.

The causes of failures are investigated in support of projects.

The lab is equipped with powerful diagnostic tools, including optical, acoustic, confocal and scanning electron microscopes, as well as energy-dispersive X-ray spectroscopy to identify individual elements. X-ray fluorescence measures coating thicknesses, electron backscatter diffraction obtains crystallographic information and X-ray tomography peers inside a PCB.

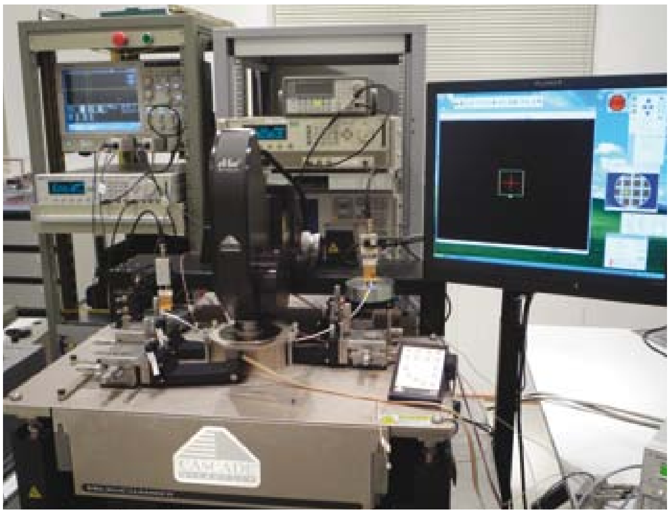
Environmental tests artificially age or shock the populated PCBs, such as thermal cycling, from –125°C to +180°C, steam bath and humidity chamber ageing, and thermal shock by solder bath float. Solderability testing and reworking is also performed.

→ MICROWAVE COMPONENT TESTING

Microwave signals are the backbone of space communications, employed by telecommunication satellites, spacecraft telemetry and remote-sensing instruments.

Novel microwave devices promise substantial performance improvements – such as the gallium nitride amplifier to be tested on ESA's Proba-V – but need verification first.

The Materials and Electrical Components Laboratories include specialised facilities to evaluate the latest in microwave technology components and independently validate their performance. Tests include direct current and radio frequency (RF) life testing, step-stress tests and high-temperature storage tests. Equipment includes an RF on-wafer semi-automated probe station and integrated thermal chuck for characterising complete wafers and individual Monolithic Microwave Integrated Circuits; an RF pull load system; a DC-200V pulsed IV measurement system, a semi-automated RF life-test system and a high-voltage DC step-stress bench.



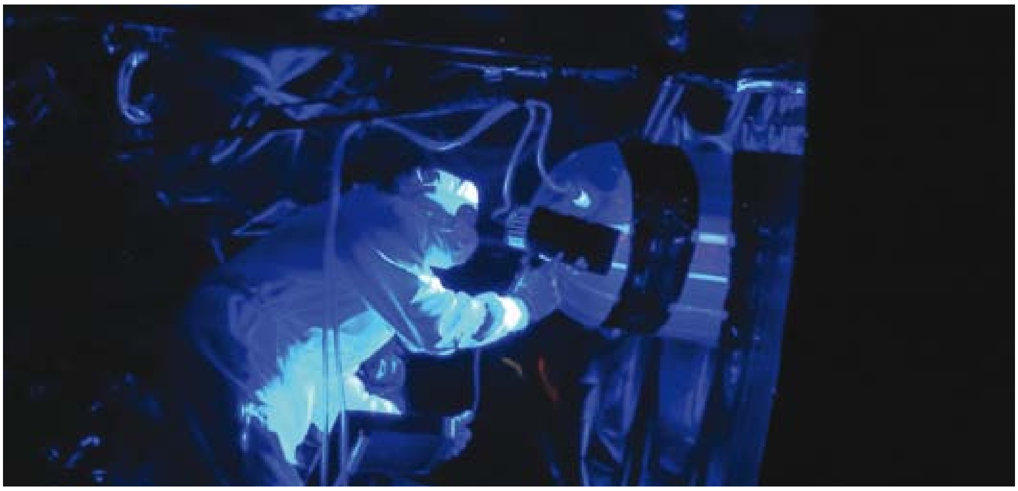
→ Specialised facilities to evaluate the latest in microwave technology components

→ CLEANLINESS IS NEXT TO... MISSION SUCCESS

Space hardware must be kept rigorously clean: any contamination could endanger instrument performance, or even astronaut health. Organic materials give off trace chemicals. In the vacuum of space this can cause molecular deposition, and even the very thinnest of layers may affect sensitive surfaces such as telescope mirrors or laser lenses, solar arrays or thermal control surfaces.

In enclosed pressurised environments, airborne contamination is the concern, as astronauts must not be exposed to toxic substances. Contamination by dust or debris – even sloughed-off skin cells – may cause beam scattering in optical devices, impede electrical connections or affect the workings of propulsion or mechanical devices.

The Materials and Electrical Components Laboratories offer expert advice on cleanliness and contamination control, quantify particulate and molecular contamination levels, audit cleanroom facilities, and test materials and flight hardware for their contamination potential.



→ Spacecraft surfaces are inspected using ultraviolet light to detect dust particles that fluoresce under UV illumination

→ OUT-OF-THIS-WORLD IDEAS ON OFFER

For entrepreneurs hunting for out-of-this-world business concepts, ESA is placing details of its intellectual property rights online, seeking to promote their terrestrial commercialisation.

The new online guide, undertaken by ESA's Technology Transfer Programme Office (TTPO), includes descriptions of the intellectual property rights in question, their innovations and advantages and their potential market applications.

"In the first place ESA files patent applications in order to safeguard its own programmes," explains Luz Becker, Secretary of the Agency's Patents Group. "We need to keep Europe a strong player in space; we want to avoid that someone else claims inventions we have made and could potentially block their use by ESA and its contractors."

"In addition, if you are a start-up company looking to attract venture capital, it's much easier if you have access to intellectual property, either through your own patents or a licence. And patents make the licensing process legally waterproof, demonstrating that we do indeed own the knowledge we are transferring," explained Luz.

ESA's TTPO has a network of brokers looking for companies that might be interested in licensing ESA patents, with a view to getting discussions going. Royalty-free licensing is available for space applications within ESA Member States, while licensing for space uses outside ESA Member States, and licensing for non-space applications, may be subject to licence fees and royalties. All licences may be subject to an administrative fee.

The most active fields for new ideas have been onboard solar power conditioning – converters, switching devices and specialised circuitry to keep a satellite's electrical power flowing smoothly – and telecommunications, including everything from antennas to amplifiers to digital video broadcasting.

→ Technology Transfer Programme

The goals of ESA's TTPO are to facilitate the use of space technology and space systems for non-space applications and to demonstrate the benefit of the European space programme to European citizens.

Most transfers are achieved through the TTPO's technology broker network of pan-European technology firms who scan the space market for exciting technologies and match them to the needs of the non-space industry world.

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Six ESA Business Incubation Centres located across Europe foster technology transfer by supporting innovative entrepreneurs

Six ESA Business Incubation Centres (BICs) located across Europe foster technology transfer by supporting innovative entrepreneurs in rearing businesses that come from the space technology world and are applied in non-space industries. ESA BIC members not only draw on business support provided by TTPO, but also on a much wider range of ESA expertise.

Entrepreneurs seeking to turn space spin-offs into viable businesses receive advice from ESA technical officers as part of the TTPO's incubation process. More than 125 companies have been supported since its creation. Fifty companies are supported annually through ESA BICs, with another 50 supported via the European Space Incubators Network (ESINET) and the ESA Investment Forum.

A €100 million early-stage Venture Capital Fund has been set up, the Open Sky Technologies Fund, which is managed by Triangle Venture and will invest in space-related technologies for terrestrial applications.

> **"Technology transfer from space has a huge potential to spur innovation in areas you wouldn't expect to find space-tech"**

Technology transfer – in a heartbeat

What if monitoring your heart rate was as easy as listening to music while you jog? Thanks to advances in space technology, an iPhone will soon be able to do double duty: keep you in tune with your favourite artists and your vital signs.

With the support of ESA's TTPO, Swiss company CSEM created the final prototype for their Pulsear device. A tiny unit embedded in a regular earphone uses infrared signals to see how fast your heart is beating. It sends infrared signals through the tissues in your ear. A tiny photo diode records the results and sends the information via the earphone wires to a device that plugs into your phone. The result is an accurate reading of your heart rate, without the irritation of wearing a chest belt.

Earlier attempts by CSEM to monitor heart rate using earphones were not satisfactory because the available technology was not sophisticated enough. But that was before CSEM developed a complex chest sensor for measuring astronaut blood oxygen levels for ESA's Long-term Medical Survey.

With a grant from the TTPO's 'Technology Transfer Demonstrator' initiative, CSEM created the prototype. This initiative supports development of new hardware and software to bridge the gap between the space technology and its terrestrial use.

The European Cupola, attached to Node-3 on the ISS, a Russian Progress vehicle and the backdrop of Earth, in this photo taken by an Expedition 26 crewmember in March 2011

→ SYMPHONY IN SPACE

ESA's virtuoso duo, Paolo Nespoli and Roberto Vittori, on the International Space Station

Maurizio Nati
Directorate of Human Spaceflight and Operations, ESTEC, Noordwijk, The Netherlands

The classical music direction 'crescendo con brio', Italian for 'increasing with spirit or vivacity' is particularly apt when describing the latest European developments on the International Space Station (ISS).

At the time of writing, ESA's Italian astronaut Roberto Vittori is ready for his launch on the STS-134 mission, in which he will join fellow Italian Paolo Nespoli on the ISS for two weeks. His seat on the last flight of the Space Shuttle *Endeavour* stems from an Italian space agency (ASI) flight opportunity in exchange for its contribution of the Multipurpose Logistic Modules. When Roberto is greeted by Paolo, he will be the first European to fly three times to the ISS. Roberto flew twice before as a Flight Engineer on Russian Soyuz flights, but this will be his first mission on a Space Shuttle. After being selected as astronauts together in 1998, and having shared many years of training, Paolo and Roberto have the opportunity to fly together in space.

Europe has contributed to the ISS since its inception back in 1998, with elements provided both to the Russian and the US On-orbit Segments (USOS). Since then, ESA astronauts have regularly participated in ISS onboard operations during a series of 'taxi flights', which culminated in

Astrolab, the first European long-duration mission to the ISS from July to December 2006.

But Roberto's latest mission is just the icing on the cake for European participation on the ISS, which has seen a continuous increase and range in activities from 2007 onwards. In November of that year, Paolo Nespoli flew on STS-120 and helped to deliver Node-2 **Harmony** to the ISS during his *Esperia* mission.

In February 2008, two ESA astronauts, French Léopold Eyharts and German Hans Schlegel, flew on the STS-22 mission to deliver the European Columbus laboratory module to the ISS. Not long after that, in April 2008, the first ATV, *Jules Verne,* docked to the ISS in a series of completely automated manoeuvres. In 2009, ESA's Belgian astronaut Frank De Winne became the first European Commander of the ISS during his long-duration OasISS mission, and then Node-3 and Cupola were installed on the ISS in February 2010.

In December, Paolo was launched again as member of Expeditions 26 and 27 on Soyuz TMA-20 for a long-duration mission codenamed MagISStra. On 23 February, he saw the arrival of ESA's second ATV, *Johannes Kepler*, and then on 26 February the final flight of Space Shuttle *Discovery* to the ISS brought with it the Italian-built Leonardo Permanent Multipurpose Module to be used as extra storage space.

MagISStra passes halfway point

Paolo has been in space for over three months, and is now well beyond the halfway point of his mission. He has performed most of the 30 ESA, NASA, JAXA and CSA experiments assigned to him. In particular, he has performed several human physiology experiments on aspects of perception, such as NEUROSPAT and 3D SPACE, and on the effects of specific diets eaten in microgravity conditions, such as SOLO. He has installed the Geoflow-2 experiment container in the Fluid Physics Laboratory, making it ready for operations, and has set up

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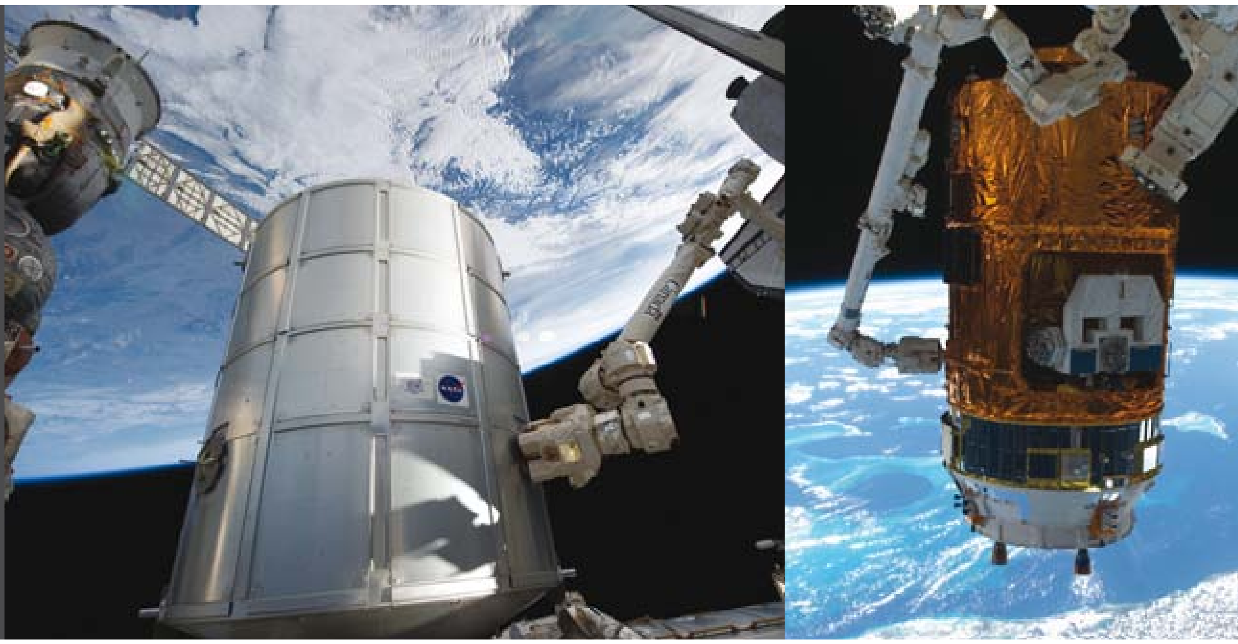
Left to right, the Leonardo Permanent Multipurpose Module installed during STS-133, the Japanese HTV-2 and ESA's ATV *Johannes Kepler* docking with the ISS



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Left, Paolo Nespoli, Expedition 26/27 Flight Engineer (ESA- G. Rigon); right, Roberto Vittori, STS-134 Mission Specialist (J. van Oene)

the *Arabidopsis* seeds of the 'Greenhouse in Space' education experiment, watering them up to their germination.

Paolo monitored the automated rendezvous and docking of the ATV *Johannes Kepler* and has berthed the second Japanese H-II Transfer Vehicle (HTV-2), completing the logistic tasks associated with the management of their payloads. As an ISS Flight Engineer, he has also carried out the system maintenance and repair operations assigned to him. So far, Paolo has also participated in seven In-Flight-Calls with European and Italian media, school children and VIPs representing both institutional and industrial space communities.

→ The Expedition 26 Soyuz TMA-01M capsule landed on 16 March near the town of Arkalyk, Kazakhstan

Paolo has often made available his free time to perform voluntary science activities and has found opportunities to take 3D pictures and make videos on the ISS, in particular with the ESA-developed Erasmus Recording Binocular (ERB-2). He has also taken many beautiful pictures of our planet Earth and shared them with us on social media, such as Flickr and Twitter: Paolo's 'tweets' already have over 35000 followers.

Busy time for ISS

The ISS is nearing completion, and this is coinciding with the approaching retirement of the Space Shuttle fleet. In the first half of 2011, the different Shuttles are making their last visits to the ISS, closing an era of spaceflight. NASA is planning to have a special 'grand-finale' STS-135 mission to the ISS with the Shuttle *Atlantis*, with its lift-off currently planned for July.

The likelihood for this mission to materialise is very high, but the formal decision is still awaited, pending the budget approval from the US Congress. The Shuttle marked the beginning of the European adventure in human spaceflight, and the assembly of the ISS would not have been possible without its versatility and capacity.

Even so, it is still a busy time for the ISS. There have never been so many spacecraft docked with the orbital complex. Japan's HTV-2 freighter began the sequence in January, then Russia's Progress M-09M docked with the ISS on 20 January, then ESA's ATV *Johannes Kepler* and the last visitor was Space Shuttle *Discovery* STS-133.

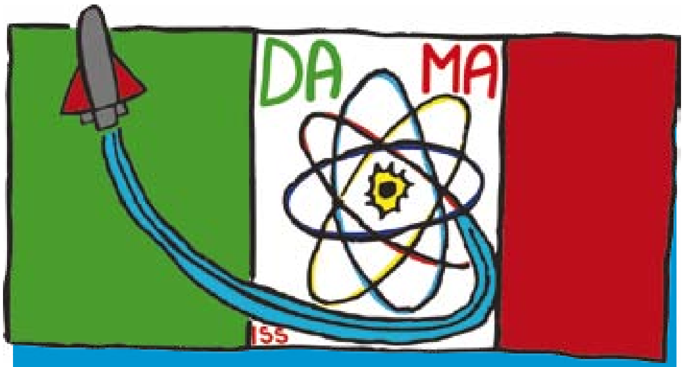
With the change of crew from Expedition 26 to Expedition 27, the command of the ISS was formally handed over by Expedition 26 Commander Scott Kelly to Russian cosmonaut Dmitri Kondratyev during a ceremony on 14 March. Scott Kelly, Soyuz Commander Alexander Kaleri and Russian Flight Engineer Oleg Skripochka left the ISS in their Soyuz TMA-01M capsule on 16 March, landing on Earth in northern Kazakhstan near the town of Arkalyk.

Expedition 27's Paolo, Dmitri Kondratyev and Catherine Coleman welcomed the Expedition 28 crew on 6 April. The newcomers, Russian cosmonauts Alexander Samokutyaev and Andrei Borisenko and NASA flight engineer Ron Garan, will remain on the ISS for about five months.

Another European astronaut on the ISS

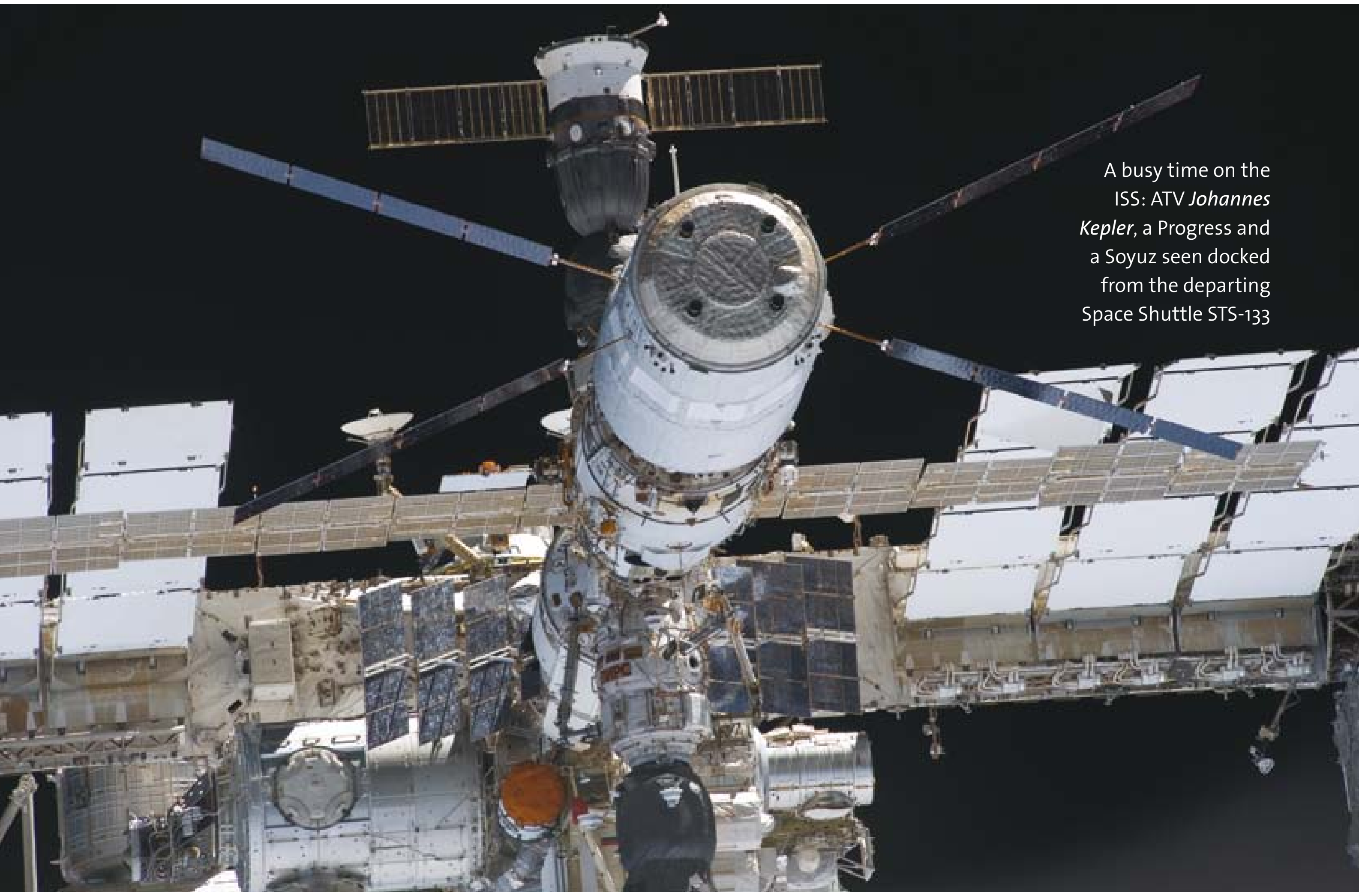
Roberto Vittori has been training for the STS-134 mission at the NASA Johnson Space Center since January 2009**.** Originally planned for July 2010, the mission has been rescheduled several times, but then targeted for launch from Kennedy Space Center at the end of April and then May.

STS-134, the 35th Shuttle flight to the ISS, the 25th and final scheduled flight of the Space Shuttle *Endeavour*, will deliver the massive Alpha Magnetic Spectrometer (AMS-02), a state-of-the-art cosmic ray particle physics detector. Along with the AMS-02, STS-134 will also deliver to the ISS the EXPRESS Logistic Carrier-3 (ELC-3), which is to be berthed to the ISS P3 Truss Common Attach System.

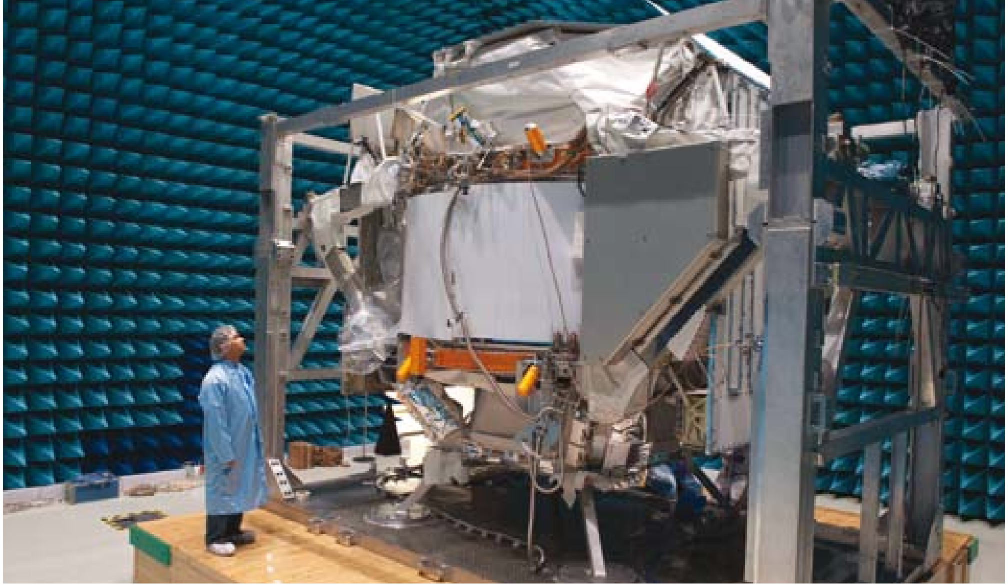


→ Vittori's 'DAMA' mission

Following a competition held in Italian primary and secondary schools, a logo and mission name 'DAMA' were selected as for Roberto Vittori's mission. The name stands for 'DArk MAtter', one of the main scientific goals of the AMS-02 payload. The winners were Alessia Casasanta from Chieti, for the mission name, and Elena Nadalini from Modena, for the logo.



A busy time on the ISS: ATV *Johannes Kepler*, a Progress and a Soyuz seen docked from the departing Space Shuttle STS-133



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The Alpha Magnetic Spectrometer (AMS-02) during testing at ESA's ESTEC Test Centre, Noordwijk, The Netherlands

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AMS-02 will be attached to the ISS on the left end of the Station's central truss

The STS-134 crew are all highly experienced space veterans. Roberto is a test pilot, a Colonel in the Italian air force and a veteran of two space missions. Mark E. Kelly, the Commander, is a Captain in the US Navy and a veteran of three spaceflights, serving as Pilot on STS-108 and STS-121, and Commander on STS-124. His Pilot on this mission is US Air Force Colonel Gregory H. Johnson. The Mission Specialists are: Michael Fincke, Air Force Colonel and veteran of Expeditions 9 and 18; Gregory Chamitoff, PhD in astronautics and veteran of Expeditions 17 and 18; and Andrew J. Feustel, PhD in geology and veteran of STS-125.

The STS-134 mission has a planned duration of 14 days and could be extended by one day. The Shuttle will be docked to the ISS for ten days, during which astronauts Feustel, Fincke and Chamitoff will perform four spacewalks: they will be the last scheduled spacewalks by Space Shuttle crewmembers.

Roberto is the Mission Specialist 2 (MS2) on this Shuttle flight and he will sit just behind and between the Commander and the Pilot on the Shuttle's upper deck. From this seat, he will help them during critical spaceflight operations, in particular the launch and reentry phases, and by operating the system that physically connects the Shuttle with the ISS after the rendezvous and docking.

As MS2, Roberto is also in charge of performing the robotic arm operations. Before docking with the ISS, the crew will perform the routine operation, as on every mission, of verifying that all the tiles of the Shuttle are in place and ensuring their integrity. This of course is a very important and safety-critical operation, which results in a complex sequence of robotic arm operations needed to accurately inspect the underside of the Shuttle.

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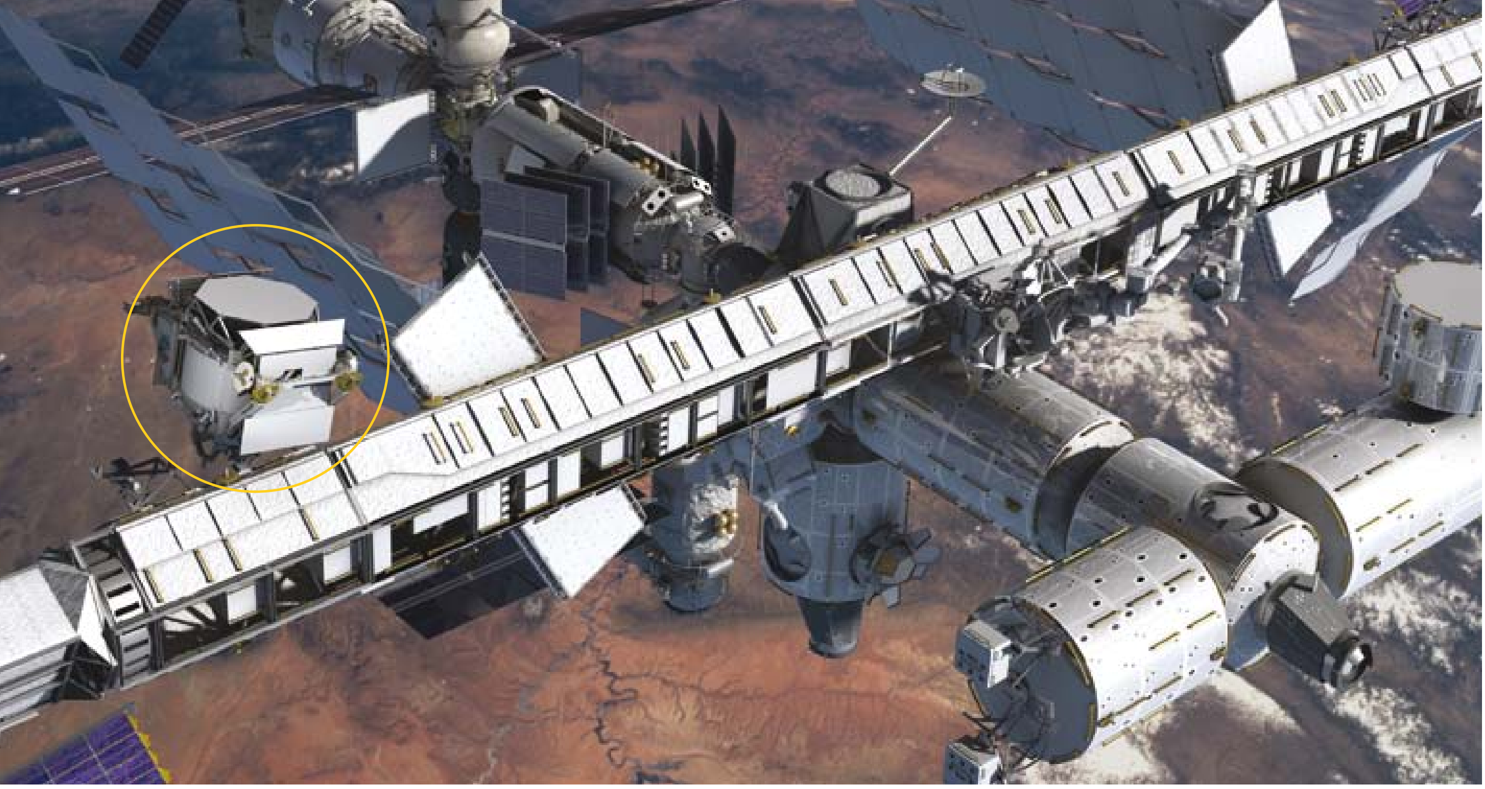
The STS-134 crew: Johnson, Fincke, Chamitoff, Kelly, Feustel and Vittori



By carrying AMS-02, STS-134 is a very relevant mission for science. AMS-02 will study the Universe and its origins by searching for antimatter and dark matter, while performing precision measurements of the composition and flux of cosmic rays. Roberto is responsible for lifting AMS-02 out of the Shuttle *Endeavour's* payload bay and handing it over to STS-134 Pilot, Gregory Johnson, who will mount it onto the upper Payload Attach Point on the S3 Truss. Roberto will also operate the robotic arm for the berthing of ELC-3.

Besides these two large pieces of equipment, the Shuttle is also carrying ISS supplies, crew rotation equipment and ISS utilisation mid-deck payloads in the Shuttle's crew compartment, and it will return a similar amount of mid-deck return items, crew equipment, utilisation payloads and cargo bay hardware.

In addition to these main objectives, the mission also has key technical goals. One of these is to transfer the new cluster of samples from the MISSE 8 Passive Experiment Container from *Endeavour's* cargo bay to the ISS External Logistic Carrier on the Truss, and then to retrieve the already completed MISSE 7a/b elements, transferring them from the ISS back to the Shuttle cargo bay for return to Earth. A very important GLACIER freezer module for one of the Station's science laboratories will also be delivered.

This mission will also bring some spare parts to the Station, including two S-band communications antennas, a high-pressure gas tank and additional spare parts for the Dextre robotic arm and micrometeoroid debris shields. *Endeavour's* crew will leave the Orbiter Boom Sensor System (OBSS) on the ISS to allow the following Shuttle crew to use the inspection boom when they arrive the ISS later this year. During these very hectic ten days, there are many other tasks on the list, such as inspecting and lubricating the ISS Port Solar Array Rotary Joint, performing Orion Relative Navigation Sensor Experiment (DTO-703) and operating the MAUI, RAMBO-2, SIMPLEX and SEITE experiments.

Like every crewmember, Roberto has daily domestic tasks on the Station, as well as being responsible for performing the experimental programme assigned to him by ESA and the Italian space agency ASI. Roberto has six experiments financed by ASI and will also be the test subject for two ESA Baseline Data Collection (BDC) ground experiments.

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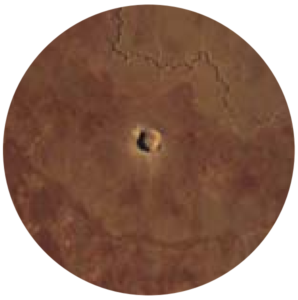
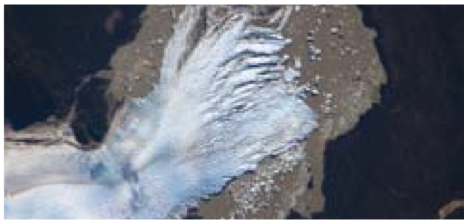
EXPRESS Logistic Carrier-3 (ELC-3)

→ Paolo's Earth gallery





Paolo's pictures of our planet have proved very popular on social media, such as Flickr and Twitter: clockwise, the Grand Canyon, Meteor Crater in Arizona, the Great Pyramids of Egypt, lightning at night, northern Canada, San Quintin Glacier in Chile, and a blue ocean

→ ESA Baseline Data Collection experiments

ZAG (Z-axis Aligned Gravito-inertial force)
Investigating the effects of weightlessness on astronaut's perception of motion and tilt as well as his level of performance before and immediately after spaceflight. Tests will take place before and after the flight, including analysis of the astronaut's motion perception and eye movements while using a track-and-tilt chair.

OTOLITH
Studying the adaptation of human balance system and eyes, which are strongly interconnected, to weightlessness for maintaining astronaut's capacity of carrying out tasks in space. This experiment makes an assessment of otolith function before and after a short-term spaceflight.

↑ Paolo celebrated the 150th anniversary of the unification of Italy on 17 March

Besides their tasks as crewmembers, one special action will characterise Roberto's and Paolo's stay on the ISS. Paolo will bring back to Earth an Italian flag that was handed to Roberto by the Italian President during the recent celebrations to mark the 150th anniversary of the unification of Italy. Paolo and Roberto will return the flag to the President during their post-flight tour.

Roberto is due to leave the Space Station with his STS-134 mission crewmates at the end of May, while Paolo's Expedition 27 crew will return to Earth a few days earlier. Expedition 29 (Sergei Volkov, Mike Fossum and Satoshi Furukawa) will soon fill the gap left on the ISS by the departure of Paolo and his crewmates, when they arrive at the Station in early June. Another ESA astronaut, Dutchman André Kuipers, will fly to ISS at the end of the year as a member of Expedition 30, picking up the baton left behind by Paolo and Roberto.

The sequence of significant European-built elements delivered to the ISS, and the confidence in human spaceflight operations achieved with the uninterrupted presence of at least one ESA astronaut per year on the Station, shows that Europe is already playing its role as a reliable partner in the International Space Station programme.

Based on these achievements, ESA Member States participating in the ISS Exploitation programme decided at ESA's Council meeting in Paris in March to concur with the ISS partners' objective to extend the duration of their involvement in ISS cooperation until the end of 2020 – a fitting new overture to Europe's continuing 'symphony' in space. ■

→ ASI experiments

IAPE (Italian Astronaut Personal Eye)
A demonstrator of a small, autonomous, programmable micro-vehicle for supporting crew 'intravehicular' and 'extravehicular' operations. The micro-vehicle is powered by lithium ion batteries and controlled by a microcontroller receiving inputs from an inertial measuring unit based on gyroscopes. The unit is equipped with a flash memory for datalogging.

NIGHT VISION
Evaluating the antioxidant capacity of macular pigment extracted from plants to protect some light-sensitive algae cells, similar to the human retina, from space radiation. This is to ameliorate night vision in astronauts as well as in aircraft pilots. Wild-type and mutants of C. Reinharditii algae cells will be used and a comparative evaluation will be done after the flight.

IENOS (Italian Electronic Nose for Space exploration)
Air quality monitoring and searching for possible anomalies in the ISS internal atmosphere; retracing the composition of the atmosphere on board and study the cycles of composition linked to human activities on board.

BIOKIS (BIOKON In Space)
A multidisciplinary scientific experiment in which different biological spices as algae, yeast, plant and tardigrades will be evaluated for the genetic alterations following a short spaceflight. Different dosimeters will be inserted as radiation control and experiment (low and high energy dosimeters, diamond dosimeters).

VIABLE ISS
Evaluating and monitoring microbial biofilm development, by measuring the formation and growth of bacterial biofilm on determined materials sent up to the ISS; results will be used for studies on advanced life support, with special regards to long-duration missions in closed environments; due attention will given to preservation of drinkable water from biological contamination.

IFOAM (Italian Foam Shape Memory)
A demonstrator of a process to create 'closed-cell memory foam' (Foaming) and the verification of their shape memory properties in the space environment in view of possible future use as energy absorbers and lightweight space actuators. The on-orbit experiment will consist in the heating of three foaming phase samples prepared on ground, having different shapes, to evaluate their shape recovery capabilities in the space environment.


United States
Atlantis

→ THE SPACE SHUTTLE: A REMARKABLE FLYING MACHINE

A tribute from European astronauts who flew on it

Carl Walker
Communication Department, ESTEC, Noordwijk, The Netherlands

> **Anyone who has put their trust in such a vehicle with their bodies and lives develops some sort of emotional relationship**
>
> Ulf Merbold

↑ Working inside Spacelab on STS-9 in 1983, astronauts Bob Parker, Byron Lichtenberg, Owen Garriott and Ulf Merbold

esa

"This is the world's greatest flying machine, I'll tell you that," proclaimed NASA astronaut John Young, Commander of the first Space Shuttle flight, when its wheels stopped after landing on 14 April, 30 years ago.

Because of its age, cost of operations and a new mission for NASA to explore beyond Earth orbit, the Space Shuttle will retire this year, just after its 30th anniversary. "In 135 missions, with two catastrophic failures, the US Space Shuttle proved itself a vehicle filled with contradictions and inconsistencies," says Roger Launius, former Chief Historian for NASA, now Senior Curator at the Smithsonian Air and Space Museum.

"It demonstrated on many occasions remarkable capabilities, but always the cost and complexity of flying the world's first reusable space transportation system ensured controversy and difference of opinion."

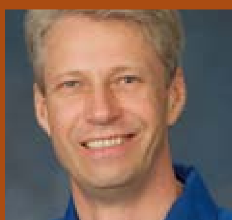
Flying on the Space Shuttle *Columbia* in November 1983, Dr Ulf Merbold became the first non-US citizen and first ESA astronaut to reach orbit in a US spacecraft. As with anyone who has flown on the Shuttle, Merbold feels sad that the programme will come to an end. "Anyone who has put their trust in such a vehicle with their bodies and lives develops some sort of emotional relationship," says Merbold.

"If you returned with the spectacular experience of viewing your home planet from a distance, and on top of that you completed the mission properly and came back with good scientific data, there is a feeling of satisfaction and happiness, and part of this is with the machine".

"From a more rational point of view, it's also sad because for some time we won't have a comparable transportation system to go to the ISS, allowing us to bring back materials and so on. The Russian Soyuz capsule, which I know very well and I like very much because it's very robust, doesn't have the same download capability."

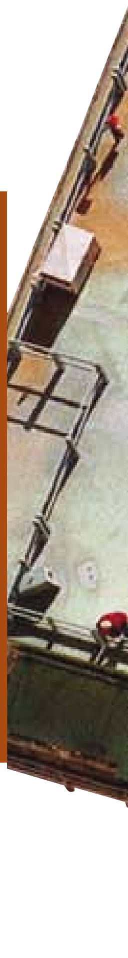
Merbold flew on the STS-9 mission that carried the first Spacelab, a reusable laboratory module developed and built in Europe. He flew again on the Spacelab IML-1 mission of STS-42 in January 1992. The following year he was the science coordinator for the second German Spacelab mission, D2 (STS-55).

↓ Astronauts Owen Garriott and Ulf Merbold brief Vice President George Bush inside Spacelab at the Operations and Checkout Building, Kennedy Space Center, in 1982



Thomas Reiter

"The Space Shuttle – one of the first reusable space vehicles – will soon be part of space history. Its size and capability to transport humans and cargo to and from space has not been exceeded. It will remain clear in the hearts of all astronauts, and all those who are maintaining a vision for future human spaceflight, as a source of inspiration. This alone would have justified its existence. And I have no doubt that its legacy will be revived in future developments."



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Space Shuttle *Discovery* on its crawler transporter before the launch of STS-96 in 1999

Ernst Messerschmid

"The Shuttle is still the most advanced machine we have to bring astronauts together with large infrastructure elements and experiments into space. However, having worked on crew safety and reliability after the *Challenger* accident and knowing that the risk associated with flying on the Shuttle is a 1% chance of not surviving a mission, this risk is not acceptable today to fly routinely to low Earth orbit. I understand the reasons for ending flights, and that it will take time to replace the Shuttle's capabilities and achieve a higher level of confidence, even with new technologies. But accepting no risks at all is the highest risk today. The flame of adventure is flickering as we become averse to taking chances. Furthermore, in drafting spaceflight programmes today, we tend to be very utilitarian, and we often forget why we started human spaceflight. The earlier pioneers of space were driven by cultural influences, by politics, but mainly they were interested in science and technology; they wanted to explore, discover and understand what surrounds us."

However, Europe's involvement in Spacelab and Space Shuttle activities dates back even earlier, to 1969, when NASA invited ESRO, ESA's predecessor organisation, to participate in its Post-Apollo Programme. Spacelab was the result of negotiations in which contributions to the Space Shuttle programme and elements of space stations were discussed. In December 1972, Europe opted to develop Spacelab as an integral element of the US Space Transportation System in which scientific missions of up to nine days could be conducted. The signing of the Memorandum of Understanding between Europe and NASA for the implementation of the Spacelab programme took place on 24 September 1973.

The laboratory's initial design was as a 'Sortie Can' to be carried into orbit in the Space Shuttle's cargo bay. Its original 'free-flying' mode was later abandoned, and so it became 'Spacelab'. Unlike Skylab, the first US space station, which had been built mostly from existing Apollo hardware, Spacelab was a new construction offering a much wider range of applications.

Merbold's flight on STS-9 marked the beginning of an extensive ESA/NASA partnership that included dozens of flights of ESA astronauts in the following years. Spacelab turned out to be one of the most important and most frequently flown Shuttle payload systems to date, with some missions funded and

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Signature of the Spacelab Memorandum of Understanding between ESRO and NASA in Washington DC, on 24 September 1973. The Memorandum was signed by Alexander Hocker, Director General of ESRO, and James Fletcher, NASA Administrator. Also present were Roy Gibson, then ESRO Director of Adminstration, Charles Hanin and Professor M. Levy

Christer Fuglesang

"This is certainly nostalgic. We've just seen *Discovery* land for the final time, and it was *Discovery* on which I flew twice. I'm a bit sad but on the other hand, it's a necessity, because we need to free up money for future endeavours. Although it has also proven to be not the safest space vehicle, it still is a fabulous machine, one of the most complicated vehicles ever built, but it is not inherently as robust as Soyuz for example. One of the things that you notice most about the Shuttle is its big windows. When you orbit around Earth, you fly upside down so the windows are pointing down and you get very good views. I got much better views from the Shuttle than I got from the ISS, until the day Cupola finally got there! I don't think anybody can see a Shuttle launch without being touched by the power and the beauty of the sight and sound, and knowing there are people on board. I think that touches everyone."

← Press conference to announce the selection of ESA's first astronauts in December 1977, from left: Claude Nicollier, Ulf Merbold, Roy Gibson (ESA Director General), Michel Bignier (ESA Director of the Spacelab Programme), Wubbo Ockels and Franco Malerba

operated by other countries, such as Germany and Japan. When Spacelab flights stopped in 1998, full Spacelab modules had flown 16 times and Spacelab pallet-only missions had flown six times. With their NASA crewmates, nine Europeans had worked inside Spacelab while in space.

Merbold had been selected in 1978, along with Wubbo Ockels and Claude Nicollier, to train as payload specialists for the first Spacelab flights, but as he recalls, it wasn't always easy. "Being the first non-American in the US space programme was really something special. When we started training for Spacelab 1 in Huntsville, we received a warm welcome. During our two years in training, people were really eager and happy to see us. They made sure everything was more than perfect," says Merbold.

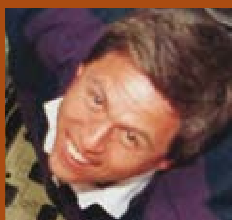
"But in Houston you could feel that not everyone was happy that Europe was involved. Some also resented the new concept of the payload specialist 'astronaut scientist', who was not under their control like the pilots. We were perceived to be intruders in an area that was reserved for 'real' astronauts. A couple of small things made us realise that Johnson Space Center management was suspicious. Now, of course, all this has changed. I think we broke the ice and all our colleagues who came after us had much easier lives."

Indeed, many things have changed since then. Of the 528 people who have flown into space from 35 countries, 355 people from 16 countries will have flown on the Shuttle – and 24 of them were Europeans.

German astronaut Ulrich Walter recalls Shuttle training only a few years after Merbold, "I remember it was very hard (we trained for five years including the basic training), but nevertheless it was worthwhile and I would do it again immediately! Yes, I would go again, and not only on a research mission but also any mission to the ISS or wherever."

"I always appreciated the very good cooperation with the ground teams because they gave everything in order to have their 'baby' fly in good shape. The ground teams are always highly motivated people and it was really fun working with them," remembers Walter.

Today's astronauts have to train to work on the ISS, which involves modules and systems from each of five partner agencies from USA, Russia, Canada, Japan and ESA. You are now more likely to find American astronauts training in Moscow, European astronauts training in Tsukuba, Japan, or Russian cosmonauts at the European Astronaut Centre in Cologne, Germany.



Ulrich Walter

"On one hand I'm sad about the end of the Shuttle flights, because I think it's a good Shuttle, but on the other I understand that we don't actually need the Shuttle anymore. It was used to build the ISS, but we don't need it to support the ISS. However, there will be no US manned space vehicles for about 5–6 years and this is a big loss. Because only the Russian Soyuz will fly to the ISS there will be a lull, but I hope that after this lull we will go to the Moon and do other things. For unmanned spaceflight, this is a totally different story with great scientific missions coming up. But the public doesn't view these the same way, so all spacefaring nations should rethink whether to do more manned spaceflight because this is where most of the general public interest lies."

The launch plume left behind *Atlantis* on STS-98 in 2001 casts a shadow on hazy sky that appears to point to the Moon low on the horizon

Michel Tognini

"It was a wonderful project but it was expensive to keep the Shuttle in order to maintain the ISS and to also start new exploration programmes. This is very sad and people will miss the Space Shuttle afterwards for many years. It was just beautiful, something to witness, and great achievement of humankind to build this Space Shuttle and make it fly. Even just the look of the Shuttle, with its black and white lines, and all the individually numbered heat shield tiles, it's an amazing machine."

> **The Space Shuttle is a wonderful 'bird', a special vehicle capable of doing so many different things**
>
> Michel Tognini

For all its shortcomings, the Shuttle is still one of the most complex and yet capable space vehicles ever built. It remains the only vehicle in the world with the dual capability to deliver and return large payloads to and from orbit. The design, now more than three decades old, is still state-of-the-art in many respects: computerised flight controls, airframe design, electrical power systems, thermal protection system and main engines. At the same time, it is extremely expensive to fly and has been unable to deliver its original promise of routine access to space.

Michel Tognini, Head of the European Astronaut Centre and Mission Specialist on STS-93, said, "The Space Shuttle is a wonderful 'bird', a remarkable flying machine with a diversity of uses. Soyuz is limited in the orbit inclinations it can fly, but the Shuttle could fly to any inclination needed, to deliver any type of payload and to do any type of repair, to grab satellites, for example the Hubble Space Telescope. It was a special vehicle capable of doing so many different things."

Gerhard Thiele, Mission Specialist on STS-99, said: "I think the missions that stand out the most to me, as a physicist, are those to the Hubble Space Telescope. That doesn't diminish the other missions, such as life sciences missions, or Earth observation missions such as the one that I had the privilege to fly on, but when people look back in many years I think the contributions to Hubble or Chandra will stand out."

Gerhard Thiele

"It's always sad when something so important, accomplishing so many goals, is leaving for good. But this is a farewell with gratefulness, for all the achievements, and for the small role that I had to play in part in this entire system. There are two ways to look back at the Shuttle programme. One is from the technical or engineering point of view, but having flown on the Shuttle there is definitely an emotional aspect as well. That leads to a question: was the Shuttle the right thing to do at the time, was it right to build it and fly it into space? I mean does it make sense to send a 100-tonne vehicle into space just to launch a 20-tonne payload? It might be too early to say today what the Shuttle has meant as a vehicle or a tool, either it was well ahead of its time or it was a necessary detour on our way to develop the proper vehicles to go into space."

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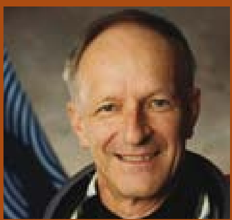
NASA astronaut Michael Foale assists ESA's Claude Nicollier (right) during the second of three STS-103 spacewalks to service the Hubble Space Telescope in 1999



Claude Nicollier

"I had the privilege, as an ESA astronaut of the first group (1978), to be sent to Houston two years after selection, and to spend there 35 of the 39 years I was employed by ESA. My time at the Johnson Space Center covered most of the operational period of the Space Shuttle, from STS-1 to STS-114, the first flight after the *Columbia* accident. I always felt intimately involved with the Shuttle programme, not only in terms of the four spaceflights I had the privilege to accomplish, which all were Shuttle flights, but also, and at least as much, through the various job assignments I got before my first flight, and then between spaceflights. I finally only spent 43 days on orbit, and a total of about five years in mission-specific training, out of the 35 years in Houston! All the rest of the time was mainly spent in Shuttle-related job assignments. These were really interesting, and I learned so much about this very remarkable spacecraft through these, and at least as much as during formal training! Some of these jobs were in the Shuttle Avionics Integration Laboratory (SAIL), a Shuttle flight software verification laboratory, and also within the Robotics and EVA Branches of the Astronaut Office in Houston. I was really happy, in this way, to be able to contribute, even in a very modest manner, to this programme, and I also developed, through this activity, an enormous respect for the men and women who had designed, built and were operating this amazing machine!"

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Ground crews begin towing Space Shuttle Atlantis after landing at Edwards Air Force Base on 24 May 2009, concluding the STS-125 mission to service the Hubble Space Telescope

> **I shall be proud to tell my grandchildren, 'I was there', hoping to inspire in them a taste for adventure**
>
> Jean-François Clervoy

French astronaut Jean-François Clervoy has flown three times on the Shuttle. His third mission, STS-103, was to repair the Hubble Space Telescope. "On this flight we were carrying responsibility for the careers of hundreds of scientists whose entire working lives were devoted to analysing the data transmitted by this telescope, still unequalled for the quality of its visible light images of distant parts of the Universe. The discoveries from Hubble are seen as significant today as were the observations of Galileo in their day," explained Clervoy.

"On our return, the Space Telescope Science Institute, which manages the use of the HST, presented us with the spectacular results of our rescue mission, making us feel that we had performed a really significant service to science. I shall be proud to tell my grandchildren, 'I was there', hoping to inspire in them a taste for adventure," said Clervoy.

Looking back at the achievements of the Space Shuttle, there are so many that it is very hard to select just a few highlights. The construction flights to the ISS and the Hubble Servicing Missions have captured the public imagination, but there have been other less well-known but equally impressive missions.

For example, Jean-François Clervoy's first mission, STS-66, studied the atmosphere and the Sun, with the results giving a better understanding of ozone depletion and atmospheric warming. "During my work shift, I flew each day over the Americas, Europe, Africa, the Middle East and the whole of Asia, in beautiful sunny conditions without any cloud interference. I brought back more than 8000 photographs, with the most wonderful views of Earth from space: the Great Barrier Reef, Khamchatka, New York, the Carribean, the Alps, the Nile and the pyramids, Mount Everest and many other views that will stay in my memory for ever," said Clervoy.

Jean-François Clervoy

"As we prepare for the final spaceflights in 2011, I feel really lucky, proud and honoured to have been part of this programme. For me, the Shuttle will remain the most remarkable machine invented by humans. It does it all: it launches like a rocket; it orbits like a laboratory for research, a workshop for satellite repairs, or an outpost for exploration and spacewalks; it flies like a glider for reentry and lands on wheels like an aircraft. I have loved my spaceship because she was my ultimate life protection against such a hostile and extreme environment. She took care of my crewmates and me, allowing us to admire our planet Earth like no other spaceships had done before. I'll remember most the fantastic view through the windows of the flight deck. But I'll remember also the feeling of gigantic power at liftoff, and the smooth atmospheric entry surrounded by the flashing orange plasma. The last time I 'kicked' the tyres of the Shuttle was in 2001, when her first Commander John Young invited me to join him for a T-38 flight to the Cape just to see her and meet the ground team readying her for the next flight. I feel I've been part of a legend, and the experience has been so intense that I'll have a hard time to believe that I have truly lived all these emotions for real. Thanks John, thanks *Atlantis*, thanks *Discovery*."

But his next mission, STS-84, was even more dramatic: carrying vital supplies to the aging Russian Mir space station. The Shuttle took experiments and food for an American member of their crew, who was to spend four months in Mir, and then had to return to Earth with a crewmember who had finished his tour of duty. "We had forged close links with the Mir crew during joint training in Russia, and felt responsible for their safety," said Clervoy.

"The success of their mission depended on our arrival. We brought, among other equipment, a generator that produced oxygen from urine, so economising on the few remaining chemical cartridges that they had on board. We knew how they felt after already three months of isolation. Opening the hatchway after our two craft had docked was a truly emotional experience, as were the international meals that we enjoyed together on Mir and the moment when we separated from them again," remembers Clervoy.

Michel Tognini looks to the future, "Now that the Shuttle is ending, we have to think differently. Time has moved on,

> **I know *Endeavour* is scheduled for its last flight, and it seems strange to me because when you see the spacecraft close up, it looks brand new. I know it's over 20 years old, but it seems still in perfect shape**
>
> Roberto Vittori

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STS-134 Mission Specialist, ESA's Roberto Vittori

we can't stay all our lives in low Earth orbit and we have to go further. Looking at the future exploration of the Moon and Mars, we won't go there with Space Shuttles, but with capsules. However, reentry from space as a plane is still something magnificent which has to be studied, and the Space Shuttle gave us valuable 'lessons learned' on every flight. I'm sure people would have loved to fly on the Shuttle, but maybe they will have the chance on a new Space Shuttle built with new technology, materials and computers, which might be ready within ten years."

The last word should go to the last ESA astronaut and non-US citizen to fly on the Space Shuttle, Roberto Vittori. Flying on STS-134, the penultimate flight, he views the end of the Shuttle programme in a different way and agrees with Tognini about the possibilities for new winged vehicles. "I've flown in space twice before on Soyuz, but its my first flight on the Shuttle, so that's the way I look at it. I know *Endeavour* is scheduled for its last flight, and it seems strange to me because when you see the spacecraft close up, it looks brand new. I know it's over 20 years old, but it seems still in perfect shape," said Vittori.

"The Shuttles are just the first examples of future hypersonic machines so, although we expected to retire them, the question is not 'if', but 'when' there will be a new vehicle similar to the Shuttle. From a pilot's standpoint, one of the most interesting areas for me is hypersonic flight and the Shuttle is the only vehicle capable of flying in this region. So I don't think of the 'last Shuttle flight', I see the Shuttle as a prototype of transport for future generations. As a test pilot, it will be very exciting to be part of expanding this hypersonic experience." ■

→ EUROPEAN SHUTTLE ASTRONAUTS

STS-9 1983 **STS-42** 1992

Ulf Merbold

STS-51G 1985 (CNES)

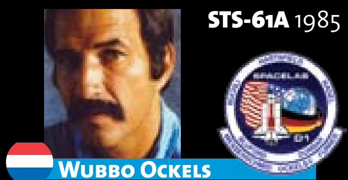
Patrick Baudry

STS-61A 1985 (DLR)

Reinhard Furrer

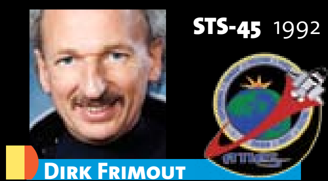
STS-61A 1985 (DLR)

Ernest Messerschmid



STS-61A 1985

Wubbo Ockels

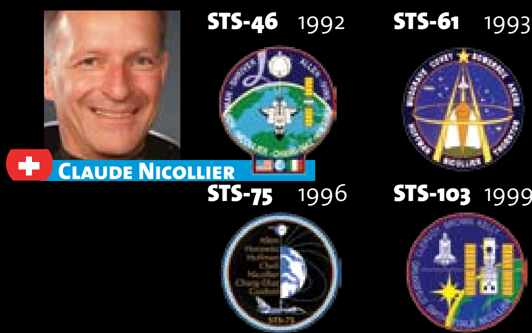


STS-45 1992

Dirk Frimout

STS-46 1992 (ASI)

Franco Malerba



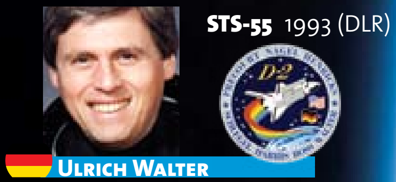
STS-46 1992 **STS-61** 1993

Claude Nicollier

STS-75 1996 **STS-103** 1999

STS-55 1993 (DLR) **STS-122** 2008

Hans Schlegel



STS-55 1993 (DLR)

Ulrich Walter

STS-66 1994 **STS-84** 1997

Jean-François Clervoy

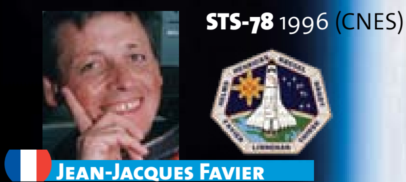
STS-103 1999

STS-75 1996 (ASI)

Maurizio Cheli

STS-75 1996 (ASI) **STS-100** 2001 (ASI)

Umberto Guidoni



STS-78 1996 (CNES)

Jean-Jacques Favier

STS-86 1997 (CNES)

Jean-Loup Chrétien

STS-95 1998

Pedro Duque

STS-93 1999 (CNES)

Michel Tognini

STS-99 2000 (DLR)

Gerhard Thiele

STS-111 2002 (CNES)

Philippe Perrin

STS-121 2006

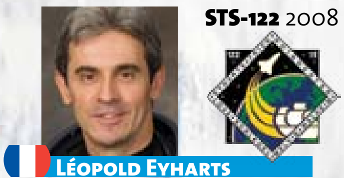
Thomas Reiter

STS-116 2006 **STS-128** 2009

Christer Fuglesang

STS-120 2007

Paolo Nespoli



STS-122 2008

Léopold Eyharts

STS-134 2011 (ASI)

Roberto Vittori

→ NEWS IN BRIEF

Ceraunius Tholus and Uranius Tholus are two volcanoes in the Tharsis region of Mars. Ceraunius (left) is 130 km across and 5.5 km high, Uranius is of 62 km and 4.5 km high. Long after volcanic activity ceased, the area was transformed by meteor impacts that deposited ejected material over the lower flanks of the volcanoes (ESA/DLR/FU Berlin)

Walking on 'Mars'

Three crewmembers of the Mars500 virtual mission to Mars 'landed' on their destination planet, and two took their first steps on the simulated martian terrain In February.

Three of the crew, Russian Alexander Smoleyevski, Italian Diego Urbina and Chinese Wang Yue, entered their lander on 8 February and 'landed' on Mars four days later. Their martian surface is housed just above the cylindrical modules housing the Mars500 crew in the Institute of Biomedical Problems in Moscow, where they have already been isolated for more than eight months during the first full-duration simulated flight to Mars.

After the first sortie, lasting for one hour and 12 minutes, they ventured out twice more onto the surface simulator wearing Russian Orlan spacesuits. "Europe has for centuries explored Earth, led by people like Columbus and Magellan," said Diego at the beginning of his three-hour 'marswalk' with Alexander. "Today, looking at this red landscape, I can feel how inspiring it will be to look through the eyes of the first human to step foot on Mars. I salute all the explorers of tomorrow and wish them godspeed."

The next sortie, by Alexander and Yue, followed on 18 February, and the last, again by Alexander and Diego, was made on 22 February. The three marswalkers lived in their six metre square lander for 16 days, eating the type of food carried on Russia's Soyuz spacecraft and enjoying only limited exercise.

The lander 'returned to orbit' on 23 February and docked with the mothership the next day. The hatch between the modules was opened on 27 February for them to rejoin Romain Charles, Alexei Sitev and Sukhrob Kamolov, who continued to 'orbit' Mars.

The most difficult but the most interesting part of this psychological study of long flights is still ahead: the crew is now faced with another monotonous 'interplanetary cruise' without a highlight like the Mars landing to look forward to. They started their eight-month journey back home on 1 March, after loading the lander with rubbish and discarding it, as would likely happen during the first real Mars flight.

Children finish their mission

A new class of fit explorers is now ready for further adventures and exploration of the fascinating world of space – and being healthy.

After eight weeks of exercises and classroom activities, 4000 children from more than 25 cities worldwide concluded their 'Mission X: Train Like an Astronaut' challenge that promotes healthy nutrition and regular exercise.

Acrobatic space somersaults and climbing martian mountains werer just some of the fun activities – inspired by astronaut training – performed by children and teachers from Austria, Belgium, Colombia, Czech Republic, France, Germany, Italy, Japan, the Netherlands, Spain, United Kingdom and the USA. This has helped pupils aged 8–12 years to understand the

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Diego Urbina and Alexandr Smoleyevski in their spacesuits before the Mars EVA

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The prize-winning schools from the Netherlands attended an event at Space Expo, Noordwijk

importance of staying fit for astronauts and children alike, in space as on Earth.

To conclude the challenge, each country organised a ceremony for their explorer teams. They had the opportunity to be in contact with ESA astronaut Paolo Nespoli, the ambassador of the Mission X programme currently living on the ISS. Several other serving and former astronauts from Europe, USA and Japan have contributed to the programme with their personal experiences and encouraging messages to the children.

Parmitano assigned to 2013 mission

ESA astronaut Luca Parmitano has been assigned to fly on the International Space Station from May to November 2013, serving as a Flight Engineer for Expeditions 36 and 37.

Recently qualified as a European astronaut, Luca will head into orbit on the Soyuz TMA-09M spacecraft and will work on the ISS for over six months as part of a six-strong international crew. This will be his first spaceflight and the fifth long-duration mission for an ESA astronaut.

From May to September 2013, Luca will accompany cosmonaut Maxim Surayev and NASA astronaut Karen Nyberg to the ISS, joining Pavel Vinogradov, Alexander Misurkin and Christopher Cassidy. From September to November 2013, cosmonauts Oleg Kotov and Sergei Ryazansky, with NASA astronaut Michael Hopkins replace the Expedition 35 crew.

NASA announced the crewmembers to fly to the ISS for Expeditions 36 to 39, and Luca was proposed by the Italian space agency ASI for this mission on a flight opportunity provided by ASI in agreement with NASA.

Aged 34 and a Captain in the Italian air force, Luca has logged more than 2000 hours of flying time, is qualified on more than 20 types of military aircraft. He will be the fourth Italian citizen to fly to the ISS.

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Luca Parmitano, Expedition 36/37 Flight Engineer

Soyuz launch site ready

The Soyuz site at Europe's Spaceport in French Guiana is now ready for its first launch. ESA handed over the complex to Arianespace on 31 March, marking a major step towards this year's inaugural flight.

Construction of the Soyuz site began in February 2007, although initial excavation and ground infrastructure work began in 2005 and 2006 respectively. Russian staff arrived in French Guiana in mid-2008 to assemble the launch table, mobile gantry, fuelling systems and test benches.

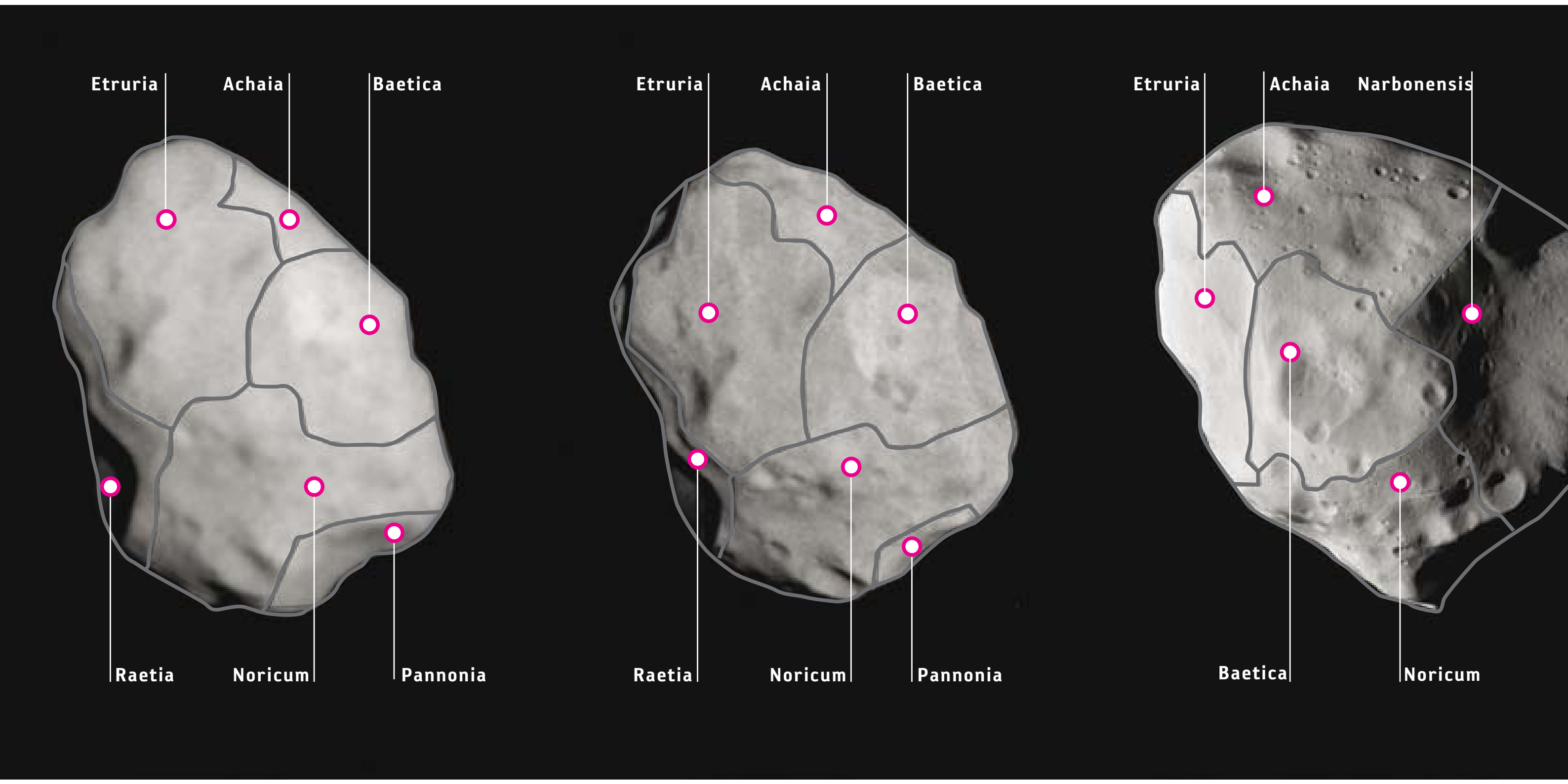
The first two Soyuz launchers arrived from Russia by sea in November 2009 to be assembled in the new preparation and integration building. The French space agency CNES, as prime contractor for the building work, along with its European and Russian partners, has spent recent months qualifying the site – known as the Ensemble de Lancement Soyuz.

The tests covered all the mechanical, fluid and electrical elements, such as the pad's umbilical arms and fuelling vehicles, and all the buildings, including the launch control centre that will house the combined European and Russian teams.

This 'acceptance review' declared that the site was ready for its first rocket, and CNES handed over the facilities to ESA and then Arianespace. From now on, Arianespace is responsible for the Soyuz launch site and is beginning the campaign to qualify its launch operations. A launch rehearsal will ensure that the Soyuz and the new facilities work together, while allowing the teams to train under realistic launch conditions.

This simulated launch campaign will include the vehicle's transfer to the launch zone, its erection into the vertical position, its installation on the pad and the testing of ground and launcher interfaces. These final tests will give the green light for the first Soyuz flight from French Guiana later in 2011.

Asteroid regions named

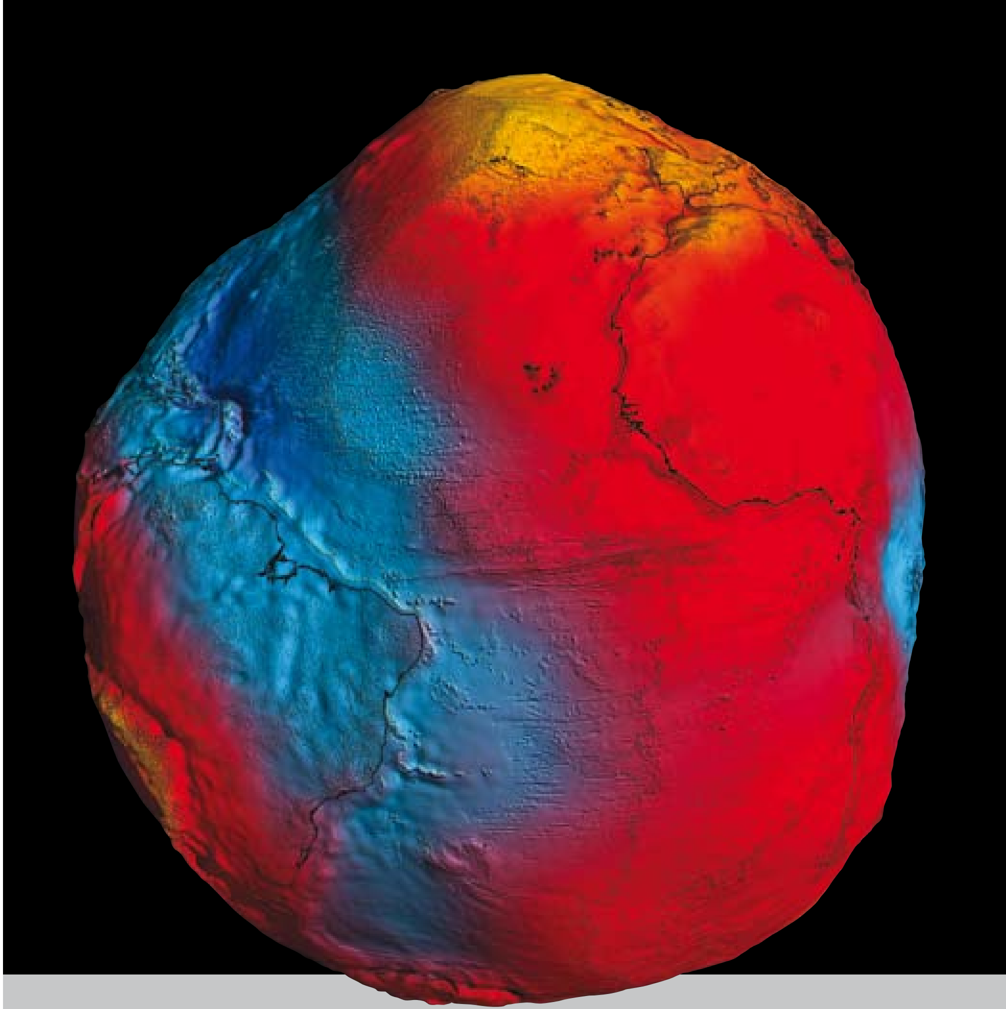


↑ Soyuz launcher in simulated launch campaign

Based on images from the Rosetta flyby of asteroid (21) Lutetia, the scientifically most relevant surface features have received official names by the International Astronomical Union (IAU).

In the first round, a total of 18 craters, one 'dorsum', two 'fossae', three 'labes', eight regions, two 'rimae' and two 'rupes' were named. The asteroid surface was divided into eight regions (the one not visible to Rosetta during the flyby was named 'Goldschmidt Regio' after the discoverer of the asteroid). The IAU Naming Committee agreed that the names of all surface features on Lutetia should be chosen from three categories all related to the time when the town of Lutetia existed. Craters are named after cities, regions after provinces of the Roman Empire, and other features after rivers at the time of Lutetia (52 BC to 360 AD).

← Regions of asteroid Lutetia named after provinces of the Roman Empire



GOCE delivers on its promise

After just two years in orbit, ESA's GOCE satellite has gathered enough data to map Earth's gravity with unrivalled precision. Scientists now have access to the most accurate model of the 'geoid' ever produced to further our understanding of how Earth works.

The new 'geoid' was unveiled in March when scientists from around the world were treated to the best view yet of global gravity. The geoid is the surface of an ideal global ocean in the absence of tides and currents, shaped only by gravity. It is a crucial reference for measuring ocean circulation, sea-level change and ice dynamics – all affected by climate change.

The GOCE geoid will make advances in ocean and climate studies, and improve our understanding of Earth's internal structure. For example, the gravity data from GOCE are helping to develop a deeper knowledge of the processes that cause earthquakes, such as the event that recently devastated Japan.

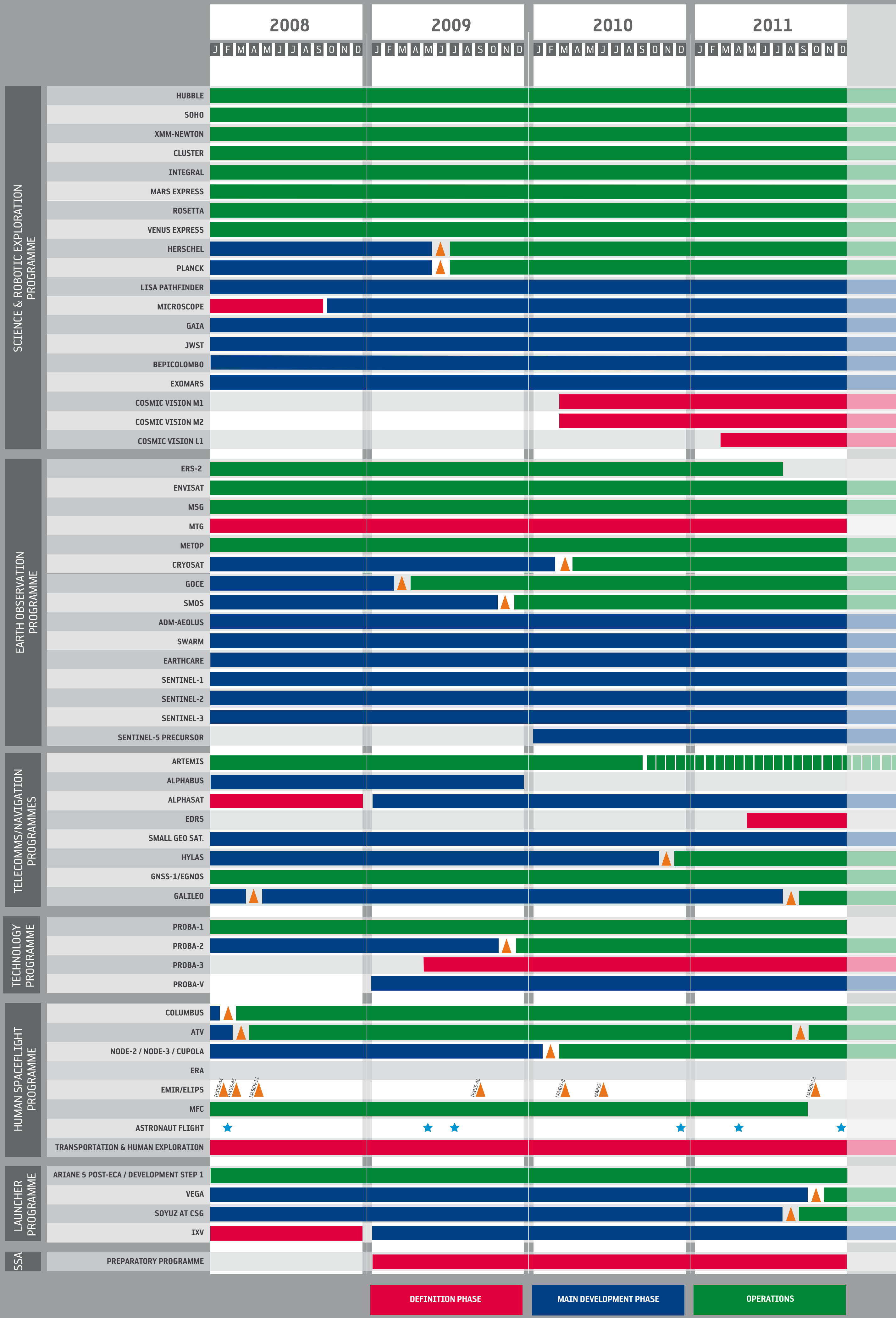
Because this earthquake was caused by tectonic plate movement under the ocean, the motion could not be observed directly from space. However, earthquakes create signatures in gravity data, which could be used to understand the processes leading to these natural disasters and ultimately help to predict them.

The GOCE satellite was launched in March 2009 and has now collected more than 12-months of gravity data. Although GOCE has completed its planned mission, the low solar activity during the last two years led to lower fuel consumption than expected.

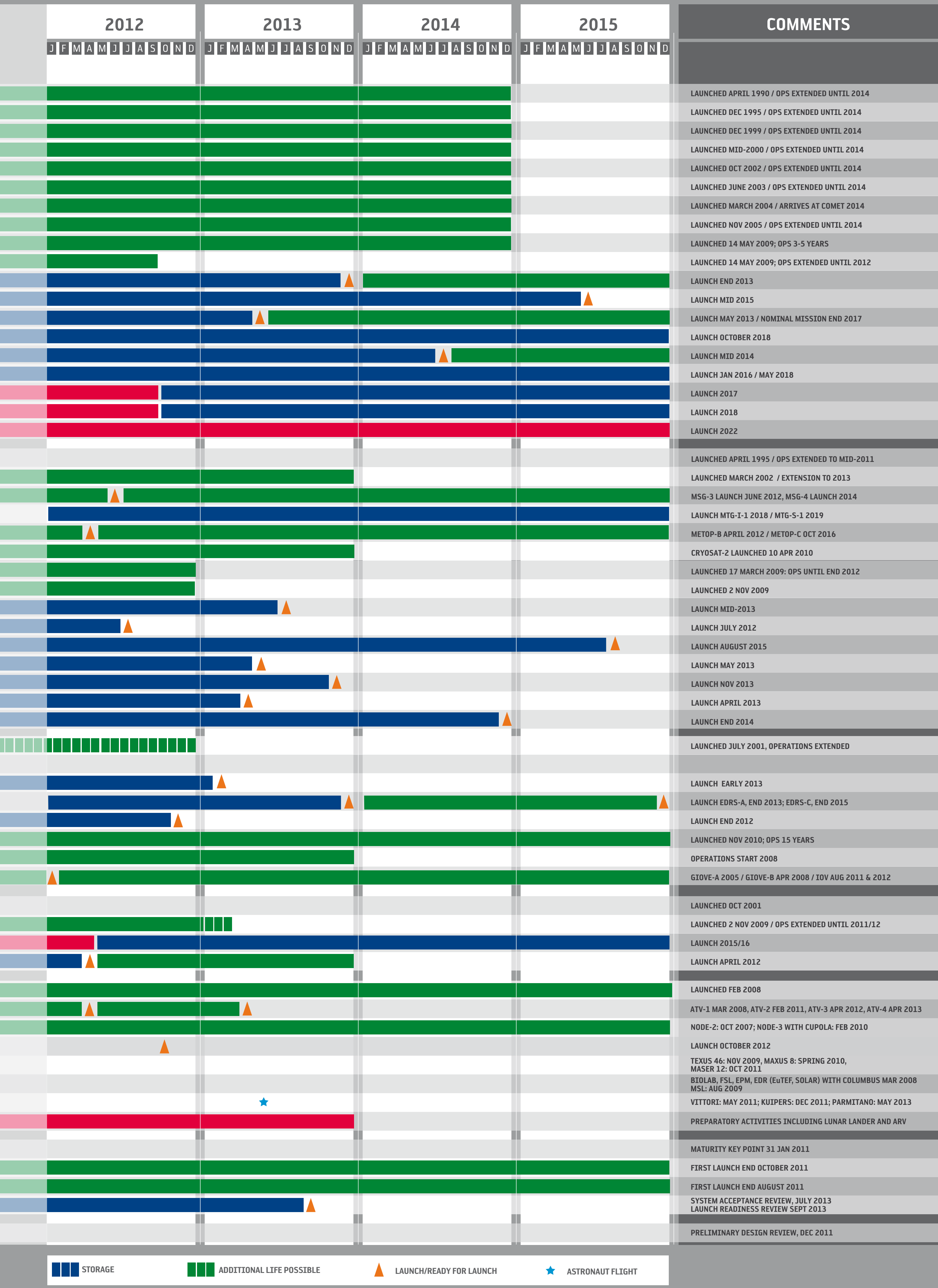
Volker Liebig, Director of ESA's Earth Observation Programmes said, "GOCE has been able to stay in low orbit and achieve coverage six weeks ahead of schedule. This also means that we still have fuel to continue measuring gravity until the end of 2012, thereby doubling the life of the mission and adding even more precision to the GOCE geoid."

→ PROGRAMMES IN PROGRESS

Status at end April 2011



2008
2009
2010
2011
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
SCIENCE & ROBOTIC EXPLORATION PROGRAMME
HUBBLE
SOHO
XMM-NEWTON
CLUSTER
INTEGRAL
MARS EXPRESS
ROSETTA
VENUS EXPRESS
HERSCHEL
PLANCK
LISA PATHFINDER
MICROSCOPE
GAIA
JWST
BEPICOLOMBO
EXOMARS
COSMIC VISION M1
COSMIC VISION M2
COSMIC VISION L1
EARTH OBSERVATION PROGRAMME
ERS-2
ENVISAT
MSG
MTG
METOP
CRYOSAT
GOCE
SMOS
ADM-AEOLUS
SWARM
EARTHCARE
SENTINEL-1
SENTINEL-2
SENTINEL-3
SENTINEL-5 PRECURSOR
TELECOMMS/NAVIGATION PROGRAMMES
ARTEMIS
ALPHABUS
ALPHASAT
EDRS
SMALL GEO SAT.
HYLAS
GNSS-1/EGNOS
GALILEO
TECHNOLOGY PROGRAMME
PROBA-1
PROBA-2
PROBA-3
PROBA-V
HUMAN SPACEFLIGHT PROGRAMME
COLUMBUS
ATV
NODE-2 / NODE-3 / CUPOLA
ERA
EMIR/ELIPS
TEXUS-44
TEXUS-45
MASER-11
TEXUS-46
MAXUS-8
MARES
MASER-12
MFC
ASTRONAUT FLIGHT
TRANSPORTATION & HUMAN EXPLORATION
LAUNCHER PROGRAMME
ARIANE 5 POST-ECA / DEVELOPMENT STEP 1
VEGA
SOYUZ AT CSG
IXV
SSA
PREPARATORY PROGRAMME
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
OPERATIONS


2012
2013
2014
2015
J F M A M J J A S O N D
COMMENTS
LAUNCHED APRIL 1990 / OPS EXTENDED UNTIL 2014
LAUNCHED DEC 1995 / OPS EXTENDED UNTIL 2014
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 3-5 YEARS
LAUNCHED 14 MAY 2009; OPS EXTENDED UNTIL 2012
LAUNCH END 2013
LAUNCH MID 2015
LAUNCH MAY 2013 / NOMINAL MISSION END 2017
LAUNCH OCTOBER 2018
LAUNCH MID 2014
LAUNCH JAN 2016 / MAY 2018
LAUNCH 2017
LAUNCH 2018
LAUNCH 2022
LAUNCHED APRIL 1995 / OPS EXTENDED TO MID-2011
LAUNCHED MARCH 2002 / EXTENSION TO 2013
MSG-3 LAUNCH JUNE 2012, MSG-4 LAUNCH 2014
LAUNCH MTG-I-1 2018 / MTG-S-1 2019
METOP-B APRIL 2012 / METOP-C OCT 2016
CRYOSAT-2 LAUNCHED 10 APR 2010
LAUNCHED 17 MARCH 2009: OPS UNTIL END 2012
LAUNCHED 2 NOV 2009
LAUNCH MID-2013
LAUNCH JULY 2012
LAUNCH AUGUST 2015
LAUNCH MAY 2013
LAUNCH NOV 2013
LAUNCH APRIL 2013
LAUNCH END 2014
LAUNCHED JULY 2001, OPERATIONS EXTENDED
LAUNCH EARLY 2013
LAUNCH EDRS-A, END 2013; EDRS-C, END 2015
LAUNCH END 2012
LAUNCHED NOV 2010; OPS 15 YEARS
OPERATIONS START 2008
GIOVE-A 2005 / GIOVE-B APR 2008 / IOV AUG 2011 & 2012
LAUNCHED OCT 2001
LAUNCHED 2 NOV 2009 / OPS EXTENDED UNTIL 2011/12
LAUNCH 2015/16
LAUNCH APRIL 2012
LAUNCHED FEB 2008
ATV-1 MAR 2008, ATV-2 FEB 2011, ATV-3 APR 2012, ATV-4 APR 2013
NODE-2: OCT 2007; NODE-3 WITH CUPOLA: FEB 2010
LAUNCH OCTOBER 2012
TEXUS 46: NOV 2009, MAXUS 8: SPRING 2010,
MASER 12: OCT 2011
BIOLAB, FSL, EPM, EDR (EuTEF, SOLAR) WITH COLUMBUS MAR 2008
MSL: AUG 2009
VITTORI: MAY 2011; KUIPERS: DEC 2011; PARMITANO: MAY 2013
PREPARATORY ACTIVITIES INCLUDING LUNAR LANDER AND ARV
MATURITY KEY POINT 31 JAN 2011
FIRST LAUNCH END OCTOBER 2011
FIRST LAUNCH END AUGUST 2011
SYSTEM ACCEPTANCE REVIEW, JULY 2013
LAUNCH READINESS REVIEW SEPT 2013
PRELIMINARY DESIGN REVIEW, DEC 2011
STORAGE
ADDITIONAL LIFE POSSIBLE
LAUNCH/READY FOR LAUNCH
ASTRONAUT FLIGHT

KEY TO ACRONYMS

AM	Avionics Model	MoU	Memorandum of Understanding
AO	Announcement of Opportunity	PDR	Preliminary Design Review
AU	Astronomical Unit	PRR	Preliminary Requirement Review
CDR	Critical Design Review	QM	Qualification Model
CSG	Centre Spatial Guyanais	SM	Structural Model
ELM	Electrical Model	SRR	System Requirement Review
EM	Engineering Model	STM	Structural/Thermal Model
EQM	Electrical Qualification Model	TM	Thermal Model
FAR	Flight Acceptance Review		
FM	Flight Model		
ITT	Invitation to Tender		

→ HUBBLE SPACE TELESCOPE

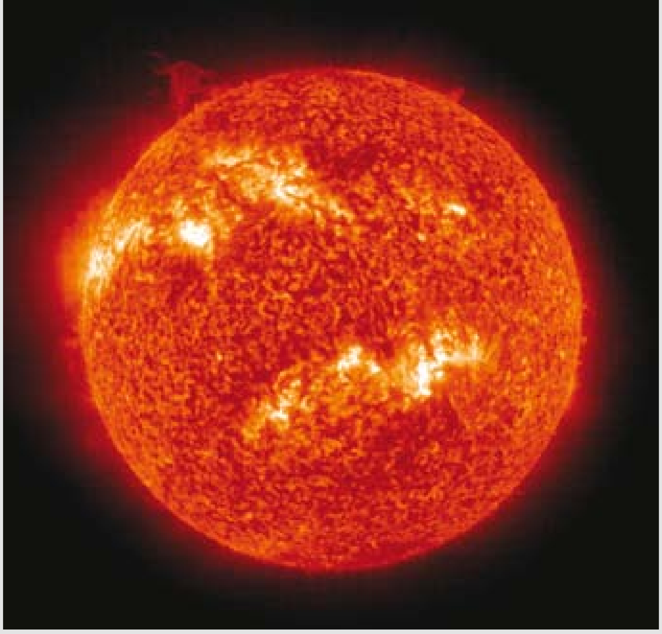
Using the Hubble Space Telescope, astronomers have uncovered one of the youngest galaxies in the distant Universe, with stars that formed 13.5 billion years ago, only 200 million years after the Big Bang. This finding helps to answer questions about when the first galaxies arose, and how the early Universe evolved. Hubble was the first to spot the new galaxy. Detailed observations from the Keck Observatory on Mauna Kea, Hawaii, revealed that the observed light dates to when the Universe was only 950 million years old (the Universe formed about 13.7 billion years ago).

Infrared data from both Hubble and the Spitzer Space Telescope revealed the galaxy's stars are quite mature, having formed when the Universe was just 200 million years old. This galaxy is not the most distant ever observed, but it is one of the youngest to be observed with such clarity. Normally, galaxies like this one are extremely faint and difficult to study, but in this case, by gravitational lensing, the galaxy's image is being magnified by a massive cluster of galaxies (Abell 383) in front of it, appearing 11 times brighter.

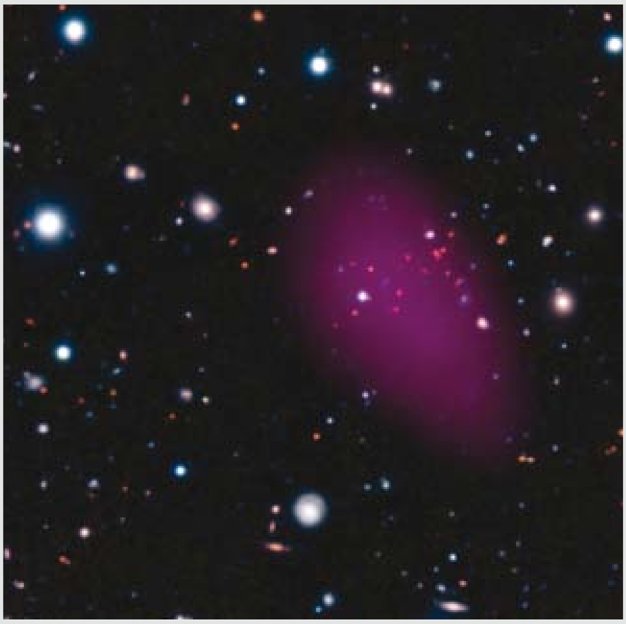
→ SOHO

A side-by-side comparison of the Sun from two years ago to the present dramatically illustrates just how active the Sun has become. Viewed in extreme ultraviolet light by SOHO, the Sun now sports numerous active regions that appear as lighter areas that are capable of producing solar storms. Two years ago, the Sun was in a very quiet period, called a 'solar minimum'. "The Sun's maximum period of activity is predicted to be around 2013, so we still have quite a way to go," said Bernard Fleck, ESA SOHO Project Scientist.

The Abell 383 'gravitational lens' galaxy cluster as seen by Hubble (NASA/ESA/CRAL/STScI)



Left, the Sun as seen by SOHO on 30 March 2009, and right, on 30 March 2011 (SOHO/EIT)



Composite near-infrared and X-ray image of the galaxy cluster CL J1449+0856, from XMM-Newton data and ground-based observations (ESA/ESO/Subaru/R. Gobat et al.)

→ XMM-NEWTON

Astronomers working with data from several observatories, including ESA's XMM-Newton, have discovered the most distant, mature galaxy cluster yet. The cluster is seen as it was when the Universe was only about a quarter of its current age. In contrast to other structures observed in the young Universe, this object is already in its prime, as is evident from its diffuse X-ray emission and evolved population of galaxies. This shows that fully-grown galaxy clusters were already in place this early in cosmic history.

→ CASSINI–HUYGENS

The Cassini–Huygens mission continues to return excellent science on the Saturn system. The second extension of the mission, called 'Cassini Solstice mission', runs from October 2010 until September 2017. ESA's participation in the Solstice mission has been increased, with support for the science operations of instruments on Cassini: the MAG magnetometer, the CAPS plasma spectrometer and the Composite Infrared Spectrometer.

A series of images from the Cassini spacecraft shows changes on the surface of Titan, as seasonal methane rains fall at the moon's equatorial latitudes. Some of the most significant changes appear within a period of only a couple of weeks (NASA/JPL/Space Science Institute)

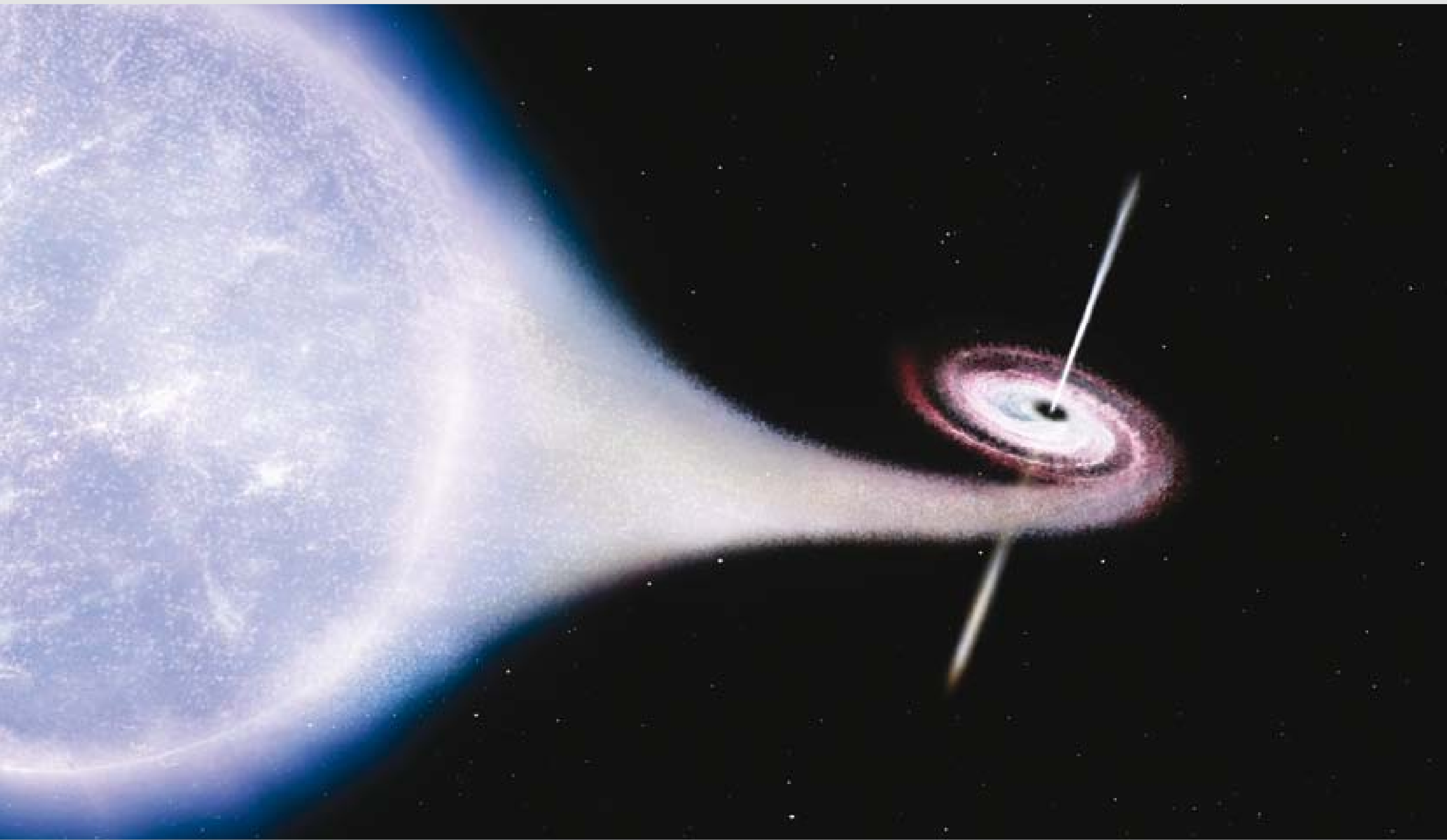
This extension will address new questions raised by Cassini and study seasonal and temporal effects on Saturn, Titan, other icy satellites, and within the rings and magnetosphere, from northern hemisphere late spring until summer solstice, a previously unobserved seasonal phase. The original mission and the first extension took place during northern winter and spring (the equinox occurred in August 2009), so by the end of the mission in 2017, Cassini will have been in orbit around Saturn for almost half a saturnian year.

Cassini's trajectory is currently embedded in Saturn's equatorial plane until 2012. This specific mission phase is dedicated to the study of Saturn, its magnetosphere, Titan and the icy moons.

→ CLUSTER

The four Cluster satellites are nearing the end of their long eclipse season in July. After last year's call for proposals and subsequent review, four guest investigators were selected. This call was for suggestions of new and compelling spacecraft operations for Cluster and in March special operations were carried out in the cusp regions of the magnetosphere.

The first results from Cluster's Auroral Acceleration Region campaign are being published. This is the first time this region has been sampled simultaneously by more than one satellite and has allowed the electric potential structure (the heart of the acceleration) to be mapped. Some of these first results examine observations made by Cluster C3 and C1 during an oblique crossing of the auroral oval region. The dual observations revealed spatial and temporal variations in the electric fields and associated particle signatures. For the first time it was possible to constrain the size and longevity of these regions. The data showed that the electric field structures measured at least 800 km across and remained stable for at least 5 minutes. These new results do not yet provide a complete explanation of the dynamics of the aurora, since the Cluster instruments are not optimised for measuring this region, but they provide theoreticians with much tighter constraints on their models of exactly how such accelerators work and give greater insight into the workings of space plasma.



The Cygnus X-1 black hole system: gas from a nearby supergiant star spiralling down into the black hole but a small fraction is diverted by magnetic fields into jets that shoot back into space

→ INTEGRAL

Intregral operations continue smoothly with the spacecraft, instruments and ground segment all performing normally.

The next SPI annealing will take place from 26 April to 16 May.

Integral recently spotted some extremely hot matter just a millisecond before it plunged into the oblivion of a nearby black hole, Cygnus X-1. Ordinarily, it takes just a millisecond for particles to cross this final distance, but Integral's unique observations suggest that some of the matter may be making a great escape, because we now know that this chaotic region is threaded by magnetic fields. This is the first time that magnetic fields have been identified so close to a black hole. More importantly though, Integral shows they are highly structured magnetic fields that are forming an escape tunnel for some of the doomed particles. The evidence points to a magnetic field being strong enough to tear away particles from the black hole's gravitational clutches and funnel them outwards, creating jets of matter shooting into space. The particles in these jets are being drawn into spiral trajectories as they climb the magnetic field to freedom and this is affecting the polarisation of their gamma-ray light. It is this polarisation that Integral has found in the gamma rays.

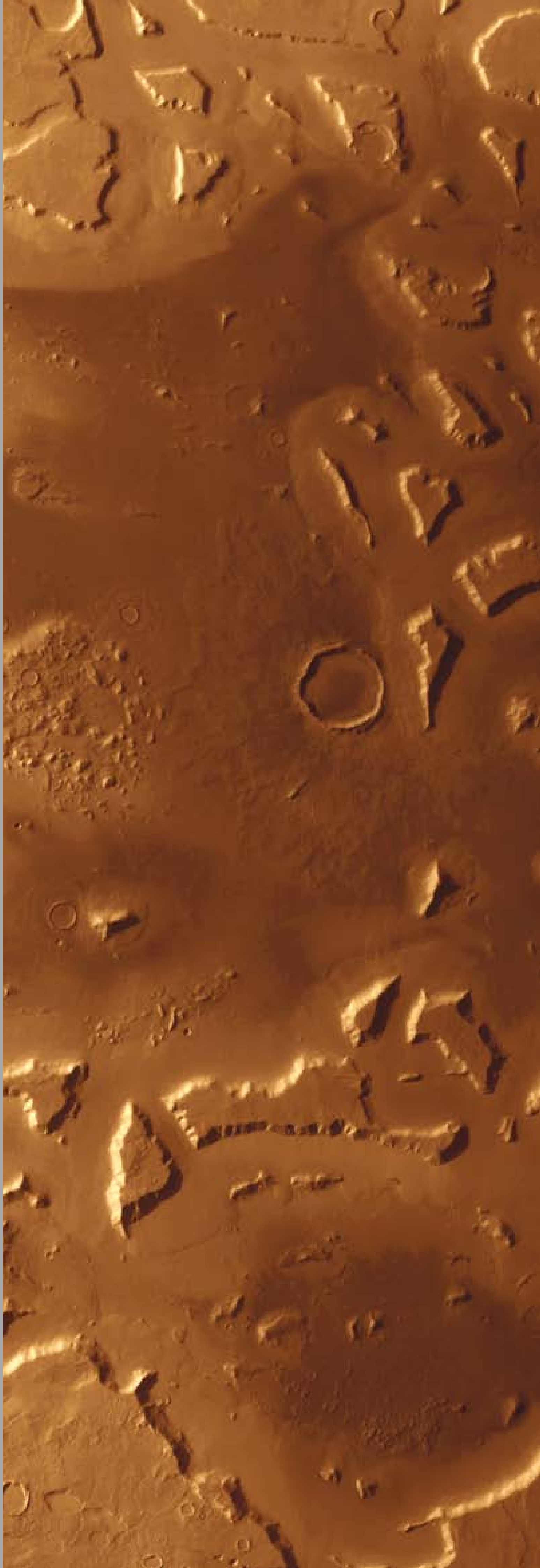
→ MARS EXPRESS

Mars Express spacecraft and instruments are working normally and continue their harvest of scientific results.

Mars Express took this image (right) on 23 June 2010, showing part of a region called Deuteronilus Mensae. This area is at the limit of the 'martian dichotomy', the sharp difference between the young, low plains of the northern hemisphere and the old highlands of the southern hemisphere. On Mars, a 'mensa' is a flat butte. There are many of them in this region; remnants of a large plateau that has been eroded, probably by fluvial and glacial processes. The small, rounded hills at middle left are called Deuteronilus Colles. Their morphology is unusual compared to the rest of the region. They may be the eroded remnant of the floor of an ancient filled crater. The darker material on the surface of the plain is probably wind-blown volcanic sand, as deduced from Mars Express OMEGA data (ESA/DLR/FU Berlin)

→ ROSETTA

Rosetta's first rendezvous manoeuvre was completed on 17 February after a complex sequence of seven burns. The manoeuvre was almost perfect in that a possible correction would have required a trim of only few mm/s, well below the threshold and hence unnecessary.

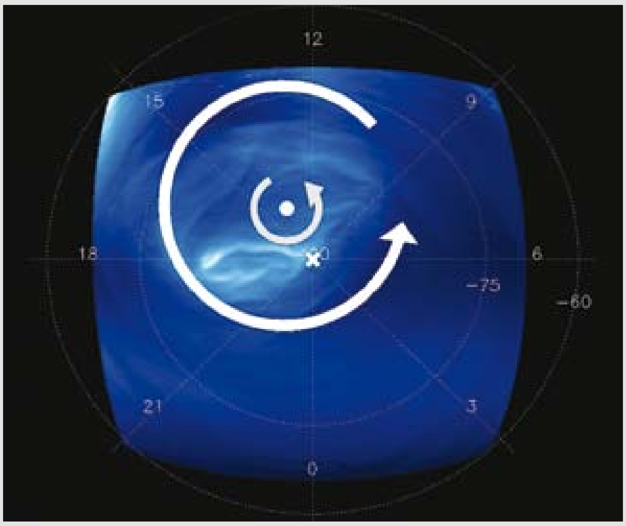


The spacecraft is now on a flyby trajectory with Comet 67P/Churyumov-Gerasimenko. It is in active cruise mode and going through an opposition phase until 20 May, after which the hibernation preparations will be finalised. Rosetta enters its hibernation phase on 8 June.

→ VENUS EXPRESS

Investigations of the Southern Polar Vortex, as seen in infrared by the VIRTIS instrument, have revealed new insights into this complex phenomenon. The polar vortex, which extends more than 2000 km across, had been found earlier to be highly variable in its appearance, sometimes changing completely from highly symmetrical to completely irregular in less than 24 hours. Now D. Luz et al. (*Science*, 2011) have found that the rotation centre of the vortex is offset from the geographical pole up to about three degrees in latitude and that this rotational centre itself precesses around the geographical pole. Images taken at 3.8 µm and 5.0 µm wavelengths show the patterns of the circulation at approximately 65–70 km altitude. These are compared to UV images at 360 nm that show the situation at about 75 km altitude. The rotation of the vortex itself has a period of about two Earth days while the precession takes from five to ten days to complete a revolution around the geographical pole.

These findings provide important clues to the long-standing question of how the super-rotation of the atmosphere is maintained. The atmosphere at mid and low latitudes rotates 60 times faster that the solid body of the planet. The newly discovered behaviour at the polar vortex involves transfer of angular momentum both in latitude and altitude, which may be of importance for the understanding of this unusual phenomenon.



The southern region of Venus with intricate patterns of the central part of the polar vortex at an altitude of 65–70 km. The rotation of the vortex is centred on a point (white dot) about three degrees off the geographical pole (white cross)

→ HERSCHEL

Herschel is carrying out routine science observations with its three instruments: PACS, SPIRE, and HIFI, and generates excellent science data with high efficiency. Preparations for the issuing of the final call for open time observing proposals in June 2011 are under way.

An example of another striking science result, Herschel has seen an extended filamentary structure in the star-forming cloud IC5146. A detailed study of this complex has shown 27 filaments that appear to have all very similar widths of about 0.3 light years. Over 350 compact starless cores have been detected embedded in these filaments: about 45 of these are gravitationally bound, pre-stellar core candidates, the seeds of future stars. However, all pre-stellar cores are located only in the densest, unstable filaments of the cloud. Herschel is showing us that stars like the Sun form like 'pearls on strings' in cosmic star factories.

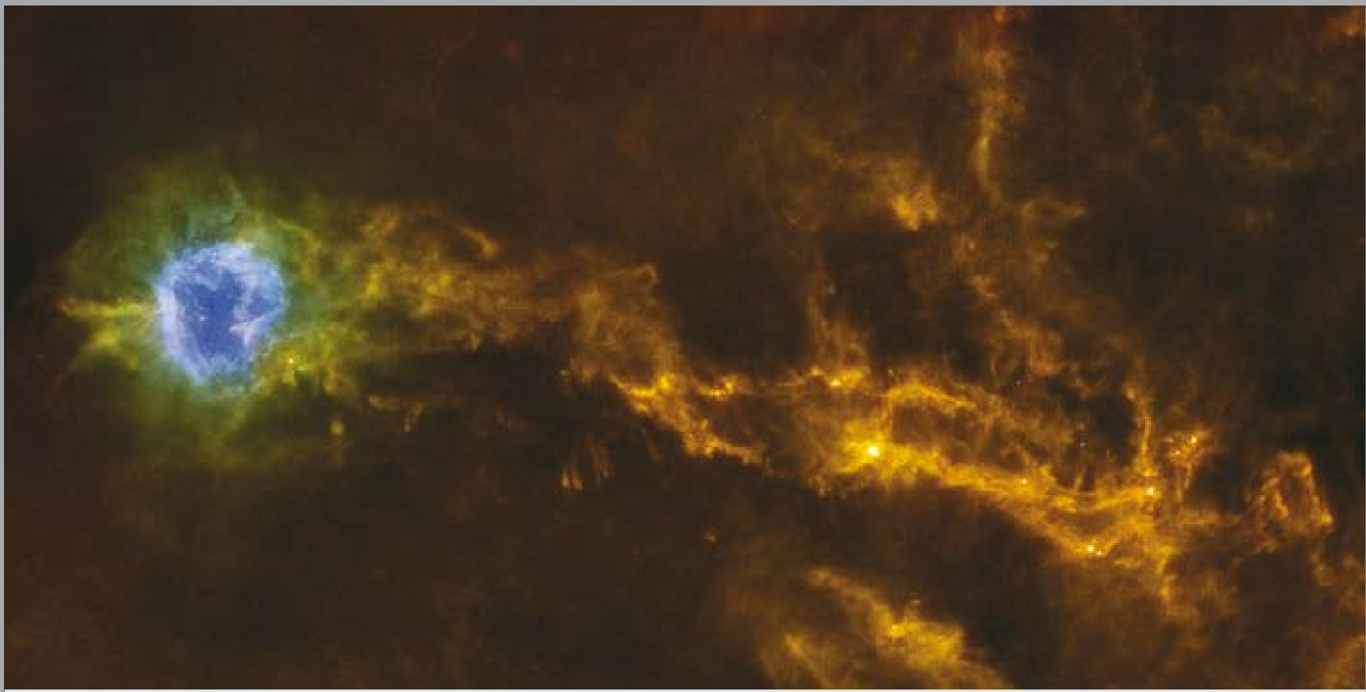
→ PLANCK

While targeting the Cosmic Microwave Background, Planck has also captured another important diffuse radiation, the 'Cosmic Infrared Background', which consists of the light emitted by all galaxies since their formation. This signal, detected by Planck at submillimetre wavelengths, exhibits a high degree of structure and enables astronomers to investigate the still unclear link between star-forming galaxies and the underlying distribution of 'dark matter', up to the earliest phases of the formation of cosmic structure.

→ COROT

COROT continues to operate normally after more than 1600 days in space. The data pipeline is working excellently for both the asteroseismology and exoplanetology segments of the mission. At the COROT symposium in June, a number of new exoplanets will be announced.

A new and unique type of observation will be carried out during 2011. The planet CoRoT-9b, which was announced in 2010, is a gaseous giant planet slightly smaller than Jupiter and it orbits around a star somewhat smaller than our Sun with a period of 95 days. It is one of a few transiting objects with such a long period that have been found and it is orbiting within the 'temperate zone' of this star (meaning under certain atmospheric conditions, water could exist in liquid form at this distance from the star).



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Herschel image of star-forming cloud IC5146, showing extended 'filaments'. The Cocoon Nebula (left) is a region of ionised atomic hydrogen gas, illuminated by a young bright star. Some young stellar objects are visible as bright spots along the main filaments. IC5146 belongs to the Gould Belt, a giant ring of stars and star-forming clouds about 1500 light years from our Sun (ESA/PACS/SPIRE/Gould Belt consortium)

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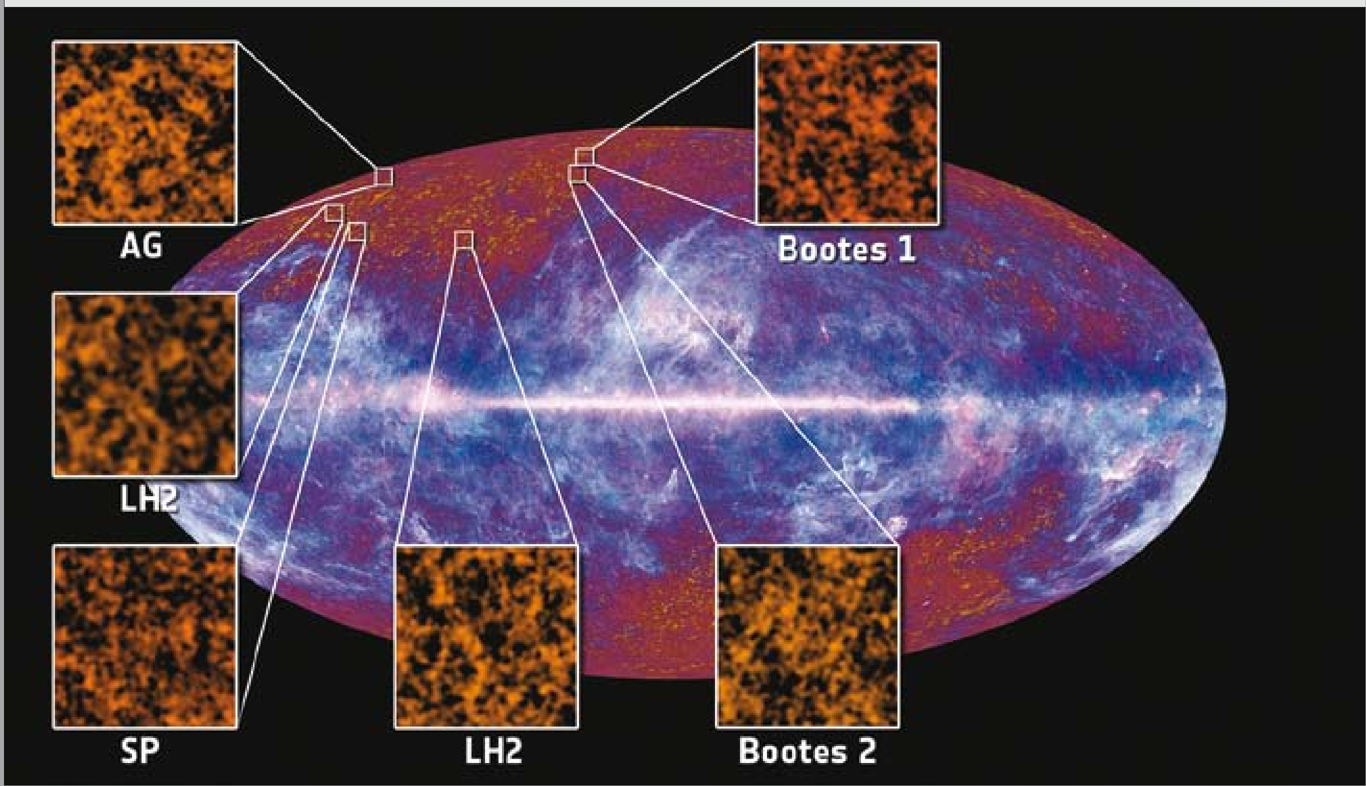
Planck's all-sky one-year survey with the superimposed locations of the first six fields used to detect and study the Cosmic Infrared Background anisotropies (ESA/Planck Consortium)



On 4 July, the planet will transit the star when it is visible from Earth and COROT will take time off from its summer observations to revisit this object in order to refine the 'ephemeris', or timing, of the transit. Since any changes in the time when the eclipse is expected to start and end would have to be due to a gravitational influence, this would enable a search for a large moon orbiting the planet or possibly also detect other small and non-transiting planets within the CoRoT-9 system. NASA's Spitzer telescope will be observing at near-infrared wavelengths.

→ GAIA

The integration of the Payload Module is progressing. The four flat flight mirrors have been mounted on the optical bench. The integration of the three curved flight mirrors of telescope 1 is ongoing. The integration of the Focal Plane Assembly FM has started and the first row of CCDs is already in place.

On the spacecraft, the Power Control and Distribution Unit and the two transponders were delivered to Astrium SAS in Toulouse and they will be integrated on the Service Module soon.

The spacecraft functional tests on the AM are running at Astrium in Stevenage, UK. More than 90% of the Integrated Subsystem Tests have been performed. The Preliminary Mission Analysis Review with Arianespace was completed in March.

→ LISA PATHFINDER

The LISA Pathfinder FM is undergoing the sine vibration test in IABG, Ottobrunn. This is the first of a series of tests on the FM aimed at qualifying the spacecraft for flight. The Vega compatibility shock tests, the electromagnetic compatibility (EMC) test and the thermal vacuum test will follow. The sine test is performed on the spacecraft in launch configuration with the Propulsion Module (PRM) mated to the Science Module (SCM).

Gaia's Service Module ready to be weighed at the integration facility in Toulouse (Astrium)

LISA Pathfinder Flight Model in launch configuration installed on the sine vibration shaker in Ottobrunn, Germany (IABG)

The SCM has all its platform flight units and most of the payload electronic units. Only the micro-propulsion thrusters, the LTP Core Assembly (LCA) and a few payload electronic units are replaced by dummies. The missing payload units will be integrated before the EMC test, and the LCA dummy will be replaced by a thermo-optical simulator capable of performing an interferometry measurement during the thermal vacuum test, which is not be possible with the LCA FM. The LCA and micro-propulsion FM are undergoing a further development activity and will be ready only few months before flight.

The micro-propulsion system (the FEEP thrusters) had a problem during the second lifetime test in October, which would have confirmed the performance obtained in the first lifetime test of two years ago. The test failure was investigated and new tests performed to confirm the cause of the failure. ESA and industry are considering alternative micro-propulsion systems as a back-up, in case the FEEP is not adequate for flight. Fortunately, the FM hardware is not required until later and can be integrated even just before installation of the spacecraft on the launcher.

The LCA is undergoing redesign activities of the caging mechanism. This redesign is being performed by industry and a breadboard of a new caging mechanism lock assembly has been built and tested. Because of the delay in the LCA and uncertainties with FEEP qualification, LISA Pathfinder will be launched no earlier than the end of 2013.

→ MICROSCOPE

The PDR is ongoing at CNES. ESA propulsion experts are attending to cover in particular the new baseline micro-propulsion system (cold gas is now replacing the electrical propulsion). The conclusions of the PDR board are expected in April. The competitive tender for the industrial phase of the ESA contribution (the cold-gas micro-propulsion system) has been released and the proposals from the bidders are also expected in April.

→ JAMES WEBB SPACE TELESCOPE

NASA is developing a revised programme plan to fit the provided funding profile. A new baseline project plan is expected this summer, but a launch is now assumed for late 2018. The final primary mirror segments assembly cryogenic test for the first six flight mirrors starts in April. The Integrated Science Instrument Module FM is undergoing its final proof load test.

NIRSpec is back at Astrium GmbH after the first cycle of cryogenic tests. The full optical train has seen 'first light' and instrument performance is as expected. The refurbishment of the flight instrument, including cleaning of the Micro Shutter Arrays and reducing the flux levels of the Calibration Unit, is ongoing. NASA is investigating the cause of the hot pixels observed on all the near-infrared detectors. An exchange of the flight detectors is assumed.

The MIRI Focal Plane Electronics were delivered to Rutherford Appleton Laboratory after a pre-shipment review at JPL. The qualification campaign for all three MIRI wheel mechanisms (two dichroic/grating wheel mechanisms and the filter wheel mechanism) is complete. An outgassing test of the instrument optical module was also completed and the instrument is now in the thermal chamber ready to start the cryogenic verification test. The MIRI European Consortium agreed to provide carbon-fibre reinforced plastic struts to support the MIRI thermal shield under development at NASA. The purpose of this shield is to increase the thermal margins on the MIRI cooling system. Post-processing activities for the launcher Coupled Load Analysis are ongoing at Astrium.

→ BEPICOLOMBO

The Mercury Planetary Orbiter (MPO) STM is being integrated in Turin, including the propellant tanks, linking heat pipes and the large radiator panel, as well as parts of the propulsion pipework, equipment and harness. The Mercury Transfer Module STM is at Astrium in Stevenage, UK, to begin the system integration activities. The PDR of the solar array has been concluded. A 1500-hour ultraviolet confidence test on solar cell assemblies was completed. The electric propulsion thruster STM completed its vibration testing. The qualification thruster will start its test programme, and the flight thruster is being built. The spacecraft flight structures are being manufactured. The PFM integration sequences are being optimised to accommodate late deliveries from some suppliers.

MPO Structural and Thermal Model during integration (Astrium)

Eight of 11 MPO instrument EMs were delivered and subjected to integrated systems test on the Engineering Test Bed at Astrium in Friedrichshafen. The remaining three instruments will follow in May to June 2011. All MPO instruments STMs were delivered to Thales Alena Space Italy, Turin, ready for integration.

After the March natural disasters in Japan, the teams for the Japanese contribution to BepiColombo (Mercury Magnetospheric Orbiter, MMO) are fortunately safe and no MMO hardware was damaged, but impact on the spacecraft development is being assessed. The MMO subsystem CDRs are ongoing. Launch is planned in the Mercury launch opportunity of mid-2014.

→ EXOMARS

The major task in early 2011 was the finalisation of the ExoMars programme 'Cost at Completion', which is based on an industrial price proposal for the Phase-CD/E1 implementation submitted on 14 February. The proposal was based on the System PDR completed in 2010, and included the two missions of the ExoMars programme and certain assumptions related to the international cooperation which was developed over the past year.

In March, NASA informed ESA of changes to their approach for the second mission in 2018. Until that time, the 2018 mission was a NASA-led mission with two rovers supported by a platform. One of the rovers was ESA's, which had been progressing at Phase-B level for the last four years, while the other was a NASA rover in a pre-Phase-A type study. This two-rover mission would be launched on a NASA-supplied Atlas launcher with an entry system similar to that being used for their Mars Science Laboratory mission later this year. NASA had to change this 2018 mission concept to a single rover mission owing to budgetary limitations, which have affected planning for future Mars exploration, as well as other space missions. As a result, ESA and NASA agreed to develop a single rover for the 2018 mission with capabilities that satisfy the objectives of both agencies. This rover may be larger than the existing ESA rover design and will certainly require significant design changes to make it compatible with the NASA landing system.

In this new situation in the international cooperation, it was necessary to reorient the work for the 2018 mission to join NASA in studies of a new rover, profiting from the best contributions of the two partners. The start of ESA hardware development is effectively on hold pending the outcome of studies undertaken by Joint Engineering Working Groups made up of ESA and NASA engineers. These activities will carry on through to the end of 2011, when a mutually agreeable configuration can be agreed with Participating States of the ExoMars programme.

In the meantime, the 2016 mission will continue into Phase-C/D (implementation), based on the System PDR configuration and the existing agreements in the international cooperation, once negotiations for an acceptable price for the ExoMars programme have been concluded.

Development has begun for all ExoMars Trace Gas Orbiter (TGO) instruments and the Experiment Interface Requirements Document, giving the requirements guiding their development and accommodation, has been issued by ESA to all instrument developers. Proposals for the Entry, Descent and Landing Demonstrator Module Science Sensors are under evaluation and a selection will be confirmed in mid-2011. The instruments of the Pasteur Payload for the 2018 mission continue their accommodation work in the Analytical Laboratory Drawer. Some modifications may be necessary for the definition of the new single rover for the 2018 mission.

→ PROBA

Proba-3 is dedicated to the demonstration of technologies and techniques for high-precision formation flying in preparation for future formation missions. Proba-3 consists of two small satellites launched into high elliptical orbit to demonstrate formation flying in the context of a giant (150 m) solar coronagraph science experiment.

Phase-B1 was completed in 2010, and the mission is now in its next development Phase-B2. The contract was signed on 29 March and the PDR is planned for mid-2012. An industrial team was formed under the leadership of SENER Ingeniería y Systemas, including GMV Aerospace and Defence, EADS CASA Espacio, Qinetiq Space (formerly Verhaert Space), Spacebel, NGC Aerospace, Swedish Space Corporation, Deimos Space, Deimos Engenharia and Qinetiq UK. Phase-B of the payload will be initiated in parallel with Phase-B2 of the two satellites.

→ HYLAS

Hylas-1 reached its designated geostationary position (33.5oW) on 24 February. The payload was switched on and configured on 27 February for in-orbit testing (IOT). The ESA ground station of Redu, with its newly updated Ka-band IOT antenna, has hosted facilities and the engineering teams from ESA and industry for the full campaign. Test activities lasted two weeks, during which key payload and antenna performances were measured and validated by comparison with ground test data. All active payload equipment and redundancies were tested. The review of test results has confirmed the excellent performances of the payload through all of its 66 active items. Testing of the platform had already been performed shortly after launch.

The main Ka-band Earth station for Hylas-1 is at Goonhilly, in Cornwall, UK. Goonhilly holds a unique place in satellite telecommunications history: in 1962, it received the first live transatlantic TV broadcast from the USA via the Telstar satellite (Avanti)

Control of the satellite was then handed over from the ISRO Master Control Facility in Hassan, India, to Inmarsat in London for the routine satellite operations. IOT was followed by the System Acceptance Test to prepare for the commercial rollout of broadband customers. A series of end-to-end tests was performed to validate all the elements of the ground segment (gateways, hubs, network infrastructure) required for the provision of satellite connectivity services. Since 4 April, the existing 4000 broadband customers of Avanti Communications are being migrated to Hylas-1 from the Ku-band capacity currently leased on another telecom satellite.

→ ALPHABUS AND ALPHASAT

The Alphabus SM was mated with the Alphasat Communications Module on 15 March. Satellite integration and test activities are under way. Launch of Alphasat on an Ariane 5 is scheduled for the first quarter of 2013.

Technology Demonstration Payload 5 (TDP5) is a Q/V-band communications experiment to assess the feasibility of these bands for future commercial applications. A contract was signed with Joanneum Research, Austria, in March for the development of a TDP5 complementary ground station in coordination with the Italian space agency, ASI. It consists of the definition, selection, installation and operation of a high-performance Q/V-band ground station with tracking antenna at a fixed location in Graz, Austria.

Alphabus Extension

The second part of the extension contract to develop a more powerful Alphabus was signed in Toulouse on 1 April. The contract, signed by EADS Astrium, Thales Alenia Space, ESA and CNES, will qualify Alphabus for the very-high-power end of the communication satellite market, extending the range up to 22 kW. Other improved characteristics include: thermal rejection capability up to 19 kW (payload power) from 11.5 kW; payload mass increased from 1250 kg up to 2000 kg from, at 18 kW payload power; an increase of repeaters from 190 to 230 transponders; double compatibility maintained with the 4 m fairings of Ariane 5 and Proton.

Alphasat Ground and User Segment and Applications

Inmarsat and ESA are jointly initiating the development of innovative value-added applications based on Inmarsat BGAN and GSPS (Global Handheld Service) services using Alphasat and Inmarsat 4. ESA launched an Open Call for Proposals in March, inviting companies to apply for ESA funding to develop and trial applications that address new and/or under-served markets.

→ EUROPEAN DATA RELAY SATELLITE

The competitive ITT for the European Data Relay Satellite (EDRS) system Phase-B/C/D/E1 contract was issued in February 2010. Astrium GmbH (Business Unit Services) was selected as the prime contractor and operator of the system in October. In January, final approval for the programme was given by the Joint Communication Board, based on the mission technical baseline negotiated between ESA and Astrium, and on the funding from the Participating States. Negotiations are now in their final phase, with contract signature expected this summer.

There is strong pressure on launch dates, because of the need to begin EDRS operations in time for the Sentinel-1 and -2 missions. The industrial consortium already had to start the SRR, the first major programme milestone, planned for June. After the SRR, detailed technical definition of the mission will continue through Phase-B2, with the PDR planned for early 2012.

On 22 April, Ariane 5 ECA flight VA201 lifted off from Europe's Spaceport in French Guiana on its mission to place two telecommunications satellites, Yahsat Y1A and Intelsat New Dawn, into their planned transfer orbits (ESA/CNES/Arianespace/Photo-Optique vidéo du CSG)

→ ARIANE 5 POST-ECA

Eleven hot firing tests were performed in the Vinci M3 engine test campaign at the P4.1 stand, DLR Lampoldshausen. The final test was made on 17 February and the engine was dismounted. During the last test, a firing at very high thrust level was followed by a second firing (50 seconds duration) at very low thrust (35 kN), simulating a deorbit scenario. This successful demonstration of variability of thrust is a major breakthrough for the Vinci engine. Thrust chamber tests on stand P3.2 have been run 15 times and all test objectives were achieved. The condensation problem of the engine is now under control.

→ VEGA/P80

The Z9A qualification review steering committee was held. The qualification review was completed for the new design of the retrorocket. The mechanical redesign activities of the Roll Attitude Control System sub-system are proceeding and the FM Qualification Reviews are expected in May. The second phase of the launch system Ground Qualification Review began in April.

For Vega, the payload composite integration activities were carried out in the S3B Payload Integration Building and the payload composite was mounted on a mock-up

The Vega payload composite on a mock-up launcher on its Mobile Gantry, at Europe's Spaceport in French Guiana, in February launcher at the Mobile Gantry in February. Full-scale mock-up launcher mechanical tests were completed in March. The AVUM propellant filling campaign is under preparation to start in May.

Production activities for P80 Flight Model 1 (FM1) are under way in the Bâtiment Integration Propulseur (BIP) building. Production of Z23, Z9 AVUM and upper stages is under way with delivery expected in the next few months. About 80% of First Article Configuration Reviews has been completed.

→ SOYUZ AT CSG

The Ensemble de Lancement Soyuz (ELS) Qualification Review was held in March, followed by the acceptance of the ELS site by ESA from CNES on 31 March. On the same day, ESA formally handed over the ELS site to Arianespace for exploitation.

The Mobile Gantry was transferred to the launch zone for six weeks for validation tests of the launcher's ventilation systems. Mobile Gantry integration activities progressed on schedule. Cladding of the south doors was completed and installation of the hydraulic and electrical power supply is nearing completion. North doors activities, which include installation of the door's hydraulic actuators, hinge modification and integration on the gantry structure, are completed and the first moves in opening and closing the north doors were made.

Maintenance started on the Russian system (service cabin and kerosene rail trailer) on 11 March. Under Arianespace responsibility, the campaign to configure Soyuz ST-A started on 1 April in its operational qualification phase. The Soyuz launcher was transferred to the launch zone on 29 April. A simulated launch 'dry run', without filling its propellant tanks, is scheduled on 4 May.

→ FUTURE LAUNCHERS PREPARATORY PROGRAMME

Intermediate eXperimental Vehicle (IXV)

All subsystem CDRs were held in December. IXV Phase-C activities are nearing completion, with the system CDR starting on 1 April. The industrial proposal for Phase-D activities is under evaluation.

Next Generation Launcher (NGL)

As part of the Astrium Frame Contract (system studies for the preparation of NGL), four launch vehicle concepts are being analysed; each of these four concepts will be reviewed in April/May. For the High Thrust Engine, after the Architecture Key Point of the Stage Combustion Rocket Engine Demonstrator, the SRR started on 3 March. Activities at technology level are progressing. In solid propulsion, the Pressure Oscillation Demonstrator (POD-X) PDR was completed in December and the following phase, which includes Manufacturing Release Review (MRR) of the demonstrator, is scheduled for May.

The Soyuz is transferred to its launch zone at Europe's Spaceport for a complete 'dry run' to test the ground facilities and their compatibility with the launcher on 29 April

Work is progressing on upper-stage propulsion, with an Architecture Key Point in February; activities are now in the preliminary design phase with a PDR in mid-2011. In cryogenic upper-stage technologies, the CDR for the inflight experiment of the Propellant Management Device, to be flown on a Texus sounding rocket before the end of 2011, was performed in February.

→ SMOS

In routine operation since May 2010, SMOS celebrated its first year in orbit in November. All data have been released to the science community, along with the first global map of soil moisture and ocean salinity. The reprocessed data from the commissioning phase have recently been released.

→ CRYOSAT

CryoSat-2 is performing well. After the commissioning phase, ground processors were upgraded to take into consideration the main internal bugs identified during that period. The first CryoSat Validation Workshop was held in February at ESRIN. Preliminary results were presented by the calibration/validation community, which has been receiving data since July 2010. The performance of the mission is excellent and data products are of high quality, although further improvements are still required, mainly in Level 2 data. During the workshop, access to CryoSat Level 1b and 2 data was open to the scientific community. Since then, data have been processed regularly and disseminated to users. The first reprocessing campaign is planned to start at the end of this year.

→ ADM-AEOLUS

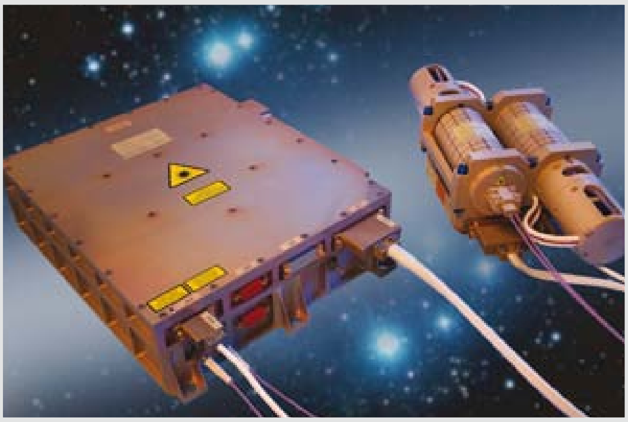
The work required to implement 'continuous mode' has been progressing well: modifications to instrument electronics and the transmitter laser are being put into effect. Integration of the first Transmitter Laser FM is progressing, with some delays because of non-conformances on the electrical current supply of the laser amplifiers.

Performance degradations of the laser transmitter (when installed in the Aladin instrument) have been identified and solutions are being considered. The prime contractor is evaluating a combined instrument and satellite assembly, integration and test programme.

Activities to upgrade the end-to-end simulator and ground payload data processing software for continuous mode operation of the Aladin instrument have begun. Two scientific impact studies have also been launched to establish the potential of continuous mode operation and the assimilation of the data.

→ SWARM

The second satellite FM is fully integrated with all avionic units and instruments, and the integrated system tests are complete. The environmental test campaign, lasting five months, starts soon. All six Absolute Scalar Magnetometer (ASM) FMs have been delivered by CNES/LETI, France. They have excellent performances, exceeding requirements. The design is based on a laser exciting a helium-filled cell, and produces a much-improved signal compared with previous magnetometers. The preliminary mission analysis review for the launcher was completed with Eurockot and Khrunichev. The PDR for Level 2 Algorithms and Processing Facility was completed in January.



The last Swarm Absolute Scalar Magnetometers instrument with its sensor head (CNES/LETI)

→ EARTHCARE

The Earth Observation Programme Board requested an independent project assessment. This assessment reaffirmed the high scientific value of the EarthCARE mission and the unique synergies between its four instruments. It reviewed the remaining uncertainties on the ATLID instrument development in terms of technical feasibility and schedule, and found that the additional margins available are adequate to proceed with Phase-C/D.

Attention has remained on definition of the ATLID bistatic lidar and PDR actions and recommendations. An alternative laser operating point with a lower repetition rate has been evaluated, and selection of the operating point is imminent. The thermal analysis has been updated along with the instrument budgets. Work is progressing on the alignment sensitivity of the laser transmitter. Laser-induced contamination testing of the pressurised environment has started.

In Japan, work on the Cloud Profiling Radar (CPR) SM and EM is under way, however the devastating earthquake of 11 March has affected progress. Besides the heavy human toll of the earthquake and its aftermath, some limited damage was reported on the CPR SM. While no damage was visible on the EM, the detailed impact on both CPR models is being investigated.

→ METEOSAT

Meteosat-8/MSG-1

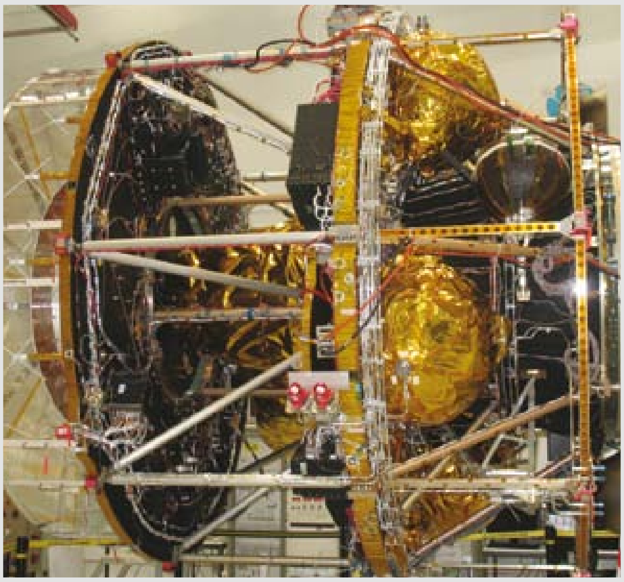
Having completed eight and a half years in orbit (design life was seven years), the satellite continues to perform normally. It provides the Rapid Scan Service, complementing the full-disc mission of the operational Meteosat-9/MSG-2. The north/south position is now in free drift, with the inclination increasing at a rate of about one degree per year, while the east/west position is still maintained. The satellite's consumables will allow six more years of operation.

Meteosat-9/MSG-2

MSG-2 is Eumetsat's nominal operational satellite at 0° longitude. Launched in December 2005, the satellite has completed five years in orbit without any problems.

→ MSG-3

MSG-3 was prepared for testing in January and for the Integrated System Test (functional and performance verification of the satellite and all subsystems), including an Optical Vacuum Test. This test, in a vacuum chamber that is able to cool down the imager to operational temperatures, will verify the performance of the imaging instrument. Arianespace carried out the preliminary mission analysis, identifying areas where additional analysis is needed, related to the characteristics of the current version of the launch vehicle (Ariane 5 ECA, instead of Ariane 5G/GS for MSG-1/2). The launch is still planned for summer 2012.



MSG-3 in the cleanroom at Cannes (Thales Alenia Space)

→ MSG-4

Investigation of the new SEVIRI Drive Unit has identified the problem with movement accuracy. A replacement part is under manufacture.

→ MTG

The SRR is ongoing, with the industrial datapack delivery at the end of February. The MTG Industrial Days were held in January, with large industrial participation: over 200 delegates, representing more than 80 different companies. The revised programme declaration was approved at the Special Earth Observation Programme Board on 29 March, while consolidation of the ESA/Eumetsat Cooperation agreement, required before Phase-C/D, is well advanced.

→ METOP

MetOp-A

After four and a half years of operation, the satellite is performing well. HRPT data transmission continues, but with restricted coverage area due to potential radiation issues; Eumetsat increased the coverage from January 2011. The assessment review and trend analysis shows that MetOp-A could operate for another six years or more, well beyond its design life.

MetOp-B

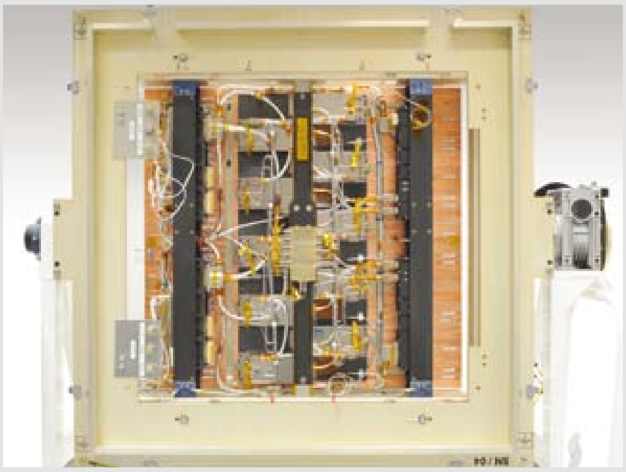
The MetOp-B Payload Module (PLM) was retested, including functional and thermal vacuum tests. Then it was returned to storage. Several instruments were removed from the PLM for calibration prior to launch. Two instruments (SEM/MHS) had some out-of-specification results during thermal vacuum testing and were swapped with MetOp-C units to reduce schedule risks for the launch date of MetOp-B.

GOME2 was calibrated and is back with Astrium for re-integration. Reference tests were completed for the Service Module (SVM), which is being prepared for thermal vacuum testing in June. The Preliminary Cosmodrome Readiness Review including the site survey was held in January.

MetOp-C

In December, MetOp-C SVM, PLM and solar array were tested in preparation for mating. All the three modules arrived as planned in Toulouse and were mated together for the first time without any problem. Vibration and acoustic tests confirmed the good health of the structure and all units.

MetOp-C inside the acoustic chamber in Toulouse with the Astrium, NOAA/NASA, CNES, Eumetsat and ESA teams (Intespace)



Sentinel-1 CSAR Tile Electrical Qualification Model (Astrium GmbH)

→ SENTINEL-1

The Sentinel-1 project is well into Phase-D (production of flight units). Development of the SAR instrument at Astrium Friedrichshafen is also progressing, with the manufacture of the flight equipment under way. Production of the Electronic Front-End modules at Thales Alenia Space Italy was consolidated after final EQM tests and design modifications. The Interface CDR of the Optical Communication Payload is under way. Preliminary mission analysis began with the launch service provider Arianespace.

→ SENTINEL-2

The Visible and Near Infrared (VNIR) Focal Plane Assembly radiometric testing was completed. The Short Wave Infrared (SWIR) EM Focal Plane Assembly is integrated and ready to enter the thermal vacuum chamber for a radiometric test campaign at 190K. The silicon carbide telescope baseplate FM is awaiting the three flight mirrors. These are undergoing fine polishing before mechanical integration and alignment of the telescope FM. The instrument optical filter FMs are being redesigned to remove an unexpected stray light effect observed during EM testing. An improved test characterisation programme will be applied for the selection of the final flight VNIR detectors to optimise spectral uniformity over the full swath.

At platform level, GPS receiver and startracker EMs have been integrated with the onboard computer using a first version of the flight software. The instrument Video and Compression Unit EM was connected to a breadboard model of the Mass Memory and Formatting Unit, and demonstrated the proper operation of the very high data rate communication interface between the instrument and the platform (500 Mb/s). There are some delays in component deliveries, e.g. the ASIC FMs (application-specific integrated circuits) for the onboard computer, and the qualification of multilayer printed circuit boards.

For Sentinel-2A, the Optical Communication Payload Interface CDR is scheduled for April, to release the remaining FM manufacturing activities conducted under the leadership of DLR. Image quality activities are proceeding at CNES and the Ground Prototype Level 1c Processor Detailed Design Review was carried out. The prime and core contractor teams for the development of the Sentinel-2 Payload Data Ground Segment were selected.

→ SENTINEL-3

Phase-C/D activities are proceeding with CDRs at all levels. The OLCI and SLSTR instrument CDRs are well advanced, however, formal closure is expected when the results of the instrument EM (and for SLSTR, also STM) test campaigns are available. Nevertheless, most of the Proto Flight Model (PFM) subsystems of these instruments have been or will be released shortly for manufacturing. The satellite CDR is also under way, with its first Board planned in April. Subsequent 'delta' Boards may be required for changes, depending on the results of still-open instrument CDRs. At ground segment level, the PDGS PDR is in progress and will also be completed in April.

Coding of the flight software is proceeding, with validation in April. In parallel, the ground processor simulators are being testing and validated before delivery to ESA. At spacecraft level, manufacture and test activities have allowed not only the completion of several equipment EQM test campaigns, but also the start of manufacture of several PFM units. Platform PFM integration is planned to start before the summer with the propulsion subsystem, assuming availability of the satellite structure. In the meantime, the first phase of the Virtual EM bench testing has started, allowing the first compatibility tests between the onboard computer and the attitude and orbit control system units. At instrument level, the late availability of some components is still delaying the manufacturing process for several units. Nevertheless several equipment tests have been completed with excellent results.

→ SENTINEL-5 PRECURSOR

The satellite/system Phase-A/B1 studies with OHB and Astrium are ongoing. SRRs are expected in June and selection of one of the two contractors in the summer. Phase-B2/C/D/E1 is scheduled for October. The Technical Evaluation Boards for procurements of the Passive Cooler and Electrical Ground Support Equipment were held in March. Negotiations with the two contractors took place in April, which concludes the ESA Best Practice procurement process for the TROPOMI payload elements. The TROPOMI payload PDR is in May.

→ HUMAN SPACEFLIGHT

Decisions on the future of the European space sector were made at ESA's Council meeting in Paris on 16 and 17 March. ESA Member States participating in the ISS Exploitation programme decided to extend the duration of their ISS cooperation until the end of 2020.

Participating States committed €550 million to cover the period until the next ESA Ministerial Council in 2012. This decision provides the framework for new development activities aimed especially at fulfilling Europe's obligations towards financing its part of the exploitation costs of the ISS, thereby opening the door to future industrial developments to be undertaken by European industry. The governments of Japan and the Russian Federation have likewise approved continued ISS operations beyond 2016. The NASA Authorization Act of 2010 extended operations until at least 2020.

Following launch on 15 December, the Soyuz TMA-20 spacecraft carrying ESA astronaut Paolo Nespoli (IT) and his crewmates – Russian cosmonaut Dmitri Kondratyev and NASA astronaut Catherine Coleman – docked with the ISS on 17 December, marking the start of ESA's third long-duration mission aboard the ISS, MagISStra. Since his arrival, Paolo Nespoli has been undertaking an intensive programme of experiments in different research fields.

In February, the Multilateral Coordination Board reaffirmed its commitment to reducing ISS operational costs, to develop an integrated transportation plan and maximise the return by increasing research aboard the ISS. The partners also renewed their commitment to use ISS resources and observation capability to assist with humanitarian efforts, such as aiding in disaster recovery, and monitoring climate change as well as health research.

Expedition 26 and STS-133 crews inside the new ISS 'habitation' module, the Permanent Multipurpose Module Leonardo, after it was installed on the Earth-facing port of the Unity node

ESA received 28 full proposals after October's Announcement of Opportunity (AO-10-IBER) to study the effects of radiation exposure by means of the ground-based accelerator facility (GSI in Darmstadt). Of these, seven are for continuation of research already begun in conjunction with a previous AO and the others are new.

→ SPACE INFRASTRUCTURE DEVELOPMENT/ISS EXPLOITATION

ESA's second Automated Transfer Vehicle, ATV *Johannes Kepler*, rendezvoused and docked automatically with the ISS in February, and the Space Shuttle *Discovery,* which lifted off on its STS-133 mission and final flight on 24 February, docked shortly after the ATV. *Johannes Kepler*'s mission includes taking essential supplies to the ISS, plus ISS reboost manoeuvres. The launch of ATV *Edoardo Amaldi* is planned for the end of February 2012. The Pre-Shipment Review for Kourou is expected at the beginning of August.

→ UTILISATION

The experimental programme for Increment 26 is almost complete and will run until the arrival of the Increment 27/28 crew in April. This is the largest part of the science programme planned for Paolo Nespoli's MagISStra mission. Already a variety of experiments and education activities have been performed, despite the tight constraints on crew time because of the unusually heavy vehicle traffic to the ISS.

External Payloads

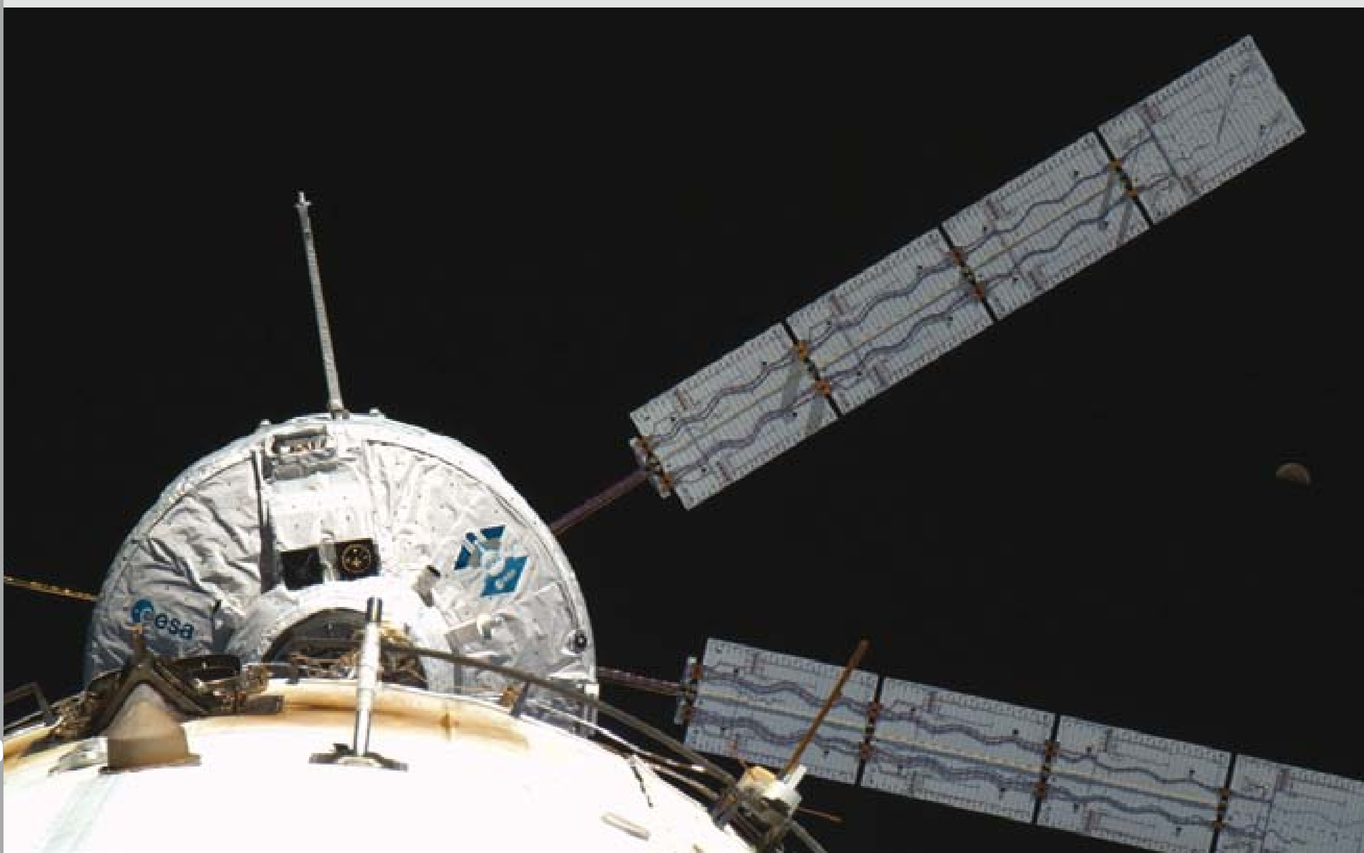
The SOLAR platform continues to acquire data at various intervals during Sun visibility windows. The Expose-R payload was retrieved during a Russian EVA on 21 January. It hosted a suite of nine new astrobiology experiments (eight from ESA, one from IBMP, Moscow), some of which may help understand how life originated on Earth. Installed outside the Zvezda Service Module in March 2009, it endured almost two years of exposure to the harsh open space environment and functioned extremely well, continuously acquiring scientific data over this period. The exobiology sample trays, as well as other European Modular Cultivation System biology samples from the Genara-A experiment, were returned to the ground in March. A tentative new experiment complement for the future Expose-R2 mission has been identified, and implementation with Russian partners is commencing.

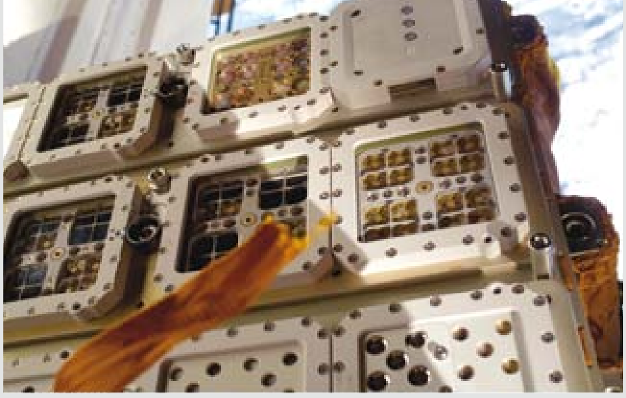
Life Sciences

The functional recovery activities for the Biolab facility are under way. Biolab utilisation will be resumed in 2012 with the TripleLux experiments, once the microscope unit has been repaired on the ground. The objective of the TripleLux experiments is to further understand the cellular mechanisms underlying the aggravation of radiation responses, and the impairment of the immune function under spaceflight conditions.

Paolo Nespoli conducted his first six-day session of the Sodium Loading in Microgravity (SOLO) experiment in February. Nespoli consumed a high-salt-level diet and

ATV *Johannes Kepler* about to dock at the ISS





Close-up image of the Expose-R experiment

logged what he ate and drank daily. Over this period, his body mass was also recorded; blood samples were taken and spun in the refrigerated centrifuge of the Human Research Facility 2, and put into the MELFI-3 freezer for return to ground for further analysis. Blood was also analysed on orbit using a Portable Clinical Blood Analyser. Human samples from the test subjects of the SOLO experiments during Expeditions 24 and 25 were returned on STS-133 in March. Nespoli repeated these procedures for a second session but this time on a low-salt diet. SOLO is researching salt retention in space and the related physiological effects, which are important for long-duration human spaceflights.

The Portable Pulmonary Function System (PPFS) is continuing to support ESA's ThermoLab experiment in conjunction with NASA's Maximum Volume Oxygen (VO_2 Max) experiment. On 24 February, Catherine Coleman performed her third session of the experiment. ThermoLab uses the ESA-developed PPFS (combined with exercise) to investigate thermoregulatory and cardiovascular adaptations during rest and exercise in weightlessness.

On 10 March, Nespoli relocated the Matroshka 'phantom' facility to the Russian segment of the ISS, where all the passive radiation dosimeters were removed by Flight Engineers Alexander Kaleri and Oleg Skripochka. The dosimeters were returned to Earth for analysis on 16 March.

Equipment for the PASSAGES experiment was set up in front of the European Physiology Modules by ISS Commander Scott Kelly on 14 February. The following day he performed his first session of the experiment. On 16 February, Nespoli carried out activities for the downlink of the associated data. PASSAGES is designed to test how astronauts interpret visual information in weightlessness: it aims at studying the effects of microgravity on the use of the 'Eye-Height' strategy for estimating allowed actions in an environment, and whether this could possibly decrease after a long exposure to weightlessness.

After Nespoli set up the experiment hardware, he and Catherine Coleman carried out sessions of the 3D-Space experiment on 21 January and 12 February. This human physiology study investigates the effects of weightlessness on the mental representation of visual information during and post-flight.

The four biocontainers for the Coloured Fungi in Space experiment (CFS-A) arrived at the ISS with STS-133 on 26 February. Three of these contained live cultures, while one contained dry spores. The first photos of the experiment samples were taken by Scott Kelly on 28 February. The photos were retrieved by the Biotechnology Space Support

Paolo Nespoli with 3D-Space experiment

Centre (BIOTESC) in Zurich, Switzerland, the following day. Kelly carried out a second photo session on 4 March. The three live culture biocontainers for the short-term part of the experiment were returned with STS-133. The dry spore biocontainer is remaining in orbit for several months and is scheduled to return on a Soyuz in September. CFS-A is examining the survival and growth of different-coloured fungi species, which can be relevant to spacecraft contamination, panspermia and planetary protection issues.

Materials and Fluids Research

The final sample for the MICAST experiment was inserted into the newly installed Solidification and Quenching Furnace of the Material Science Laboratory on 18 January by Catherine Coleman. The following day, after a chamber leak test, the experiment started. It concluded on 20 January after heating of the sample to a molten state, solidification and cooling went as planned. Coleman removed the sample the following day, completing the processing of the first batch of samples for the ESA/NASA CETSOL/MICAST experiments.

Italian schoolchildren at the Greenhouse in Space event at ESRIN, Frascati

Activities for Geoflow-2 are scheduled to begin soon, with the removal of the Experiment Container from ATV *Johannes Kepler* and Paolo Nespoli installing it in the Fluid Science Laboratory.

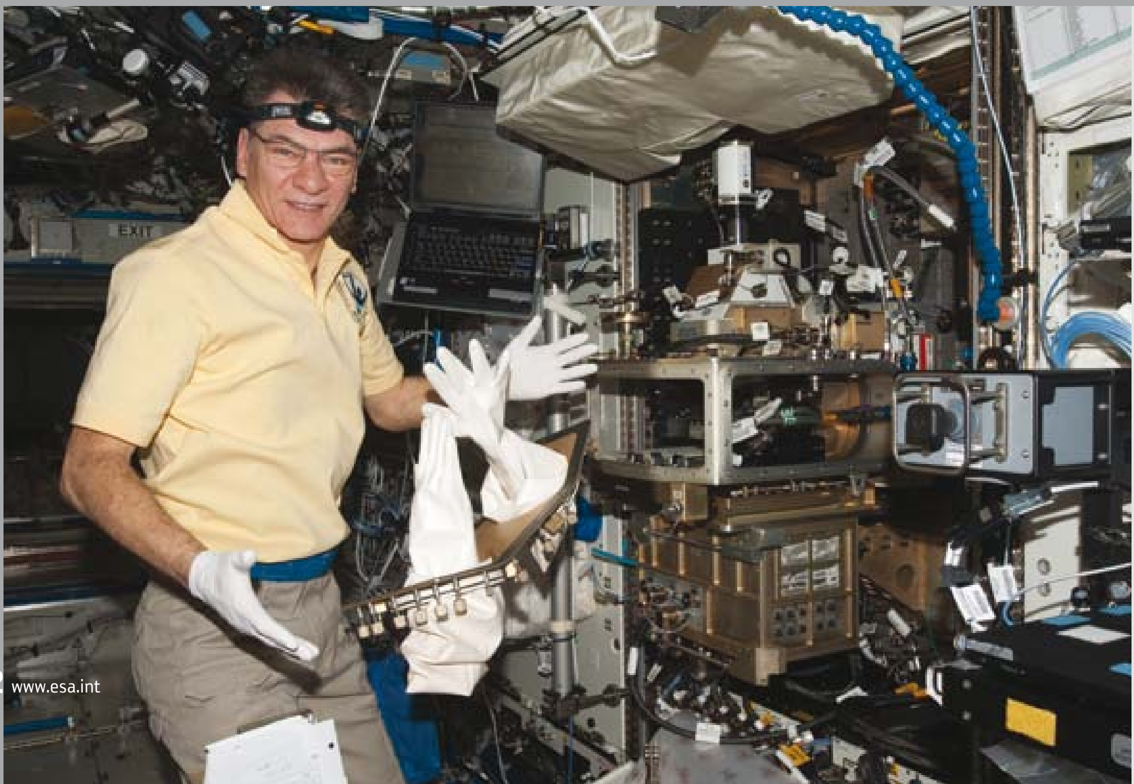
Educational activities

Several sites in Europe were connected live with the ISS on 17 February when Paolo Nespoli encouraged several hundred children, aged 12–14, to take part in the 'Greenhouse in Space' education experiment. The experiment in the Columbus laboratory involved Nespoli adding water to two plant growth chambers (one containing lettuce seeds, the other *Arabidopsis* seeds). Photos taken on orbit confirmed two plants growing.

Unfortunately, towards the end of the experiment, mould growth was seen in photos of the *Arabidopsis* chamber. To stay within ISS safety guidelines, the chamber had to be sealed and marked for disposal.

→ ASTRONAUTS

Crew training for ISS Expeditions 28 to 31 is on schedule. André Kuipers (NL) continues his training for ISS Expeditions 30/31, starting with a launch on Soyuz at the end of 2011. Luca Parmitano (IT) has been assigned as Flight Engineer for Expeditions 36 and 37, flying on a long-duration mission to the ISS from May to November 2013.



Paolo Nespoli works with the Light Microscopy Module of the Fluids Integrated Rack in the Destiny laboratory

Roberto Vittori spent a great deal of time at Houston, Texas, and Kennedy Space Center, Florida, in training for his STS-134 mission. Here, the STS-134 crew practise emergency procedures, making their way towards a slidewire basket that would take them to a safe bunker below the pad (NASA/K. Shiflett)

→ CREW TRANSPORTATION AND HUMAN EXPLORATION

Expert

Vehicle integration at the Thales Alenia Space Italy is progressing. Agreements to finance the European industrial subcontractors have been confirmed by Belgium, Austria, Switzerland, the Netherlands and Italy. Permission for launch is expected from Russian authorities in time for a mid-2011 launch.

Lunar Lander Activities

In Phase-B1, the ITT for lidar breadboard activities with Canadian companies closed in March. New ITTs are in preparation for additional activities with Spanish industry. The Arianespace Soyuz launcher performance analysis is in progress. In response to the four ITTs for payload accommodation studies from November, several proposals have been received and evaluated. One activity, on Dust Microscopy and Composition, was initiated on 7 March with SEA, UK.

International Architecture Development and Scenario Studies

The ESA internal mid-term scenario review was held on 13 January for the development of ESA benchmark scenarios and the methodology for a comparative scenario assessment.

Luca Parmitano during spacewalk familiarisation training in ESA's Neutral Buoyancy Facility at the European Astronaut Centre in Cologne, Germany

US President Obama and First Lady meet with STS-134 crew after their postponed launch on 29 April. From left, Andrew Feustel, Roberto Vittori, Michael Fincke, Gregory H. Johnson, Greg Chamitoff and Mark Kelly (NASA/B. Ingalls)

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