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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, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Slovenia is an Associate Member. Canada takes part in some projects under a cooperation agreement. Bulgaria, Cyprus, Malta, Latvia, Lithuania and Slovakia have cooperation agreements with ESA.

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.

EAC, Cologne, Germany.

ECSAT, Harwell, United Kingdom.

ESA Redu, Belgium.

Chair of the Council:
Jean-Yves Le Gall

Director General:
Jan Woerner

←

On cover:
ESA astronaut Thomas Pesquet photographed by NASA colleague Shane Kimbrough during their spacewalk from the International Space Station on 13 January 2017 (NASA/ESA)

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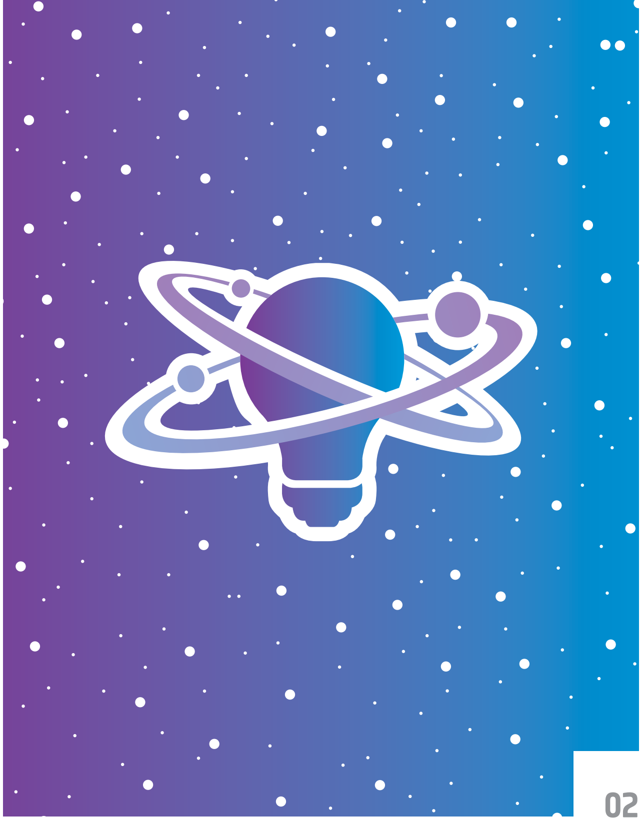

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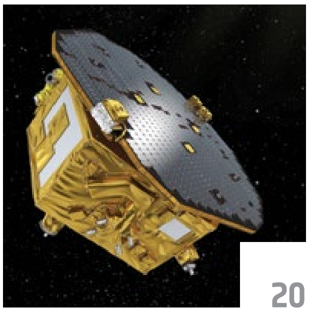

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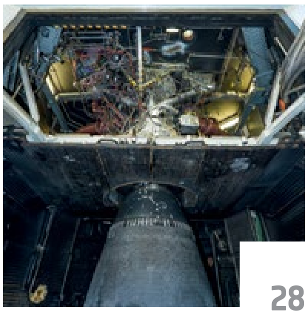

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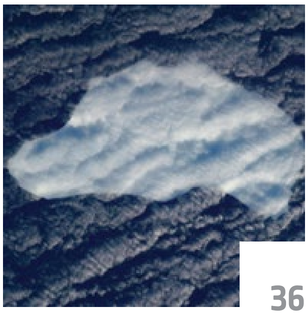

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→ OPEN FOR BUSINESS

Opportunities for private sector industry in space

Bernhard Hufenbach
Directorate of Human Spaceflight and Robotic Exploration,
ESTEC, Noordwijk, the Netherlands

A new era of space foresees a future with more partnerships with the private sector and where space agencies won't be the only actors.

An unprecedented event took place last year in London: for the first time, ESA invited the space and non-space industry to sit together and exchange ideas on what the future of space exploration holds for them – both on Earth and in space. The event, Space for inspiration – ISS and beyond, was born with the aim of inspiring new and exciting ventures. It was an open invitation to a broader community to join the space club, a unique opportunity to build cross-sector relationships and learn about promising research taking place in orbit.

Nearly 300 people gathered in one of the world's most renowned science venues, the London Science Museum, on 14–15 September. One third of the audience came from industry, and that was part of the plan. The idea was to engage new stakeholders from institutional and private sectors with the non-space community.

"We wanted to draw more people into the future, and explain how they can get involved. The opportunities are unlimited," said David Parker, ESA's Director of Human Spaceflight and Robotic Exploration. "We all have to take advantage of the amazing thing we have created on the International Space Station," he added.

Reinventing 'low Earth orbit'

There was much talk about the value and benefits resulting from the International Space Station (ISS) – without doubt a beacon of human achievement. The Space Station is a global platform for research and development, with scientists from over 90 nations running experiments to drive innovation.

The main part of the assembly of the Space Station was completed in 2011, and since then there has now been five years of operations and intensive research. "The ISS is the fastest moving incubation centre. It has proven itself as a business accelerator," pointed out Rainer Horn, from SpaceTec Partners.

A recent study presented during the event assessed the economic and wider impact of the investment on the Space Station programme, and the figures unveiled were quite revealing: every euro spent on the Station produces a 1.8 euro return for the European economy. The Space Station is also a job generator, for each new job supported in the space sector thanks to the Space Station programme, one additional job was supported in the wider economy.

More and more, this platform in low Earth orbit (LEO) is becoming a place that is not just limited to what space agencies do. For Marybeth Edeen, manager of NASA's ISS Research Integration Office, the formula is clear. "We should allow companies as much time, effort and risk they are willing to accept. Whether their research is going to be successful has to be their discussion, not our decision. We need to scale back our requirements to make it as simple as we can for them to get to orbit."

Scientists and private companies were invited to take advantage of the Space Station. David Parker even made an offer – a third of all the research opportunities should be offered to industry. NASA is already proposing 50% of ISS resources to be allocated to commercial utilisation.

However, there was also the acknowledgement that research in space is not an easy thing to take on. "It is not immediately obvious where microgravity experimentation can come in handy for industry," explained Chris Bee, ESA Technology Transfer Broker for UK.

When contacting companies to promote research and development of their products and ideas in space, "We just have about a 100 to 1 success rate. It is like truffle hunting," Bee added. According to him, this 'Space for Inspiration' event was key to improve that success rate.

ESA Member States decided during the ESA Council at ministerial level in December 2016 on the continued funding for ISS exploitation activities through 2024, and the international partners wish to keep it orbiting Earth as much as they can, taking into account that it has been technically certified for operations up to 2028. However, there is the need to find a way to transition smoothly from the Station to a new platform. NASA intends to cede low Earth orbit to commercial ventures.

When more and more people regularly enter orbit, "We could industrialise spaceflight, and that will allow us to explore deep space in a sustainable way," believes Michael Suffredini, president of the commercial space division of Stinger Ghaffarian Technologies.

Space goes commercial

In March 2015, ESA launched an initiative aimed at opening new opportunities to the private sector. Industrial partners were invited to come forward with partnership ideas that will help us advance objectives for exploration, but driven by an industrial business plan.

Agencies would no longer be the only customer, and by doing so they could strengthen the economic dimension

↓ David Parker, ESA's Director of Human Spaceflight and Robotic Exploration (ESA/M. Alexander)

"Experts called for a broader access and use of the Space Station. Let's be more flexible and open-minded."

of space exploration, and ultimately contribute to the sustainability of space exploration of low Earth orbit and beyond.

ESA is offering a launch pad to develop products and services. Following a call for ideas, ESA and eight private partners have concurred their mutual interest on projects that will each be carried forward through a pilot phase to assess its feasibility and commercial viability.

Most of the attendees confirmed this trend. During a live poll among the audience, most of the participants voted for industry having a driving role in the push for commercial utilisation of space, an opinion shared by Walter Cugno, vice president of Exploration and Science Domain at Thales Alenia Space Italy. "The role of the private companies in LEO should be increased, and business plans put in place," he said.

"In the US there is a tremendous amount of risk taken. It takes some guts, passion and long-term commitment going after commercial space," maintains John Roth, who works in strategy and business development at Sierra Nevada Corporation.

Public–private partnerships seem to be the key for low Earth orbit operations. "The end users of LEO commercialisation will be hybrid," thinks Bart Reijnen, head of Airbus Defence & Space, Bremen.

New space

The 'new space' is a crossroad of sectors, resources and people. ESA is already forging new partnerships with the private sector and planning new ways of working together.

Mariana Mazzucato, professor of Science Policy Research at the University of Sussex, highlighted the success of mission-oriented organisations like ESA, and the role of the governments supporting them.

"I want to debunk the dichotomy between the boring-but-needed fix-the-basics-problems-public sector versus revolutionary Elon Musk. Elon, be part of the new conversation. Government is more than just the money it collects from taxes," she said.

Rainer Horn explained, "While billionaires such as Elon Musk attract other entrepreneurs into the game, this 'new space' is very particular in the way it motivates a unique type of personnel. The talented staff is not motivated for technological perfection, but to achieve ambition."

"Why don't we provide our platforms to entrepreneurs, investors and the public to enable them to start working with all these technologies?" asked Rob Suters, Melissa X.

"Now is the time to plan new ways of working together. The clock is ticking."

↑ Mariana Mazzucato, Professor of Science Policy Research at the University of Sussex (ESA/M. Alexander)

"We decided to move away from the classical technology transfer model, and change the paradigm," he said.

ESA Director General Jan Woerner has coined the concept 'Space 4.0'. This new version of space is will be driven by 'innovation, information, inspiration and interaction'.

ESA Director General Jan Woerner's vision for space, 'Space 4.0', will be driven by innovation, information, inspiration and interaction (ESA/M. Alexander)

→ Success story: Resting for science

Similar to bedridden people on Earth, astronauts' muscles lose strength from underuse in space. Bedrest studies offer scientists a way to see how the human body adapts to weightlessness, and to evaluate countermeasures. "This research has been a tremendous accelerator in the development of high-resolution scanners and non-invasive techniques allowing us to look at the microstructure of the bone with unprecedented resolution," says Laurence Vico, research director from French National Institute of Health and Medical Research.

Bedrest volunteer during a leg scan in Toulouse, France (CNES/E. Grimault)

Space to inspire

Exploration is not only science, but also economic gain. It is not only international cooperation, but also inspiration - for everyone on planet Earth.

Engagement is an important part of the process. "Whether you work in the fashion, farming, food or film industries, the message is to be as inclusive as you can," said film producer Duncan Copp. "The more we assimilate the idea of space into the fabric of society, the easier people will accept it," he added.

Truly inspirational were the talks by ESA astronauts Tim Peake and Luca Parmitano, as well as by NASA astronaut Don Pettit. Their breathtaking stories about their experiences in orbit fascinated the audience. Social media are an innovative and direct tool in the mission communication strategy, pointed out Luigi Scatteia, senior manager at Space PwC Paris. We know that Twitter and Facebook accounts of astronauts have a following comparable to Prime Ministers and rock stars. "This is a real indication of astronaut reach and inspirational value," said Luigi. It is not by chance that six out of ten most watched videos published on the ESA YouTube account are related to human spaceflight.

'Space for Inspiration' was also a celebration of the diversity and pervasiveness of space in technology, industry and culture. Other speakers introduced work that used space as inspiration, including Danish Michelin-starred chef Thorsten Schmidt, British research doctor Beth Healey (who spent a year in Antarctica), Italian professor of design Annalisa Dominoni of the Politecnico di Milano and David Honess, Raspberry Pi Foundation's education engineer.

Down to Earth

Innovative solutions 'made in space' are helping to shape our daily lives and address global challenges on Earth in areas such as energy, health and food production.

An ESA-developed water treatment system was chosen as one of the 100 top climate technologies at the latest UN climate change conference. It was developed for the remote Concordia station in Antarctica and it is being used right now in Morocco.

Rob Suters, managing director of IPStar BV, said, "The challenges in space are essentially the same as on Earth: water, waste, food and energy." Abhay Bhagwat, senior director for sustainable innovation at Unilever, agreed saying "I don't see any conflict between meeting the basic needs of the human population and thinking about the future of mankind."

In this context, Pedro Matos, project manager of the World Food Programme, believes that it would be unrealistic to ask mankind to stop dreaming about space exploration for two decades until we solve our problems on Earth. "Incredible technological advances in the past years have lifted a billion people out of poverty," he claimed.

Future steps

The 'Space for Inspiration' event has been the start of a process, and it is not intended to be a one-off. "We want to build new partnerships and explain that the Space Station is not just about space agencies. We want to use this opportunity as a kick starter to interact with a broader community," said ESA's David Parker.

ESA wants to keep exploring our Solar System and beyond, and Europe is at the beginning of an exciting adventure, mobilising efforts and ideas to get farther into space. After all, as Kirk Shireman puts it, in his role of manager of NASA's ISS programme, "Our teenagers have never known a time when humans didn't live and work in space. What a wonderful thing that is."

Event website: space4inspiration.esa.int

> **"We don't want to stop dreaming about a better future on Earth and in space."**

→ Success story: Plasma for a safer world

When physicist Gregor Morfill began studying the fundamental science behind plasma (electrically charged gas) on the Space Station more than two decades ago, he paved the way to a technology that can save many lives with the touch of a button. "Cold-plasma tools can be used to fight superbugs that are increasingly resistant to antibiotics," explained Gregor. A revolutionary device is being developed to treat chronic wounds in hospitals, and should one day make it into our homes.

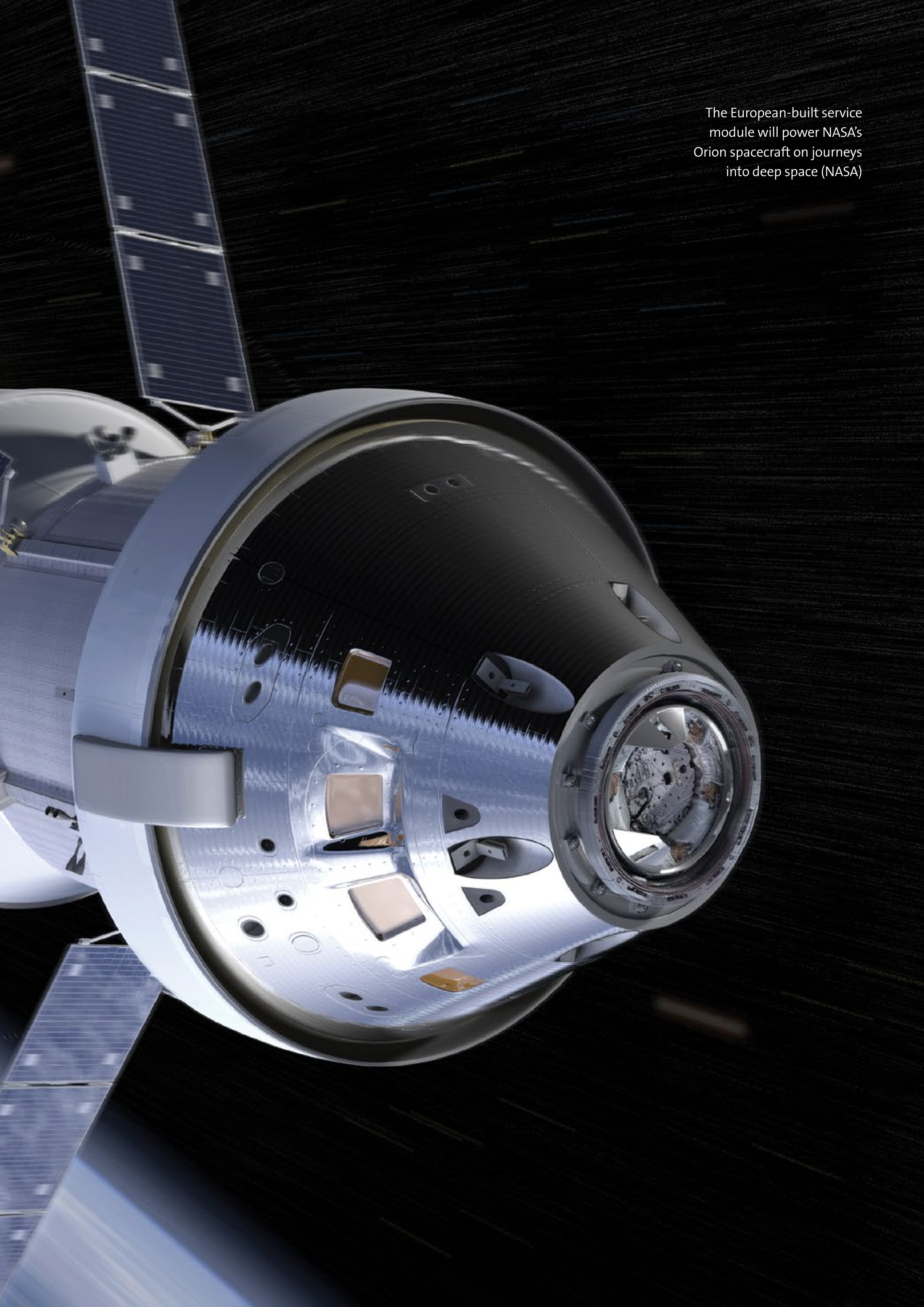
↓ Russian cosmonaut Oleg Kotov inspects the Plasma Kristall Experiment laboratory, on the International Space Station (RKK-Energia)

→ EUROPE'S TICKET TO DEEP SPACE

The Orion European Service Module

Nadjejda Vicente
Directorate of Human Spaceflight & Robotic Exploration, ESTEC, Noordwijk, the Netherlands

Carl Walker
Communications Department, ESTEC, Noordwijk, the Netherlands



The European-built service module will power NASA's Orion spacecraft on journeys into deep space (NASA)

Sixty years into the history of spaceflight, Europe is now supporting humanity's deep-space ambitions with its contribution to NASA's Orion spacecraft – the European Service Module (ESM).

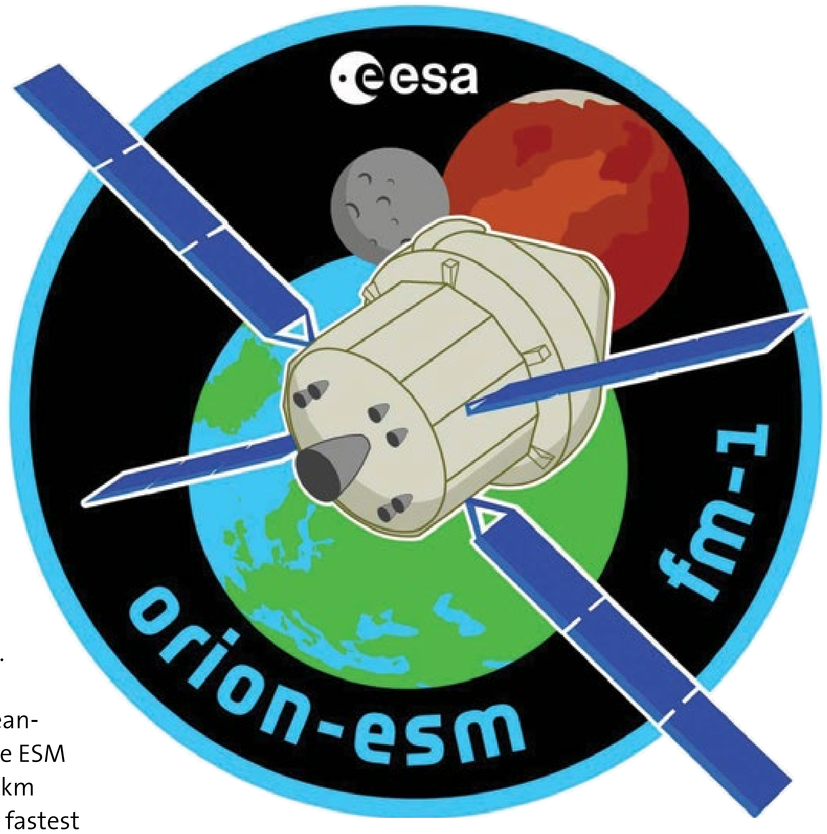
NASA's Orion is steadily taking shape, promising to take astronauts farther than they have ever gone before. This versatile vehicle is designed to take humans into deep space, away from low Earth orbit. Orion will be the most advanced spacecraft ever built for humans, flexible enough to be upgraded with technical innovations as the challenges of its missions increase.

Orion embarked on its first journey into space in 2014, when it made a successful four-and-a-half hour test flight. Now, NASA is getting its next spaceship ready for a bold mission beyond the Moon.

The first Orion exploration mission to use the European-built service module is targeted to launch in 2018. The ESM will power the spacecraft on its journey over 64 000 km beyond the Moon, returning to Earth at 11 km/s – the fastest reentry ever for a crew capsule since the Apollo era.

Although uncrewed, the ESM will also provide electricity, water, oxygen and nitrogen, testing these functions that will help sustain future crews during long journeys into deep space. In the second mission, the ESM will have extra oxygen tanks added.

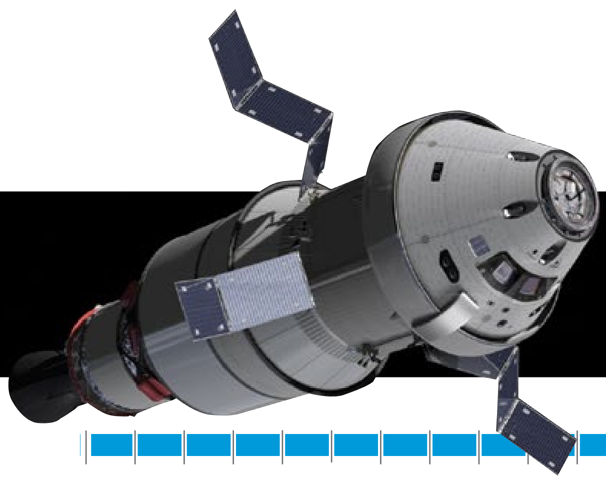
NASA has plans for many missions for Orion to gain experience with deep-space operations and prepare for future missions to Mars.



The European push

For the first time since 1972, the end of the Apollo era, a crewed mission will fly around the Moon in the early 2020s, and European technology will be part of it. This is also the first time that ESA is playing such a crucial technical role for a US human transportation vehicle.

ESA has signed agreements with NASA to provide the ESM for the first two Orion flights with the Space Launch System rocket. This way, ESA fulfils a portion of its share of operational costs and supporting services for the International Space Station.



→ ORION MISSIONS

DECEMBER 2014

Exploration Flight Test-1
- Validation of flight control systems, heat shield and reentry

2019

Exploration Mission-1
- Uncrewed flight around Moon (distant retrograde orbit)
- First flight on NASA's new Space Launch System

2021

Exploration Mission-2
- First crewed flight
- Eight-day lunar flyby on free-return trajectory

← Engineers and astronauts conduct an evaluation of the design of the docking hatch in a mock-up of the Orion spacecraft at NASA's Johnson Space Center, Houston (NASA)

"ESA's provision of the Orion service module builds on our partnership and extends it to exploration activities beyond low-Earth orbit, including the journey to Mars," explains James Free, NASA Deputy Associate Administrator for Human Exploration and Operations.

ESA has a huge background of cooperation with NASA. "We have been working with them since Spacelab and the early days of the International Space Station, and we have a good understanding of their needs," says Philippe Deloo, ESA's Orion ESM Programme Manager.

The ESM relies on derived Automated Transfer Vehicle (ATV) technology. More than 20 companies around Europe are working on the project, most drawing on the expertise earned from the five ATVs that made regular deliveries of experiment equipment, spare parts, food, air and water for the Space Station from 2009 to 2015.

↑ Solar array test deployment on 29 February 2015 at NASA's Plum Brook Station test facility in USA (Airbus D&S)

→ Orion European Service Module

An international collaboration

Germany

- Prime contractor
- European Service Module assembly integration and verification
- Propulsion and propulsion drive electronics
- Centralised parts procurement agent
- Onboard data network harness for qualification module

Belgium

- Tank bulkhead
- Electrical ground support equipment
- Pressure regulation units

Denmark

- Front end electronics
- Electrical ground support equipment

Switzerland

- Secondary structure
- Solar array drive assembly
- Solar array simulator
- Mechanical ground support equipment

France

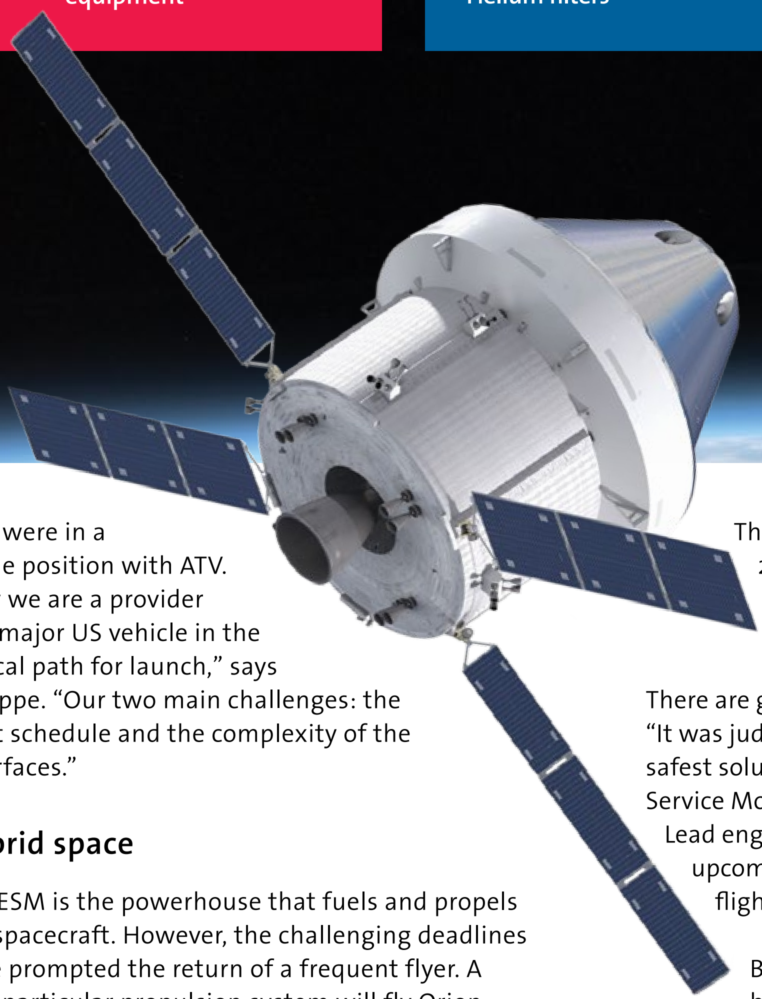
- System tasks
- Avionics qualification
- Direct current harness
- Front-end electronics
- Helium filters

Sweden

- Propulsion Qualification Model integration

USA

- Gas tank
- Valves
- Onboard data network harness for Flight Model



"We were in a prime position with ATV. Now we are a provider of a major US vehicle in the critical path for launch," says Philippe. "Our two main challenges: the tight schedule and the complexity of the interfaces."

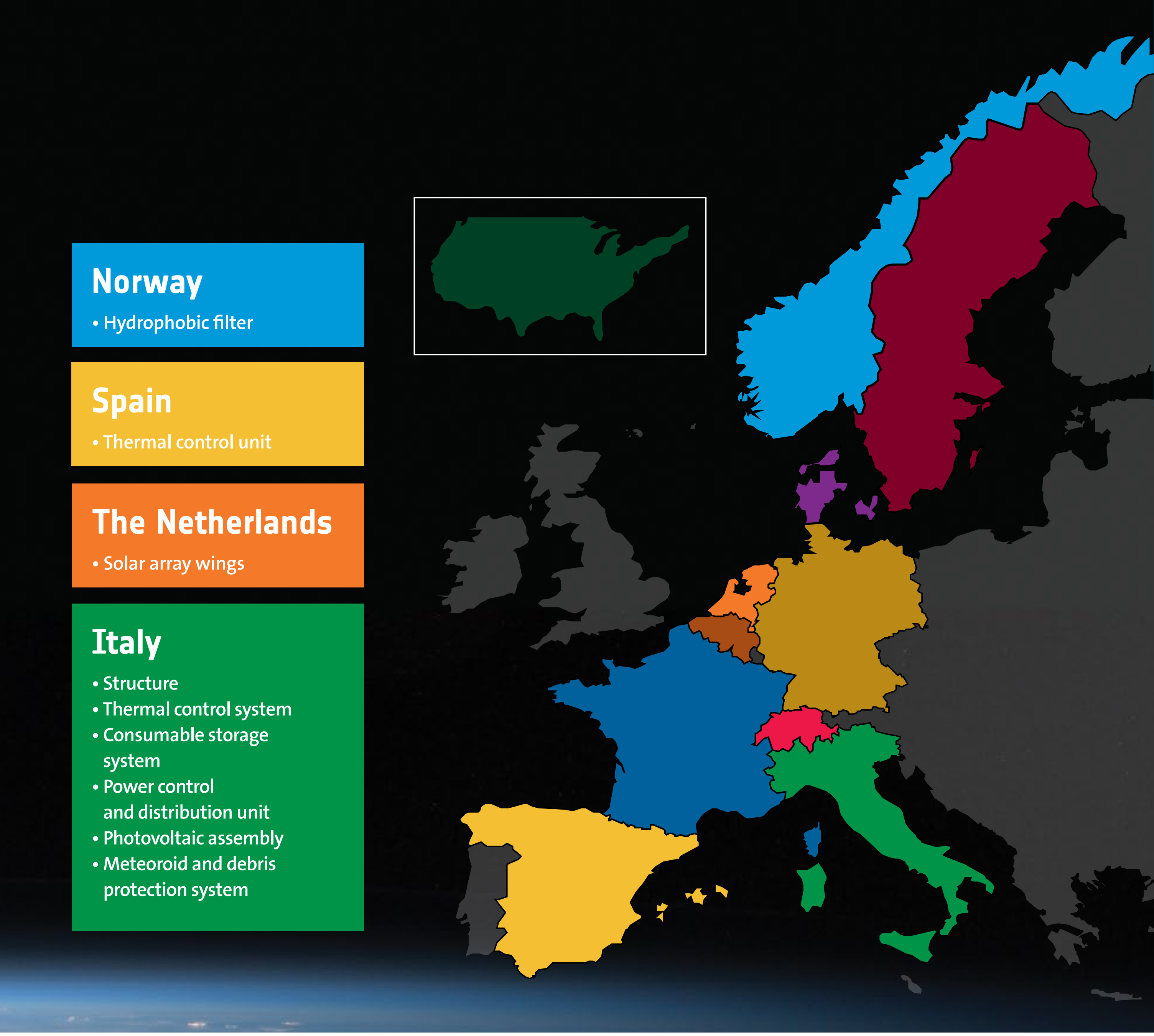
Hybrid space

The ESM is the powerhouse that fuels and propels the spacecraft. However, the challenging deadlines have prompted the return of a frequent flyer. A very particular propulsion system will fly Orion beyond the Moon and back: the Space Shuttle Orbital Manoeuvering System. Having provided the Space Shuttle's final orbit insertion and deorbit manoeuvres for all its flights, this engine returns to the space arena for a new mission, to propel NASA's next-generation spacecraft.

The production of this Shuttle engine stopped in 2000, but the recall of a batch from storage is making possible a hybrid of old and new. The formula is unusual, but not unique.

There are good reasons to rely on past Shuttle technology. "It was judged as the most cost-efficient, fastest and safest solution to provide the main engine to the European Service Module," explains Thierry Kachler, ESA Propulsion Lead engineer in this programme. The one flying on the upcoming Orion mission (serial number 111) had its first flight in 1984.

Besides its long flight experience, the engine is human-rated. In the space jargon, that means it is capable of accommodating human needs and is safe enough for the crew. The whole system was extensively tested in the 1970s and 1980s to be qualified for the transportation of astronauts. Three European astronauts have flown on Shuttle missions using this particular



Orbital Maneuvering System engine in 1992: Belgian Dirk Frimout, Italian Franco Malerba and Swiss Claude Nicollier.

Orion's main engine is the same one as used by the Space Shuttle. It has a thrust of roughly three tonnes and burns propellant that can be stored under room temperature for long periods. This propellant is directly fed from the ESM tanks into the combustion chamber through valves.

These engines will be used for a few missions and repurposing them is not an easy task. "The main challenge is to prove that these engines, built in the 1970s, are still in good condition. Some parts are subject to ageing, but NASA is ensuring that the long storage did not affect their reliability," says Thierry.

Actually, the ESM has 33 engines in total to provide thrust and manoeuvre the spacecraft on all axes.

Here Thierry emphasises another challenge: the interface of the Thrust Vector Control – the gimballing system that orients the thrust – is based on analogue systems, an obsolete technology for the current digital standards. "We had to adapt the ATV-derived control interface to work with

> **"Named after one of the largest constellations in the night sky, the spirit of exploration is at its very core."**

↑ The NASA Orbital Maneuvering System engine (NASA)

↑ The Propulsion Qualification Model will be used to check that the Orion European Service Module spacecraft's propulsion subsystem functions correctly

NASA technology from the 1970s. It is like playing a Nintendo game with an emulator on a modern PC," said Thierry.

The next milestone will be the Propulsion Qualification Model testing later this year. This is where the main engine will be tested in hot-firing conditions at NASA's White Sands Test Facility in New Mexico. Here, the main engine, with the rest of the propulsion subsystem including eight auxiliary thrusters and 12 smaller reaction control system (RCS) thrusters produced by Airbus Safran Launchers, will be fired for real. The ESM Flight Model itself has 24 RCS thrusters compared to Qualification Model's 12. The extra set of RCS thrusters have been left out of the Qualification Model, because they are not required to verify the overall propulsion system and are therefore redundant.

↑ ESA astronaut Claude Nicollier

The astronaut's view

When Claude Nicollier flew into space for the first time on STS-46 in 1992, the Space Shuttle Atlantis used the same engine for orbital manoeuvres that will soon take Orion beyond the Moon.

The two Orbital Maneuvering System engines generated about 5.5 tons of thrust. "It provided an acceleration which was less than a tenth of the gravity on the surface of Earth. Not very spectacular, but it felt like a lot for the crew in the weightless environment of space," remembers Claude, now a professor at the Swiss Federal Institute of Technology in Lausanne, almost 25 years since this flight.

As an ESA astronaut, he was involved in Shuttle avionics testing and supported International Space Station robotics development. He is pleased with the choice of propulsion for the Orion spacecraft, and highlights its success rate. "The most significant technical feature is the remarkable reliability of this engine. With zero failures in 135 missions, the Shuttle engines helped ensure the critical functions of final orbit insertion and the deorbit manoeuvres before reentry into Earth's atmosphere," explained Claude.

Team work

The ESM would not be possible without a unique collaboration across space agencies, countries and companies. Hundreds of suppliers and businesses from both sides of the Atlantic are approaching the end of Orion's development phase, having taken on the engineering challenges of deep space travel. Their components will form the chassis and supply life support and propulsion to the crew capsule.

→ WHAT'S NEXT FOR ESM-1?

2017

Propulsion Qualification Model test
- Extensive testing of the propulsion system, including 'hot-firing'

NASA White Sands Test Facility, New Mexico, USA

ESM avionics
- Qualification of software with an electronic mockup of vehicle avionics

Lockheed, Denver, USA

LATE 2017

ESM integration
- Equipment coming from all over Europe and USA assembled

Airbus, Bremen, Germany

2018

ESM delivery

Kennedy Space Center, USA

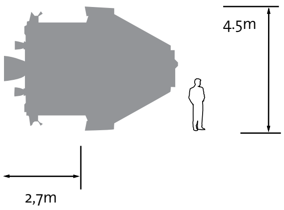
MID 2018

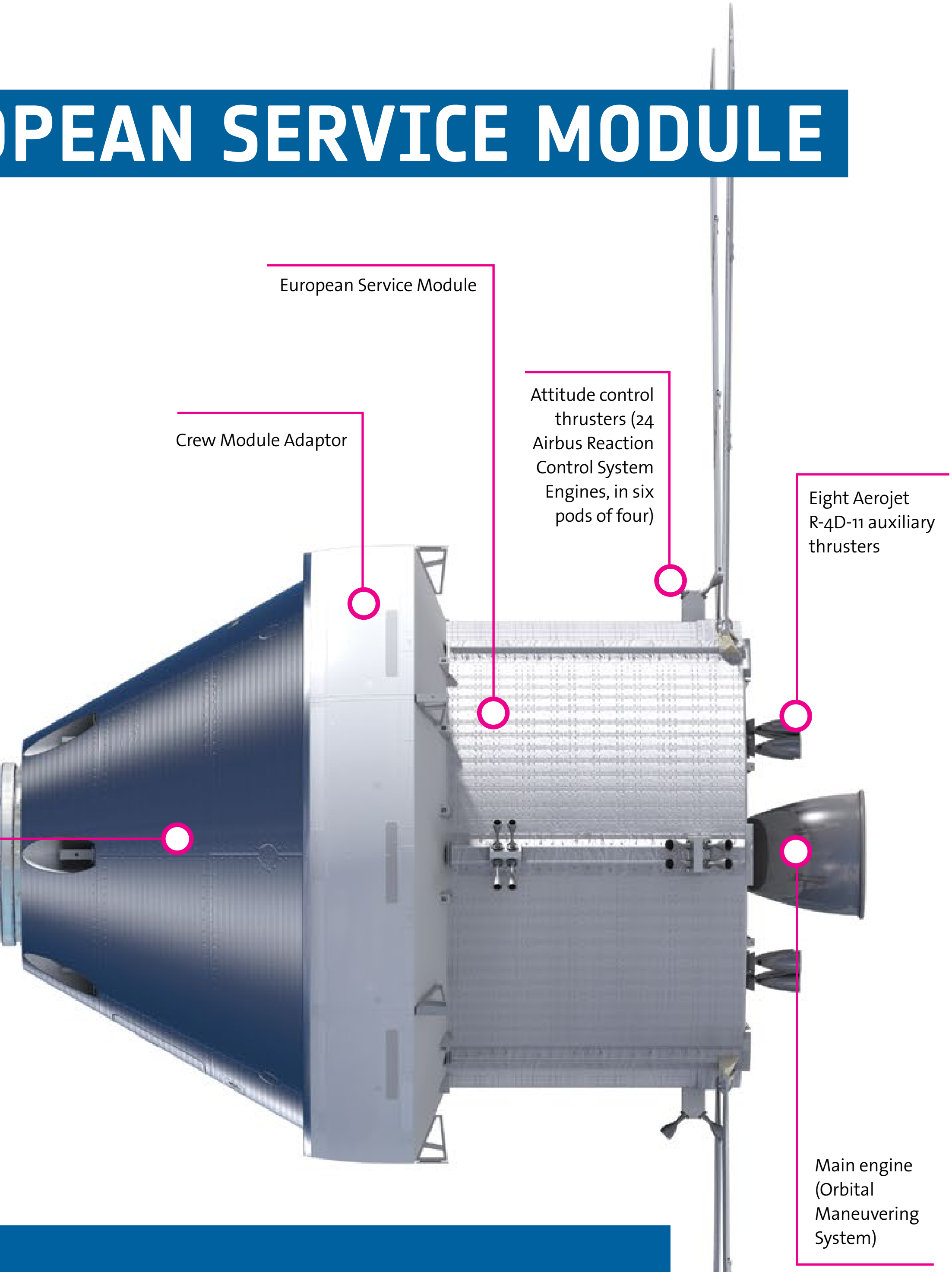
Stacking
- Crew Module and ESM fitted together for launch vehicle. Final outfitting and assembly process

Kennedy Space Center, USA

→ EUROPEAN SERVICE MODULE

Dimensions

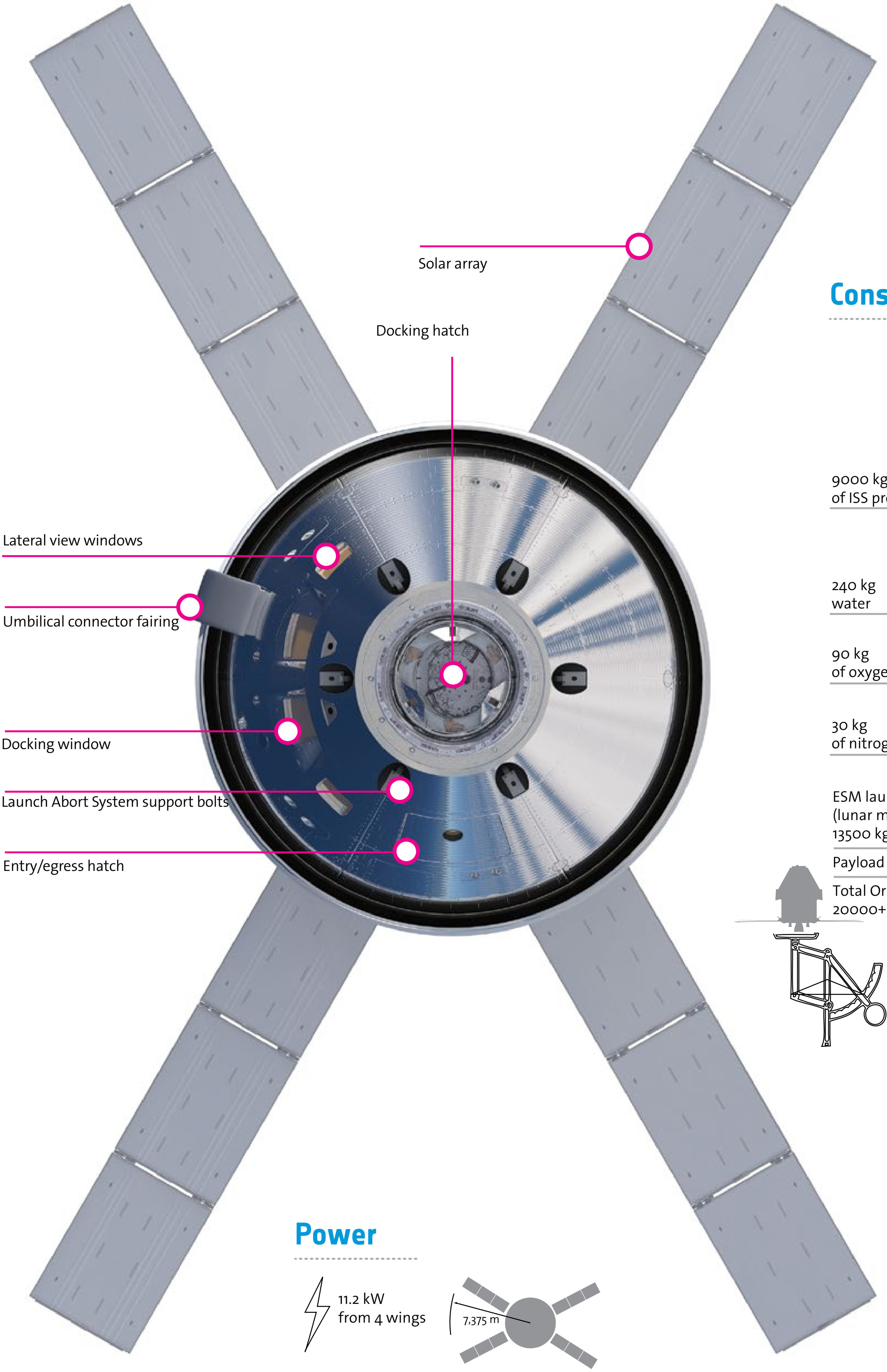




→ About the European Service Module (ESM)

The ESM sits directly under the Crew Module and provides four major system functions to Orion: propulsion, power, thermal control and life support for the astronauts (water and a breathable atmosphere). It detaches from the Crew Module shortly before the capsule reenters Earth's atmosphere.

The module is a quarter of the length of that of its predecessor, the ATV. The solar arrays attached to the ESM collect and transport energy to charge the batteries on the Crew Module. These solar panels use gallium arsenide technology and supply over 11 kW – enough for the energy needs of a typical household, and twice as much as the Apollo Command Service Modules which previously took man to the Moon. The ESM will be able to support a crew of four for 21 days against the 14-day endurance for the three-man Apollo.



Consumables

9000 kg
of ISS propellant

240 kg
water

90 kg
of oxygen

30 kg
of nitrogen

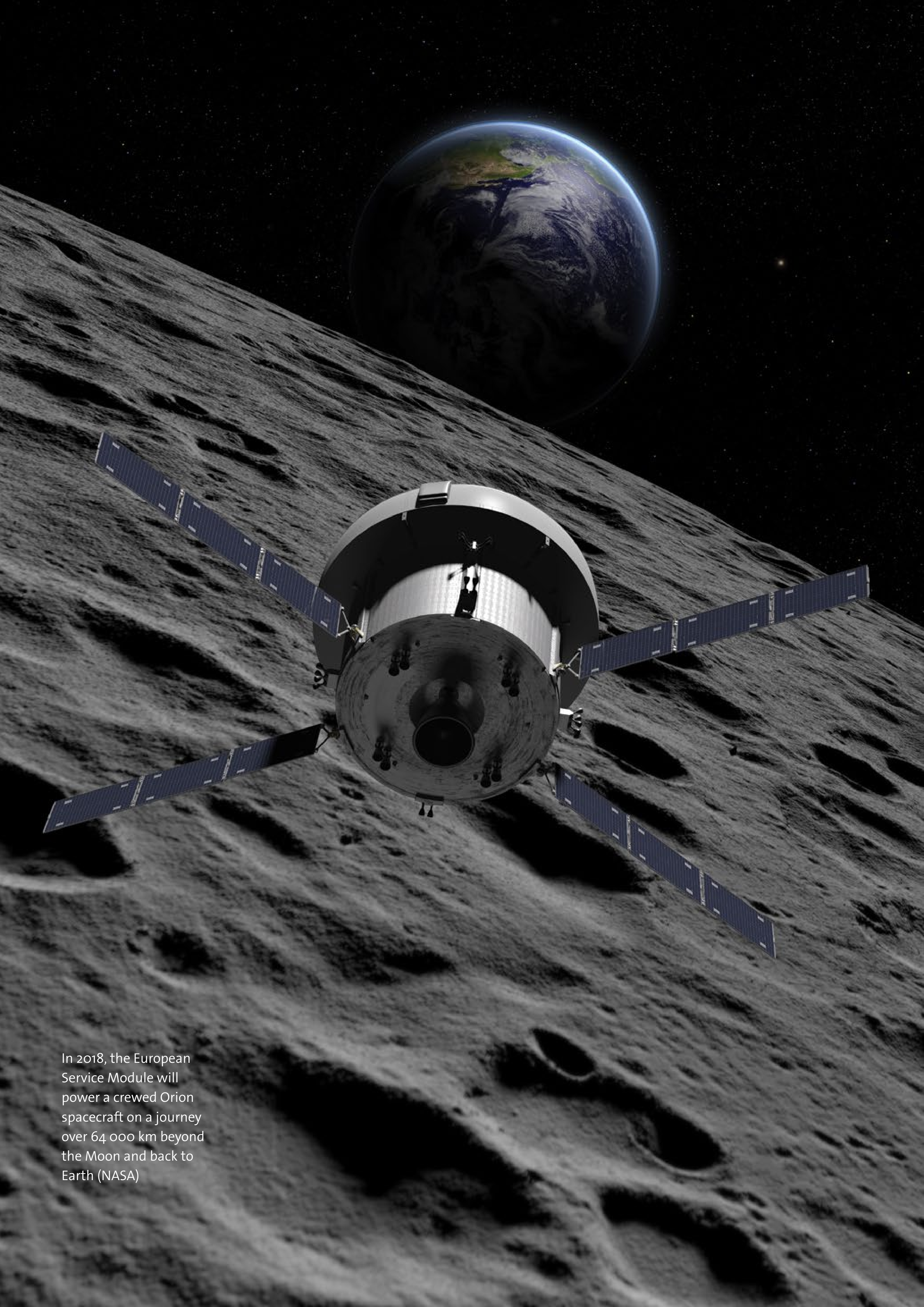
ESM launch mass
(lunar missions):
13500 kg

Payload mass: 380 kg

Total Orion mass:
20000+ kg

Power

11.2 kW
from 4 wings



In 2018, the European Service Module will power a crewed Orion spacecraft on a journey over 64 000 km beyond the Moon and back to Earth (NASA)

←

Marking the kick-off of Orion European Service Module assembly on 19 May 2016 with, from left: NASA's James Free, ESA Director General Jan Woerner, Carsten Sieling (Lord Mayor of Bremen), Bart Reijnen of Airbus Defence & Space, and Michael Hawes of Lockheed Martin (Airbus D&S)

Team spirit has played a key role in bringing people and resources together right from the start. "International collaboration is an important part of the effort that NASA is leading to pioneer deep space, and the European Space Agency is one of our oldest partners in this endeavour," says James Free, Deputy Associate Administrator of NASA's Human Exploration and Operations Mission Directorate.
ESA's involvement in Orion is productive and mutually beneficial, says James. "NASA looks forward to continuing cooperation with ESA on the Orion service module, the International Space Station to at least 2024, and exploration into deep space."

↓ Engineers at NASA Glenn's Plum Brook Station in Ohio preparing for the first major structural test of Orion's European Service Module for Exploration Mission-1 (NASA)

In Europe, companies from 11 countries have built spacecraft-specific parts for Orion or supplied their proven space-hardware to construct the spacecraft that will fly farther than any other human-rated spacecraft.

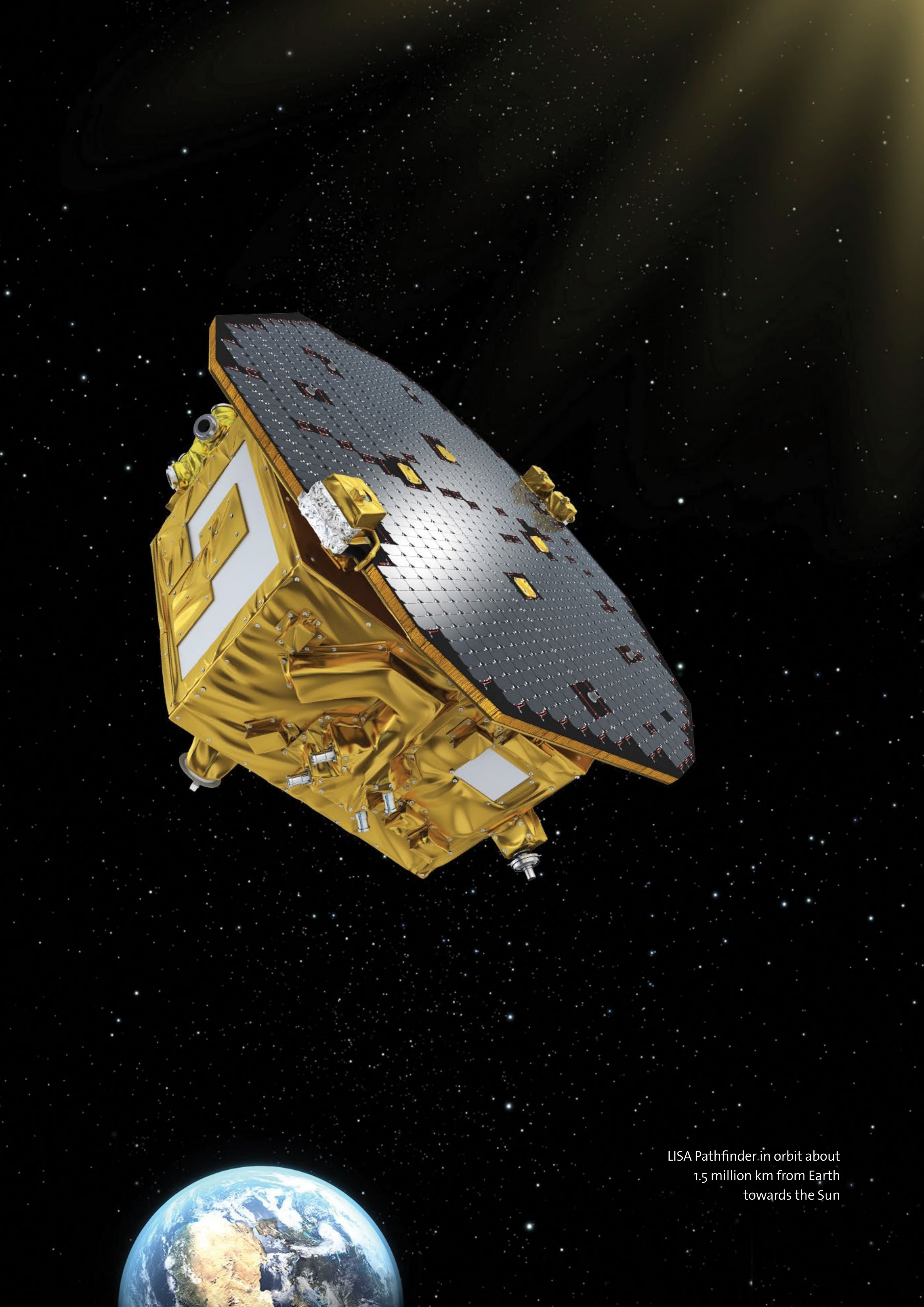
Airbus Defence & Space, the world's second largest space company, is managing the development and construction of the ESM for ESA. Its Bremen facility is the main hub, bringing together the expertise that partners and suppliers have gained over the years.

"Although we all have a long tradition, knowhow and expertise in human spaceflight all the way back to the Spacelab era, this is the first time we are involved in a such an exciting programme to send astronauts to the Moon," says Bas Theelen, Head of Orion ESM at Airbus.

Bas highlights the close and trustful cooperation between Europe and USA, but doesn't underestimate the challenges. "Our engineers are very aware that the European Service Module is a step further in complexity in several aspects. Among them, mass requirements, safety, schedule and new ways of working. And we love it," he adds.

For many European engineers, this is a lifetime opportunity to help send a spacecraft beyond the Moon. A giant leap for Europe, and yet another important and exciting chapter in the history of human spaceflight. ■

Nadjejde Vicente is an HE Space writer for ESA



LISA Pathfinder in orbit about
1.5 million km from Earth
towards the Sun

→ SIMULATION BEYOND FLIGHT OPERATIONS

The LISA Pathfinder Mission and Operational Simulator

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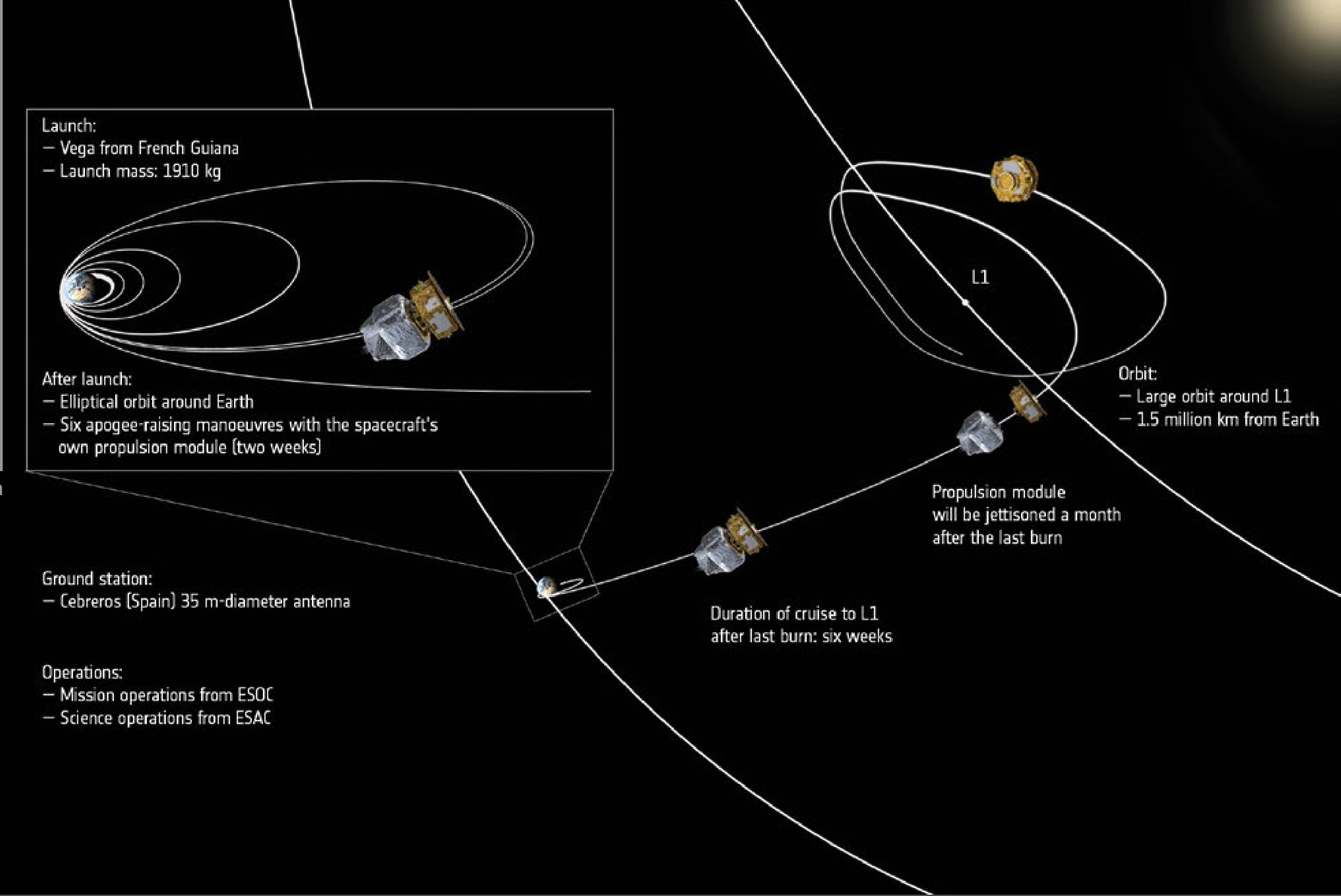
ESA's LISA Pathfinder is an unusual, unique and challenging mission, so the operational simulator needed to train its flight control and science teams needed to be equally special.

The LISA Pathfinder operational simulator was originally developed to train the flight control teams involved in the most critical mission phases, as is typical for complex space missions. This complex software-only system implements computer models of the spacecraft and of all relevant aspects of the mission to deliver a high-fidelity simulation.

For example, it models the space environment, the ground stations, the spacecraft dynamics and all spacecraft subsystems with high accuracy. It even emulates the onboard computer, i.e. the 'brain' of the spacecraft, and executes the real software running on the spacecraft.

The operational simulator generates the same housekeeping telemetry and reacts to telecommands in the same way as the real spacecraft.

But extensions of the simulator made to accommodate also science operations expanded its scope significantly. For the first time in ESA history, the same simulator was used by both the Flight Control teams and by the Science team to validate the ground segment and the scientific experiments, respectively.



↑ LISA Pathfinder's journey through space to the first Sun/Earth Lagrange point L1

The mission

LISA Pathfinder's main objective is to demonstrate inflight the key technology needed to detect gravitational waves in space, including how to build and operate a gravitational-wave observatory in space. The spacecraft consists of a science module and a separable and expendable propulsion module used to bring the spacecraft to the first Sun/Earth Lagrange point L1, 1.5 million km away from Earth in the direction of the Sun This is a 'quiet' place in space, far away from massive objects that induce forces on the spacecraft, has constant illumination from the Sun, and has a quasi-constant distance from Earth for communication.

The science module carries the LISA Technology Package, which contains two identical cubes of gold/platinum alloy measuring 46 mm on a side and weighing 1.96 kg. These cubes act as test masses and are suspended in a vacuum container. They serve as inertial references for the drag-free control system, which uses laser interferometry to measure the relative position and orientation of the test masses.

The spacecraft was launched on the 3 December 2015 from Europe's Spaceport in Kourou, French Guiana.

For 11 days, LISA Pathfinder went through the critical Launch and Early Orbit phase, consisting of several complex manoeuvres needed to take the spacecraft to its final destination at L1. The spacecraft is operated by ESA's flight control teams at the European Space Operations Centre (ESOC) in Darmstadt, Germany.

Initially, the LISA Pathfinder simulator was developed exclusively to fulfil the typical tasks of an operational simulator, which include testing and validating the LISA Pathfinder ground segment, and training the Mission Operations team. This does not require the modelling of the onboard scientific instruments. In parallel, a science simulator was available to support the LISA Pathfinder Science team to prepare the scientific operations. However, it lacked some functionalities and interfaces required to properly validate science operations and therefore a solution was needed.

The solution was found by extending the LISA Pathfinder operational simulator to cover also science operations. This provided the Science team with a versatile and reliable environment to prepare and validate the scientific operations and, for the first time, the operational and science teams shared a common simulator, which brought them even closer together.

Science operations extensions

The extended LISA Pathfinder simulator represents the first ESOC experience in the development of a fully integrated simulator for flight and science operations. It extended the operational simulator by providing both enhanced and new functionalities required by the Science team based at the European Space Astronomy Centre in Madrid, Spain.

The simulator now also allows the generation of high-fidelity science data, to exercise end-to-end procedures for scientific experiments, and to connect the science processing software through the same interfaces that are used operationally.

In order to demonstrate the fidelity of the simulator, comparisons were made after launch between the results of the scientific experiments executed on the spacecraft and the corresponding simulated data. As an example, the displacement of one of the test masses along the x-axis (the axis connecting the two test masses) was measured while an artificial disturbance was introduced into the system. This disturbance was applied at different frequencies from 1 mHz to 50 mHz. Once the disturbance is detected by the spacecraft (or equivalently by the simulator), the control system on board reacts to compensate it.

Launch of LISA Pathfinder on the Vega VV06 in December 2015

↑ The LISA Technology Package containing two identical cubes of gold/platinum alloy, acting as test masses and suspended in a vacuum container

One simulator for three teams

Complex space missions require special and diversified expertise and resources. In our specific case, three teams were involved: the Mission Data Systems team, the Flight Control team and the Science team. Typically, these teams have clear responsibility for specific tasks and their interaction is defined via specific interfaces that aim at optimising the result, but do not necessarily promote the cross-fertilisation between their different expertise. On the contrary, the experience of the LISA Pathfinder simulator has brought these three teams closer, stimulating and bringing out the best in each of them.

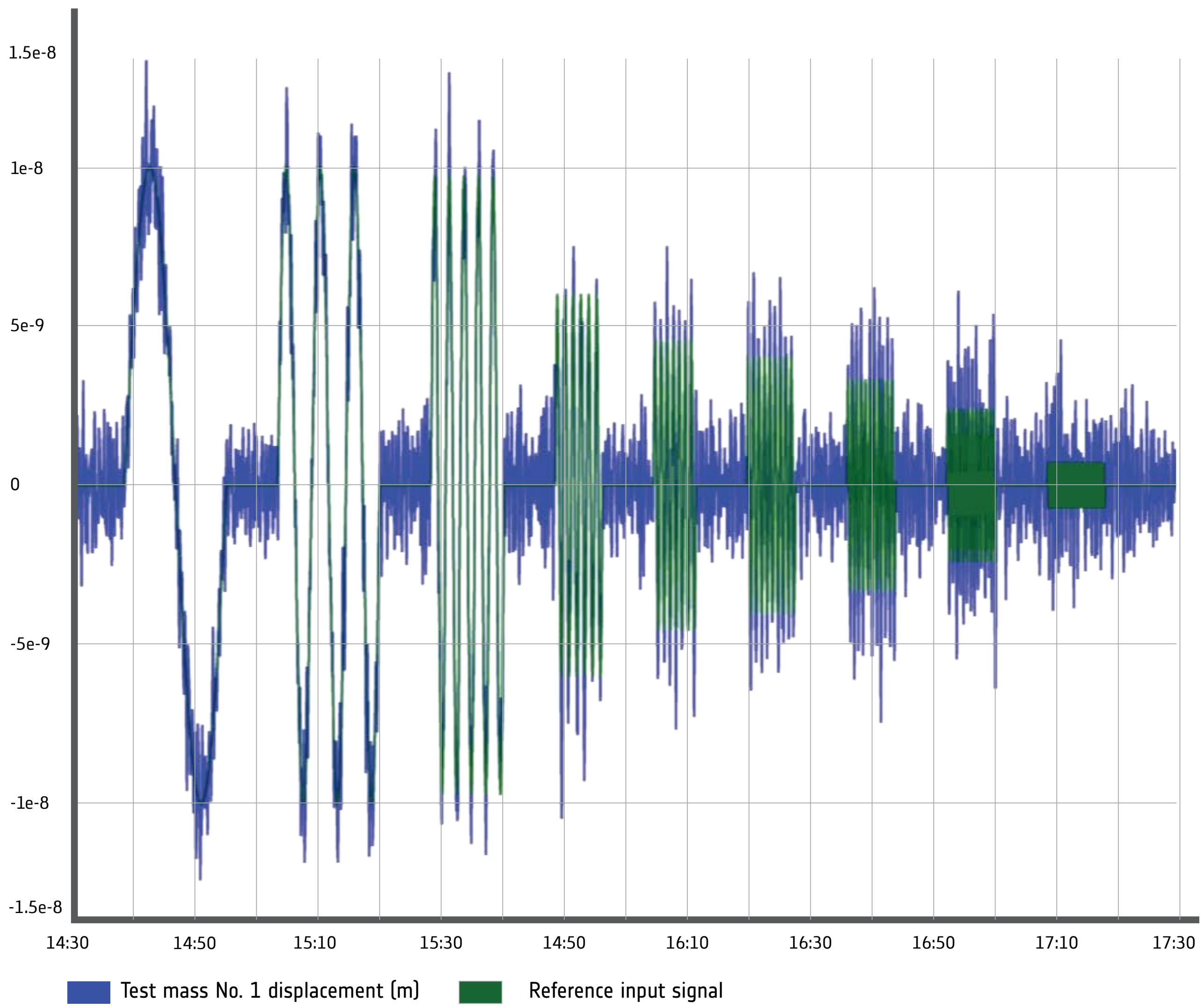
Mission Data Systems team

This team is responsible for the full lifecycle of complex operational software systems, mainly mission control systems, operational simulators and mission planning systems. A new set of mission data systems is developed for each mission based on the large reuse of the ESOC infrastructure software.

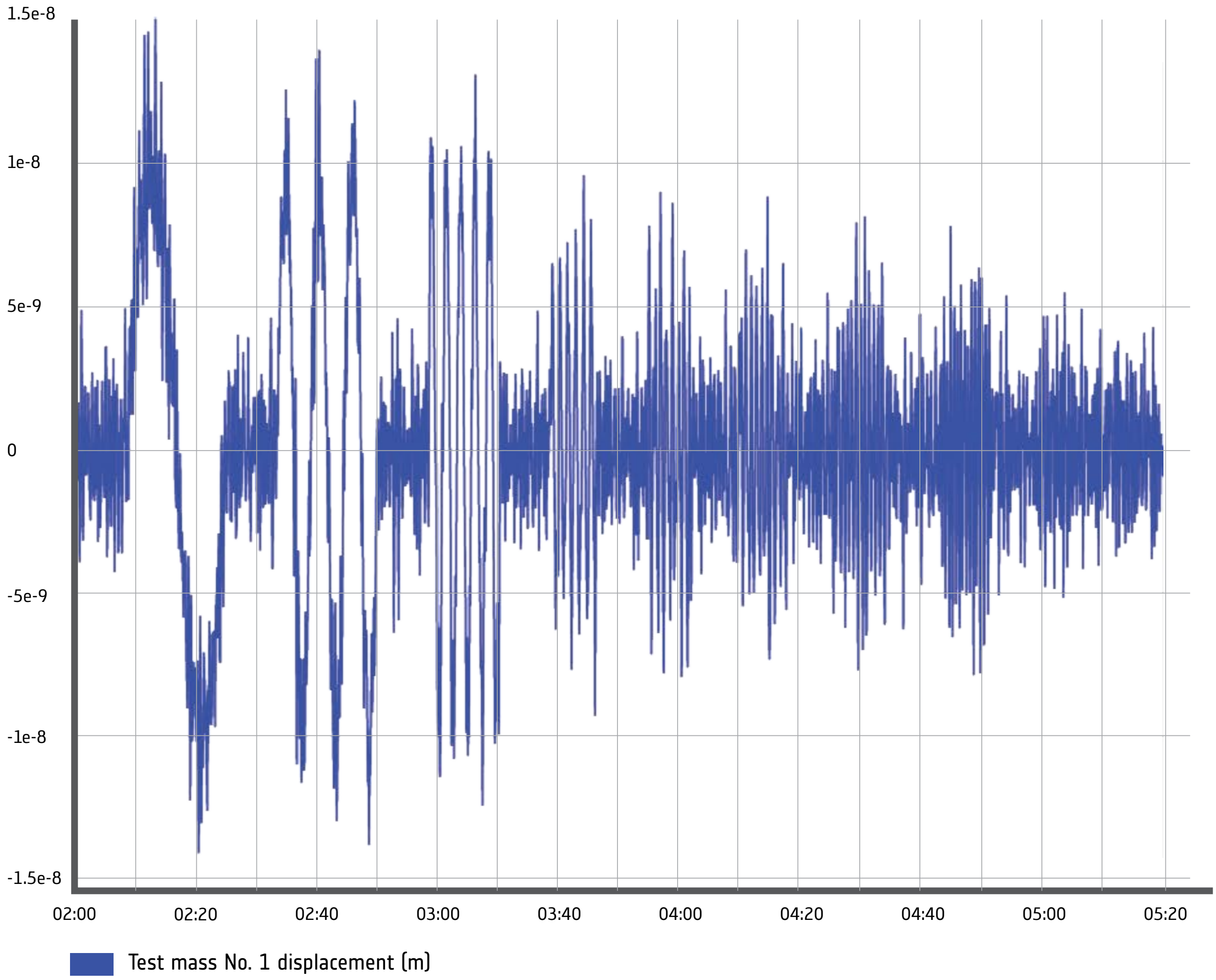
This team is in charge of the LISA Pathfinder mission control system and operational simulator that were developed based on the MICONYS and SIMULUS infrastructure, respectively.

↓

On the left, the data generated by the operational simulator, while on the right the spacecraft data measured in flight, test mass no. 1 displacement in metres along the axis (blue line) and the reference input signal (green line). The results are extraordinarily similar: the fidelity of the simulator data compared to the real spacecraft, i.e. the ability of the simulator to reproduce the spacecraft behaviour during the scientific experiment, is remarkable



← LISA Pathfinder Mission Control team at ESOC



↑ The LISA Pathfinder Dedicated Control Room at ESOC

For this team the extension of the operational simulator was a brand new and very rewarding experience. Besides contributing to a unified team spirit that comes from working side by side for a common goal and using the same software tools, it stimulated very interesting and fruitful discussions. Several workshops were organised to present the functionality of the operational simulator in order to assess their relevance for the science teams, to agree on the extensions required, and to validate the implementation.

The Science team became acquainted with the LISA Pathfinder data systems, namely the simulator and the mission control system (the system used to telecommand the spacecraft and to monitor the telemetry data produced by the spacecraft, including science data).

Conversely, the Mission Data Systems team gained experience and understanding on the needs of the Science team and on the implementation of complex scientific algorithms and extremely accurate models. This allowed establishing a 'common language' and provided a better reciprocal insight on the work.

With all teams using the same software, the comparison of the results obtained became easier thus speeding up the troubleshooting during the simulator development.

Science team

The extended simulator is a key operational tool used by the Science team to validate the commands to the LISA Pathfinder scientific instruments before they are uplinked to the spacecraft. Because of the tight coupling of the spacecraft attitude control system with the scientific instruments, the best way to check that a scientific sequence of commands runs without upsetting the extremely sensitive test masses controllers is to carry out a full simulation before actually sending the commands to the spacecraft.

In addition to this, the performance and high fidelity of the simulator allows the scientific experiments to be optimised. In essence, this is done by reducing the force and torque margins of the test mass controllers which reduces one of the main contributors to the experiment measurement noise.

The LISA Pathfinder simulator allows the Science team to test and validate these optimisations to demonstrate that they are safe. In fact, during the nominal phase of the mission, test mass control was never lost because of a faulty scientific schedule, since these have always been tested against the simulator beforehand.

The integration of the simulator into the Science team environment was straightforward, since the simulator has the

← By launch day, the 80-plus people on the mission teams had completed many months of training, including a lengthy series of simulations using the Main Control Room at ESOC, this view of a Launch and Early Orbit Phase simulation session on 7 October 2015

same interfaces as the real spacecraft and ground science telemetry processing systems. For example, the Science team uses the same planning and scheduling tools to prepare input for the simulator as for the actual spacecraft. Similarly, telemetry from the simulator can be processed and analysed directly by the science processing systems.

Flight Control team

LISA Pathfinder is a 'commissioning' type of mission, meaning it is continuously evolving and expanding the scope and envelope of the science activities. The Flight Control team plays a key role by assisting in the development and validation of new experiments and onboard software updates. The simulator has provided an exceptionally accurate tool for the spacecraft's platform and payload.

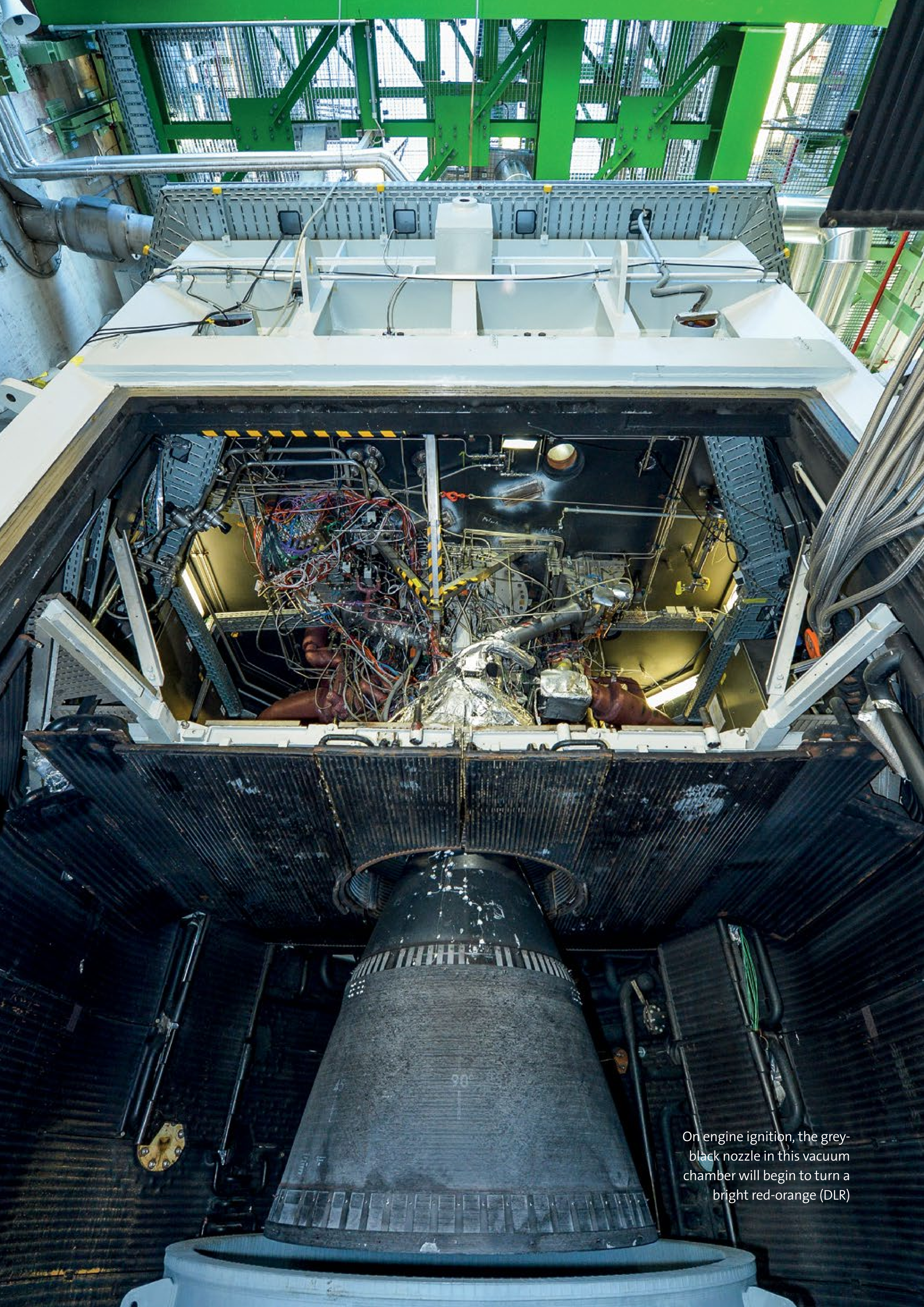
These extensions of the operational simulator has allowed the Flight Control team to build expertise on payload design and science operations that is uncommon and would otherwise not be possible, which has transformed the daily routine operations into a challenging and fruitful development environment.

The contribution of this endeavour to mission success should not be underestimated and will continue to provide an invaluable input into the mission extension by:

- fostering the building of platform and payload knowledge with the Flight Control and Science teams;
- allowing routine operations to be performed smoothly and free of errors by following a strict validation of all payload timelines prior to execution on the actual spacecraft;
- providing a development platform that allows new experiments and operational concepts to be developed and validated 'in-house', saving time and costs,

And all of this in addition to the traditional training and validation roles that the operational simulator typically provides.

The highly positive feedback from all involved parties and the advantages that the science extensions to the simulator provide make this kind of activities extremely interesting for future missions, and also for what concerns the improvement of the payloads' models. The operational simulator is the ideal starting point for a joint operational/science simulator for future missions. In fact, it is developed with large reuse of generic software, it has the same interfaces as the flying spacecraft and runs the real onboard software. Last, but not least, this experience demonstrates that the approach of having 'one' spacecraft simulator can strengthen 'one' mission team.



On engine ignition, the grey-black nozzle in this vacuum chamber will begin to turn a bright red-orange (DLR)

→ LAUNCH INTO SPACE WITH A DOWN-TO-EARTH ATTITUDE

Testing the Vinci engine for Ariane 6

Manuela Braun
DLR Corporate Communications, Linder Hoehe, Cologne, Germany

Vinci is a cryogenic liquid rocket engine designed to power the upper stage of the new Ariane 6 launcher. Hot-fire tests of this engine took place at the German Aerospace Centre's (DLR) Institute of Space Propulsion in Lampoldshausen, Germany, in May 2016.

The first barriers will be set up at 10:45. The Talstrasse, which passes directly below the test facilities at the DLR site in Lampoldshausen, is now closed to traffic at a distance of about 300 metres. And the traffic light is red at approximately 50 metres from the P4.1 test stand, built and operated by DLR on behalf of ESA.

A warning sign dangling on the chain that stretches across the access road to the test stand reads 'Danger zone' in bright red uppercase letters. "When the chain is locked: Life-threatening danger! Major DLR test under way!"

Today, liquid oxygen at a temperature of –183 °C and liquid hydrogen at –253 °C will flow through feed lines, a Vinci engine will be ignited twice in a vacuum, followed by a two-hour simulated propulsion-free flight. In doing so, the vibrations that occur in the feed line filled with liquid oxygen will be dampened as effectively as possible with a newly developed system.

Caution: Ongoing test at P4.1 test stand. An engine is being ignited in a vacuum, that is, under near space conditions, making the large facility at the DLR Lampoldshausen site unique in Europe (DLR)

All this happens under the space conditions that the Ariane 6 launch vehicle would endure during a flight – yet it takes place close to the ground. The P4.1 test stand is the only one in Europe that can maintain a stable vacuum during a test in which the engine and nozzle can operate as if at an altitude above 70 km.

Choreography of a test

"The test stand has been cleared." Bernhard Linseisen puts down the telephone receiver. He is responsible for ensuring that the strict safety barriers around the test stand are met during the engine test, and ensures contact between the test director and the safety centre. Only those who have permission from the test director and express clearance from the safety centre can remain in the restricted area.

Manuel Müller nods and reaches for his ballpoint pen. One more item checked off the long list of around 1500 that must be completed during today's test. Müller is responsible for this chronology today and will therefore be test director Stefan Grunwald's right hand. This evening, at approximately 19:00, the last note will be added to the thick pile of paper and the last item checked off. An engine test follows an elaborate choreography with many participants who are each responsible for their respective fields. The chronology ensures that no detail is forgotten and everything falls into place.

Waiting for clearance

The atmosphere in the control room is still relaxed. Since 10:00 this morning, the engine has been covered with a special protective heat shield, all equipment and tools from the vacuum chamber in the test stand have been dismantled, and the heavy door of the vacuum chamber has been closed.

One of the screens in the control room seems to show nothing – the camera is pointed at a black nozzle in a pitch-black chamber. Only during the hot run will this screen show something – the orange-coloured glow of the engine nozzle. While the last preparations are under way, Grunwald is sitting next door in the meeting room. Together with his team, he is discussing the last measured values and the deviations from these values during the final rehearsal with the client, the company Airbus Safran Launchers (ASL). The green light for the planned test run will only be given if both parties – DLR as the test stand operator and ASL as the contracting entity – agree on the framework conditions for today's test.

From test run to test run

At 11:30, the time has come: Grunwald attaches the clearance document to the white board in the control

→ New test stand for Ariane 6

A new facility is being developed and built at the DLR site in Lampoldshausen for testing the upper stage of the new Ariane 6 launcher. The upper stage of the Ariane 6 will be tested extensively on this new P5.2 test stand – the only place in Europe where this will be possible. These tests will include fuelling and defuelling tests, as well as hot run tests for the upper stage. The commissioning of the new test stand is scheduled to start in 2018. The DLR Institute of Space Propulsion is technically responsible for the construction and subsequent operation of the test stand.

→
Test director Stefan Grunwald and chronicler Manuel Müller (foreground) are under tension. All the information is gathered by these two positions (DLR)

room. 'Green light for test M5R-12' and the signatures of the test director and client are on the paper. The twelfth test run since April 2016 – and number 108 in total with a Vinci engine – can begin. After the decision made at the ESA Ministerial Council in December 2014 to develop the Ariane 6 launcher, the previously tested Vinci engines and nozzles were also changed. Instead of an extendable nozzle, for example, a shorter, more compact one is now being developed and thoroughly tested.

At the DLR site in Lampoldshausen, the tried and tested P4.1 high-altitude test stand was therefore modified and adapted to the new development targets. While a hot run without a nozzle was carried out in the first test in order to keep the risk low, the final configuration has meanwhile edged a bit closer with each test.

Today, several newly developed components are in the test stand, such as the engine, the nozzle and the liquid-oxygen feed line and valve, as well as a vibration damping system. The 'Go' is given. Oxygen and hydrogen are now flowing through the test stand feed lines – it will take between two-and-a-half and three hours until the test stand and engine have cooled down enough for the test conditions to be reached.

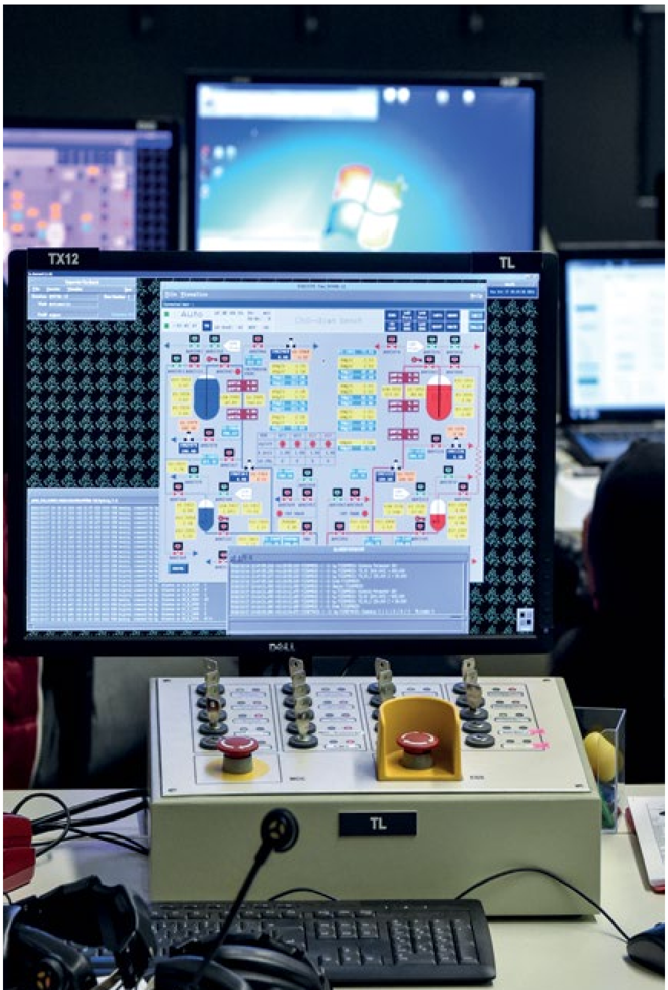
"LH2?" – "Tank pressure control is running." "What is the gas composition in the vacuum chamber?" There is less and less background noise in the control room. Only brief questions and answers are exchanged. Everyone is now sitting in position as a specialist for their area and looking at the graphics and measured values displayed on the screen.

At the beginning of the test, many things are still set manually – important in this case are the boundary values, and the experience and instinct of the scientist. Later, the computer will increasingly take over. Approximately 150 sequences with countless lines of code will then ensure that the processes in the test stand are automatically and precisely executed – and that the test is stopped if the measured values require it.

Ignite, cool, fly

The engine will run for 600 seconds after the first ignition. Shortly before that, four steam generators will be ignited that – after a large, 3 m diameter flap has connected the vacuum chamber and high-altitude system – will produce an air pressure of only a few millibars, almost like a vacuum, in the facility for the duration of the test. A short 120-second period follows in which the engine is purged and cooled again before reigniting for 60 seconds.

Then, there is a two-hour 'free flight', a so-called coast phase in which the upper stage of the Ariane 6 rocket 'flies' without propulsion. The test on P4.1 should then end with a final cooling of the engine. Approximately 900 sensors installed in the engine and test stand record pressure, temperature and acceleration levels throughout the test. On this test day, however, not everything will go as planned.



↑ The test director's station: the test is followed via computer screens and can be interrupted in the event of an emergency (DLR)

13:00. "Now it's getting cold." Today, Ralf Hupertz is the Supervisor of the test team. He looks at two screens crammed with data, measured values and graphics. "Now there is liquid in the lines."

"13:30, then the next safety barrier," Grunwald says. Linseisen informs his colleagues in the safety centre. From this moment, the radius of the secured zone is drawn even wider than before. The control room is now cut off from the outside world – only voice communications with the safety centre and fire brigade remain. It gets even quieter in the control room. Hardly any words are exchanged across the room. Rather, everyone is wearing headphones with radio communication.

Separated only by a thin wall, in the control room next door, sits the team responsible for the steam generator system, which will develop the necessary vacuum conditions just before engine ignition. The telephone between test director Stefan Grunwald and 'chronicler' Manuel Müller is off the hook. During the hot phase of the test, no telephone ringing should disturb people's concentration or the procedure.

Damaging vibrations

Before the test run is initiated, the system that is used to induce a simulated vibration onto the oxygen column within the feed line is checked once more. In the worst case, such so-called 'pogo' oscillations could occur in the resonant frequency range of the rocket. "This could destroy the entire rocket," says supervisor Hupertz.

Even the great Saturn V rocket, which flew the Apollo astronauts to the Moon, had engine failures due to these vibrations during an unmanned test flight. The Pogo Suppression Device (PSD), which should dampen the artificially induced vibrations in the engine above the liquid oxygen turbopump, could later ensure that the Ariane 6 will not have problems with this.

Delayed start-up

It is just minutes after 14:00. The 20-minute warning is heard from loudspeakers across the entire site. But it will not be 20 minutes – the hot run will not start for 25 minutes. The cooling criteria are only reached after a few additional minutes. On the following day, in the team session with the client, these deviations will be discussed in order to set different, optimised conditions for the next test, if necessary.

The cameras now only send images from an abandoned test stand to the screens. The only people in the immediate vicinity of the test stand, with the engine ready for ignition, are sitting in the protected control room. The exchange of questions and answers starts once again. "Pressure in the vacuum chamber?" "32 millibars." "Mass spectrometer, close valves for the hot run!" "Closed."

↑ During the test, cameras transmit what is happening in and around the test stand. The control room is a protected area (DLR)

The steam generators are started. On the screen, the test stand is cloaked in more and more clouds. A muffled rumbling sound can be heard from outside. Just a few seconds until the large vacuum control valve is opened – and the engine can ignite. The countdown clock over the screens jumps to zero, the engine is running in the vacuum chamber, and the camera image changes colour – from black to bright red.

"No alarms so far." The nozzle glows in the hot run for 10 minutes. "OK, engine cut-off," Grunwald calls. On the screen, the nozzle slowly darkens again.

Dealing with the unexpected

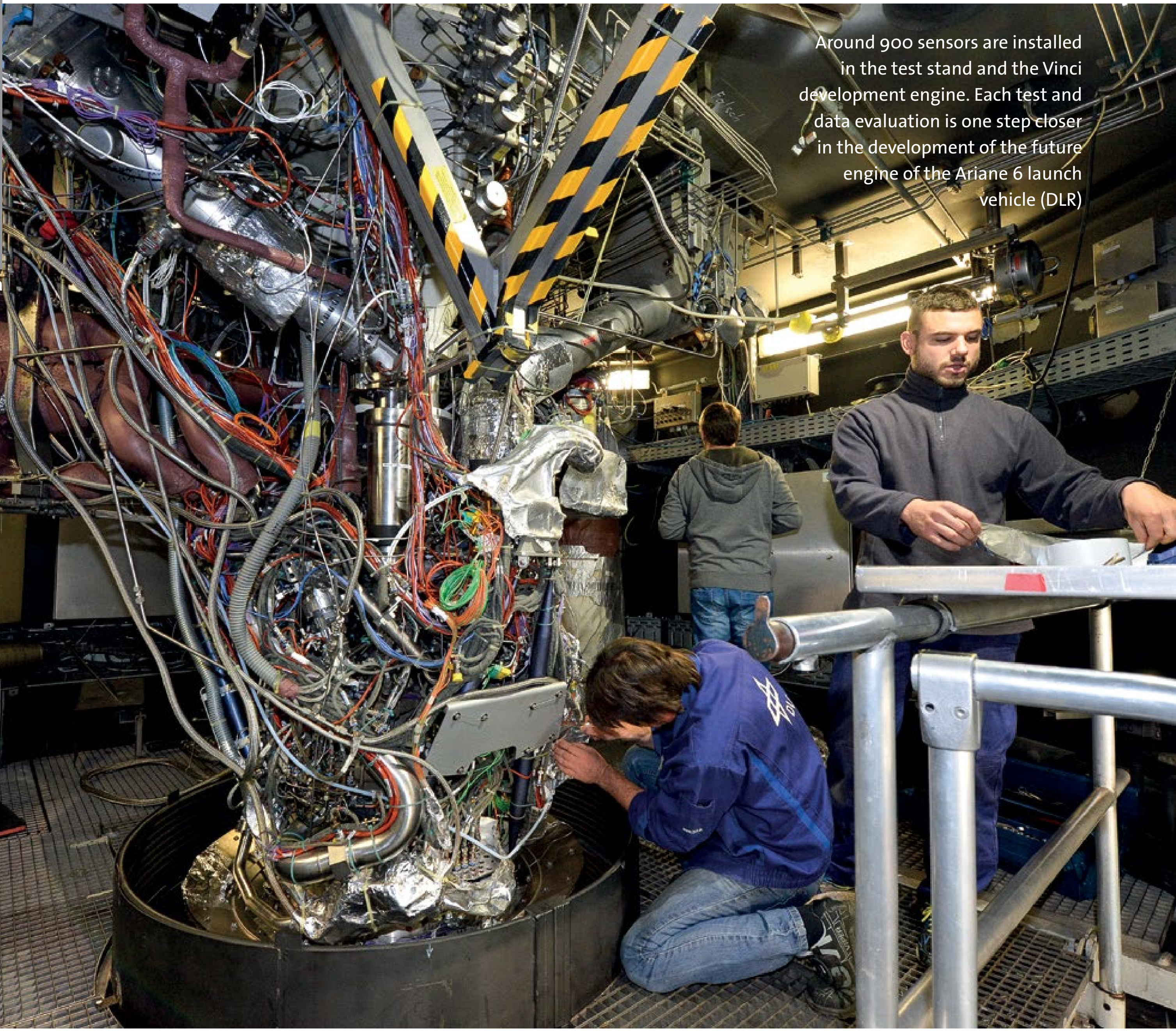
Just two minutes pass between the first and second ignitions. The atmosphere in the control room remains tense. "Now the second ignition…" Grunwald's voice is hesitant. If it takes place at all. The planned second ignition does not happen. All eyes turn to the measured values. No one can intervene now. Two minutes pass – the hissing of the steam generators from outside fades and the white cloud around the test stand slowly dissipates.

Even though the second ignition has failed, the test continues with the planned free-flight phase and a recooling of the engine. It will take about one and a half hours before the next phase starts again at the consoles.

Meanwhile, in the next room a discussion about why the planned ignition did not take place is going on. "It could be, for example, that the parameters for the test sequence could not be realised for technical reasons," Grunwald says. "The analysis of the measured values will show this."

At 16:35, the next 20-minute warning echoes from the loudspeakers. Again, the test stand and engine will be cooled and the steam generators will generate a vacuum. Today's test will end as soon as the Vinci engine is ready for a third ignition. Shortly before the steam generators are supposed to start, a message from the neighbouring control room comes through the headphones: "We have a problem with the tank pressurisation."

The options are clear: the steam generator team could leave the control room once again and fix the problem on site. But that would prolong the current coast phase.



Around 900 sensors are installed in the test stand and the Vinci development engine. Each test and data evaluation is one step closer in the development of the future engine of the Ariane 6 launch vehicle (DLR)

And it is not certain that the steam generators will run. The test director nods briefly and decides with the client: the free-flight phase will be simulated as planned – should the steam generator not run, this would not be decisive for the desired measurement data.

Finally, the last warning – the one-minute warning – inundates the site. And the hissing of the steam generators starts again. "Well, it is working as planned after all," murmurs Ralf Hupertz.

Measurement data for the future

Felix Löhr, who is responsible for running of the automatic sequences, looks at his screen. "LH2 is already cold." In the chronology, Manuel Müller is almost on the last page, checking off items, one by one. "LOX has met two of three cooling criteria." When the liquid oxygen has also reached the prescribed temperature, Stefan Grunwald looks up. "OK, then the test ends here."

The noise of the steam generators subsides. At 17:18, the main test run is complete. All that remains is the decommissioning of the individual test stand systems as well as the reconditioning of the engine, which will take another one and a half hours.

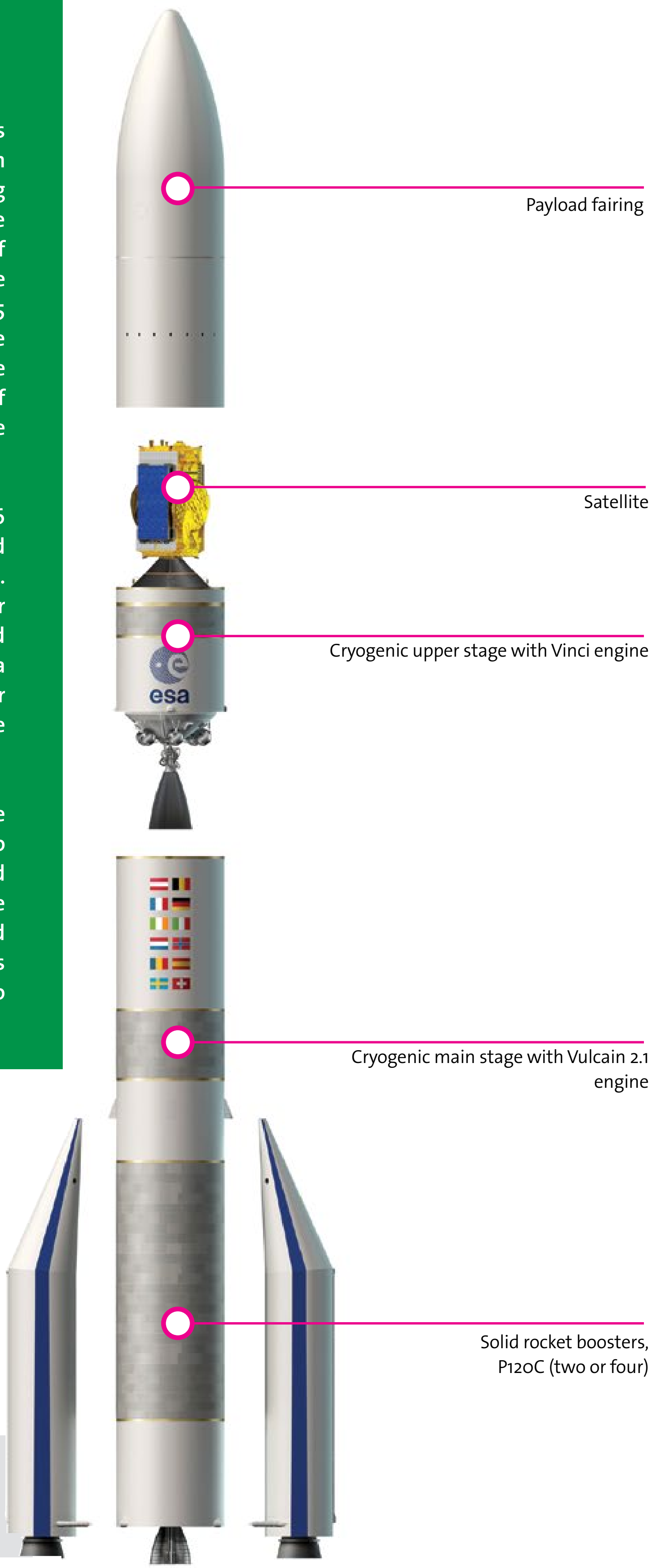
Thousands of measurement values will be analysed and evaluated on the following day. 'After the test' is immediately 'before the test' because each result flows

→ Ariane 6: European launch vehicle of the future

The Ariane 6 development programme was approved at the ESA Ministerial Council in December 2014 and signed by 12 participating states. Studies conducted in the run-up to the conference had shown that, on the basis of previous experience with the existing Ariane 5 and the development work on the Ariane 5 ME, the prerequisites for implementing a viable launcher concept are fulfilled. By combining these existing building blocks and the development of further elements, it is possible to fully develop the Ariane 6 in just five years.

The carrier configuration of the new Ariane 6 uses the fuel combination of liquid hydrogen and liquid oxygen in both the lower and upper stages. The new lower stage is based on the 'old' lower stage of the Ariane 5, but has been improved technologically and has been cost-optimised. As a transitional step, a modification of the new upper stage already designed for the Ariane 5 ME will be used with the reignitable Vinci engine.

Depending on the configuration, the Ariane 6 can transport five or 11 tons of payload into Geostationary Transfer Orbit. It will be equipped with either two or four solid rocket boosters. The first launch of the 70 m long rocket is scheduled for 2020. The French/German company Airbus Safran Launchers was commissioned by ESA to develop the Ariane 6.



into the next test run. A new Vinci engine is expected to be installed in the test stand in December 2016 – one that will be very similar to the engine that the Ariane 6 will launch with in 2020. The changes that come from the tested development engine will be based mainly on one thing: today's results from the DLR P4.1 test stand. ■

This article was previously published in *DLRmagazine* 151/152, 2016

ESA astronaut Tim Peake saw this iceberg (called A56) from the International Space Station 400 km above Earth on 2 June during his six-month Principia mission (NASA/ESA)

→ 2016 IN PICTURES

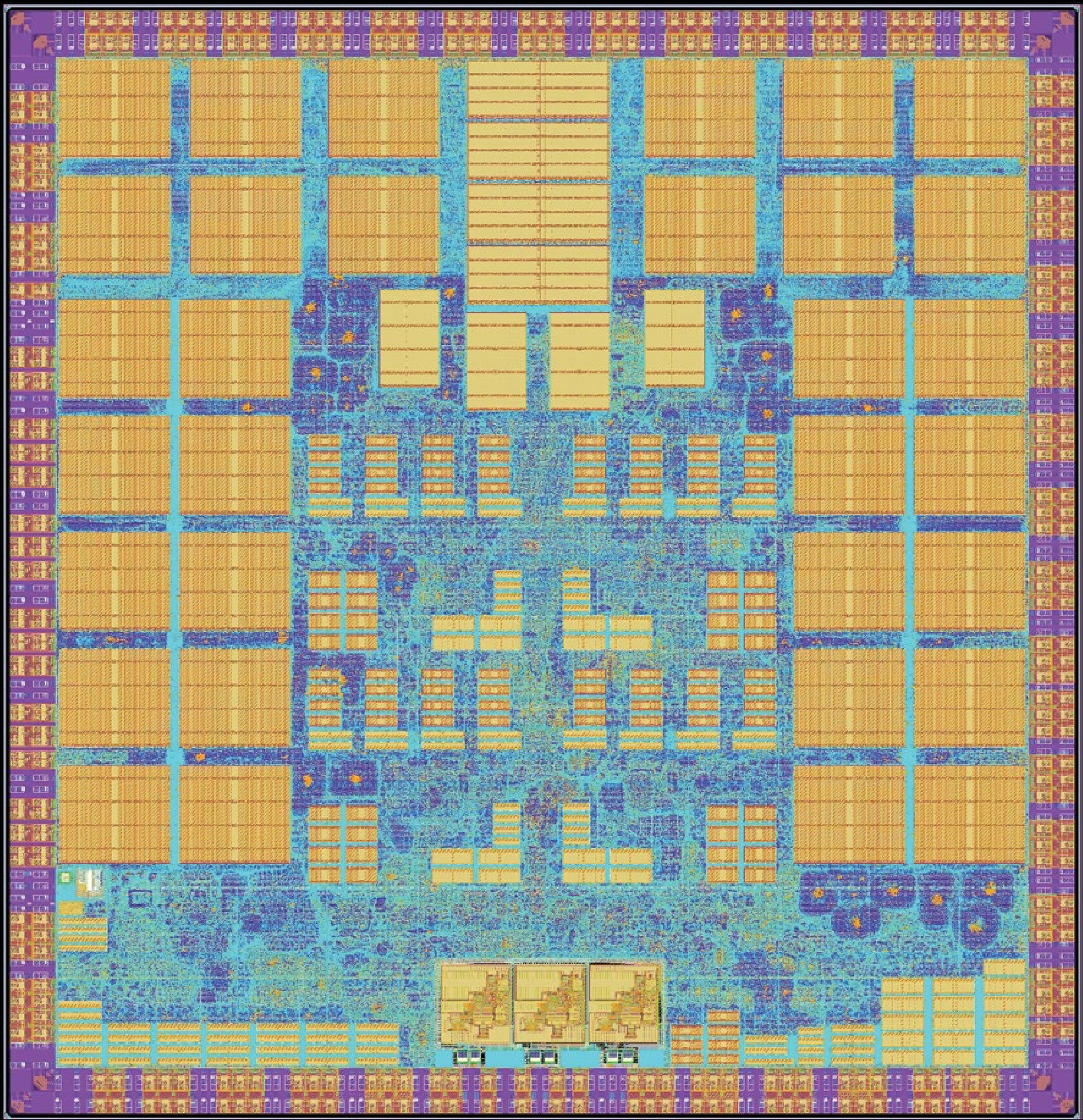
Some of the most memorable moments and unusual images taken last year

Just two weeks after launch, the Copernicus Sentinel-3A satellite returned its first image, showing the transition from day to night over Svalbard, Norway, on 29 February (Copernicus data (2016)/ESA)

→

The eastern part of the Sundarbans in Bangladesh, in this natural-colour image captured by the Sentinel-2A satellite on 18 March (contains modified Copernicus Sentinel data (2016)/ ESA)

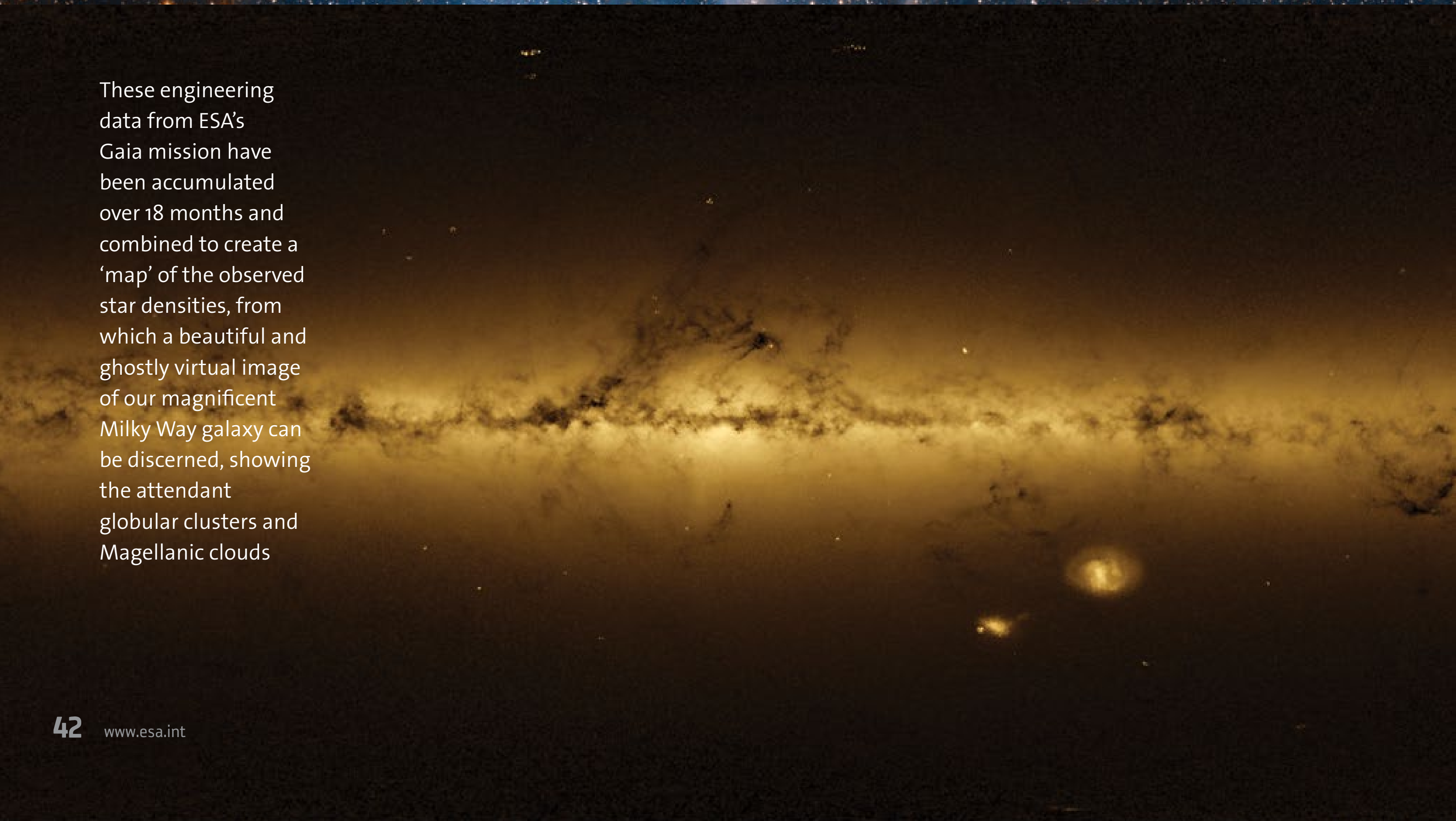
↓ A close-up of the next-generation microprocessor that will serve a wide variety of future space missions. This is a GR740 microprocessor, developed by Cobham Gaisler of Sweden and manufactured by France-based STMicroelectronics (STMicroelectronics)



Soyuz TMA-19M returning under its main parachute to the steppe of Kazakhstan on 18 June, carrying ESA astronaut Tim Peake, NASA astronaut Tim Kopra and cosmonaut Yuri Malenchenko after their 186-day mission on the International Space Station

Tim Peake relaxes in the recovery helicopter after returning from his long-duration Principia mission on 18 June

This shot from the NASA/ESA Hubble Space Telescope shows a maelstrom of glowing gas and dark dust within one of the Milky Way's satellite galaxies, the Large Magellanic Cloud (NASA/ESA)



These engineering data from ESA's Gaia mission have been accumulated over 18 months and combined to create a 'map' of the observed star densities, from which a beautiful and ghostly virtual image of our magnificent Milky Way galaxy can be discerned, showing the attendant globular clusters and Magellanic clouds

←

Comet 67P/ Churyumov–Gerasimenko seen on 29 September by the Rosetta OSIRIS wide-angle camera taken at 22.9 km from the comet (ESA/Rosetta/ MPS for OSIRIS Team MPS/UPD/LAM/IAA/ SSO/INTA/UPM/ DASP/IDA)

←

Tissues on hand for the confirmation of the end of the Rosetta mission at ESA's control centre in Darmstadt, Germany, 30 September (ESA/J. Mai)

←

Rosetta flight controllers Armelle Hubault and Sylvain Lodiot share tearful hugs with Head of Mission Operations Paolo Ferri after loss of signal on 30 September (ESA/J. Mai)

↑ ESA's Sentinel-2B Earth-observing satellite being lowered into ESTEC's 15 m-diameter Large Space Simulator, Europe's largest vacuum chamber, in June at the start of a test campaign to ensure it is ready to serve in space

→ The Trace Gas Orbiter of ESA's ExoMars 2016 successfully performed the long 139-minute burn required to be captured into martian orbit. Here ESA flight directors Michel Denis and Andrea Accomazzo give each other a celebratory hug (ESA/J. Mai)

→ In another image from ESA's ESOC mission control centre, Darmstadt, Germany, flight controllers passed around 'lucky peanuts' (a gift from NASA colleagues) while waiting for the arrival of ExoMars in martian orbit (ESA/J. Mai)


EXOMARS
2016

→

ESA astronaut Thomas Pesquet waves farewell to friends and family from the bus taking him to the launch pad in Baikonur, Kazakhstan, a few hours ahead of his launch on 17 November 2016 (NASA/V. Zelentsov)

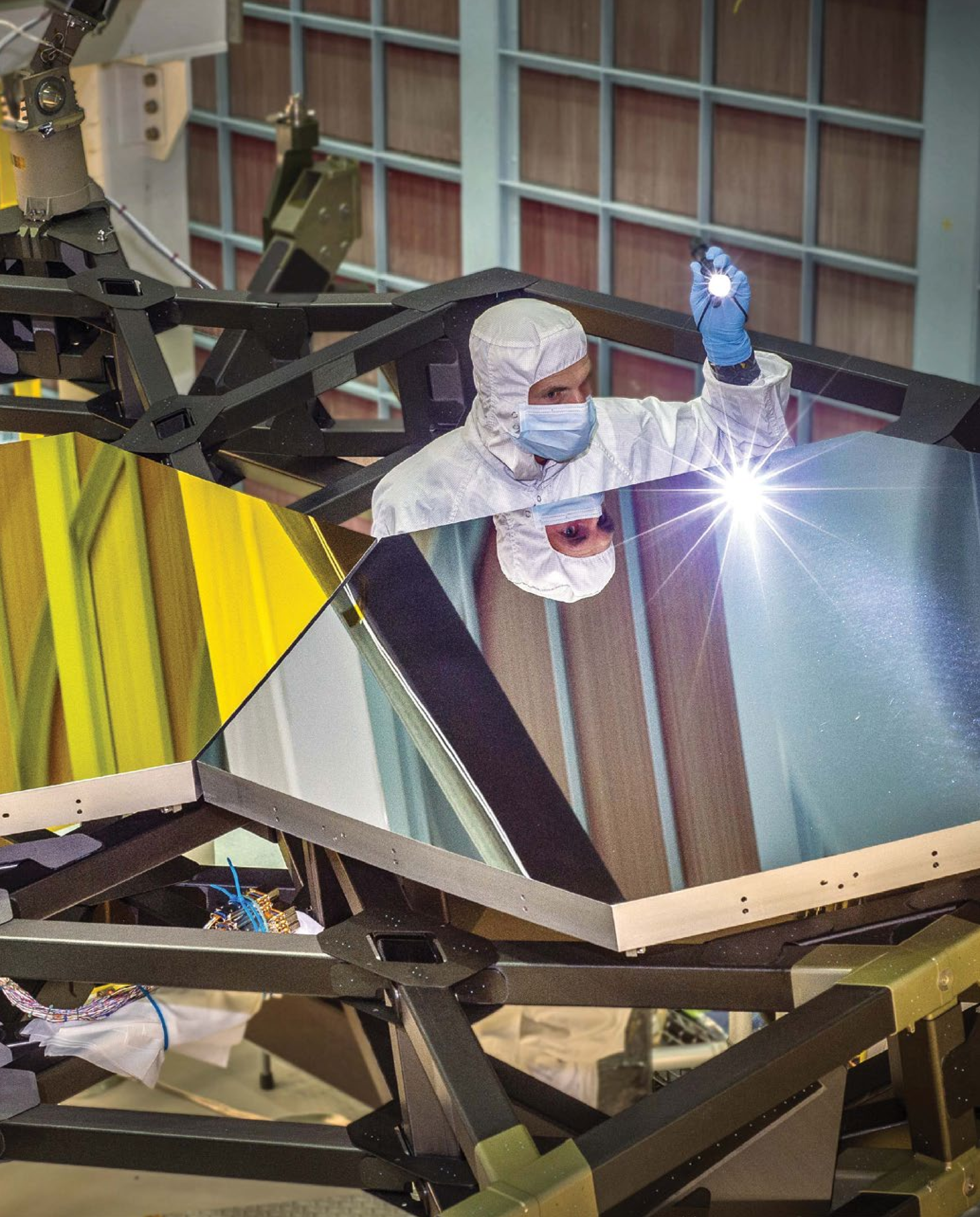
→

Some special visitors to ESA's annual Open Day at ESTEC in Noordwijk, the Netherlands, on 2 October (ESA/SJM Photography)

↑ Expedition 50 crew Peggy Whitson, Oleg Novitsky and Thomas Pesquet await final qualification exams in October at Star City, Moscow (NASA/B. Ingalls)

↓ Launch day at Baikonur for Thomas Pesquet on 17 November, the support arms for the Soyuz rocket swing down leaving light trails in the long-exposure photo (Roscosmos)

The launch of Galileo satellites 15, 16, 17 and 18 (Flight Models 07, 12, 13 and 14) on Ariane 5 flight VA233 from Europe's Spaceport in Kourou, French Guiana, on 17 November, captured by the automatic cameras of ESA photographer Stephane Corvaja



↑ Two polished test mirror segments for the James Webb Space Telescope being inspected at Goddard Space Flight Center in August (NASA/C. Gunn)

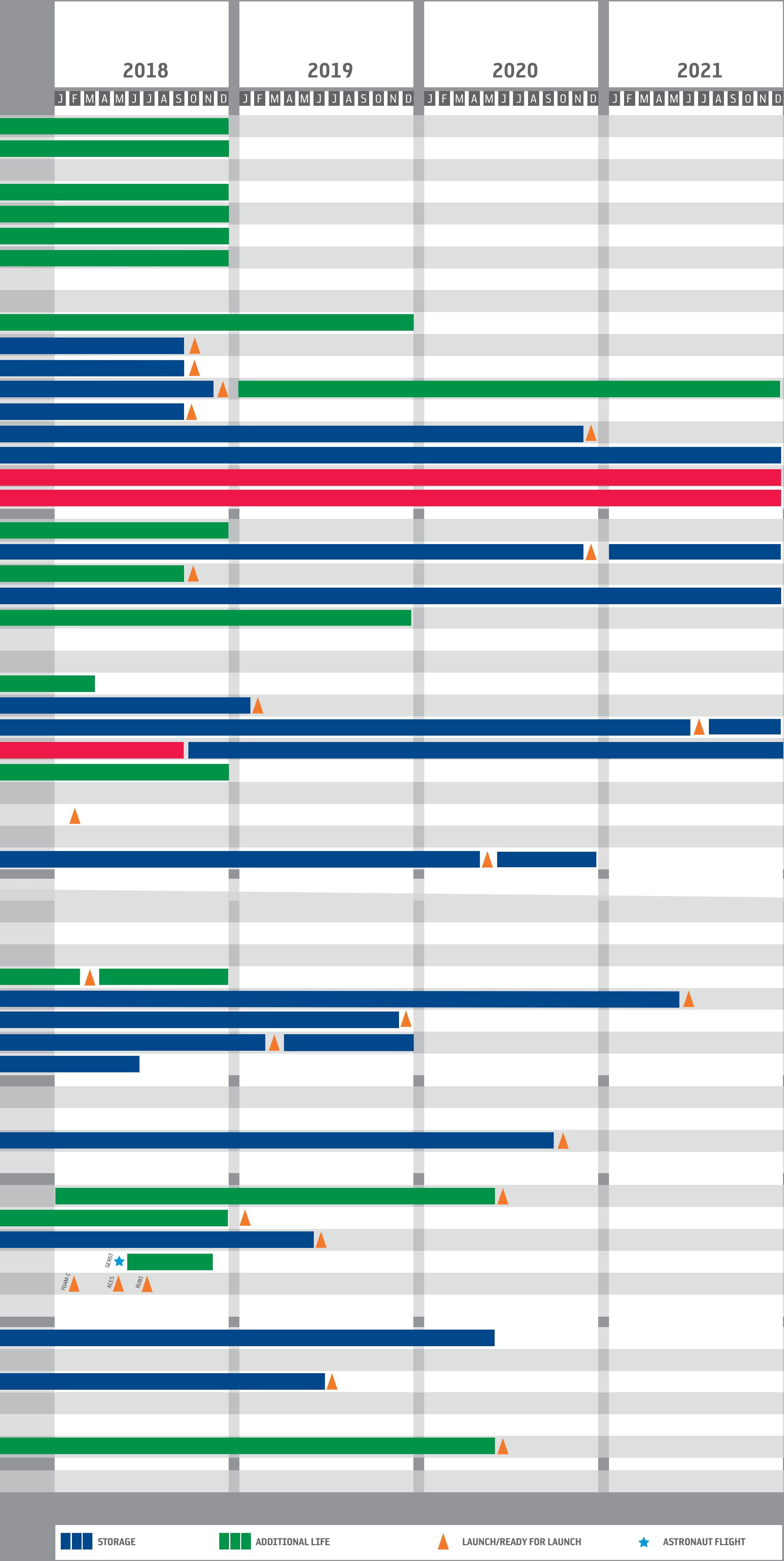

300 AREA
PROPULSION VISITOR
PLEASE RETURN TO BLOCKHOUSE
esa
ATV Program
June 2015

→ PROGRAMMES IN PROGRESS

Status at February 2017

The ESA European Service Module's Propulsion Qualification Model arrived at NASA's White Sands Test Facility in New Mexico in February for 'hot firing' tests of the Orion main engine and thrusters (NASA/R.Elliott)

2014
2015
2016
2017
J F M A M J J A S O N D
SCIENCE PROGRAMME
HUBBLE
SOHO
CASSINI-HUYGENS
XMM-NEWTON
CLUSTER
INTEGRAL
MARS EXPRESS
LISA PATHFINDER
MICROSCOPE
GAIA
JWST
BEPICOLOMBO
CHEOPS
SOLAR ORBITER (M1)
EUCLID (M2)
JUICE (L1)
PLATO (M3)
ATHENA (L2)
EARTH OBSERVATION PROGRAMME
MSG
MTG
METOP
METOP-SG
CRYOSAT
SMOS
AEOLUS
SWARM
EARTHCARE
BIOMASS
FLEX
SENTINEL-1
SENTINEL-2
SENTINEL-3
SENTINEL-5 PRECURSOR
SENTINEL-6
TELECOMMS/NAVIGATION PROGRAMMES
ALPHASAT
EDRS
SMALLGEO
GNSS-1/EGNOS
GALILEO
ELECTRA
NEOSAT
QUANTUM
SAT-AIS
TECHNOLOGY PROGRAMME
PROBA-1
PROBA-2
PROBA-3
PROBA-V
HUMAN SPACEFLIGHT & ROBOTIC EXPL.
EXOMARS
ISS (COLUMBUS & ERA)
MPCV-ESM
ASTRONAUT FLIGHTS
ELIPS PAYLOADS
TRANSPORTATION & HUMAN EXPLORATION
GERST
MOGENSEN
PEAKE
PESQUET
NESPOLI
PK-4
EML
ASIM
LAUNCHER PROGRAMME
ARIANE 6
VEGA DEV. AND EXPL.
VEGA C
SOYUZ AT CSG
IXV
SPACERIDER
SSA
PERIOD 2
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
OPERATIONS



COMMENTS
LAUNCHED APR 1990 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 1995 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 1999 / END OF MISSION 15 SEPT 2017
LAUNCHED OCT 1997 / OPS EXTENDED UNTIL 2018
LAUNCHED MID-2000 / OPS EXTENDED UNTIL 2018
LAUNCHED OCT 2002 / OPS EXTENDED UNTIL 2018
LAUNCHED JUN 2003 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 2015 / OPS EXTENDED UNTIL MAY 2017
LAUNCHED 22 APRIL 2016
LAUNCHED 19 DEC 2013 / NOMINAL MISSION END 2019
LAUNCH OCT 2018
LAUNCH OCT 2018 / MERCURY ARRIVAL 2025 / OPS 2026-27
LAUNCH DEC 2018 / OPERATIONS TO AUG 2022
LAUNCH OCT 2018
LAUNCH DEC 2020
LAUNCH JUN 2022
LAUNCH 2024
LAUNCH 2028
MSG-3 LAUNCHED JUL 2012 / MSG-4 15 JUL 2015 / OPS BEYOND 2018
LAUNCH MTG-I-1 DEC 2020 / MTG-S-1 AUG 2022
METOP-B SEP 2012 / METOP-C OCT 2018
LAUNCH METOP-SG A1 2021 / METOP-SG B1 2022
LAUNCHED 10 APR 2010 / OPS UNTIL 2019
LAUNCHED 2 NOV 2009 / OPS UNTIL END 2017
LAUNCH SEPT 2017
LAUNCHED 22 NOV 2013
LAUNCH 2019
LAUNCH 2021
LAUNCH 2022
LAUNCHED APR 2014 / SENTINEL-1B LAUNCH APR 2016
LAUNCHED 23 JUN 2015 / SENTINEL-2B LAUNCH MAR 2017
LAUNCHED SENTINEL-3A 16 FEB 2016 / LAUNCH SENTINEL-3B 2018
LAUNCH AUG 2017
LAUNCH MAY 2020
LAUNCHED JUL 2013
LAUNCHED EDRS-A 29 JAN 2016 / EDRS-C LATE 2017
LAUNCHED 18 JAN 2017
OPERATIONS START 2008
IOV OCT 2011 & OCT 2012 / FOC 2014–15
LAUNCH MID 2021
LAUNCH END 2019
LAUNCH EARLY 2019
LAUNCH READINESS SATELLITE-A, MID 2018
LAUNCHED OCT 2001
LAUNCHED 2 NOV 2009 / OPS EXTENDED UNTIL 2011/12
LAUNCH LATE 2020
LAUNCHED MAY 2013
LAUNCHED 14 MAR 2016 / JULY 2020
COLUMBUS: FEB 2008 OPS UNTIL END 2020 / ERA LAUNCH DEC 2017
LAUNCH JUN 2019
CRISTOFORETTI: NOV 2014; MOGENSEN: SEP 2015; PEAKE: NOV 2015; PESQUET: NOV 2016; NESPOLI: MAY 2017; GERST: MAY 2018
LAUNCHES MASER 13: DEC 2015 / MAXUS-9: APR 2017
PREPARATORY ACTIVITIES INCLUDING LUNAR EXPLORATION; PILOT & PROSPECT PDR OCT 2017
QUALIFICATION FLIGHT JUN 2020
FIRST LAUNCH FEB 2012 / VV02 LAUNCHED JUN 2013; VV03 LAUNCHED APR 2014 / VV04 LAUNCHED NOV 2014
LAUNCH JUL 2019
LAUNCHED FEB 2015
FIRST LAUNCH OCT 2011
LAUNCH 2020
SYSTEM REQUIREMENT REVIEW, DEC 2011

KEY TO ACRONYMS

AM	Avionics Model
AO	Announcement of Opportunity
AIT	Assembly, integration and test
AU	Astronomical Unit
CDR	Critical Design Review
CSG	Centre Spatial Guyanais
EFM	Engineering Functional Model
ELM	Electrical Model
EM	Engineering Model
EMC	Electromagnetic Compatibility
EQM	Electrical Qualification Model
EQSR	Equipment Qualification Status Review
FAR	Flight Acceptance Review
FM	Flight Model
FQR	Flight Qualification Review
GEO	Geostationary Earth orbit
IPC	Industrial Policy Committee
ITT	Invitation to Tender
LEO	Low Earth orbit
LEOP	Launch and Early Orbit Phase
MoU	Memorandum of Understanding
NEO	Near Earth object
PDR	Preliminary Design Review
PFM	Proto-flight Model
PLM	Payload Module
PPP	Public–private partnership
PRR	Preliminary Requirement Review
QM	Qualification Model
SM	Structural Model
SRR	System Requirement Review
STM	Structural/Thermal Model
SVM	Service Module
SVT	System Validation Testing
SWE	Space Weather
TM	Thermal Model

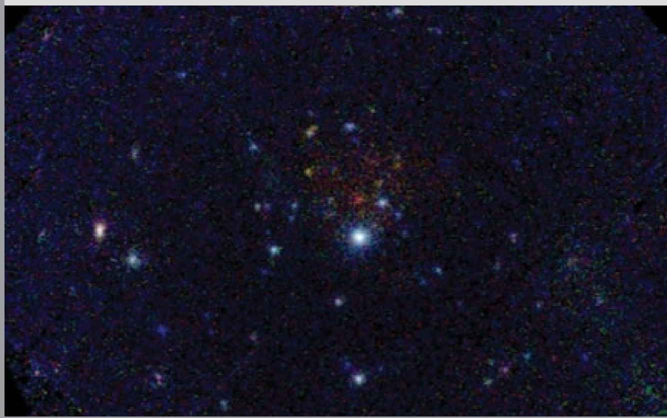
→ CASSINI

A study of the long-term variations of the albedo of surface features of Titan has noted darkening and brightening of some equatorial regions that could be linked to seasonal effects. This study was particularly challenging because a proper radiative transfer treatment must be applied to constrain the atmospheric contribution to the reflectance observed in the Cassini VIMS atmospheric windows. The Huygens albedo measurements were used as the ground truth to calibrate the method. Specific regions were studied in detail in terms of albedo variations, since they may be linked to activities such as cryo-volcanism, which is potentially important as a source of methane in the atmosphere, but never clearly demonstrated on Titan to date. In particular, one of the most promising candidate sites for cryo-volcanic activity, Hotei Regio, was shown in this analysis to not display any significant albedo variation over the mission timescale.

→ XMM-NEWTON

An ultra-luminous X-ray source is an astronomical source of X-rays that is less luminous than an active galaxy nucleus but more consistently luminous than any known stellar process. One possibility to explain their immense X-ray brightness is accretion onto black holes with masses of hundreds to thousand times that of our Sun. Joint XMM-Newton and NuSTAR observations have led to the discovery of pulsations with a period of about half a second in the light curve of an ultra-luminous X-ray source in the nearby galaxy NGC 7793. Since black holes do not show pulsation of this kind, the compact source must be a neutron star. This discovery establishes the second ultra-luminous X-ray source known to be powered by an accreting neutron star.

Three-colour X-ray image of NGC 7793

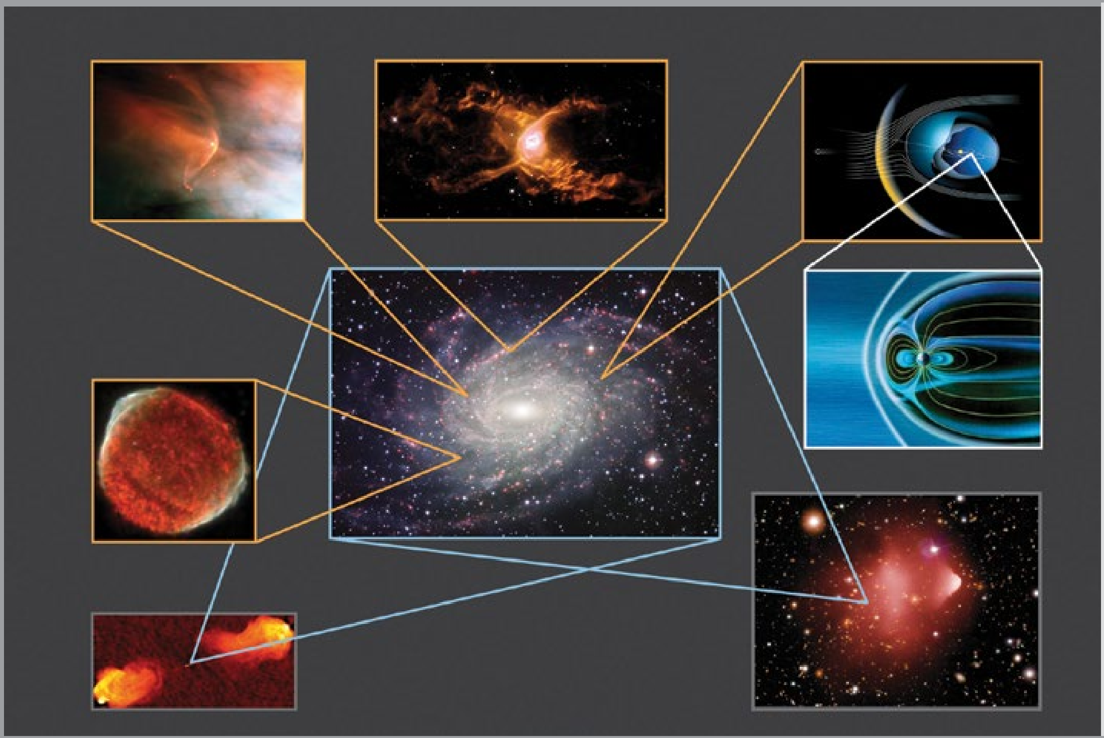


→ CLUSTER

The interaction between Earth's magnetic field and the solar wind results in the formation of a collisionless bow shock usually at 70 000–90 000 km upstream of our planet, in the Sun direction. Earth's bow shock is an extraordinary laboratory to directly probe plasma dynamics and to explore scales that are inaccessible to astronomical observations. These abrupt transitions between supersonic and subsonic flows are indeed observed in a variety of cosmic environments, most notably in stellar winds gusting from young and massive stars, in the shell-like remnants of supernova explosions and in the proximity of the lobes and jets emanating from radio galaxies.

Over the past years, the four-spacecraft Cluster mission has revealed many new aspects of this very dynamic boundary layer. To name a few, ripples along the bow shock have been detected. These ripples have been then found to enable the direct entry of solar wind plasma without being affected by this shock wave, forming high-speed jets. An investigation of the vast collection of data gathered by Cluster has led to an accurate estimation of the thickness of bow shock, only 17 km. This means that it may be a far more efficient particle accelerator than expected. Hence, in early 2016, two Cluster spacecraft have been put at only 3 km distance to investigate the physics of the bow shock at electron-scale level.

A new aspect of the bow shock has been recently investigated and detailed in a study published in *Nature Communications* (Lugaz *et al.*, 2016). A few times per decade, the solar wind density is so low that Earth's bow shock disappears. This extremely unusual situation occurred for several hours on 17 January 2013. Simultaneous measurements collected by more than ten spacecraft in the near-Earth environment, including Cluster, provided a unique set of data. It not only revealed the evanescence of the bow shock, but also its consequences including: the sunward motion of the magnetopause and the extremely rapid and intense loss of electrons in the outer radiation belt for one week.



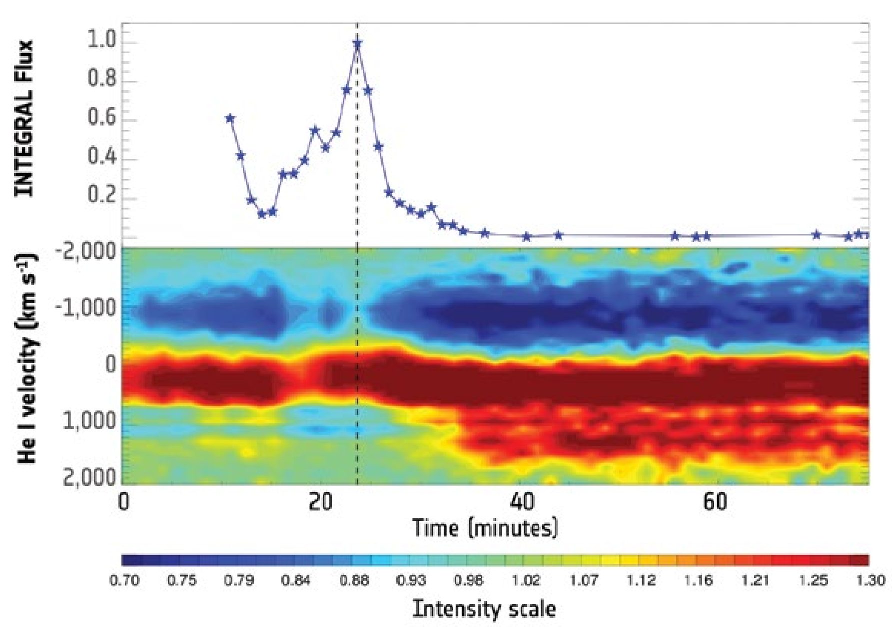
Astrophysical shocks on various cosmic scales, ranging from planetary systems and stellar shocks to supernova explosions, radio galaxies and hot gas in galaxy clusters

Understanding the complex interlink between regions inside and outside Earth's magnetosphere is crucial to predict the content of the radiation belts in particular.

This region is indeed a known danger to satellites crossing it. Furthermore, while this type of solar wind/magnetosphere coupling is unusual for planets in our Solar System, it may be common for extrasolar planets. See **http://www.nature.com/articles/ncomms13001**

→ INTEGRAL

V404 Cygni is a transient X-ray binary system, where a black hole of around 10 times the mass of the Sun is swallowing material from a nearby companion star. During this process material falls towards the black hole and forms an accretion disc, whose hotter, innermost zones emit in X-rays and gamma rays. In June 2015, V404 Cygni went into outburst after a quiescence of over 25 years. During this period its brightness



Top: Integral/IBIS/ISGRI (25–200 keV) normalised light-curve taken on 19 June 2015. Bottom: trailed spectrum of the He I-5876 Å emission line, covering 75 minutes with 55 optical spectra taken at the same time as the Integral data. The normalised intensity scale is such that absorptions, caused by the presence of the wind, are represented in blue, while emissions are represented in red (TM Darias/IAC Tenerife) increased a millionfold in a few days, becoming temporarily the brightest X-ray source in the sky. The evolution of the outburst was extensively monitored by Integral.

But, Integral was not the only observatory. V404 Cygni was followed at every wavelength possible. The example below shows the importance of multi-wavelength observation, providing crucial information through different channels.

Optical spectroscopic observations carried out with the Gran Telescopio Canarias (GTC) 10.4 m telescope discovered the presence of a wind of cold material, which is formed in the outer layers of the accretion disc, regulating the accretion of material onto the black hole. This wind has a very high velocity (up to 3000 km/s) so that it can escape from the gravitational field around the black hole.

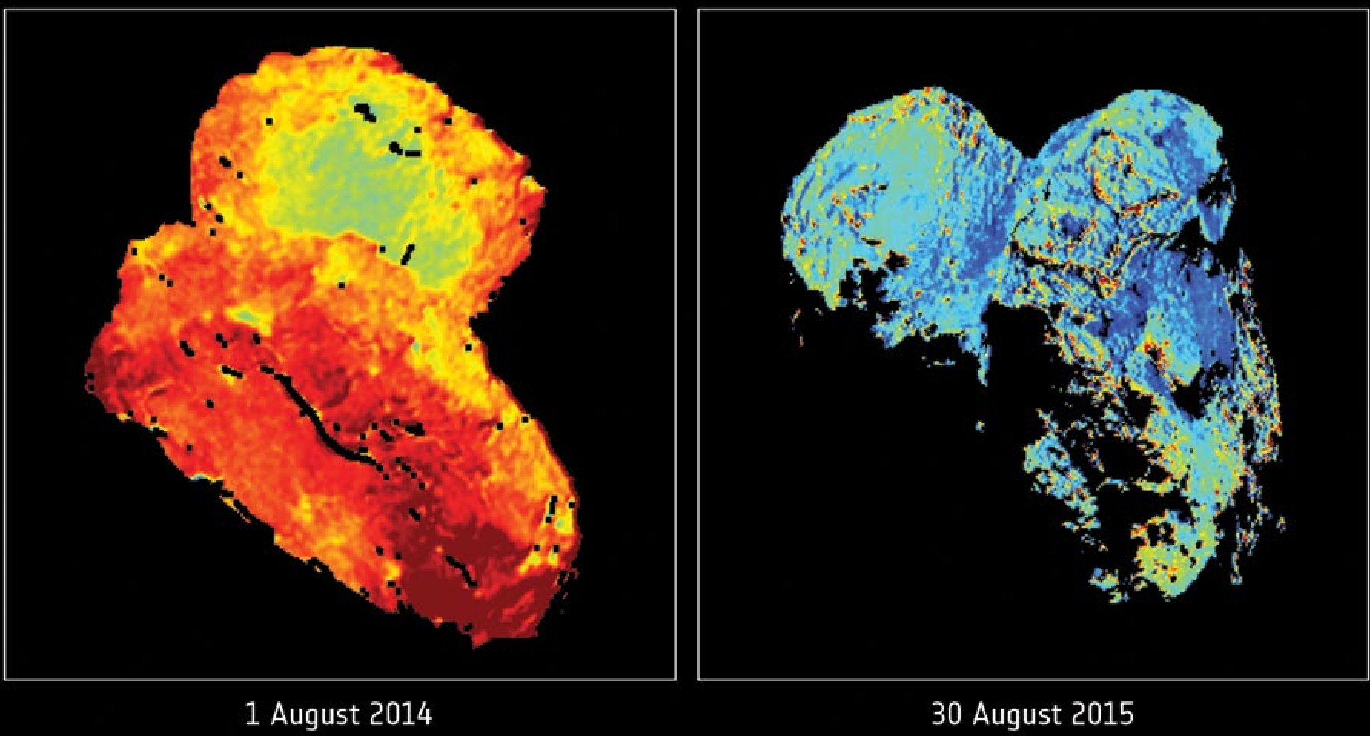
The simultaneous Integral and GTC observations reveal that the outflowing wind is detected along the observation, but its properties quickly change in response to the X-ray flaring, which modifies the temperature and, therefore, ionisation state of the accretion disc. The strongest features become evident at low X-ray fluxes, right after Integral detected a sharp flare. During this event the wind almost disappeared, and higher excitation emission lines appear in the optical spectrum.

→ ROSETTA

CO_2 ice was detected on a comet for the first time, based on data obtained during the approach to perihelion in early 2015. On two occasions very large patches of CO_2 ice were detected in the southern hemisphere of the nucleus. CO_2 is the second most abundant volatile after water but, with a very low sublimation temperature (80K), it is very hard to catch in solid form. The observations demonstrated that the patches were rather short-lived, having disappeared some three weeks later. CO_2 ice has a seasonal cycle over the comet's 6.5-year orbit, suggesting that the patches are a leftover from the previous apparition and are a result of condensation on the surface of previous activity. The patches were only able to sublimate in April 2015, because of seasonal effects, with the southern hemisphere summer equinox in May 2015 and the southern summer only lasting until March 2016.

Scientists have also been looking at the evolution of water ice on the surface of the nucleus. Large patches (100 m^2) were observed, persisting for around 10 days before disappearing. In fact one such patch appeared in the same region of the CO_2 patch after that has disappeared. By examining various dust/ice mixtures on Earth, it was shown

Colour of visible light reflected by Comet 67P/Churyumov–Gerasimenko on 1 August 2014 (left), before Rosetta arrived at the comet, and (right) a year later, on 30 August 2015, after the comet's closest approach to the Sun. Bluer colours are are richer in water ice. As the comet moved closer to the Sun and its activity increased, the outgassing of water vapour and other gases lifted off large amounts of dust, exposing more of the ice-rich terrain underneath



that these patches contained around 30–40% water ice mixed with darker material. Overall, on a global scale the distribution of water ice beneath the surface of the comet seems widely but not uniformly spread, with small patches punctuating the nucleus, appearing and disappearing as a result of the comet's activity. Observations have revealed that the comet surface became brighter and bluer in colour as it approached the Sun, consistent with a higher ice content and the comet losing its 'dusty coat'. Now, as the comet has receded from the Sun, the surface appears to be gradually turning redder again.

→ HERSCHEL

Now in the final year of its post-operations phase, the provision of support to the science exploitation of Herschel data by the astronomical community is continuing, in parallel with the preparations for the legacy science phase, beyond the formal end of the mission. All 'standard' pipeline final products have been produced and ingested into the Herschel Science Archive.

The archive itself has been released as a fully web-based tool (**http://archives.esac.esa.int/hsa/whsa/**) providing access to all Herschel science data products at various (user selected) levels of processing, including user provided data products delivered by consortia of Herschel observers. An important related ongoing task is the provision of documentation and instructional videos to enable the general community to continue the science exploitation of the Herschel data for many years to come, building on the already outstanding Herschel publication record.

→ MARS EXPRESS

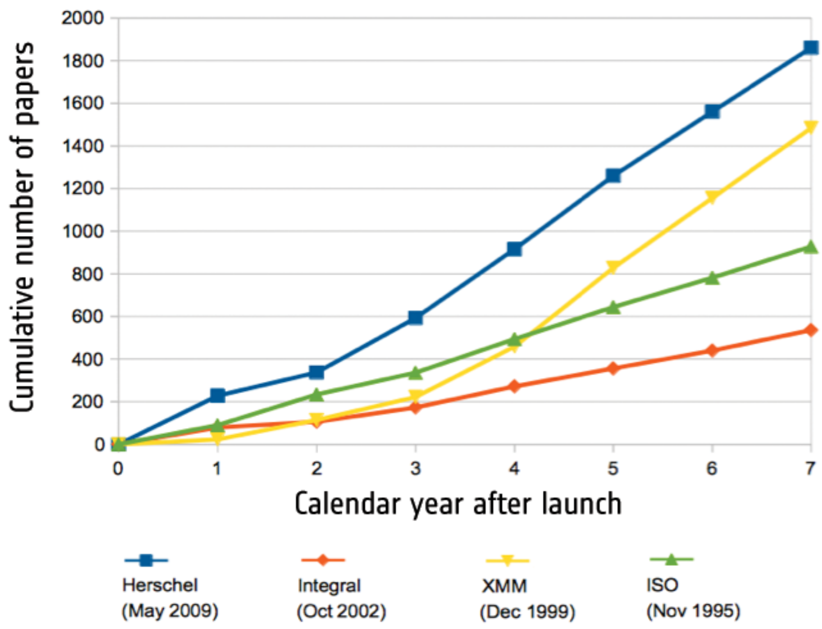
The spacecraft is in an excellent state and operations proceed flawlessly. In November 2016, it was confirmed by the Science Programme Committee that the mission would be extended to the end of 2018. The decision to extend the mission to the end of 2020 is expected in early 2017.

→ GAIA

A small adjustment to the spin phase is being made to optimise a light bending experiment with Jupiter and a background star. With the adjustment, the star can be caught at the moment it is very close to the limb of the planet.

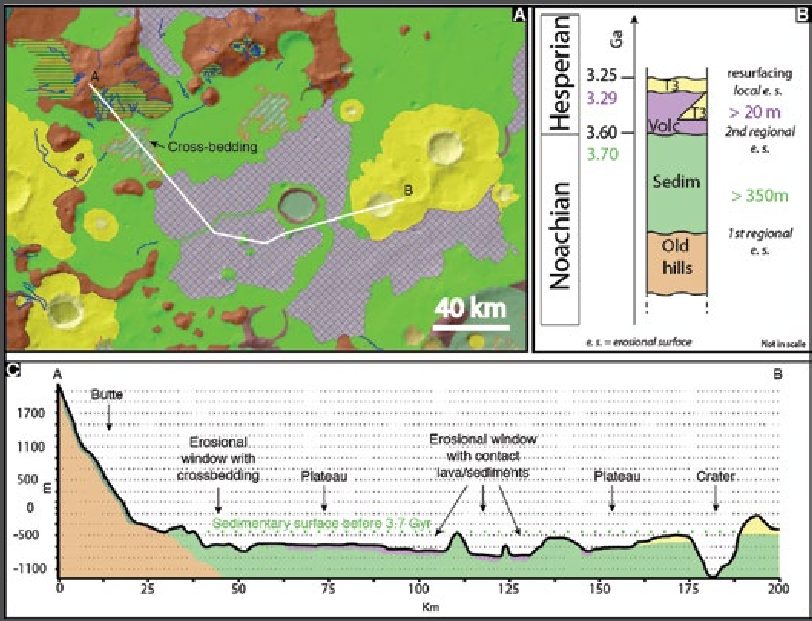
The second Gaia Data Release (Gaia DR2) is in production. The contents cover astrometry, photometry and, for the first time, radial velocities from spectrometry. In addition, expansion of variability data will be provided and, if processed successfully, also for the first time, some astrophysical parameters and Solar System data. The release is scheduled for April 2018.

Use of the data from Gaia DR1 continues. Some 50 papers have appeared either in preprint or final accepted form in the first four months since the release. The main categories of studies are: 1) examinations of distances deduced from the Gaia data to various stellar types, 2) comparisons of Gaia positions to radio positions of quasars, and 3) combining Gaia data with ground-based spectroscopic data for galactic structure studies.



Cumulative numbers of refereed papers from the ESA-led astronomical space observatories ISO, XMM-Newton, Integral and Herschel, in the first seven calendar years following their respective launches. Note that while ISO and Herschel had inflight operational durations (limited by their superfluid helium cryostats) of slightly less than 2.5 and 4 years, respectively, XMM-Newton and Integral are still observing

→ New evidence for a warmer and wetter early Mars



Geological history of the part of the Hellas basin: (a) geological map showing the main units and cross-bedding outcrop inside the erosional window, (b) stratigraphic column showing the main units of the studied area (between volcanic flows and fresh impact craters there are some local erosional surfaces), (c) geological cross-section to summarise stratigraphic relationships. The green dashed line is the upper surface of sedimentary rocks extrapolated from buttes and outcrops preserved after erosion

One of the most intriguing questions in martian research is whether the climate conditions in the past had been more habitable than they are now. A recent study from ESA's Mars Express and NASA's Mars Reconnaissance Orbiter (MRO) provides new evidence for a warm young Mars that hosted water across a geologically long timescale, rather than in short episodic bursts – something that has great consequences for habitability and the possibility of past life on the planet.

The findings follow an analysis of a region of relatively smooth terrain (so-called inter-crater plains) just north of the Hellas Basin. With a diameter of 2300 km, the Hellas Basin is one of the largest identified impact craters both on Mars and within the Solar System, and is thought to have formed some 4 billion years ago. The plains on the northern rim of Hellas were previously interpreted as being volcanic, but recent results revealed widespread swathes of sedimentary rock. This suggests that a generally aqueous environment was present in the region some 3.8 billion years ago for a geologically long period of time in the order of hundreds of millions of years.

There are a couple of key models for early Mars both involving the presence of liquid water, but in vastly different ways. Some studies suggest that over 3.7 billion years ago (Noachian period) Mars had a steadily warm climate, which enabled vast pools and streams of water to exist across the planet's surface.

This watery world then lost both its magnetic field and atmosphere and cooled down, transforming into the dry, arid planet we see today. Alternatively, rather than hosting a warm climate and water-laden surface for eons, Mars may instead have only experienced short, periodic bursts of warmth and wetness that lasted for less than 10 000 years each, facilitated by a sputtering cycle of volcanism that intermittently surged and subsided across the years.

Imaging and spectro-imaging data from Mars Express and MRO allowed creation of a detailed geological map of the area around northern Hellas, taking advantage of 'erosional windows' — geological formations that act as natural drill holes down into the plains, revealing deeper material (examples include impact craters, grabens and outcrops). These data showed the plains to be composed of a band of flat, layered, light-coloured sedimentary rocks and large amounts of clays known as smectites, over 500 m thick, indicating that a wet and thus potentially habitable environment once existed at that location.

The rock then underwent an intense period of volcanic erosion during the Hesperian period (3.7 to 3.3 billion years ago) and was covered by volcanic flows, creating the morphology we see today. Extrapolating these finding to the rest of Mars one conclude that the global climate conditions of Noachian Mars were sufficient to support significant liquid water.

→ LISA PATHFINDER

The satellite is in good health and the mission is now in the extension science operations phase. This phase is due to end on 31 May.

Following the science operations of the LISA Technology Package (LTP), the NASA-provided Disturbance Reduction System (DRS) operations began. The DRS achieved all of its Level 1 performance requirements, and in so doing, demonstrated a different thruster technology (colloidal microthrusters) and a different drag-free control strategy, both of which are options for future spaceborne gravitational wave detectors. Unfortunately, one (out of eight) of the colloidal thrusters suffered an anomaly towards the end of the operational phase. A workaround was quickly put in place whereby a hybrid mode of cold gas and colloidal thrusters was used to control the spacecraft. For all future DRS operations, the hybrid control mode will be used.

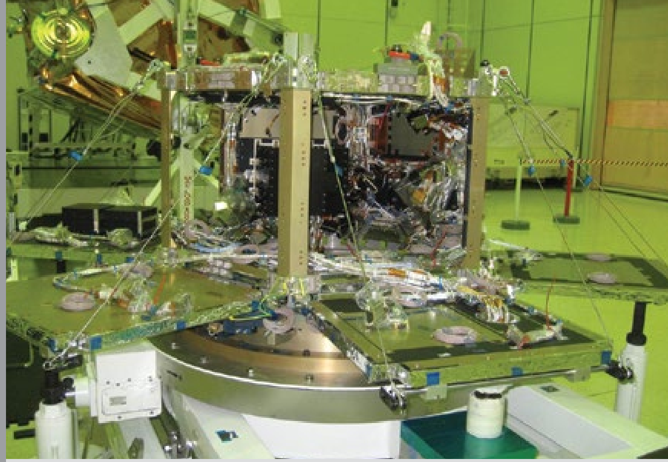
Following the DRS operations, the LTP payload resumed operations. The prime focus of the mission extension is to understand the physics of the instrument at the very lowest measurement frequencies of future spaceborne gravitational wave observatories. This is very much beyond the original scope of the mission, however the excellent performance of LPF opens the door to directly measure the forces that disturb the test masses from their inertial orbit, even at frequencies more than one order of magnitude lower than LPF was designed for.

As well as investigating the low frequency end of the measurement bandwidth, the science team are also pushing the performance in the mid-band frequency range. The performance is limited by viscous damping because of the residual gas surrounding the test masses (Brownian noise). This limiting noise has been decreasing over time as the enclosure is vented to space. To reduce the Brownian noise further, the decision was taken to lower the satellite temperature, thereby lowering the pressure in the housing. This non-standard operation was accomplished during January, resulting in a payload temperature about 10 degrees cooler. The resulting performance gains will be known following subsequent noise runs.

The LTP science archive is now available. The archive can be accessed via **http://lpf.esac.esa.int/lpfsa/**. The archive will be updated with both new data and data products as they become available.

→ CHEOPS

Mechanical and electrical integration of the FM equipment on the platform is nearing completion. The FM solar arrays, S-band transceiver and propulsion module were delivered



Integration of the flight equipment onto the Cheops flight platform in September 2016 (Airbus D&S Spain)

to Airbus Defence & Space, Spain. The first Integrated Sub-System Tests (Data Management System and Electrical Power System) started. Instrument development has progressed; in particular, the integration of the FM telescope has started and the focal plane module EM underwent thermal/vacuum testing. Launch readiness will be end of 2018, in line with the first potential launch opportunity.

→ BEPICOLOMBO

AIT activities on the Mercury Planetary Orbiter (MPO) progressed as planned. Integration activity of all payloads as well as platform units is complete and the module preparation for electrical- and mechanical- stack testing is progressing. The MPO solar array procurement was completed and will be integrated in February.

On the Mercury Transfer Module (MTM), a failure occurred on one of the Power Processing Units (PPU) of the Solar Electric Propulsion System. Both units have been removed from the spacecraft have been, after refurbishment, returned and reintegrated and subjected to first electrical checkout tests. Work on the JAXA-provided Mercury

Reintegration of the second Power Processing Unit on the BepiColombo Mercury Transfer Module

Magnetospheric Orbiter (MMO) is complete and the orbiter is being prepared for the advanced stack testing.

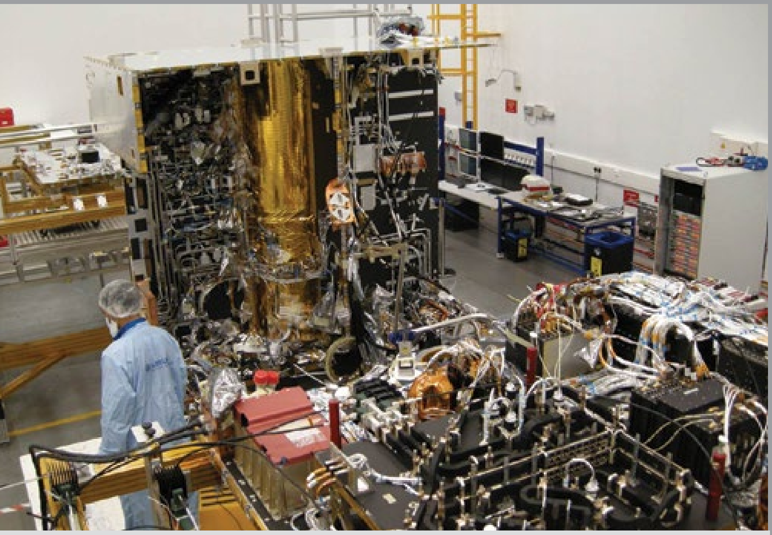
The delay in the schedule because of the PPU failure is nearly four months. Because of unavailability of the thermal facility, the system test sequence has been changed. The Mercury Composite Stack (all three spacecraft mounted in launch configuration) testing will be advanced to early 2017 and the MTM thermal test performed afterwards. Because of this delay, the launch date has shifted from April 2018 to the next opportunity in October 2018.

→ SOLAR ORBITER

The manufacture and delivery of spacecraft FM units and subsystems approaches completion. The spacecraft FM integration is going as planned. The FM Heat Shield integration, using the refurbished STM support panel, took place as well as integration of the various payload support elements, e.g. feedthroughs, doors and mechanisms. Preparations are under way in the test facility for the final Heat Shield thermal test simulating the high temperature and high Sun flux phase of the mission.

Solutions to the Cleanliness and Contamination Control issues are under implementation. In particular most contamination control baffles are approaching their Manufacturing Readiness Review, while the design of the last three is being finalised.

The components of the reaction control subsystem have been integrated with the spacecraft core primary structure and the proof pressure test carried out. The Service Panel integration and the Communication Panel integration have been completed. The Payload Panel is available for integration of the available instruments. Functional testing continues on the two spacecraft Engineering Test Benches. The first Integrated Ground Segment Test has been executed as planned at the end of 2016. Interface work with NASA and United Launch Alliance for the baseline Atlas V-411 launch vehicle is progressing.



Solar Orbiter Flight Model integration

For the payload FM development, instrument deliveries have started with the first three out of a total of ten having been delivered. The other instruments are under final acceptance testing and delivery ranges up to end of April for the last one, later than previously expected.

The spacecraft system schedule has been adapted to instrument delivery dates. Schedule recovery actions are agreed with industry to be able to accommodate the instrument deliveries with the minimum shift in the spacecraft readiness for launch. A shift of launch date from October 2018 to the next opportunity in February 2019 is being considered.

→ JAMES WEBB SPACE TELESCOPE (JWST)

The overall programme continues according to the new schedule established in 2011 with a planned launch date in October 2018. The pre-environmental tests of the Optical Telescope with the Integrated Science Instrument Module (OTIS), the instrument electronics module, the harness and the thermal hardware have been completed. The OTIS sine vibration test started and the first axis has been completed. The sine test will be followed by a cryogenic functional and optical end-to-end test at the NASA Johnson Space Center. This test facility is fully commissioned after the completion of the OTIS Thermal Pathfinder test. The integration of the spacecraft and the sunshield continues as planned. JWST will be launched on an Ariane 5 ECA and the contracts for the Launch Service Agreement and the launcher delta-qualification study specific to JWST are progressing.

→ EUCLID

Prime contractor Thales Alenia Space Italy completed the system PDR and the PDR at subsystem and unit level. By the end of 2016, many units had passed their Equipment Qualification Status Review (EQSR) or a proper CDR, depending on their heritage status.

The PLM under responsibility of Airbus Defence & Space in Toulouse is also proceeding in the detailed design and many flight components are being manufactured. All the SiC reflectors optics have been manufactured and mechanically polished and are now under ion-beam figuring, an operation that will continue for many months in order to reach the extreme smoothness required by the optical image quality

The Webb Optical Telescope with the Integrated Science Instrument Module on the shaker table with the cleanliness cover being installed (NASA) of the telescope. The main SiC part, the optical bench, is also being manufactured. This very important element, built in four pieces, was affected by a number of issues that led to significant delay. A revised system integration and test sequence has been studied and will now be implemented. This keeps the launch date in December 2020.

On the Visible Imager (VIS) instrument, subsystem EMs and STMs have been manufactured and the STM tests at instrument level have been performed. The VIS Instrument CDR data package was delivered at the end of 2016. The contract with e2v for the development, QM and FM production of the (ESA-procured) CCD detectors is proceeding. Assembly of the FM devices is under way. The first FM devices were ready for delivery in December 2016.

The design consolidation for the Near Infrared Spectro-Photometer (NISP) was completed with all the subsystem CDRs. The Instrument CDR was completed in December. The NISP STM was manufactured and tested under vibration and thermal/vacuum conditions, ready for the PLM STM campaign.

The procurement of the NISP HgCdTe detectors FM production, under NASA responsibility, is ongoing. All flight detector elements have been manufactured and tested, showing excellent performance. The front-end electronics faced some technical issues, which caused a substantial delay. The first two FM units were delivered by the manufacturer (Teledyne, USA) and are under test. The assembly and final test of the detector system is now driving the NISP schedule.

The Euclid Ground Segment development is progressing. The Science Ground Segment is preparing the next series of the so-called 'scientific and system challenges', operational tests to simulate the science data intake and processing as implemented in the Science Data Centres. Launch is planned for December 2020 on a Soyuz-Fregat from Kourou.

→ JUICE

The procurement of the subsystems and equipment progresses, with all flight hardware and most of the mechanical ground support equipment selected. The remaining procurement is mostly electrical ground support equipment.

The spacecraft PDR began in December. All required documentation was delivered. Technology development activities, initiated to mitigate risks in the spacecraft development, are progressing. The most critical ones, addressing the solar cell performances validation in the harsh jovian environment (high radiation, low temperature and low illumination) are approaching completion. The spacecraft schedule is stable and under control. However, the schedule of most of the instruments is still under consolidation with some major issues declared by some. Six instrument PDRs out of ten have been passed. The remaining four IPDRs will take place between February and July.

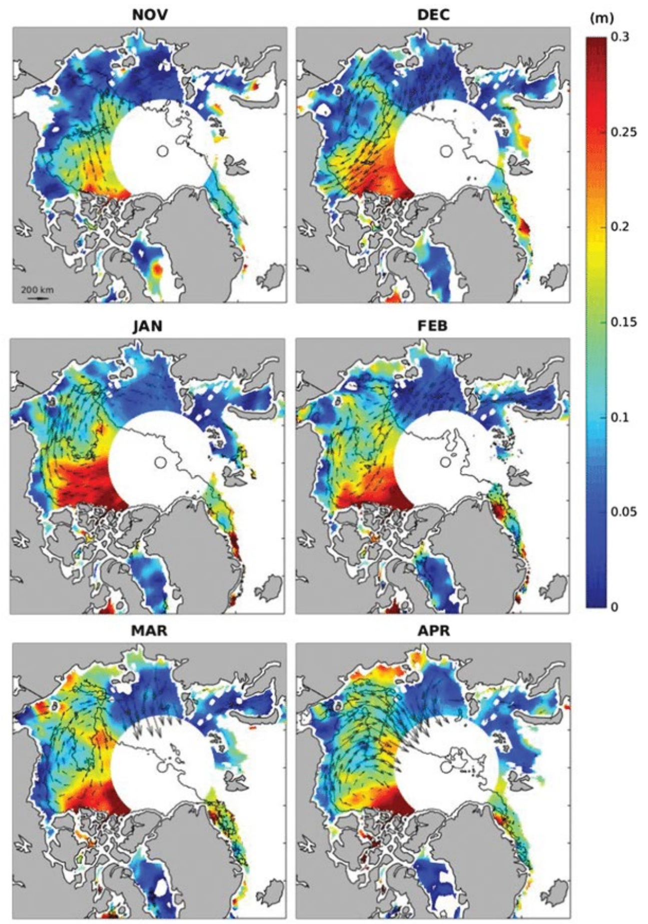
Work has concluded in ESOC to improve the mission scenario with the objectives of reducing the overall radiation dose accumulated during the mission, to optimise the operation of one instrument (the ocean finding radar) and to reduce the number of eclipses.

The launch vehicle will be an Ariane 5 ECA. Arianespace is running a Preliminary Couple Load Analysis in support of the JUICE PDR. The launch date remains 1 June 2022.

→ SMOS

Operations have been extended by both ESA and CNES to the end of 2017.

→ CRYOSAT

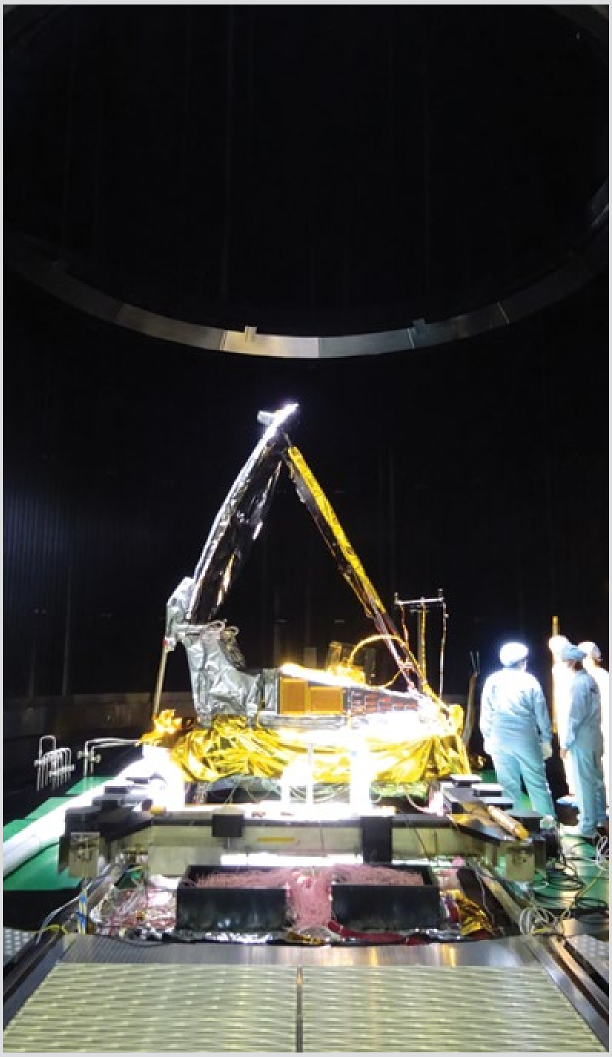


Spatial maps of monthly snow depth obtained using CryoSat-2 and Altika data for November 2013 to April 2014 (Guerreiro *et al.*, *Remote Sensing of Environment* 186 (2016) 339–349)

The mission has been extended until late 2019. CryoSat continues to provide also valuable data to a handful of non-cryospheric domains, in particular, ocean, marine gravity and hydrology. A new improved version of the CryoSat ocean and ice products will be released in 2017. The next important results were discussed at the CryoSat North American Science Meeting, held in Banff (Canada) in March 2017 **www.cryosat2017.org**

→ SWARM

Driven by the continuous excellent science data from the three-satellite constellation, the mission return quickly proliferates. Scientific production is extremely high in all mission areas, ranging from the deep interior (liquid outer core), via the mantle, lithosphere and crust, through to the thermosphere, ionosphere and magnetosphere. Recently, three major breakthroughs were published. First, the world-first ability to probe the electrical structure of the mantle through observations of the tiny magnetic field caused by the tidal motion of ocean water has opened up new avenues to understanding Earth's mantle and lithosphere. Second, a 'jet stream' (extremely fast rotating movements of molten iron) was discovered in the outer core beneath Alaska, Canada and Siberia using Swarm data. Third, through combinations of several instruments on Swarm, it was demonstrated that often-observed technical issues in spacecraft flying above the South Atlantic Anomaly may not be due to increased radiation impact alone, but also to a bubblestorm-like nature of the ionised plasma, comparable to thunderstorms in terrestrial weather.



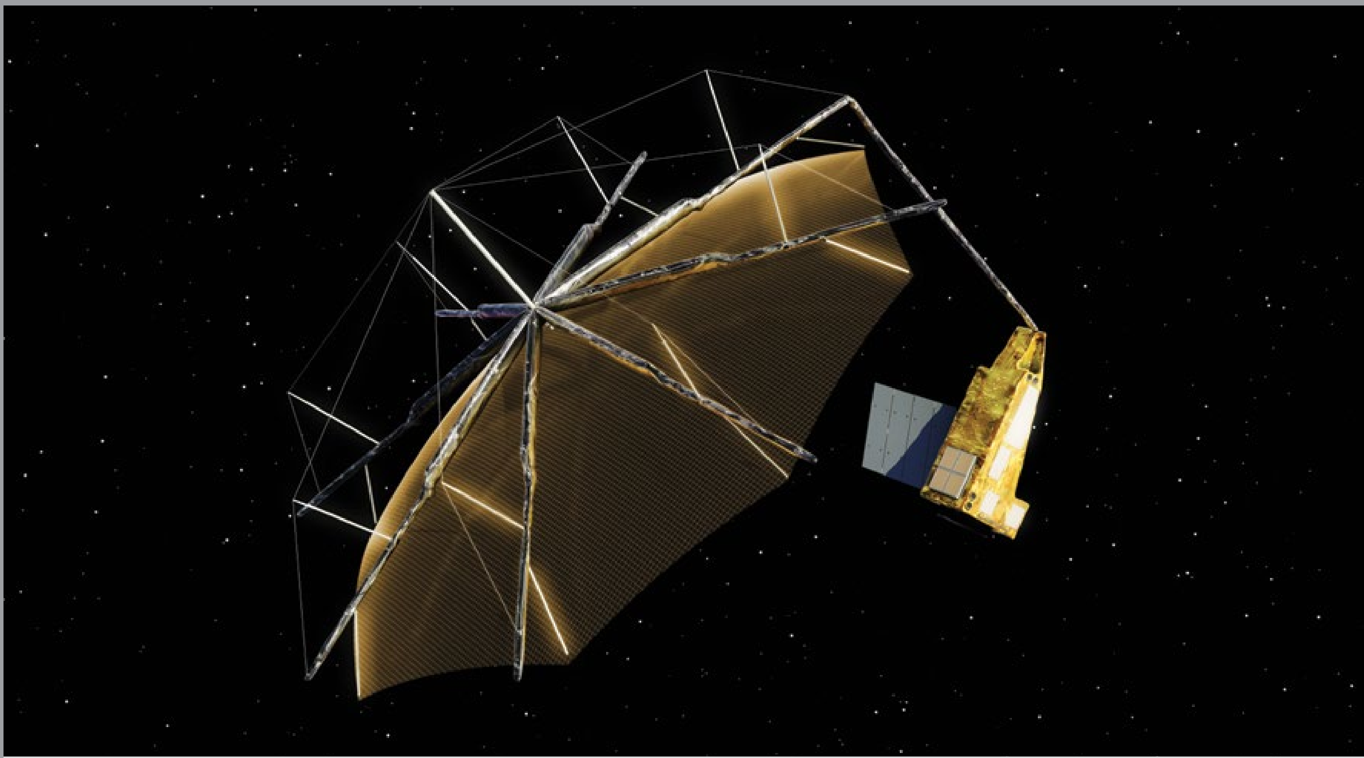
EarthCARE Cloud Profiling Radar PFM thermal balance/vacuum test (JAXA/NEC Japan)

→ AEOLUS

Mechanical and electrical integration of the satellite was completed at Airbus Defence & Space. The integrated system test at satellite level and system validation tests at mission level were also completed. The satellite is being shipped to the environmental test facility at Intespace in Toulouse for mechanical and EMC verification. The system validation test executed from ESOC confirmed the progress for the Flight Operation Segment and the operational database. The integration test phase for the Payload Data Ground Segment in ESRIN is ongoing. The final mission analysis campaign will start soon with Arianespace, with launch planned on a Vega.

→ EARTHCARE

Base Platform integration is complete and the prime contractor Airbus Defence & Space (DE) has initiated the formal testing of its sub-systems. On the Atmospheric Lidar (ATLID) instrument, the PFM transmitter was delivered to Airbus (FR) for integration testing with the support of Leonardo (IT). Integration of the ATLID PFM receiver is nearing completion. The stray light of the Thermal Infrared Camera (TIR) of the Multi-Spectral Imager (MSI) has been measured and its internal baffling scheme finalised by SSTL (UK). The Visible, Near Infrared and Short Wave infrared camera qualification campaign was completed and its extensive calibration campaign started at TNO (NL). Integration of the MSI Optical Bench, common to both TIR and VNS cameras was completed. The calibration campaign of the Broad-Band Radiometer Optical Unit is proceeding at RAL (UK) with the support of Thales Alenia Space (UK). In Japan, the Cloud Profiling Radar PFM instrument qualification test campaign was interrupted to allow the investigation of an anomaly affecting one of its two redundant power transmitters. Meanwhile, the instrument mechanical and thermal balance/vacuum test campaigns were completed and JAXA is preparing to ship the instrument to Europe.



Biomass satellite (Airbus D&S)

→ BIOMASS

The SRR was completed. The technical requirements were translated into a set of requirements documents by industry to allow the start of the procurement of the individual satellite units. The satellite has been broken down into about 50 individual units, which will be built by industries from all ESA Member States. An equivalent number of contracts will have to be run by the Biomass Core Industrial Team and will be supported by the ESA project. Ten ITTs were already released in 2016, and the completion of all procurements will be the main activity in 2017. The system PDR will take place in 2017. On the ground segment, work started for the processing of the satellite data and the preparation of flight operations. Development work for the processing of the next level of data, to get the biomass, forest height and forest disturbance, will begin in February. This work is well supported by excellent results from ground based and airborne campaigns that were carried out throughout 2016.

→ METEOSAT THIRD GENERATION

The Intermediate Design Check Points for MTG-I and MTG-S Part 1 have been implemented, confirming the design of both satellites. Implementation of the MTG development models is progressing, the major milestone achieved relates to the completion of the platform STM integration and subsequent thermal/vacuum testing at IABG. Mechanical integration of the platform EM is completed.

For the FCI and IRS instruments, the predicted instrument performances remain stable, with high level of compliance predicted. Effort has been focused on mitigating significant delays declared by several key sub-contractors. This has resulted in an evolution of the FCI instrument development logic and associated instrument model build standards. For the IRS, effort to optimise AIT activities on the FCI will directly benefit the IRS. A full-size configuration model of the instrument was made to confirm interfaces and assembly provisions for the integration of the interferometer and detector chain assembly from Thales Alenia Space France. The quantum efficiency (QE) of the LI detectors still needs to be improved. The full QE measurement activity should be completed by mid-May.

FAR dates for the MTG-I and MTG-S PFM are December 2020 and August 2022 respectively.

→ METOP

MetOp-C

The Infrared Atmospheric Sounding Interferometer was integrated on the PLM. After system functional testing, the PLM was shipped to ESTEC for thermal/vacuum testing and mass properties measurements. The GOME-2 instrument was shipped to ESTEC after repair. It will be reintegrated on the PLM at ESTEC before the thermal/vacuum test.

The SVM has been taken out of storage at Airbus Defence & Space (FR) in preparation for the test campaign. After completion of the PLM and SVM standalone tests, expected in June, the PLM will be shipped to Airbus in Toulouse for coupling with the SVM and the subsequent satellite-level testing activities. Launch will be on a Soyuz from Europe's Spaceport in October 2018.

MetOp Second Generation

Satellite design activities progressed with mass, power and data rate budgets all within requirements. Lower-level sub-systems and equipment PDRs are nearing completion and CDRs have started. The main focus remains on the complex Customer Furnished Item instruments (particularly METimage, IASI-NG and Sentinel-5), as well as the technologically challenging receiver front-end and back-end equipment for the microwave radiometers (MWS, MWI and ICI).

→ COPERNICUS

Sentinel-1

Sentinel-1A and -1B remain stable using all of their prime units, running in a preprogrammed operational mode that ensures the continuous production of consistent long-term data series. The mission capacity will increase with the integration of the EDRS service providing additional mission downlink capability. The volume of data was of 8 TB/day at the end of 2016, with the mission goal of 10 TB/day of core products reached early this year.

More than 53000 users were registered in the Sentinels Scientific Data Hub (**https://scihub.copernicus.eu**) to access the data from the three Sentinels (1A and 1B, 2A and 3A) in November 2016.

Development of the new Sentinel-1C and -1D models is on schedule. Equipment and spacecraft qualification status has been reviewed in line with launching the FM production by mid-2017.

Sentinel-2

Sentinel-2B is ready for shipment to Europe's Spaceport in French Guiana on 5 January for a launch on Vega in March. Sentinel-2B had its FAR on the 25 November and was approved for shipping to the launch site. Preparations for LEOP and in-orbit commissioning are progressing with the control team at ESOC and the Payload Data Ground Segment team at ESRIN. A launch on 6 March permits a handover of the second spacecraft for routine operations to the Mission Manager early in June. Sentinel-2C and -2D redundant spacecraft production continues, with the first flight hardware already delivered.

Sentinel-3

On the instrument side, the SLSTR thermal/vacuum campaign has started which will then be followed by the instrument calibration in vacuum, last test activity planned before delivery. The OLCI cameras are being rebuilt to correct some defective element identified during previous testing. At satellite level, the topographic payload (SRAL, MWR and DORIS) has been integrated on the spacecraft. The satellite, which is now complete except for the optical instruments, is now undergoing functional testing.

For Sentinel-3C and -3D, most EQSR and Unit Production Reviews with suppliers have been completed, allowing Hardware Production Reviews at instrument and satellite level to start. The MWR and SLSTR instrument already completed these reviews, while the platform, OLCI and SRAL are running their reviews in parallel with the Satellite Production Review.

Sentinel-4

OHB (DE) and Airbus Defence & Space (DE) completed the environmental test campaign of the STM of the Optical Instrument Module at IABG (DE). This module will be the first formal hardware delivery, planned for May. Integration and electrical testing of the instrument EM is continuing at Airbus in Munich: the parts manufacturing for its structure was completed. Testing of the Life Test Unit of the scanner mechanism, one of the key subsystems of the Sentinel-4 instrument, is progressing at Ruag (CH). The system CDR should be complete by January.

Sentinel-5

Industrial consortium is now complete. A separate procurement for the Level-2 processor prototype development has taken place and the activity has started. All sub-system EQSRs were completed and most of their PDRs have taken place as well. The first sub-system CDRs have started. Detailed design of the Instrument Optical Module structure and radiators for the STM is complete and parts manufacturing is ongoing. The first breadboard models of the CCD and Short-Wave Infrared sensors have been delivered to Airbus Defence & Space. Detailed characterisations of the UVN (CCD) and SWIR detectors are ongoing to optimise bias parameters. Interface checks between a UVN detector and the Front End Electronics concluded.

Sentinel-5 Precursor

The satellite was removed from storage in mid-November for a six-week maintenance programme. The Overall Ground Segment is ready. LEOP rehearsals at ESOC are planned to start three months before launch. The Rockot launcher authority announced a launch delay, with the earliest possible date not before June.

Sentinel-2B satellite at ESA's site in the Netherlands, on 14 November 2016, before being packed up and shipped to French Guiana for its spring launch

Sentinel-6/ Jason-CS
The ESA, NASA, NOAA and Eumetsat three parties/four partners MoU was approved, formalising the cooperation. The ESA/CNES cooperation agreement was extended to include CNES support to ESA in the navigation, altimetry and system domains. The project is in Phase-C. All the satellite procurement actions were completed and the satellite CDR will begin in March. The NASA-provided radiometer and radio-occultation payloads development is in Phase-B. The US payload PDR took place in February. The mission PDR will follow the terminated mission-level SRR in March.

→ EDRS

The EDRS-A test campaign finished with the start of the EDRS service to the Sentinel-1A satellite on 23 November 2016. This marked the formal start of the commercial EDRS service, a 'giant leap' in providing Earth observation data to the ground at 'near real time'.

The EDRS-C mission CDR will take place in the first half of 2017 and will ensure the consistency of the EDRS-C satellite with the ground segment, thereby verifying the overall performance of the EDRS-C mission. The Platform Module was mated with the Repeater Module to constitute the EDRS-C satellite, followed by a series of functional and performance tests at OHB in Bremen, before shipping to the environmental test facility at IABG.

The full suite of ground stations in Weilheim, Redu and Harwell has been fully deployed to support the provision of the commercial EDRS service through EDRS-A. Up to 14 regular link sessions per day for the (currently only) customer Sentinel-1A are prepared at and conducted from the EDRS Mission Operations Center in Ottobrunn. Development of an additional data receiver station in Matera will begin in early 2017. The GlobeNet programme will extend coverage area of EDRS by adding a third node – EDRS-D – in the Asia/Pacific region to complement EDRS-A and EDRS-C. Following submission of the GlobeNet programme at the 2016 Ministerial Council, Phase-B activities are planned to start in early 2017.

→ IRIS

The Iris programme has the objective to develop the end-to-end satellite-based communication system for safer and more efficient skyways. The Iris system will form part of the future European Air Traffic Management System (EATMS), being implemented through the Single European Sky initiative of the European Commission.

Initial flight trials were completed last year as part of the PPP between ESA and UK satellite operator Inmarsat to provide air–ground communications for initial '4D' flight path control. This will enable precise tracking of flights and more efficient management of traffic by pinpointing an aircraft in four dimensions: latitude, longitude, altitude and time. Four aircraft from the Netherlands Aerospace Centre carried prototype Iris terminals connected to Inmarsat's next-generation SwiftBroadband-Safety satellite service as they took off from Amsterdam towards different destinations in Europe. These flight trials complement a separate test flight by Airbus with Inmarsat and other partners earlier in 2016, when first data link communication between the pilot and air traffic control was established.

Following the 2016 Ministerial Council, Iris is now entering the implementation phase to provide, as complementary technology to the terrestrial infrastructure, the overall reliability and capacity required in Europe by 2025.

Enhancements and upgrades to existing Iris technology, as well as new developments, will be implemented both on the ground segment and on the user terminal segment. A validation activity will be performed in collaboration with two major European airlines, where up to 20 aircraft will be equipped with certified Iris avionics on revenue flights, connecting national service providers with the Airlines Operations Centre.

→ QUANTUM

Developed under a partnership between ESA, Eutelsat and Airbus Defence & Space, Quantum is an innovative satellite with a flexible payload that can be retasked in orbit. The baseline design review process for the pioneering 'software-programmable' Quantum satellite is being finalised, and the team is working towards the spacecraft CDR planned the end of 2017. Launch is planned for early 2019.

→ ARIANE 6

The Rider 1 of Launcher System contract was signed in November. Preparation of the Maturity Gate 6.1 is ongoing. This includes a reference consolidation loop that is fed by several sub-system architectures Key Points. The objective is to authorise, at Launcher System level, the start of the QM manufacturing. The transfer of assets developed in Ariane 5 programmes to Ariane 6 is being prepared and mainly related to Vinci/Fluid Propulsive System items.

For the Launch Base, the PDR covering the Ground and Launcher interface connection system took place on 6 December. The industrial CDR took place for the Mobile Gantry, the BAL launcher assembly building and water systems. An industrial PDR took place for mechanical systems (table, deflector, pallets and mast).

Launch of Vega VV08 with Göktürk-1 on 5 December 2016 (ESA/CNES/Arianepace/Optique video du CSG/JM Guillon)

The Interface Requirement Documents and the Interface Control Documents were updated before the Launch Base and Launcher System step 2 procurements in November. The Interface Control meetings are ongoing. The Launcher System Optimisation Key Point will begin on 28 February. The purpose of this review is to check the Launch System consistency in view of development milestones to be achieved by end March.

For the P120C solid-rocket motor activities, the P120C inert motor case delta PDR was held in December. The P120 multi-function connection ring PDR and the Thrust Vector Control/ Thrust Vector Actuator System PDR were held in December.

→ VEGA EXPLOITATION

On 5 December 2016, Vega flight VV08 successfully put Göktürk-1, Turkey's first governmental satellite for Earth observation, into orbit. VV08, the eighth success in a row, confirmed once more Vega's outstanding performance. The next launch, VV09, is planned for March with Copernicus Sentinel-2B. The qualification process was closed with the Launch System Delta FQR step 2 closed on 15 December 2016, clearing the way to the full commercial exploitation of the Vega launch system. After the subscriptions at the 2016 Ministerial Council related to the 2017–19 period, discussions have been initiated with industry to implement relevant activities.

→ VEGA-C AND VEGA-E

Building on the implementation of the industrial change concerning the P120C solid-rocket motor, it was requested to make changes in the Vega-C Launcher System baseline configuration, and to adapt the Launch Complex Mechanics, Fluidic and Avionics Ground Proximity Means accordingly. This will enlarge the Vega-C market by capturing the two-tonne class of Earth observation missions in LEO at 600–700 km (for example, SAR satellites), without impact on the Vega-C master plan based on a launch by mid-2019.

Thomas Pesquet's launch to the International Space Station from Baikonur in Kazakhstan on 17 November 2016 (NASA/B. Ingalls)

The Vega-C Launch System Definition Review took place from November to January, encompassing Launcher System, Launch Complex and Launch Range PDR. Phase C/D follows, with target for the maiden flight by mid-2019. With full subscription from participating Member States, the 2016 Ministerial Council approved the programme proposals for 2017–19 activities on both Vega-C and Vega-E.

→ FUTURE LAUNCHER PREPARATORY PROGRAMME

Preparations started at the P3.2 test bench for ETID-1 (Expander Technology Integrated Demonstrator) hot-firing test campaign, after the CDR was in November. The ETID-2 propulsion system concept phase began in December. The turbine by-pass valve and the hydrogen chamber valve passed their respective Manufacturing Readiness Reviews in October. The Concept Review for the LOX/hydrocarbon combustion chamber for Prometheus (the ultra-low cost engine demonstration) was performed in December.

→ SPACE RIDER

The 2016 Ministerial Council approved the Phase-B2/C activities up to the CDR planned for 2019. Phase-A activities concluded with the PRR in November. Phase-B1 activities were redirected to account for the integration of Vega-C/AVUM as an Orbital Service Module with the SRR planned for mid-2017.

→ HUMAN SPACEFLIGHT

At the 2016 Ministerial Council, ESA Member States took the strategic decision to start a new programme, the European Exploration Envelope Programme which aligns ESA's human and robotic activities to the its Space Exploration Strategy. They decided to continue to operate and use the ISS until 2024 with international partners, as well as provided funding for ExoMars 2020, the European contribution to the Luna-Resource mission and the study of future missions and development of the related enabling technologies.

→ ISS

Thomas Pesquet (FR) was launched on Soyuz MS-03 from Baikonur on 17 November and docked to ISS after a two-day flight. During his Proxima long-duration mission, he will perform around 50 scientific experiments for ESA and CNES, as well as taking part in many research activities for the other ISS partners.

Logistics flights from October to December 2016 helped in transporting supplies to the ISS including hardware and consumables for different ESA experiments. ISS Soyuz crew exchanges also occurred which assist in rotating ISS crew members and hence bringing new test subjects for ESA human research activities to the ISS. This included two Soyuz launches to the ISS and one Soyuz landing.

Astronauts

Paolo Nespoli (IT) performed Columbus specialist level training and payload training at EAC from 26 September to 7 October. He also was in Russia as part of the backup for Thomas Pesquet on Soyuz MS-03. On 24 November, the name 'Vita' and logo for Paolo's mission were announced in Rome.

The logo for ESA astronaut Paolo Nespoli's Vita mission

Thomas Pesquet adapting to life on the Space Station on 20 November (NASA/ESA)

The Moon seen rising behind the Soyuz MS-03 rocket at Baikonur on 14 November 2016, just days before NASA astronaut Peggy Whitson, cosmonaut Oleg Novitsky and Thomas Pesquet launch to the ISS (NASA/B. Ingalls)

ESA's Matthias Maurer, Luca Parmitano and Pedro Duque on a field trip in Lanzarote for their Pangaea planetary geology course

Thomas Pesquet setting up the Muscle Atrophy Research and Exercise System (MARES) on 28 November (ESA/NASA)

Vita stands for Vitality, Innovation, Technology and Ability and was chosen by the Italian space agency ASI, providing the mission through a barter agreement with NASA.

Alexander Gerst (DE) continued his training in Russia and the US. Pedro Duque (ES), Matthias Maurer (DE) and Luca Parmitano (IT) participated in the PANGAEA Geological Field Training session in October in Lanzarote, Spain. This training is designed to provide sample identification and collection skills to astronauts in view of future Moon or Mars surface exploration missions.

European Robotic Arm (ERA)

Roscosmos, Energia and GCTC confirmed the launch date of December 2017. A signed flight plan was handed over to ESA, including software interface testing at Energia in February, moving ERA to Baikonur in March or April and starting cosmonaut training in March.

ACES/ASIM

Atomic Clock Ensemble in Space (ACES) encountered some new critical issues when components were found not to be suitable. All components that have to be replaced are on stock, but the overall schedule impact is still under evaluation.

The situation with Atmosphere-Space Interactions Monitor (ASIM) has improved and the ASIM ground model is integrated and fully tested, although with a delay of two weeks. This delay impacts all other activities, with a possible impact on the delivery to Kennedy Space Center, scheduled for July.

Paolo Nespoli as Soyuz MS-03 backup flight engineer, seen with prime crew Thomas Pesquet (left) during pre-flight press conference in November

→ ISS UTILISATION

Human research

The Skin-B experiment concluded for all test subjects in November 2016. The experiment is helping to develop a mathematical model of aging skin (and other tissues in the body) to improve our understanding of skin-aging mechanisms, which are accelerated in weightlessness.

A new human research experiment (Sarcolab-3) started in November with on-orbit activities for the first astronaut test subject and making first scientific use of the Muscle Atrophy Research and Exercise System (MARES). Sarcolab-3 is studying the effect of weightlessness on loss of muscle mass, function and motor control, by determining the contractile characteristics of muscles particularly affected.

Materials research

One sample cartridge assembly for the METCOMP experiment was processed inside the Materials Science Laboratory (MSL) in October. METCOMP is one of the experiments undertaken in the MSL which are studying

Peggy Whitson working with the European Microgravity Science Glovebox in the US Destiny laboratory in December (ESA/NASA)

different aspects of the solidification process in metal alloys which will help to optimise industrial casting processes. The METCOMP experiment will deliver samples of bronze where a complex peritectic reaction has taken place with no influence of convection.

Fluids research

The SODI DCMIX-3 experiment was completed in November with all mandatory science runs and additional bonus runs performed. The main purpose of the SODI-DCMIX experiment is the measurement of diffusion coefficients of selected ternary water-based and hydrocarbon mixtures. Results from space experiments, performed in the Selectable Optical Diagnostic Instrument (SODI) will be used to test thermodiffusion theories and develop physical and mathematical models for the estimation of (thermo) diffusion coefficients. The data complements data gathered earlier in 2016 with the SCCO experiment on the Chinese SJ-10 capsule.

A new campaign of science also started with the Geoflow-II experiment in the Fluid Science Laboratory (FSL) in Columbus in November 2016. The majority of the highest priority runs was completed by the end of 2016. GEOFLOW-II investigates instabilities in an incompressible fluid with pronounced temperature dependent viscosity between two concentric spheres rotating about a common axis under the influence of a simulated central force field. This fundamental experiment is a rough approximation of geophysical fluid flow.

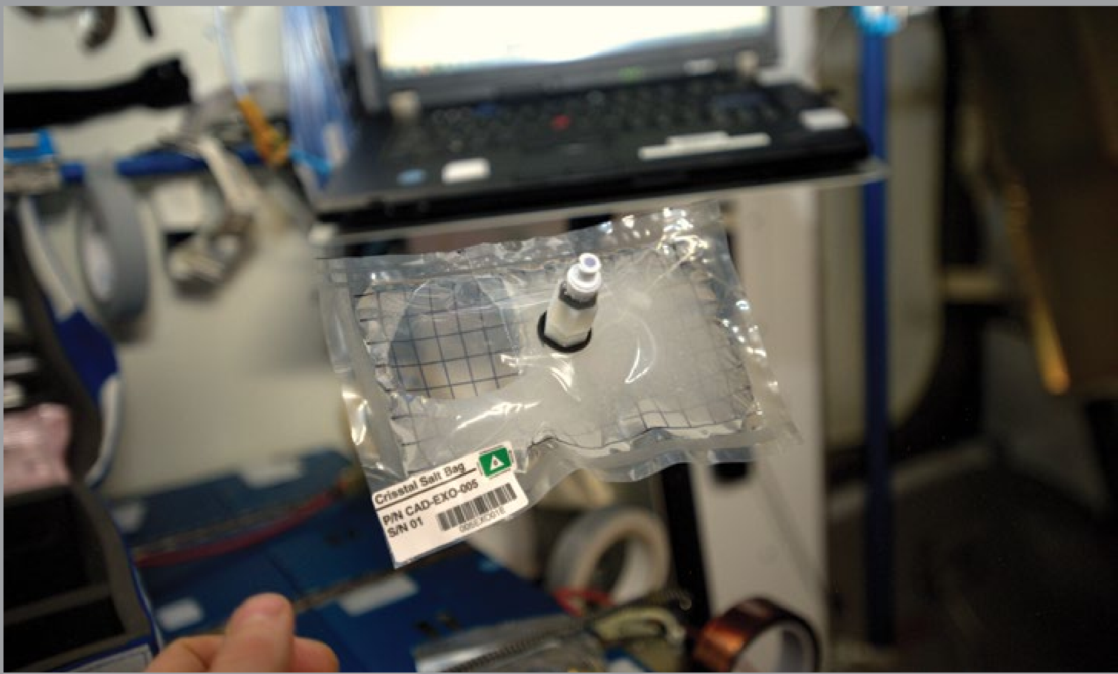
Complex plasma research

The third science campaign for the Plasma Kristall-4 (PK-4) experiment was performed in October 2016 with different experiments performed across the three days of science activities. Interesting results have also been presented recently from the first two campaigns. The main interest of this joint ESA/Roscosmos experiment lies in the investigation of the liquid phase and flow phenomena of complex plasmas for which PK-4 is especially suited.

Solar/radiation research

ESA's SOLAR facility completed another three standard periods of data gathering from October to December 2016 performing measurements of solar spectral irradiance. Only two more data acquisition periods are planned until SOLAR is decommissioned after more than eight years in orbit. This has by far exceeded expectations, surpassing its originally planned mission of 18 months to two years in orbit.

A first astronaut test subject has started wearing a Personal Active Dosimeter mobile unit as part of the ESA Active Dosimeter project. This will be used to measure an astronaut's time-dependent radiation exposure, to support risk assessment and to enable dose management by providing a differentiated



During his Proxima mission, Thomas Pesquet also ran experiments with CNES for students. This is the CrilSStal experiment bag that was used to grow crystals in microgravity (ESA/NASA)

Thomas Pesquet working with a French experiment called Everywear to monitor his sleeping patterns, using an arterial 'tonometer' to measure his blood pressure and a patch to record temperature (ESA/NASA)

data set. The system will be tested for its capabilities to enable complex environmental measurements and cross calibrations and for medical monitoring at the highest standards. A mobile unit will be worn continuously including weekly exchange of the unit and associated data downlink.

Radiation research also continued within the Dose Distribution inside the ISS 3D (DOSIS-3D) experiment that undertook continuous data acquisition of the radiation environment inside Columbus. The set of 11 passive dosimeter packages deployed in Columbus were collected in and returned to Earth in October on a Soyuz. A new set of 11 dosimeter packages was deployed in Columbus by Thomas Pesquet in November.

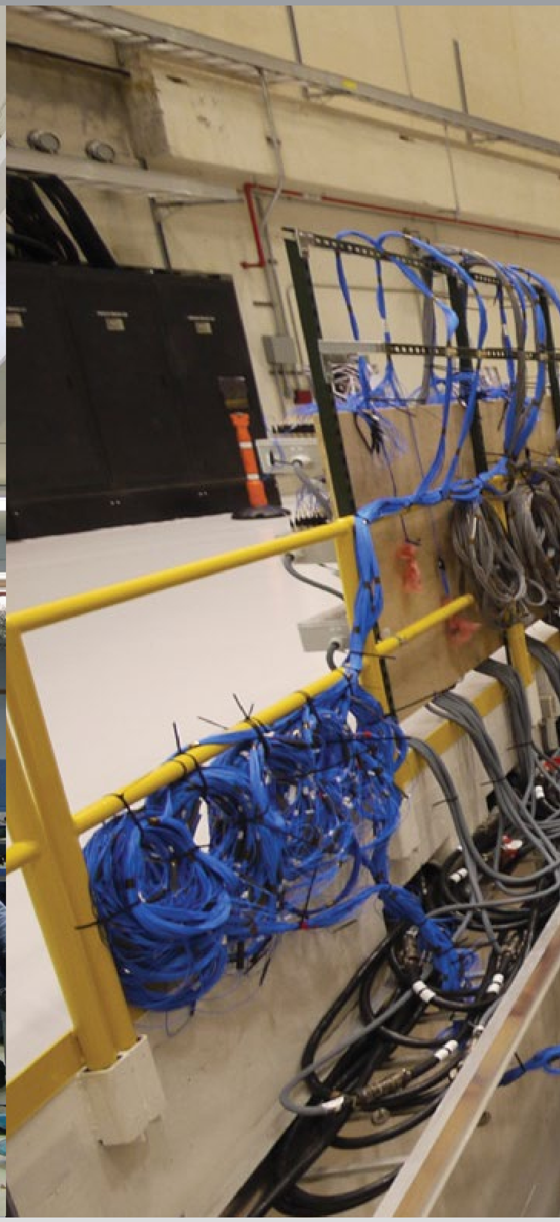
Non-ISS research in ELIPS

The 65th ESA Parabolic Flight Campaign was performed in November 2016 and with 12 experiments (seven physical sciences, one life sciences, four education) including VIP-GRAN and ESA's Fly Your Thesis educational programme.

The 2016 Concordia Antarctic winter-over season with five ESA-selected experiments concluded in November 2016. This season's science programme covers different areas including human performance, musculoskeletal and neuroscience research.

A 60-day 'Cocktail' bed rest study at MEDES in Toulouse is planned to start in January with the implementation of 15 science proposals.

Preparations for the MAXUS-9 sounding rocket launch in April include drop tower tests at the ZARM Drop Tower in Bremen for one of the science modules (PERWAVES). Additional drop tower tests were performed in October for Drop Your Thesis! 2016 (two payloads, five flights each).



The MAXUS-9 team at Esrange, Sweden (SSC Rockets & Balloons)

→ EXPLORATION

European Service Module (ESM)

The CDR was held in October, and a number of major critical issues still remain. The ESM-1 delivery planned for 30 April is no longer possible. The expected slip of the delivery date was not accepted by ESA and NASA, and Airbus delivered a schedule acceleration plan in December. A Technical Interface Meeting is planned in January to consolidate the schedule. All ESM Structural Test Article (E-STA) tests were performed and the E-STA was accepted and ownership was transferred to NASA. The ESM Integrated Test Laboratory and the Propulsion QM Pre-shipment Review were also concluded.

International Berthing Docking Mechanism (IBDM)

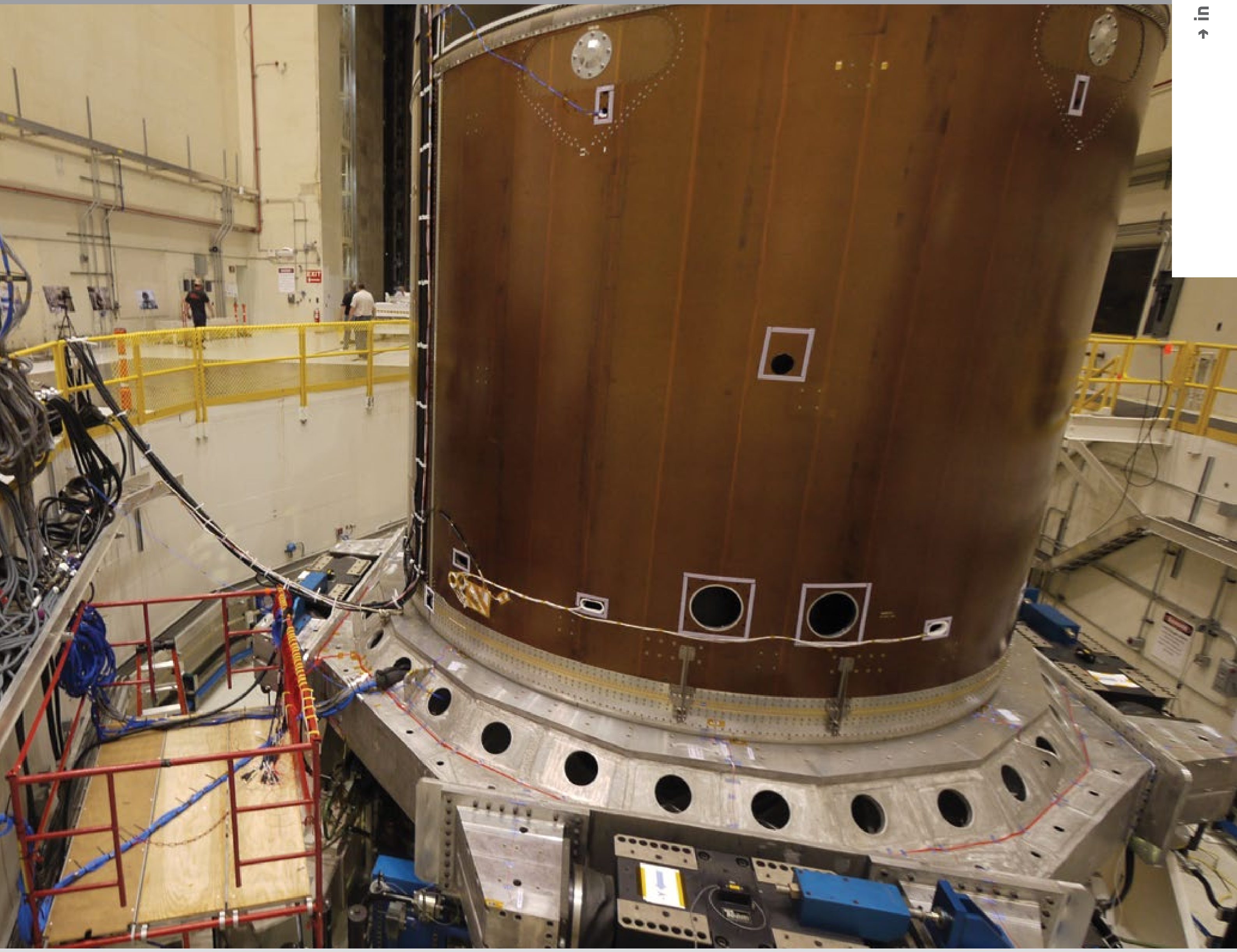
The IPC approved ESA's proposal to negotiate and award Qinetiq Space (BE) and a consortium of European industries the development contract for the IBDM. Negotiations on the tripartite cooperation between ESA, Sierra Nevada Corporation and European industry have started.

Lunar exploration activities

The first models of the demonstration cameras for the Luna-Glob mission were shipped to IKI. They were inspected and handed over in December 2016 at the ESA Moscow Office.

ExoMars 2016

Schiaparelli separated from the Trace Gas Orbiter (TGO) on 16 October as planned. While the TGO Mars orbit insertion



The ESM Structural Test Article at NASA's Plum Brook Station in Sandusky, Ohio, in June 2016

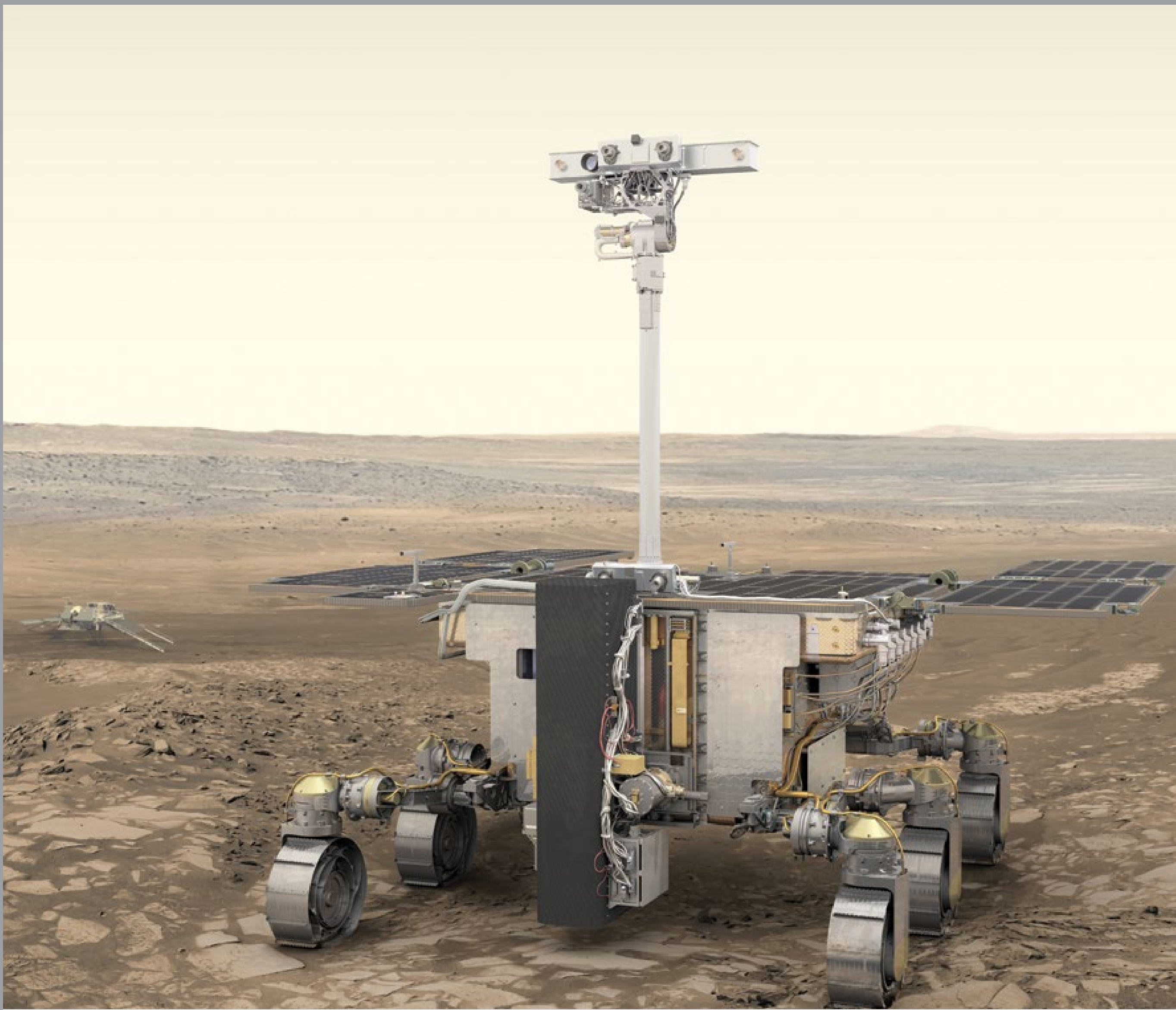
was completed on 19 October, an anomaly occurred during the descent of Schiaparelli towards the surface of Mars, resulting in a destructive landing. The Schiaparelli Anomaly Investigation Team (SAIT) was set up immediately after the events on 20 October to review available data and determine the cause of the Schiaparelli failure to land as designed.

The SAIT submitted its final report to the ESA Inspector General. On the Director General's request the Inspector General set up an independent Schiaparelli Inquiry Board composed of external experts and industry, including NASA JPL, to verify/confirm the findings of the ESA SAIT. The definition of remedial actions has started in parallel on project level. The first meeting of the Schiaparelli (independent) Inquiry Board (led by the ESA Inspector General) was held on 14 December with project presentations to the Board.

The TGO completed a first set of science and relay operations in the capture orbit prior to starting orbit manoeuvres to change the plane and descend to the final orbit through the use of aerobraking.

ExoMars 2020

The Record of Agreements defining the contractual relationship between industry and ESA as well as a special arrangement for carrying out the FM AIT in Europe were signed. The latter agreement is between ESA, Roscosmos, Lavochkin and Thales Alenia Space Italy. The Key Performance Review (KPR) Delta Board of the ExoMars



The 2020 mission of the ExoMars programme will deliver a European rover and a Russian surface platform to the surface of Mars (ESA/ATG medialab)

2020 mission was held in November. The ExoMars Lessons Learned Exercise was performed and KPR concluded in November between ESA and Roscosmos in Moscow with the support of the independent ExoMars Tracking Committee.

Mars Robotic Exploration Preparation (MREP)

MREP continues to implement technology activities and studies in support of preparation towards the long-term goal of European participation in an international Mars Sample Return (MSR) mission. More than 30 technology activities funded by MREP are currently in implementation.

Multi-Purpose End-To-End Robotic Operation Network (METERON)

A number of runs of Haptics-2 were conducted. Haptics-2 is a real-time force feedback teleoperation experiment performed by crew from the ISS to control robotic components on Earth. The scenario for lunar surface robotic operations is being reworked: more detail and consistency is needed in the mission definition to plan the correct and necessary METERON future activities.

→ SPACE SITUATIONAL AWARENESS (SSA)

Space Weather (SWE)

The SWE Service Portal was updated in October 2016 almost doubling the number of products available to the SWE end users. The portal now provides access to a first version of 17 of the 39 SWE services. The 13th European Space Weather

Thomas Pesquet works with controls for the European Haptics-2 experiment aboard the Space Station in January (ESA/NASA)

Week took place in Ostend in November, co-organised by the SSA Programme, the Belgian Solar-Terrestrial Centre of Excellence and the Space Weather Working Team and attended by around 400 scientists, engineers, end users and agency representatives. Bilateral meetings with NASA and NOAA were organised to initiate coordination and collaboration for the planning of the space weather missions to L1 and L5 points.

Near Earth Objects (NEO)

A number of contracts for dedicated software came to an end: The 'NEO User Tools' allowing planning and visualisation of NEOs; an impact corridor visualisation, and a flyby visualiser. These tools are currently being integrated into the web portal. The Calar Alto Schmidt telescope is now being used on a regular basis.

Space Surveillance & Tracking (SST)

Activity for the establishment of laser and optical systems passed its CDR. First tests using ESA's robotic test-bed telescope at Cebreros were completed. The development of the supporting analysis and visualisation software finished. The development of a multi-source correlator prototype finished.

Activity on integration, testing and validation of the data processing, planning, scheduling, catalogue querying and event detection software is progressing with the start of the developments to close identified gaps and the scheduling of data acquisition. For support observations and sensor qualification, the test campaign is nearing completion. International standardisation activities are continuing within CCSDS and the CEN/CENELEC.

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