number 165–168 | 2016

# bulletin

→ space for europe

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European Space Agency

# 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.

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.

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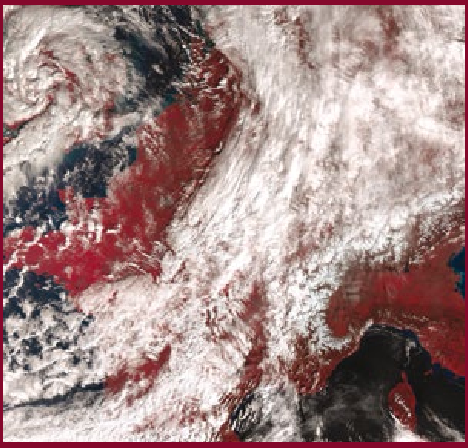

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On cover:
Visible image from Sentinel-3A's Sea and Land Surface Temperature Radiometer taken in March 2016, showing a large part of Europe with vegetated areas in red
(ESA/Copernicus data 2016)

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Because of organisational and resource reasons, the four *Bulletins* of 2016 have been merged into one issue. We apologise for any inconvenience caused, and we will return to the regular schedule of four issues per year in 2017.
Thank you.


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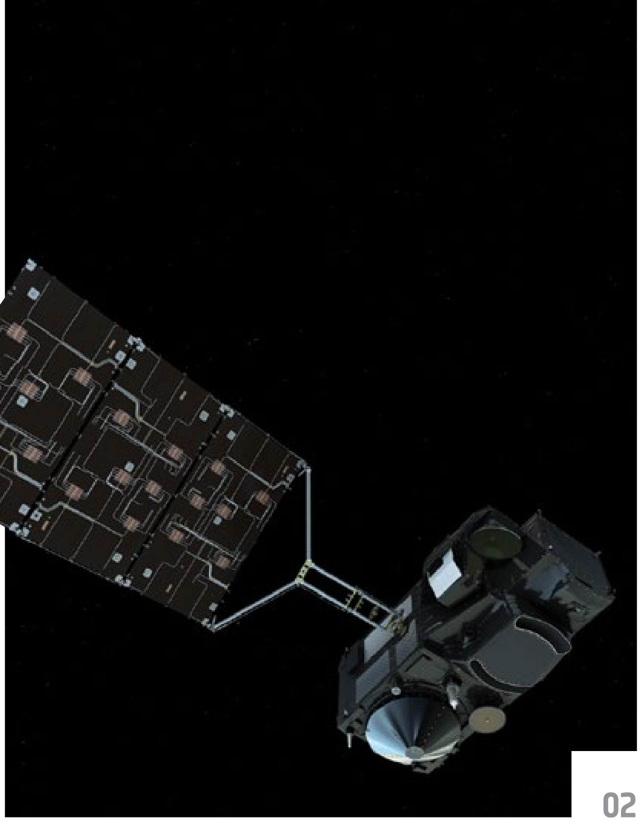

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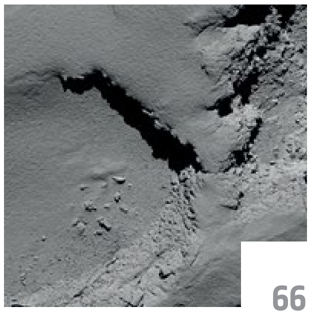

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# → A BIGGER PICTURE FOR COPERNICUS

## The Sentinel-3 mission

**Craig Donlon, Bruno Berruti, Constantin Mavrocordatos and Honora Rider**
Directorate of Earth Observation, ESTEC, Noordwijk, the Netherlands

**Susanne Mecklenburg**
Directorate of Earth Observation, ESRIN, Frascati, Italy

The launch of Sentinel-3A in February 2016 marked an precedented step forward for operational oceanography. This latest Sentinel is providing continuous and essential measurements for ocean analysis and forecasting. The mission is also playing a key role in monitoring our changing land, ice and atmosphere (ESA/ATG medialab)

**Launched in February, and carrying a suite of cutting-edge instruments, Sentinel-3A has joined the Sentinel-1A radar satellite and the Sentinel-2A high-resolution optical satellite in orbit to monitor the health of our planet.**

The Copernicus programme, led by the European Union, is now well and truly powering ahead as its comprehensive integrated system of Sentinel satellites grows. Copernicus is a revolution in Earth observation, offering a range of operational and sustained environmental services to benefit European policymakers and citizens alike.

## Eyes on Earth

Sentinel-3A maps Earth's surface systematicallyusing instruments that include a medium-resolution multispectral imager, a precision infrared radiometer and a powerful synthetic aperture radar altimeter. This workhorse mission can deliver data within three hours of sensing, 24 hours a day, 65 days a year.

While these data will feed primarily into the Copernicus Marine Environment Monitoring Service, all the Copernicus services will benefit to produce knowledge and information products in near-real time for a wide range of applications.

Sentinel-3A is essential for applications for ocean and coastal monitoring, numerical weather and ocean prediction, sea-level change and sea-surface topography monitoring, ocean primary production estimation and land-cover change mapping.

As well as delivering data for these types of service, the mission opens up exciting opportunities for scientific research to better understand how our integrated Earth system works – the science of today becomes the operational applications of tomorrow.

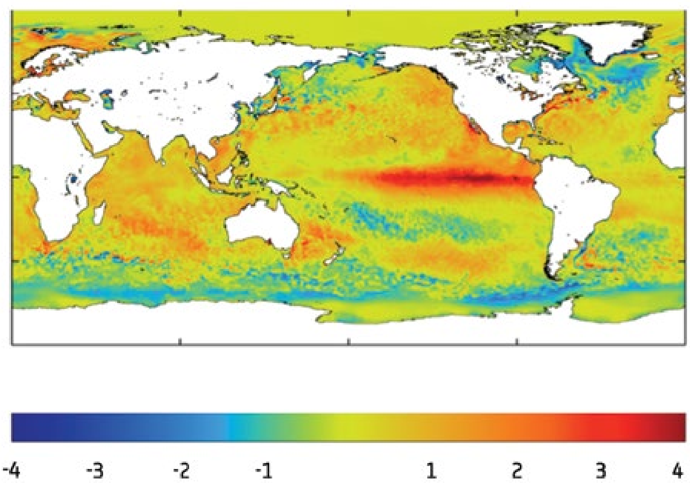
> **"The launch of the Sentinel-3A satellite marked an unprecedented step forward for operational oceanography."**

The full mission comprises two identical satellites flying in a constellation to meet the demanding coverage and revisit needs of Copernicus services. Sentinel-3B will join Sentinel-3A in orbit in 2017. The mission is the result of close collaboration between ESA, the European Commission, Eumetsat, French space agency CNES, industry, service providers and data users. Both satellites have been designed and built by a consortium of around 100 companies under the leadership of Thales Alenia Space France. Data from all the Sentinels are used worldwide and are free of charge for all users.

## Oceans of change

Earth is an integrated system of systems and, some would say, a living organism. Oceans cover 70% of the planet and what happens far out to sea has a direct impact on society in every country of the world.

For example, the gigantic build-up of warm surface waters in the eastern tropical Pacific Ocean, characteristic of the El Niño phenomenon, brings significant changes in rainfall patterns and regional weather around the world. Both El Niño and its opposite phase, La Niña, have a widespread impact on the economics of crop production and food security.




←

Weekly mean of daily sea-surface temperature (from Operational Sea Surface Temperature and Sea Ice Analysis, OSTIA, minus National Centres for Environmental Prediction, NCEP, daily climatology), December 2015. During an El Niño, the temperature of the sea surface rises across the tropical Pacific Ocean. This map, which uses a blend of satellite and in situ measurements, shows this temperature anomaly (K) of the 2015 El Niño. By accurately measuring temperature changes, Sentinel-3's Sea and Land Surface Temperature radiometer will make a significant contribution to monitoring large events such as this (Crown copyright/Met Office)

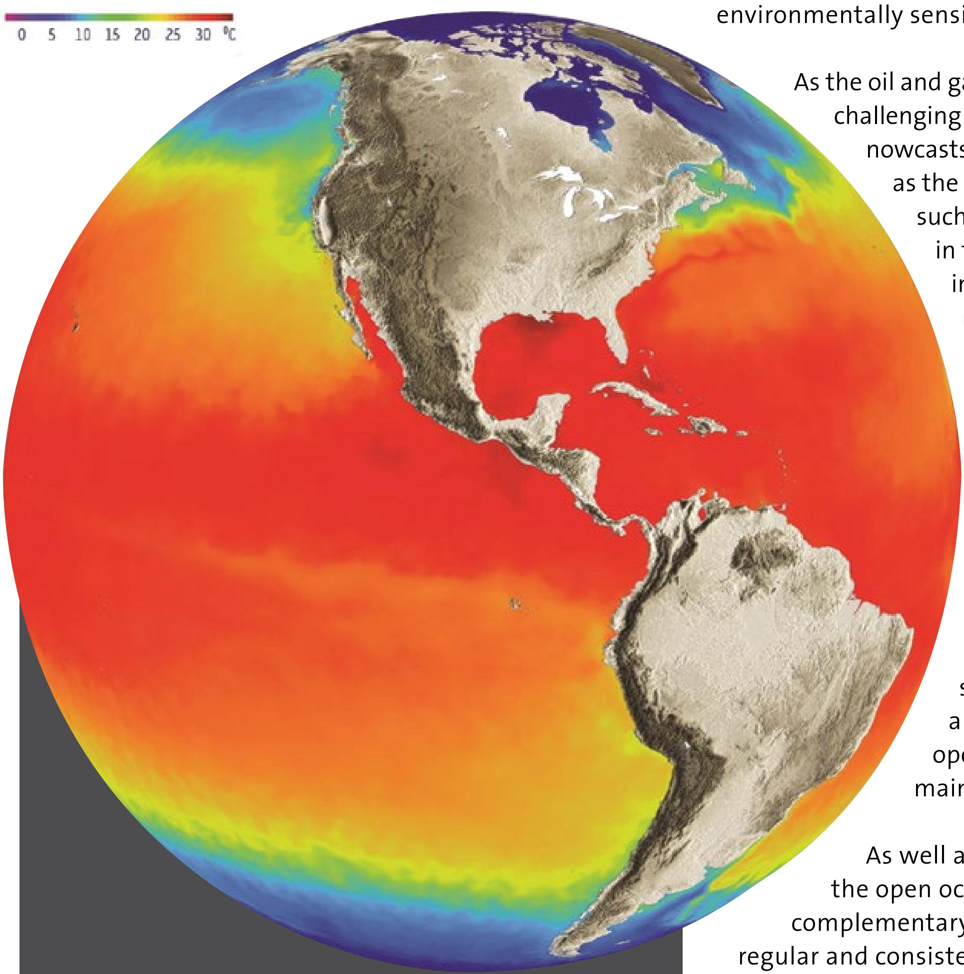
Sentinel-3's measurements of sea-surface temperature and sea-surface height will be used to monitor the onset and evolution of future El Niño events.

## Colour of life

The health and vulnerability of our oceans can put vital fish stocks at risk, a food source on which many rely in coastal megacities and worldwide. Sentinel-3's Ocean and Land Colour Instrument (OLCI) provides data for a variety of marine biogeochemical products including algal pigment concentration, total suspended matter, coloured dissolved organic matter and chlorolophyll-a, among others.

Information such as this will, for example, help to improve the prediction of harmful algal blooms. In turn, this will help oceanic food sources to be managed more efficiently. The input of waste products into ocean and coastal waters can also be monitored so that the possibility of accidents and risks of major pollution incidents can be reduced.

We should not forget that the oceans regulate the redistribution of heat across our planet, exerting a significant influence on our daily, seasonal and multi-decadal weather. The surface temperature of the oceans also affects the intensity of hurricanes and tropical cyclones, which cause damage costing hundreds of millions of euro. Sentinel-3's Sea and Land Surface Temperature Radiometer (SLSTR) and its Synthetic Aperture Radar Altimeter (SRAL) are a vital tool for closely monitoring changes in surface ocean waters, sea-state, sea-ice thickness and estimating the heat content of the upper ocean.




↑ Sea-surface temperatures for the global ocean, 2009. The Sentinel-3 radiometer can provide the sea-surface temperature measurements in near-real time that are needed by operational oceanographic and weather forecasting centres (Crown copyright/Met Office)

## Economic benefit of the oceans

Worldwide trade, 90% of which goes by sea, is expected to double over the next decade. This means that improved nowcasting and forecasting services are needed not only to ensure safe navigation, but also for cost-effective and environmentally sensitive operations.

As the oil and gas industry operates in more challenging waters, it demands improved marine nowcasts and forecasts in remote areas such as the Arctic Ocean. If disasters occur, such as the Deep Water Horizon oil spill in the Gulf of Mexico in 2010, these industries also need accurate and reliable forecasts of the ocean state for planning efficient rescue efforts, predicting the flow of a pollutants, containment, shoreline protection and clean-up operations.

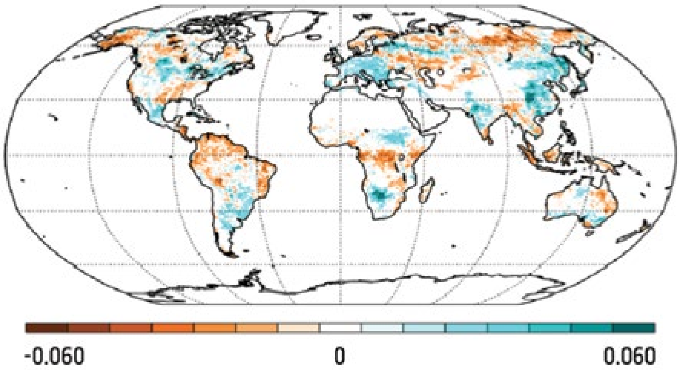
Sentinel-3's multi-instrument package provides measurements of sea state, sea-surface temperature, sea ice, water clarity, biogeochemical parameters and surface wind speed – all of which are necessary for the day-to-day operations of the maritime service and maintenance industries.

As well as providing information about the open ocean, Sentinel-3 data offers complementary measurements that are synoptic, regular and consistent for coastal zone applications. Demands for information on the state of coastal waters are also growing as coastal megacities continue to emerge with consequent increased runoff from waste products and fertilisers from land, and in response to coastal seas being used more for recreational activities, fishing, and aquaculture. In addition to weather and ocean nowcasting and forecasting, this sets a

↑ Sentinel-3 supports the shipping industry with measurements of surface waves, surface currents and surface temperatures – all of which play a role in effective ship routeing and help operators comply with international regulations that limit carbon emissions (D. Groves)

requirement for environmental monitoring and habitat assessment to support the impact of policies to maintain water-quality standards.

Concerns such as the health of coral reefs, migration of marine species or the destruction of mangroves must all be addressed. In coastal seas, an increasing number of well-instrumented, local-area, observation networks are being set up to meet these various demands.




↑ Variations in vegetation dynamics in 2014 relative to a 16-year average (N. Gobron)

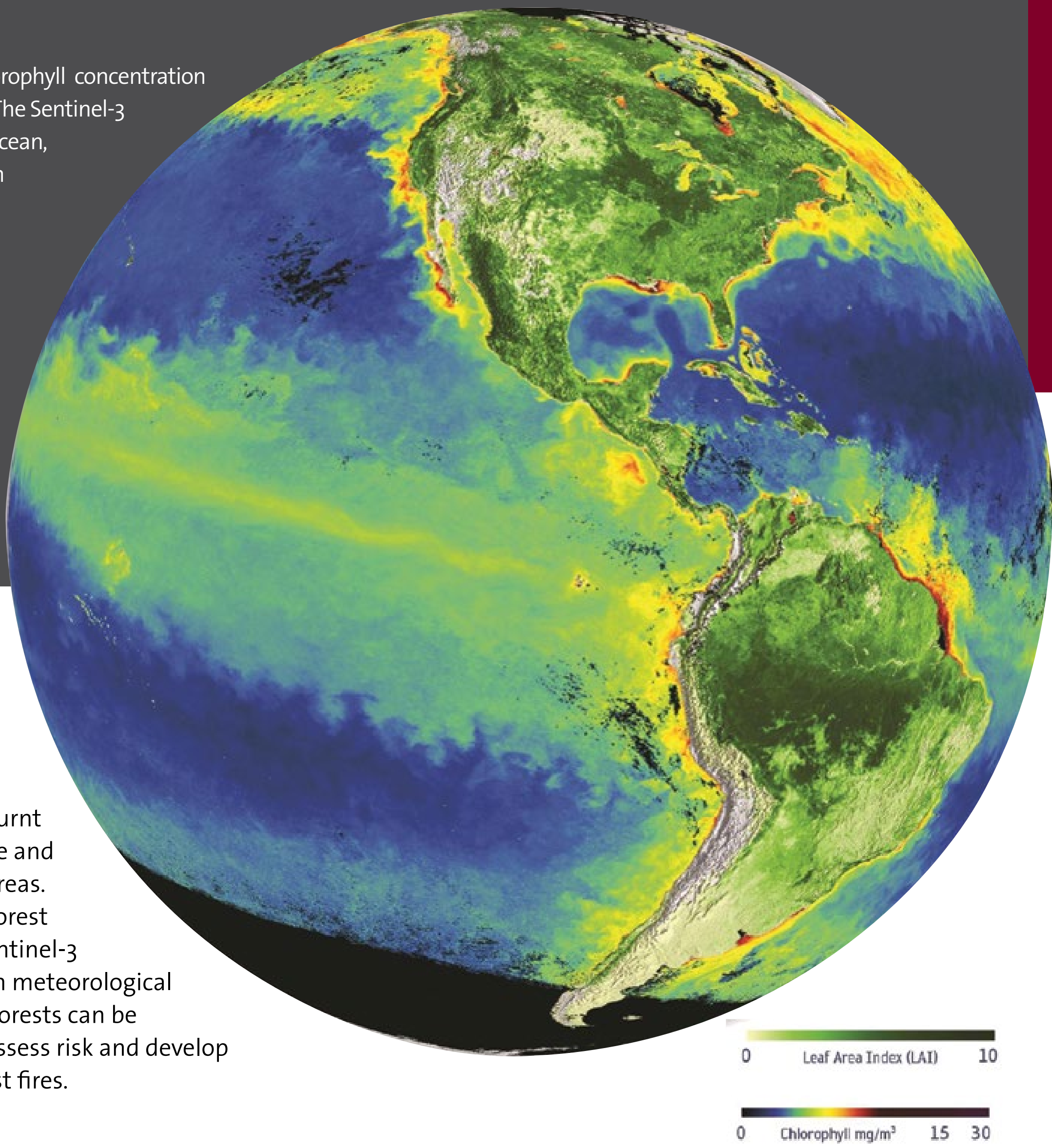
## Mapping out our terrestrial world

Agriculture, forestry, biodiversity, water resources, public health, food production and security are all subtlety tied to the dynamics of our vast global ocean. As citizens, and as policymakers, we need to know, with confidence, how our ocean is evolving to manage our society and our economic and environmental security over the land.

As well as measuring biological activity in the upper ocean, Sentinel-3's OLCI will also deliver unique and timely information about changing land cover and vegetation state by measuring variables such as leaf area index, fraction of absorbed photosynthetic active radiation in the plant canopy and terrestrial chlorophyll index.

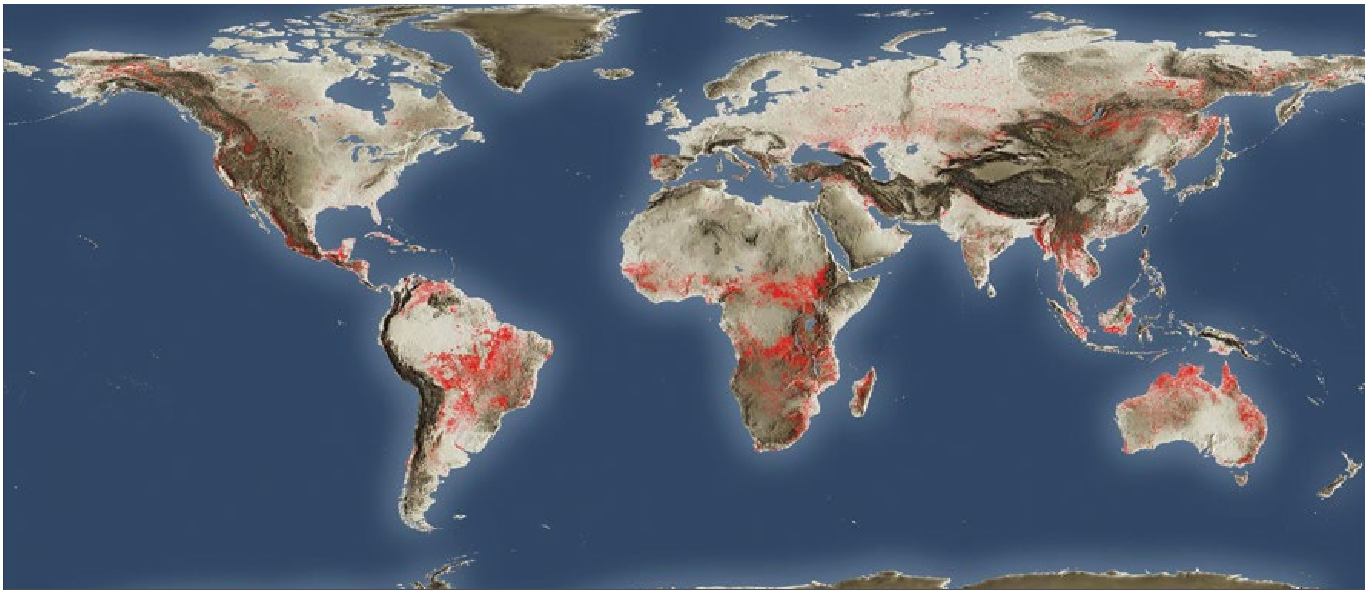
→

Leaf area index over land and chlorophyll concentration in surface ocean waters in 2006. The Sentinel-3 OLCI measures the colour of the ocean, which contains latent information on the abundance of the marine microflora. Invisible to the naked eye, phytoplankton have huge collective impact visible from space. Phytoplankton are highly vulnerable to changes in environmental conditions and represent the marine equivalent of the 'canary in the coal mine' (ACRI-ST/CNES/ESA/GeoEye/NASA/VITO)




## Feeling the heat

Sentinel-3's SLSTR includes dedicated channels for measuring fires. This helps to map carbon emissions from burnt biomass and to assess damage and estimate recovery of burned areas. Information to help manage forest fires will be available using Sentinel-3 measurements combined with meteorological forecasting data. In addition, forests can be monitored systematically to assess risk and develop efficient plans to prevent forest fires.



↑ Sentinel-3's SLSTR includes two dedicated active-fire monitoring channels that are used to extend more than 20 years of active fire monitoring from the ERS and Envisat heritage satellites. Both SLSTR and OLCI will be used to for ESA's Climate Change Initiative Fire project (World Fire Atlas)

Information from Sentinel-3 about the health of Earth's vegetation is not only important for mapping our changing land cover, but also for agricultural management and food security (E. Chesnutt)

## Building on technological excellence

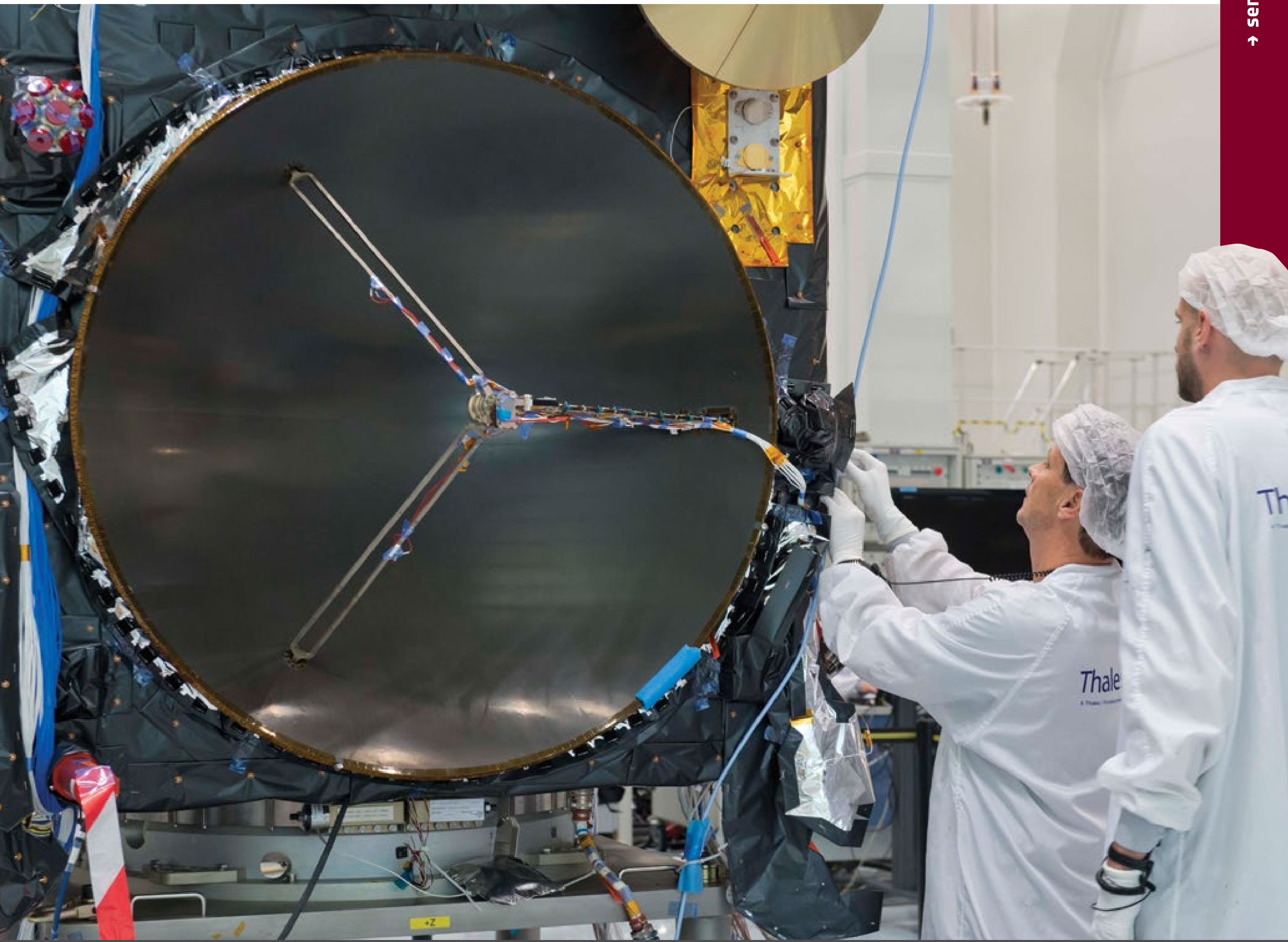
As the overall system architect and technical coordinator of the Copernicus Space Component, ESA is responsible for the development of the Sentinel-3 mission, including the launch.

The design of the satellites and their instruments benefits from investments made in previous world-class European heritage missions including ESA's ERS, Envisat and CryoSat missions, and the CNES SPOT Vegetation and Jason missions. Each satellite is designed for at least seven years of service in orbit.

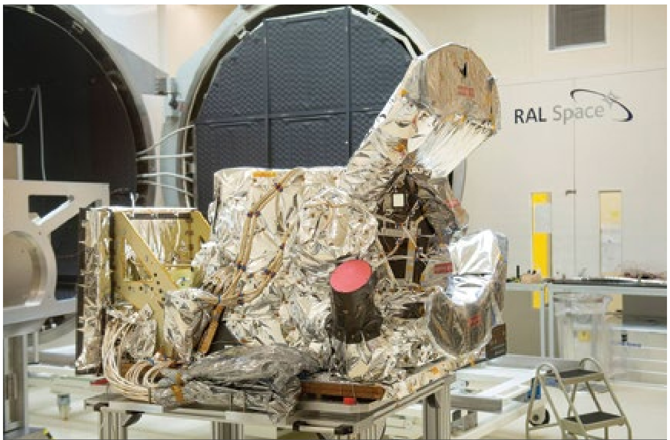
This robust approach ensures that Sentinel-3 incorporates the latest technology innovations building on lessons learned to provide a state-of-the art mission to serve Copernicus.

**"Sentinel-3 is arguably the most complex of all the Sentinel missions."**

Through the development of all of the Sentinel missions, European industry remains at the cutting-edge of Earth observation technology and is uniquely poised to pull through the best heritage technologies to respond to the needs of modern day science and applications to benefit society at large.



↑ Work on Sentinel-3A's radar altimeter at Thales Alenia Space in Cannes, France

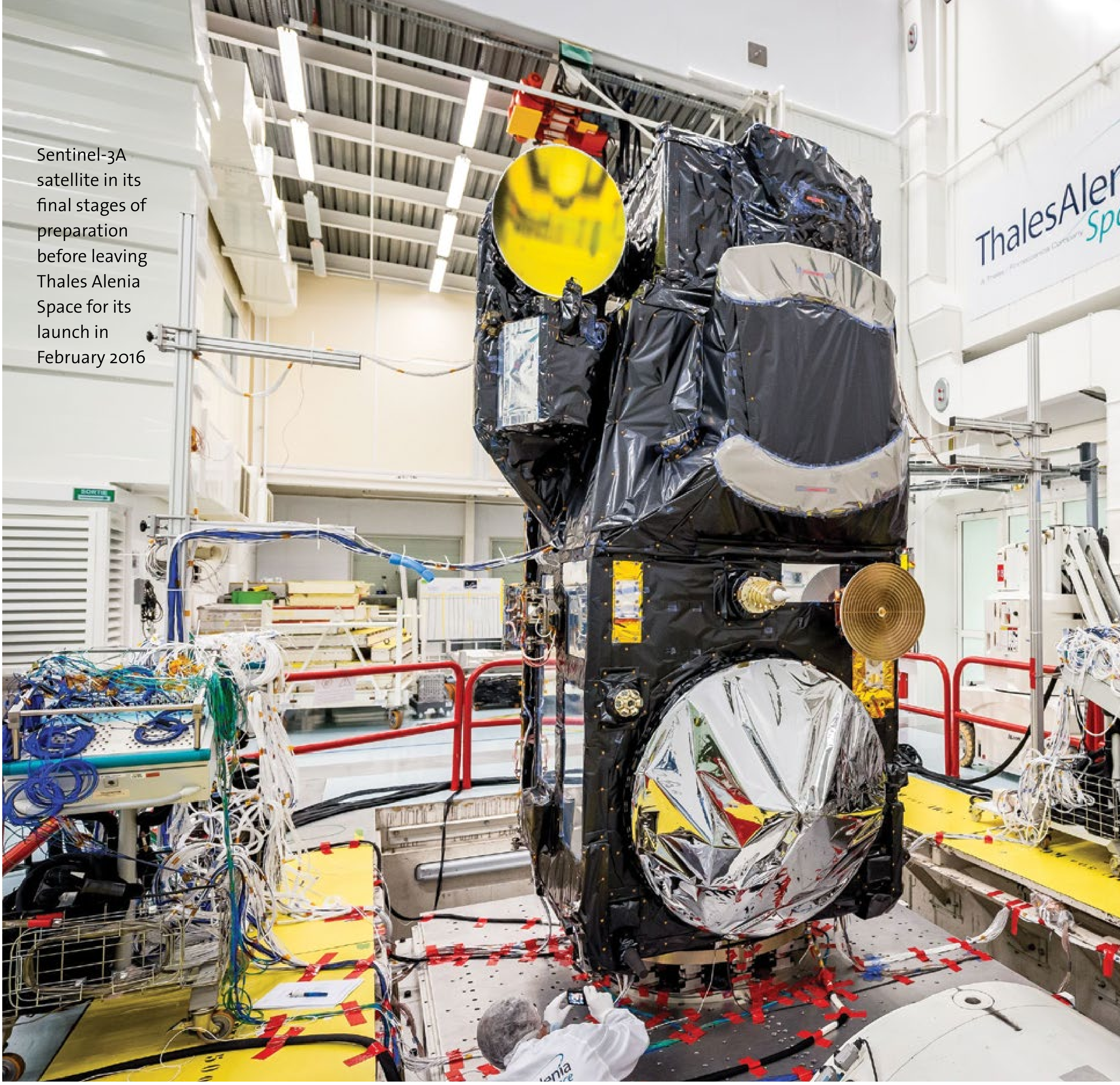



↑ Sentinel-3's SLSTR being calibrated at RAL Space, UK (STFC)

## A multi-talented package

Carrying four instruments that work in synergy, Sentinel-3 is arguably the most complex of all the Sentinel missions.

The SLSTR measures global sea- and land-surface temperatures every day to an accuracy of better than 0.3 K. Continuing the legacy of Envisat's Advanced Along Track Scanning Radiometer, it maintains a dual-view along-track-scanning approach and delivers measurements at a spatial resolution of 500 m for visible/near-infrared and short-wavelength infrared channels and at 1 km for the thermal infrared channels. Furthermore, SLSTR includes two dedicated thermal infrared channels that are optimised for active fire detection and fire radiative power measurement – important for Copernicus Emergency Response and Climate Services.




Sentinel-3A satellite in its final stages of preparation before leaving Thales Alenia Space for its launch in February 2016

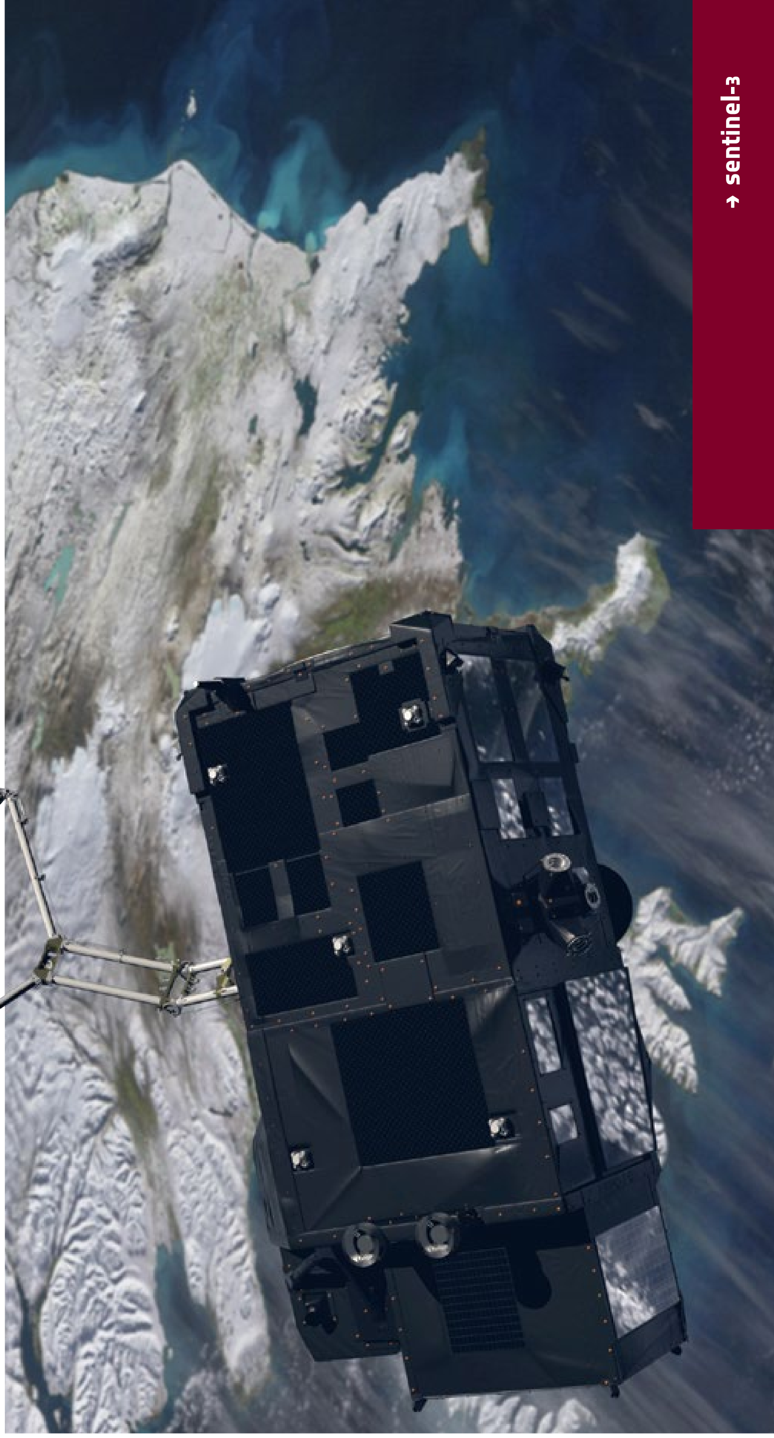
©esa

> **Sentinel-3 will make a unique contribution to the paradigm shift in Earth observation in the coming decades.**

The OLCI is based on heritage from Envisat's Medium Resolution Imaging Spectrometer and features 21 distinct bands in the 400–1020 µm spectral region tuned to specific ocean colour, vegetation and atmospheric correction measurement requirements. It has a spatial resolution of 300 m for all measurements and a swath width of 1270 km, overlapping the SLSTR swath.

OLCI's new eyes on Earth allow ocean ecosystems to be monitored, support crop management and agriculture and provide estimates of atmospheric aerosol and clouds – all of which bring significant societal benefits through more informed decision making.

The Sentinel-3 topography package brings a step change in satellite altimetry, measuring the height of the sea



surface, waves and surface wind speed over the oceans. It also delivers accurate topography measurements over sea ice, ice sheets, rivers and lakes.

The package includes the dual-frequency (Ku and C band) radar altimeter, which is based on heritage from the CryoSat and Jason missions. Measurements are at a resolution of approximately 300 m in the along-track direction after SAR processing and it is the first satellite altimeter to provide 100% coverage over all of Earth's surfaces in SAR mode.

The SRAL instrument is supported by a dual-channel microwave radiometer that is used to derive atmospheric correction and atmospheric column water vapour measurements necessary to reach the demanding performance requirements for Sentinel-3.

## Working together

ESA and Eumetsat will share the responsibility for the smooth running of the mission. After launch and the subsequent five-month commissioning phase, ESA handed over operations to Eumetsat. ESA continues to monitor the health of the satellite, including platform and instruments. ESA is also responsible for the operations of the Sentinel-3 ground segment for land products, as well as the continuous improvement of the data products through research and development activities. Eumetsat is responsible for providing the marine products and operating the satellite.

Together with the rest of the Sentinel fleet, the Sentinel-3 satellites will make a unique contribution to the paradigm shift in the quality and quantity of Earth observation measurements over our planet in the coming decades.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T. PESQUET

# → BRINGING SPACE CLOSER TO EARTH

## Thomas Pesquet's Proxima mission

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

**Carl Walker**
Communications Department, ESTEC, Noordwijk, the Netherlands

**Proxima is the name of French ESA astronaut Thomas Pesquet's six-month space mission, launched to the International Space Station this November and packed with science and education activities.**

The 38-year-old French astronaut was launched on a Russian Soyuz spacecraft from Baikonur Cosmodrome in Kazakhstan on 17 November. He became the tenth French citizen to fly into space and the fourth French astronaut to visit the International Space Station. This is also the first six-month mission to the Station by a French astronaut.

Speaking earlier about his mission name, Thomas said, "I am really pleased with this name and the logo. It ticks all the boxes I had in mind by continuing the naming tradition for French astronauts and recognising the legacy of human spaceflight so far while also being forward-looking and futuristic."

Thomas said: "Another reason I chose Proxima was because I want to stay close to Europeans. It highlights how human spaceflight is at the service of our planet through scientific results and exploration, and I want to share the experience and inspire the public.


↑ → The Soyuz MS-03 crew, NASA astronaut Peggy Whitson, Soyuz commander Oleg Novitsky and Thomas Pesquet

"We fly to space not for ourselves, but because we believe it is useful for people on Earth. It's everybody's adventure, made possible by the dreams and hard work of many. That's why I want to share it as much as possible. I invite everyone to follow the adventure on social media."

For six months, Thomas's home and workplace will be some 400 km above Earth, where he will serve as a flight engineer for Expeditions 50 and 51 on the International Space Station (ISS). He will return to Earth in May 2017.

Thomas shared the ride with experienced Russian cosmonaut Oleg Novitsky and veteran NASA astronaut Peggy Whitson. Peggy is one of NASA's most experienced astronauts: she has spent over a year on the International Space Station in two six-month expeditions. She was part of Expedition 5, flying on a Space Shuttle in 2002, and returned to the Station in 2007 on a Soyuz.
Both Peggy's expeditions were notable for being busy periods of assembly. Peggy installed the truss 'backbone' of the Space Station on her first mission and even did a spacewalk with the Russian Orlan spacesuit. On her second mission, she completed five spacewalks to add the Harmony node, ESA's Columbus laboratory, the Japanese Kibo laboratory and Canada's robotic arm Dextre.

Peggy will take over command of the Space Station for a second time during the Proxima mission as Expedition 51 commander, having already commanded Expedition 16 in 2008.

Russian cosmonaut Oleg Novitsky is returning to space for a second time. Oleg joined the Russian cosmonaut corps in

> **We fly to space not for ourselves, but because we believe it is**

# → Proxima

When an ESA astronaut is assigned a mission, ESA usually asks the general public to suggest names. The name for ESA astronaut Thomas Pesquet's six-month mission to the International Space Station was chosen from over 1300 entries to a competition held in 2015. The winning name Proxima was provided by 13 year-old Samuel Planas from Toulouse, France.

"Proxima is the closest star to our Sun and is the most logical first destination for a voyage beyond our Solar System," explained Samuel. "Proxima also refers to how human spaceflight is close to people on Earth."

The logo continues the exploration theme, with star trails evoking future space travel and exploration beyond low-Earth orbit. Two stylised planets can represent our Earth and Moon or the Moon and Mars. The 'x' in Proxima is centred in the middle of the patch to signify the star Proxima Centauri. It also refers to the unknown as well as Thomas being the tenth French space voyager.

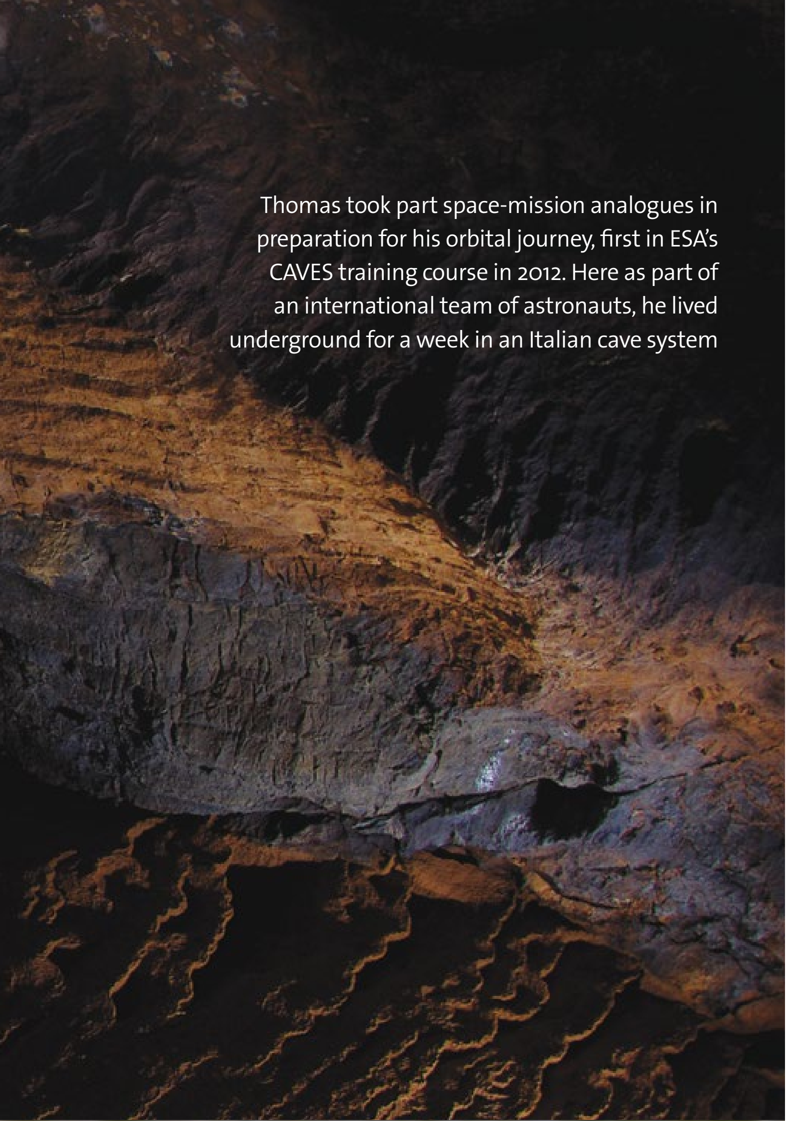
The three vertical lines form the distinctive outline of the International Space Station as well as representing the colours of Earth, the Moon and Mars, while hinting at the French national flag. Minister Mandon handed Thomas a French flag during the press conference to carry into space.


2006 and his first flight was as commander of Soyuz TMA-06M. Oleg was a pilot in the Russian air force reaching the rank of Lieutenant Colonel before retiring from service. He is also an experienced diver and parachuting instructor. Himself a former aerospace engineer turned airline pilot, Thomas travelled in the left-hand seat of the Soyuz capsule. In his role as co-pilot, he is trained to assist Oleg, the Soyuz commander, during the trip into space and back, monitoring the systems and taking over when necessary. With his Proxima assignment, all six ESA astronauts from the class of 2009 have now flown to the Station within seven years of graduation.

"I'm thrilled to fly to space with such talented people. Oleg is the best pilot-cosmonaut Russia has to offer, and Peggy knows the International Space Station inside out. I will have to keep up with the pace and learn as much as possible," said Thomas.

**useful for people on Earth. It's everybody's adventure ”**

↓ During his 16-month ‘Basic training’, Thomas learned special skills such as robotic operations, rendezvous and docking, Russian language, human behaviour and performance, as well as basic medical skills and first aid techniques, seen here in 2010



Thomas took part space-mission analogues in preparation for his orbital journey, first in ESA's CAVES training course in 2012. Here as part of an international team of astronauts, he lived underground for a week in an Italian cave system

Thomas seen during a water survival training session near Star City, Russia, in June 2014 (GCTC)

## About Thomas

Thomas Pesquet is the youngest member of the European astronaut corps. He was born in Rouen, France, on 27 February 1978. He had dreamed of going to space when he was a child, playing with a Space Shuttle his father had made out of cardboard boxes and pillows. But ideas about space were unrealistic and still distant dreams, as Thomas recalls, "I saw things on TV but I did not identify with what I saw because it seemed so far away and surreal."

However, by pursuing his passions and interests throughout his education and career, Thomas acquired the experience and skills to be an astronaut. "My childhood was extremely important to me, with parents who were very attentive to me and my brother, and who allowed us to discover many things, like music, learning foreign languages, doing sports and being encouraged to travel. I know now that I owe a lot to my parents and I am very grateful for what they have done for both me and my brother."

He would go on to study aerospace engineering, graduating from the Lycée Pierre Corneille in Rouen, France, in 1998 and eventually working as a spacecraft dynamics engineer and as a research engineer on space mission autonomy for Thales Alenia Space and France's space agency CNES. "By 2001, I received a master's degree from the École Nationale Supérieure de l'Aéronautique et de l'Espace in Toulouse, France, majoring in spacecraft design and control. I spent my final year before graduation at the École Polytechnique de Montréal, Canada, as an exchange student on the Aeronautics and Space Masters degree course."

An avid private pilot in his spare time, he was selected in 2004 for Air France's flight-training programme and became a pilot for the airline in 2006. He has logged more than 2500 flight hours on commercial airliners and became an instructor on the Airbus A320. Thomas sees many parallels between flying aircraft and spacecraft: both require detailed technical knowledge, leadership, team work as well as good communication and analytical skills.

When ESA called for candidates from its Member States to reinforce the European astronaut corps, more than 8000 people applied. Thomas and five others passed a demanding year-long selection process and became proud members of the European astronaut class 2009.

After graduating as an astronaut, Thomas worked as a Eurocom, communicating with astronauts during spaceflights. He was also in charge of future projects at the European Astronaut Centre, including initiating cooperation with new partners such as China. He took part in space-mission analogues for his orbital journey, first in ESA's CAVES training course, as part of an international team of astronauts living underground for a week and exploring

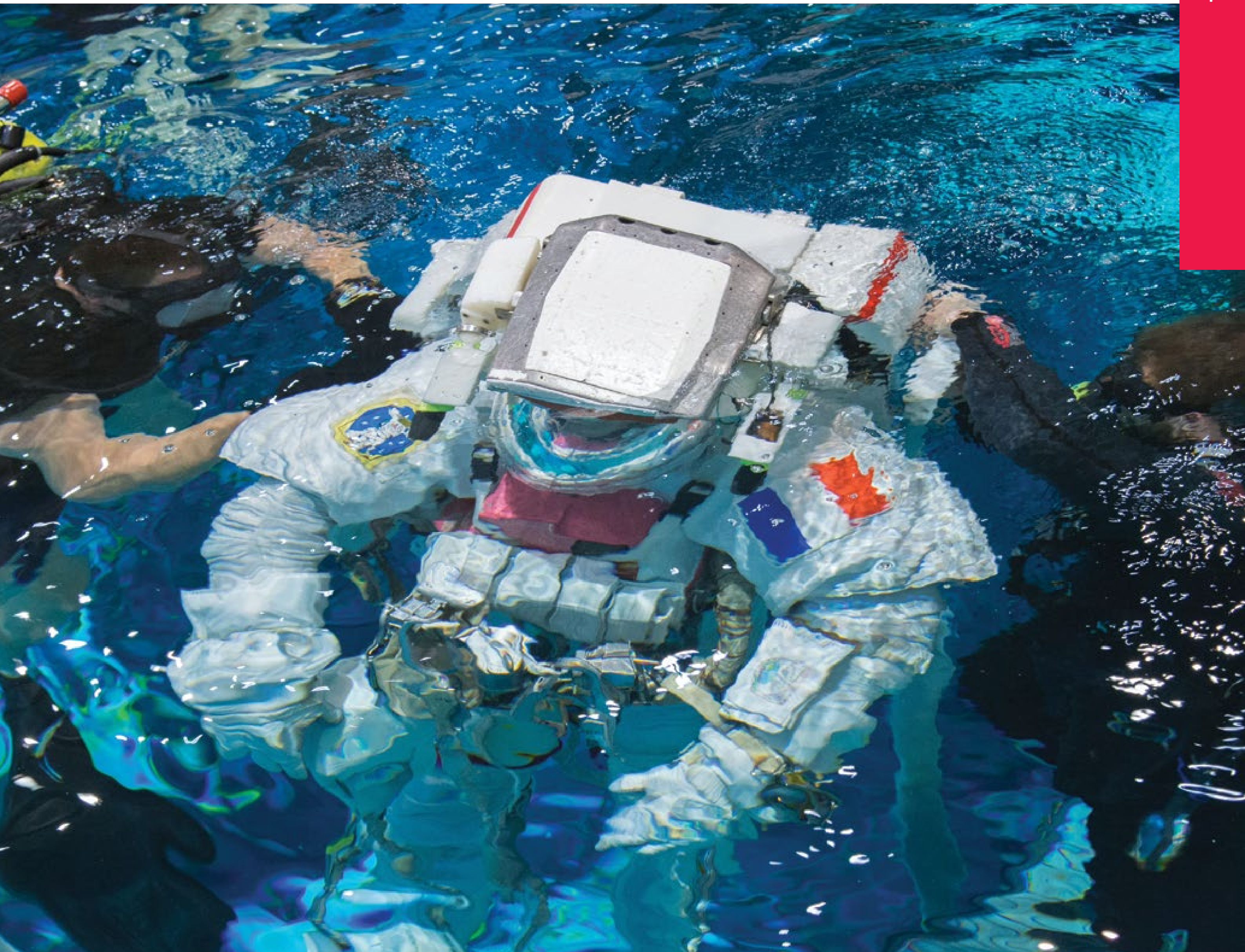
↑ Thomas joined the 12-day NEEMO 18 exploration mission on the Aquarius underwater base in 2014. Thomas (left) seen with a safety diver and NASA astronaut Jeanette Epps (right)

a cave system in Sardinia, Italy, then joining a 12-day exploration mission underwater at the Aquarius base, the world's only undersea research station. Much like in space, he had to deal with confined living quarters and a total reliance on life-support systems, 20 m below the sea off the coast of Florida, USA.

On 17 March 2014, it was announced that Thomas was assigned to a long-duration mission on the International Space Station. After finishing basic and pre-assignment training, he could now embark on the next phase of his space journey, the start of assigned crew training. It takes International Space Station astronauts two and half years of intensive preparations to be ready for launch.

Then the pace increased for Thomas, training almost without break, travelling between all international partners' sites. An intense schedule took him to Houston, USA, Star City near Moscow, Russia, Tsukuba near Tokyo, Japan, and Montreal in Canada.

As Soyuz flight engineer, Thomas requires a great amount of 'flying hours' in the Russian spacecraft simulator, so he trained until he felt at home in the cockpit and could operate the Soyuz flawlessly in any situation. He has been trained also on Space Station systems in full-size mockups, where he learnt how to run experiments and technology demonstrations, and got to know every corner of Europe's Columbus laboratory.



↑ After EVA familiarisation training and basic SCUBA skills, ESA astronauts move on to full spacewalk training, here at NASA's Neutral Buoyancy Lab in Houston, as well as in Russian spacesuits at Star City, Moscow (NASA)

He learnt to use the Station's robotic arm to help berth visiting spacecraft, he went through survival courses in extreme environments, he prepared himself to face all kinds of situations in prolonged isolation and under psychological stress. He prepared for spacewalks in huge water tanks to simulate working in weightlessness outside the Station. If the opportunity arises, he is fully qualified to venture into outer space.

## European science in space

Science is the most important part of the Proxima mission – Thomas will conduct a wide range of experiments on the Space Station, an out-of-this world research outpost that serves as a stepping stone for human exploration. European science will be in full swing during the Proxima mission. Thomas will work on 62 experiments coordinated by ESA and France's space agency CNES. They cover human research, physical sciences and biology, as well as demonstrating new technology on the Space Station. As with previous French missions to the Russian Mir space station and the International Space Station, the emphasis will be on human physiology. Scientists hope to gain more insight into cognition and motor skills as well as bones and muscle health for future space exploration missions.

Thomas's brain, bones and muscles will be examined to research the impact spaceflight has on humans. He will be


↑ Thomas Pesquet (left) training together with Italian ESA astronaut Luca Parmitano for an Expedition 50 maintenance spacewalk, in NASA's Neutral Buoyancy Laboratory pool in Houston in January 2015 (NASA)

↓ Thomas's final weeks of training see his crew work through emergency scenarios that will be played out –from a fire in the Soyuz spacecraft to loss of pressure or problems with the docking mechanism

↑ Expedition 50 fire scenario training with Shane Kimbrough and Oleg Novitsky in the Space Station mock-up in Houston in July (NASA/L. Harnett)

> **Thomas will work on 62 experiments coordinated by ESA and France's space agency CNES, covering human research, physical sciences and biology.**

↑ Recording the mission visually, for technical and outreach purposes, is another task that has to master. Thomas reviews the various pieces of camera equipment in September (NASA)

↑ Expedition 50/51 crew members Peggy Whitson, Oleg Novitsky and Thomas Pesquet during Depressuriation Scenario training in the ISS mock-up in Houston in 2015 (NASA)

↓ Sharpening piloting skills in the Soyuz simulator in the days before liftoff, October 2016

↑ Thomas with fellow crew members Peggy Whitson and Shane Kimbrough during simulation of capturing a free-flying visiting spacecraft with the robotic arm (NASA/J. Blair)

↓ Ever humorous, Thomas in playful mood with Star City technicians fitting him for his Soyuz seat couch shortly after being assigned his mission (GCTC)

↓ Fitness is important in space, as on Earth. Thomas participates in an advanced Resistive Exercise Device training session at NASA's Johnson Space Center in 2014 (NASA)

testing a new generation of health sensors that will benefit both future exploration missions and people on Earth.

Thomas will take full advantage of the Space Station's scientific facilities and perform valuable science for Europe in the European Columbus laboratory. The results will bring benefits to people on Earth and pave the way for future space exploration missions. Thomas will not only contribute to European science. During Proxima, he will play a role in about 55 other experiments from the US, Canadian and Japanese space agencies.

## Inspiring the next generation

Thomas is also determined to inspire the next generation of explorers, both his parents and brother are teachers so he has a head start as an ambassador for science and space-based careers. He is involved in an intensive outreach programme to inspire children, with Proxima school activities running alongside the mission with elements of science or technology in them, from computer coding and growing plants, to chemistry, fitness and nutrition.

Though Thomas is keen to share his enthusiasm for all aspects of his spaceflight adventure with the rest of the world, indeed children in particular get his full attention. "Children have the best questions ever, you learn a lot from talking to kids and I wish I could have talked to an astronaut when I was young," said Thomas.

"I remember when I was a child there was a certain frustration with not having access to a lot of information about space travel. Now we live in the age of the internet, which is important because it means we can share our experiences. Today, we post photos on Twitter and Flickr, we share our journeys on Facebook and Instagram, or we keep a blog. It's not always easy, but we all try to dedicate some time to sharing our experiences and hope it inspires others," said Thomas.

An active blogger and great communicator, Thomas will also pass his message through various social media channels about the importance of fitness, love for learning and care for our planet. He has a whole set of educational activities that will challenge students to join his spaceflight adventure and continue learning. ■

### Follow Thomas on:

- @astro_thomas
- www.facebook.com/ESAThomasPesquet
- www.instagram.com/thom_astro
- www.flickr.com/photos/thom_astro
- Also access his Proxima minisite, blogs and YouTube channel: http://thomaspesquet.esa.int/

# → REACHING NEW HEIGHTS

## Celebrating 50 years of Esrange Space Center

**Sarah Humphrey,**
Records Management Office, Director General's Cabinet,
ESTEC, Noordwijk, The Netherlands

**Carl Walker**
ESA Communication Department, ESTEC, Noordwijk, The Netherlands

A sounding rocket launched from Esrange, Kiruna, in northern Sweden

**This year, the Esrange sounding rocket range and research centre in Kiruna, northern Sweden, celebrated the 50th anniversary of its inauguration on 24 September 1966.**

To date, the facilities of Esrange have seen the launches of 550 rockets and 520 balloons and now include a large satellite ground station. With plans on the way for the development of launch capabilities for small satellites, Esrange has grown into one of the world's busiest ground stations, serving a large variety of customers.

The history of Esrange can be traced back to 1957 with the establishment of the Kiruna Geophysical Observatory (KGO) in July of that year. The setting up of this academic institution was important in itself, but also had an impact on the process of establishing a sounding rocket range in the same region a few years later.

The Kiruna Geophysical Observatory would conduct atmospheric studies, to a large extent concerning measurements of the geomagnetic field and cosmic radiation. This included the two specialities of Swedish space science: noctilucent clouds and the aurora borealis (the 'Northern Lights'). Furthermore, the international scientific community was interested in the possibility of sounding rocket experiments north of the polar circle, considering it important to carry out a sounding rocket programme in the auroral zone.

Bengt Hultqvist, head of the Kiruna Geophysical Observatory, recognised this potential, realising that a sounding rocket base in Kiruna would be important, not only for his own observatory and research, but also for the entire Kiruna region.


↑ Esrange construction site, 1965

↑

Esrange inauguration, 24 September 1966, with ESRO Director General Alexander Hocker (present at left, front of the room)

Above all else, the location of a launching range for sounding rockets in Sweden became a vehicle for Swedish membership of the European Space Research Organisation (ESRO). From 1962, when Sweden signed the ESRO Convention, until 1964 when it was ratified, the discussions on the membership conditions were intense, and Esrange was an important part of those discussions.

Why Kiruna? Access to Kiruna was good by air, road and rail, and the range was relatively close to the town. The area was crown land and so it was not necessary to compensate land owners, plus it was rarely visited by tourists. Perhaps most importantly, Esrange would be near the Geophysical Observatory (later renamed the Swedish Institute of Space Physics).

But difficulties soon arose in the area of safety: up to what altitude should the sounding rockets be allowed to go? This depended on the size of the area available, so that they would not come down on a populated area. At about 140 km long and 80 km wide, this would mean rockets could be launched safely up to an altitude of a few hundred kilometres.

At first, Sweden would allow only 150 km, which ESRO considered far too low. At one point, the whole idea of sounding rockets started to seem less attractive to ESRO, but eventually these discussions led to a recalculation, which allowed altitudes up to 300 km. The safety criteria turned out to be the key point of the negotiations, because once agreement had been reached here, others quickly followed. In March 1964, the ESRO Council finally approved the Esrange agreement.

The idea of having an international rocket base on Swedish territory also became controversial for other reasons.

Esrange main building, seen in 1968


↑

Preparing MAXUS-4 for launch in 2001. The MAXUS sounding rocket programme is funded by ESA through the European Programme for Life and Physical Science in Space (ELIPS) with the rocket and launch services provided to ESA by a joint venture between SSC and Astrium (now Airbus Defence & Space). The programme started in 1991 and continues today

The then Soviet Union had expressed some concern that the station might be used for military purposes, and thus it was extremely important for Sweden to make sure that there was complete transparency over all projects at Esrange.

Another issue was the length of the contract for Esrange. ESRO wanted the Esrange contract to be valid for 50 years, but Sweden thought it fitting to renegotiate the terms for Esrange after a period of eight years. The Esrange contract gave ESRO members the right to use the station according to ESRO's programme, but a contract for longer than eight years could have meant signing a blank agreement for foreign countries to use this rocket base on Swedish territory and with Sweden left with sole responsibility for upkeep of the facility.

On 19 November 1966, the first rocket was launched from Esrange, a Centaure 1 carrying Belgian science payloads. This was followed by many launches planned by various ESRO members. In all 152 sounding rockets were launched from Esrange between 1966 and 1972: 72 under ESRO's direction and 80 within national programmes. Most of these were Centaure, Nike Apache or Skua rockets reaching altitudes of 100–220 km .

In the early 1970s, ESRO decided to cancel its sounding rocket programme as part of the preparations for the creation and expansion of ESA, but space activities had now become a mainstream area of work for Sweden. Indeed, at the European Space Conference in 1970, Sweden wanted activity at Esrange to continue as before.

Individual Member States with national sounding-rocket programmes still needed a launch site though, and to that end the Esrange Special Project was set up by eight ESRO countries in December 1971 for five years. Not only did this mean that national sounding rocket projects could continue, but also that they could be coordinated.

Esrange came into Swedish hands on 1 July 1972, when ownership and operation of the range was transferred to the newly formed Swedish Space Corporation (SSC). The SSC's tasks included carrying out reviews for the Swedish Board for Space Activities, managing the national sounding-rocket programme and running the range.

With a permanent Space Board, a state-owned Corporation and a sounding-rocket range, Swedish space activities had finally become established. Over the coming years, the SSC and Swedish industry built themselves up to be trustworthy partners in international space projects. Furthermore, state funding was increased and Swedish space activities developed, of which Esrange had become a very important part.

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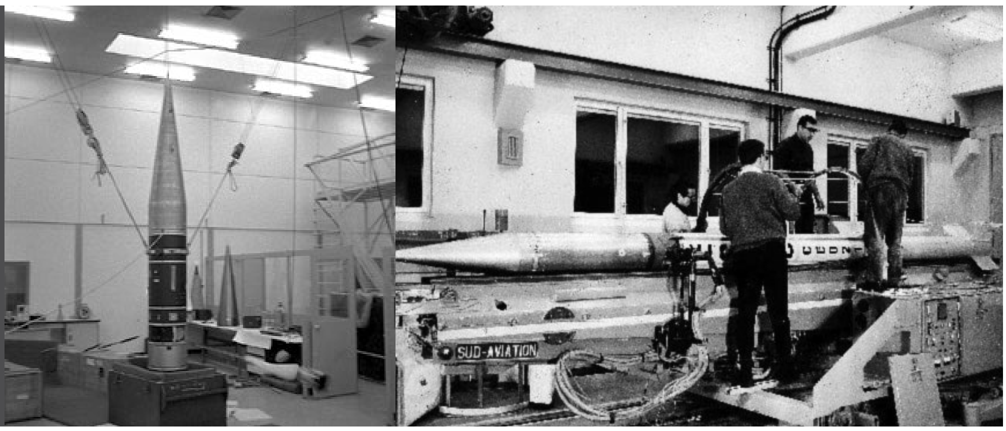
Preparation of a Centaure rocket for the first launch campaign at Esrange in late 1966



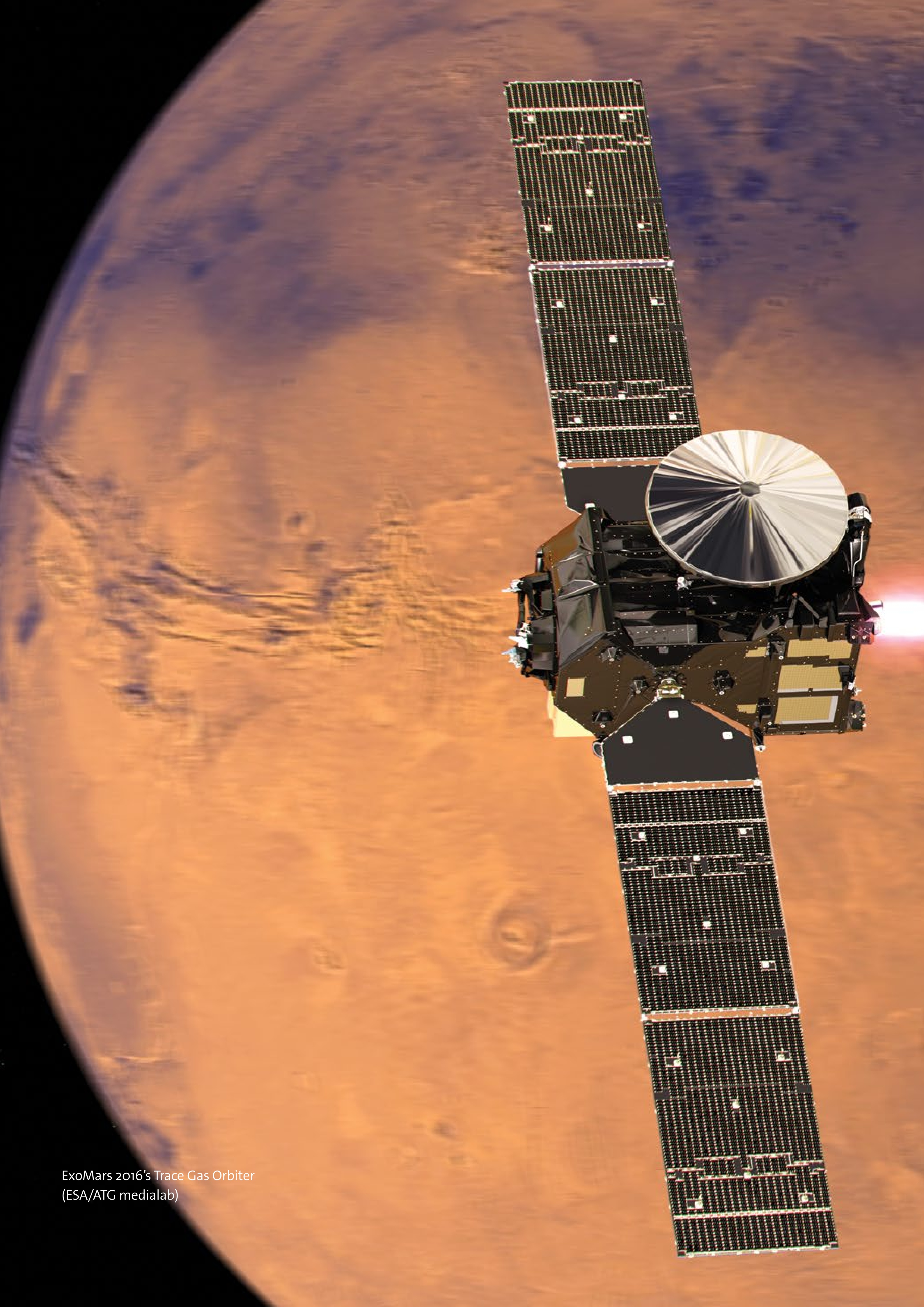
↑ The ESA Kiruna station is home to part of ESA's Estrack network: the ground station here provides support for satellites in routine mission phases, as well as specialised support during the Launch and Early Orbit Phase. It hosts one 15 m antenna and one 13 m antenna, both operating in S-band for uplink and downlink and X-band for downlink. The station's high-latitude position in northern Sweden makes it ideal for supporting ESA's low-Earth orbit satellites. Operations of the Kiruna station are fully automated and controlled from the Estrack Control Centre at ESOC, Darmstadt, Germany. Local station operations and maintenance at the station are performed by SSC

When the Esrange Special Project was first established with eight European countries - Belgium, France, Germany, the Netherlands, Norway, Sweden, Switzerland and the UK – its objective was to provide sounding-rocket and balloon launch services from Esrange and Andøya in Norway, which was also included in the Special Project via a special Swedish/ Norwegian Agreement. This enabled coordinated European sounding-rocket research at high latitudes could thus be continued after ESRO's activities had ended.

Further amendments followed the 1971 agreement, firstly the extension of the Esrange Agreement of 17 March 1977, followed by various other amendments, including the respective amendments by full accession to the Agreement by Norway on 2 July 1990. The Esrange Special Project is still in operation, but with fewer participating states (Belgium left in 1977, and the Netherlands and UK in 1980).

Today, rocket and balloon activities continue to be co-ordinated and financed by the Esrange Andøya Special Project within ESA. The Kiruna base is used by the international scientific community for launching sounding rockets for microgravity and atmospheric research as well as high-altitude balloons for astronomy, atmospheric research and drop tests of space and aerial vehicles.

Looking to the future, there are even more ambitious plans. Private company Spaceport Sweden aims to make Kiruna Europe's premier space hub, based on 50 years of scientific expertise and Esrange's very fruitful partnership with the Swedish Institute of Space Physics. The company signed an agreement with Virgin Galactic in 2007, whereby Spaceport Sweden would be the first spaceport outside the USA that Virgin Galactic could use for flight campaigns. ■



ExoMars 2016's Trace Gas Orbiter
(ESA/ATG medialab)

# → EUROPE'S NEW ERA OF MARS EXPLORATION

## The ExoMars 2016 and 2020 missions

Emily Baldwin
Communications Department, ESTEC, Noordwijk, the Netherlands

**ExoMars is opening a new era for Europe: moving from remote observation to surface and subsurface exploration of Mars. The first ExoMars mission was launched in March, and the second is planned in 2020.**

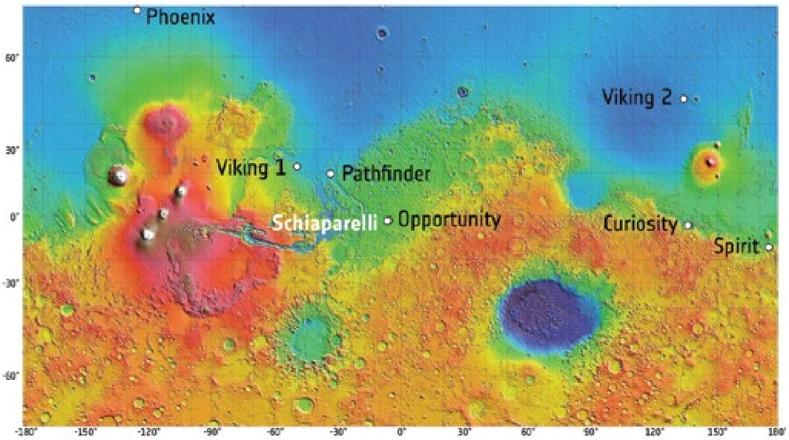
Mars has captured the imagination of humankind for millennia, from artists and writers to scientists and astronomers alike. People often speculated that our neighbouring planet might host intelligent extraterrestrial life – a fantasy strengthened by 19th century Italian astronomer Giovanni Schiaparelli (for whom the ExoMars entry, descent and landing demonstrator module is named), who observed bright and dark straight-line features that he called 'canali'.

This term was mistakenly translated into English as 'canal' instead of 'channel', conjuring up images of vast irrigation networks constructed by intelligent beings living on Mars. The controversy ended in the early 20th century, thanks to better telescopes offering a clearer view of the planet.

With the dawn of the space age in the latter half of the century, scientists instead began to look for evidence of the presence of water – an essential element for the emergence of life as we know it. Water is now known to have played an important role in the Red Planet's history, with numerous ancient dried-out riverbeds, channels and gullies observed by the fleet of spacecraft orbiting the planet and, more recently, evidence found of brief flows of briny water. But establishing whether life ever existed on Mars, even at a

→

The landing sites of the seven rovers and landers that have conducted a mission on the surface of Mars. Schiaparelli targeted the Meridiani Planum region on 19 October 2016, close to the landing site of NASA's Opportunity rove. The background relief map of Mars is based on data from the Mars Orbiter Laser Altimeter (MOLA) on NASA's Mars Global Surveyor (ESA/NASA)




↑ ExoMars 2016 lifted off on a Proton-M rocket from Baikonur, Kazakhstan at 09:31 GMT on 14 March

microbial level, remains one of the outstanding scientific questions of our time.

The present-day surface of Mars, dry and subject to harsh radiation, is too hostile for living organisms to survive. However, primitive life may have gained a foothold when the climate was warmer and wetter, more than 3.5 billion years ago, potentially leaving traces of early lifeforms still to be discovered below the surface.

## Martian chronicles

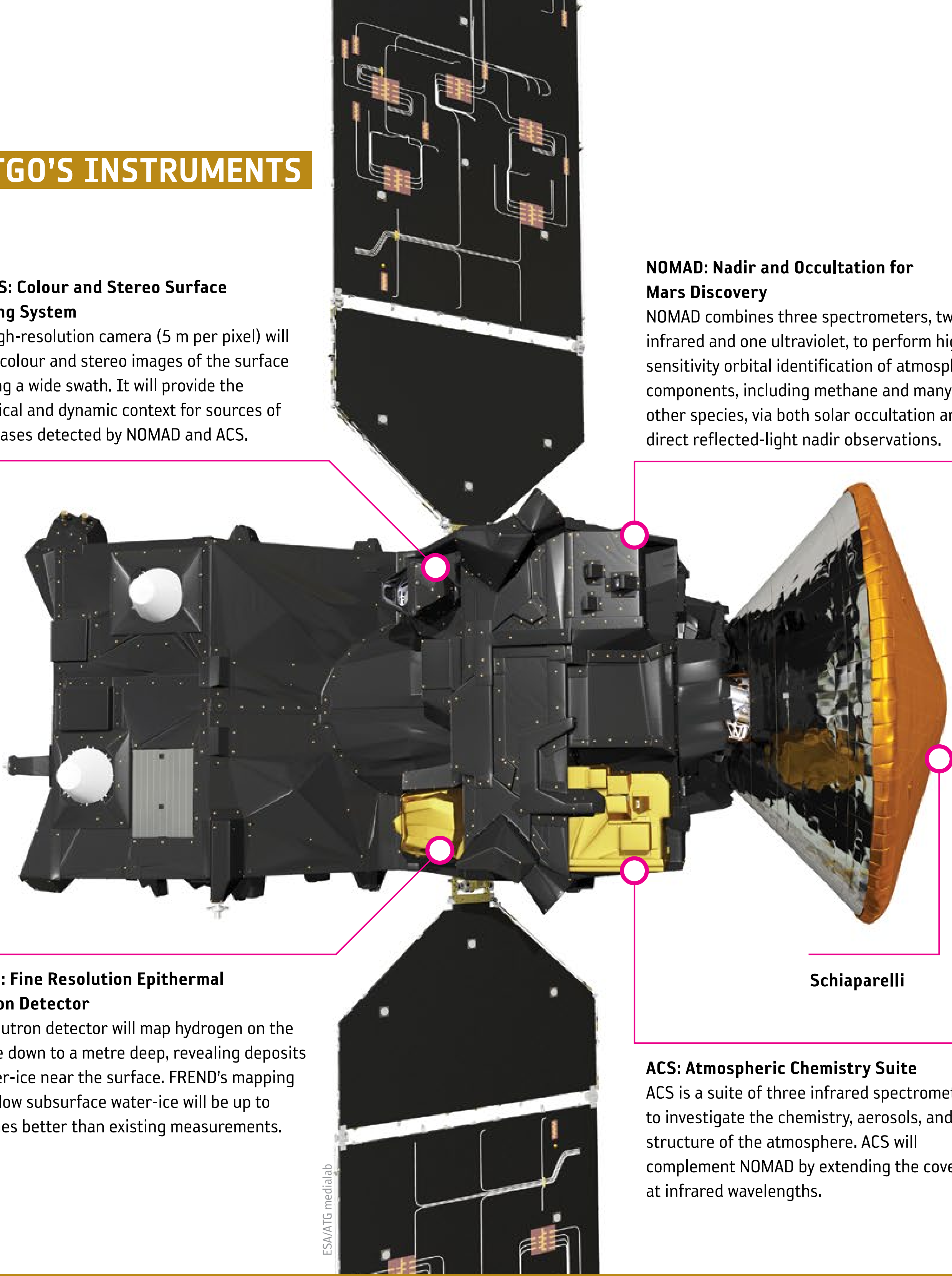
Mars exploration began in the 1960s, and over 40 spacecraft have attempted to reach the Red Planet to date, with varying degrees of success. European countries have participated in US, Russian and Japanese-led missions through scientific collaboration and the contribution of instruments since the early 1970s. In particular, European instruments have flown on NASA's Mars orbiters, landers and rovers since 1992.

Possibilities for ESA-led Mars missions were studied from the early 1980s onwards, with the first, Mars Express, initiated following the loss of the Russian-led Mars 96. Mars Express was launched in 2003 with a suite of instruments and the Beagle-2 lander. The orbiter continues to yield world-class scientific data 12 years later, although the lander did not operate. The instruments on Mars Express provide extraordinary views of the planet and its environment.

One unsolved question raised by the mission was the intriguing detection of atmospheric methane. On Earth, methane is produced almost exclusively by biological processes, with a small fraction due to volcanic or hydrothermal activity.

> **“Determining whether Mars is ‘alive’ today is at the heart of ESA's ExoMars programme.”**

## → TGO'S INSTRUMENTS



ESA/ATG medialab

**CaSSIS: Colour and Stereo Surface Imaging System**
This high-resolution camera (5 m per pixel) will obtain colour and stereo images of the surface covering a wide swath. It will provide the geological and dynamic context for sources of trace gases detected by NOMAD and ACS.

**NOMAD: Nadir and Occultation for Mars Discovery**
NOMAD combines three spectrometers, two infrared and one ultraviolet, to perform high-sensitivity orbital identification of atmospheric components, including methane and many other species, via both solar occultation and direct reflected-light nadir observations.

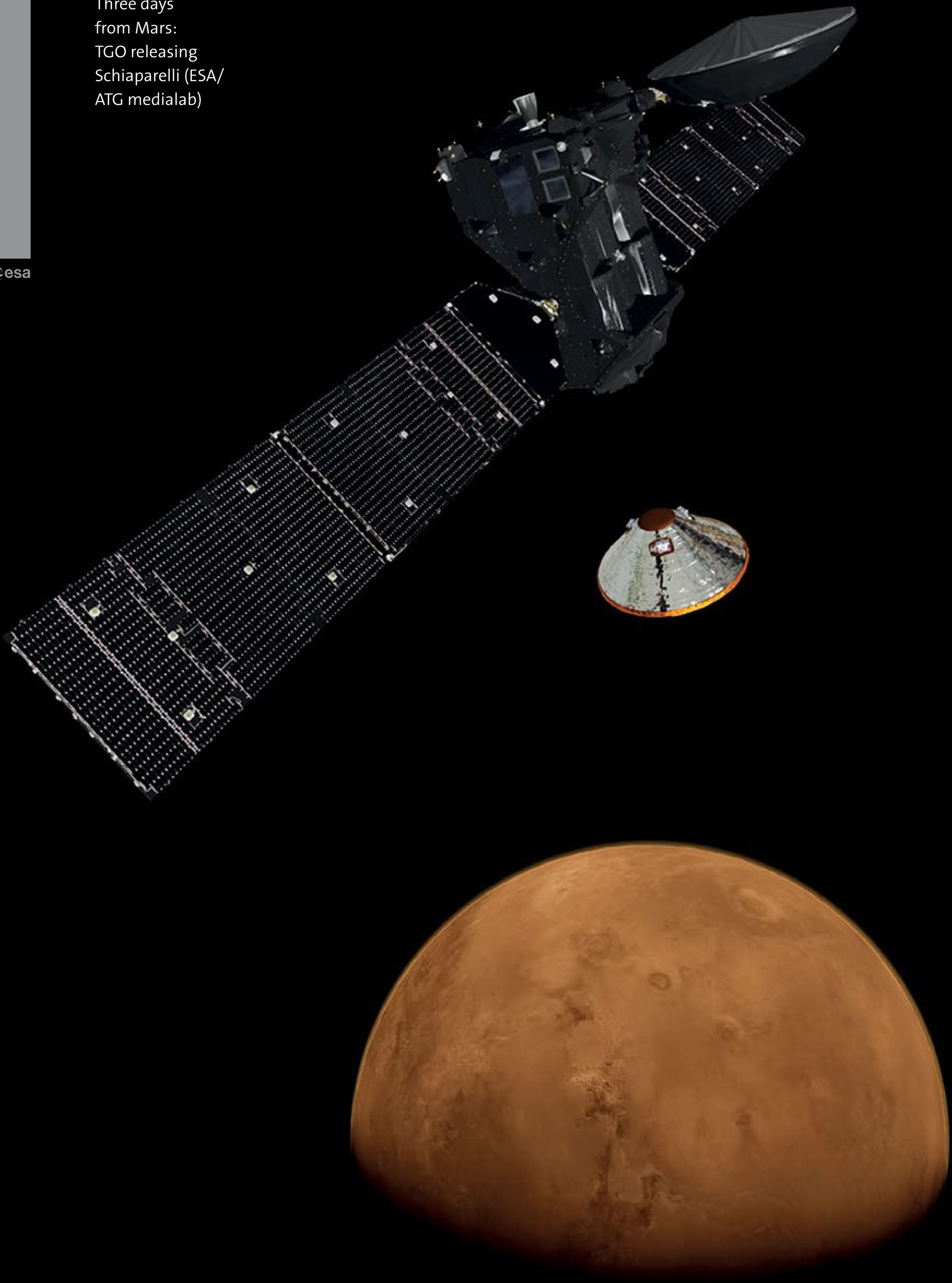
**FREND: Fine Resolution Epithermal Neutron Detector**
This neutron detector will map hydrogen on the surface down to a metre deep, revealing deposits of water-ice near the surface. FREND's mapping of shallow subsurface water-ice will be up to ten times better than existing measurements.

**Schiaparelli**

**ACS: Atmospheric Chemistry Suite**
ACS is a suite of three infrared spectrometers to investigate the chemistry, aerosols, and structure of the atmosphere. ACS will complement NOMAD by extending the coverage at infrared wavelengths.

### Trace Gas Orbiter vital statistics

**Spacecraft:** 3.5 x 2 x 2 m, with solar wings spanning 17.5 m providing about 2000 W of power
**Launch mass:** 4332 kg (including 135.6 kg science payload plus the 577 kg Schiaparelli)
**Propulsion:** bipropellant, with a 424 N main engine for Mars orbit insertion and major manoeuvres
**Power:** in addition to solar power, two lithium-ion batteries to cover eclipses, with ~5100 Wh total capacity
**Communication:** 2.2 m-diameter X-band 65 W high-gain antenna for communication with Earth; UHF band transceivers (provided by NASA) with a single helix antenna for communication with surface rovers and landers
**Science:** four instrument packages
**Nominal mission end:** 2022



Three days from Mars: TGO releasing Schiaparelli (ESA/ATG medialab)

Determining whether Mars is 'alive' today is at the heart of ESA's ExoMars programme. ExoMars is a cooperation between ESA and the Russian space agency, Roscosmos, and comprises two missions.

The first, launched in 2016, is made up of the Trace Gas Orbiter (TGO), which will carry out investigations to try to determine the biological or geological origin of important trace gases on Mars, plus Schiaparelli, an entry, descent and landing demonstrator module.

The second mission, planned for launch in 2020, comprises a European rover and a stationary Russian surface science platform. The rover will be the first mission to combine the capability of moving across the surface with the ability to drill down to two metres below the surface, in order to retrieve and analyse samples using the Pasteur payload of sophisticated instruments.

> **The 2020 rover will be the first mission to combine moving across the surface with the ability to drill down to 2 m below the surface.**

The ExoMars 2016 mission, comprising the Trace Gas Orbiter (TGO) and Schiaparelli, were launched on a Russian Proton rocket in March and arrived at Mars in October. After releasing Schiaparelli three days earlier, TGO performed a critical orbit insertion burn on 19 October, arriving at the Red Planet on its foreseen highly elliptical four-day orbit.During much of 2017, TGO will use the atmosphere to slow itself down - aerobraking - to arrive at its final near-circular orbit about 400 km above the planet's surface. Aside from some initial science measurements during two orbits in November 2016, the primary scientific mission is expected to begin in late 2017.

TGO includes state-of-the-art instruments designed to take a detailed inventory of Mars' atmospheric gases. Emphasis will be placed on analysing gases such as methane, water vapour, nitrogen dioxide and acetylene, which could point to active biological or geological processes, even though they are only present in small concentrations – less than 1% of the atmospheric inventory.

To complement these measurements, TGO will also image and characterise features on the surface that may be related to trace-gas sources such as volcanoes.

Understanding the source of methane is of particular interest. Previous investigations have shown, for example, that the amount of methane can vary with location and time. Methane is short-lived on geological timescales, so its presence implies the existence of an active, current source. Data collected by TGO will be used to help assess the nature and origin of the methane.

The orbiter will monitor seasonal changes in the atmosphere's composition and temperature in order to create detailed atmospheric models. It will also map hydrogen on the surface and to a depth of a metre beneath, with improved spatial resolution compared with previous measurements. This could reveal deposits of water ice hidden just below the surface, which, along with locations identified as sources of the trace gases, could influence the choice of landing sites of future missions. As well as carrying Schiaparelli, TGO will serve as a data relay for the ExoMars 2020 rover mission.

## Landing on Mars

Despite a number of prominent US successes since the 1970s, landing on Mars remains a significant challenge. As part of the ExoMars programme, a range of technologies has been developed to test controlled landing techniques. These include a special material for thermal protection,a parachute system, a radar altimeter system and a final-braking system controlled by liquid-propellant retrorockets.

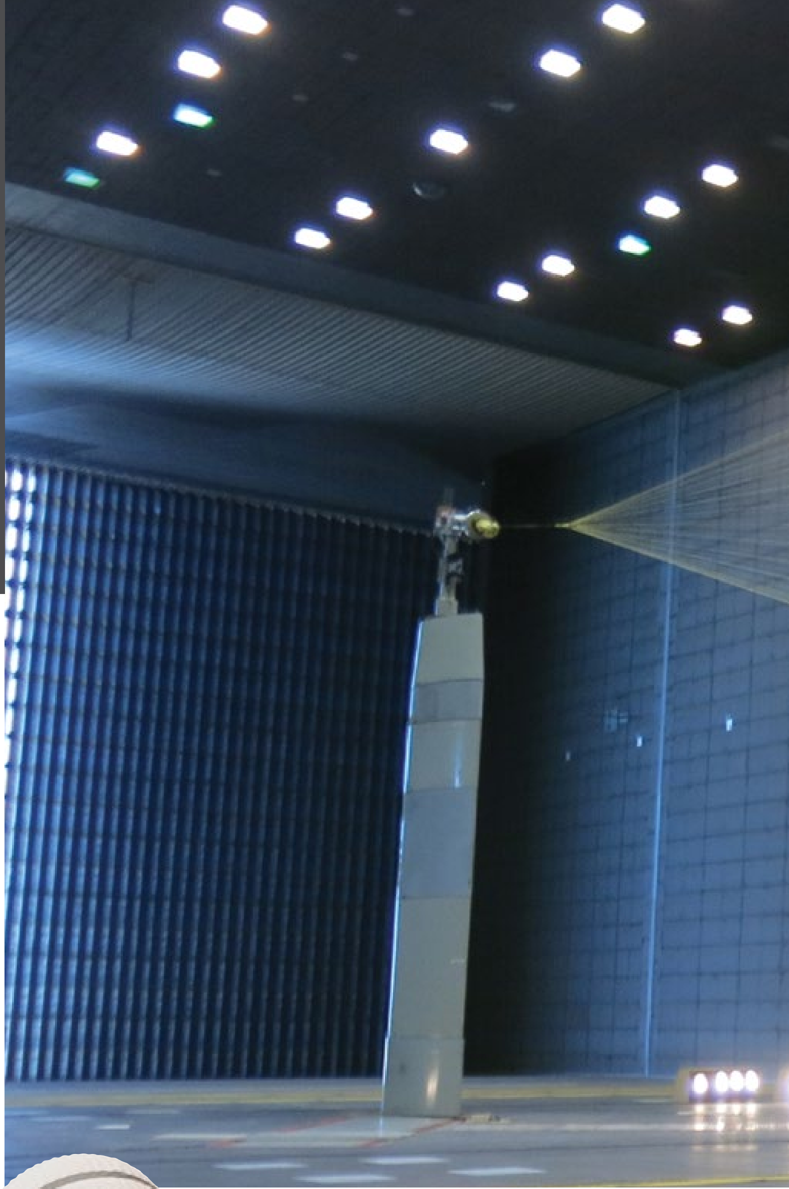
Three days before reaching Mars, Schiaparelli separated from TGO and coasted towards the planet in hibernation mode, to reduce its power consumption. It was activated just over an hour before entering the atmosphere, which it did at an altitude of 121 km and at a speed of 21 000 km/h.

An aerodynamic heatshield slowed the lander down such that at an altitude of about 11 km, when the parachute is deployed, it was predicted to be travelling at a speed of 1650 km/h. It then released its front shield and turnedon its radar altimeter, which can measure the distance to the ground and its velocity across the surface.

This information was supposed to be used to activate and command the liquid propulsion system once the rear heatshield and parachute was jettisoned 1.3 km above the surface. At this point, Schiaparelli was expected to still be travelling at nearly 270 km/h, with the engines slowing it to less than 2 km/h by the time it was 2 m above the surface.

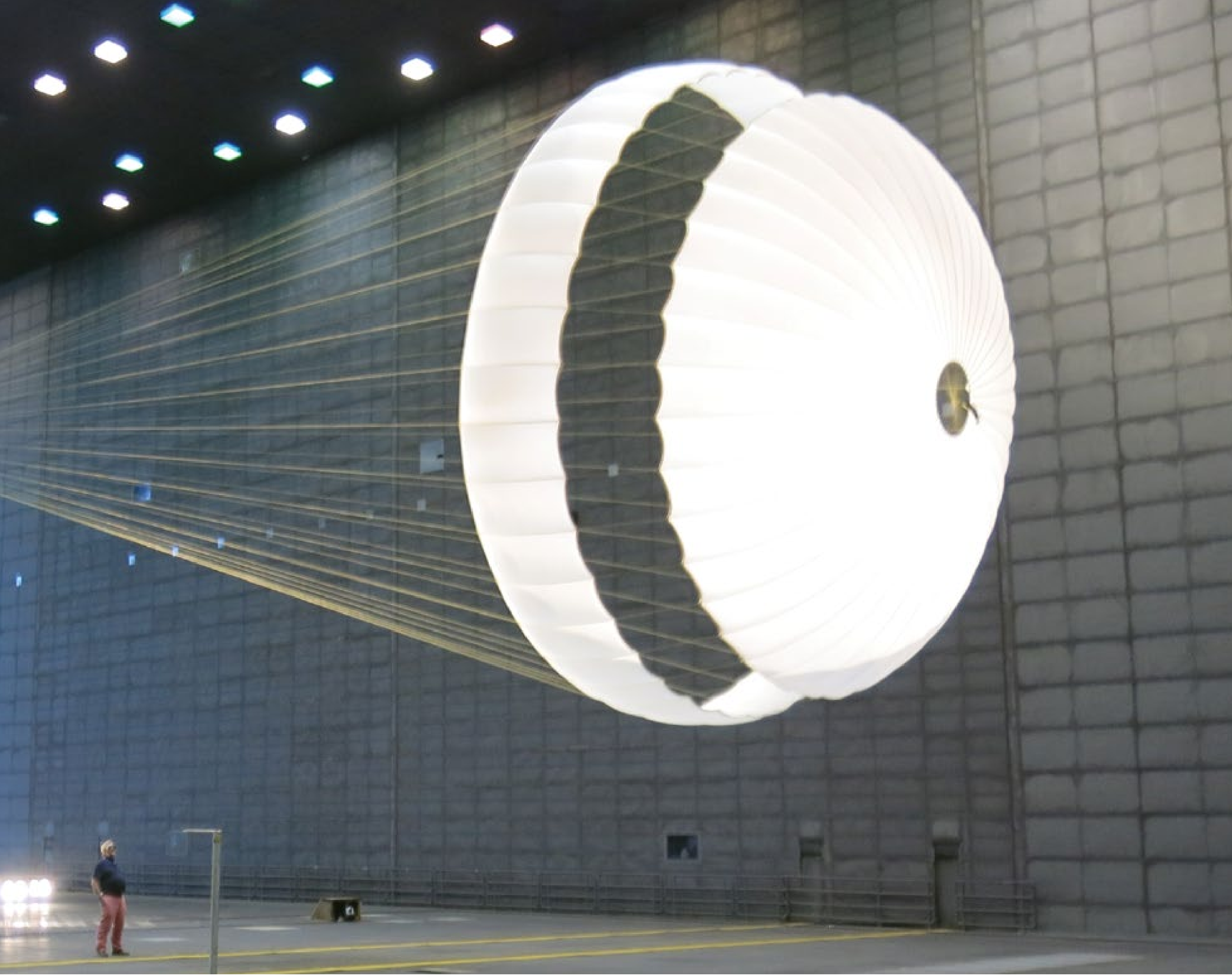
→

The parachute that helped to slow Schiaparelli down during the middle stages of its descent through the martian atmosphere. This is the same type that was used for the ESA Huygens probe descent to Titan and for all NASA planetary entries so far; its nylon canopy measures 12 m across and has Kevlar lines. The full-scale qualification model pictured here was used to test the pyrotechnic mortar deployment and the strength of the parachute in the world's largest wind tunnel at the National Full-Scale Aerodynamic Complex (NFAC) in the Ames Research Center, California (USAF Arnold Engineering Development Complex)



At that moment, the engines would be switched off and Schiaparelli would freefall the final second where the impact would be cushioned by a crushable structure on the base of the lander.

Although the first stages were completed well – the hypersonic atmospheric entry phase, the parachute deployment at supersonic speeds and the subsequent slowing of the module – an anomaly in the latter stages meant that the lander ultimately made a hard landing on the surface. For some reason, the parachute and rear heatshield were ejected from Schiaparelli earlier than



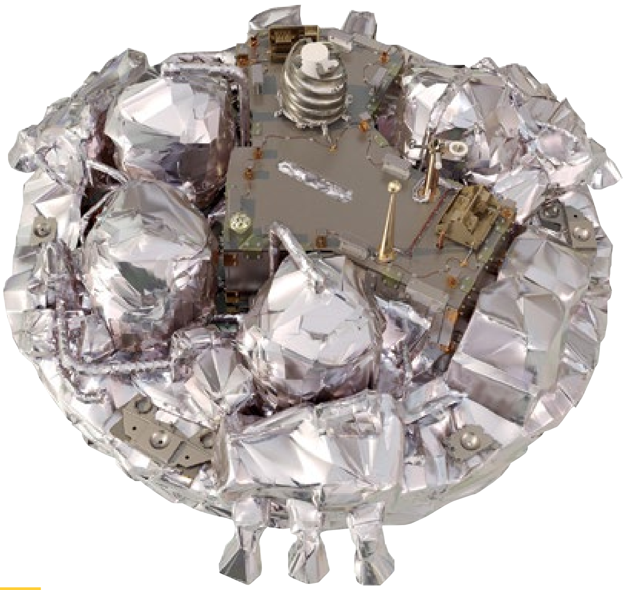
Schiaparelli's planned entry, descent and landing sequence on Mars, with approximate time, altitude and speed of key events indicated if everything had been executed as expected

**Parachute jettisoned with rear cover**

**Time:** 5 min 22 sec
**Altitude:** 1.2 km
**Speed:** 240 km/h

**Thruster ignition**

**Time:** 5 min 23 sec
**Altitude:** 1.1 km
**Speed:** 250 km/h

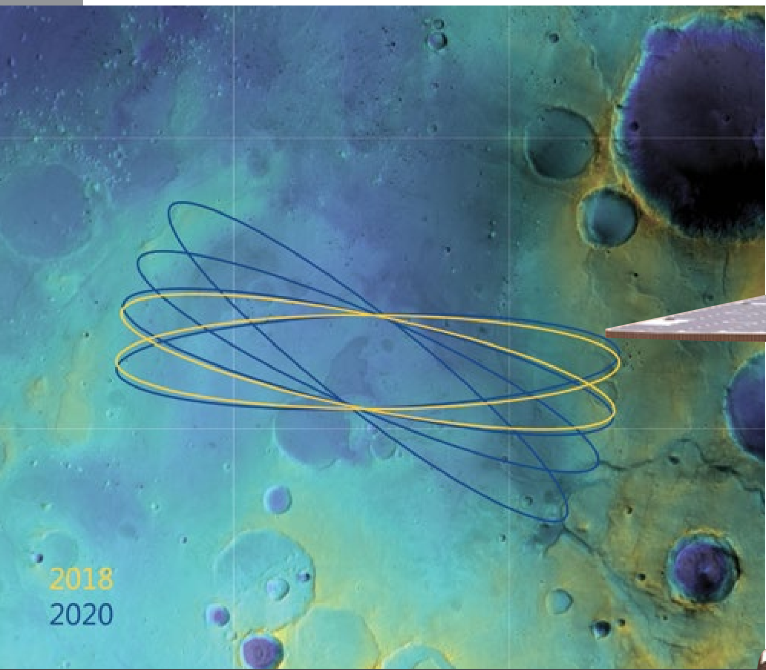


**Thruster off freefall**

**Time:** 5 min 52 sec
**Altitude:** 2 m
**Speed:** 4 km/h

**Touchdown**

**Time:** 5 min 53 sec
**Altitude:** 0 m
**Speed:** 10 km/h

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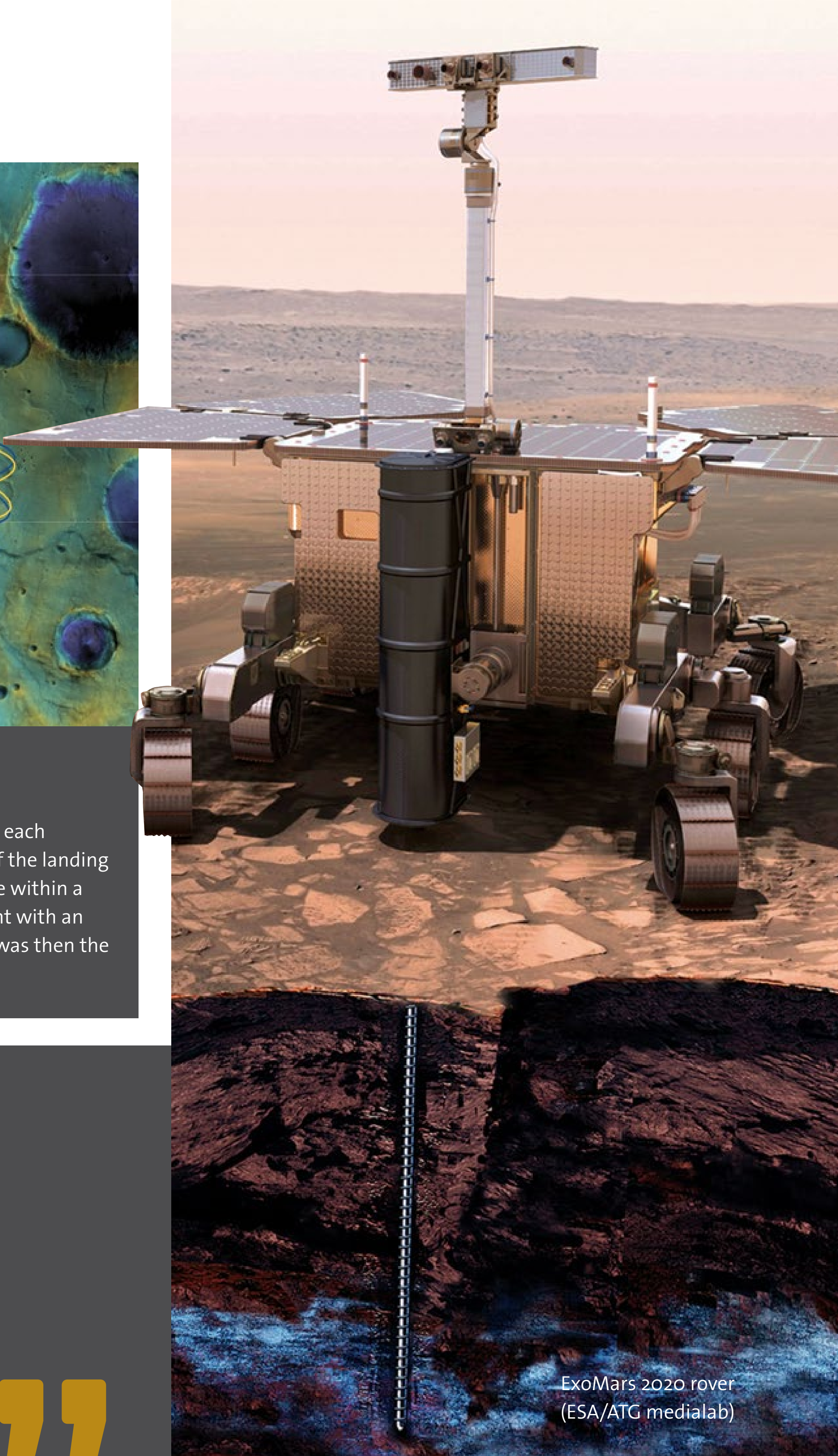
Oxia Planum landing ellipses under evaluation, each covering an area 104 x 19 km. The orientation of the landing ellipse depends on when the launch takes place within a given launch window –they had to be compliant with an earlier launch window in 2018 as well as what was then the backup launch window in 2020

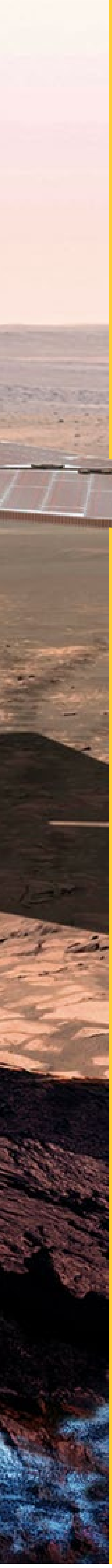


ExoMars 2020 rover (ESA/ATG medialab)

**"The rover is fitted with a drill – a first in Mars exploration – to extract samples from various depths."**

anticipated, with the module only firing its thrusters for a few seconds before falling to the ground from an altitude of 2-4 km and therefore reaching the surface at more than 300 km/h. At the time of print, the exact cause of the anomaly was still under investigation, and expected to be reported during mid or late November. A communication link with TGO successfully provided real-time transmission of the most important operational data measured by Schiaparelli during its descent, which is being analysed as part of this investigation.

Schiaparelli did however successfully arrive close to the centre of the planned landing ellipse, in the plain known as Meridiani Planum. Under normal circumstances, the module was designed to cope with landing on a terrain with rocks as tall as 40 cm and slopes as steep as 12.5°.



## → Roving the Red Planet

Like its predecessor, the 2020 mission of a European rover and a Russian surface platform will also be launched on a Russian Proton rocket. During the launch and nine-month cruise to Mars, a carrier module (provided by ESA) will house the surface platform and the rover within a single protective aeroshell. A descent module (provided by Roscosmos with some contributions by ESA) will separate from the carrier shortly before reaching the martian atmosphere. During the descent, a heatshield will protect the payload as it passes through the atmosphere.

Parachutes, thrusters and damping systems will reduce the speed, allowing a controlled landing. After landing, the rover, which is about the size of a golf buggy, will leave the platform to start its science mission. The primary objective is to search for well-preserved organic material, particularly from the early history of the planet.

With its suite of nine scientific instruments, collectively known as Pasteur, the rover will study the geology of the landing site and establish the physical and chemical properties of the samples, mainly from the subsurface. Underground samples are more likely to include ancient biosignatures in a good state of preservation since the tenuous atmosphere of today offers little protection from space radiation and surface photochemistry.

The rover is fitted with a drill – a first in Mars exploration – to extract samples from various depths, down to a maximum of two metres. Once collected, each sample is delivered to a number of instruments in the rover's next-generation analytical laboratory, which will perform investigations to determine the sample's mineralogy and chemistry. The rover is expected to travel several kilometres during its mission, collecting samples from a variety of locations.

“Underground samples are more likely to include ancient biosignatures in a good state of preservation.”

Because Schiaparelli was primarily demonstrating technologies, it did not have a long scientific mission lifetime, and was only intended to survive a few days on the surface using the excess energy capacity of its batteries. However, a set of scientific sensors were included to analyse the local environment during descent and after landing. Unfortunately no data could be returned from the surface.

The day after and also in the two weeks after landing, NASA's Mars Reconnaissance Orbiter imaged the landing site as planned. The images revealed components of the module's hardware as expected, including the parachute still attached to the rear heat shield, and the front heatshield. The images also confirmed that the module had crash-landed.

### Choosing a landing site

The surface area of Mars is some 145 million km², almost the same area as Earth's land masses. Fortunately, thanks to the fleet of spacecraft that has been studying Mars for over 50 years, a wealth of detailed information already exists about the surface, making the search for a suitable landing site less challenging than it was for the first missions that landed on the planet.

Since the objective of the ExoMars rover is to seek out signs of life, the candidate landing sites must show evidence for the past presence of abundant liquid water. At the same time, the sites have to satisfy a number of technological constraints.

Four sites have been under discussion: Mawrth Vallis (one of the oldest outflow channels with exposures of clay-rich rocks), Oxia Planum (one of the largest exposures of layered clay-rich rocks), Hypanis Vallis (the remnant of an ancient river delta) and Aram Dorsum (home to alluvial sediments associated with a channel running through the site). While Oxia Planum has been recommended by the Landing Site Selection Working Group as the primary focus for further detailed evaluation, the final decision will be made by ESA and Roscosmos at a later date. ■

Emily Baldwin is an EJR-Quartz writer for ESA

# → PROGRAMMES IN PROGRESS

**Status at February 2016**


Soyuz TMA-19M carries Expedition 46 crew members Yuri Malenchenko, Tim Kopra and ESA's Tim Peake into space on 15 December 2015 (J. Kowsky/NASA)

## KEY TO ACRONYMS

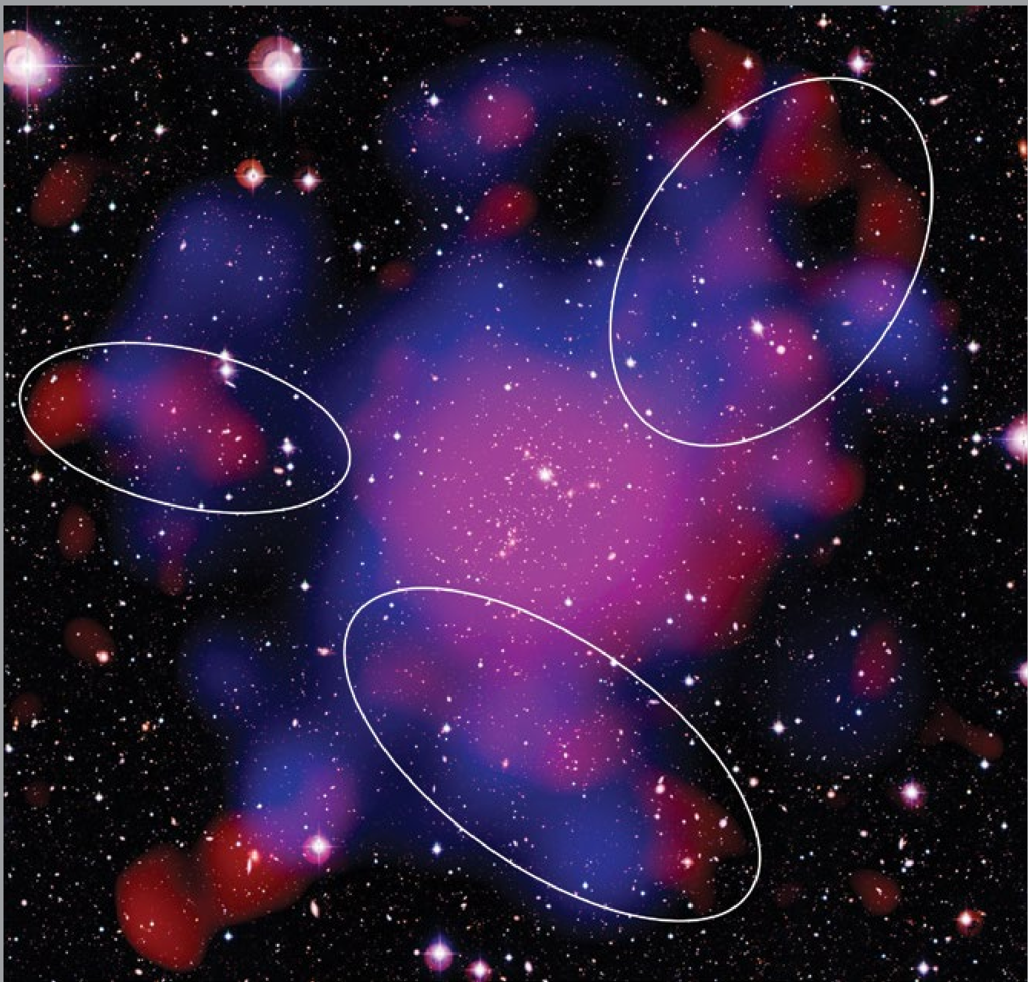
| | |
|---|---|
| AM - Avionics Model | LEOP - Launch and Early Orbit Phase |
| AO - Announcement of Opportunity | MoU - Memorandum of Understanding |
| AIT - Assembly, integration and test | PDR - Preliminary Design Review |
| AU - Astronomical Unit | PFM - Proto-flight Model |
| CDR - Critical Design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

## → CASSINI-HUYGENS

A new study published in *Nature* reports the first direct observations of magnetic reconnection at Saturn (that is, with a direct observation of B-field line polarity change and energetic ion escape detection). How Saturn's magnetosphere gets populated with plasma has been understood since the cryo-activity of Enceladus was discovered, injecting water ions and their photolytic products along the field lines. Magnetic reconnection was thought to be a sink process for ions, as the magnetic field lines of opposite polarity rearrange, allowing the ions to escape and being picked up by the surrounding solar wind. Until now, this process had not been observed unambiguously.

## → XMM-NEWTON

Galaxy clusters are the most massive cosmic structures held together by gravity. They consist of galaxies, hot gas and dark matter and sit in the densest hubs of the filamentary 'cosmic web' that pervades the Universe. Using XMM-Newton, astronomers have detected three massive filaments flowing towards the core of galaxy cluster Abell 2744, which connect it with the cosmic web. The filaments consist of galaxies, hot gas and dark matter. Astronomers detected the hot gas in the cluster and filaments with X-ray observations and the galaxies with optical observations. To reconstruct the distribution of dark matter, they used the gravitational lensing effect that the mass of the cluster and filaments exerts on more distant galaxies.



Composite image the galaxy cluster Abell 2744 based on XMM-Newton (X -rays), ESO (optical) and Hubble (dark matter) observations. Massive filaments of hot gas flowing towards the core of galaxy cluster Abell 2744 are indicated with ellipses in the image

## → CLUSTER

Cluster data have enabled a new way to detect magnetic reconnection in space, one of the hottest topics in space physics. Magnetic reconnection is a fundamental plasma process converting magnetic energy into particles' kinetic and thermal energy, and has been widely accepted as a mechanism responsible for many explosive phenomena in the Universe such as stellar flares, coronal mass ejections, gamma ray bursts, substorms and strong emissions at the galactic centre, as well as disruptions in fusion experiments. Close to us, magnetic reconnection creates holes in Earth's magnetic field where the solar wind plasma can penetrate and reach Earth.

In a three-dimensional regime, such reconnection often occurs at magnetic nulls, where the magnetic strength becomes zero and the particles get unmagnetised. Investigating the properties and topology of magnetic nulls, therefore, can help us to understand the energy conversion during reconnection process.

One key aspect of this physical process is its multiscale nature. From a large-scale perspective (thousands of kilometres), large blobs of plasma and accelerated beams of particles are observed as a consequence of magnetic reconnection. On Earth, Jupiter, Saturn, Uranus and Neptune, it creates bright auroras. Observed at a few hundreds of kilometres distance, called the ion scale, the ions were found be decoupled from the electrons. At a few kilometres from the centre of this process (or X-line), called the electron scale, the physics remain largely unknown, as it requires the measurements of the distributions of particles and electromagnetic fields at extremely high cadence.

In a few occasions, the four Cluster spacecraft were encompassing an X-line at ion scale. The X-line was inside the tetrahedron formed by the Cluster flotilla. This was detected thanks to a method called the Poincare index.

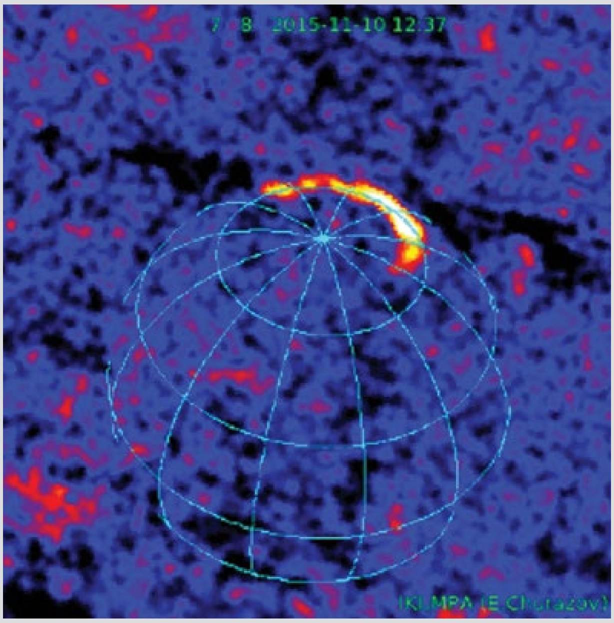
Up to March 2015, Cluster was the first and only multi-spacecraft mission investigating this phenomenon at ion scale. Since 12 March 2015, the NASA Magnetospheric MultiScale mission (MMS), a four-spacecraft mission, has joined Cluster in space to study magnetic reconnection with a focus on the electron scale. The first part of the mission is dedicated to catching magnetic reconnection on the dayside magnetopause in the equatorial plane, with Cluster measuring its large-scale consequences at high latitudes thanks to coordinated observations already foreseen up to 2018. But catching an X-line at such a small scale is like finding a needle in a haystack.

Luckily, a team of Chinese and Swedish researchers involved in both missions has recently published a new method to find an X-line. This new method, the first order Taylor expansion, enables to find the presence of magnetic nulls not only within the volume defined by four-point measurements, but also ones nearby, outside the Cluster constellation. A revisit of the Cluster database has enabled us to dig out a much larger number of X lines skimmed by the ESA flotilla. It could prove essential to select burst mode of measurements on the MMS mission, so as not to miss the rare occasions where this new flotilla will pass by an X-line.

## → INTEGRAL

Normally busy with observing the high-energy Universe, Integral recently had the chance to look back at our own planet's aurora. Auroras are well known as the beautiful light shows at polar latitudes as the solar wind interacts with Earth's magnetic field. As energetic particles from the Sun are drawn along Earth's magnetic field, they collide with different molecules and atoms in the atmosphere to create dynamic, colourful light shows in the sky, typically in green and red.

But what may be less well known is that auroras also emit X-rays, generated as the incoming particles decelerate. Integral detected high-energy auroral X-rays on 10 November 2015 as it turned to Earth – although it was looking for something else at the time. Its task was to measure the diffuse cosmic X-ray background that arises naturally from supermassive black holes that are gobbling up material at the centres of some galaxies. To achieve this, Integral records the X-ray brightness with and without Earth in the way, blocking the background.



X-ray image taken by Integral's IBIS/ISGRI instrument on 10 November 2015. The image covers the energy range 17–60 keV and shows the intense auroral emission visible on the opposite side of the pole above Canada. Earth's position is shown by its coordinate grid (ESA/Integral/IKI/MPA/ISDC/Univ. Geneva)

Note that it is unusual to point the spacecraft at Earth: it requires innovative planning by the operations teams to coordinate the necessary manoeuvres to ensure it can operate safely with Earth inside the instruments' field of view and then return to its standard observing orientation. Unfortunately, on this occasion, the X-rays from Earth's aurora drowned out the cosmic background – but the observations were not a waste.

They help us to understand the distribution of electrons raining into Earth's upper atmosphere, and they reveal interactions between the solar wind and Earth's protective magnetic bubble, or magnetosphere.

## → ROSETTA

Observations made by the VIRTIS infrared instrument on Rosetta of the Imhotep region (the belly region of the 'duck-shaped' comet) have provided conclusive evidence of the existence of water ice on the surface of the comet. Analysis of these regions has revealed larger ice grains than observed in other areas, hinting at particular mechanisms of ice particle growth and the larger scale structure of the comet. Continued study of these features throughout the mission will reveal whether they are a result of a specific activity or left over from the formation of the comet.

The Rosetta Science Working Team (the scientific authority of the mission) has been discussing the goals of the extended mission and the various requirements needed to address them. This includes the finale of the Rosetta journey – the controlled impact of the orbiter onto the surface of the comet.

The OSIRIS team have begun releasing an 'image of the day', which will continue for the rest of the mission. A recent release shows the 'head' part of the 'duck' from around 78 km distance. The image was taken shortly after an attempt by the Philae lander team to command the flywheel on the lander to operate. The lander has not been in contact since July 2015 and this attempt was carried out to see if the lander could be moved to a region of better illumination. There was no indication that this was successful. We hope to capture high-resolution images of the lander later this year, when Rosetta is closer to the comet.

## → HERSCHEL

Herschel is in the post-operations phase. The entire content of the Herschel Science Archive is being reprocessed with the latest version of the data processing software (HCSS 14). New and improved data products will be generated and made available to the community, and the archive itself has also

The Hatmehit region on Comet 67P/Churyumov-Gerasimenko seen on 10 January from a distance of 78 km (ESA/Rosetta/MPS for OSIRIS Team)

Multicolour image of Stephan's Quintet. Herschel far infrared data in yellow and red, XMM-Newton X-ray emission in blue and SDSS optical data in white (ESA/Herschel/PACS & SPIRE (infrared), ESA/XMM-Newton (X-rays) and SDSS (optical))

been augmented. All Herschel science data and generated data products are freely available, and the Herschel Science Centre supports the astronomical community exploiting the Herschel data to undertake science.

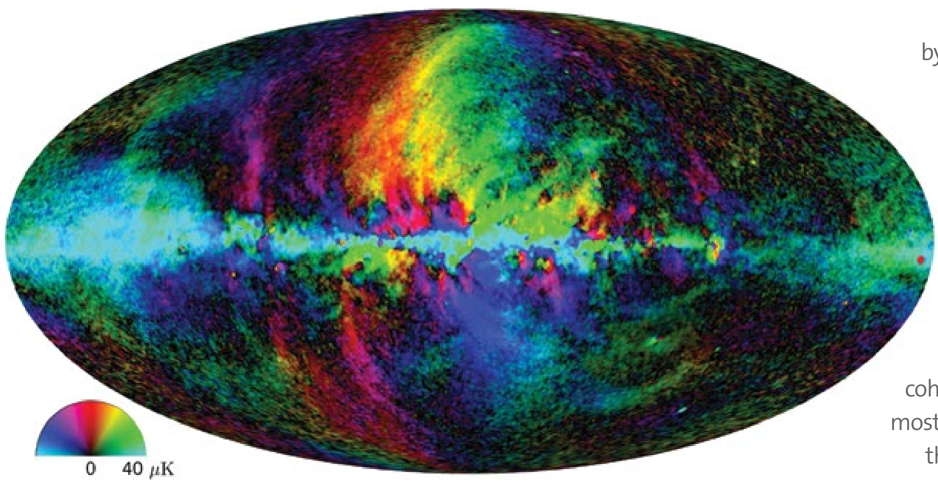
Herschel far-infrared data together with XMM-Newton and optical data have been used to produce a spectacular image of the galaxy group known as Stephan's Quintet. By observing these galaxies in infrared light with Herschel – shown in red and yellow – astronomers can trace the glow of cosmic dust. Dust is a minor but crucial ingredient of the interstellar matter in galaxies, which consists mainly of gas and provides the raw material for the birth of new generations of stars.

One galaxy stands out in the infrared light: the nearby NGC 7320, a spiral galaxy busy building new stars, however, it is actually a foreground galaxy, not physically connected to the others.

The intense dynamical activity of the distant group is also portrayed in the distribution of diffuse hot gas, which shines brightly in X-rays and was observed by XMM-Newton. Represented in blue, the hot gas appears to sit mostly between the four interacting galaxies. It is likely a mixture of primordial gas pre-dating the formation of the galaxies and intergalactic gas that has been stripped off the galaxies or expelled during their interactions.

## → PLANCK

Since July 2015, all of the data acquired by Planck have been released to the public via the Planck Legacy Archive (**http://www.cosmos.esa.int/web/planck/pla**). It is foreseen that a new and higher quality set of data products will be released in mid-2016, and they will constitute the 'legacy' of Planck. In the meantime, many papers continue to be published




The distribution of polarised intensity across the sky at low frequencies, as seen by Planck. The colour half-disc (bottom left) encodes the projected magnetic field angle, while the brightness represents intensity. Horizontal directions are concentrated in the plane of the Milky Way, indicating the large-scale structure of the galactic magnetic field. However, the map also shows a multitude of additional features that appear as loops or rings exhibiting coherent magnetic field directions; these are most likely caused by remnants of supernovae that took place in our own neighbourhood based on the data already public. A recent highlight is *Planck 2015 results. XXV. Diffuse low-frequency Galactic foregrounds* **(http://arxiv.org/abs/1506.06660v1 )** in which a detailed analysis is made of polarised synchrotron emission across the entire sky. This analysis, enabled by the high quality of Planck data, allows the tracing of the magnetic field that threads the interstellar medium of our Milky Way galaxy.

The morphology of the polarised synchrotron emission allows us to discriminate between the large-scale structure of the galactic magnetic field, and that caused by local events such as supernovae, which manifests itself as a large number of loops and spurs covering a good fraction of the sky. Comparison of the morphology of polarised synchrotron and dust emission allows even more quantitative analysis of the distribution of the magnetic field in our galaxy, as described in another very recent paper, *Planck intermediate results. XLII. Large-scale Galactic magnetic fields* (**http://arxiv.org/abs/1601.00546**).

## → VENUS EXPRESS

Venus Express is in the post-operations phase. Work is focusing on finalising the archive in the Planetary Science Archive. Almost all data have now been delivered and the peer review of the data sets is in progress.

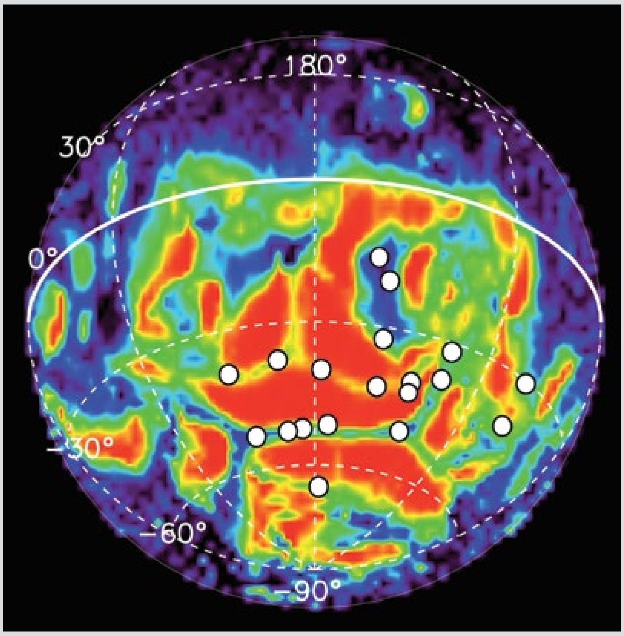
An in-depth analysis of ultraviolet and infrared images from the VMC instrument has shown new properties related to the ultraviolet darkening material responsible for the contrast in the upper cloud layer, at about 65–70 km altitude. Using observations of glory at ultraviolet and infrared wavelengths, aerosol particle radius and refractive index have been derived. For the main population of particles, in the 1.0 to 1.6 micron radius range, the so-called mode 1 particles, these parameters are nearly constant, at low latitudes and near local noon. Consequently, the differences of the dark and the bright clouds must come from the less dominating population of submicron-sized particles. This is a new and significant result that may eventually lead to the solution to the long-standing mystery of the origin of the ultraviolet absorber.

The first profiles of neutral hydrogen densities in the exosphere have been derived from measurements of Lyman-a emission in the hydrogen corona surrounding Venus at high altitude. By analysing ultraviolet channel data of the SPICAV instrument it was found that the concentration is 40 times higher at the night side compared to the earlier determined values at the day side. A dynamic three-dimensional model that allows estimates of the hydrogen density at all local times has been constructed. These results complement the previously published results of ionised hydrogen measurements from the ASPERA instrument and are very important for reaching a full understanding of the magnitude of the escape of hydrogen from the atmosphere. Until now the ratio of the escape of ionised hydrogen to that of neutral hydrogen has been poorly known. The new results show that the escape of neutral hydrogen is much smaller than the escape of ionised hydrogen as seen by ASPERA.

## → MARS EXPRESS

The spacecraft and the payload remain in excellent state. The mission successfully passed the combination of eclipse season with aphelion passage that severely limited the power budget and returned to full-scale science operations. Two new interdisciplinary scientists were appointed in January. They will foster the research in the field of Mars climatology and aeronomy.

Recent science highlights are related to the combined investigation of the Mars aurora and its properties derived from a decade-long record of SPICAM observations, Monte Carlo modelling and relationship of the aurora to the flux of incoming energetic electrons – which is the energy source – measured by the ASPERA instrument. The Mars auroras appear to be confined, rare and transient events that vary in time and space. They are very different from those on Earth and on the giant planets. Interestingly, all detected auroral events occur near the boundary between open and closed lines of the crustal magnetic field. An unexpected displacement has been observed between the location of the electron bursts measured by ASPERA and locations of




Locations of 19 auroral detections by SPICAM on the night side in the southern hemisphere (white circles). Red/blue areas indicate regions of open/closed field lines of the crustal magnetic field

This Mars Express HRSC image captured on 15 July 2015 shows the region, known as Noctis Labyrinthus, with ground resolution of about 16 m per pixel. This 'grand canyon' of the Solar System lies on the western edge of Valles Marineris and is etched with an intricate pattern of graben, landslides and wind-blown dunes. (ESA/DLR/FU Berlin)

the ultraviolet aurora (Gerard *et al*., *J. Geophys. Res. Space Physics* 120, 6749, 2015 and Soret *et al*., *Icarus* 264, 398, 2016). These aurora features were confirmed and scrutinised by investigations of NASA's MAVEN mission.

The interaction of solar wind with Mars on a large spatial scale was studied by the ASPERA team. They used a hybrid model and found that the solar wind is disturbed by Mars out to 100 Mars radii downstream of the planet, and beyond suggesting that the planet behaves in many ways like a comet. On this large scale the ion escape has two channels: a polar plume of ions picked-up by the solar wind and a more fluid outflow of ions through the tail of the planet.

The region shown is a small segment of a vast labyrinth of valleys, fractures and plateaus constituting part of a complex feature whose origin lies in the swelling of the crust due to tectonic and volcanic activity in the Tharsis region, home to Olympus Mons and other large volcanoes. As the crust bulged in the Tharsis province, it stretched apart the surrounding terrain, ripping fractures several kilometres deep and leaving blocks (called 'graben') stranded within the resulting trenches. The entire network of graben and fractures spans some 1200 km, about the equivalent length of the river Rhine from the Alps to the North Sea.

The segment presented here is 120 km-wide portion of that network, with one large, flat-topped block taking centre stage. Landslides are seen in extraordinary detail in the flanks of this unit and along the valley walls in the background with eroded debris lying at the base of the steep walls. In some places, particularly notable in the lower right corner of this view, wind has drawn the dust into dune fields that extend up onto the surrounding plateaus. Near-linear features are also visible on the flat elevated surfaces: fault lines crossing each other in different directions, suggesting many episodes of tectonic stretching in the complex history of this region.

## → GAIA

Gaia continues its science programme. On average some 50 million stars are measured per day. When the scanning direction is parallel to the Galactic Plane, then more than 200 million stars crossing the focal plane are measured. Since the decontamination operation on 3 June 2015, a slight transmission loss has been observed. The trend is very shallow and it is unlikely that another decontamination operation will be needed for some time.

Data processing is also in full swing. These activities are conducted by the Gaia Data Processing and Analysis Consortium (DPAC). The main focus is on the processing of the data intended for the first intermediate data releases (Gaia-DR1). This first release contains positions and broadband magnitudes for about one billion sources. In addition to some two million stars common between Gaia and earlier Tycho-2 catalogue, parallaxes and proper motions were also released. The third element in Gaia-DR1 consists of light curves of selected RR Lyrae stars and Cepheids. The release is targeted for summer 2016.


Vega's mobile gantry rolls out minutes before LISA Pathfinder's launch on 3 December 2015 (ESA/CNES/Arianespace)

While Gaia-DR1 is the main focus within DPAC, there are already parallel activities preparing for the second data release in summer 2017. There are three additional elements planned for Gaia-DR2. Parallaxes and proper motions will be given to all Gaia objects. In addition to the broadband photometry, there will also be integrated blue-band and red-band photometry allowing some work on astrophysical parameters. Radial velocities for the brightest stars will be provided.

## → LISA PATHFINDER

LISA Pathfinder was launched on 3 December 2015 on board Vega VV06 from Europe's Spaceport in Kourou. Vega orbited Earth once before separating from LISA Pathfinder over Kourou. The injection of the spacecraft into orbit was very accurate, and the first acquisition of signal was achieved while still flying over Kourou.

Over the following 12 days, LISA Pathfinder's orbital apogee was raised through a series of six manoeuvres that were planned and commanded from ESOC, ESA's operations centre in Germany. In-orbit commissioning activities started on the various subsystems, including the cold-gas microthrusters. With the last push of the 450 N engine, LISA Pathfinder started its trip towards L1, the Lagrange point in the direction of the Sun.

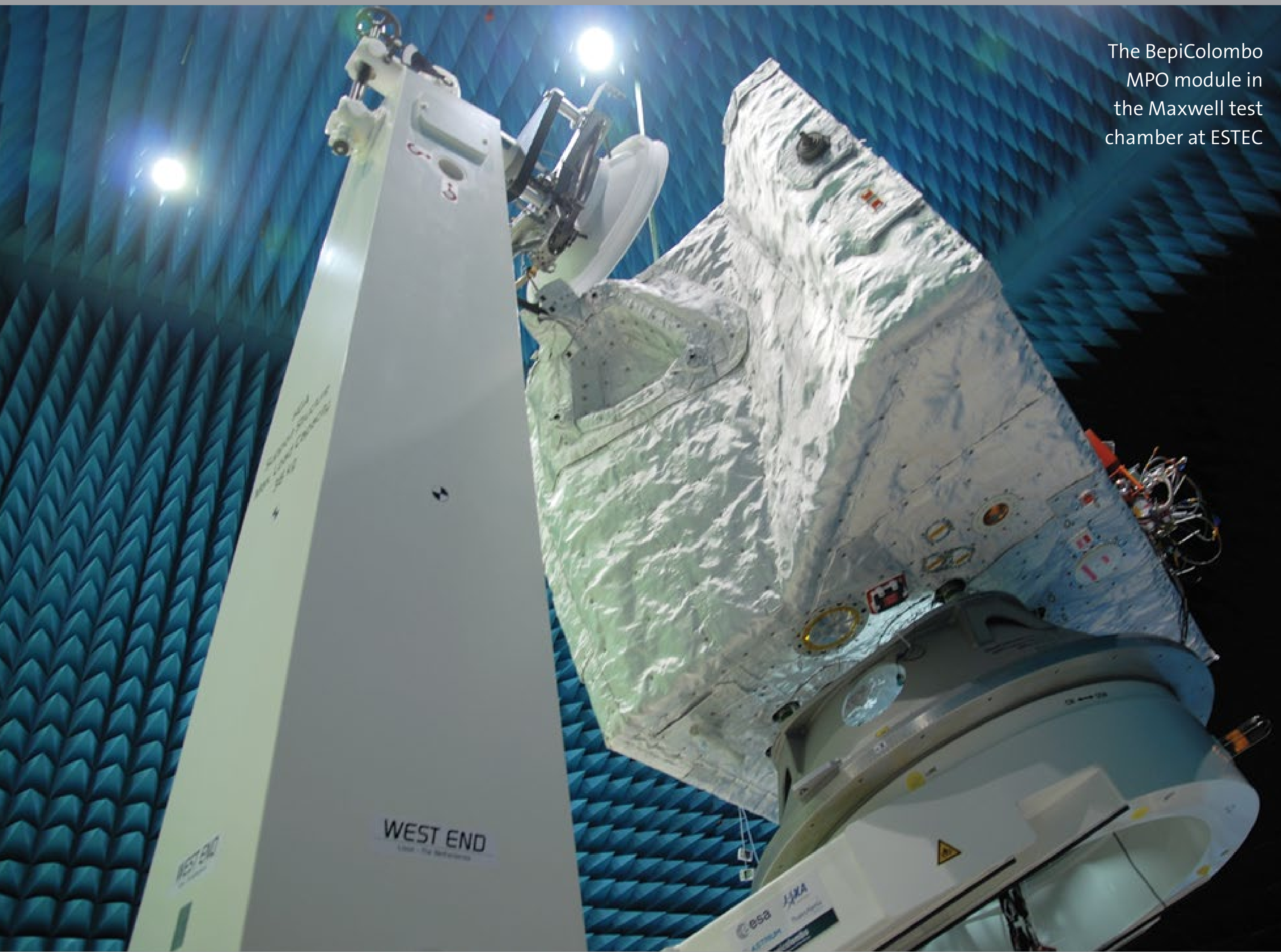
On 22 January, after two correction manoeuvres, and having reached sufficient energy to orbit around L1, the passive propulsion module of LISA Pathfinder ended its mission and was separated from the Science Module.

The spacecraft and payload commissioning activities continued with the release of the two gold-platinum test masses into freeflight inside their electrode housing. The position and attitude of the test masses is measured via the change of capacitance between them and the electrodes with an accuracy of a few nanometres. Furthermore, the distance between the masses is measured by a set of interferometers with an accuracy of a few picometres. This is a world first in space technology.

To date, the challenging objectives of LISA Pathfinder have all been met, and the mission is ready to commence the science operations in March 2016.

## → BEPICOLOMBO

Integration and test activities on the Mercury Planetary Orbiter (MPO) are progressing as planned with the completion of the EMC test and also the magnetic test campaign. The FM ISA payload was integrated and tested. All FM instruments are now integrated on the spacecraft with exception of the BELA instrument. Apart from BELA,




The BepiColombo MPO module in the Maxwell test chamber at ESTEC

the solar array and the High and Medium Gain Antenna Assemblies (MGA/HGA), the MPO module has reached flight configuration. On the Antenna Pointing Motors (APM) of the MGA/HGA, the repeated life test was completed. The APM FMs are in production for delivery in May. Unexpected reboots on the Solid State Mass Memory has triggered a dedicated series of tests on spacecraft level, which revealed a bus disturbance when executing a high-voltage command by the MGNS instrument. Investigations are continuing.

On the Mercury Transfer Module (MTM), AIT work has continued while waiting for delivery of the PPUs of the Solar Electric propulsion System (SEPS). With respect to the PPU, progress was achieved with the thermal test under high voltage conditions for the EQM unit. The root cause investigations on the BELA instrument are continuing. AIT work on the JAXA-provided Mercury Magnetospheric Orbiter (MMO) is complete. The critical path of the overall system schedule remains defined by the Power Processing Units of the SEPS in the MTM, the Antenna Mechanism Assembly of the MPO, and the availability of the BELA instrument. Launch readiness will be achieved in February 2018, with a launch window opening in April 2018.

## → MICROSCOPE

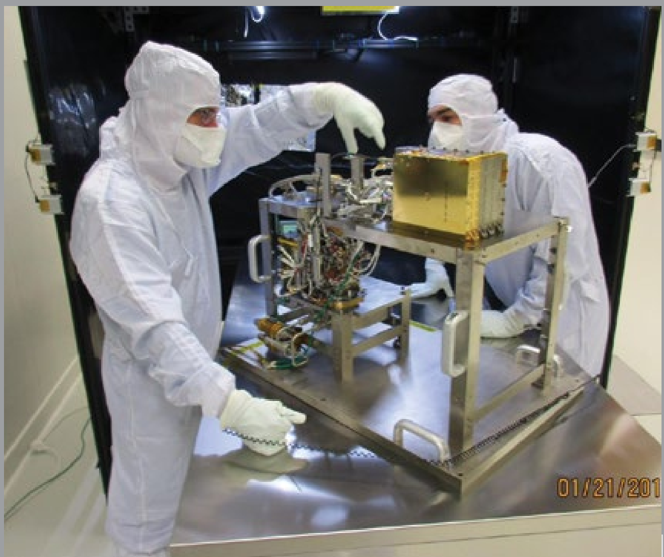
All elements of the ESA-provided cold-gas micropropulsion system were delivered by Selex-ES (now Finmeccanica) to CNES. The delivered hardware was integrated and tested on the spacecraft. The environmental test campaign of Microscope was completed giving the green light for the preparation of the Flight Acceptance Review.

## → EXOMARS

Implementation of the ESA/Roscosmos ExoMars programme is proceeding in line with the planned activities of the 2016 and 2018 (now 2020) missions respectively. The 2016 mission system-level AIT was completed, marking the end of the Phase-C/D activities and the start of the Phase-E1 activities with the shipment of the spacecraft to Baikonur in the third week of December. Negotiations for the implementation phase contract of the 2018 (now 2020) mission continued throughout the quarter with many industries joining the industrial team through Best Practices and final negotiations.

On the 2016 mission, the Qualification and Acceptance Review (QAR) Board was held on 19 November addressing a number of important issues to be cleared prior to shipment of the spacecraft to Baikonur. Issues related to the shipment were cleared and Phase-E1 began. The launch campaign in Baikonur started on 17 December with an advanced team of engineers and managers from ESA and industry participating in the Cosmodrome Readiness Review. The launch team worked through Christmas and New Year to assure the scheduled activities needed for launch on 14 March.

The 2020 mission Phase-C/D/E1 negotiations proceeded with success in achieving agreements up to the Rover lead contractor and the prime contractor. The latter two companies will continue the negotiations into the next quarter with a goal of completion by March. The Rover Analytical Laboratory Drawer (ALD) STM test programme has been completed, verifying the basic design of this complex unit housing three of the Pasteur Payload instruments. The ALD EQM is now under assembly with several of the mechanism units constructed and the EQM instrument units arriving at the integration facility in Thales Alenia Space Italy in preparation for the start of the EQM build in an ultra-clean environment. The facility will be used for the integration of the Sample Preparation and Distribution System (SPDS) QMs and the Pasteur Payload analytical instrument EQMs to prove the concept for the FM build.




ExoMars 2018 (now 2020) mission: MOMA instrument EQM in integration room before entering the ultraclean facility for integration into the ALD (Thales Alenia Space Italy)

## → SOLAR ORBITER

Open issues identified during the CDR are being closed. The CDR will be completed in June. The mechanical and thermal tests of the spacecraft STM have been completed. The spacecraft STM was shipped back to the prime contractor and is undergoing post-testing complementary checks.

On the spacecraft Engineering Test Bench (ETB), testing of several instrument and spacecraft unit EMs continues. The On-Board Computer Test Bench (OTB) has been upgraded and recommissioned as a second parallel ETB. This increases the robustness of the schedule for functional verification and preparations for functional testing at spacecraft FM level.

The supplier of the Solar Generator panel substrate has completed the Solar Orbiter QM panels and made good progress on FM panel substrate production, still scheduled for delivery by March. Back-up substrate manufacturer CASA produced the qualification panel. Assembly of Solar Orbiter Solar Cell Assemblies and several other solar array items at Airbus Defence & Space Ottobrunn and subcontractors has been completed; they await integration to the solar generator structure panels. Procurement of the reaction wheels, their wheel drive electronics and the corresponding Reaction Wheel Adaptation Box are progressing. All relevant platform units (except for the reaction wheels) and most instrument units have been EMC-characterised. Mitigations are under study for the identified non-conformances. Further EMC tests are still coming for the new reaction wheels and a couple of instruments.

Regarding particulate contamination, solutions have been identified for most instruments. Further analyses with refined models have been carried out and show results that are converging to satisfactory levels for the remainder of the payload complement. As a further input to the analysis, a specific particle migration test was completed on the STM Heat Shield. Regarding molecular contamination, the model has been updated and the analysis runs are ongoing. Regarding contamination from the thruster plumes, spacecraft design modifications are being implemented to protect the instruments. For most of the instrument sensors affected, protective shielding and baffling can be applied and design concepts have been established, detailed design is ongoing.

The last instrument CDR (METIS) has been initiated and is scheduled to be completed in March. Instrument schedules are closely monitored. The spacecraft schedule was rearranged to cope with a couple of small instrument delays by making use of the fact that the integration sequence of the ten instruments is planned within a period of about two and half months. The delivery dates of all ten instruments are compatible with the spacecraft needs. A number of instruments schedules, however, remain critical.

The Mission Operations Centre and Science Operations Centre developments are progressing. Science activities proceed normally. Joint observation sequences for the mission's top-level Science Activity Plan are under definition with all ten instruments, to address the first of four top-level science objectives of Solar Orbiter, "What drives the solar wind and where does the heliospheric magnetic field originate?" A real-time planning exercise was carried out as part of the recent Science Operations Working Group meeting, which for the first time tested the science operations approach of this complex deep-space mission.

Interface work with NASA and United Launch Alliance for the Atlas V-411 launch vehicle is progressing. An updated consolidated Master Schedule has been established and is compatible with a launch in October 2018 with an ESA contingency of 2.6 months, on top of separate margins on the unit deliveries to spacecraft integration. The Solar Generator and the reaction wheel assemblies remain the most critical schedule items for the spacecraft platform and, along with instruments, for the mission.

## → JAMES WEBB SPACE TELESCOPE (JWST)

The overall programme continues to progress according to the plan established in 2011 with a planned launch date in October 2018. The final and third Integrated Science Instrument Module (ISIM) cryo verification test at NASA Goddard Spaceflight Center has been completed.

The Telescope pathfinder completed its second cryo-test at the NASA Johnson Space Center. The objective of this test was primarily to the test the set up and planning for the final flight ISIM plus Telescope cryogenic test.

Integration of all the 18 primary mirror segments to the telescope structure has been completed. Next major step is the integration of the ISIM and Telescope followed by its environmental test campaign. The MIRI FM Cryo Cooler Assembly cryo-performance test after the vibration test confirmed the required performance. The contract for the provision of the launch service on an Ariane 5 ECA has been signed.

## → EUCLID

The project is now in Phase-C/D. The prime contractor Thales Alenia Space Italy completed the PDR in July 2015, and the main subsystems have all undergone their PDRs. In parallel, the unit procurement continued and the process is completed. Thales Alenia Space Italy and its subcontractors are proceeding with the design consolidation, implementing the PDR outcomes and integrating into their design the newly procured units.

A delay occurred in the Visible Imager (VIS) instrument progress. CDRs at instrument subsystem level started at the end of 2015, as planned, but the full sequence will last longer than expected. EM and STM manufacturing is completed and testing of many subsystems has started. The VIS instrument CDR will be held in mid-2016.

Integration of the last JWST primary mirror segment (NASA/C. Gunn)

The contract with e2v for the development, qualification and FM production of the (ESA-procured) CCD detectors is proceeding. The qualification phase was completed with the delivery of all EM and STMs. FM production has started. The Near Infrared Spectro-Photometer (NISP) instrument PDR is complete, subsystem-level PDRs are continuing with preparation for the subsystem CDRs that started in 2015. The instrument CDR is now expected in late 2016. Procurement of the detectors reached an important milestone with the completion of the qualification phase last year. The flight production phase, under NASA responsibility, started in parallel and the first three flight detector elements have been manufactured and tested, showing excellent performance.

Following the Euclid Science ground segment SRR, the schedule for both science and operations ground is continuing to plan. The operational ground segment at ESOC is preparing the documentation for the GSRqR (Requirements Review) that will take place later in 2016. Launch is planned for December 2020 on a Soyuz-Fregat from Kourou.

## → JUICE

Procurement activities to build up the industrial consortium are according to plan. The preparation of a new test campaign to better characterise the end-of-life performances of the solar cells started. The pre-qualification test of the Airbus S400 main engine continued smoothly, with the objective to confirm the capability to sustain the number of on/off cycles required for JUICE. More than half of the required cycles were done by the end of the year with no noticeable change of the engine performances.

A lot of emphasis was placed in the discussion of system topics where the involvement of the instruments is of paramount importance, for example, electromagnetic compatibility, contamination control and software. The fourth major area of work was, and still is, the power availability and the associated timeline of the instruments at the Europa flyby and Ganymede final circular orbit.

The kick-off of the Mission and System Requirement Review (MSRR) took place in December. A deep review of the schedules of all ten JUICE instruments started. The objective is to assess the declared delays and initiate corrective actions.

## → CHEOPS

The prime contractor, Airbus Defence & Space Spain, completed the mechanical test campaign conducted on the satellite STM (the instrument STM and the platform QM). The campaign included quasi-static, sine and acoustic vibration tests and was concluded by a clamp-band separation test. The post-test analysis confirmed the compatibility of the measured load levels with the structural design. Refurbishment of the platform QM into the flight structure started in January. The EFM tests are being implemented. Procurement of the platform equipment is progressing, with the delivery of the S-band antennas and the AOCS units.

The instrument CDR was completed in January. The instrument progress was satisfactory, except for the Focal Plane Module for which the review board required a dedicated closeout report and project monitoring. The consortium, led by the University of Bern, will be delivering the instrument EM to the spacecraft prime contractor. Environmental testing of the Baffle Cover Assembly FM is nearing completion.

The ground segment CDR was completed in January and the first SVTis planned for February. The System CDR is planned for later this year, and the target remains to have the spacecraft ready for launch by the end of 2017, enabling CHEOPS to be a passenger with another spacecraft in 2018. ESA has started procurement activities for the launcher selection.

## → AEOLUS

It was confirmed that Aeolus will be able to fly in a lower orbit, enabled by the low solar activity in the period 2017–21, The new orbit will provide higher signal-to-noise ratio for the laser-scatter receive spectrometers and thereby improved wind measurement accuracies.

The Aladin instrument is verified for adequate leak tightness, the emission path has been confirmed robust to the laser fluence and gravity release, and the instrument EMC test is ongoing. The final instrument functional and performance test is about to start. Delivery of the fully tested Aladin PLM is planned for April.

The satellite platform has been completed and final functional and operational tests are running. An SVT will be conducted with the satellite from the Flight Operations Segment in ESOC in advance of the platform mating with the Aladin PLM. The Vega launch service contract with Arianespace is being finalised.

## → EARTHCARE

Production of all ATLID PFM units and subsystems is well advanced at Airbus Defence & Space (France) and at their sub-contractors premises. A major project milestone was achieved with the continuous operation of the ATLID PFM laser transmitter with stable ultraviolet performance during the first part of its qualification campaign.

The satellite EFM PFM activity progressed with the integration of the ATLID instrument control unit and electrical integration of the EQM Mass Memory and Formatting Unit, delivered recently by SYDERAL (CH), is now proceeding.

The Test Readiness Review of the Multi-Spectral Imager (MSI) Thermal Infrared Camera is on going at SSTL (UK). In parallel, the MSI Visible, Near Infrared and Short Wave infrared PFM camera is undergoing a refurbishment to overcome a spectral response anomaly discovered during its calibration campaign.

In Japan, the Cloud Profiling Radar operational and test procedures development is taking place. In parallel, JAXA and their prime contractor NEC are running refined tests of the RF sub-system in advance of the PFM final integration.

## → BIOMASS

Contract negotiations are currently being held with the winning consortium. Following their completion, the industrial prime contractor will be announced at the contract signature in early 2016.

## → METEOSAT SECOND GENERATION

### MSG-4

After launch in July 2015, commissioning by Eumetsat confirmed system operational readiness in December. The satellite was placed in on-orbit storage mode for an expected period of 2.5 years. It will ultimately bridge the gap between Meteosat-10 and the first Meteosat Third Generation satellites.

## → METEOSAT THIRD GENERATION

Integration activities of the platform STM began at OHB at the end of 2015. The initial assembly activities should be completed by end of February to allow delivery to Airbus (Lampoldshausen) for the integration of the STM propulsion subsystem.

The preparations for the integration activities of the platform EM are under way with the formal Integration Readiness Review now scheduled for April. In parallel, activities on the Platform Avionics Verification Model (AVM) are progressing

The instrument PDR for the Lightning Imager was completed in October 2015. Initial analyses, utilising reference scenes defined by ESA, show performances well in line with expectations. A particular challenge that has appeared during last period relates to the LI detector performance, where quantum efficiencies are significantly lower than those previously demonstrated during pre-development activities. For the PFM satellites schedules, a detailed reassessment in industry, taking into account the revised instrument development logic, and reinstating the logical development links, resulted in predicted FAR dates in 2020 and 2021 for MTG-I and MTG-S respectively. Based on the current health of the MSG satellites in orbit, which includes the last (fourth) MSG satellite is now in on-orbit storage, these dates remain consistent with Eumetsat needs.

## → METOP

### MetOp-A

The satellite is will be operated in parallel with MetOp-B until the successful commissioning of MetOp-C.

### MetOp-B

Launched in September 2012, MetOp-B is Eumetsat's primary operational polar-orbiting satellite.

### MetOp-C

The satellite is in storage and following the latest annual reactivation is confirmed to be in good health. Launch, on a Soyuz from French Guiana, is planned for October 2018.

## → METOP SECOND GENERATION

MetOp-SG consists of two series of satellites (Satellite A and Satellite B) embarking a total of ten different instruments, which will provide the operational meteorological observations from polar orbit from 2021 to the mid-2040s.

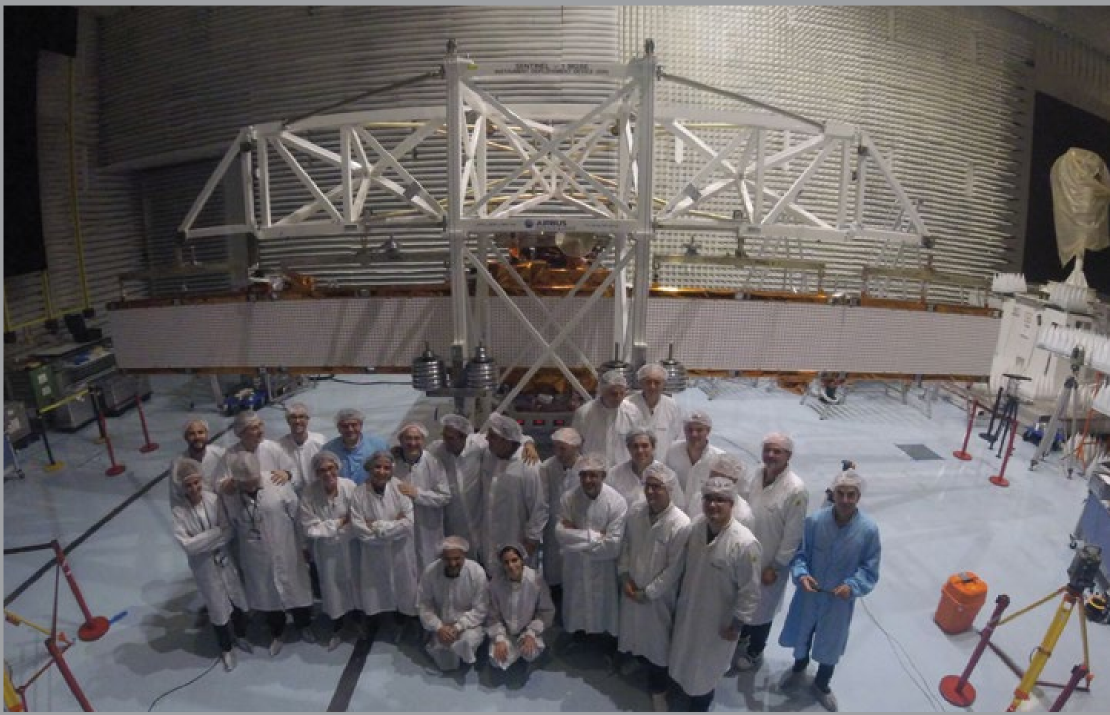
The PDR (for both Satellite A and Satellite B as well as the six instruments procured under the MetOp-SG contracts) was completed in November and the project is now in Phase-C/D.

## → COPERNICUS

### Sentinel-1

A total of 15 243 users have registered at the Sentinels Scientific Data Hub (**scihub.esa.int**), and more than 343 000 Sentinel-1A products are available online which resulted in 2 761 369 downloads in the last 14 months, corresponding to more than 3.3 petabytes.

Sentinel-1A remains very stable using all of its prime units, running in preprogrammed operational mode that ensures the continuous production of consistent long-term data series. Its identical sister, Sentinel-1B, has meanwhile completed its environmental tests and is going through the



Sentinel-1B with Synthetic Aperture Radar deployed with the Thales Alenia Space and Airbus GmbH teams

final stages of its preparation for the launch campaign in the facilities of Thales Alenia Space in Cannes. Sentinel-1B will be launched in 2016 on a Soyuz rocket from Kourou.

The contract for procuring the next Sentinel-1C and -1D spacecraft, that guarantee the continuation of the Sentinel-1 mission through the next decade, began in December with the same industrial team that developed Sentinel-1A and -1B, in particular with Thales Alenia Space Italy as prime contractor and Airbus Defence & Space responsible for the Synthetic Aperture Radar system.

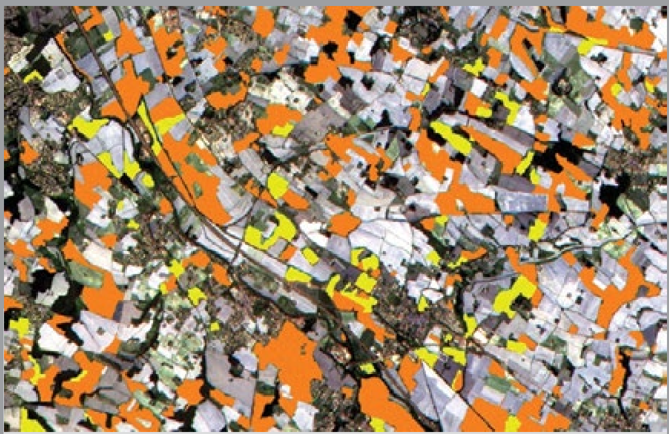
### Sentinel-2

Sentinel-2A underwent its in-orbit commissioning review in October 2015, and responsibility for the spacecraft was formally transferred to the mission manager. The spacecraft now delivers outstanding optical performance. It is currently undergoing a ramp-up to routine operations phase that should start in July.

Instrument multispectral data that are being acquired by X-band ground stations located in Matera, Svalbard and Maspalomas are processed 'on the fly' to Level-1C. These products are already reliably available to users via the Copernicus science data hub. During the ramp-up phase, Sentinel-2A is acquiring Europe and Africa systematically, while the rest of the world landmasses are mapped with a 30-day revisit time. Level-1C products are systematically archived, and users are now downloading 7 Tbytes daily. The unique spatial, spectral and revisit capabilities of Sentinel-2 coupled to excellent radiometric and geometric performance also motivated several pilot acquisitions of coastal and marine environment, and attempts to image Antarctica.

The second spacecraft FM is being integrated and will be shipped to ESTEC in April to undergo its environmental test campaign. The Sentinel-2B FAR is scheduled for a launch in November. Launch preparation activities with Eurockot and Khrunichev resumed in December 2015.

The Sentinel-2C and -2D spacecraft procurement contract began in December 2015 with Airbus Defence & Space to guarantee the continuation of the Sentinel-2 mission through the next two decades.



Sentinel-2 is the first optical Earth observation mission of its kind to include three bands in the 'red edge', which provide key information on the state of vegetation. In this image acquired near Toulouse, France, the satellite's multispectral instrument was able to discriminate between two types of crops: sunflower (orange) and maize (yellow)

### Sentinel-3

The Sentinel-3A satellite AIT campaign was completed in October. The final version of the onboard software was uploaded and the last SVT with the Flight Operation System performed at ESOC and Eumetsat. In parallel the Sentinel-3 Qualification and Acceptance Review) took place, starting the launch campaign. The Sentinel-3A satellite arrived at the Cosmodrome of Plesetsk at the end of November 2015, allowing the start of the launch campaign.

All satellite standalone activities, aimed to confirm the good health of the satellite before mating the launcher, were completed in December. After a break through the Christmas and New Year celebrations, the activities will restart in January with the fuelling of the satellite and the launcher upper stage, followed by 11 days of combined activities that led to a satellite launch foreseen for mid February.

Concerning the Sentinel-3B model, the SLSTR PFM refurbishment is continuing, as well some testing of the OLCI camera's to verify their final flightworthiness before proceeding with the instrument final assembly.

The Sentinel-3C and Sentinel-3D spacecraft procurement contract started in December 2015 with Thales Alenia Space to guarantee the continuation of the Sentinel-3 Mission through the next two decades.

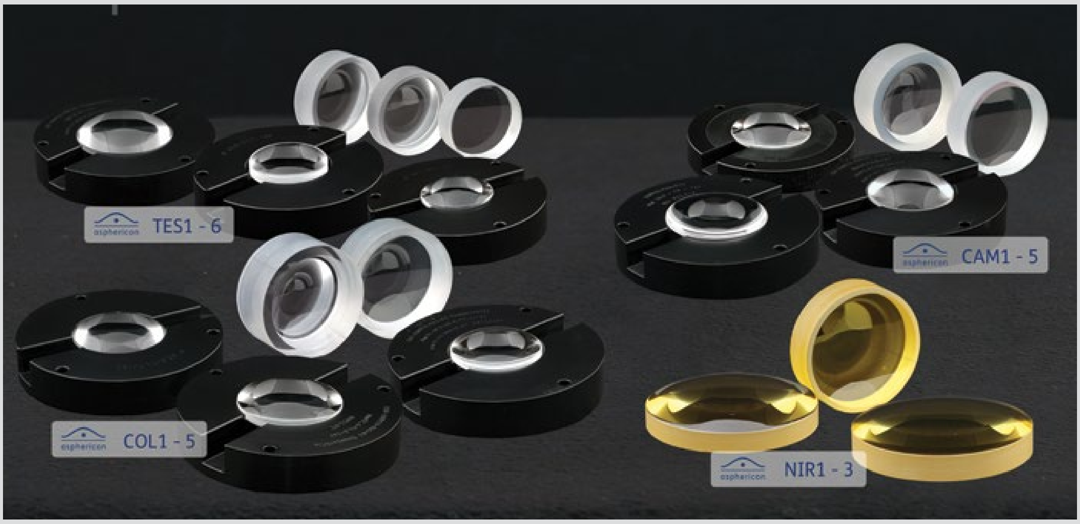
Sentinel-3A, the third ESA-developed satellite for Europe's Copernicus environmental monitoring programme, lifted off on a Rockot launcher from Plesetsk, Russia, on 16 February

Sentinel-3A inspection at Plesetsk Cosmodrome after transport

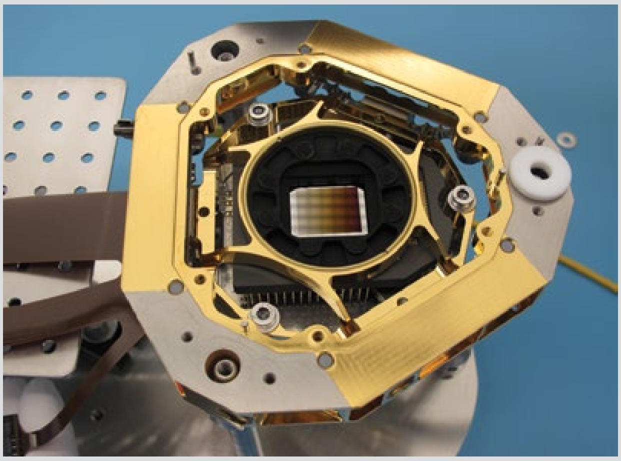
### Sentinel-4

Manufacturing of the STM is progressing as planned. The integration of the Nadir Baffle is almost complete. Manufacturing, polishing and optical coating of the set of 19 lenses for the PFM optical train is progressing. Integration of the Focal Plane Assembly with the detector assembly and its interconnecting flex harness has been completed. Manufacturing and testing of several EQM subsystems continues and electrical tests on the Instrument Control Unit will be completed in January.

Structural Thermal Model of Sentinel-4 Nadir Baffle [Invent/OHB)




Subset of Sentinel-4 Protoflight Model lenses in fused silica, calcium fluoride and LAK9 (Asphericon/JOP)



Qualification Model of the Focal Plane Assembly with its detector Engineering Model and flex harness (Airbus Defence & Space)

**Sentinel-5**
The setup of the industrial consortium is complete. All spectrometers, electronics and calibration unit sub-contractors have started work. Procurement of the various ground support equipment's and test facilities is almost completed.

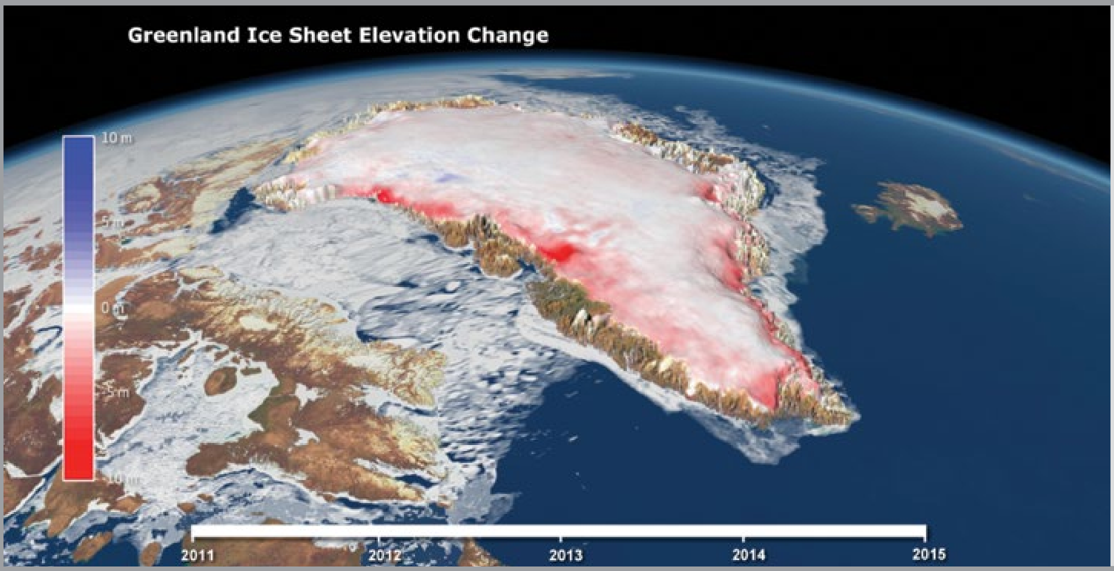
Performance measurements on a new diffusor material (intended to be used in the calibration assembly) confirm the lower spectral features compared to previous designs. The material has undergone environmental tests. The degradation caused by ultraviolet and gamma radiation could be alleviated through a specific treatment of the material.

In PDR preparation, the instrument's optical assembly structure was optimised. To tackle some remaining technology risks, a Design Validation Sample was created. All thermo-mechanical tests on this unit, which is about half the size of the instrument structure's base-plate, were concluded and confirmed the robustness of the design. The system PDR concluded all review objectives achieved.

**Sentinel-5 Precursor**
The satellite AIT programme had to be rearranged because of a delay in satellite/launcher compatibility testing. Following thermal vacuum/balance testing at Intespace in Toulouse in August and sine vibration/acoustic testing in September, a full electrical checkout of the satellite was performed in November after which mass properties and solar array Deployment took place in December. For the ground segment, system validation tests are complete. A ground segment acceptance review is planned for January to March 2016. A satellite/launcher fit-check and separation/shock test planned for the Rockot launcher in October 2015 was rescheduled for February. A second solar array deployment test will then follow. A launch window of June to July was confirmed by the launcher authority. On completion of the satellite test programme, a Qualification Acceptance Review was scheduled for March to April.

## → SMOS

Following a joint mission extension review with CNES (operating the platform), mission operations have been extended to the end of 2017. All brightness temperature, soil moisture and ocean salinity data are available to the science community since 2010. New products, such as sea-ice thickness and soil moisture data in near-real time based on a neural network approach, have been included in the SMOS data catalogue. A second reprocessing of the entire SMOS data set is completed and all reprocessed data are available. The summary and recommendations for the Second SMOS science conference, which took place in May 2015 at ESAC, are available on **http://www.smos2015.info/www.smos2015.info**




Greenland ice sheet elevation change, 2011–15 (ESA/CPOM – PlanetaryVision)

## → CRYOSAT

The mission continues to operate flawlessly, acquiring and generating science data systematically to measure the variation of sea-ice mass floating in the Arctic and trend of land ice volume over Greenland and Antarctica. The onboard startracker software was upgraded to improve robustness and performance, and to account for the natural degradation of the CCDs. The validation of this critical software will continue throughout winter and will be declared operational around Easter.

The mission also continues to provide valuable data to a handful of non-cryospheric domains; in particular, ocean, marine gravity and hydrology. The latest scientific results and status of the mission will be presented at the Fourth Cryosat User Workshop in Prague in May as part of ESA's Earth Observation Living Planet Symposium **http://lps16.esa.int**

## → SWARM

Supported by the continued excellent quality science data from the three-satellite constellation, the mission exploitation continues. Scientific data 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. Second-generation comprehensive and dedicated field models in all areas will be ready in spring 2016.

Swarm has also demonstrated the capability of the constellation approach to the disentangling and separation of complex and dynamic contributors to the total magnetic and electric field measurements. Furthermore, what is emerging (as new fields of science) is the mission's unique potential to unravel the mysteries of coupling in 'geospace'. Swarm highlights coupling between the troposphere and the ionosphere, for example, which makes plausible links between traditional weather and weather in space. Likewise, the mission is contributing to studies of the coupling between the ionosphere and the magnetosphere.

The flight operations and constellation maintenance activities are proceeding, keeping in particular the lower pair at optimum operation for measurement of magnetic field gradients. Likewise, in terms of external fields and geospace measurements, Swarm instruments continue to demonstrate their feasibility to detect current systems and ionospheric features, thereby also underlining the high quality of the mission data. This holds for both elements of the electric field instrument, the Langmuir probe and the thermal ion imager.

## → EDRS

The launch of EDRS-A on board Eutelsat 9B took place on 29 January. After separation from the Proton's Breeze-M upper stage some nine hours after liftoff, platform commissioning activities commenced and have been completed. Following a number of apogee boost burns, the satellite reached its in-orbit test location at 2 degrees East, where the EDRS-A payload commissioning activities began. The first tests of the laser-optical link with Sentinel-1A and -2A are planned for April, after the transfer to the satellite's final orbital location at 9 degrees East. This will be followed by the start of the commercial EDRS service in summer.

The EDRS-C mission CDR is planned for the second half of 2016 and will ensure the consistency of the satellite with the ground segment, thereby verifying the overall performance of the EDRS-C mission. Integration of flight hardware is now progressing at several sites in parallel. Integration of the Core Platform Module is ongoing at OHB in Bremen (DE).

EDRS-A launched with Eutelsat 9B on 29 January on a Proton rocket with a Breeze-M upper stage (ILS)

Assembly of the Propulsion Module is taking place at Avio (IT). The EDRS-C payload is being integrated on its dedicated repeater panel by payload prime contractor TESAT (DE). The hosted Hylas-3 payload from Avanti has been assembled on its dedicated repeater panel at its supplier MDA (CA) and was shipped to OHB in January.

## → SMALLGEO/AG1

The spacecraft went through sine vibration tests in December, followed by acoustic tests in January, at IABG in Germany. No anomalies were found and test results confirm that SmallGEO/AG1 met its qualification targets for an Ariane 5 launch. The industrial team led by OHB System are preparing for thermal vacuum test, planned for March. In parallel, the ground segment activities are also progressing with the start of the Test Acceptance Review for the LEOP/In-orbit Test activities.

## → ELECTRA

On 10 February, the Phase-B2/C/D/E1 contract was signed with SES. SES and OHB System signed their contract for the realisation of what will be the first full electrical propulsion satellite built by OHB System. The first 15 months of the project will be dedicated to platform accommodation design. Then two phases related to platform and mission development over four years will lead to a launch planned in 2021.

## → QUANTUM

The equipment qualification status reviews for this pioneering software-programmable satellite have finished, and payload design started. Quantum is an innovative, generic payload that can be retasked in orbit. The first one, developed under a partnership between ESA, Eutelsat and Airbus Defence & Space, will be launched at the end of 2018.

## → ARIANE 6

Industrial activities are ongoing with the implementation of the Industrial Procurement Plan. The evaluation of proposal following the ITT for the Inertial Measurement Unit Avionics is completed, while the ITTs for Cutting Cords, Pyro Firing Unit and Multi-Channel Acquisition Unit were released in December. A key point within the third Design Analysis Cycle took place in December, freezing elements for the Launcher System PDR.

### P120C and synergy with Vega

The Nozzle PDR and the Insulated Motor Case PDR were held in December. The Loaded Motor Case PDR was held in February. The ITT for the P120C igniter was released in January.

The industrial proposal on the new booster case technology demonstration was received in March and is under evaluation. The BEAP adaptations PDR was held in December.

### Launch base

The Infrastructure and Control Bench Family PDRs took place in December and January. Sub-system contractual activities (civil work, mechanical activities, low current and safety and control benches) were initiated in February. Earthwork activities are ongoing with all the site zones and roads modelled and the first anti-capillary layer installed.

### System architect activities

The Launch System SRR began in February. For P5.2 test bench activities, an updated proposal was evaluated in December. The contract proposal is ready to be submitted to the ESA's Industrial Policy Committee. Studies are ongoing on the operational launcher integration building (BAL) and Mobile Gantry optimisation.

## → VEGA EVOLUTION AND VEGA C

The Vega C Launch System SRR was completed and the Launcher System PDR was completed in March. Also Vega E Working Group activities are ongoing. The enlarged fairing concept design phase was concluded and the enlarged fairing was introduced into the Vega C baseline configuration.

## → LAUNCHERS EVOLUTION PREPARATION PROGRAMMES

In system studies for Evolution of Launcher Technology, several Requests for Quotations are in preparation: Future Liquid Propulsion and Future Launcher Systems, and Microlauncher Phase-0/A. In propulsion, the Post Test Review for the hot-fire test of the full-scale 3D printed injection performed in December. The contract for rider 1 of the Expander Technology Integrated Demonstrator-1 was finalised. The Test Readiness Review for the Booster Attachment Demonstrator was performed for the test campaign to begin.

## → PRIDE

The high-level mission requirements were completed with the involvement of several representatives of the states participating in the programme. These requirements were: a Reusable Integrated Space Transportation System to be launched on a Vega C, with a payload mass capability higher than 300 kg for a multitude of orbits altitudes and inclinations (including the International Space Station), to be able to operate in orbit, deorbit, reenter, land on the ground and be relaunched after limited refurbishment. Industrial activities will begin by spring 2016 and the industrial proposal is currently under evaluation.

## → HUMAN SPACEFLIGHT

### ISS

ESA astronaut Tim Peake (GB) was launched on his long-duration Principia mission from the Baikonur Cosmodrome in Kazakhstan on Soyuz TMA-19M on 15 December, together with fellow Expedition 46/47 crew members Yuri Malenchenko (Roscosmos) and Tim Kopra (NASA). As part of his mission, Tim will be undertaking a full spectrum of ESA research activities covering the life and physical sciences, technology and education. He will be the subject of human research experiments as well as assisting ISS partner agencies with their research programmes. The three new crew members replace Oleg Kononenko (Roscosmos), Kimiya Yui (JAXA) and Kjell Lindgren (NASA) who undocked from the

ESA astronaut Tim Peake ready to board the Soyuz TMA-19M spacecraft on 15 December 2015, with Tim Kopra and Yuri Malenchenko

Soyuz TMA-19M carries Expedition 46 crew members Yuri Malenchenko, Tim Kopra and ESA's Tim Peake into space on 15 December 2015 (J. Kowsky/NASA)

ISS on 11 December. This undocking marked the transition from Expedition 45 to Expedition 46 with NASA astronaut Scott Kelly remaining as ISS Commander. The six-member ISS crew also includes Roscosmos cosmonauts Mikhail Kornienko and Sergei Volkov.

On 15 January, Peake and Kopra performed a 4-hour 43-minute spacewalk to replace a failed power regulator and install cabling. The meticulously planned and executed sortie was stopped early after Kopra reported a small amount of water building up in his helmet.  When their main task was completed, they were instructed by Mission Control to return to the airlock earlier than planned.

Between October and December 2015, two Russian Progress spacecraft docked with the ISS. Orbital ATK launched a Cygnus spacecraft to the ISS in December, it fourth commercial flight. Progress 62P was the first flight of the new Progress MS spacecraft (MS-1) which includes upgraded navigation systems, communications and electronics from previous Progress vehicles. Three spacewalks were undertaken in the last quarter of 2015 with work including preparations for installation of docking adapters for future US crew vehicles, returning ammonia coolant levels to normal in the primary and backup radiator, arrays and troubleshooting on the starboard Crew Equipment Translation Aid (CETA) cart and Mobile Transporter (MT) on the ISS truss.

### Astronauts

Thomas Pesquet (FR) and Paolo Nespoli (IT) continued their assigned crew training in preparation for their launches scheduled for November 2016 and May 2017, respectively. Andreas Mogensen (DK) and Samantha Cristoforetti (IT) continued post-flight duties.

On 12 November, Thomas Pesquet revealed the mission name and the logo for his six-month mission to the ISS starting in November 2016. The name Proxima was chosen from over 1300 entries to ESA's competition. The winning entry was provided by 13 year-old Samuel Planas from Toulouse, with the following explanation: "Proxima is the closest star to our Sun and is the most logical first destination for a voyage beyond our Solar System, and also refers to how human spaceflight is close to people on Earth."

Tim Peake seen during his 4-hour 43-minute spacewalk with Tim Kopra on 15 January to replace a failed power regulator and install cabling outside the Space Station (NASA)


Thomas Pesquet reveals his mission name and the logo in November 2015

# → RESEARCH

## European research on the ISS

In addition to the Principia mission, the European ISS utilisation programme has been continuing with the assistance of the Expedition 45/46 crew in orbit. Highlights of the three months until 31 December 2015 are:

### Human research

Tim Peake became a new test subject for ESA's Circadian Rhythms, Skin-B and Space Headaches experiments following his arrival on the ISS in December. Two additional test subjects also concluded their on-orbit participation in Space Headaches prior to their return from the ISS.

The Circadian Rhythms experiment is studying alterations in circadian rhythms in humans during long-duration spaceflight to provide insights into the adaptation of the human nervous system in space over time.

The Skin-B experiment helps 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. Space Headaches is looking into headache incidence/characteristics during (long-duration) spaceflight.

Additional sessions of two ESA experiments (with Russian cooperation), Immuno-2 and EDOS-2, were also performed in the Russian segment of the ISS. EDOS-2 continues the research from the Early Detection of Osteoporosis in Space (EDOS) experiment, though with inflight sampling, in determining post reentry bone loss and long-term

## ERA

The launch date at the end of 2017 was reconfirmed by Roscosmos and also industry is working towards that date. A new formal schedule for the Multi-purpose Laboratory Module (MLM), on which ERA will be launched, will not be provided before early 2016 because it awaits approval in the Russian federal budget.

## Exploitation

ESA's Hexapod, accommodating NASA's Stratospheric Aerosol and Gases Experiment III (SAGE III) was transferred to the Kennedy Space Center waiting for launch on SpaceX CRS-10 in June.

recovery from spaceflight-induced bone loss. Immuno-2 is an integrative study protocol to provide a more holistic approach to increase the knowledge of the complex physiological adaptation of humans during long-term space missions. The research follows up the positive research from the first Immuno experiment.

### Materials research

Processing of the second set of samples in the Electromagnetic Levitator (EML) in Columbus started in the second half of November. This second set covers two alloy samples: a zirconium-based bulk metallic glass alloy (Vit106a) and an iron/cobalt alloy (FeCo) with one about 100 sample thermal cycles planned over a period of weeks. The EML is performing containerless materials processing involving melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and/or high gas purity conditions.

### Complex plasma research

The first science campaign was completed with the Plasma Kristall-4 (PK-4) facility installed inside the European Physiology Modules. PK-4 is investigating complex or dusty plasmas. These are plasmas (ionised gases) that contain micro-particles, for example dust grains, besides electrons, ions, and neutral gas. The main interest lies in the investigation of the fluid phase and flow phenomena of complex plasmas for which PK-4 is especially suited thanks to a DC-discharge and its geometry (elongated glass tube with a large observational access).

### Radiation monitoring

The Dose Distribution inside the ISS 3D (DOSIS-3D) experiment undertook continuous data acquisition of the radiation environment inside Columbus including one week in a special monitoring mode in November. This special mode measured the direction of the individual incoming charged particles as well as their energy, and also helped to acquire more data for the evaluation of the influence of the geomagnetic field on the average quality factor (or dose) of the Galactic Cosmic Rays radiation field. In the usual monitoring mode, data is averaged over one orbit. The set of 11 passive radiation dosimeter packages was also swapped in December with the old set returned to Earth for analysis.

←←

ESA astronaut Tim Peake seen during his first blood draw in space in February, taken as part of the Canadian MARROW investigation (NASA/ESA)

←

Tim Peake takes part the Airway Monitoring experiment in the US airlock, an ESA study using an ultra-sensitive gas analyser looking for miniscule dust particles or other organic materials in exhaled breath (NASA/ESA)

### Additional research

Solar research continued within the SOLAR facility that completed three data acquisition periods in October, November and December. The Vessel ID System continued monitoring of global maritime traffic and the Expose-R2 payload continued astrobiology research that could help understand how life originated on Earth and survivability of samples in conditions on for example, Mars, the Moon or other astrophysical environments.

### Non-ISS research in ELIPS

MASER-13 was launched on 1 December 2015 following a few weeks delay because of bad weather conditions. The flight included four modules covering two materials experiments (CETSOL-MEDI, XRMON-SOL) concerning solidification studies, one fluids experiment (CHYPIE-MARCH) and two biology experiments (GRAMAT and SPARC, sharing one module) focusing on root growth mechanisms of *Arabidopsis thaliana* including gravity-related gene expression and relocalisation of auxin-transporting cells in weightlessness.

The 63rd ESA Parabolic Flight Campaign was performed with 10 experiments (four physical sciences/six life sciences) in November 2015. The list of experiments for the 64th campaign is finalised. This campaign was shifted from February to April to add new experiments to the list.

A 60-day bedrest study was completed at DLR in December with 12 volunteers. The study evaluated the effectiveness of a reactive jump countermeasure to protect from the negative effects of muscle disuse experienced by astronauts as well as bed-ridden patients. The second campaign of the study started in January.

The two latest Antarctic winter-over seasons (Concordia and the British Antarctic Survey's Halley Station) concluded in November with five ESA experiments undertaken at Concordia and two ESA experiments at Halley.

A Drop Your Thesis! educational campaign was undertaken in November. The Dropping Drops experiment studied the penetration of a liquid droplet into a porous surface in its short inertial phase.


A volunteer in the second campaign of a 60-day bedrest study being held at the German Aerospace Center DLR's ':envihab' facility in Cologne, Germany (DLR)

## → EXPLORATION

### Multi-Purpose Crew Vehicle/European Service Module (MPCV/ESM)

The integration of the Structural Test Article (E-STA) was completed. The E-STA was shipped from Turin and arrived at the NASA Plum Brook facility on 9 November. The system CDR was postponed to April with a board review in June. NASA is reassessing the FM2 delivery date, and potential design changes to be implemented in ESM2.

The FM1 structure delivery to Bremen was delayed by two months to March.

### International Berthing Docking Mechanism (IBDM)

On 14 January, NASA announced the names of the companies selected for the ISS Cargo Resupply Service-2 (CRS-2) contract. From the original five bidders, NASA kept only three: Orbital ATK, Space-X and Sierra Nevada Corporation (SNC). The SNC bid includes the European IBDM. The proposal for a temporary Element 5 in the General Support Technology Programme, complementing the ETHEPA programme in supporting the Dream Chaser cooperation, was approved by the interested countries at the end of January. An industrial proposal for completion of the IBDM development and its first flight on the SNC Dream Chaser vehicle is under preparation by the European industrial consortium.

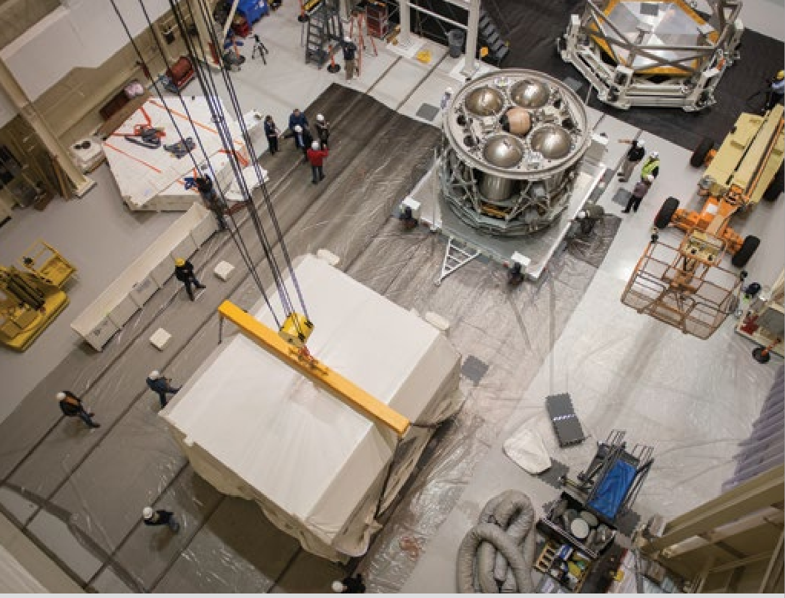
### Multi-Purpose End-To-End Robotic Operation Network (METERON)

Various sessions of the Haptics-1 investigation took place as part of a suite of Exoskeleton experiments to demonstrate full bilateral control interaction between ground and space. Haptics-1 is part of ESA's METERON project which aims to demonstrate communications and operations concepts and technologies for future human exploration missions with human robotic elements.

### Lunar Exploration

The PILOT and PROSPECT Phase-B proposals were evaluated and negotiations started in December with selected bidders.


ESA's European Service Module Structural Test Article here being unpacked after transport to NASA Glenn's Plum Brook facility in November for testing in the Space Power Facility in 2016 (NASA)



Overhead view of the ESM Structural Test Article at NASA Glenn's Plum Brook facility where it will undergo crucial tests to verify its structural integrity for the dynamic environment of launch (NASA)

The ESM Structural Test Article being prepard for acoustic and vibration testing at NASA Glenn's Plum Brook facility, Sandusky, Ohio (NASA)

The hardware from PROSPECT Phase-A, specifically the drill prototype, is under integration and testing. The design of the Landing Processing Unit, Camera and LIDAR has been advanced during PILOT Phase-A, supported by hardware and software prototyping and testing.

### International Exploration Framework

In December, ESA organised the Moon Symposium 2020–30 at ESTEC with more than 250 participants of 25 different nationalities.

## → SPACE SITUATIONAL AWARENESS

### Space Weather (SWE)

The Mission Architecture Reviews for both SSA SWE mission concept studies for the dedicated space weather missions to the first and fifth Lagrange point were started in December 2015. The 12th European Space Weather Week was held in November in Ostend, Belgium.

### Near Earth Objects (NEO)

Observations using ESA's 1-m telescope on Tenerife, the Very Large Telescope of ESO, and with other collaborating partners continued. The NEO information plan describing how ESA would distribute information on a potential imminent asteroid threat was presented to the Programme Board. An updated version of the web portal was released. A consolidated architecture for the NEO segment was presented to the Programme Board in December.

### Space Surveillance & Tracking (SST)

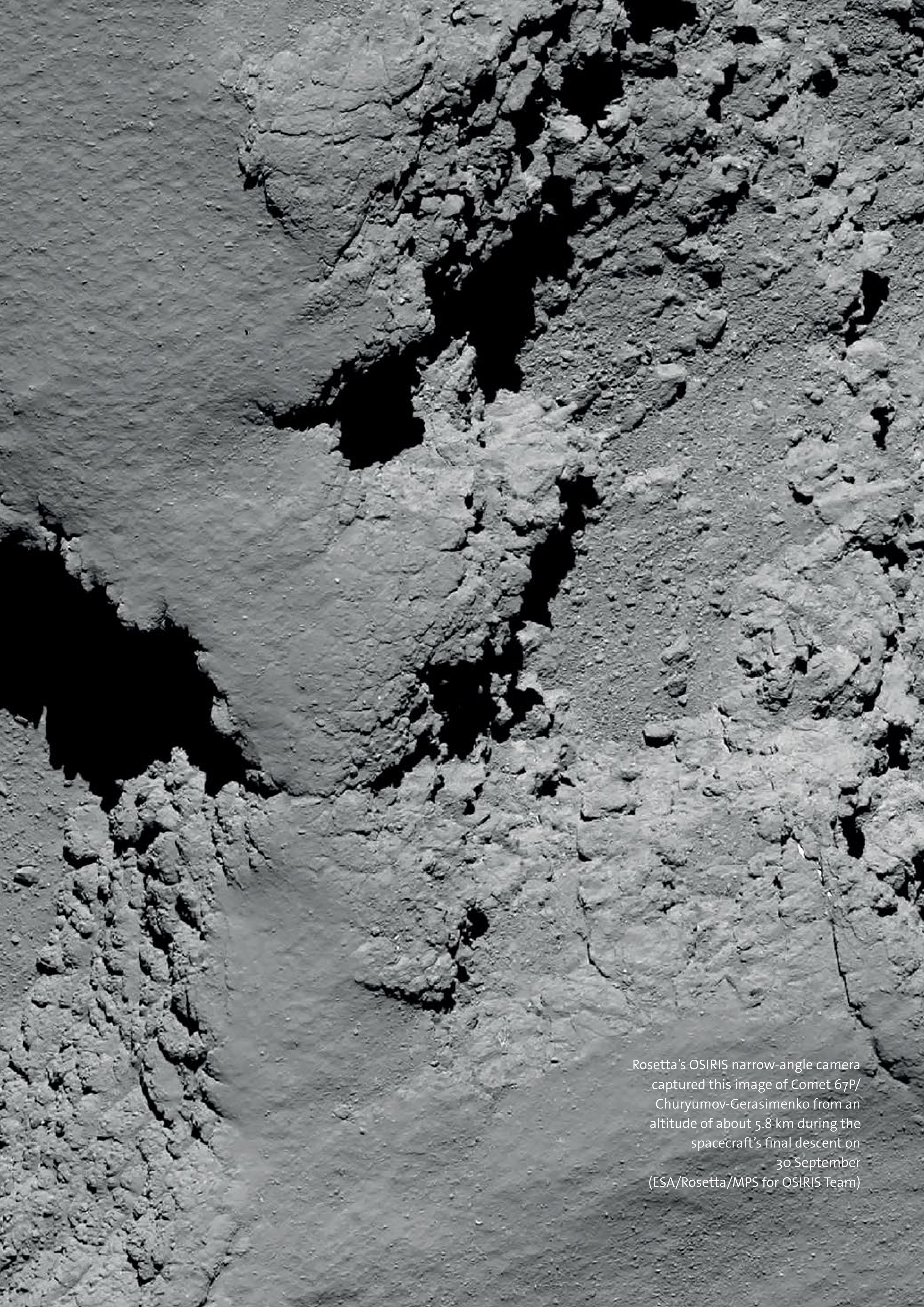
Integration, testing and validation of the various elements of the data processing, planning, scheduling, catalogue querying, and event detection software is ongoing with an extensive gap analysis, also addressing the SST application software. The activity for the establishment of an expert centre for federated laser and optical systems is under negotiation. An activity to develop supporting analysis and visualisation software and to contribute to international standards is progressing.

### Radars and telescopes

The test and validation campaigns of the monostatic breadboard radar delivered by Indra Espacio (ES) to ESA have been finalised. To date, no data has been exported outside the radar secure zone because of security restrictions. In the meantime, as of 25 June 2015, responsibility for operations of the radar was passed to the Spanish Ministry of Defence, under the framework of the agreement signed with ESA. The development of the second breadboard radar in bistatic technology with a consortium of industries led by Onera (FR) has been completed and the radar has been accepted by ESA. The test and validation campaigns are continuing and will be finalised in early 2016. Documentation for the Final Design Review for the first prototype of the NEO Survey Telescope using fly-eye technology was finalised.

# → PROGRAMMES IN PROGRESS

**Status at October 2016**



Rosetta's OSIRIS narrow-angle camera captured this image of Comet 67P/Churyumov-Gerasimenko from an altitude of about 5.8 km during the spacecraft's final descent on 30 September (ESA/Rosetta/MPS for OSIRIS Team)

## KEY TO ACRONYMS

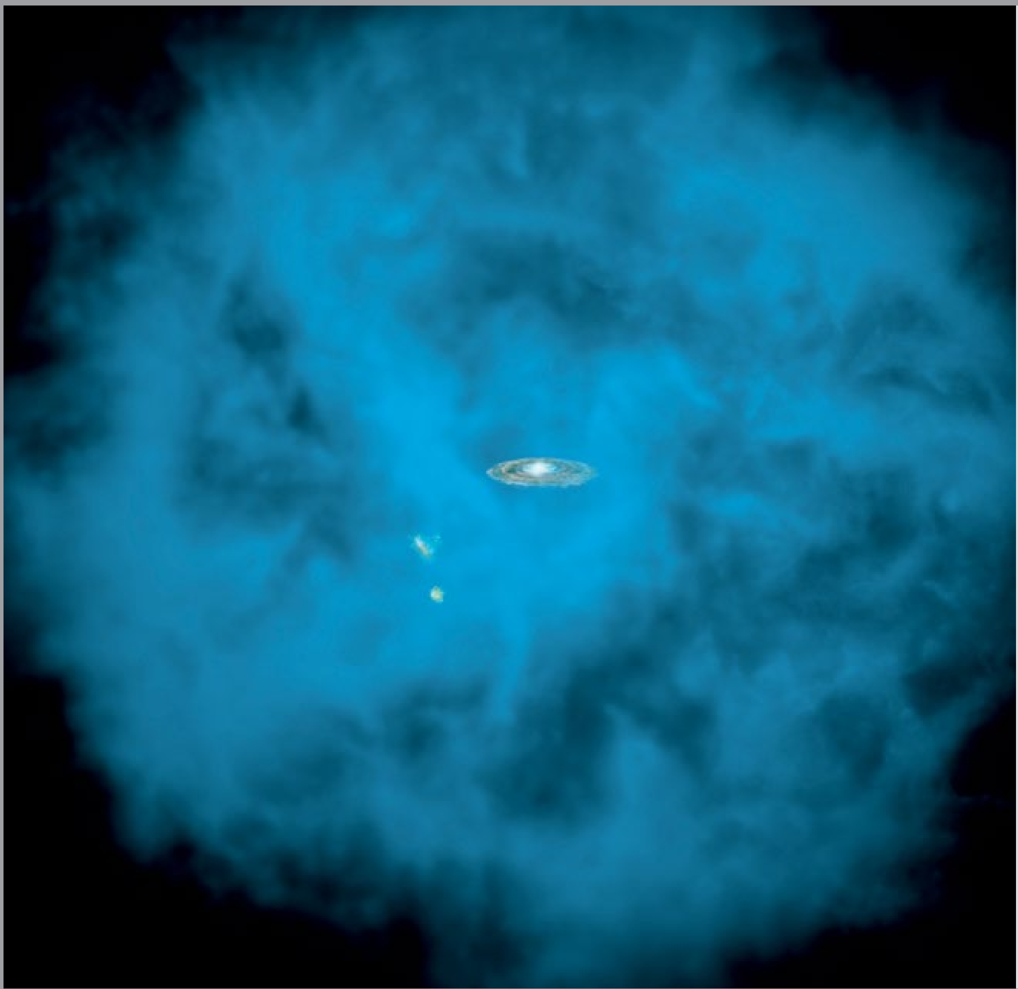
| | |
|---|---|
| AM - Avionics Model | LEOP - Launch and Early Orbit Phase |
| AO - Announcement of Opportunity | MoU - Memorandum of Understanding |
| AIT - Assembly, integration and test | PDR - Preliminary Design Review |
| AU - Astronomical Unit | PFM - Proto-flight Model |
| CDR - Critical Design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

## → CASSINI-HUYGENS

Radar data acquired during one flyby (T91) allowed the measurement for the first time of the depth of one of the largest Titan seas, Ligeia Mare (northern polar region). All data obtained over this lake by the radiometer mode of the radar from 2007 until 2015 were used in order to constrain its composition, establish a bathymetry map of the lake's bottom as well as to monitor changes that occurred with seasons. The lake (liquid and bottom) thermal emission at 2.2 cm is recorded in 'passive mode' by the Cassini radar – the liquid is extremely transparent at this wavelength, allowing to identify the signal from the lake bed, and the most likely composition is nearly pure methane. This result is surprising because the rain filling the lakes was expected to be made of a mixture of ethane/methane with nitriles and heavier hydrocarbon products formed in the atmosphere. The variation of temperature of the lake during season change (from northern winter to spring) appears to be less than 2K, which will be used to constrain evaporation models.

## → XMM-NEWTON

Our galaxy, the Milky Way, and its small companions are surrounded by a giant halo of million-degree gas that is only visible to X-ray telescopes in space. Using XMM-Newton, astronomers discovered that this massive hot halo spins in the same direction as the Milky Way and at a comparable speed. The rotation of the hot halo is a clue to how the Milky Way formed and tells us that this hot atmosphere is the original source of much of the matter in the galaxy's disc.



Our Milky Way galaxy and its small companions surrounded by a giant halo of million-degree gas

## → CLUSTER

Cluster has provided the first direct evidence of cross-scale energy transport, explaining why Earth's magnetic environment is so hot. Earth's internal magnetic field creates a giant protective bubble called the magnetosphere, necessary for life to develop. This magnetic bubble helps deflect more than 99% of the incoming solar wind expelled by the Sun. Because of this interaction, the magnetosphere has a 'bullet-like' shape. At its border, the magnetopause, the plasma is 50 times hotter inside Earth's magnetic environment than just outside, puzzling scientists since the beginning of the space age. Why is Earth's environment so hot, and how does plasma get heated in a medium where no particles collide?

One of the few physical processes enabling solar wind plasma to enter the magnetosphere is called the Kelvin-Helmholtz (K-H) instability. This instability is ubiquitous in space and on Earth. Such K-H waves have been detected in various media including the surface of oceans, in clouds, in the solar corona or in the atmosphere of giant planets. K-H waves can form at Earth's magnetopause, mainly due to the velocity difference between the plasma flowing outside at higher speed than inside the magnetosphere.

Back in 2004, Cluster revealed that these waves can roll up, turning into giant vortices of about 36 000 km wide, or about six times Earth's radius (Hasegawa *et al*., 2004). A new article, published in *Nature Physics* (Moore *et al*, Sept. 2016), presents a detailed study of small-scale (ion-scale) wave packets captured by Cluster within such a macroscopic (fluid-scale) K-H vortex. This study reveals for the first time that these wave packets are ion 'magnetosonic' waves with sufficient energy to account for the observed level of ion heating. In other words, these waves can heat the cooler ions of magnetosheath origin (the magnetosheath is the boundary layer located just outside the magnetopause). These observations may be evidence for cross-scale energy transport in space plasmas. It may have universal consequences in understanding the energy transport from fluid to ion scales, and can play a role in a variety of plasma systems with a velocity shear.

## → CASSINI-HUYGENS

IceCube is the world's largest particle detector at the South Pole that records the interactions of high-energy neutrinos. It searches for neutrinos from the most violent astrophysical sources: exploding stars, gamma-ray bursts or cataclysmic phenomena involving black holes and neutron stars. So far, 54 events have been seen in the period 2010–14. The sources of the neutrinos are also expected to radiate at X-ray and gamma-ray wavelengths. Integral is able to measure the gamma-ray emission from such highly energetic events.

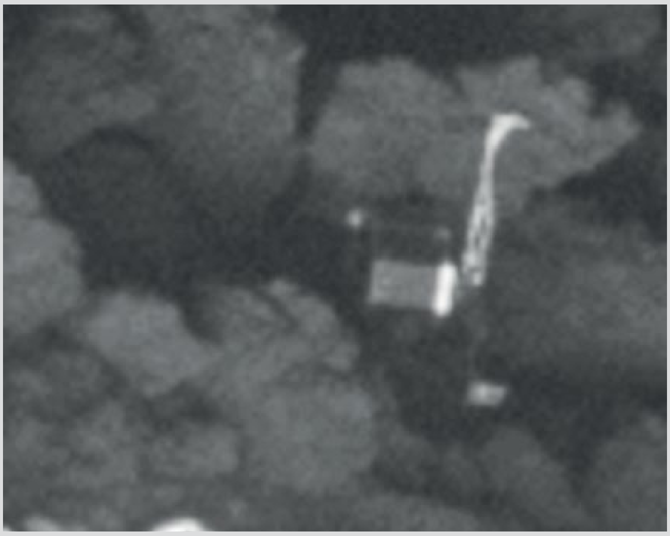
On 14 August, the IceCube detector observed a high-energy neutrino of likely astrophysical origin, called 'HESE 128340 58537957'. Integral performed a prompt search for a gamma-ray counterpart. No significant high-energy transients in coincidence with the neutrino event were found. Integral also performed a pointed target-of-opportunity observation of the region, starting only 36 hours after the neutrino event, with a total on-target time of about 28 hours. Again, no significant new sources were found in the field-of-view of both the imager IBIS/ISGRI and X-ray monitor JEM-X. The observations provide, however, stringent upper limits on the presence of a high-energy source.

## → ROSETTA

Results were published in early 2016 pertaining to one of the key goals of the mission – do comets harbour the ingredients regarded as crucial for the origin of life on Earth? The ROSINA instrument made the first unambiguous detection of glycine at a comet, which is commonly found in proteins and phosphorus, a key component of DNA and cell membranes. The first detection was made in October 2014 while Rosetta was just 10 km from the comet. The next occasion was during a flyby in March 2015, when it was 30–15 km from the nucleus. Glycine was also seen on other occasions associated with outbursts from the comet in the month leading up to perihelion, when the spacecraft was more than 200 km from the nucleus but surrounded by a lot

Comet 67P/Churyumov–Gerasimenko on 27 March, taken at a very large phase angle so that the comet lies between the spacecraft and the Sun, and that all three are very close to being on the same line. The scale is 28 m/pixel and the image measures 28.7 km across (ESA/Rosetta/NAVCAM)

Comet 67P/Churyumov–Gerasimenko on 10 April, seen at a distance of 30 km, with a scale of 0.55 m/pixel. The unique viewing geometry puts the spacecraft almost exactly between the Sun and comet, resulting in a near shadow-free view that reveals characteristics of the surface that cannot be seen otherwise (ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA)



Close-up of the Philae lander, imaged by Rosetta's OSIRIS narrow-angle camera on 2 September from a distance of 2.7 km. The image scale is about 5 cm/pixel. Philae's 1 m-wide body and two of its three legs can be seen extended from the body. The images also provide proof of Philae's orientation

of dust. While some comets and asteroids are already known to have water with a composition like that of Earth's oceans, Rosetta found a significant difference at its comet – fuelling the debate on their role in the origin of Earth's water. These new results reveal that comets nevertheless had the potential to deliver ingredients critical to establish life as we know it.

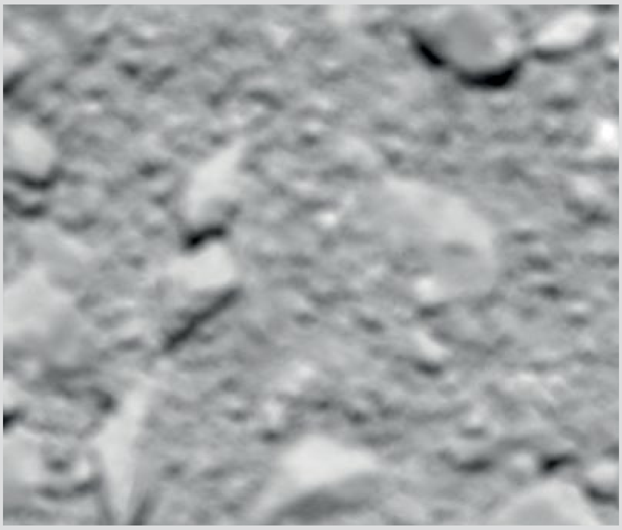
Rosetta's Visible and InfraRed Thermal Imaging Spectrometer, VIRTIS, has shown that prior to Philae landing, gradual warming of the comet resulted in the older dust layers being slowly ejected and revealing a brighter and 'bluer' sub-surface, indicative of more icy material. Initial inferences from the data taken following the landing into early 2015 show a similar trend, addressing a core goal of Rosetta – revealing how the comet surface evolves with activity.

When Giotto flew past Halley in 1986, it detected a magnetic free region, where the outer atmosphere of the comet prevented penetration of the solar wind (and its magnetic field). Rosetta had hoped to detect a similar region, but it was considered highly unlikely to be achieved, due to the navigational constraints imposed by the dusty atmosphere around perihelion in summer 2015. Surprisingly Rosetta DID detect such a region and on many occasions. These observations by the Magnetometer instruments, part of the Rosetta Plasma consortium, indicate that the boundary is much more dynamic than previously considered and have only been possible due to Rosetta's long-term study of the comet.

Observations from Earth revealed the comet's dust trail stretching more than 10 million km. More local to the comet, Rosetta has recently carried out an excursion into the tail of the comet, reaching around 1000 km in the anti-sunward direction, examining the way the solar wind and cometary coma interacts in this region. Immediately after the tail excursion, a zero-phase (flying though the comet-Sun line) flyby at 30 km from the comet was carried out, the second and final such a flyby carried out (the other one was carried out on 14 February 2015).

Rosetta scientists also reported the first unambiguous detection of solid organic matter in the dust particles of micrometre scale, ejected by the comet in the form of complex carbon-bearing molecules. The carbon is found to be mixed with other previously reported elements and is bound in very large macromolecular compounds similar to the insoluble organic matter found in meteorites, but these results have much more hydrogen. This suggests the material from Comet 67P/Churyumov–Gerasimenko has experienced less processing to have retained the hydrogen, and therefore must contain more primitive material. On the even smaller scales (nanometres), Rosetta has shown that dust at the comet is made up of even smaller particles, so the comet is made up of aggregates across all scales. These measurements provide insight into the overall construction of the comet and also how low-tensile dust layers on the surface could aid dust release into the coma.

One of the key science focuses of this mission was the evolution of the comet's activity with relation to input of



This was the last ever image taken by Rosetta, about 20 m above the surface. The scale is 2 mm/pixel and the image measures about 96 cm across. The OSIRIS wide-angle camera was not designed for use below a few hundred metres, so as expected, the image is out of focus (ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA)

energy from the Sun. A combination of various instrument data sets has been analysed, along with numerical models and computer simulations, to provide information on how the water production rate changed with time around the comet's closest approach to the Sun. It was found that 10 000s of kg of water were emitted per day at the comet during maximum activity. This study also connected ground-based measurements to those at Rosetta, a major goal of the mission.

During the summer, the spacecraft entered its end of mission phase and began a series of close flyovers of the comet. On 2 September, during one such flyover, from 2.7 km altitude, Rosetta observed the Philae lander on the surface, in a location suspected by many but lacking unambiguous proof. The image obtained (with resolution 5 cm/pixel) provided this proof, and now new science can be carried out with the Philae and Rosetta data sets, given the location of the ground truth measurements by Philae.

On 30 September, the operational phase of the mission ended with a controlled impact with the surface of the comet. A number of instruments operated until the impact and provided unique data to analyse. The impact location, in the Ma'at region on the head lobe of the comet, was named Sais, after the original location of the Rosetta stone (as noted by ESA Mission Manager Patrick Martin, 'Rosetta has finally gone home'). There are now decades of science to be done with this data set, likely by many of the young scientists the mission has inspired.

## → HERSCHEL

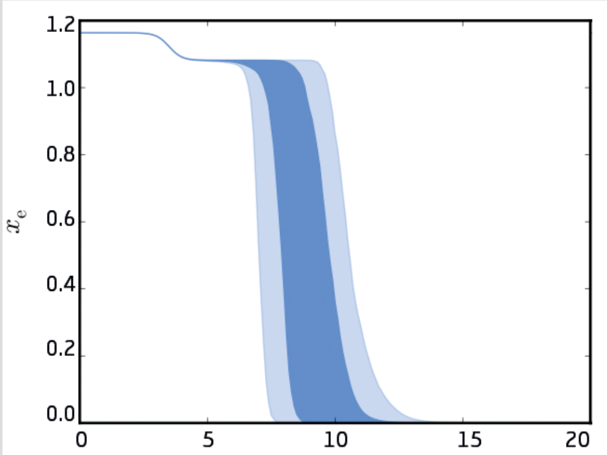
Herschel is in the post-operations phase, however, with preparations for the legacy science phase underway. This year the instrument teams will formally cease to exist. By Spring, the entire contents of the Herschel science archive, about 25 000 hours of scientific observations, were reprocessed with the latest version of the data processing software (HCSS 14), providing improvements and new data products. All Herschel data and data products are freely available to the community for science exploitation.

Some Herschel consortia have been very successful in competitively attracting European Union funding for science exploitation, a good indicator of the value of the Herschel data. A prime example is the Hi-GAL consortium that has surveyed the entire galactic plane with Herschel, making it the largest of Herschel's datasets in both observing time and sky coverage. The Hi-GAL consortium will eventually provide maps of the full galactic plane in five observing bands, importantly together with catalogues of sources. The first release has recently been done, covering almost 40% of the galactic plane centred on the Galactic Centre. A few examples of the stunning imagery are provided below.

The Eagle Nebula, also known as M16, seen by Herschel. A group of young, bright stars, not visible in infrared, are near the centre of the image, a composite of images taken in different wavelengths, 70 microns (blue), 160 microns (green) and 350 microns (red). The powerful light emitted by these stars is setting the surrounding gas ablaze, causing it to shine; the stars also drive mighty winds that are carving the giant cavities in the cloud. At the borders of these cavities, the interstellar mixture of gas and dust becomes denser, eventually collapsing and giving rise to a new generation of stars (ESA/Herschel/PACS, SPIRE/Hi-GAL Project)

Observations of the simplest ingredients in organic chemistry, the ions C+ and CH+, and the neutral molecule CH, in the most intense part (the BN/KL source) of the Orion nebula have led to a new understanding of the chemistry of all life as we know it. The Herschel/HIFI instrument was used to map the amount, temperature and motions of these species, the starting point in organic chemistry.

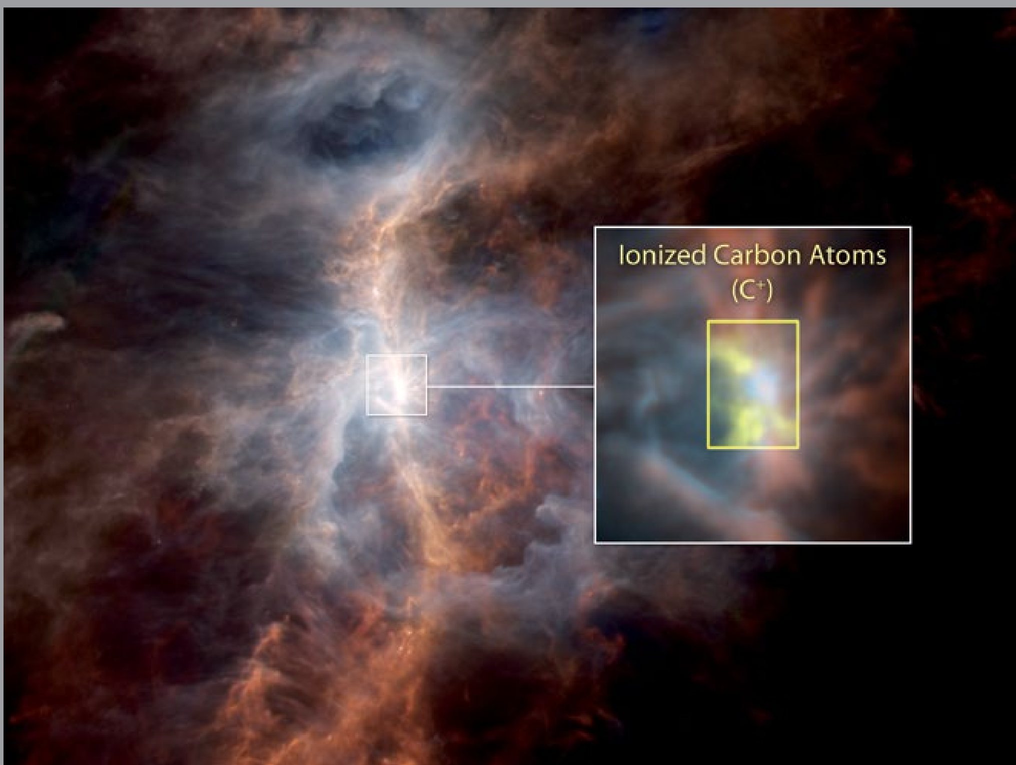
It has been known that much CH+ can be found in molecular clouds such as the Orion Nebula. This ion molecule needs a lot of energy to form and is very reactive, thus its high abundance is posing a mystery. The common thinking about the formation of the simple hydrocarbons is that they are formed in 'shocks', turbulent motions of gas in these nebulae, driven for instance by exploding supernovae. However, the Herschel/HIFI observations have not shown any correlation between shocks and CH+ in Orion, but rather suggest that they are formed in the ultraviolet light field created by the massive young stars already formed in the nebula.




Planck's constraints on the evolution of the ionisation fraction in the Universe, as a function of time (in units of redshift, 0 corresponds to now, and high redshifts to early times – for reference, the Cosmic Microwave Background was released at a redshift of about 1000)

## → PLANCK

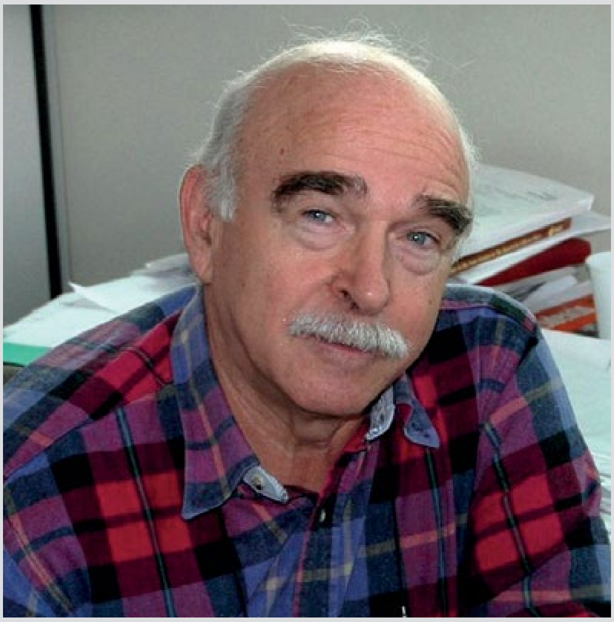
The next data release will take place at the end of the year or early 2017. It will contain products with improved quality, allowing full exploitation of polarisation data for cosmology. Two recent results from the Planck Collaboration highlight the potential of these Planck data. In the first, systematic effects that created spurious signals are reduced sufficiently to allow the measurement of the angular power spectrum of the so-called 'E-mode' polarisation at the largest angular scales. This measurement allows the estimation of optical depth to the epoch of reionisation with the highest precision possible until now. The value of this parameter turns out to be lower than believed until recently, and implies that the first stars in the Universe formed relatively late, and ionised the Universe quite quickly. The second paper analyses the detailed implications of this measurement for the history




Herschel/PACS/SPIRE multi-colour image of the M42 Orion nebula, with Herschel/HIFI C+ emission overlaid. The emission is the 'glow' (blackbody emission) from trace amounts of dust grains mixed within the gas, where PACS 100 mm emission is red, 160 mm green and SPIRE 250 mm is red. The brightest region is the BN/KL source, the inset is Herschel/HIFI C+ emission in yellow. The image spans about 3 degrees on the sky, which is about 80 light-years at the distance of Orion (ESA/NASA/JPL) of formation of the first generation of stars. The results show that the Universe is less than 10% ionised at redshifts larger than 10. This is fully consistent with measurements of ionisation levels based on ultraviolet and infrared fluxes of high-redshift galaxies. Additional sources of reionisation, such as non-standard early galaxies, are not required.

## → MARS EXPRESS

Spacecraft and the payload remain in excellent state. After a period of severe power limitations because of eclipse season, the mission is back to full-scale science operations. The infrared channel of the imaging spectrometer OMEGA resumed its operations. In October, the science case for a mission extension to the end of 2020 was presented to ESA advisory committees. The proposed programme includes augmentation of coverage of the surfaces of Mars and Phobos, extending long time series of measurements of climatological and plasma parameters, studies of couplings between atmospheric layers and atmospheric response to dust storms. Mars Express will work in tight cooperation with the NASA MAVEN mission and ESA's ExoMars Trace Gas Orbiter.



With great sadness, the Mars Express team announced that Prof. Vittorio Formisano, former Principal Investigator of the Planetary Fourier Spectrometers on Mars Express and Venus Express and a great enthusiast of planetary science, passed away on 28 March

The great martian 'plume' (a bright 'cloud' rising up to about 250 km altitude with horizontal dimension of around 600 km) that was detected in the martian atmosphere by amateur astronomers in March 2012 has not yet found a reasonable explanation. The extremely high projected altitude for the plume places it in the martian ionosphere, the upper layers of the atmosphere, which directly interact with the incoming solar wind. At the time the plume was observed, Mars Express made several passes over the same region of the planet but at the evening terminator.

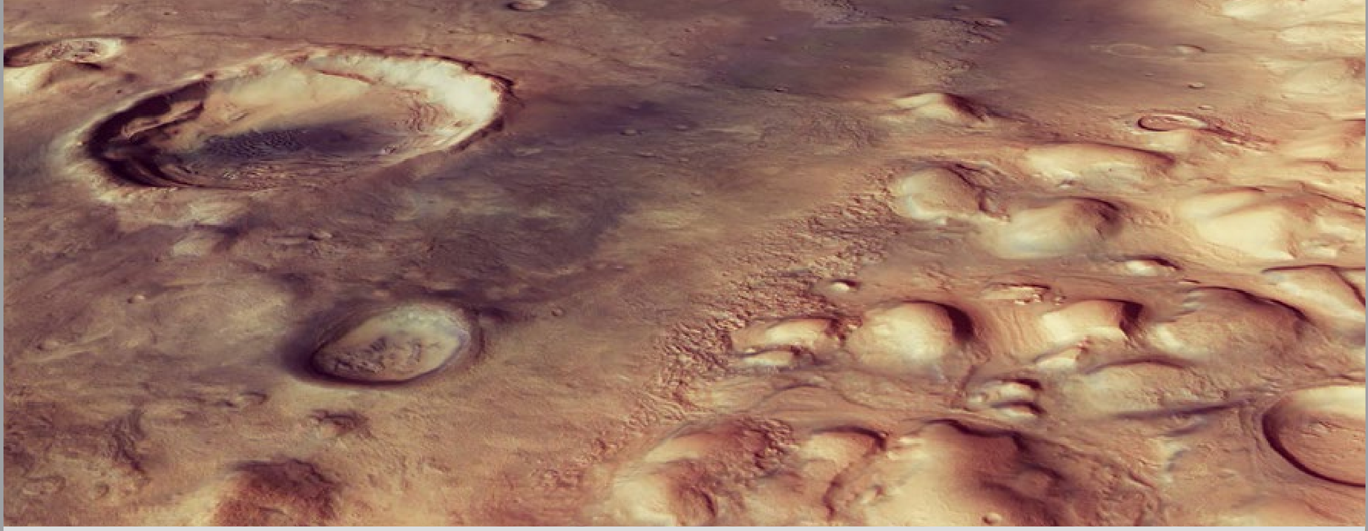
The observations by the plasma particle detector ASPERA suggest a temporal correlation of the 'plume' occurrence with the impact of a large and fast Interplanetary Coronal Mass Ejection (ICME). These ICMEs are well known to have a significant effect on the configuration of the martian ionosphere, and lead to enhanced escape of plasma from the planet. This correlation of the plume occurrence with impact of an ICME was also seen in case of the only other recorded plume observation, made by the Hubble Space Telescope in 1997. A physical mechanism explaining the correlation has not yet been found, but if it appears that these plumes were in fact driven by space-weather disturbances at Mars, this would be a truly unique discovery with potentially great significance in the debate regarding the loss of the martian atmosphere to space.

In contrast to Earth, Mars has no intrinsic global magnetic field, but local strong crustal field sources can affect the ionosphere. Multi-instrument observations performed by Mars Express have shown that the sunlit ionosphere over regions with strong crustal fields is more dense and inflated to higher altitudes than compared to other ionospheric regions. As a result, the ionospheric plasma 'climbs up' to altitudes where it makes contact with the solar wind. This process appears most efficient near the terminator plane.

Reconnection of solar magnetic field lines, carried by the solar wind, with the field lines of the crustal origin then open channels through which the ionospheric plasma escape to space, producing strong narrow cavities in the density. On the nightside of Mars, the situation is very different, where the ionosphere has a patchy structure. Such patchy ionisations are observed in the regions where crustal field lines have a dominant vertical component. Through these patches, the ionospheric plasma from the dayside penetrates and supplies the nightside ionosphere. Another source of the nightside ionosphere is ensured by precipitation of solar wind or magnetospheric electrons along these paths.

## → VENUS EXPRESS

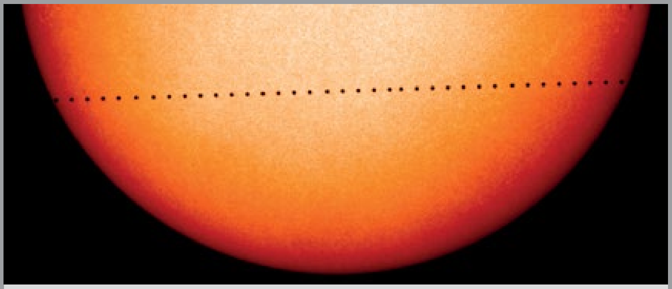
An in-depth analysis of the data acquired during the aerobraking campaign in July 2014 has revealed evidence of gravity waves in the atmosphere at altitudes between 130 km and 150 km. Atmospheric waves carry energy and



Perspective view of Colles Nili on Mars with remnants of ancient glaciation features, one example of terrain found on the global dichotomy boundary between ancient highlands in the planet's southern hemisphere and its younger northern plains. This boundary is one of the most prominent surface features on Mars, marking a topographic difference over several kilometres. Similar features are found all along the boundary are thought to represent multiple episodes of glaciation within the past several hundred million years. Later, volcanic dust has blown in from elsewhere to create the striking streaks of dark material seen in various spots especially in the large impact crater top left. This image was taken by Mars Express on 29 May (ESA/DLR/FU Berlin)

momentum between different regions in the atmosphere and have a major importance on the local and global atmospheric dynamics. The new findings contribute significantly to the understanding of the global circulation and may be the missing piece needed to explain the not-yet-fully understood super-rotation of the planet's atmosphere. In addition to these scientific results of the aerobraking activity, a one-dimensional engineering model has been created. This model is already being used by the teams preparing future Venus missions. Several mission ideas require aerobraking for operational purposes in order for the spacecraft to reach their final orbit.

Analysis of data from the ASPERA-4 and MAG instruments has found that Venus's electric potential is much higher than earlier thought. The new value indicates a potential of +10 V, which is five to ten times the value at Earth. Such a high potential means that the corresponding electric field can be responsible for a significant part of the escape of oxygen ions from Venus. The escape of oxygen ions and hydroxyl ions previously measured has been difficult to explain until now. These ions are resulting mostly from water molecules that have lost one or both hydrogen atoms through photo-dissociation and other processes. This new finding is an important contribution to the understanding of the problem of atmospheric erosion of the planet.



SOHO MDI composite of the Mercury transit on 9 May 2016

## → SOHO

On 9 May, skywatchers around the world were able to catch a glimpse of Mercury as it passed between Earth and the Sun in a rare astronomical event known as a planetary transit. Mercury appeared as a tiny black dot as it glided in front of the Sun's blazing disk over a period of seven and a half hours. Although Mercury zooms around the Sun every 88 days, Earth, Sun and Mercury rarely align. And because Mercury orbits in a plane that is tilted from Earth's orbit, it usually moves above or below our line of sight to the Sun. As a result, Mercury transits occur only about 13 times a century.

Five solar missions (SOHO, SDO, IRIS, Hinode and Proba-2) watched the transit, mainly for calibration purposes of the various instruments. Two of SOHO's instruments – the Extreme ultraviolet Imaging Telescope (EIT) and the Michelson Doppler Imager (MDI) – were brought back into full operation to take high-cadence measurements during the transit after five years of quiescence. The transit was of particular importance for the MDI team as it offered a unique opportunity to confirm the exact roll angle of the instrument and to determine image distortions and non-uniformities in the optical system and CCD. Better knowledge of these will help establish a coherent data set of helioseismic measurements covering two complete solar cycles.

## → PROBA-2

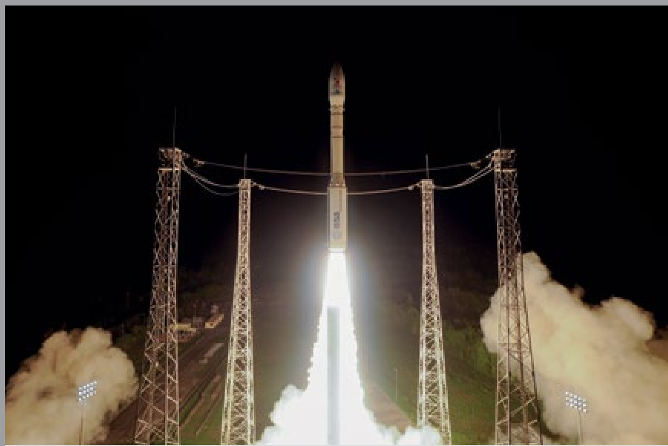
The spacecraft and its suite of in situ and remote sensing instruments continue to provide an uninterrupted stream of data to the scientific as well as the space weather community. The mission is under the management of the Space Situational Awareness Programme. In October 2014, the SWAP (Sun Watcher with Active Pixels and Image Processing) EUV solar telescope observed an eruption that led to the formation of perhaps the largest post-eruptive loop system seen in the solar corona in solar cycle 24. It can be concluded from these observations that ordinary post-eruptive loops and so-called post-flare giant arches are fundamentally the same and are formed by the same magnetic reconnection mechanism.

## → GAIA

A decontamination procedure was carried out in August to recover transmission of all optical elements. After cooling down, the focus is being monitored but there appears to be no need for a refocusing in the short term. The first Gaia data release (Gaia DR1) took place in September. The release contained four elements. A catalogue of more than one billion sources with positions and brightnesses provided the most precise stellar map ever; with a subset of two million sources parallaxes and proper motions, which helps to deduce distances and motions of these objects. A special solution was provided for quasars due to their relevance in aligning the radio and the optical reference frames. The release also contained about 3000 light curves of pulsating stars.

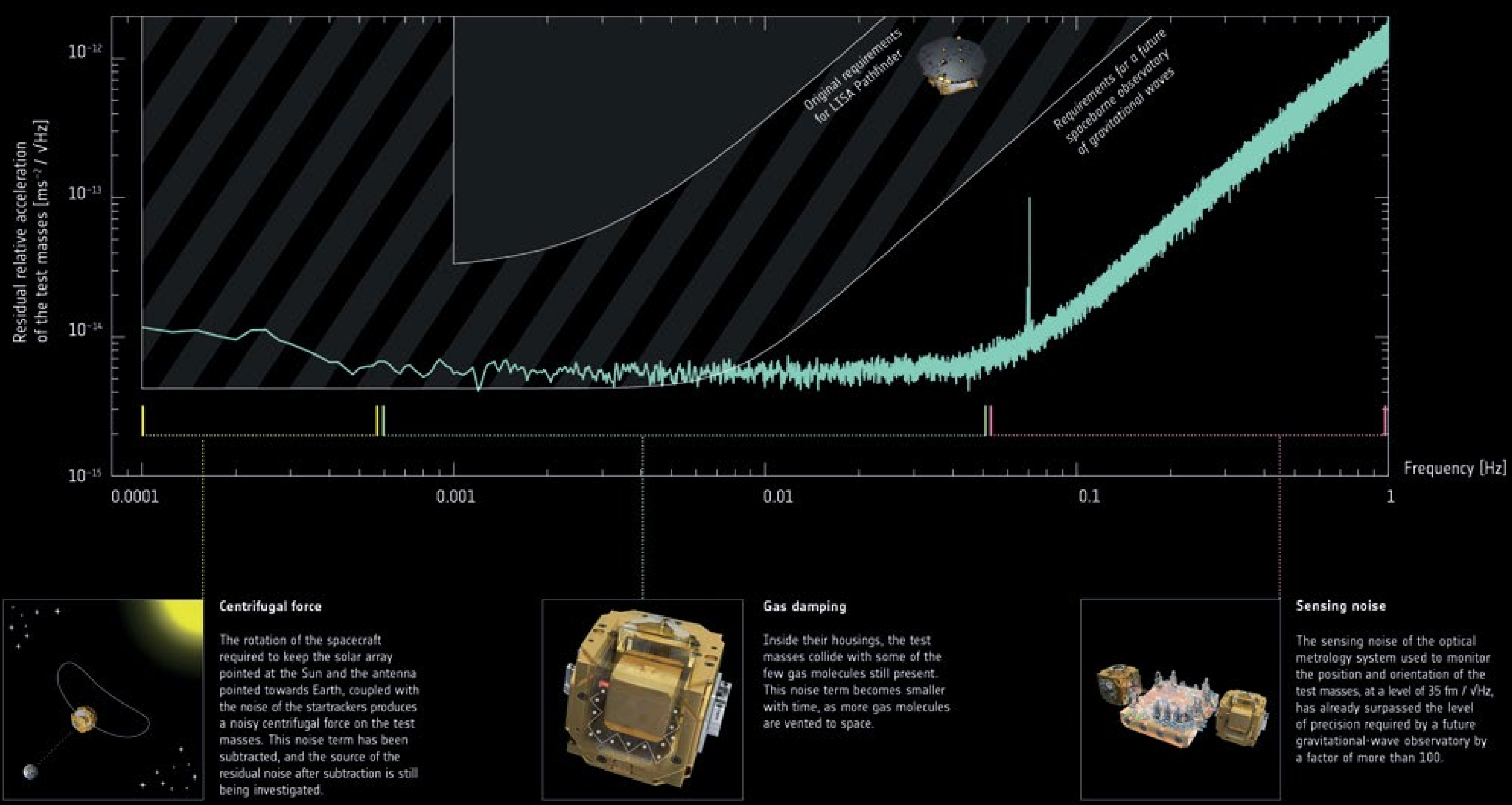
## → LISA PATHFINDER

LISA Pathfinder was launched on 3 December 2015 on board Vega VV06 from Europe's Spaceport in Kourou. Science operations started in March. Commissioning operations and tests included the release of the gold-platinum test masses



LISA Pathfinder was launched on 3 December 2015 on board Vega VV06 from Europe's Spaceport in Kourou

## → LISA PATHFINDER EXCEEDS EXPECTATIONS




The published differential acceleration between the two test masses is shown in the attached figure, along with both the performance requirements for LISA Pathfinder and for a future gravitational wave detector, for example, LISA (ESA/ATG medialab).

in near-perfect free-fall within the spacecraft. Another key result was the first operation of the interferometric position sensor, measuring the change of distance between the two free-falling test masses with picometre accuracy. During these early operations, the ability to measure and change the electrical charge of the test masses, using the photoelectric effect and without any physical contact, was verified and exercised.

LISA Technology Package (LTP) science operations have now ended. Between 1 March and 25 June, 136 different experiments were run in addition to around 1500 hours of noise measurements being taken. The performance of the mission has vastly exceeded performance requirements, in many cases by several orders of magnitude. The first results were published in the journal *Physical Review Letters* in June. The performance in the period after publication, has steadily improved demonstrating the viability of a spaceborne gravitational wave detector.

Following the LTP operations, operations of the NASA-provided payload, the Disturbance Reduction System (DRS), began. The DRS consists of a processor running a drag-free and attitude control system, and a set of micro-Newton colloidal thrusters. The DRS will use the LTP inertial sensors as the input to the control system. DRS operated until October. The goal of DRS is also related to technology demonstration but, in this case, the focus is on the micro-Newton propulsion system as opposed to the inertial sensor (and associated interferometric readout) of the LTP.

The Science Programme Committee granted a seven-month extension to the mission. Routine operations will continue until early December 2016, following which the mission extension will begin. The main focus of the mission extension is to investigate and characterise the inertial sensor system (free-falling test masses) over the full measurement bandwidth of future spaceborne gravitational wave observatories, for example as proposed for the third 'Large' class mission of the ESA Science Programme.

The LTP science archive is now open to the public. The archive can be accessed via **http://lpf.esac.esa.int/lpfsa.** The repository contains all data from the spacecraft, as well as data products produced by the LISA Pathfinder science team. The archive will be continually updated as new data becomes available.

## → BEPICOLOMBO

AIT activities on the Mercury Planetary Orbiter (MPO) progressed, with integration of all FMs completed, except the solar array. Following the integration of the BELA instrument, all MPO flight instruments are now under test. Both high-gain and medium-gain antennas were integrated, deployed and tested. With finalisation of alignment activities, the radiator completion and the installation of the various layers of the high-temperature MLI, the MPO will be ready for integration into the Mercury Composite Stack by the end of January 2017.


Integration of the thruster floor into the BepiColombo Mercury Transfer Module

On the Mercury Transfer Module (MTM), both Power Processing Units (PPU) of the Solar Electric Propulsion System were delivered, integrated and tested. The thruster floor integration was completed, a major achievement in the MTM AIT. The MTM thermal test will be complete by December and the module ready for MCS integration by mid February 2017. The JAXA-provided Mercury Magnetospheric Orbiter (MMO) has been completed and is ready for the MCS integration.

## → MICROSCOPE

Launch took place with Sentinel 1B on a Soyuz from Kourou on 22 April. During the summer eclipse season, the spacecraft was put in a standby mode. Commissioning resumed by the end of August, starting with the ESA-provided micro-propulsion system being activated. A pre-validation test was performed in preparation for the first session of science measurements. The instrument was switched on in September and this session, including calibration, ended in October. Commissioning will end in November and will include a presentation of the first science results.

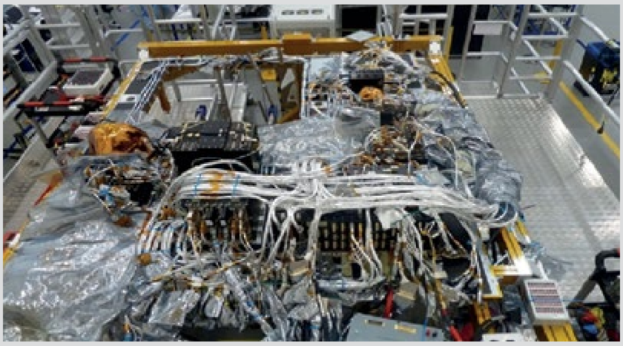
## → SOLAR ORBITER

The CDR was completed in June. Cleanliness and Contamination Control activities are progressing well. On the spacecraft Engineering Test Benches, functional testing of most instruments and spacecraft unit EMs continues towards completion of Short Functional Tests and Full Functional Tests by end of the year.

Spacecraft FM integration has started. The core primary structure was delivered to the prime contractor and integration with components of the reaction control subsystem was completed. On the service panel, integration of most of the equipment was completed and the payload panel is on track for instrument integration in November.

The Heat Shield STM support panel was refurbished to flight standard. All FM solar array panels have been manufactured and the final FM wing integration start. All instrument FM hardware are progressing. The Delivery Review Board for the EPD instrument suite was held, marking the first Solar Orbiter FM instrument delivery, a major milestone for the project. The bulk of the payload complement is scheduled for delivery in February and March 2017, later than originally expected. Interface work with NASA Goddard and Kennedy centres and United Launch Alliance for the Atlas V-411 launch vehicle is progressing.

A first assessment was made of the impact of the latest instrument delivery dates on the overall schedule. Measures were proposed for schedule recovery options. The launch date remains October 2018.



Solar Orbiter service panel Flight Model integration

## → EUCLID

Spacecraft development is proceeding in the detailed design phase. All PDRs at subsystem and unit level are complete. Unit-level CDRs have started. The Payload Module (PLM) is also proceeding in detailed design and many flight components have been manufactured. All the SiC reflector optics are being polished, an operation that lasts for many months. All the SiC parts, including the optical bench baseplate, are being manufactured.

On the Visible Imager (VIS) instrument, subsystem-level CDRs are complete. The subsystem EMs and STMs have been manufactured and the associated tests performed. The VIS instrument CDR will start in January 2017. For the CCD detectors on the VIS instrument, FM production continues and the assembly of the FM devices is under way. The first FM CCDs are expected in December.

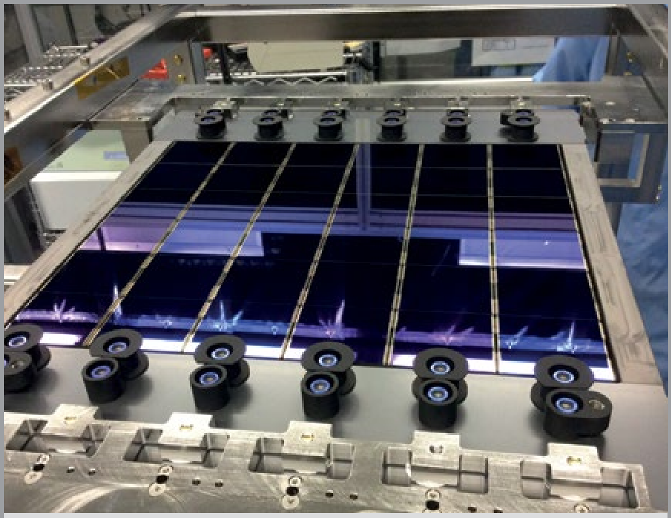
Subsystem CDRs have been completed for the Near Infrared Spectro-Photometer (NISP) with the instrument CDR starting in September. The NISP STM has been manufactured and undergone vibration and thermal vacuum testing. This is the first model delivered PLM STM campaign. Procurement of the NISP HgCdTe flight detectors, under NASA responsibility, started. Many flight detector elements have been manufactured and tested, showing excellent performance.

However a considerable delay in the delivery of the front-end electronics is delaying integration of the FM focal plane.

Ground segment development is progressing. The Science Operation Centre, under ESAC responsibility is proceeding on the development of the Survey planning and commanding, Level 1, Quick Look and Science Health monitoring services. The operational ground segment is continuing development of the various mission control subsystems, simulator and upgrade of the ground stations. Launch is planned for December 2020 on a Soyuz-Fregat from Kourou.

## → CHEOPS

The System CDR was completed on 25 May. The satellite EFM test campaign, including the instrument EM was completed in mid-May. The prime contractor, Airbus Defence & Space in Spain, is continuing integration of the flight equipment in the spacecraft platform and its electrical tests. The key avionic units, the Onboard



Euclid Visible Imager focal plane assembly STM (CEA)

Computer, Remote Interface Unit and Power Distribution and Conditioning Unit, are mechanically integrated and the first electrical tests performed. Integration of the propulsion module is complete and its delivery for integration in the platform is expected before the end of the year. The instrument consortium, led by the University of Bern, is progressing with the manufacturing, assembly and testing of the flight units.

Technical difficulties encountered in the manufacturing of the flight telescope and in the development of the Focal Plane Module have affected the delivery date of the instrument FM, now planned in early 2018. A second Radio Frequency Compatibility Test was performed at ESOC in June. The first release of the Integrated Mission Control system was installed at the CHEOPS Mission Operations Centre (INTA, Torrejon de Ardoz) and tested in July. Flight readiness is on schedule for the end of 2018.

## → JAMES WEBB SPACE TELESCOPE (JWST)

The overall programme continues to plan established in 2011 with a launch scheduled in October 2018. The Optical Telescope with the Integrated Science (OTIS) instrument module, the instrument electronics module, the harness and the thermal hardware have been completed. The environmental test campaign for OTIS began and includes vibration, acoustic and optical end-to-end test at operational cryogenic temperatures.

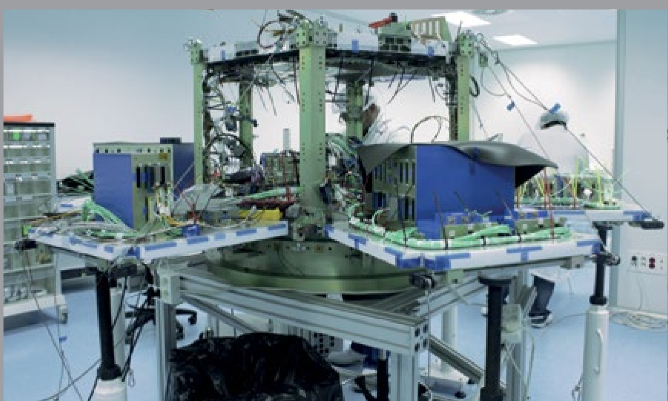
The thermal pathfinder test for OTIS was completed as planned, with the objective to de-risk the thermal/optical verification test of the OTIS FM, starting in early 2017. All the sunshield layers have now been manufactured. Integration of the sunshield and spacecraft modules continues as planned.

## → JUICE

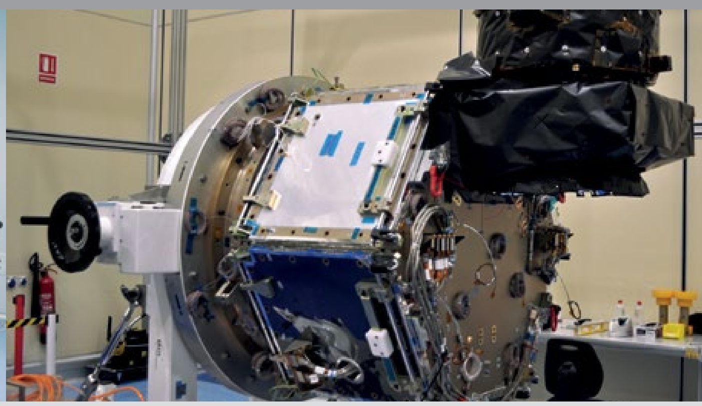
The Best Practice procurement is completed. Seven Requirement Reviews and three PDRs were completed for subsystems/equipment. The preparation of the spacecraft PDR is progressing with a board meeting planned for March 2017. Technology development activities, initiated to mitigate risks in the spacecraft development, are progressing with strong focus on the solar cell performance validation in the harsh jovian environment (high radiation, low temperature and low illumination levels).

Design optimisation and changes are to be implemented to reduce the EMC and magnetic disturbances to the instruments (mainly, but not only, caused by the solar array, the power distribution system and the reaction wheels). A further worsening of the radiation environment has materialised, based on latest available data from JPL. The intensity of the proton flux is larger than previously assumed in the energy range critical for the solar cell performances. A corrective action on the solar array will be to improve the protection of the solar cells by increasing the thickness of the cover glass. Increased local shielding on units and instruments mounted externally on the spacecraft is under evaluation.

The spacecraft schedule is under control, however, a few instruments still might have a potential impact on the environmental test campaign at system level. Two (out of 12) Spacecraft Interface Simulators were delivered for the first two instruments in October (these represents the spacecraft electrical and software interfaces and, when connected to the instrument, will allow to operate it as if electrically integrated on the spacecraft). Four instrument PDRs were successful, but two failed, so another review will be necessary in 2017.



↑ CHEOPS Flight Model platform during the integration of the flight harness in April (AD&S/ECE)



↑ CHEOPS Flight Model platform alignment exercise conducted on the instrument Baffle Cover Assembly (AD&S/ECE)

The mission scenario was optimised for power/energy availability at the Europa flyby. This was achieved by avoiding undesired long eclipses. However, one drawback was the increased radiation dose and a non-optimum operation of one instrument (the ocean-finding radar). The scenario will be reanalysed to resolve identified drawbacks without compromising power but allowing a larger fuel consumption.

Launch date remains 1 June 2022, on an Ariane 5 ECA. Arianespace is running a Preliminary Couple Load Analysis in support of the JUICE PDR.

## → SMOS

The SMOS mission has now been in orbit for more than seven years. Mission operations have been extended to 2017. New products, such as sea-ice thickness and soil moisture data in near-real time based on a neural network approach, have been included in the SMOS data catalogue. Reprocessed data from the second mission reprocessing were released in March.

Fully integrated JWST Optical Telescope with the Integrated Science instrument module, ready for the environmental test campaign (NASA)

## → CRYOSAT

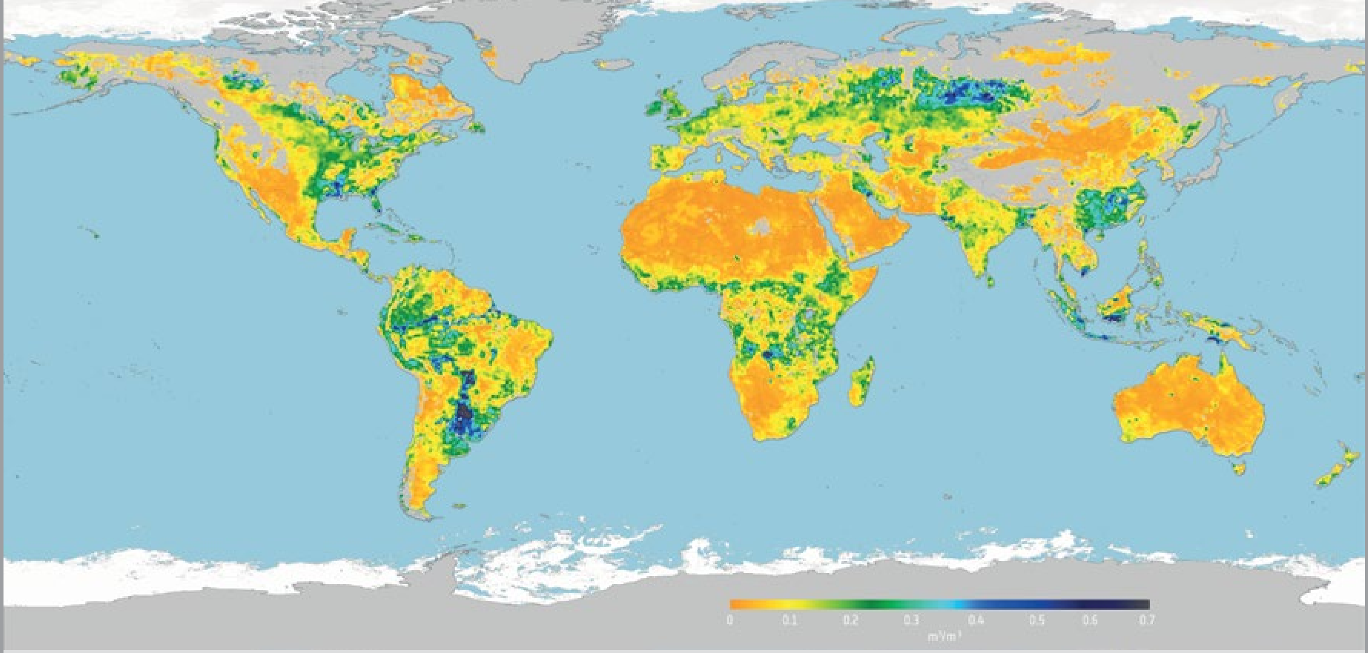
The first validation of critical onboard Star Tracker software was completed. A refined version was expected to be operational by end of June. The mission continues to provide also valuable data to a handful of non-cryospheric domains; in particular, ocean, marine gravity and hydrology. Plans are being reviewed for the spring 2017 validation campaigns, which will take place in the Arctic regions in close collaboration with national and international institutions

The latest scientific results and status of the mission were presented at the Living Planet Symposium in May **http://lps16.esa.int**. The next results will be discussed at the CryoSat North American Science Meeting, in Banff (Canada) in March 2017, **www.cryosat2017.org**. The conference will offer also the opportunity to discuss new requirements, identify new scientific challenges in view of its potential extension beyond 2019 and in general, for its successor.

## → SWARM

Second-generation comprehensive and dedicated field models in all areas have been released. Swarm has demonstrated the capability of the constellation to disentangle and separate the complex and dynamic contributors to the total magnetic and electric field measurements. This has enabled several models of Earth's magnetic field to be developed, with due impact on the understanding of the outer core, for example. As a direct result, several major breakthroughs in Earth science have been achieved. Furthermore, what is emerging as new fields of science is the mission's unique potential to unravel the mysteries of coupling and energy transport in geospace. Swarm highlights coupling between the troposphere and the ionosphere, for example, which makes plausible links between traditional weather and weather in space. Likewise, the mission is contributing to studies of the coupling between the ionosphere and the magnetosphere, and even between the lithosphere and the ionosphere.

Flight operations and constellation maintenance activities keep the lower pair at optimum operation for measurement of magnetic field gradients. Likewise, in terms of external fields and geospace measurements, Swarm instruments continue to demonstrate their feasibility to detect current systems and ionospheric features, thereby also underlining the high quality of the mission data. This holds for both elements of the electric




Drought monitoring using SMOS soil moisture data. Drought can cause crops to fail and compromise food security, particularly in developing countries. Deriving and monitoring soil moisture in the root zone based on SMOS data allows us to detect the onset of drought and provides information on the water available to plants. Detecting droughts over longer time periods based on SMOS data also provides the potential to monitor changes in the climate (Cesbio)

field instrument, the Langmuir probe and the thermal ion imager. Preparations are under way for extension of the mission beyond March 2018.

## → AEOLUS

The Aladin instrument was mechanically and electrically integrated with the satellite at Airbus Defence & Space in Stevenage. Agreements have been made with the satellite environmental test facilities in Intespace, Toulouse, for mechanical and EMC verification and Centre Spatial de Liège for thermal vacuum verification. Compatibility tests between the main modules have been completed and preparations for the integration test phase are ongoing. The launch window on a Vega opens in November 2017.

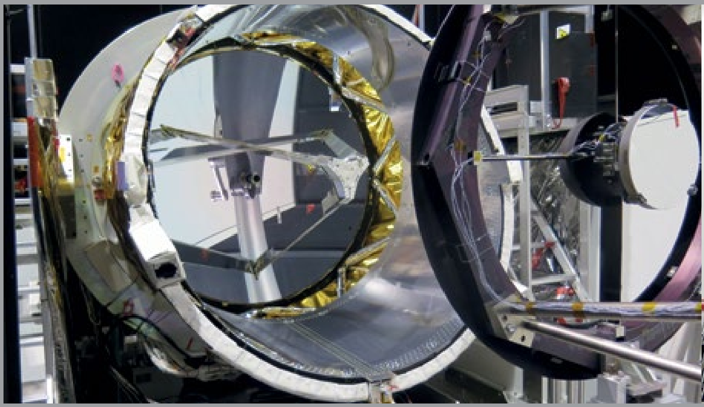
## → EARTHCARE

The System CDR concluded pending a close-out report. The Atmospheric Lidar (ATLID) PFM transmitter qualification campaign was completed. The second transmitter FM test campaign is ongoing.

The performance of the Thermal Infrared Camera of the Multi-Spectral Imager (MSI) is being characterised at SSTL. The Visible, Near Infrared and Short Wave infrared camera qualification campaign began. In Japan, the Cloud Profiling Radar (CPR) PFM instrument qualification test campaign started.

## → BIOMASS

The SRR was conducted in the summer. A successful SRR is an important step in the Project's life cycle because it begins the procurement of the individual satellite components and the build-up of the full industrial consortium. Ground-based and airborne campaigns to collect data to support the algorithm development and validation are being conducted, underpinned by a study to tackle the end-to-end performance calibration of a P-band synthetic aperture radar system in the presence of the ionosphere.



←
Aladin instrument undergoing optical tests in Toulouse in April (Airbus D&S)

←
Aeolus satellite integrated with the Aladin instrument (Airbus D&S)

The development of a prototype processor for the next level of data processing, namely to get to the biomass, forest height and forest disturbance is in preparation.

## → METEOSAT SECOND GENERATION

**Meteosat-11/MSG-4**
Launched in July 2015, the spacecraft is in a storage mode and position in orbit. It will ultimately bridge the gap between Meteosat-10 (MSG-3) and the first Meteosat Third Generation satellites.

## → METEOSAT THIRD GENERATION


Meteosat Third Generation platform Structural Thermal Model (OHB)

The Platform STM is will be completed by the end of the year with thermal/vacuum testing in December. The Central Tube STM was completed and tested. This tube will now be integrated into the (qualification) Primary Structure to start static load testing in 2017.

Manufacture of the FCI and IRS instrument STM and EMs is progressing, but with some delays due to late equipment availability. For the LI, the main challenge is to improve the quantum efficiency of the LI detectors. Following identification of the cause of this anomaly, three different solutions are being investigated. First results are expected early 2017.

For MTG-I and MTG-S PFMs, FAR dates are 2020 and late 2021 respectively. Based on the health of the MSG satellites in-orbit, and launch of the last (fourth) MSG in July 2015, these predicted dates remain consistent with Eumetsat needs.

## → METOP

**MetOp-C**
The PLM was taken out of storage in September at Airbus Defence & Space, Friedrichshafen. The Infrared Atmospheric Sounding Interferometer (IASI) was delivered from CNES for integration on the PLM. The PLM will undergo system functional testing before the thermal/vacuum tests at ESTEC in 2017. The GOME-2 instrument is being repaired at Leonardo (IT) formerly Finmeccanica, following an anomaly identified during its recalibration at TNO. It will be reintegrated on the PLM at ESTEC before the thermal/vacuum test. The SVM is in storage at Airbus Defence & Space, Toulouse. Launch on a Soyuz from French Guiana is planned for October 2018.

## → METOP SECOND GENERATION

All lower level equipment suppliers and contractors have been selected. The cycle of lower level PDRs, Equipment Qualification Status Reviews and Software Requirements Reviews is now under way. The major concern remains with the Receiver Front-Ends for the microwave instruments, which represent the most technologically challenging developments under the MetOp-SG contract. While the PDRs for the lower frequency Front-Ends have been completed, the PDRs for the higher frequency Front-Ends have been delayed. Overall satellite mass, power and data rate budgets all remain within requirements.

## → COPERNICUS

**Sentinel-1**
Sentinel-1B in-orbit commissioning was concluded in September. The satellite was handed over to Sentinel-1 mission management to join Sentinel-1A, her twin sister, for the systematic operations of the Sentinel-1 mission. Sentinel-1 is the first Copernicus mission that has its two fully functional satellites in orbit.

The Sentinel-1 mission capacity will increase with Sentinel-1B operational and the integration of the EDRS service providing additional mission downlink capability. The estimated volume of data is of 8 TB/day in 2016, reaching the goal of 10 TB/day of core products in early 2017.

A micrometeorite of about 5 mm diameter impacted the Sentinel-1A solar array on 23 August, causing a sudden power drop of few watts (out of 6000 W) as revealed by the onboard camera. The effect both on operations or satellite lifetime is negligible since it is fully covered by design margins. The likelihood for such an event to occur in the Sentinel-1A mission remains between 1:35 (for man-made debris) and 1:130 (natural meteoroid).

More than 47000 users have self-registered on the Sentinels Scientific Data Hub (https://scihub.copernicus.eu) to access the data from the three Sentinels (1A and 1B, 2A and 3A)

The Sentinel-1C and -1D production, to eventually replace the operational Sentinel-1A and -1B at their end of life, continues according to plan. Equipment and spacecraft qualification reviews are being completed before FM production.

### Sentinel-2

Sentinel-2A has been in orbit one year, with three ground stations receiving its multispectral instrument data: Matera (IT), Svalbard (NO) and Maspalomas (ES). By September, 1.52 PB of Sentinel-2A data had been downloaded by user communities.

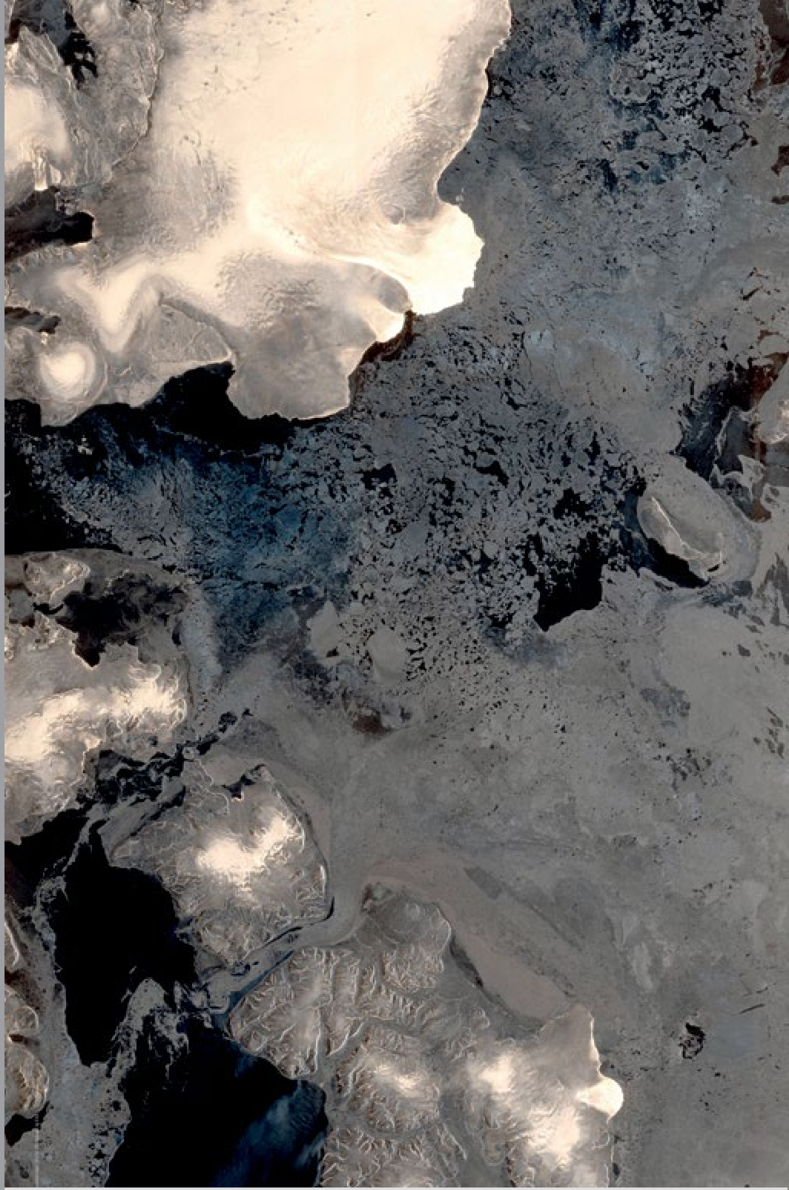
Sentinel-2B arrived at ESTEC in June and completed its full environmental test campaign. The FAR was initiated in September, leading to a Sentinel-2B launch in early 2017. Negotiations with Arianespace were also completed for a launch of Sentinel-2B on a Vega from Kourou (instead of Rockot from Plesetsk). Sentinel-2B could be launched as early as February.

The Sentinel-2C and -2D production, to eventually replace the operational Sentinel-2A and -2B at their end of life, continues according to plan.

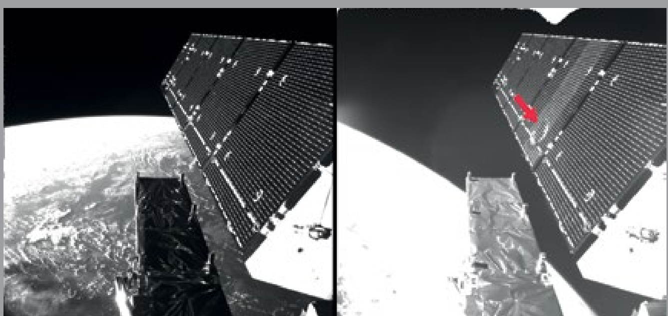
### Sentinel-3

Sentinel-3A satellite was launched on 16 February on a Rockot launcher from the Russian Plesetsk cosmosdrome. Commissioning was completed and the In-Orbit Configuration Review took place in July, confirming the excellent status and performance of the satellite. Sentinel-3A was handed over to the mission management teams for the operational phase.

Sentinel-3B activities are continuing, with SLSTR integration complete and instrument calibration planned for October. OLCI testing identified an anomaly at camera level that needed to be corrected. With the Equipment Qualification Status Review completed, the Sentinel-3C and -3D spacecraft development move into the Unit Production Review phase, when manufacturing of the equipment is authorised.



Launched on 25 April from Europe's Spaceport in French Guiana, Sentinel-1B produced its first images only two hours after the radar was switched on – a record time for a space radar. The first image, 250 km wide, captured Svalbard, the Norwegian archipelago in the Arctic Ocean (ESA/Copernicus Sentinel data 2016)



Sentinel-1A in space, fragment impact indicated on right

### Sentinel-4

ESA and Airbus Defence & Space (DE) accepted the FMs and the FM spares of the two CCD detectors, produced by E2V (UK), for the Ultraviolet-Visible and the Near-Infrared Spectrographs. Invent (DE) and OHB (DE) completed the integration of the Optical Instrument Module STM. The environmental test campaign has started, led by OHB at the IABG test centre in Munich. Performance testing on the Focal Plane Subsystem QM was completed at the DLR test facility in Berlin. Electrical interface verification testing on the Instrument EM is progressing at the Airbus Defence & Space, Munich.

### Sentinel-5

The industrial consortium is nearing completion, and negotiations are ongoing for the instrument environmental test facilities. All sub-system Equipment Requirement Reviews are complete. The detailed design of the Instrument Optical Module Structure and Radiators for the STM is completed and manufacturing has started. The first breadboard models of the CCD and Short-Wave Infrared sensors have been delivered to Airbus Defence & Space.

### Sentinel-5 Precursor

The satellite has been in storage since May at Airbus Defence & Space, Stevenage. It will be taken out of storage in October for a six-week maintenance test programme. The Overall Ground Segment is ready. LEOP rehearsals at ESOC are planned to start three months before launch. Launch on a Rockot will be no earlier than March 2017.

### Sentinel-6/Jason-CS

Detailed design activities continue towards the satellite CDR in April 2017. Manufacturing of the first elements of the satellite structure has been authorised. The NASA-provided radiometer and radio-occultation payloads have passed the mission concept and requirements definition review. The mission-level SRR was finalised and the mission PDR is in preparation. The MoU defining the roles and responsibilities of the mission partners (ESA, NASA, NOAA and Eumetsat) was reviewed by the US Department of State.

## → EDRS

LEOP and In-orbit test activities were completed, followed by a test campaign of the EDRS-A Laser Communication Terminal (LCT), using the LCT on Sentinel-1A as a spaceborne counter terminal. This will be followed by user commissioning of Sentinel-1A as the first commercial user of EDRS thereafter. This will mark the formal start of the commercial EDRS service, a 'giant leap' in providing Earth observation data to the ground at 'Near Real Time'.

The Structural Thermal Model of the Sentinel-4 Optical Instrument Module at the IABG Test Centre, Munich (OHB)

The second EDRS node based on a dedicated satellite built by OHB, using a SmallGEO-type platform, carries the EDRS-C payload, which includes a second LCT. It will also embark Avanti's HYLAS-3 communication payload as well as the Next Generation Radiation Monitor (NGRM) developed by RUAG in Switzerland as a 'hosted payloads', and will be launched on an Ariane 5 into its geostationary slot at 31°E in late 2017. The EDRS-C mission CDR is planned for early 2017.

Integration of EDRS-C flight hardware is taking place with the prime contractor OHB. The repeater panel carrying the EDRS-C payload has been integrated with the Avanti HYLAS-3 payload. Final integration and test activities are

Sentinel-2B entering the Large Space Simulator at ESTEC in June (Airbus D&S)

ongoing on both Platform and Repeater Modules. }Satellite mating is planned for November, to followed by functional and performance tests before shipping the satellite to IABG for environmental testing 2017.

## → ALPHASAT

The Alphabus Deployable Panel Radiator (DPR) QM was shipped to ESTEC in June for mechanical environmental testing. The final qualification review is planned for the end of the year.  The DPR adds an additional 1 to 1.5 kW thermal dissipation capability to the spacecraft. The DPR is manufactured by EHP (Belgium), while the ground handling equipment is made in Gradel (Luxembourg).

## → QUANTUM

Quantum is an innovative satellite with a flexible payload that can be retasked in orbit. The PDR for the pioneering 'software-programmable' satellite is being finalised, and teams are working towards the CDRs for various equipment. Developed under a partnership between ESA, Eutelsat and Airbus Defence & Space, launched is planned for early 2019.

## → ELECTRA

The objective of Electra is to develop, launch and validate in orbit a satellite system based on an innovative geostationary platform in the three-tonne launch mass range, using 'full electric propulsion' for transfer to geostationary orbit and station-keeping. Following contract signature in February, activities with Luxembourg operator SES and prime contractor OHB System have started. The first project milestone, the System Design Consolidation Review, which aims to confirm that the preliminary design presented by the contractor in Phase-B1 is still valid, started in May. On completion of subsystem PDRs, the prime contractor will finalise negotiations with suppliers.

## → SMALLGEO/AG1

Following an internal commercial reorganisation, Spanish operator Hispasat renamed its satellite fleet. SmallGEO AG1 will be called Hispasat 36W-1. After post-mechanical test alignment checks, the spacecraft was readied for the combined thermal balance/thermal vacuum test at IABG in Munich. Ground segment activities are ready for the Operational Readiness Review.

## → ARIANE 6

After a programme review completed in September, the riders to the contracts awarded in August 2015 were signed in November. This confirms the continuation of the preparation of Europe's Ariane 6 and its launch complex.

### P120C and synergy with Vega

The P120C Nozzle Delta-PDR concluded in September, highlighting a good status for nozzle development, with

The Alphabus Deployable Panel Radiator Qualification Model seen with representatives from Airbus Defence & Space (FR), EHP (BE), Gradel (LU) and a joint ESA/CNES team (Airbus D&S)

no technical issues raised. The P120C TVC/TVAS PDR was conducted in September. The Review Report is being finalised, identifying a number of actions in order to solve these identified issues. The Solid Booster Test Bench (BEAP) adaptations are on track, most of the industrial consultations concluded. In new booster case technology demonstration, the Pathfinder mandrel LLI Key Point was organised in October, giving the go-ahead for the mandrel procurement (a mandrel is a solid round object against which materials can be machined in the nozzle production process, for example).

### Launch Base

Two complementary sessions of Launch Base PDR were held in October. Activities in Kourou are progressing as planned.

## → LAUNCHERS EVOLUTION AND VEGA-C

Following Launcher Evolution Elements (LEE) initial activities, preparations for the LEE bridging phase started with system studies mostly consolidating requirements for the Prometheus engine. The bridging phase contract was signed and industrial activities started.

Reorientation of Vega-C activities took place, implementing the change of configuration of P120C SRM, Vega-C first stage. The increased mass and dimensions of P120C led to a change of configuration that had to be reflected in the development baseline of Vega-C together with some advanced ground proximity means activities.

## → FUTURE LAUNCHERS PREPARATORY PROGRAMME

Microlauncher contract activities progressed. The contract was placed for reusability elementary demonstration with an airborne lift and drop of a liquid propellant stage, followed by recovery and inspection. The propulsion bay will be equipped with a functional engine, hot-fire tested before and after the drop test and recovery. These operations will provide concrete inputs for the economic assessment of reusability.

A low-cost version of the storable bipropellant engine demonstrator is being started, based on the extensive use of powder-bed additive manufacturing. Hot-firing tests of the produced hardware are foreseen by end of 2017, possibly with 'green' propellant. The P8 has been prepared and is now operational for LOX/ethanol hot-firing tests. This new capability will be used in the frame of the FLPP New Economic Opportunities programme. The Manufacturing Readiness Review for the Nucleus rocket is scheduled in December, for a flight in mid-2017. Concept studies for LOX/hydrocarbon combustion devices in coordination with the French national project Prométhée are progressing. A meeting for consolidation of the functional specifications at engine level took place in September. Midway to the concept key-point, an number of possible designs were reviewed.

The Fibre Optimised Reinforced Carbon Skirt was manufactured and a non-destructive inspection performed. A decision keypoint in November will release the final assembly of the demonstrator before a Test Readiness Review planned in December. NASA funding for the US part of the contract for the Integrated Stiffened Cylinders activity (aiming at low-cost upper-stage cryotanks by metal flow forming) was released.

## → SPACE RIDER

The PRR began in October and is due for completion in December.

## → HUMAN SPACEFLIGHT

### ISS

The Principia mission of ESA astronaut Tim Peake (GB) began in December 2015. He was involved in the first of two spacewalks performed in the first quarter of 2016. In this spacewalk with NASA astronaut Tim Kopra, Tim replaced hardware which helps regulate voltage generated by the

Astronauts Tim Peake, Tim Kopra and Yuri Malenchenko land in Kazakhstan on 18 June in the Soyuz TMA-19M spacecraft, after spending 186 days on the International Space Station (NASA)

ISS solar arrays and installed cabling in preparation for installation of docking adapters for future US crew vehicles.

Tim's mission came to an end with the landing of Soyuz TMA-19M on 18 June. Tim had undertaken a full spectrum of ESA research activities covering the life and physical sciences, technology and education including being the subject of human research experiments as well as assisting ISS partner agencies with their research programmes.

The impact of the SpaceX launch pad failure on 1 September on the International Space Station flight programme is being assessed. Roscosmos confirmed the reduction of Russian crews on the ISS from three to two per expedition as of March 2017.

Tim Peake's recovery brings his Principia mission to an end but the research continues. Tim is the eighth ESA astronaut to complete a long-duration mission in space (NASA/ESA)

### Astronauts

Alexander Gerst (DE) was assigned a second long-duration mission to the Space Station in 2018 (Expedition 56/57). During the second half of the mission, Alex will become ISS commander, the second time a European astronaut has been assigned this position. Alex started his training for this mission with a summer survival course at the Gagarin Cosmonaut Training Centre followed by training at Johnson Space Center and EAC. Most of his training will now be in the US and Russia where he will be trained on the new Soyuz MS spacecraft.

The ESA Cooperative Adventure for Valuing and Exercising human behaviours and performance Skills (CAVES) course this year was held in Sardinia in June and July. For the first

NASA astronaut Tim Kopra presents ESA's Tim Peake with a patch to commemorate his 100th day in space on 24 March (ESA/NASA)

From left:
Ricky Arnold (NASA),
Ye Guangfu (China),
Sergei Korsakov (Roscosmos),
ESA's Pedro Duque,
Jessica Meir (NASA) and
Aki Hoshide (JAXA)

time, this training brought together astronauts from four of the ISS partner agencies: NASA, Roscosmos, JAXA and ESA with a Chinese astronaut. The multinational crew worked together to explore a cave and performed various experiments during their six-day subterranean mission.

EAC Eurocom Matthias Maurer (DE) participated in the NASA Extreme Environment Mission Operations (NEEMO-21), which took place in July and August. It provides training opportunities in the world's only undersea research station, Aquarius Reef Base, off the coast of Florida. Groups of

NEEMO-21 aquanauts: ESA's Matthias Maurer, Marc O Griofa, NASA astronauts Megan McArthur and Reid Wiseman, Dawn Kernagis and Noel Du Toit. Inside the Aquarius habitat are technicians Hank Stark and Sean Moore (NASA) astronauts, engineers and scientists live in Aquarius and experience a convincing analogue for space exploration.

Thomas Pesquet (FR) continued preparations for his mission to the Space Station in November. Two weeks of training at EAC in April included final payload training and briefings in support of the back-up function for the Soyuz MS-01 launch in July. The Baseline Data Collection for the life-science experiments and medical preparations completed the activities. He completed his final training at Johnson Space Center. In September, there was more payload training at EAC with medical examinations and data collection for a number of physiological experiments. He is now in Russia for the final preparations for a launch on 17 November.

Paolo Nespoli (IT) continued his training at the Johnson Space Center and the Gagarin Cosmonaut Training Centre for his mission in 2017. This mission is a flight opportunity from the Italian space agency ASI as part of a bilateral agreement with NASA. The training in Russia focuses on the Soyuz vehicle, while training in the US included Station systems and payload operations. Paolo finished his Columbus Systems Specialist Level training and started with payload training at EAC in September. He served as backup for Thomas Pesquet on Soyuz MS-03.

### ERA

A launch date at the end of 2017 was reconfirmed by Roscosmos. A new schedule for the Multipurpose Laboratory Module (MLM), on which ERA will be launched, is still to be received from Russia. ERA will be transported from Moscow to Baikonur in February 2017, after the last (software) interface tests between ERA and the MLM in the second half of 2016.

### ACES/ASIM

A technical solution was defined for resolving the Atomic Clock Ensemble in Space (ACES) Space Hydrogen Maser (SHM) issues and is under implementation. This came with additional costs and a delay of about six months, which led to the decision to launch ACES on SpaceX CRS-15 in 2018. The SHM was successfully operated for the first time and final integration with electronics is foreseen in January 2017. All Atmosphere-Space Interactions Monitor (ASIM) elements were accepted at component level and delivered for final integration and testing. The tests will start at the end of November.

## → ISS UTILISATION

### European research on the ISS

In addition to the Principia mission, the European ISS utilisation programme continued with the assistance of the

↑ Tim Peake uses hardware for the Vascular Echo experiment on the Space Station in May (ESA/NASA)

Expedition 46/47 crew members in orbit. These activities were supported by the successful ninth commercial flight of the SpaceX Dragon logistics spacecraft to the ISS transporting hardware and consumables for different ESA experiments and by later Soyuz crew exchanges bringing new test subjects for ESA human research activities to the ISS.

### Human research

Tim Peake and Tim Kopra participated in the Airway Monitoring experiment including low-pressure measurements taken in the US airlock. Airway Monitoring is studying the presence of pulmonary nitric oxide as a measure of airway inflammation related to future exploration missions.

Tim also undertook additional sessions as a test subject for ESA's Circadian Rhythms, Skin-B and Space Headaches experiments. The Circadian Rhythms experiment is studying alterations in circadian rhythms in humans during long-duration spaceflight to provide insights into the adaptation of the human autonomic nervous system in space over time. The Skin-B 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. Space Headaches is looking into headache incidence/characteristics during (long-duration) spaceflight.

Additional sessions of two ESA experiments (with Russian cooperation), Immuno-2 and EDOS-2, were also performed in the Russian segment of the ISS. EDOS-2 continues the research from the Early Detection of Osteoporosis in Space (EDOS) experiment, though with inflight sampling, in determining post re-entry bone loss and long-term recovery from spaceflight-induced bone loss. Immuno-2 is an integrative study protocol to provide a more holistic approach to increase the knowledge of the complex physiological adaptation of humans during long-term space

↑ Tim Peake performs an ocular health fundoscope exam on the Space Station in June (ESA/NASA)

↑ Tim Peake waters pea and corn seedlings as part of JAXA's Auxin Transport plant growth experiment (ESA/NASA)

missions. The research follows up the positive research from the first Immuno experiment. A new test subject started the Energy experiment, looking into derivation of an equation for energy requirements of astronauts in weightlessness to contribute to planning adequate crew supplies.

### Biology research

ESA's Spheroids experiment was processed in the Kubik-5 and -6 incubators in April. After processing samples were fixed and kept in conditioned storage until their return to Earth on the SpaceX CRS-8 in May. These are now with the science team for analysis. The experiment is investigating the effects of microgravity on endothelial cell function, their programme of differentiation and apoptosis (programmed cell death). Results of this experiment will be compared against results obtained from similar experiments in simulated weightlessness on ground.

### Astrobiology research

The Expose-R2 astrobiology facility was removed from the external surface of the Russian Zvezda Service Module during a spacewalk on 3 February and brought back inside the Station. This concluded more than 15 months of exposure of the associated samples to differing environmental conditions in open space. The three sample trays were removed from the facility and one has already been returned to Earth. The ground control experiment for the Expose-R2 experiments was completed in August.

It was running with a scheduled two-month delay to incorporate parameters derived from both the on-orbit telemetry data and calculations of solar irradiation on the samples. This will support and facilitate interpretation of the scientific results. The final samples were returned from orbit in June on Soyuz TMA-19M. Expose-R2 hosted three ESA experiments (BIOMEX, BOSS and PSS) and one from IBMP in Moscow. Some experiments may help to understand how life originated on Earth and the survivability of samples to conditions on for example Mars, the Moon and in other astrophysical environments.

### Fundamental physics

Tim Peake carried out initial activities in advance of the future launch of the Atomic Clock Ensemble in Space (ACES) including routing cabling in Columbus for the Space Acceleration Measurement System (SAMS). ACES consists principally of two very high-performance atomic clocks, which will be the most precise measurement of time in space, accurate to about one second over 300 million years. ACES will be able to tackle 'relativistic geodesy', a new kind of Earth monitoring that will be made possible by using extremely precise measurements of Einstein's 'gravitational redshift'. ACES will also benefit metrology (the science of measurement), and contribute to evolutions of the global navigation satellite network and support the use of precision clocks in major Earth science activities.

### Technology research

Tim Kopra performed a maintenance task in Columbus (inspection of a dessicant module of the Condensate Water Separator Assembly) using the iPad-based 3D-VIT procedure viewer training tool. Kopra was intentionally not trained for this inspection activity preflight in order to use it as an 'impromptu task' on orbit for testing this training technology. ESA developed the tool for the purposes for building a 3D visualisation of procedures for refresher training on orbit. This technology is now being assessed for its efficiency for training of impromptu tasks occurring at short notice on orbit that could be very useful considering future human exploration missions beyond low Earth orbit.

Additional runs for the Magvector experiment were carried out inside the European Drawer Rack in Columbus. The MagVector experiment from DLR qualitatively investigates the interaction between a moving magnetic field (of Earth origin) and an electrical conductor.

## Materials research

Three sample cartridge assemblies for the Solidification along a Eutectic path in Ternary Alloys (SETA) experiment were processed inside the Materials Science Laboratory from July to September. SETA is one of the experiments undertaken in the MSL which are studying different aspects of the solidification process in metal alloys which will help to optimise industrial casting processes. The SETA experiment is dedicated to the investigation of eutectic growth in ternary alloys of aluminium copper and silver.

## Fluids research

The SODI DCMIX-3 experiment was set up in the Materials Science Glovebox on the Station in September. A total of 10 different thermodiffusion runs were performed on five different ternary fluid samples with different mass fractions of water, ethanol and triethylene-glycol. The main purpose of the SODI-DCMIX experiment is the measurement of diffusion coefficients of selected ternary water-based and hydrocarbon mixtures representative of different petroleum field samples. Experimental 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.

## Solar/radiation research

ESA's SOLAR facility completed another extended period of data gathering (in June/July) during which the ISS was rotated from its normal orbital attitude for 10 days. This allowed measurements of solar spectral irradiance to be acquired during a full Sun rotation cycle (which lasts around 26 days at the Solar equator and up to 36 days at the solar poles). These extended campaigns have been the only times that the attitude of the Space Station had been changed for scientific reasons. Two additional standard data acquisition periods were also undertaken in August and September. Following more than eight years in orbit, the SOLAR facility has exceeded expectations, surpassing its originally planned mission of 18 months to two years in orbit. This is scheduled to continue until the end of February 2017.

ESA Active Dosimeter hardware was installed in Columbus in July including the Personal Storage Device (PSD) within which Personal Active Dosimeter (PAD) mobile units were inserted. On the second day of commissioning, three mobile units were distributed across the Station, being collected in and reinserted into the PSD a week later.

Data was downlinked which confirmed that all systems are working. Data from the mobile units showed that the Columbus End Cone is less shielded and a similar dose is appearing for the Permanent Multipurpose Module. This proves that the system can be used for area monitoring.

Within the project, an active (powered) dosimeter system 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 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. The system remains active with a weekly data downlink.

Radiation research also continued within the Dose Distribution inside the ISS 3D (DOSIS-3D) experiment that continuously collected data on the radiation environment inside Columbus. A new set of 11 dosimeter packages was deployed in Columbus on 9 July after being transported to the Station on Soyuz MS-01.

## Non-ISS research in ELIPS

The second campaign of a 60-day bedrest study started at DLR in January with 12 volunteers. The bedrest study is evaluating the efficacy of a reactive jump countermeasure to protect from the negative effects of muscle disuse which astronauts but also bed-ridden patients experience. The 2016 Concordia Antarctic winter-over season started in February with five human research experiments. This season's science programme covers different areas including human performance, musculoskeletal and neuroscience research.

The Soret Coefficient in Crude Oil (SCCO) experiment was launched on a Chinese Shi Jian spacecraft on 6 April landing two weeks later. Maintaining the very high-pressure liquids in the sample containers was challenging, nevertheless most retrieved samples were of good quality and scientific analysis has now started.


One of the Passive Detector Packs placed in the Columbus lab on the Space Station as part of the ISS 3D (DOSIS-3D) radiation monitoring experiments (ESA/NASA)

After four months without seeing the Sun rise above the horizon, the crew of Concordia research station welcome its return from the rooftop in August (ESA/IPEV/PNRA–F. van den Berg)

Seven Drop (catapult) tests were carried out at the ZARM Drop Tower in February for the PERWAVES experiment in advance of its launch on the MAXUS-9 sounding rocket in April 2017. PERWAVES is studying the limit of percolation of a combustion front through a cloud of solid metal particles. Drop tower tests continued with the Superfluid Helium Evolution (SHeEP) campaign that concerns thermal-flow phenomena occurring in superfluid helium.

The 64th ESA Parabolic Flight Campaign was performed with 11 experiments (nine physical sciences, one life sciences and one technology demonstration) in April 2016 and included broadcast media participating in two flights from BBC 'Blue Peter' (UK) and Sky TV (GR).

Preparations for the 65th campaign are continuing, while a dedicated Announcement of Opportunity was released in September for proposals for a life science campaign to be conducted in spring 2018 in cooperation with partners from the International Life Sciences Working Group (ISLSWG). During this campaign, gradient gravity and/or lunar and martian gravity levels will be offered.

## → EXPLORATION

### ExoMars

The ExoMars 2016 mission was launched on 14 March with the Trace Gas Orbiter (TGO)/Schiaparelli spacecraft composite on a Proton-M/Breeze-M rocket. This was the first launch arrangement of its kind for our Russian partners who were in the unusual situation of launching a foreign payload on a rocket procured and managed by the Russian Federal Space Agency. The cooperation worked very well and will be a model for the next mission in the ExoMars joint cooperation between ESA and Roscosmos.

The 2016 mission Mars Entry and Arrival Operations Readiness Review was completed on 14 September confirming all systems ready for Mars arrival. The TGO and Schiaparelli separated on 16 October as planned. While the TGO Mars orbit insertion was completed successfully 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 was set up immediately after the events of 20 October to review available data and determine the cause of failure to land as designed. A status report was issued confirming a good telemetry record and availability of extensive data for deciphering the problem. First indications show a good entry performance and parachute deployment. However, this event started a chain of events in the Guidance, Navigation and Control resulting in the eventual loss of the landing demonstrator.

On the 2020 mission, the Rover Analytical Laboratory Drawer (ALD) Engineering and QM assembly and test programme began with the operations in the ultra-clean Thales Alenia Space Italy facility. The Carrier Module STM is being manufactured and scheduled for delivery to Lavochkin later this year.

ExoMars 2016 launch in March

## Multi-Purpose Crew Vehicle/European Service Module (MPCV/ESM)

The European Service Module Test Article (E-STA) was fully assembled and mated at the Plum Brook test facility, with dynamic testing of the MPCV stack configuration starting in April. A public relation event for the Flight Model 1 (FM1) primary structure delivery to Airbus Defence & Space in Bremen was held in May. A new FM1 delivery date was agreed with Airbus for the end of April 2017.

The System CDR began in June. It was considered partially successful. A number of topics were identified that could affect the design and need to be resolved before the CDR is closed. A close-out report will be presented in October.

The schedule provided within the CDR data package contains several aspects to meet the agreed NASA delivery date. NASA formally ordered a second service module (ESM2) but at the same time requested some design changes which are currently under assessment and which might not be in line with the NASA requested ESM2 delivery date.

ESM FM1 integration of harness and piping started. Flight unit delivery date remains the end of April 2017. ESM FM2 price and associated conditions were negotiated and agreed with Airbus. The formal contract update is targeted for November, whereas formal signature will occur after the Ministerial Council 2016. The FM2 barter value was agreed with NASA and the corresponding Technical Understanding with NASA is under preparation.

The European Service Module FM1 that will power NASA's Orion spacecraft to the Moon and beyond is taking shape in the assembly hall at Airbus Defence & Space, Bremen, Germany

Tim Peake prepares to operate the Mars rover prototype remotely from the Space Station in March (NASA/ESA)

On 24 October, ESA and NASA signed the Technical Understanding for the partial CSOC 2010–14 offset, pending approval at the Ministerial Council. This covers procurement of the ESM FM2, associated changes and a study to replace the Orbital Manoeuvring System engine and Thrust Vector Control (Shuttle) hardware currently part of the ESM design.

## 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 mission. More than 30 technology activities funded by MREP are currently in implementation.

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

Tim Peake operated the Mars rover prototype (Bridget), which was located at the Airbus 'Mars yard' in Stevenage, UK, remotely from the Space Station on 29 April. This technology demonstration of human/robotic exploration cooperation was achieved using a complex set of control and telecommunications bridges between the Station, Stevenage and ESOC. The Supvis-Justin experiment (supervisory control of a semi-autonomous robot) was agreed and will be run jointly by ESA and DLR.

## International Berthing Docking Mechanism (IBDM)

The IBDM development is being focused on its application to the Sierra Nevada Corporation (SNC) Dream Chaser cargo resupply vehicle, selected by NASA in the Cargo Resupply Services 2 (CRS2) procurement. The terms of the agreement between ESA, European industry and SNC are being developed accordingly. The development contract with industry is being finalised. Indication of interest was received from other Member States to join the development. In addition, JAXA (for HTV-X) and Lockheed-Martin (for Orion) also expressed interest in IBDM.

### Lunar Exploration

The Platform for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) contract negotiations for Luna- 27 drill and instrumentation were completed. The first test models of the Precise and Intelligent Landing using Onboard Technology (PILOT) Landing Camera Demonstrator for the Luna-Glob Lander were manufactured and were shipped to IKI in Moscow in October. The first industrial assessments of robotic missions/elements beyond the Luna-Resource Lander (Lunar Polar Sample Return and a Lunar Volatile Prospector Rover) were completed.

## → SPACE SITUATIONAL AWARENESS (SSA)

### Space Weather (SWE)

Mission Design Reviews were carried out for both Phase-0 studies for the space weather missions to L1 and L5 points. Acceptance testing of new space weather products from the Expert Service Centre network continued in order to make the services available to the end users in October. Final presentation of the SSA Cost Benefit Analysis study was given in September. A benefit-to-cost ratio of 6.25 was estimated for the SSA Space Weather services for 2016–32.

### Near Earth Objects (NEO)

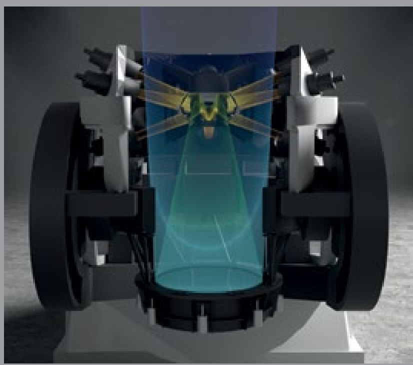
Two new tools were delivered to the NEO Coordination Centre. One allows the calculation of the impact corridor on the ground for potential impactors and the other is used for the 3D display of NEO close approaches. Another contract to develop additional software tools continued. NEO observations with cooperating sensors continued, including measurements of Object 2016 RB1 which approached Earth to within 34 000 km on 7 September. In September, a total of nine NEOs passed Earth within about one lunar distance, an unusually large number. The programme proposal for NEO activities during the SSA Period 3 was consolidated. A cost-benefit analysis for the SSA NEO segment was supported. Preparations for an ad-hoc working group on legal issues were made, initiated within the UN-mandated Space Mission Planning Advisory Group (SMPAG) and to be composed of space law experts with support from SMPAG technical expertise.

### Space Surveillance & Tracking (SST)

Activity for an expert centre for federated laser and optical systems is progressing towards CDR and procedures are being tested using ESA's robotic test-bed telescope at Cebreros. Supporting analysis and visualisation software is almost complete with acceptance tests scheduled. International standardisation activities are continuing also within the CEN/CENELEC. Integration, testing and validation of the data processing, planning, scheduling, catalogue querying and event detection software passed a first milestone with gap analysis finalisation.

### Radars and telescopes

The monostatic radar in Santorcaz (ES) and the bistatic radar near Paris (FR) will be used in an end-to-end measurement campaign to validate and compare overall performance. The corresponding contractual arrangements (CCN) have been placed, and therefore a small series of additional measurement campaigns can be performed at the end of 2016 or early 2017.

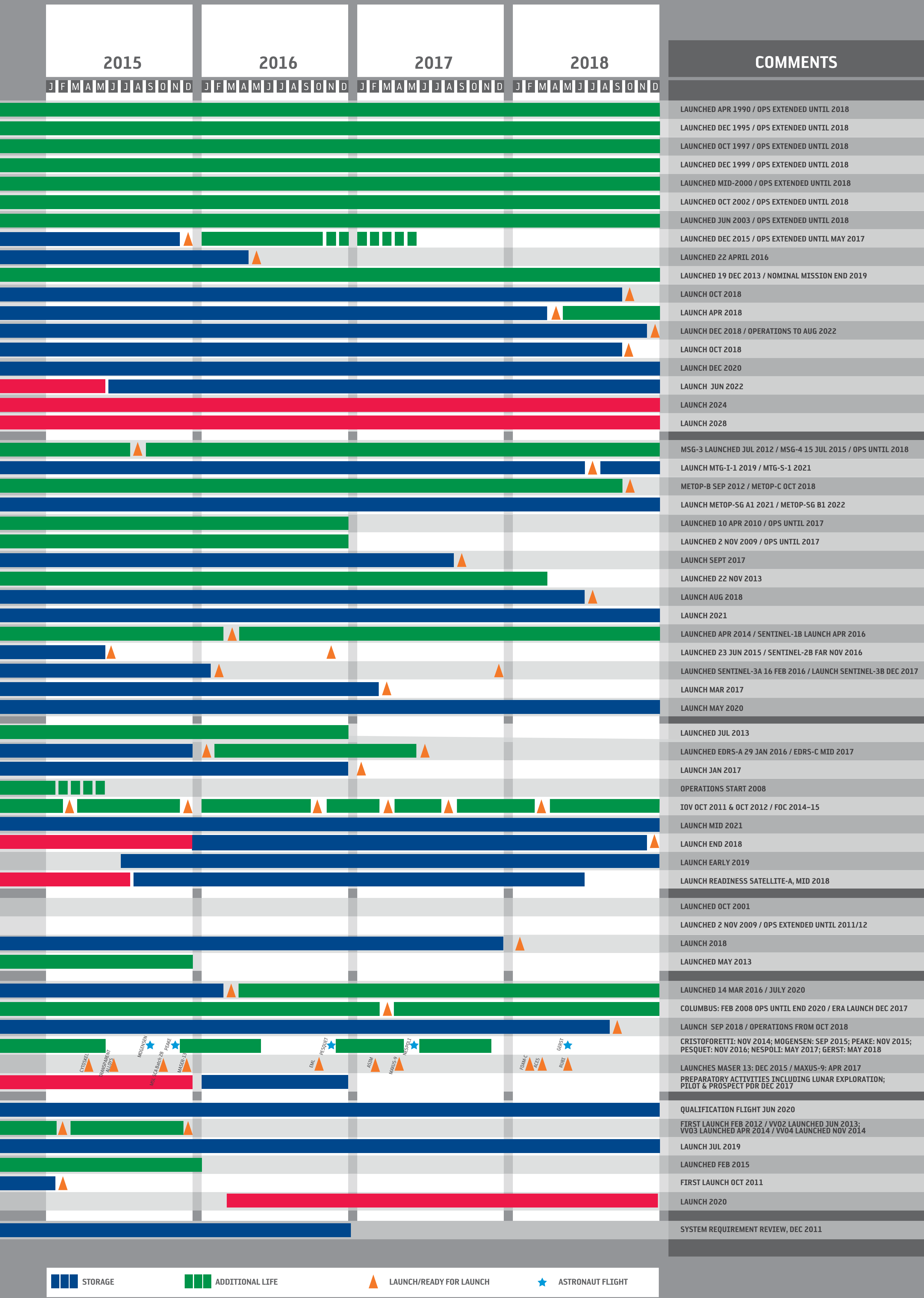


Schematic optical design of the Fly-Eye telescope. The entire field of view is split into multiple field of views

In July, the NEO-X (Fly-Eye) telescope passed the manufacturing readiness review and test campaigns were performed to characterise the critical hardware under specialised environmental conditions. Procurement of telescope elements and sub-system started. A site has not yet been identified for the Fly-Eye telescope, but a decision is required soon to allow an in-time site preparation. Candidate sites are Monte Mufara in Sicily (IT), La Palma (ES) and Tenerife (ES).


Future Fly-Eye telescope under development in ESA's SSA programme

2011
2012
2013
2014
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
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
LAUNCHER PROGRAMME
ARIANE 6
VEGA DEV. AND EXPL.
VEGA C
SOYUZ AT CSG
IXV
PRIDE
SSA
PERIOD 2
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
OPERATIONS



2015
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COMMENTS
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
LAUNCHED APR 1990 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 1995 / OPS EXTENDED UNTIL 2018
LAUNCHED OCT 1997 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 1999 / 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 APR 2018
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 UNTIL 2018
LAUNCH MTG-I-1 2019 / MTG-S-1 2021
METOP-B SEP 2012 / METOP-C OCT 2018
LAUNCH METOP-SG A1 2021 / METOP-SG B1 2022
LAUNCHED 10 APR 2010 / OPS UNTIL 2017
LAUNCHED 2 NOV 2009 / OPS UNTIL 2017
LAUNCH SEPT 2017
LAUNCHED 22 NOV 2013
LAUNCH AUG 2018
LAUNCH 2021
LAUNCHED APR 2014 / SENTINEL-1B LAUNCH APR 2016
LAUNCHED 23 JUN 2015 / SENTINEL-2B FAR NOV 2016
LAUNCHED SENTINEL-3A 16 FEB 2016 / LAUNCH SENTINEL-3B DEC 2017
LAUNCH MAR 2017
LAUNCH MAY 2020
LAUNCHED JUL 2013
LAUNCHED EDRS-A 29 JAN 2016 / EDRS-C MID 2017
LAUNCH JAN 2017
OPERATIONS START 2008
IOV OCT 2011 & OCT 2012 / FOC 2014–15
LAUNCH MID 2021
LAUNCH END 2018
LAUNCH EARLY 2019
LAUNCH READINESS SATELLITE-A, MID 2018
LAUNCHED OCT 2001
LAUNCHED 2 NOV 2009 / OPS EXTENDED UNTIL 2011/12
LAUNCH 2018
LAUNCHED MAY 2013
LAUNCHED 14 MAR 2016 / JULY 2020
COLUMBUS: FEB 2008 OPS UNTIL END 2020 / ERA LAUNCH DEC 2017
LAUNCH SEP 2018 / OPERATIONS FROM OCT 2018
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 DEC 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
STORAGE
ADDITIONAL LIFE
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