

number 170 | 2nd quarter 2017



bulletin

→ space for europe



European Space Agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European space organisations – the European Space Research Organisation (ESRO) and the European Launcher Development Organisation (ELDO). The Member States are Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Slovenia is an Associate Member. Canada takes part in some projects under a cooperation agreement. Bulgaria, Cyprus, Malta, Latvia, Lithuania and Slovakia have cooperation agreements with ESA.

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

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

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

The ESA headquarters are in Paris.

The major establishments of ESA are:

ESTEC, Noordwijk, Netherlands.

ESOC, Darmstadt, Germany.

ESRIN, Frascati, Italy.

ESAC, Madrid, Spain.

EAC, Cologne, Germany.

ECSAT, Harwell, United Kingdom.

ESA Redu, Belgium.

Chair of the Council:
Jean-Yves Le Gall

Director General:
Jan Woerner



On cover:
Launch of four Galileo satellites on Ariane 5
flight V233 from Europe's Spaceport in Kourou, French
Guiana, on 17 November 2016 (ESA–S. Corvaja)

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ESTEC, PO Box 299
2200 AG Noordwijk
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Tel: +31 71 565 3408

Email: contactesa@esa.int

Editor
Carl Walker

Assistant Editor
Ruth McAvinia

Designer
Emiliana Colucci

Organisation
www.esa.int/credits

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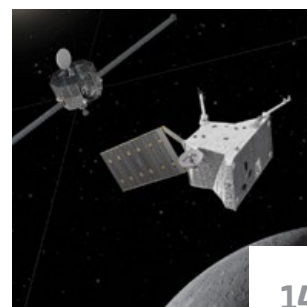
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→ LIVING THE SPACE DREAM

Paolo Nespoli's VITA mission

Nadjeđa Vicente

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

Carl Walker

Communications Department, ESTEC, Noordwijk, the Netherlands

Born in the same year that Sputnik marked the start of the Space Age, Paolo Nespoli shared the dream of many – he wanted to be an astronaut since he was a child. Now at age 60, he is living that dream for a third time.

ESA astronaut Paolo Nespoli grew up in the small town of Verano Brianza near Milan in northern Italy, fascinated by the television images of lunar rovers driving on the Moon during the Apollo era. As a schoolboy, he worked hard at his studies and had a great interest in technical subjects.

Drafted by the Italian army in 1977 as a non-commissioned officer, Paolo trained as a parachute instructor at the Scuola Militare di Paracadutismo of

Pisa. In 1980 he joined the 9° Paratroop Assault Regiment 'Col Moschin' of Livorno, where he became a Special Forces operator.

From 1982 to 1984, he was assigned to the Italian contingent of the Multinational Peacekeeping Force in Beirut, Lebanon. Following his return to Italy, he was received his commission as an officer and continued working as a Special Forces operator.

"For the first time in my life, I was really tested to the limit of my capabilities. Sure enough, every time someone pushed me to what I thought were my limits, I discovered that these were not my limits, those were the limits I thought were my limits but were not the real ones.



↑ Paolo joined the ESA Astronaut Corps in 1998 (left to right, Christer Fuglesang, Umberto Guidoni, Claude Nicollier, Gerhard Thiele, Hans Schlegel, Jean-François Clervoy, Jean-Pierre Haigneré, Léopold Eyharts, Thomas Reiter, Roberto Vittori and Paolo)

And so I discovered that after all I was able to operate in a highly operational environment. I was flexible, I was not intimidated by strange impossible situations,” said Paolo.

He learned that with enough knowledge, training and the right attitude, one could achieve almost anything. The dream of going into space resurfaced. Paolo resumed his university studies in 1985 and left active army duty in 1987.

Paolo received a Bachelor of Science in Aerospace Engineering in 1988 and a Master of Science in Aeronautics and Astronautics from the Polytechnic University of New York in 1989. Upon completing his Masters degree, he returned to Italy to work as a design engineer for Proel Tecnologie in Florence, where he conducted mechanical analyses and supported the qualification of the flight units of the Electron Gun Assembly, one of the main parts of the Italian space agency's Tethered Satellite System (which would fly on the Space Shuttle).

In 1991, he was accepted by ESA's European Astronaut Centre in Cologne, Germany as an astronaut training

engineer, where he contributed to basic training for the European astronauts. Paolo was responsible for the preparation and management of astronaut proficiency maintenance as well as the Astronaut Training Database, a system used for astronaut training.



↑ Paolo training at NASA's Johnson Space Center in Houston in 2001

THE ASTRONAUT

Name: **Paolo** Birth date: **6-4-1957**
Surname: **Nespoli** Nationality: **Italian**



Engineer



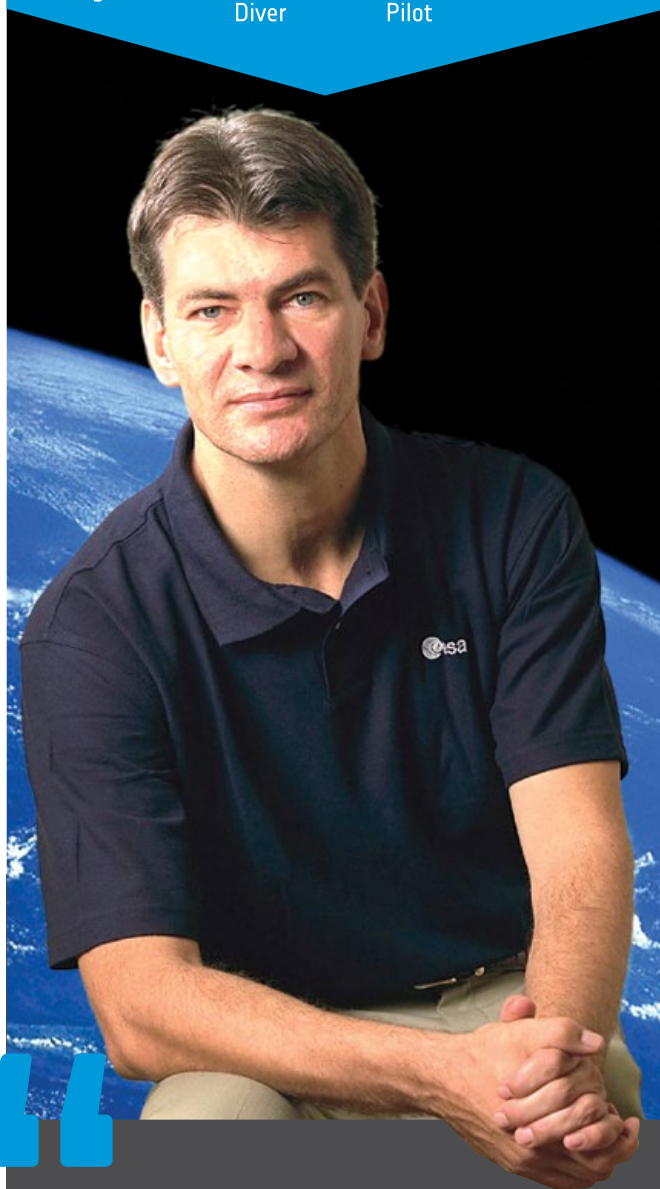
Scuba
Diver



Private
Pilot



Parachutist



In 1995, he worked on the EuroMir missions at ESA's ESTEC establishment in Noordwijk, the Netherlands, where he was responsible for the team that prepared, integrated and supported the Payload and Crew Support Computer used on Russia's Mir space station. In 1996, Paolo was transferred to NASA's Johnson Space Center in Houston, USA, where he worked in the Spaceflight Training Division on training crew for the International Space Station.

As a man of action with an engineer's mind, he applied twice to join the European astronaut corps. His stubbornness and preparation paid off on his third try – in July 1998, Paolo was selected as an astronaut by Italy's ASI space agency just at the time when all national agencies were merging their astronaut groups into one European Astronaut Corps. By August, he was an ESA astronaut based back at the European Astronaut Centre.

ESA astronauts were then training for flights either on the US Space Shuttle or the Russian Soyuz spacecraft, which meant many months spent in Houston or Moscow. Paolo found himself back at Johnson Space Center, but this time as a member of NASA's 17th astronaut class in the pipeline for assignment to a US Space Shuttle flight. In 2000, he qualified for missions on the Shuttle and to fly on the International Space Station. In July 2001, he completed the Space Shuttle robotics arm course and, in September 2003, completed advanced skills training for spacewalks.

In August 2004, Paolo was temporarily assigned to the Gagarin Cosmonaut Training Centre in Star City, near Moscow, Russia, where he followed the initial training for the Soyuz spacecraft. On returning to NASA's astronaut office in Houston, he was kept busy maintaining his qualifications, attending further courses and carrying out technical duties for NASA, ESA and ASI. Paolo's patience was rewarded in June 2006, when he was assigned to his first spaceflight, as a Mission Specialist on Space Shuttle *Discovery* for the STS-120 flight to the International Space Station.

Esperia

During the *Esperia* mission, from 23 October to 7 November 2007, Paolo played a key role inside the Station for the mission's spacewalks, and also performed a number of experiments for the European scientific community in human physiology and biology. At 188 cm, Paolo is the tallest European astronaut and one of the tallest ever (the record belongs to NASA astronaut Jim Wetherbee, at 193 cm). As his first mission, *Esperia* saw Paolo take part in building the International Space Station by installing the Italian-built Harmony module (also known as Node-2). This utility hub added much-needed living and working space to the orbital outpost, a fitting task for one of the tallest astronauts.

Every time someone pushed me to what I thought were my limits, I discovered that these were not my limits...



↑ Wearing a Shuttle launch and entry suit, Paolo awaits a training session for STS-120 in 2007 (NASA)



MagIStra

In November 2008, Paolo was assigned to his second spaceflight, Expedition 26/27. The long-duration MagIStra mission to the International Space Station was launched on 15 December 2010. As the third Italian astronaut to visit the orbital complex, Paolo's duties as a flight engineer included scientific experiments and technology demonstrations, as well as performing educational activities. After having spent 159 days in space, he returned to Earth on 24 May 2011.

→ Pioneering in space social media

During his MagIStra mission, Paolo took lots of photographs, and was the first ESA astronaut to use the Flickr platform for sharing his pictures, as well as being the first ESA astronaut to tweet. He took this iconic photo, the first taken of a Shuttle docked to the International Space Station plus an ESA ATV vehicle, from the perspective of his Soyuz TMA-20 spacecraft after undocking on 24 May 2011

(NASA/ESA)



← Paolo was assigned as a Mission Specialist for STS-120 in 2007



← Paolo prepares his EVA suit for spacewalk training in Houston for Expeditions 26/27 in 2010 (NASA)

Vita

In July 2015, Paolo was assigned a third spaceflight as part of Expeditions 52/53. He will be launched on a Soyuz vehicle this July on a five-month mission returning to

Earth in December 2017. This latest long-duration mission is part of a barter agreement between NASA and Italy's ASI space agency, and is the 10th for an ESA astronaut as well as Paolo's second.



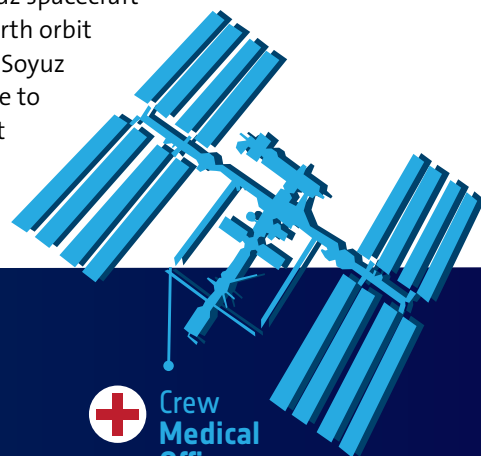
Paolo was assigned to Expedition 52/53 in July 2015 and began training in Houston (NASA –R. Geeseman)



↑ Paolo's crew for Soyuz MS-05, cosmonaut Sergei Ryazansky and NASA astronaut Randy Bresnik



He will share the ride on Soyuz MS-05 with crewmates cosmonaut Sergei Ryazansky and NASA astronaut Randy Bresnik. Being the tallest, Paolo will use every centimetre of space inside the Soyuz spacecraft that will take him to Earth orbit and to the Station. The Soyuz MS is the latest upgrade to the venerable vehicle. It is currently the only way astronauts



Mission Tasks

over
50
experiments

Hello!
Justin



Operate
a robot on Earth
from Space

Run
educational
activities



Crew
Medical
Officer



Maintain the
International
Space Station



↑ Traditions and final preparations: the Expedition 52 crew visit Red Square to lay roses at the site where Russian space icons are interred as part of traditional pre-launch ceremonies in July (NASA-B. Ingalls)

can travel to the outpost – the spacecraft has been used for crewed missions longer than any other. When it was first launched in 1967, Paolo was only 10 years old.

Paolo's mission name is 'Vita' which stands for Vitality, Innovation, Technology and Ability. The mission will certainly be full of vitality – the 60-year-old European astronaut will be involved in Station operations as part of a six-astronaut international crew and busy carrying out over 50 European experiments covering a range of scientific disciplines.

Vita's extensive scientific programme includes experiments in biology, human physiology as well as space environment monitoring, materials science and technology demonstrations. All of the experiments make use of the out-of-this-world laboratory (including the European Columbus module) to improve life on Earth or prepare for further human exploration of our Solar System.

When not performing science, Paolo will work with his colleagues to maintain the Space Station and keep the orbital outpost running smoothly for the crew of six.

→ ASTRONAUT TRAINING



200+

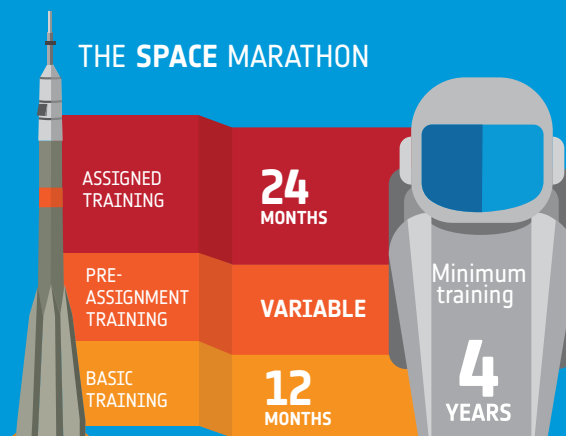
People involved in astronaut training across the globe



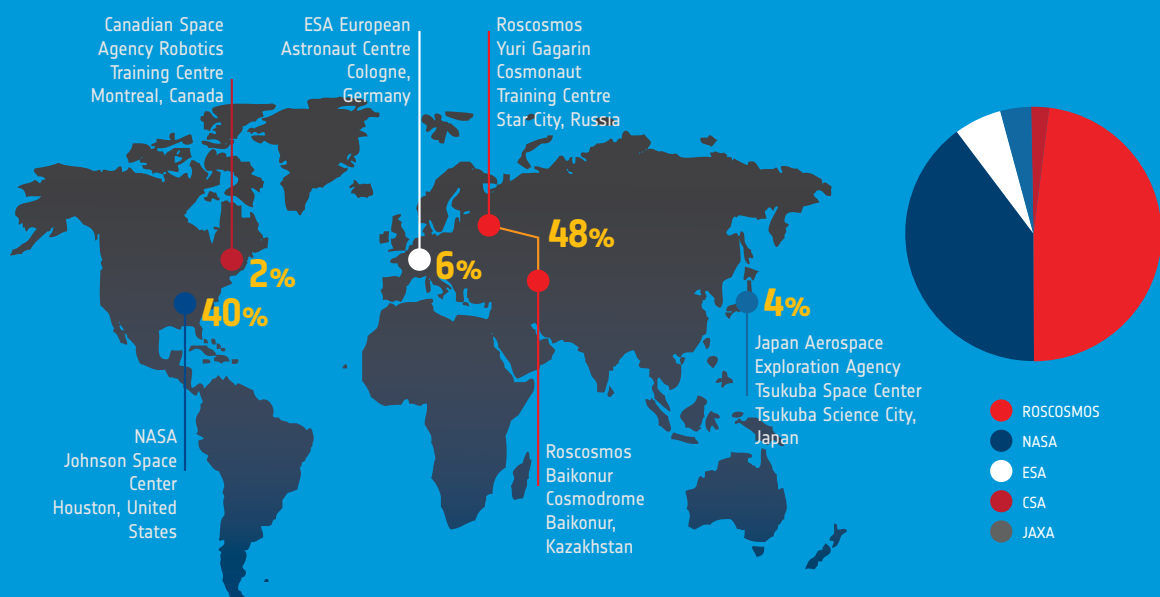
30+

Astronauts per year train at ESA's astronaut centre

THE SPACE MARATHON



Time spent at training site



Training for his third spaceflight has seen Paolo hanging in some strange positions...

These have included specialist training in USA, Japan and Europe. At far right he is on a tilt table at Star City in Moscow a few days before launch to help adjustment to microgravity.

Above, Paolo lived underground for a week in the CAVES 2013 exercise (ESA-V. Crobuz)







↑ Paolo makes a final inspection of his Soyuz spacecraft in the week before launch

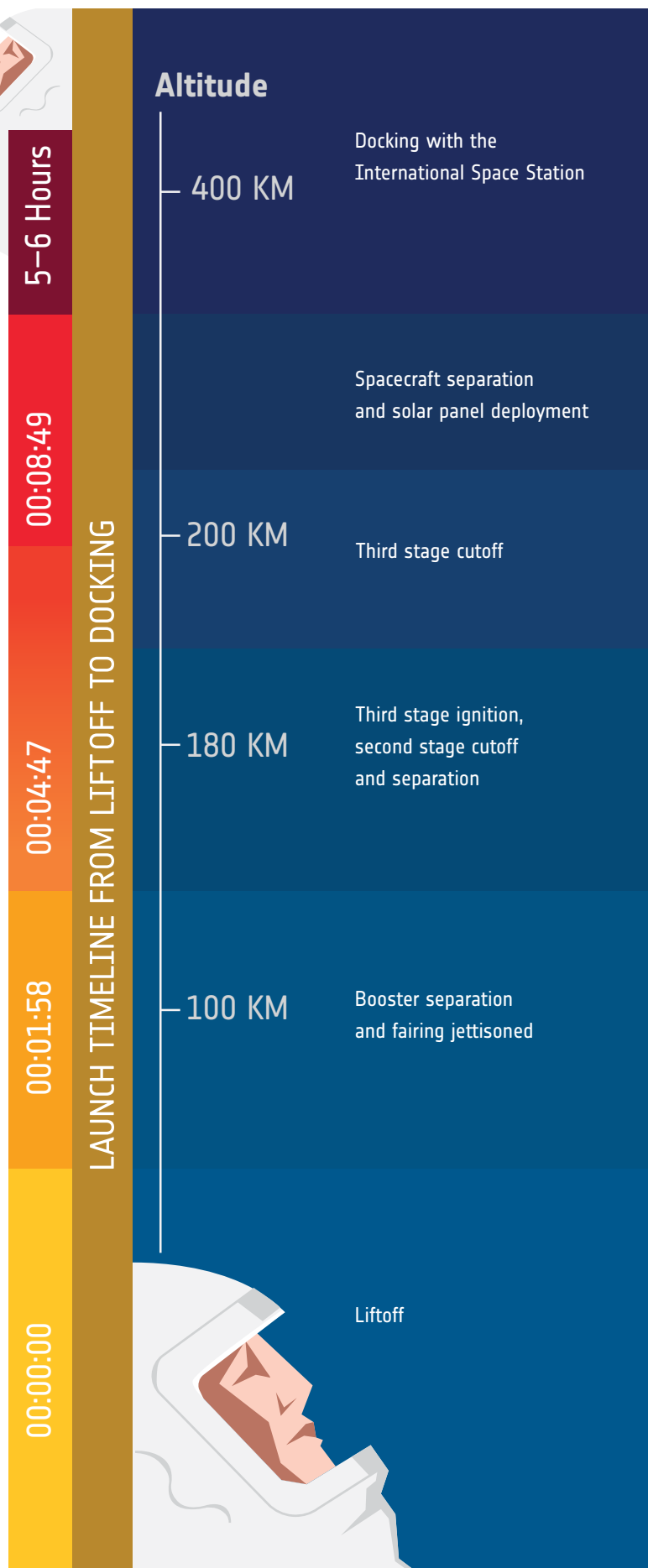
Paolo's unique home will allow him to inspire the next generation of engineers and scientists as he shares his journey with youngsters on Earth. He will encourage young generations to keep their brains active and follow a healthy lifestyle for two international challenges.

Paolo is supporting Mission-X: Train Like an Astronaut, an educational programme in which schoolchildren from more than 25 countries pursue science activities and learn how to get fit. He is also an ambassador for the European Astro Pi Challenge, a unique opportunity for European students to run their own code on Raspberry Pi mini computers installed in the Station.

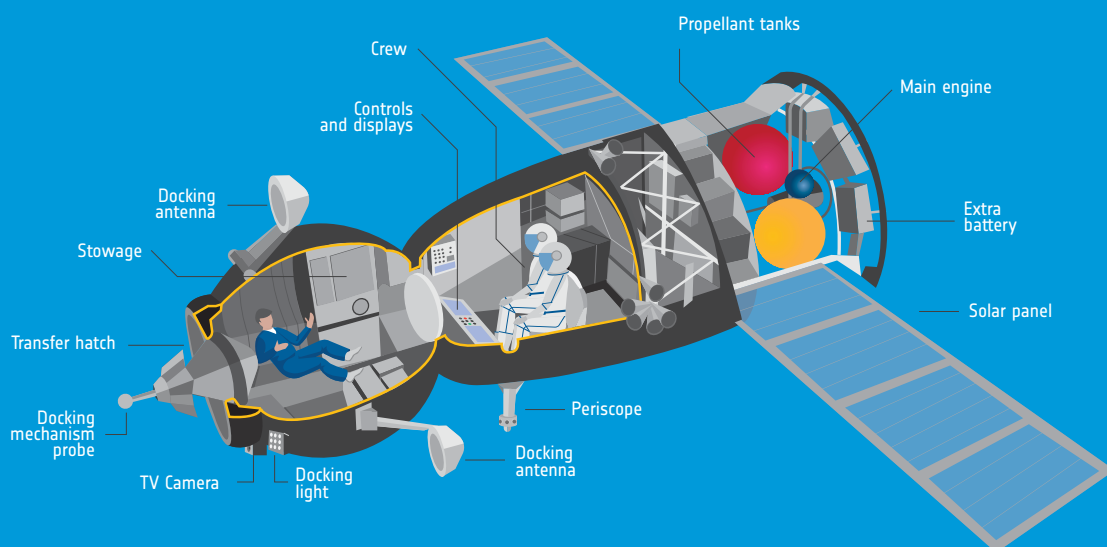
Vita also means 'life' in Italian. Indeed, Paolo's mission logo for Vita features the Third Paradise symbol by Italian artist Michelangelo Pistoletto summarising the mission's main themes: a strand of DNA as a symbol of life and science, a book as a symbol of culture and education, and Earth as a symbol of humanity.

These three elements perhaps also symbolise Paolo's third mission and his attitude towards living in outer space – and life in general. "I really look forward to being an extraterrestrial person again. This is the best way to end my career as an astronaut," says Paolo.

Nadjejde Vicente is an HE Space writer for ESA



The Russian **Soyuz MS** spacecraft is capable of transporting up to three people and limited cargo to and from the International Space Station.



SPECS

Habitable Volume: 10 m³

Maximum Diameter: 2.72 m

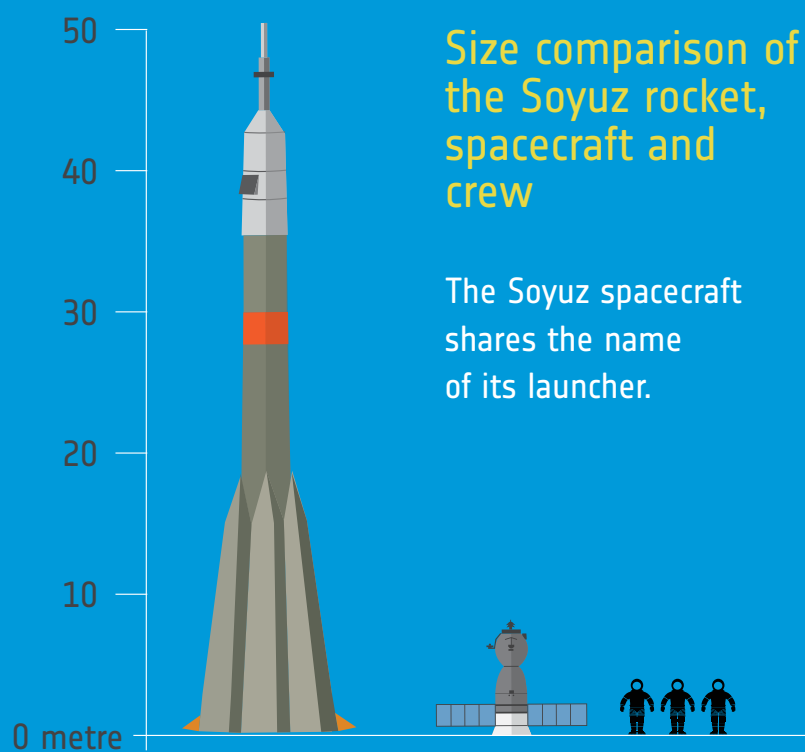
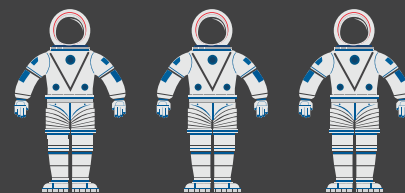
Main Engine Thrust: 2942 N

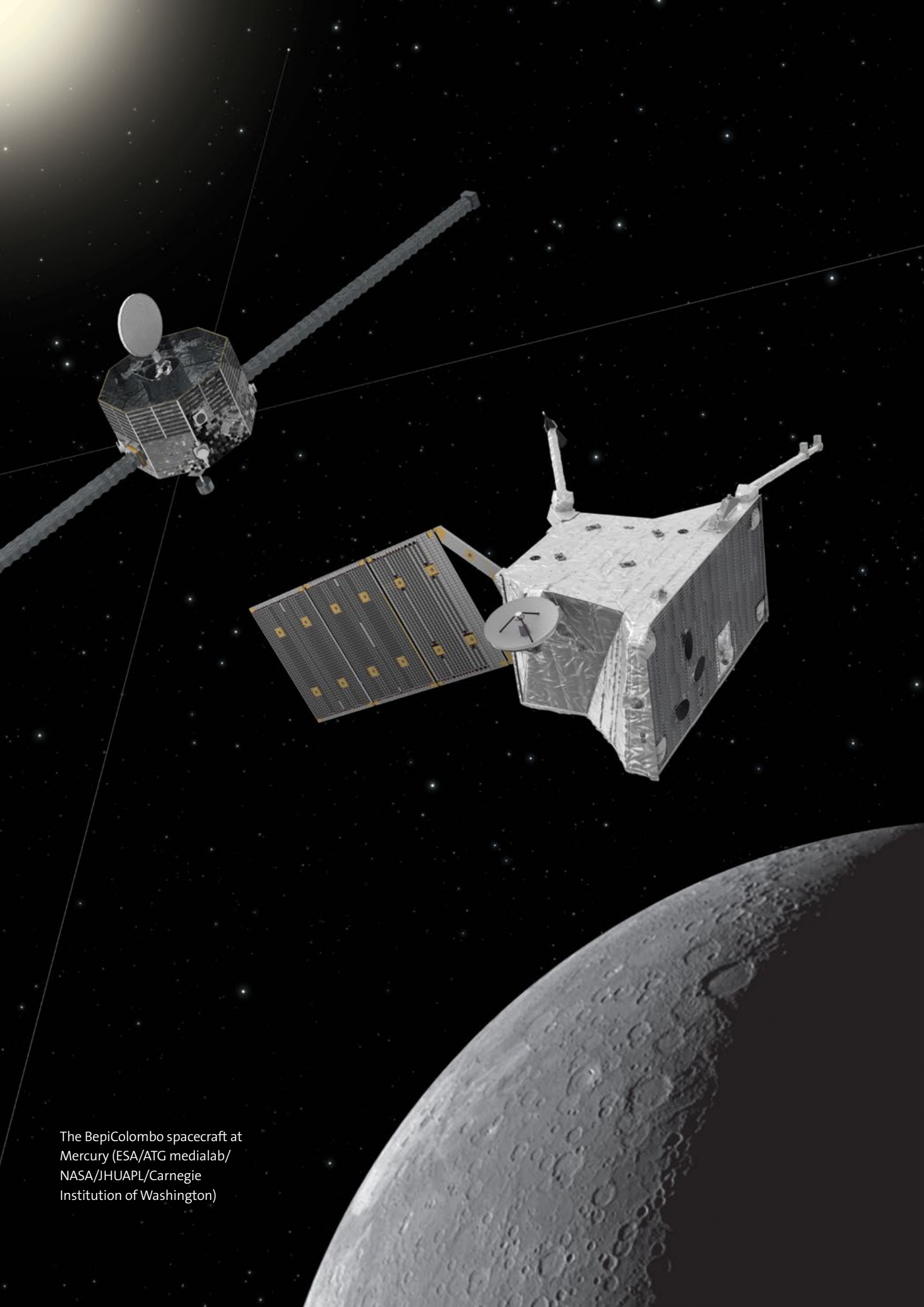
Engine Propellants: N₂O₄ / UDMH

Electrical System: Solar panels and batteries

Solar panels power: 0.60 kW average

CREW: 3





The BepiColombo spacecraft at Mercury (ESA/ATG medialab/
NASA/JHUAPL/Carnegie
Institution of Washington)

→ BEPICOLOMBO

Investigating Mercury's mysteries

Emily Baldwin

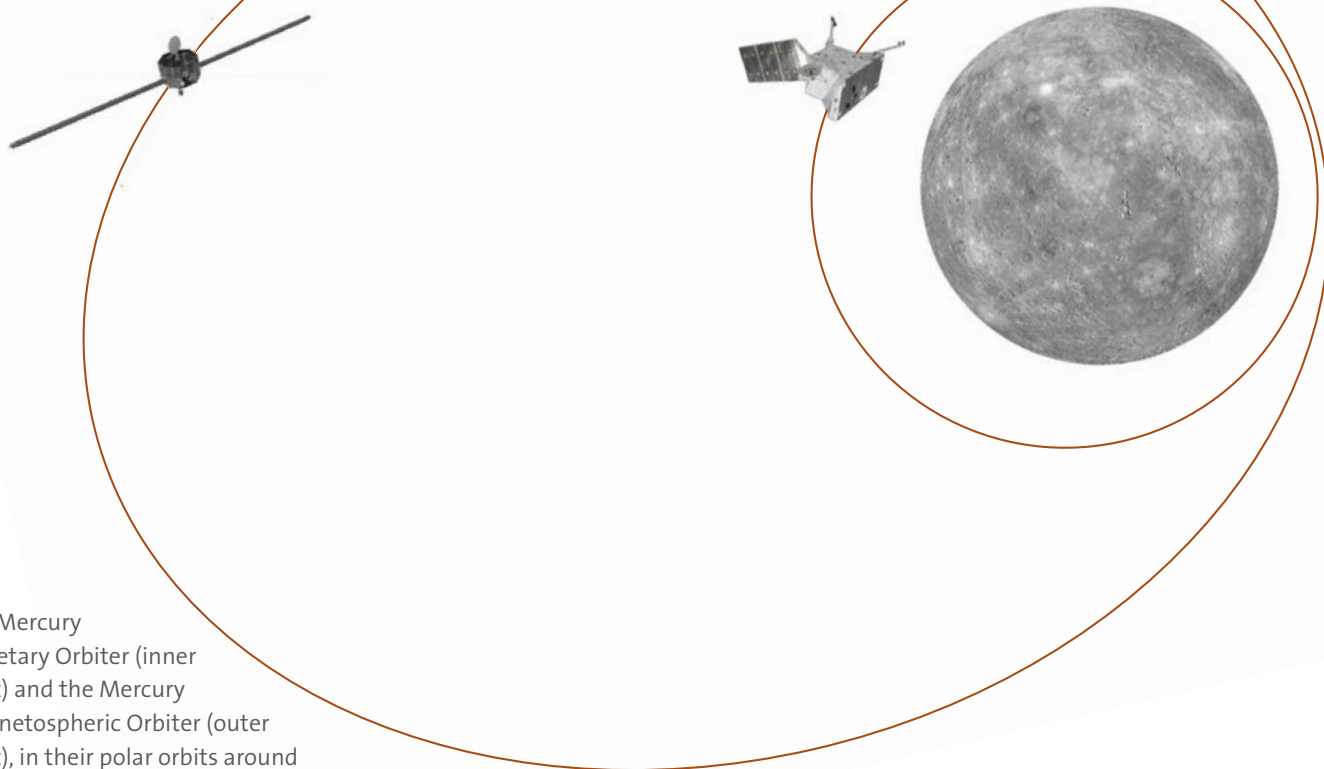
Communications Department, ESTEC, Noordwijk, the Netherlands

Europe will travel to new territory when BepiColombo launches to Mercury next year. A joint endeavour between ESA and the Japan Aerospace Exploration Agency, this mission will explore the planet's interior, surface, exosphere and magnetosphere.

Mercury is the smallest and least explored terrestrial planet in our Solar System. Only two spacecraft have visited: NASA's Mariner-10 and Messenger. Mariner-10 was a flyby mission and provided the first close-up images of the planet during three passes in 1974 and 1975.

Messenger also conducted three flybys – in 2008 and 2009 – before studying the planet from orbit between March 2011 and April 2015.

BepiColombo consists of two scientific orbiters: ESA's Mercury Planetary Orbiter (MPO) and JAXA's Mercury Magnetospheric Orbiter (MMO). The mission will build on the legacy of Messenger, providing complementary and new observations that will enable scientists to understand more about the origin and evolution of a planet located close to its parent star – as well as understanding more about the overall evolution of our Solar System.



The Mercury Planetary Orbiter (inner orbit) and the Mercury Magnetospheric Orbiter (outer orbit), in their polar orbits around Mercury (ESA/ATG medialab)

Electric propulsion to Mercury

The Sun's enormous gravity makes it difficult to place a spacecraft into a stable orbit around Mercury: even more energy is needed than for sending a mission to Pluto. BepiColombo will be launched on an Ariane 5 from Europe's Spaceport in Kourou, French Guiana. To reach Mercury, it will use the gravity of Earth, Venus and Mercury, in combination with the thrust provided by its electric propulsion system.

MTM's ion thrusters will be used during the cruise phase and for delivering the two spacecraft to Mercury. Ion propulsion was first demonstrated by ESA's SMART-1 mission to the Moon. The low-thrust nature of the ion propulsion means that it will take a long time to reduce the velocity of BepiColombo as it approaches the Sun. Based on an October 2018 launch date, the spacecraft will have a 7.2-year cruise, with one Earth flyby, two Venus flybys and six Mercury flybys before arriving in orbit at the end of 2025.

The MPO and MMO will voyage to Mercury together as a single composite spacecraft, with a dedicated transfer module (MTM) providing power and propulsion. A sunshield will protect the MMO from solar radiation and overheating during the cruise phase; this will be discarded once the craft is in orbit around Mercury.

When approaching Mercury, the MTM will separate and the two orbiters, still together, will be captured in a polar orbit around the planet. Their altitude will be adjusted using the MPO's thrusters until the MMO's desired elliptical polar orbit of $590 \times 11\,640$ km above the planet is reached. The MPO will then separate and descend to its own 480×1500 km orbit using its thrusters. The fine-tuning of the orbits is expected to take a further three months. The initial mission at Mercury is planned for one Earth year – about four Mercury years, and it may be extended for another Earth year.

Taking the heat

Most of ESA's previous interplanetary missions have been to relatively cold parts of the Solar System. BepiColombo is a new challenge. At Mercury the spacecraft will endure temperatures in excess of 350°C . To cope with this, external items, such as the antennas, solar arrays, Sun sensors and multilayer insulation, must have temperature-resistant outer layers and protective coatings. These had to be individually qualified to prove their capability.

The solar array on the transfer module needs to get just the right amount of Sun. Because of the high solar intensity travelling towards the Sun, the panels cannot directly face the Sun without overheating. Instead, they have to be rotated away and so need a large area to meet the power requirements of the spacecraft – its two wings together total 42 m^2 .



MPO undergoing electromagnetic compatibility, radiated emission and susceptibility testing



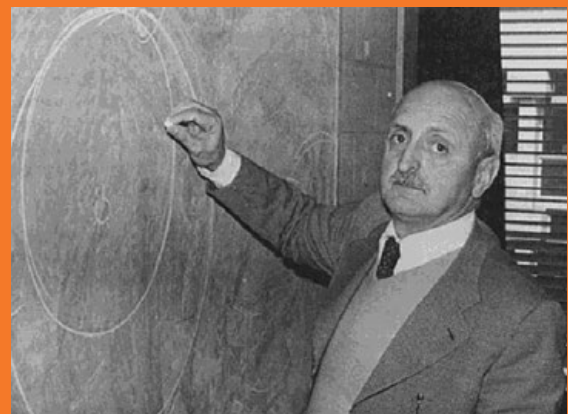
The MPO is a three-axis stabilised spacecraft with one side facing Mercury. It is equipped with a radiator at the upper limit of size compatible with the Ariane 5 fairing diameter. It is specially designed to reflect heat directionally, allowing the spacecraft to fly at low altitude over the hot surface of the planet. Heat generated by spacecraft subsystems and payload components, as well as heat that comes from the Sun and Mercury and 'leaks' through the blankets into the spacecraft, is carried away to the radiator by heat pipes. Most science instruments are mounted on the side of the spacecraft pointing at Mercury. Certain instruments or sensors are located directly at the main radiator to achieve the low detector temperatures needed for sensitive observations.

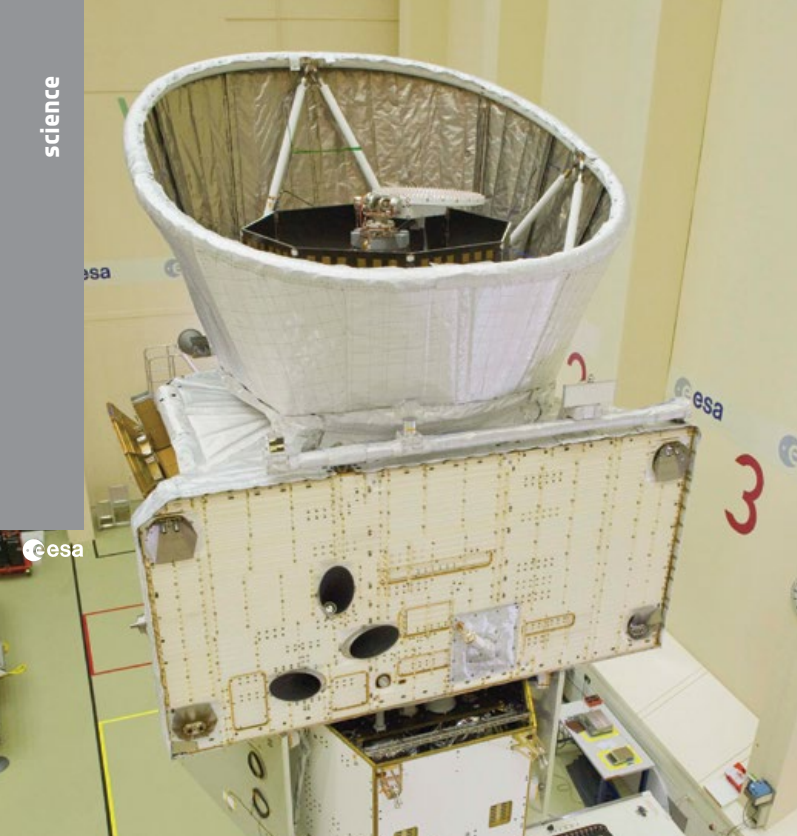
The MMO is an octagonal spin-stabilised spacecraft; its spin axis will be nearly perpendicular to Mercury's orbital plane around the Sun, ensuring that the 'top' and 'bottom' of the spacecraft are never Sun-pointed. Each of the eight side panels is fitted with solar cells. The areas that are not covered by solar cells have a mirror finish to reflect solar radiation. The spinning of the craft helps to evenly distribute the heat, a bit like roasting a pig on a spit. It will not be spinning during the cruise phase, but will instead be thermally protected by the sunshield for the journey.

The components of BepiColombo have undergone significant testing at ESA's test centre at ESTEC in the Netherlands to prove they can withstand all the hostile

→ Why BepiColombo?

The mission is named after the Italian mathematician and engineer Giuseppe (Bepi) Colombo (1920–84). He first explained Mercury's peculiar characteristic of rotating about its own axis three times in every two orbits of the Sun and also proposed interplanetary trajectories to NASA that would allow Mariner-10 multiple Mercury flybys by using gravity assists at Venus for the first time.





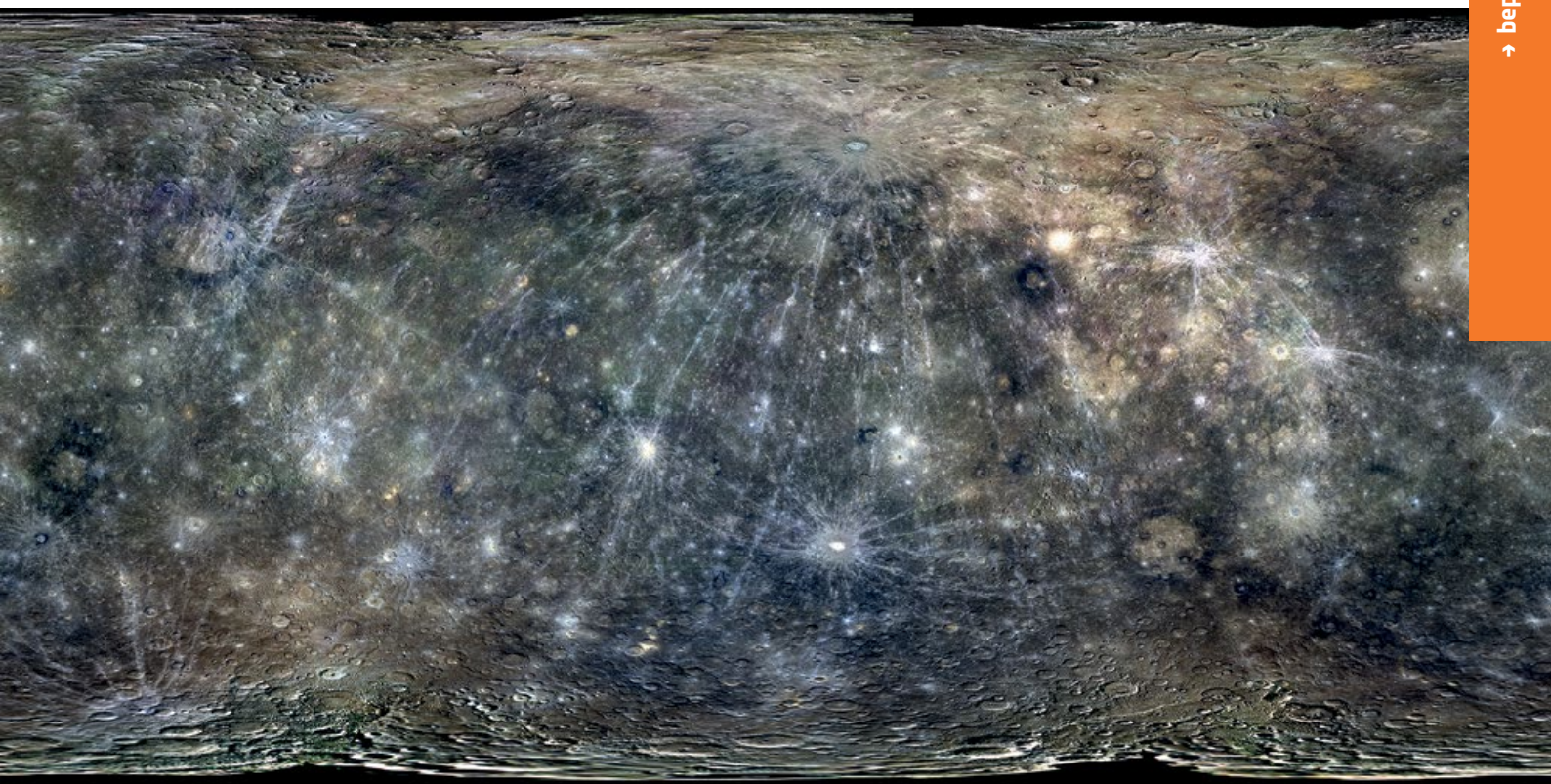
↑ The Structural and Thermal Models of the composite spacecraft fully integrated into the configuration in which BepiColombo will be launched. From top to bottom: MMO inside the solar shield, MPO and MTM, mounted on a test system (bottom) to determine the position of the spacecraft's centre of gravity



MMO (JAXA)



The MTM Structural and Thermal Model in ESTEC's Large Space Simulator, ahead of a 12-day Sun-simulation test



↑ Global colour mosaic of Mercury (NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

environments of the mission: the violent shaking occurring during launch, the harsh radiation environment of space, and the high temperatures that will be encountered close to the Sun once orbiting Mercury.

Meeting Mercury

BepiColombo will study all aspects of Mercury – from the structure and dynamics of its magnetosphere and how it interacts with the solar wind, to the origin of its magnetic field and the properties of the planet's large iron core. As the closest planet to the Sun, Mercury experiences extreme temperature variations at its surface, from about +430°C on the day side to −180°C on the night side, and even colder in permanently shadowed icy craters.

Its ancient, cratered surface shows signs of past volcanic and tectonic activity, and is heavily weathered by the harsh space environment. It will make global maps of the surface chemistry, and image features in order to better understand geological processes and how the surface has been modified over time by impact craters, tectonic activity, volcanism and polar ice deposits.

BepiColombo will build on the achievements of NASA's Messenger mission, which raised many questions scientists had not considered before. BepiColombo will help to find

the answers by providing new observations a decade later allowing for comparisons. Its two orbiters will be able to make simultaneous observations at different parts of the planet, giving unprecedented observations of the planet's magnetic field and the interaction of the solar wind.

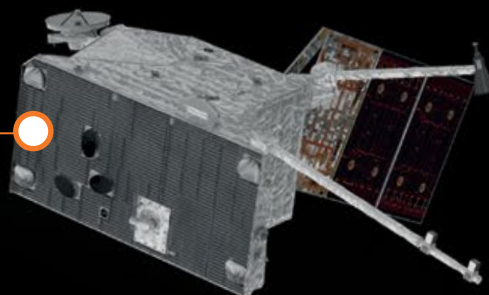
Other than Earth, Mercury is the only rocky planet in our Solar System to have a magnetic field today, although it is 100 times weaker than Earth's. Messenger observations showed that its centre of origin is offset from the centre of the planet by about 20% of its radius. ESA's MPO will orbit over the southern hemisphere of Mercury complementing data from Messenger, which reached its lowest altitude over the northern hemisphere.

The lower southern altitudes will also be important for observations of the surface, in particular of the south polar deposits. BepiColombo will determine the chemistry of the contrasting bright and dark deposits discovered by Messenger in the north polar regions, which are thought to be water ice.

The MPO's orbit is not highly elliptical and the instruments will be mainly pointing directly towards Mercury, reducing errors in height measurements of the surface topography. This will allow, for example, improvement of gravity and topography models, as well as give a higher-resolution coverage of surface features.

→ INTRODUCING THE FLEET

Mercury Planetary Orbiter



BELA: BEPICOLOMBO LASER ALTIMETER

Characterising and measuring the topography and surface morphology of Mercury to create digital terrain models (Switzerland/Germany)

ISA: ITALIAN SPRING ACCELEROMETER

Providing information on Mercury's interior structure and testing Einstein's theory of General Relativity to an unprecedented level of accuracy (Italy)

MPO-MAG: MAGNETIC FIELD INVESTIGATION

Measuring Mercury's magnetic field, the interaction of the solar wind, and the formation and dynamics of the magnetosphere, and understanding the origin, evolution and current state of the planet's interior (Germany)

MERTIS: MERCURY RADIOMETER AND THERMAL IMAGING SPECTROMETER

Detailing the mineralogical composition of Mercury's surface, its temperature and its thermal inertia, important for models of the origin and evolution of the planet (Germany)

MGNS: MERCURY GAMMA-RAY AND NEUTRON SPECTROMETER

Determining the elemental compositions of the surface and subsurface of Mercury, and identifying the regional distribution of volatiles in permanently shadowed polar regions (Russia)

MIXS: MERCURY IMAGING X-RAY SPECTROMETER

Producing a global map of Mercury's surface atomic composition at high spatial resolution (UK)

MORE: MERCURY ORBITER RADIO SCIENCE EXPERIMENT

Determining the gravity field of Mercury, and the size and physical state of its core; measuring the gravitational oblateness of the Sun and testing the most advanced interplanetary tracking system ever built (Italy)

PHEBUS: PROBING OF HERMEAN EXOSPHERE BY ULTRAVIOLET SPECTROSCOPY

Characterising Mercury's exosphere composition and dynamics and searching for surface ice layers in permanently shadowed regions of high-latitude craters (France)

SERENA: SEARCH FOR EXOSPHERE REFILLING AND EMITTED NEUTRAL ABUNDANCES (NEUTRAL AND IONISED PARTICLE ANALYSER)

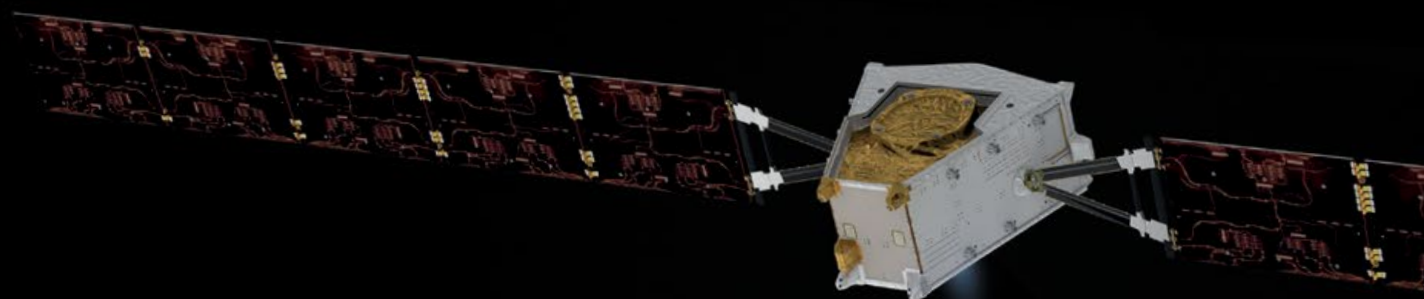
Studying the gaseous interaction between Mercury's surface, exosphere, magnetosphere and the solar wind and interplanetary medium (Italy)

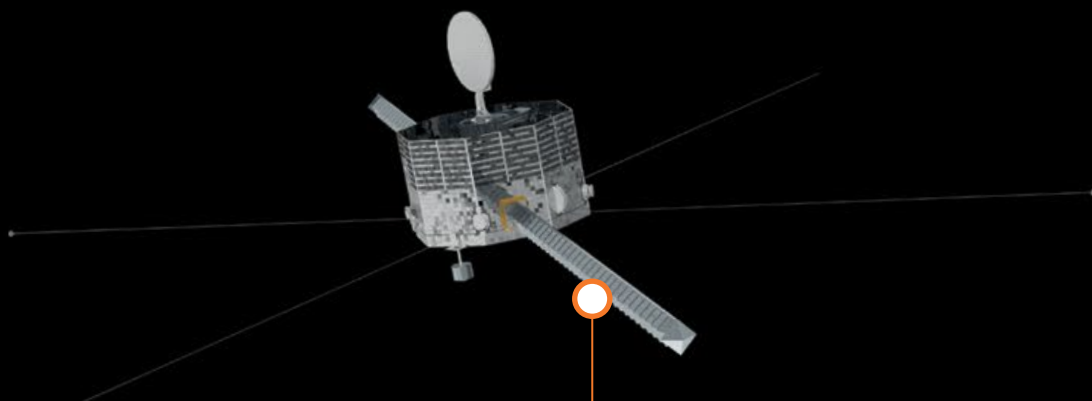
SIMBIO-SYS: SPECTROMETERS AND IMAGERS FOR MPO BEPICOLOMBO INTEGRATED OBSERVATORY

Examining with stereo and colour imaging, and spectroscopic analysis, Mercury's surface geology, volcanism, global tectonics, surface age and composition (Italy)

SIXS: SOLAR INTENSITY X-RAY AND PARTICLE SPECTROMETER

Monitoring the flux of X-rays and particles of solar origin (Finland)





Mercury Magnetospheric Orbiter

MMO-MAG: MERCURY MAGNETOMETER

Providing a detailed description of Mercury's magnetosphere and of its interaction with the planetary magnetic field and the solar wind (Austria)

MPPE: MERCURY PLASMA PARTICLE EXPERIMENT

Seven sensors studying plasma and energetic particles in the magnetosphere and the interaction between the solar wind and Mercury's magnetosphere (Japan)

PWI: MERCURY PLASMA WAVE INSTRUMENT

In situ and remote-sensing analysis of electric fields, plasma waves and radio waves in Mercury's plasma environment (Japan)

MSASI: MERCURY SODIUM ATMOSPHERE SPECTRAL IMAGER

Measuring the abundance, distribution and dynamics of sodium in Mercury's exosphere to investigate its sources and related processes (Japan)

MDM: MERCURY DUST MONITOR

Studying the distribution of interplanetary dust in the orbit of Mercury (Japan)



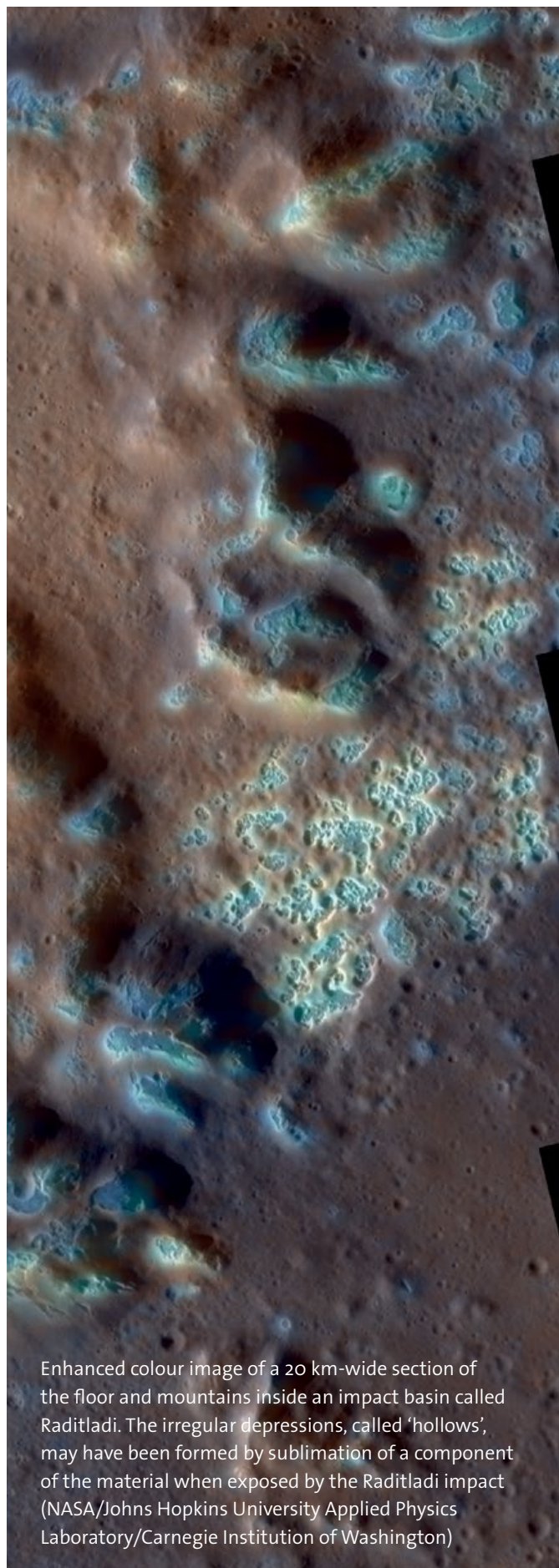
MMO Sunshield and Interface Structure

This ESA component will provide thermal protection and mechanical and electrical interfaces for the MMO during the journey to Mercury orbit

Mercury Transfer Module

This ESA module will carry the two orbiters to Mercury using solar-electric propulsion (ion thrusters)





Enhanced colour image of a 20 km-wide section of the floor and mountains inside an impact basin called Raditladi. The irregular depressions, called 'hollows', may have been formed by sublimation of a component of the material when exposed by the Raditladi impact (NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

New surface features

Another open question from Messenger is the origin of recently identified features termed 'hollows' – shallow, irregular depressions that appear to be unique to Mercury. They appear bright and young, but the exact process of their formation is an active area of research: their appearance suggests that material is somehow being lost from the surface.

We may understand more about how they form using BepiColombo's high-resolution imaging, and analysis of the chemistry of the materials associated with hollows. Detailed imaging will also be important for better understanding of the 'pitted terrain' associated with past volcanic activity, because BepiColombo can improve our understanding of the variations in volcanic eruptive style over time.

A shrinking planet

There is plenty of evidence that Mercury has been shrinking – its wrinkly surface features pointing to a contraction of the surface as the planet's interior has cooled.

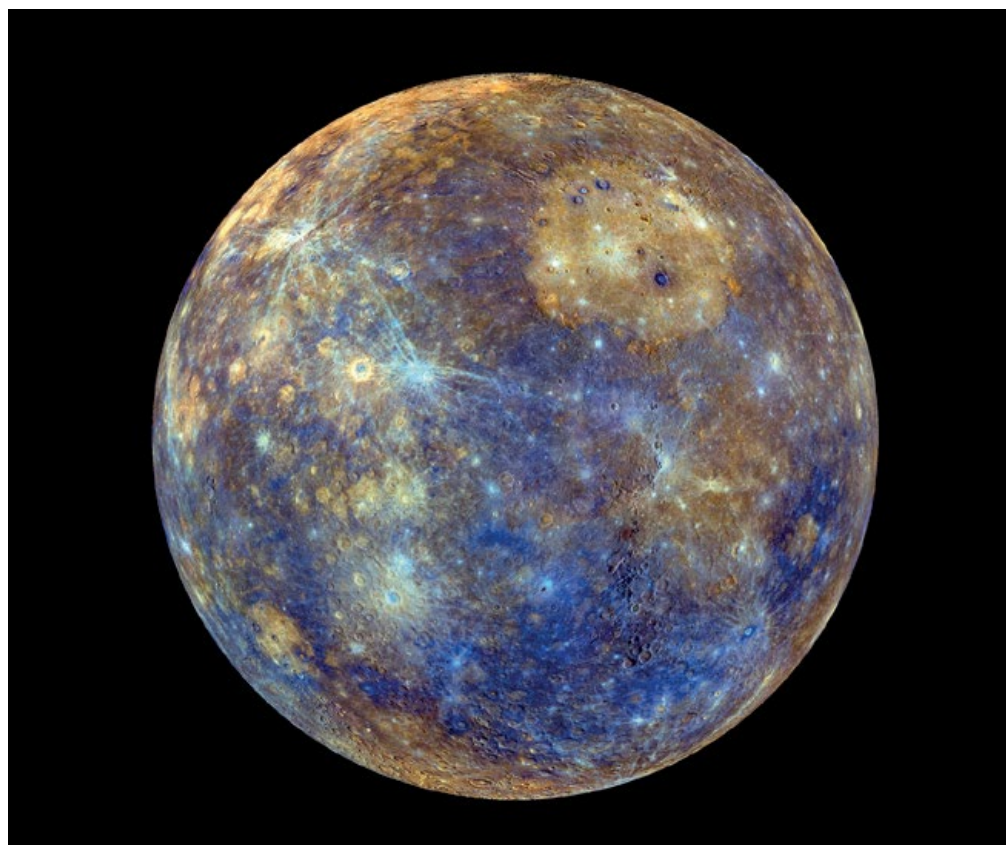
Messenger found that Mercury has contracted by as much as 7 km in radius since its crust formed, much more than previously believed. But how was this contraction distributed over time? BepiColombo's high-resolution imaging and topographic analysis will be particularly useful for identifying clues about features of different ages in the southern hemisphere, to add to the data acquired by Messenger.

What makes Mercury dark?

Mercury's global surface is much darker than would be predicted from its measured elemental composition, and several competing theories have been proposed to explain this. One early idea attributed it to carbon enrichment from comets, another to the bombardment of micrometeoroids over time.

Messenger's measurements implied that the darkening agent could be graphitic carbon. When Mercury was very young, much of the planet was so hot that there was likely a global 'ocean' of molten magma. As the ocean cooled, most minerals solidified and sank towards the core, but graphite would have floated to form a crust.

Abundant carbon on the surface suggests that remnants of Mercury's original ancient crust could be revealed in the volcanic rocks and impact ejecta observed on the surface today. BepiColombo is expected to follow up on these interesting observations, providing missing information regarding the nature and abundance of the carbon.



Enhanced colour image of Mercury, emphasising differences in surface composition. Blue is dark terrain; yellow is 'intermediate' terrain (including smoother plains/basins/lavas); white and grey correspond to young, fresh material recently excavated from craters (NASA/ Johns Hopkins Applied Physics Laboratory/ Carnegie Institution of Washington)

A tenuous atmosphere

Messenger made the first observations from orbit of Mercury's exosphere – an extremely thin 'atmosphere' that blends with the vacuum of space. The exosphere is constantly changing, influenced by the Sun and solar wind, as well as the bombardment of micrometeoroids that feed it with species such as sodium, potassium, calcium and magnesium. Messenger found that these species all exhibit different spatial distributions that do not fit with standard models.

BepiColombo will provide additional insight into the temporal evolution of the structure and composition of the exosphere over the course of a year at the planet, analysing the in situ density along the spacecraft trajectory. It is also expected to detect other species in the atmosphere. The spacecraft will study the interplay between surface processes and the variations in the exosphere, and provide missing observations of volatile species at high southern latitudes.

It will tackle questions such as: what is the role of solar events on electron impact and surface sputtering, and can this activity be identified in the exosphere? Does the exosphere vary with the Sun's radiation, solar pressure or meteoroid bombardment? Can surface composition be recognised in exosphere signatures? How do changes relate to day and night?

BepiColombo will also be able to test Einstein's theory of General Relativity to an unprecedented level of accuracy.

Massive objects such as the Sun cause a distortion in spacetime, which may be recorded in the frequency shift of radio signals travelling through space. Microwave radio links to and from the spacecraft will be able to determine BepiColombo's position to an accuracy of 15 cm, making it one of the most advanced interplanetary tracking systems ever built. The spacecraft's accelerometer will measure all inertial accelerations caused by the incoming visible solar radiation and by the planet's albedo acting on the orbiter, such that any relativistic forces can be determined very precisely. This is essential for accurate determination not only of the spacecraft's orbit, but also as a consequence the position of the planet as it moves around the Sun.

The spacecraft will also determine the gravity field of Mercury and its time variations from solar 'tides', along with local gravity anomalies, which will provide crucial constraints to models of the planet's internal structure.

Just as Messenger dramatically improved our knowledge of this fascinating world, no doubt BepiColombo in turn will find new surprises and make unexpected discoveries that will have important implications for our understanding of Mercury's place in our Solar System. ■

Emily Baldwin is an EJR-Quartz writer for ESA



Astronauts Peggy Whitson and Thomas Pesquet have fun during an Expedition 51 meal break (NASA/ESA)

→ HIGH CUISINE?

Why healthy food is important for astronauts

Nadjeida Vicente

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

Carl Walker

Communications Department, ESTEC, Noordwijk, the Netherlands

Space food has come a long way since 1961, when cosmonaut Yuri Gagarin became the first person in orbit and proved that humans could digest food in ‘weightlessness’.

But this was only the beginning of the space food challenge: in 50 years, we’ve seen space food progress from pastes squeezed out of tubes, to three-star dishes created by some of the world’s most renowned chefs. So what’s cooking for today’s astronauts?

The main role of food is, of course, to satisfy our physiological needs. Throughout history, explorers have had to deal with the daily struggle of how to get a good meal. The exploration of extreme and remote

environments has been defined by the availability of food. Severe lack of vitamin C, for example, killed millions of sailors during the Age of Sail, a period that saw expansive human migration.

Now in the age of space travel, a balanced and varied diet is even more important for astronauts. An incorrect estimate of their nutritional needs may be harmful to their health, causing tiredness, muscular atrophy, bone weakening, cardiovascular problems or deficiencies in their immune systems. As spaceflights extend to several months on the International Space Station, and perhaps to years on future trips to planetary bodies, getting the right kind of food could ultimately affect the outcomes of their space missions.

Microgravity and radiation are not easy on people. Loss of bone and muscle mass, and depleting nutrient stores such as protein, fat, minerals and vitamins, are among the negative side-effects of space travel. An astronaut's mood and stress levels can also affect their eating habits. Research shows that energy intake in orbit is usually lower than on Earth. An optimal diet, paired with constant exercise, helps counteract the impact spaceflight has on the human body.

Food is above all a physical need, but it can also have psychological benefits. A balanced diet helps the body and spirit feel better. Healthy and varied food also lowers stress, improving relationships among the team members.

A potted history of food in space

When the Soviet Union's Yuri Gagarin became the first human in space, he also ate the first meal in space. To prevent food from flying away and all over the spacecraft, the first flights served pureed foods in toothpaste-type tubes. For lunch on Vostok-1, Gagarin had three 160 g tubes that contained two servings of pureed meat and one of chocolate sauce.

The food that NASA's first astronauts had to eat in space was equally basic. John Glenn, the first US astronaut to eat in the microgravity environment of Earth orbit, found the task of eating fairly easy, but found the menu to be limited. Other Mercury astronauts had to endure bite-sized cubes coated with gelatin to prevent crumbs from escaping, or freeze-dried powders. They found that freeze-dried foods were hard to rehydrate and most astronauts agreed the foods were unappetising, and disliked squeezing the tubes.

On the Gemini missions, eating improved somewhat. The first things to go were the squeeze tubes that were often heavier than the food they contained. Bite-sized cubes were still coated to reduce crumbling, but the freeze-dried foods were encased in a special plastic packing to make reconstituting easier. The improved packaging and rehydration methods brought improved food quality and menus. Gemini astronauts had such food options as shrimp cocktail, soup puree, toast squares, bacon cubes, chicken and vegetables, butterscotch pudding and apple sauce, and were even able to select meal combinations themselves.

The Apollo programme of the late 1960s also improved the quality and variety of space food. Apollo astronauts were the first to use hot water for drinks and rehydrating foods. New packaging was also created, such as plastic zip-closure containers. These astronauts were also the first to use the 'spoon bowl', a plastic container they could open, eating the contents with a spoon, something they much appreciated.



1960s

NASA Gemini programme food in paste tube (NASA)

The whole eating experience improved dramatically with Skylab between 1973 and 1974. Unlike previous space vehicles for astronauts, Skylab featured a large interior area where space was available for dining. Crews could eat around a proper dining table and footholds allowed them to fix themselves around the table and 'sit' to eat. They used magnets to hold cutlery and other utensils down and scissors were introduced for cutting open plastic seals. Because Skylab was relatively large and had ample storage space, it could feature an extensive menu: 72 different food items, including steak and vanilla ice cream.

Skylab also featured the most sophisticated food storage system ever flown in space. A refrigerator and freezer were available, enabling astronauts to eat perishable items. Frozen and refrigerated meals were part of the menu for the first and only time in spaceflight. The Soviet space programme meanwhile stayed faithful to dehydrated and canned food.

Over time, on the Space Shuttle, space food became closer to what people eat on Earth. Space food had evolved to meet nutritional requirements while accommodating crew preferences. During longer stays in space, an increased variety of food became essential to boost crew morale and prevent them eating the same foods over and over (known as 'menu fatigue'). Crews had plenty of food choices and could design their own menus. Tubes and cubes gave way to canned and even fresh food. Astronauts were able to eat many foods that could be found at the supermarket, with additional treats like crackers, biscuits, cereal bars, chocolate and sweets.

1960s – 1970



1973

NASA astronaut Owen Garriott dines at the Skylab communal table (NASA)

The space food challenge

Space nutritionists have had a significant challenge since the earliest days of space exploration to provide quality and variety, as well as make the food appetising for the crewmembers, and all within the restrictions in weight and volume for what could be sent to space. This is where technology and experience come in.

So what foods do astronauts need? Astronauts generally need the same number of calories during a spaceflight as they need on Earth. Fats, proteins and carbohydrates provide energy to keep up their activities on the International Space Station.

Energy intake can differ for each person. The World Health Organization estimates energy requirements and issues recommendations based on a formula, indicating that, depending on their activity level, an 80 kg male astronaut needs about 3000 calories a day, while a 60 kg female astronaut needs about 2100 calories a day. Astronauts venturing out into space on spacewalks need higher energy intakes.

A spacewalk places great demands on the body and working outside the International Space Station is an extensive upper body workout. Spacewalks can last up to nine hours, and the astronauts will not be able to eat during all this time, so nutritionists recommend eating an extra 500 calories on a spacewalk day, preferably just before putting the helmets on. The spacesuit contains one litre of drinking water in a bag for the astronaut.



Gagarin:
3 tubes



FOOD TOOLS

Gemini:
Tubes, dehydrated cubes in plastic bags



Apollo:
Tubes, dehydrated cubes in plastic bags + hot water and spoon





1975

The Skylab combined food tray and heater (NASA)



1975

NASA astronauts Tom Stafford and Deke Slayton share Apollo-style food during the Apollo-Soyuz Test Project flight (NASA)

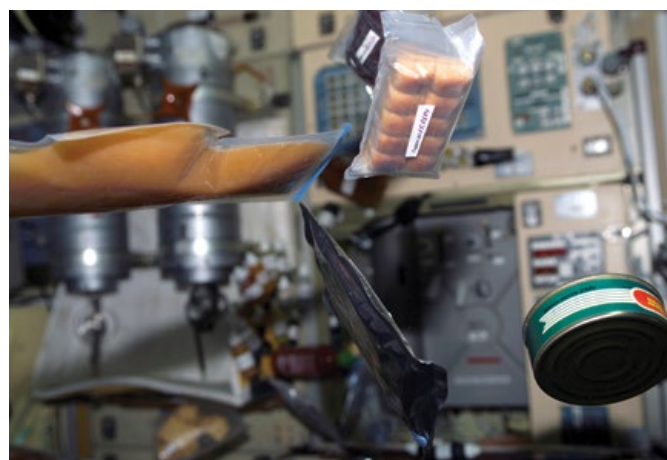
Getting enough vitamins and minerals plays a significant role to counter the effects of microgravity on astronaut bones and muscles. Almost 99% of the calcium in the human body is found in our bones. The body's ability to absorb this nutrient decreases in orbit. Scientists are researching ways to provide astronauts with the right nutrients for stronger bones. Recommended allowances for calcium in space are 1200 mg day, slightly higher than on Earth, in combination with a maximum intake of 1500 mg of phosphorous.

Vitamin K is important in blood clotting and produces proteins that hold calcium in the body. European scientists are investigating whether it can prevent bone loss in astronauts and the elderly. Vitamin K can be found in vegetable oils and green leafy vegetables, such as broccoli and spinach, but also in fish and chicken products. Vitamin D is produced in the skin after exposure to sunlight and is very important for bones, in part because it helps absorb calcium from the diet. Because the windows of the International Space Station block parts of the solar spectrum, astronauts don't get enough vitamin D. Astronauts have to consume 25 micrograms per day by taking vitamin D supplements and from certain foods such as oily fish. Antioxidants are substances that slow or stop oxidation in the body. The antioxidant properties of vitamin E may help against free-radical damage caused during spacewalks. Natural, colourful foods are usually good sources of antioxidants. An astronaut's menu includes beta-carotene found in carrots, zinc and vitamin E from nuts, and vitamin C in strawberries.

An unbalanced consumption of protein has detrimental effects on bone density and increases kidney stone

formation. Recommendations say protein intake in space should not exceed 35% of total energy intake. About a half should come from animal protein and the remaining from vegetable protein.

Crews are recommended to get 5 g of potassium per day from their space menus. This is to avoid heart complications similar to those encountered by astronauts on Apollo 15 during their flight to the Moon in 1971, when they suffered abnormal heart rhythms (arrhythmias) because of a lack of potassium in their diet.



↑ The three main kinds of food available: rehydratable, thermostabilised and canned, floating here during Expedition 7 (NASA)



1990s

Russian space food

What's special about space food?

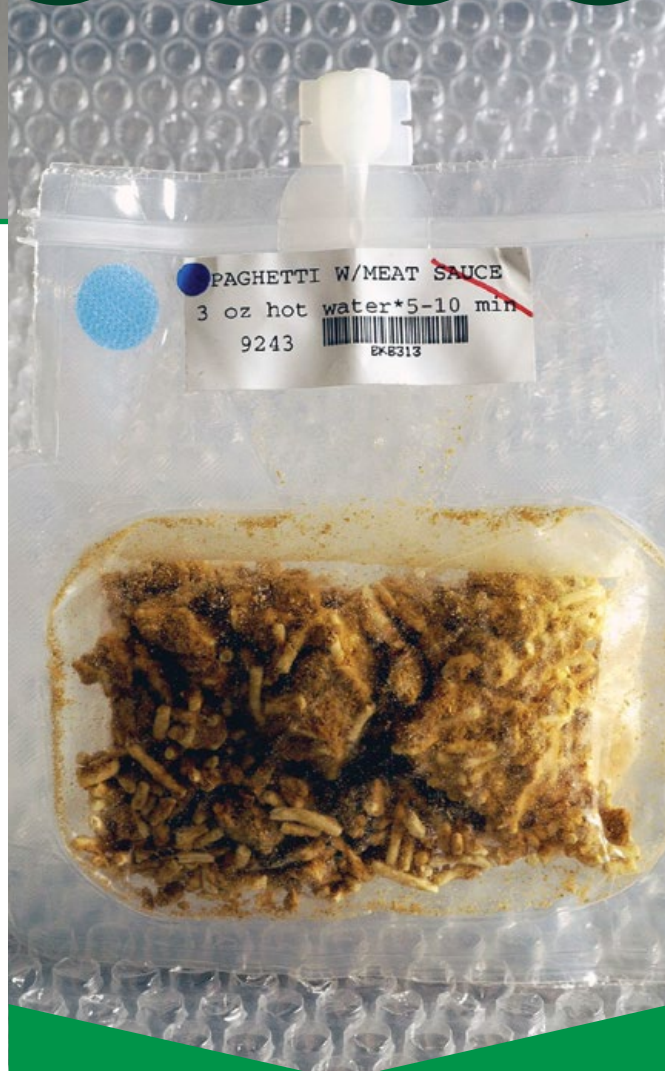
Not just any food can make the grade to be flown to the Space Station. Because of the weightless environment and the limited storage space on board, food and packaging need to be produced in a very specific way.

All foods going into space have to pass through a regime of tests to make sure they do not deteriorate over long periods of time. On launch day, the food must be good to eat for at least nine months without preservatives. Food particles should be tightly packed to avoid spilling into machinery. Every gram that is launched into space is precious, so saving weight is very important. The average weight of daily rations is 4 kg per person, including beverages.

Food for the Space Station originates mainly from the United States and Russia. A strict qualification process assures that all parts and products involved comply with safety requirements. For example, the food must be manufactured in laboratory conditions following the Hazard Analysis and Critical Control Point regulation (HACCP) put in place by NASA scientists in 1959. These guidelines analyse the raw materials as well as taking samples at critical points during processing where contamination can take place.

Bacteria are unwanted passengers in space. Food technicians neutralise germs by dehydration, sterilisation or radiation. These methods destroy microorganisms, but can also alter nutrients, taste and colour. Dieticians analyse the meals and make recommendations to ensure space food meets nutritional requirements.

1970 – 1990s



Skylab:

72 different foods (tubes, dehydrated cubes, canned and frozen/refrigerated meals)

+

Hot water, spoon, dining area, scissors, freezer/refrigerator

FOOD



TOOLS





2000s



Food packaging should be flexible and easy to handle in microgravity. Its design should maximise storage space. Wrappers and empty packages must be compressible to minimise space used for waste. The used packaging is usually bagged and placed in a cargo vehicle that burns up on reentry into Earth's atmosphere.

The menus include hundreds of types of foods and beverages. Crewmembers are not forced to follow the standard menu but can choose from it depending on their

tastes. ESA, along with the other international partner agencies, has made additions to the food list with extra items for long-duration missions (which has included inviting famous cooks to prepare special dishes for astronauts).

At least one year before their flights, crews attend tasting sessions to try the menus they helped to put together. Astronauts savour the samples, judging taste, consistency, size and presentation. Their inputs contribute



ESA astronaut Tim Peake (right) during a food tasting session with crewmate Tim Kopra (NASA)

FOOD



Hundreds types of foods and beverages (dehydrated, vacuum, canned, frozen/refrigerated and fresh)

TOOLS



Dining area, hot water, cutlery, scissors, freezer/refrigerator, oven, coffee machine



2000

NASA Space Shuttle food and utensils (NASA)



2001

Space Station snacks, 2001 onwards (NASA)

to any changes made in the menu. Every food item has a barcode, which is then scanned, so that everything an astronaut eats is recorded. This is very useful in physiological experiments that require monitoring of food consumption during a flight.

The food is launched on cargo vehicles that visit the International Space Station several times a year. When new astronauts arrive on the Space Station, most of their food is already waiting for them stored in Zarya and Node-2 modules, having been delivered by Russian Progress vehicles or Dragon and Cygnus cargo vehicles commissioned by NASA. In the past, Europe's Automated Transfer Vehicles also carried special food packages.

Food choices

There are two categories of food available on the International Space Station: 'permanent' food and 'crew-specific' food. Permanent foods are those the astronauts use to compose their daily menus. They include main dishes, snacks, bread, fruits, sweets and drinks. Before going to space, the crew have tasted and scored all food items. Once in orbit, astronauts can select their favourite foods from this list.

In addition to the permanent food provided by NASA and Russian menus, crew-specific menus are chosen by each astronaut, either just for themselves or to share. This represents about 10% of their total provisions. Every month, the crew can access a container filled with



↑ ESA astronaut Tim Peake is happy with a fresh fruit delivery to the Station in 2016 (NASA/ESA)

commercial items, such as sweets, biscuits and crackers, which are not part of the standard menu. ESA provides crew-specific food to its astronauts with items from traditional European cuisines, including special dishes prepared by national chefs for each mission.

From time to time, astronauts share some of their crew-specific food with their colleagues, especially

during 'event' meals (birthdays, departures or arrivals of crew, end-of-year celebrations and so on). Recipes from different nationalities break the monotony of the standard menu. ESA's bonus food is highly appreciated among crews to give them a feeling of being at home. Sharing and enjoying their culinary traditions with their crewmates is part of the astronaut's experience.

Although astronauts are sent limited supplies of fresh fruit and vegetables, most of the food is dehydrated or freeze-dried and sealed in a watertight, easy-to-open packaging, either cans or plastic packets.

For the dehydrated food, the crew simply add water back to rehydrate each meal item in space. Soups, shrimp cocktail and scrambled eggs fall into this category. The packages have a one-way valve to prevent liquid from escaping when not in use.

Thermostabilised meals are heated to high temperatures to remove harmful microorganisms and enzymes before being packaged into cans, flexible bags or plastic cups. The food is usually eaten directly from the container.



↑ ESA astronaut Luca Parmitano

→ How do we eat in space?

Spaceflight affects almost every part of the body, but how about the way we eat? Despite initial fears of some scientists who were unsure astronauts could swallow food in 'weightlessness', our gastrointestinal system proved it could cope in space.

Swallowing and digestion rely far more on muscles inside the body than on gravity. Swallowing is a complex sequence that uses muscles in your tongue, pharynx and oesophagus to push the food you eat through you until it's safely in your stomach.

This process of muscle contractions is called 'peristalsis'. After swallowing, a ring of muscle fibres in the lower oesophagus closes, to stop the food and stomach acid coming back up again. Once safely inside your stomach, there are various valves and muscles that help digest your food and keep it moving in the right direction.

This works exactly the same in space, with the only exceptions being that food can take longer to pass through the digestive system. With astronaut's organs in constant suspension, absorption of nutrients does not take place as efficiently as on Earth.

Fluid shifts, in combination with less fluid intake, tend to decrease gastrointestinal movement. Other than that, the gastrointestinal system continues to break down digested food into its molecular components for absorption into the bloodstream.

Some astronauts report that taste changes in orbit, and that they like spicier foods. One theory is that fluid shifts congest the nose, affecting the sense of smell, an important element of taste. Some also tend to have a reduced appetite. One of the reasons might be that food is not being pulled to the lower part of the stomach.

ESA astronaut Tim Peake said: "Like every other system in our body, the digestive system will adapt to living in microgravity, and I think mine did a much better job of digesting food after a few days in space. Though after a meal you can definitely feel that your food sits more 'lightly' in your stomach and I learnt the hard way that you shouldn't run on the treadmill for at least an hour or two after eating!"



ESA astronaut
Claudie Haigneré
enjoys a coffee
drink during the
Andromède mission

MOUTH: Digestion starts

Teeth mash food, tongue manipulates it into a lump of food, or bolus, using saliva as lubrication

OESOPHAGUS

Propels the bolus down through the digestive tract

STOMACH

Walls churn the food. Stomach digests the food and secretes hydrogen ions, creating low acidity and hostile environment for unwanted bacteria

LIVER

Breaks down digested food before transferring it to the rest of the body

PANCREAS

Secretes digestive enzymes

INTESTINES

Absorb nutrients

GUT

Absorbs water and stores waste until defecation



From time to time, crewmembers get to taste fresh apples, walnuts and dried apricots. Fresh fruit and vegetables must be eaten within the first few days of arrival or they will spoil. The shelf-life of dried fruits is increased by reducing the amount of water available for bacteria. Some foods, like nuts, are irradiated with ionising radiation before being sent into space.

The dining experience

There are usually three balanced meals per day – breakfast, lunch and dinner – plus snacks that can be eaten at any time. Foods are typically consumed on a first-in, first-eaten basis. There are rarely leftovers, the crew either eat their whole meal or throw the rest away to minimise smell and microbial growth.

At meal times, astronauts gather around the food preparation area in the Russian Zvezda module. A fold-down table is equipped with food warmers to heat cans and packages. All food is ready to eat or can be prepared by simply adding water and heating.

Astronauts use forks and spoons to eat and pairs of scissors to open food packages. Velcro comes in handy to keep cutlery and containers stuck to the table. There is no need for a dishwasher in orbit: the packaging for the daily menu food is based on single-use, disposable containers.

Because the water supply is limited, eating utensils and food trays are cleaned with disinfecting wipes. When a meal is finished, all the waste goes into bags, which are stored for disposal on the departing cargo spacecraft.

→ Quick snacks: facts about food on board the Space station



A special oven has been developed so that astronauts can heat their food



Drinks come in powdered form and range from cappuccino and tea, to fruit smoothies and lemonade. Astronauts turn the powders into a drink by plugging it to the galley water dispenser



Astronauts use a straw to drink, which can either be 'opened' or 'closed' to keep liquid from floating around the cabin



There are no carbonated (fizzy) drinks on the Space Station – in space, bubbles do not separate from other fluids in the stomach which saves the crew from unpleasant 'wet burping'



Astronauts gathering around the food preparation area in the Russian Zvezda module during visit of STS-127 to Expedition 20 in 2009 (NASA)



Condiments such as salt and pepper are available but only in liquid form. Astronauts can also add ketchup, mayonnaise or Tabasco sauce for enhancing flavours



Drinking water on the Space Station is processed from urine and cabin-air condensation. Purification machines recycle it into ultra-clean water for human consumption



Tortillas are used instead of bread, because crumbs can be dangerous if they get stuck in equipment, caught in an astronaut's eye or are breathed in



There is no chilled water – astronauts drink it only hot or at room temperature



ESA astronaut Paolo Nespoli using the Space Station food warmer (NASA/ESA)



The Space Station Potable Water Dispenser (NASA)



ESA's Thomas Reiter, with cosmonaut Mikhail Tyurin (left) and NASA astronaut Michael Lopez-Alegria (right) of Expedition 14 in 2006 (NASA)





From time to time, astronauts share meals with colleagues, especially for celebration of birthdays, departures or arrivals of crew, or holidays. Here, Thomas Pesquet is in seasonal mood in 2016 (NASA/ESA)

Happy meals

With each new flight, astronauts take advantage of the lessons learnt from previous missions. These have highlighted that food is important not only from the nutritional point of view, but also as a matter of psychological comfort. Over the last decade, space agencies have become increasingly interested in this issue.

People generally feel more positive after eating, and eat more when feeling good. In space, when the demands on an astronaut are intense and stressful, proper nutrition may be neglected. Stress is commonly measured using methods such as heart rate, blood pressure and cortisol levels in saliva. Moods and emotions are checked by asking the astronauts to rate their feelings at a specific moment in a questionnaire.

From time to time, the whole crew will share meals. Evening or weekend meals are often the only times that all the astronauts will convene on the Station. Socialising during eating increases positive moods and is important for the astronauts' mental health.

A new generation of space food

In 2004, on ESA's DELTA mission to the Space Station, astronaut André Kuipers and his colleagues tested MEDIET, or the 'Mediterranean Diet' experiment.

Designed with ESA's help, this experiment brought to space a variety of Mediterranean foods together with



Food is really something that gives us a break. It's something where we find some joy and we are really trying to take some time for our meals.

Thomas Reiter – Expedition 14



↑ The MEDINET food tray

an innovative processing and packaging system and an ergonomic food tray. The result: fresh-tasting tomatoes, cheese and other foods made out of top quality Mediterranean products, which demonstrated that the ‘fast food’ of the space age could be delicious, nutritious and safe.

The MEDINET food was individually packaged in special space-qualified transparent plastic bags in meal-size portions. The food inside the bags was either pre-cut into a bite-size pieces (cheese, bread and chocolate), or had such a viscosity that it remained intact in weightlessness. For example, when the astronaut picked up a piece with a fork, the oil that the tomatoes were served in kept them in place, and the jelly served with the peaches prevented them floating away.

This new space menu was processed using the High Pressure Processing technique, which could eliminate bacteria without altering the properties of the fresh food.

This method of preservation provided reliable long-term storage at room temperature and preserved the fragile nutrients that could get damaged by other techniques such as pasteurisation. It also didn't affect the food's taste, texture or colour (in fact, the food items received the best grades from the astronauts in terms of smell, taste, texture, colour and overall appearance compared to other foods).

MEDINET showed how different food menus could be delivered to the Space Station to increase the variety of food available for the crews.

The space chefs

In August 2006, US chef **Emeril Lagasse** was invited to cook special dishes to be served on NASA Space Shuttle flights. At the same time, French chef **Alain Ducasse** teamed up with ESA and the French space agency CNES to create special gourmet food that could be used for celebratory meals on Expedition 14, which included astronaut Thomas Reiter, the first ESA astronaut to make a long-duration flight to the Space Station.

Ducasse created 13 new recipes for the astronauts, including spicy chicken with stir-fried Thai vegetables, quail roasted in wine, swordfish, and rice pudding with candied fruit. Packaged in tins, each dish was prepared according to the same strict hygiene requirements applied by the Americans and Russians to other space food.

“It was absolutely delicious and was a really nice treat for a Sunday evening. Food is really something that gives us a break,” reported Reiter. “It’s something where we find some joy and we are really trying to take some time for our meals.”

However, there was just one thing missing to complete a perfect meal. “We all agreed that we are enjoying this food,” Reiter added, “But we have no doubt that it would taste much better if we had some wine with it as well!”

Next up in 2007, to celebrate the addition of the Italian-built Node-2 module, the STS-120 Shuttle and Station crews were treated to a special Italian meal, courtesy of Italian ESA astronaut Paolo Nespoli. The meal, initiated by Italy's Accademia Italiana della Cucina, featured dishes selected by ESA, NASA and the Italian space agency ASI. The menu included some typically Italian foods such as olives, dried tomatoes, fettuccine and risotto.

In 2008, German chef **Harald Wohlfahrt** was contacted by ESA to provide some more new menus. Astronauts had asked for more soups and meat with sauce recipes, so Wohlfahrt created a special menu based on southern German cuisine, tailored to the astronauts' tastes. This included potato soup with black pudding, veal filet and vegetables in a balsamic vinegar sauce, a puree of white beans; and for dessert, plum compote with aniseed sauce.

ESA has continued to set up collaborations with star-studded chefs to produce food just for its astronauts, particularly reminders of their home country or their favourite meal on Earth.

For Luca Parmitano in 2013, Italian Michelin-starred chef **Davide Scabin** cooked up some classic recipes that were made spaceworthy by Argotec, the Turin-based company commissioned by ESA to prepare the bonus food for its astronauts. Luca and his colleagues feasted on lasagne,



Emeril Lagasse



Alain Ducasse



Harald Wohlfahrt



Davide Scabin

aubergine parmigiana, mushroom and pesto risotto, and caponata, with tiramisu for dessert.

In 2014, Argotec worked with Harald Wohlfahrt again for German ESA astronaut Alexander Gerst, using recipes from Alexander's friend Jörg Frankenbach, also a chef, from his hometown of Künzelsau. Italian chef **Stefano Polato** was recruited to work on Samantha Cristoforetti's food for her flight later the same year.

Davide Avino, managing director of Argotec, said, "We do the same for each astronaut: we meet with them as soon as we learn of the mission and ask them their preferences, then we meet again to taste samples and do a sensorial screening. For Alexander Gerst, we made spätzle: a familiar dish very much part of his culture and culinary traditions. Samantha is very keen on good nutrition: we tried to follow her expectations."

In 2015, Andreas Mogensen's bonus food included a main course, a dessert and a chocolate surprise conceived and prepared by Danish Michelin-star chef **Thorsten Schmidt**. With nine astronauts on the Station at the time of Andreas's mission, including one-year crew Scott Kelly and Mikhail Kornienko, Thorsten had big task on his plate.

Andreas Mogensen said, "I really wanted to bring some Danish food with me to give a Danish flavour to the mission but also to be able to gather all nine crew members on the Station, sharing a meal together and giving the long-duration astronauts something special."

Schmidt's meal consisted of brisket with cabbage, vanilla custard with rhubarb and 'Space Rocks' chocolate. When the chef learned about the new espresso coffee machine on the Space Station he decided to prepare something sweet that would go well with coffee together with his former colleague Palle Sørensen, a gold-medal winner at the world championships in chocolate art.

"We made some chocolates, which we called Space Rocks because they resembled meteorites. We made a personal Space Rock for each astronaut with a surprise in it. We asked the astronauts' wives and families to send greetings on paper so we could put it inside the chocolates.

"You can imagine how happy an unexpected handwritten letter can make you – and not just any text but from someone who is very dear to you. Both Palle and I wanted to create a personal moment for each astronaut, to surprise them pleasantly," said Schmidt.

For British ESA astronaut Tim Peake's Principia mission, a competition called The Great British Space Dinner was held in the UK for schoolchildren to devise a space menu. Tim chose the winning dishes he would like to eat in space,



↑ The ISSpresso was the first espresso coffee machine designed for use in space, produced by Argotec and Lavazza in a public-private partnership with ASI, the Italian space agency (NASA/ESA)



Stefano Polato



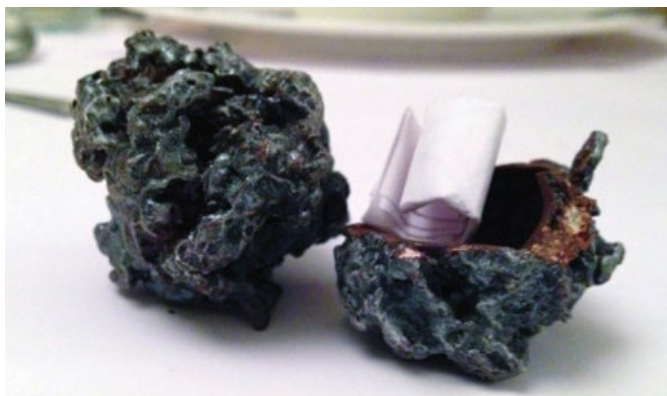
Thorsten Schmidt



Heston Blumenthal



Thierry Marx



↑ The Space Rocks chocolates designed for Andreas Mogensen's mission in 2015

I wanted to be able to gather all nine crew members on the Station, sharing a meal together and giving the long-duration astronauts something special

Andreas Mogensen - Soyuz TMA-18M

and British chef **Heston Blumenthal** was tasked with the technical challenges of producing them. Tim's favourite foods were the breakfast menus (scrambled eggs, baked beans and sausages) and Blumenthal's 'Space Dinners' salmon dish.

On the most recent ESA mission, French ESA astronaut Thomas Pesquet teamed up with chef **Thierry Marx** to create a dinner with French flavours. Thomas chose to take along a meal in his personal reserve for his six colleagues for Christmas and for New Year's Eve.

After Italian, German, Danish and British gastronomies were savoured by his colleagues of the class of 2009, Thomas honoured French cuisine with ox-tongue as an appetiser, chicken breasts with mushrooms and white wine sauce as a main course and to top it off, gingerbread for dessert.

Creating dishes that are attractive, tasty and varied while supplying the human body with all its needs is an essential and a rare skill. Nutritional technology has become a core competency at ESA and advances in nutritional science made by ESA have brought benefits back to Earth. As well as new food packaging, preservation and preparation techniques, advancements in nutritional science in meeting the challenges of space food has all resulted in many commercial products.

Not only that, space food also provides opportunities to increase international cooperation. In 2016, a cheesecake created for Thomas Pesquet's mission was sent into space to two Chinese astronauts on board the Tiangong-2 space station, and now there are plans for a European astronaut to enjoy a Chinese space meal on the International Space Station! ■

Nadjejde Vicente is an HE Space writer for ESA



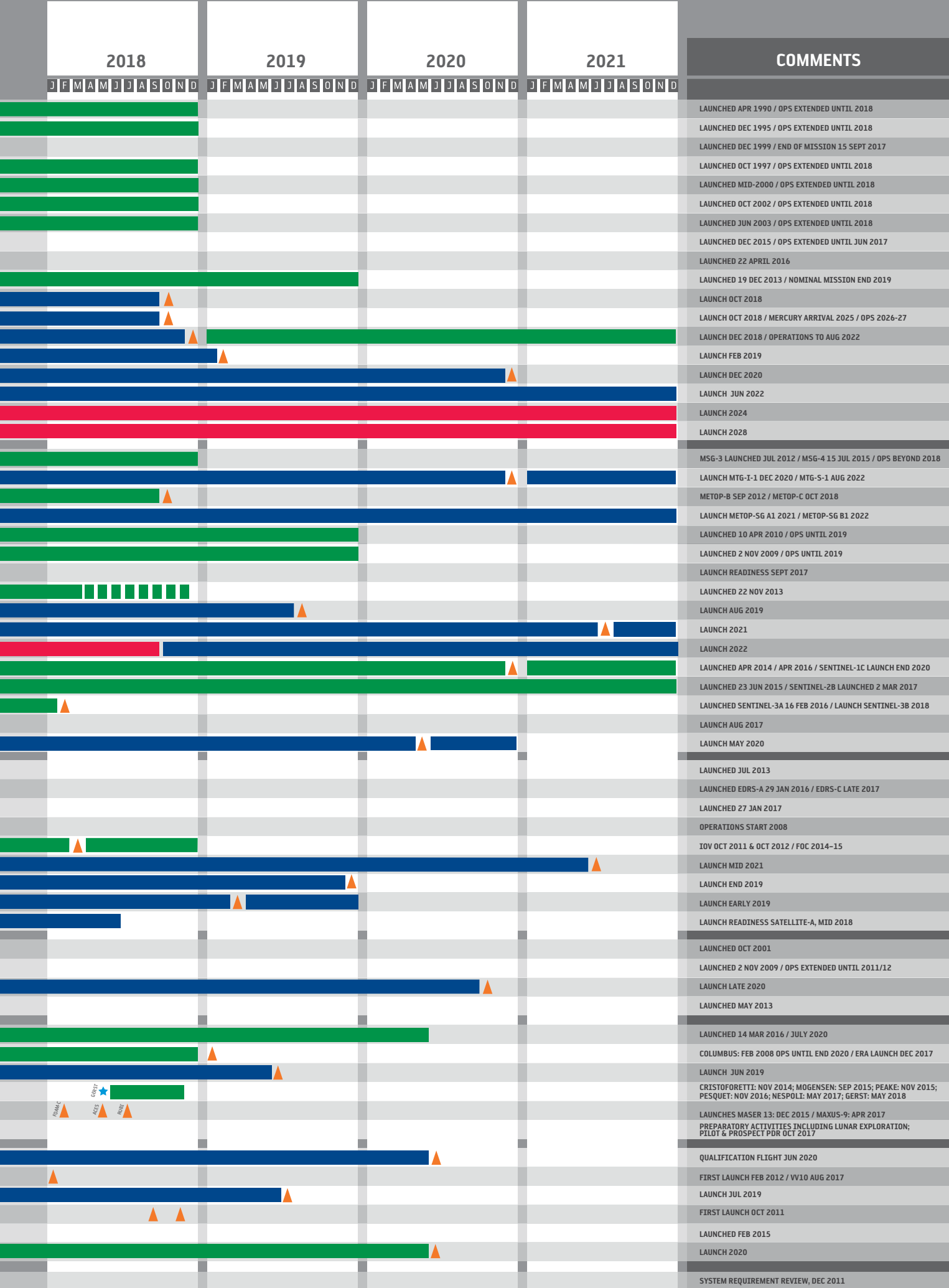
→ PROGRAMMES IN PROGRESS

Status at May 2017

James Webb Space Telescope
undergoing a 'lights out'
inspection at Goddard Space
Flight Center (NASA—C. Gunn)







KEY TO ACRONYMS

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

→ CASSINI

Cassini scientists have revealed the presence of thermal anomalies in the subsurface at the south pole of Enceladus, a few tens of kilometres north of the four active 'sulci' that are the source of the moon's geysers. These thermal anomalies had not been detected in infrared before.

Two or three of the prominent thermal anomalies coincide with large fractures, and are similar or structurally related to the active sulci. One could be a dormant sulcus, suggesting episodic geological activity. The thermal anomalies imply a broadly distributed heat production and transport system in the subsurface of the moon's south pole and suggest a thin ice shell there: the liquid ocean could be only a few kilometres beneath the surface.

→ XMM-NEWTON

The XMM-Newton and NuSTAR teams have made the most detailed observations ever of an ultra-fast wind flowing from the vicinity of a supermassive black hole at nearly a quarter of the speed of light. They studied the black hole for 17 days, revealing the extreme variability of the wind. They saw changes in the temperature of the wind that are almost certainly in response to changing amounts of X-ray emission from close to the black hole.

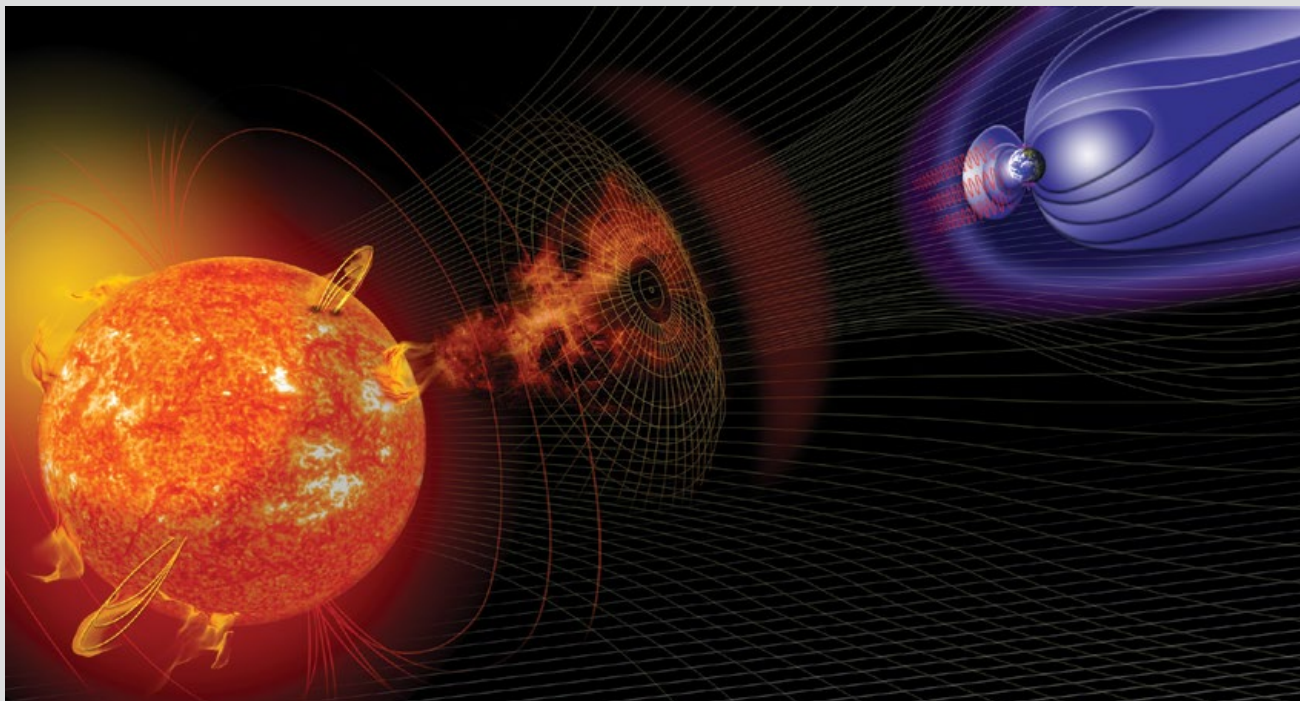
The study of these winds may provide insights into one of the most important questions in galactic astronomy: how does the central black hole in massive galaxies clear the surrounding gas and therefore suppress the formation of stars?

False-colour image of Enceladus highlighting the sulci, informally known as 'tiger stripes', in blue (NASA/JPL/SSI)



Illustration of a supermassive black hole with X-ray emission emanating from the inner disc regions (pink) and ultrafast winds streaming from the surrounding disk (purple)





Events on the Sun changing the conditions in near-Earth space (NASA)

→ CLUSTER

Magnetic clouds are a subset of coronal mass ejections (CMEs), characterised by a strong magnetic field. They are an important influence on space weather experienced at Earth, and understanding more about how they interact with Earth's environment will help predict their effects. The orientation of their magnetic fields – and in particular the presence of a southward B_z component, which is favourable to reconnection with Earth's magnetic field – is key to determining whether a magnetic cloud will trigger a geomagnetic storm.

Spacecraft such as ACE or Wind measure the magnetic field of magnetic clouds 1.5 million km from Earth. But magnetic clouds then cross the outer regions of the magnetosphere, namely the bow shock and the magnetosheath, which may alter their properties leading to incorrect space weather forecasting.

A database of spacecraft observations during magnetic cloud events has been studied in detail to investigate whether the magnetic field of magnetic clouds was altered when crossing the bow shock and the magnetosheath. It includes the first 14 years of the ESA Cluster mission, the CNSA/ESA Double Star TC1, and other missions.

The analysis of 82 magnetic clouds with simultaneous observations in the solar wind and the magnetosheath shows that their magnetic field direction can be significantly

modified when the bow shock is in a quasi-parallel configuration. More work is needed to check potential effects on the development of magnetic storms triggered by such CMEs and magnetic clouds, which is an essential aspect of space weather prediction.

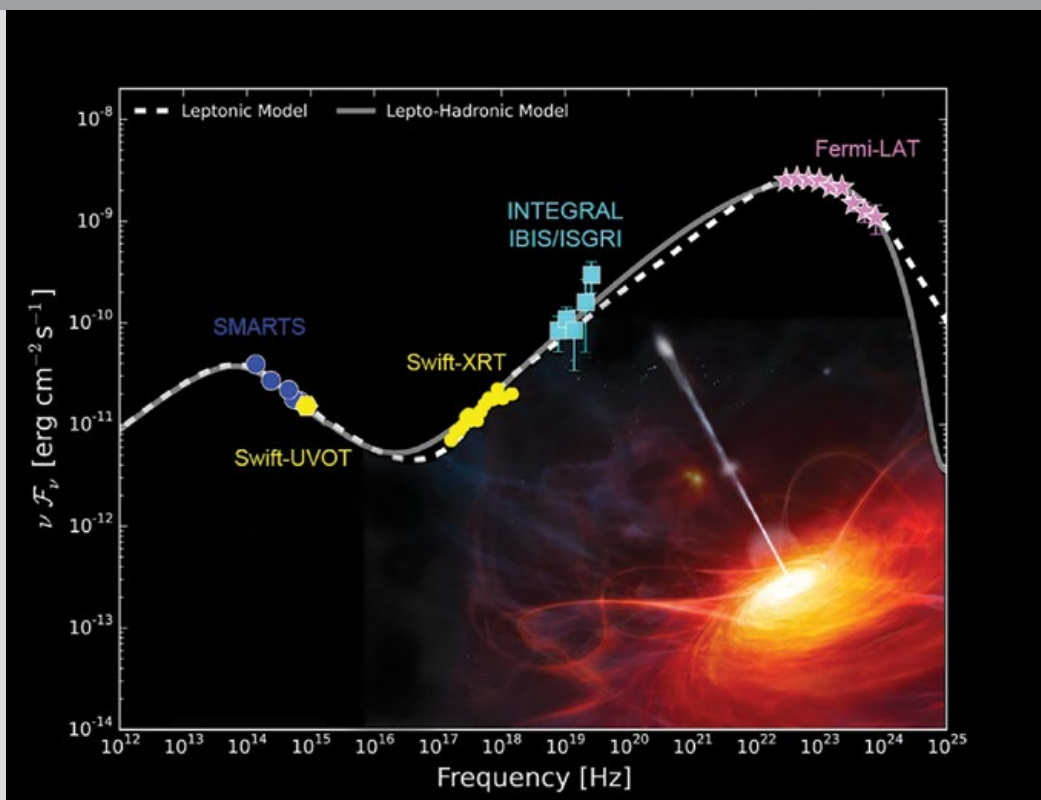
→ INTEGRAL

Blazars are very compact quasars consisting of an active, giant elliptical galaxy with a supermassive black hole at the centre. They are bright from radio to gamma-ray wavelengths and also emit a relativistic jet. The blazar, 3C 279, five billion light-years away, was measured during its brightest intensity flare at high energies by the IBIS/ISGRi instrument on board Integral.

The multi-wavelength campaign around this event covered 10 orders of magnitude in wavelength, involving observations at gamma-rays by the LAT instrument on board NASA's Fermi satellite, at hard X-rays by Integral/IBIS, at X-rays and UV by NASA's satellite Swift, and in optical to near-infrared wavelengths by the Small And Moderate Aperture Research Telescope System at Cerro Tololo Interamerican Observatory in Chile.

This wide coverage allows for a detailed study of the blazar by using two complementary radiation transfer models known as a leptonic model and a lepto-hadronic model. For now, these two models can equally well represent the data.

Quasi-simultaneous spectral-energy distribution of the blazar 3C 279, along with two complementary radiation transfer models: a leptonic model (grey solid line) and a lepto-hadronic model (white dashed line). Background, artist impression of 3C 279 (E. Bottacini (GCSU)/ESO/M. Kornmesser)



Yet, the derived parameters of these models challenge the physical conditions in the jet.

→ ROSETTA

Rosetta scientists published a paper summarising the types of surface changes observed during Rosetta's two years at Comet 67P/Churyumov-Gerasimenko. Notable differences were evident after the comet's most active period – perihelion – as it reached its closest point to the Sun along its orbit.

The changes, which were either unique transient phenomena or took place over longer periods, are linked to different geological processes – *in situ* weathering and erosion, sublimation of water-ice and mechanical stresses arising from the comet's spin. *In situ* weathering occurs all over the comet, where consolidated materials are weakened – such as by heating and cooling cycles on daily or seasonal timescales – and fragment. Combined with heating of subsurface ices that lead to outflows of gas, this can ultimately result in the sudden collapse of cliff walls, the evidence of which is apparent in several locations on the comet.

Although many small-scale localised changes have occurred, there were no major shape-changing events that significantly altered the comet's overall appearance. Ground-based observations over the last few decades suggest similar levels of activity during each perihelion, so Rosetta scientists

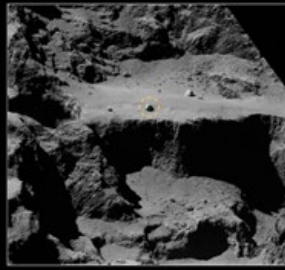
think that the major landforms seen during the mission were sculpted during a different orbital configuration. One possibility could be that earlier perihelion passages were much more active, perhaps when the comet had a larger inventory of more volatile materials.

In another study, the first definitive link between a cometary outburst and a crumbling cliff face was made, helping the Rosetta team to understand the driving forces behind such events. The first close images of the comet taken in September 2014 revealed a 70 m long, 1 m wide fracture on the prominent cliff-edge subsequently named Aswan, in the Seth region of the comet, on its large lobe. Comet activity increased around perihelion and this was punctuated by outbursts: sporadic and brief high-speed releases of dust and gas. One such outburst was captured by Rosetta's navigation camera on 10 July 2015, which could be traced back to a portion of the comet's surface that encompassed the Seth region. The next time the Aswan cliff was observed, five days later, a bright and sharp edge was spotted where the previously identified fracture had been, along with many new metre-sized boulders at the foot of the 134 m high cliff. Both daily and seasonal temperature variations may have propagated fractures deeper into the subsurface than previously considered, predisposing it to the subsequent collapse.

It is believed that fractures in the cliff face permeate volatile-rich layers, allowing heat transfer to these deeper layers of ice. Sublimation from these layers further widens the

→ COMET CLIFF COLLAPSE

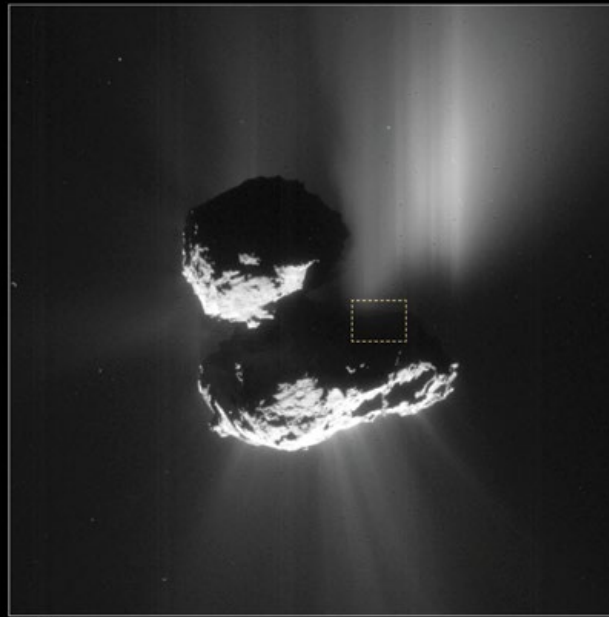
Before



19 Sep 2014



21 Sep 2014

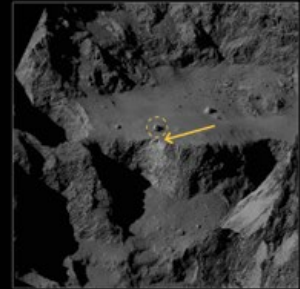


10 Jul 2015

After



26 Dec 2015



8 Jun 2016

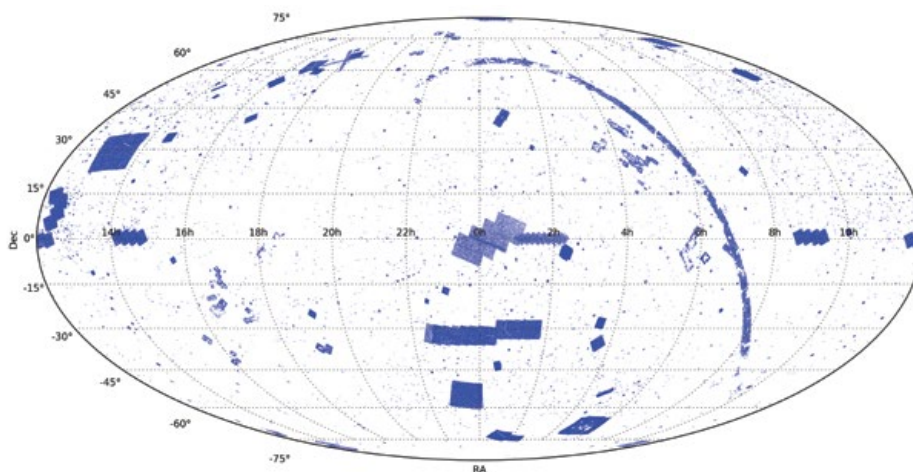
Left: the fracture at the top of the Aswan cliff (marked with arrow). Centre: a broad plume of dust is imaged by Rosetta's navigation camera on 10 July 2015, which can be traced back to an area on the comet that encompasses the Seth region (the Aswan cliff is included within the marked rectangle). Right: two example images taken after the cliff collapse, showing the exposed material in the cliff face (top) and the new outline of the cliff top (bottom). The same boulder is circled in all images as a guide.

fractures, leading to a cumulative effect eventually leading to the cliff collapse.

Rosetta's images already suggested that cliff collapses are important in shaping cometary surfaces, but this particular event has provided the missing 'before and after' link between such a collapse, the debris seen at the foot of the cliff, and the associated dust plume. This evidence supports a general mechanism in which comet outbursts can indeed be generated by collapsing material.

→ HERSCHEL

Herschel is in the final year of its post-operations phase. The Herschel Science Archive has been deployed as a web tool, similar to those of other ESA astronomy missions. It provides access to standard 'pipeline' data products from all 37 000 science observations as well as for 6600 calibration observations taken in science modes, representing 26 000 hours of Herschel observations.



Sky coverage of the photometric data in the Herschel/SPIRE Point Source Catalogue (HSPSC) recently released, listing approximately 950 000, 525 000 and 220 000 entries, respectively, for the 250, 350 and 500 μm bands. Aimed primarily at point sources, the catalogue also contains a significant number of slightly extended sources. Due to the relatively large spatial extent of the SPIRE beams, a number of point or extended sources can actually be composites of multiple sources as seen at shorter wavelengths

Additional user-provided data products are being collected from members of the community and shared. A third type of product, provided by experts, called highly processed data products, is also being produced and deployed. For some observations these will become the 'default' ('legacy') products rather than the pipeline standard products, in other cases they will become alternative and/or additional products. A good example of the latter is the Herschel/SPIRE Point Source Catalogue, which has been made publicly available, listing a total of almost 1.7 million entries in three bands.

→ PLANCK

The next Planck ('legacy') data release will take place after the summer. It will contain products with improved quality, allowing for the full exploitation of Planck's polarization data for cosmology.

A special issue of *Astronomy & Astrophysics* (Vol. 594) was published in December 2016, and includes 28 papers by the Planck Collaboration describing the data products released in 2015 and scientific results based on them. Between launch and December 2016, the community published 1282 refereed papers using Planck data (142 of these are by the Planck Collaboration). More than 12 000 individual papers cite Planck Collaboration results.

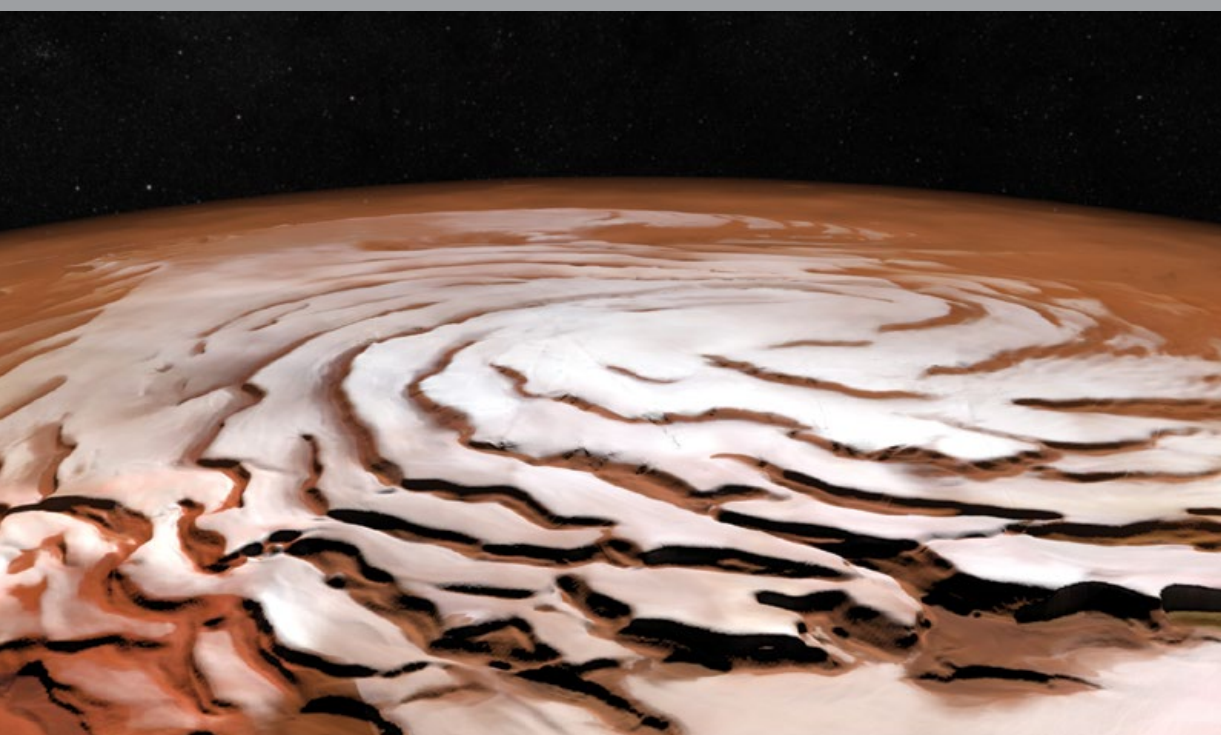
The detection of relic gravitational waves via their imprint on the Cosmic Microwave Background ('B-mode' polarisation signals) is one of the strongest drivers of current and future

CMB experiments. The primordial signals are easily confused with the emission of dust from our own Milky Way, as was shown in the case of the purported (and retracted) detection by the BICEP2 experiment in 2014. Planck's all-sky maps of polarised dust emission are currently the best way to evaluate and subtract the effect of this confusing signal, a process that requires extrapolating Planck channels from sub-millimetre wavelengths to the lower-frequency channels where the CMB dominates.

A recent paper (in *Astronomy & Astrophysics*) by the Planck Collaboration shows that the spatial properties of polarised dust emission vary significantly across the sky, significantly affecting the reliability of the extrapolation. It becomes especially problematic in the areas where dust emission is weakest, which are the preferred targets for B-mode searches. All future experiments will have to find ways to account for these variations, which would otherwise lead to biased measures of B-mode levels.

→ MARS EXPRESS

The beginning of 2017 corresponds to the northern hemisphere winter on Mars. A new High Resolution Stereo Camera colour image mosaic reveals the beauty of the northern ice cap. The pictured north polar ice cap of Mars consists of water ice and dust and covers an area of approximately 1×10^6 km². The volume of the permanent cap is estimated to be 1.2×10^6 km³, about half the size of the Greenland ice cap. Only in the martian winter are temperatures cold enough for carbon dioxide to precipitate



This colour mosaic was generated from 32 individual orbit 'strips' captured between 2004 and 2010 by the High Resolution Stereo Camera on Mars Express. The north pole is marked. The ice cap covers an area of around one million square kilometres, and has a volume equivalent to almost half the size of the Greenland ice sheet on Earth (ESA/DLR/FU Berlin)

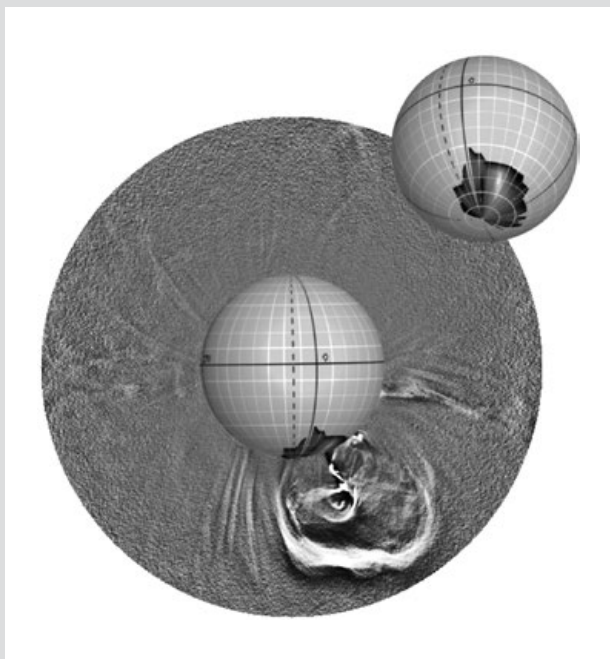
from the atmosphere, forming an additional seasonal cap of carbon dioxide ice.

Characteristic features of the north polar cap are the dark troughs that spiral outwards anti-clockwise, and a prominent trench at about 300°E with a length of 500 km and a width of up to 100 km known as Chasma Boreale. These troughs and chasmas have been formed over thousands of years by katabatic winds – the winds that carry high density air from a higher elevation down a slope under the force of gravity, and whose direction is deviated by the Coriolis force.

Both imaging and radar investigations of the north polar cap were performed by MARSIS on Mars Express and by SHARAD on Mars Reconnaissance Orbiter. They show that the ice cap is made up of many individual layers that are considered a valuable archive for the climate of Mars during the past millions of years. Some of the radar data are suggestive of wind transport and atmospheric deposition as dominant processes for the formation of the spiral troughs and trenches.

→ SOHO

Scientists have presented a new automated method of detecting coronal mass ejections (CMEs) in three dimensions combining data from the SOHO/LASCO and STEREO coronagraphs. The automated CME triangulation



CME detected in SOHO/LASCO data with the new Automated CME Triangulation method (Hutton & Morgan, 2018, A&A 599, A68)

method is both quick and easy to implement, with no need for human input or intervention, and ideally suited for real-time space weather forecasting applications. The authors plan to incorporate the new method into the CORIMP database, enabling improved space weather diagnostics and forecasting.

→ GAIA

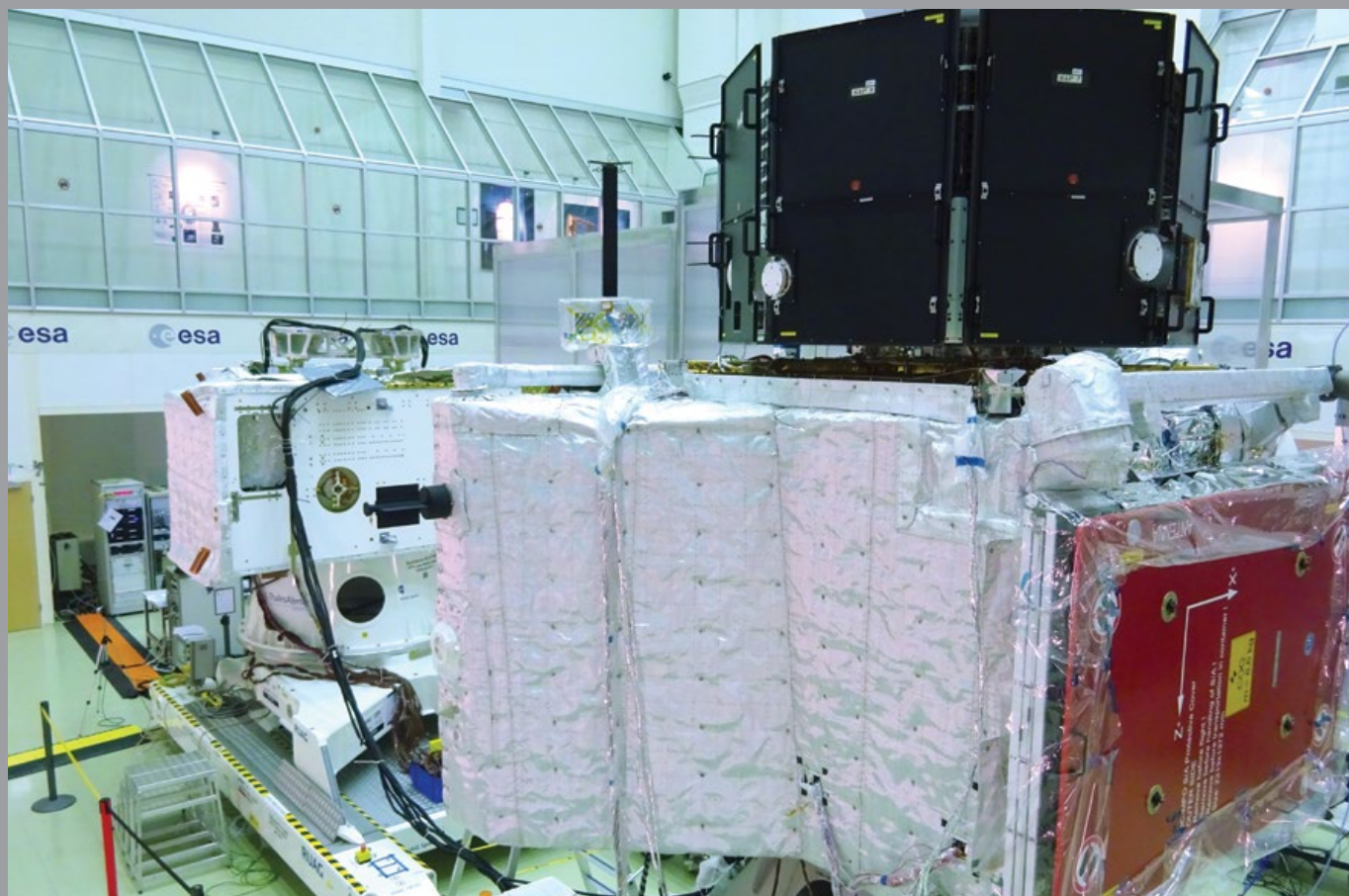
The scientific community continues to use data from Gaia DR1. Scientific preprint services typically deliver one new Gaia data related study per day. Among the many publications it is interesting to point out the discovery of a new stellar cluster, Gaia 1. The cluster is large and not very far away making it relatively easy to detect but has been missed by previous surveys due its proximity to Sirius, the brightest visible star. Most telescopes avoid bright stars due to detector saturation and often surveys suffer from the intense flux in large areas around the bright stars. The discovery of Gaia 1 demonstrates the excellent capability of Gaia to perform its high precision sky survey in the environs of even the brightest stars.

→ LISA PATHFINDER

The satellite is in good health and the mission is in the extended phase of science operations. Extended mission operations are concentrated on understanding the limiting noise source at the lowest frequencies of interest to future spaceborne gravitational wave detectors, such as LISA. Performance at these frequencies (tens of micro-Hertz) cannot be tested on the ground because of Earth-induced noise. The performance of LISA Pathfinder has vastly exceeded its design requirements, allowing the system behaviour to be investigated.

The measurement of the residual differential acceleration between the free-floating test masses has now exceeded the performance required for the LISA mission, over the full measurement bandwidth. However, the physics at the very lowest frequencies is not yet fully understood. The remainder of the mission is focused on understanding the physics of the system on timescales of days.

The extended mission also allows for the continuation of the NASA-provided Disturbance Reduction System (DRS) payload. The DRS consists of a set of micro-Newton thrusters, and a processor unit running a drag-free control system. The DRS uses the test masses of the LISA Technology Package to sense the spacecraft motion. The extended operations allow for a better characterisation of the thrusters, as well as demonstrating the low frequency performance of the drag-free control system. DRS operations began on 18 March, and will end on 29 April.



Mini-stack configuration ready for System Validation Testing with ESOC, BepiColombo MPO in front with MMO installed, MTM at rear

During the DRS operations, the final de-orbiting manoeuvre of the satellite was performed. This involved firing the cold-gas micro-Newton thrusters at maximum thrust continuously over a four-day period, providing a change of velocity of about 1 m/s in the direction of the Sun. The manoeuvre was conducted before end of mission for two reasons: 1) the timing reduces the probability that the spacecraft will reenter the Earth/Moon system within the next 100 years, and 2) the orbit decays very slowly, allowing the final two months of operations to be conducted without the need for station-keeping manoeuvres, thereby optimising the science return of the final 10 weeks of operations (the orbit is stable for about four months after the deorbiting burn). Science operations will cease on the 30 June, with the final telecommand to passivate the satellite being sent on 18 July.

Although the performance requirements were relaxed compared with the full LISA mission, LISA Pathfinder has validated the LISA performance over the full LISA measurement bandwidth. LISA Pathfinder has demonstrated that the detection of low-frequency gravitational waves from space is within reach, opening the door for the LISA mission. The LISA Technology Package science archive is now available via <http://lpf.esac.esa.int/lpfsa/>

→ BEPICOLOMBO

System-level AIT activities on the Mercury Planetary Orbiter (MPO) progressed. The mechanical and electrical integration of the Mercury Magnetospheric Orbiter (MMO) onto the MPO was completed and related interface tests on 'mini stack' level were carried out. The solar array was installed and deployed, while electrical system tests were conducted as planned. The module is ready for electrical and mechanical stack testing (all three modules integrated in launch stack configuration) and the SVT.

Following the repair of the Power Supply and Control Unit, the AIT on the Mercury Transfer Module (MTM) is progressing. Electrical check-out and module-level testing was performed and the MTM is ready for stack testing. The solar array has been delivered to ESTEC and the first wing is in preparation for module-level integration.

The work on the JAXA-provided MMO is complete; the orbiter is installed on the MPO, ready for stack testing. The electrical and mechanical stack test campaigns are planned for spring/summer and the MTM thermal test for November/December.



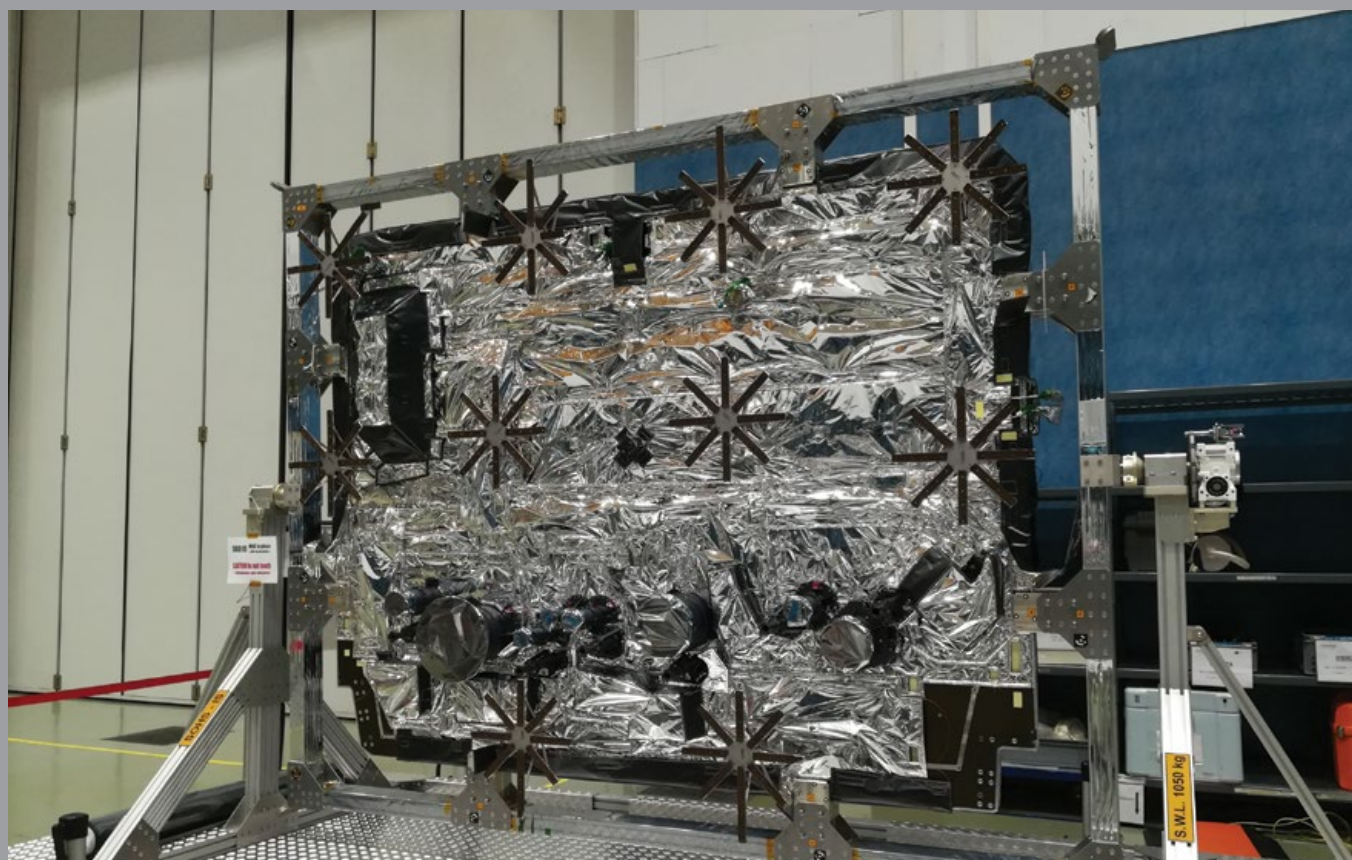
BepiColombo Mercury Transfer Module solar array wing in the zero-g rig during preparation for integration

→ SOLAR ORBITER

The manufacture and delivery of spacecraft FM units and subsystems is approaching completion, in particular all Attitude and Orbital Control System equipment has been delivered. The spacecraft FM integration is ongoing. Functional testing continues on the two spacecraft Engineering Test Benches and on the FM avionics already installed on the spacecraft.

Of the remaining spacecraft units in production, the FM heat shield is ready for environmental tests; the solar generator QM wing completed its environmental testing; the first FM wing is under testing, and the second FM wing is being integrated. The payload radiator panel is being fitted with its thermal management equipment. Solutions for straylight protection, for surface conductivity and for cleanliness and contamination control are being manufactured.

Of the ten instruments designed to simultaneously perform *in situ* measurements and remote observations of the Sun at 0.3 AU, seven concluded their delivery review boards by April and are being integrated onto the spacecraft. The three remaining instruments are expected in early June.



Solar Orbiter's Flight Model heat shield showing the colder set of multi-layer insulation, with 28 layers of embossed aluminised material, the star-shaped supports that will hold the 18 layers of titanium insulation on the hotter side looking towards the Sun, and the feed-through tubes for the instruments behind the shield (TAS)



Inspection of the JWST NIRSpec micro-shutter array through the telescope optics. The telescope wings are folded in launch configuration (NASA)

The Mission Operations Centre and Science Operations Centre developments are progressing. The second pre-radio frequency compatibility test was conducted. Interface work with NASA and United Launch Alliance for the baseline Atlas V-411 launcher services is progressing.

→ JAMES WEBB SPACE TELESCOPE (JWST)

The overall JWST programme continues according to the plan established in 2011, with a planned launch date in October 2018. The vibration and acoustic test campaign of the Optical Telescope with the Integrated Science (OTIS) instrument module, has been completed. The OTIS is now on the way to NASA's Johnson Space Center for a cryogenic functional and optical end-to-end test. The integration of the spacecraft has been completed and the integration of the sunshield onto the spacecraft is ongoing.

→ EUCLID

Thales Alenia Space Italy finalised the system design in advance of the system CDR to be begun later this year. The first two subsystem CDRs have been held (Structure and Thermal and the Fine Guiding Sensor). The PLM CDR is expected in mid-2017.

All SiC reflectors optics have been manufactured and mechanically polished and are now under ion-beam figuring. The main SiC part, the optical bench, is also being manufactured. All four pieces have now been manufactured for both FM and STM and the brazing process is being prepared. Some changes have been implemented in the integration and test sequence of the STM and in the AM to keep the overall spacecraft development schedule on track. The overall schedule of the Visible Imager (VIS) instrument has suffered considerable delay in the last year.

The subsystem EMs and STMs have been manufactured and the STM tests at instrument level have been performed. The instrument EMC and electrical functional tests of the EM have been shifted to the second quarter of this year. The CDR at instrument level was held in January. No major technical issues were discovered, but the development schedule of the FM showed a delay of about six months, placing VIS delivery in the critical path of the project.

The contract with e2v for the development, qualification and FM production of the (ESA-procured) CCD detectors is proceeding. The FM production phase continues and the first 16 FM devices have been delivered.

The Near Infrared Spectro-Photometer (NISP) instrument has completed the instrument CDR and is now proceeding with the flight hardware manufacturing and integration. The NISP STM, used for instrument vibration and thermal vacuum tests, has now been delivered for the PLM STM campaign.

The procurement of the NISP HgCdTe detector FMs, for which NASA is responsible, is ongoing. All flight detector elements have been manufactured and tested, showing excellent performance. The front-end electronics have incurred considerable delay and their production is not yet complete. The first three complete FM devices have recently been delivered for characterisation tests in the LAM/CPMM laboratory in Marseille.

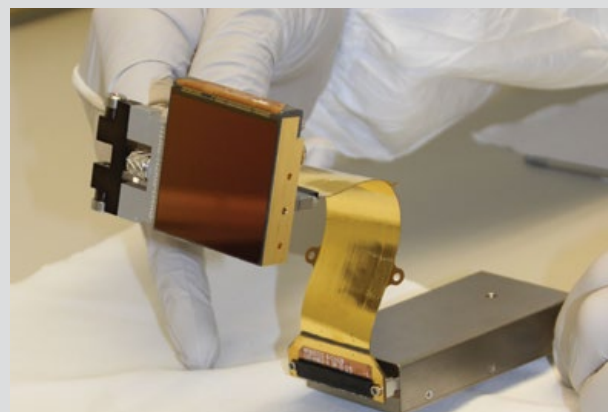
The Science Ground Segment is preparing the next series of the 'scientific and system challenges', operational tests to simulate the science data intake, processing and archiving as implemented in the Science Data Centres. Launch is planned to take place on a Soyuz-Fregat from Kourou in December 2020.

→ JUICE

The last flight hardware to be procured is the Low Gain Antenna, while the remaining important procurements are the test facilities for the spacecraft environmental tests. The spacecraft PDR board meeting took place on 1 March. The review concluded Phase-B and authorised the start of Phase-C/D.

A few remaining technology development activities related to the solar array and solar cells are still running. These should be completed by summer for a review that will give the go-ahead for solar array qualification. Two additional instruments passed their instrument PDR (IPDRs). The last of the ten instruments – the infrared spectrometer – will undergo IPDR in July. The mass and the schedule of the instruments remain critical.

Two payload operation scenarios will be used to verify the detailed design of the spacecraft: one covering the Europa



One of the first three flight HgCdTe (2040 x 2040 pixels, 18 μm in size) near-infrared detectors for the NISP instrument, fitted with proximity electronics through a gold coated cryo-cable, delivered by NASA/JPL

flyby (12 hours either side of closest approach) and one covering eight days of Ganymede circular orbit. They represent scientifically realistic operations of the instruments within the allocated power/energy envelope, memory occupation and downlink rate. The pointing is also realistic.

The launch vehicle will be an Ariane 5 ECA. The Preliminary Coupled Load Analysis was delivered by Arianespace to support the spacecraft PDR. All calculated loads are below the Ariane 5 User's Manual specifications therefore covered by the current spacecraft design. The overall schedule of the spacecraft is stable. Launch is planned for 1 June 2022 (launch window starts on 20 May and closes on 10 June).

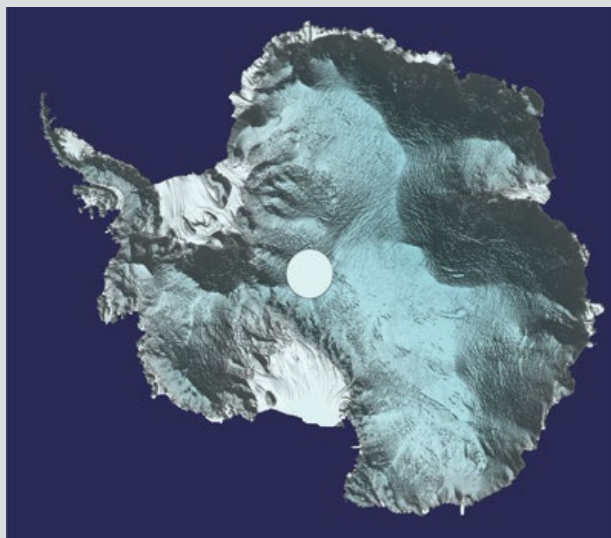
→ SMOS

Current operations have been extended to 2019 and beyond, pending an extension review in 2018. CNES is reviewing the mission operations extension beyond 2017. Future data products include severe wind speed over oceans and freeze/thaw information over land. There has been a decrease in radio frequency interference, in particular over Europe, with more than 70% of sources being switched off.

→ CRYOSAT

The spring Arctic campaign took place. Observations were carried out in collaboration with national and international institutions. This year's campaign focused on exploring the role of dual frequency altimetry in reducing the error in retrieving sea-ice freeboard due to snow load.

The North American CryoSat Science Meeting discussed the recent results and worked to identify new scientific



Using around 250 million measurements taken by ESA's CryoSat mission between 2010 and 2016, scientists at the UK Centre for Polar Observation and Modelling have generated a unique 3D view of Antarctica (CPOM/ESA)

challenges in view of the potential extension of CryoSat and more generally for a sought-after successor.

Around 250 million measurements taken by ESA's CryoSat over the last six years have been used to create a unique 3D view of Antarctica, offering a snapshot of the undulating surface of this vast ice sheet. The dataset will be soon released to the scientific community.

→ SWARM

The Fourth Swarm Science Meeting took place in Banff, Canada, in March and was attended by around 260 participants from 25 nations. The meeting demonstrated Swarm's appeal in Earth and space sciences with a rapidly expanding user base and new scientific achievements.

One example is the discovery, thanks to Electric Field Instrument data, of supersonic plasma jets driven by the Birkeland currents, the systems of vast sheets of electric current in the upper atmosphere at high latitudes. These newly identified jets, named 'Birkeland current boundary flows', can drive the ionosphere to temperatures approaching 10 000 °C and change its chemical composition.

Another remarkable finding was made using the Absolute Scalar Magnetometer to acquire data in 'burst mode' at 250 Hz. Scientists were able to detect high frequency field fluctuation during plasma bubble events and also clearly identify the signature of lightning-generated whistlers propagating into the ionosphere.

In solid Earth research, new insights into the Earth's core were presented and an innovative methodology to model the lithospheric field provided an unprecedented global view of the magnetic stripes associated with plate tectonics reflected in the mid-oceanic ridges.

The community highlighted the effective merging of data from ground-based infrastructure and other missions, and also requested ESA to support the implementation of an additional complementary nanosatellite. With all platforms performing essentially free of any anomalies and the space segment constellation geometry evolving in line with expectations, the Swarm community is asking for the mission to be extended as long as possible (even into the 2030s) to cover another full solar cycle, and for different constellation geometries to respond to many key open scientific challenges.

→ AEOLUS

The satellite's mechanical test campaign was completed in the Intespace test centre. The complex thermal/vacuum test campaign will be conducted in Centre Spatial de Liège, for which facility preparations are progressing. A blank test, involving all dedicated test equipment fitted within the vacuum chamber, will be executed at the beginning of May. The integration phase of the Ground Segment Overall Validation is ongoing and the planning of the Ground Segment Acceptance Review is consolidated with the board planned for June. The final mission analysis campaign has started with Arianespace and ELV for the launch on a Vega.

Aeolus during testing at Intespace



→ EARTHCARE

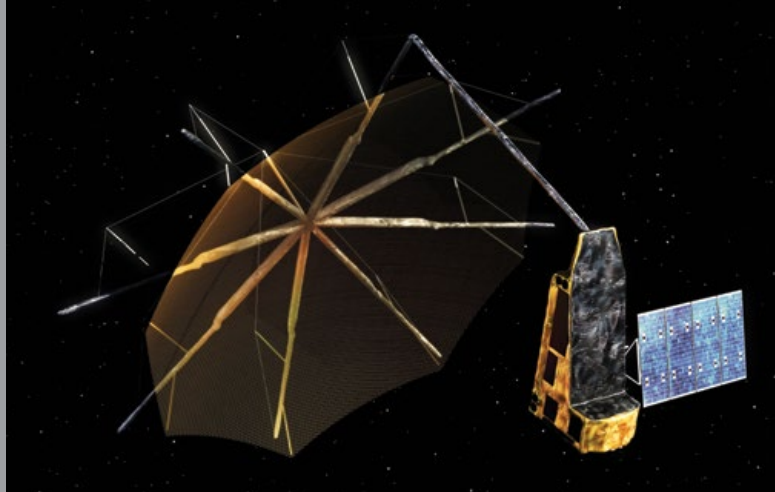
The Atmospheric Lidar PFM UV laser transmitter was handed over to Airbus Defence & Space (FR) by Leonardo (IT).

The calibration of the visible, near-infrared and shortwave infrared (VNS) camera of the Multi-Spectral Imager is nearing completion at TNO (NL). Integration of the instrument Thermal Infrared Camera (TIR) is progressing at Surrey Satellite Technology Ltd (UK). The calibration campaign of the Broadband Radiometer (BBR) optical unit in vacuum is nearing completion at Rutherford Appleton Laboratory (UK). The unit will then undergo a series of ambient tests, micro-vibration tests and EMC test campaigns, along with the FM Instrument Control Unit.

The JAXA Cloud Profiling Radar (CPR) PFM instrument environmental test campaign was completed in Japan, but one of the two high-power transmitters had to be replaced by a dummy unit because of a failure. The remaining CPR PFM tests, including antenna pattern and functional tests, were completed in March. The non-redundant instrument was then shipped to Europe for its pre-integration and test on the satellite. The refurbishment of the instrument is planned to start in April 2018 when the repaired transmitter (HPT-A) will be available. The Ground Segment CDR began in March. In parallel, most of the procurement of the Flight Operation Segment and Payload Data Segment has been initiated by ESOC and ESRIN respectively.

→ BIOMASS

Industrial partner teams are concentrating on building up the full industrial consortium for the project. About 50 satellite sub-units and equipment items have to be procured



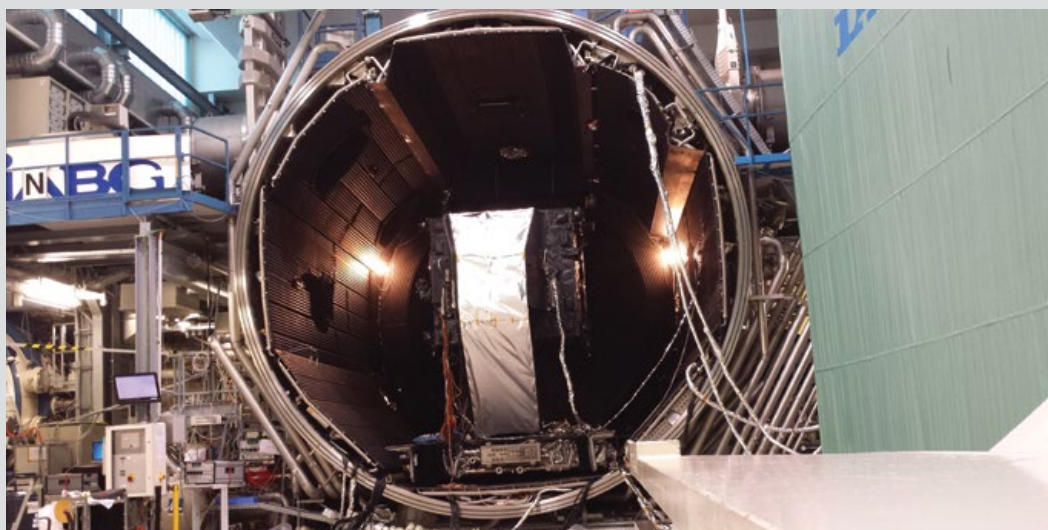
Biomass Equinox 2016 reflector (Airbus D&S)

in this process and at least 100 European companies are expected to be involved directly in building the satellite. The SRR formally closed in January and preparations have started for the PDR, to be held later in the year.

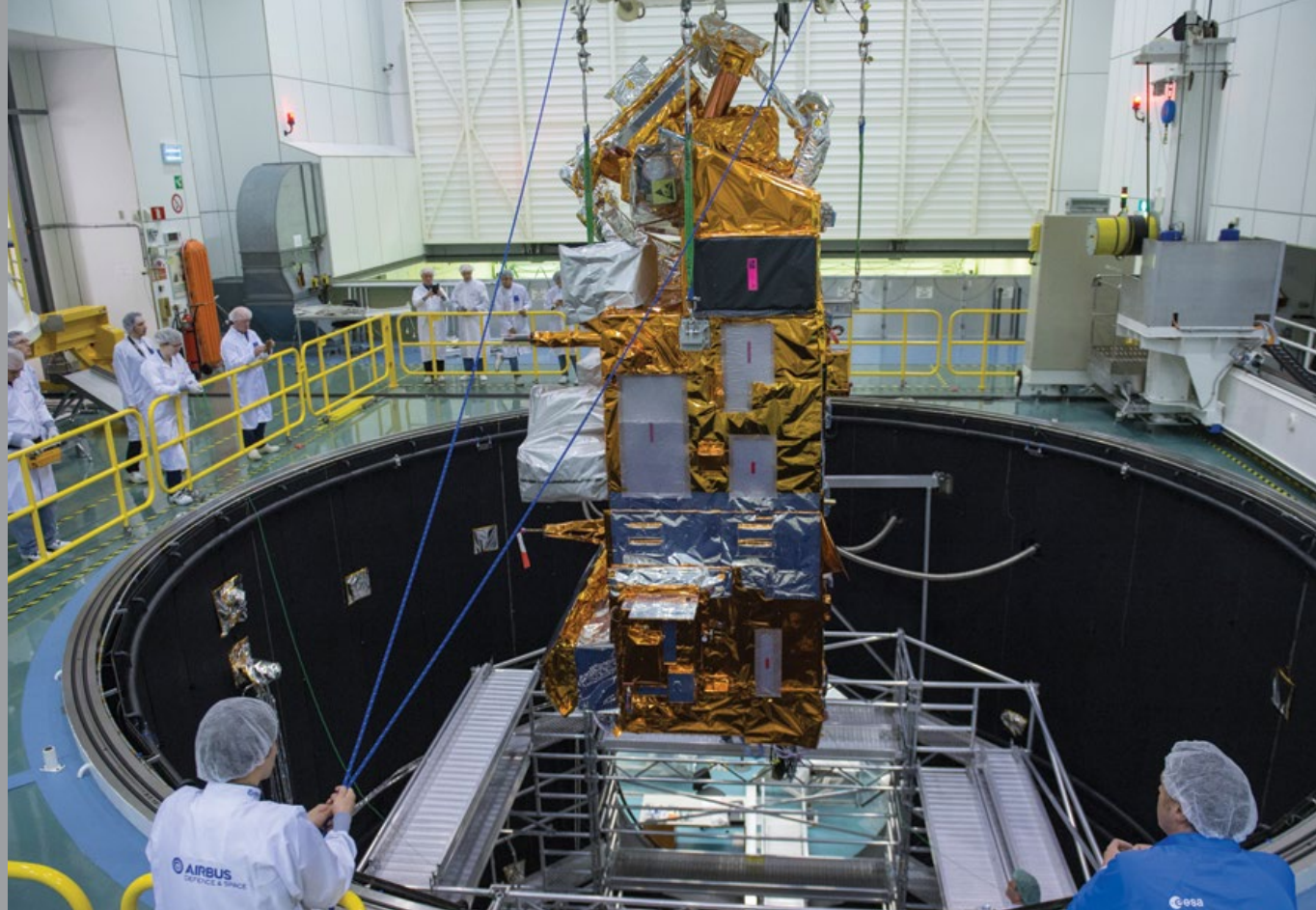
Work on the ground segment includes the spacecraft operations and the processing chain of the satellite data into the final mission products: tons of biomass per hectare of forest, forest height and forest disturbance.

→ METEOSAT THIRD GENERATION (MTG)

The lower level CDRs are ongoing. The main engineering budgets remain stable and the predicted instrument performances show a high level of compliance to customer requirements. MTG development models are progressing with the platform AIT well advanced and the instrument development model integration (Flexible Combined Imager and Lightning Imager) under way. A formal Integration Readiness Review was held to allow the start of the integration of the FM Platform.



MTG Platform
Structural Model
thermal balance/
vacuum test (OHB/
IABG)



MetOp Payload Module transfer to Large Space Simulator at ESTEC

For the Flexible Combined Imager and Infrared Sounder instruments, the STM and EM development model manufacturing is progressing. For the Lightning Imager, the STM has now been integrated and mechanical testing is scheduled to begin in May.

The MTG-I and MTG-S PFM FAR dates are in December 2020 and August 2022 respectively, taking into account the latest known availability of sub-contracted hardware and best predictions for Core Team AIT activities. These dates are in line with Eumetsat needs.

→ METOP

MetOp-C

The PLM has completed thermal/vacuum tests at ESTEC. This will be followed by the mass properties measurements. The GOME-2 instrument will be removed from the PLM to undergo calibration at the TNO facilities in Delft (NL). The MHS instrument, furnished by Eumetsat, will also be removed for investigations regarding the observed performance degradation. Both instruments should be ready in January 2018 for reintegration on MetOp-C in time for the SVT. The SVM is in thermal/vacuum testing in ITS Toulouse (FR).

At the completion of the PLM and SVM standalone tests, expected by the end of June, the PLM will be shipped to Airbus Defence & Space (FR) for coupling with the SVM and

the subsequent satellite-level testing activities. Launch is planned on a Soyuz from French Guiana in October 2018.

MetOp Second Generation

The satellite and instrument development activities have progressed according to schedule. The cycle of lower level subsystem/equipment PDRs is nearly complete, and the lower level CDRs have started. The first hardware for the satellite EM has been delivered and the EFM AIT programme has started. Manufacturing of the satellite and instrument STMs is under way.

The Microwave Sounder development model has been completed and will be used to perform early antenna pattern measurements and to demonstrate end-to-end performances as a risk mitigation measure. The optical breadboard for the 3MI (Multi-view Multi-channel Multi-polarisation Imager) instrument has been completed and is being used to characterise and correct straylight issues. A breadboard of the Radio Occultation electronics has been used to test and confirm the ASIC processor and associated algorithms that will be used to mitigate radio frequency interferences from ground-based aircraft tracking systems.

Schedule-wise, the main focus remains on the complex Customer Furnished Item instruments (particularly METImage, IASI-NG and Sentinel-5), as well as the Receiver Front-End and Back-End equipment for the microwave radiometers (Microwave Sounder, Microwave Imaging Radiometer and Ice Cloud Imager).



Sentinel-2B satellite before being installed on its payload launcher adapter, at Europe's spaceport in Kourou, French Guiana, ready for launch on 7 March

→ COPERNICUS

Sentinel-1

Sentinel-1A and -1B remain stable using all of their prime units, running in pre-programmed operational mode that ensures the continuous production of consistent long-term data series. Stringent orbit control is kept with systematic manoeuvres performed once a week.

The data downlink is routinely performed over Matera, Svalbard and Maspalomas stations and circulated within the Payload Data Ground Segment to systematically process to Level-0 and Level-1 products and archive. The use of the EDRS-A service by Sentinel-1A is now part of the routine operations, allowing a further increase of the overall mission capacity.

A total of 75 732 users are registered on the Sentinels Scientific Data Hub on 30 March who have downloaded 7.5 million Sentinel-1 products, corresponding to about 8.9 PB of data. Statistics are available in real time at the Data Hub home page: <https://scihub.copernicus.eu>

The development of the new Sentinel-1C and -1D models is ongoing. After completing the qualification status reviews for all equipment, subsystems and spacecraft, production reviews are being conducted at all levels. These are in line with the schedule to have Sentinel-1C completed and ready for flight by the end of 2020. Sentinel-1C and -1D will

eventually replace the operational Sentinel-1A and -1B at the end of their lives.

Sentinel-2

Sentinel-2B was shipped to the launch site in French Guiana on 6 January. After a flawless launch campaign it was launched on the scheduled date of 7 March. The launch injection was excellent and the spacecraft concluded its LEOP activities two days later, as planned. The In-orbit Verification phase is ongoing and the satellite behaviour is excellent. The first image was released on the 16 March and is already of very good quality. The In-orbit Commissioning Review will take place mid-June.

The Sentinel-2C and -2D spacecraft, which will eventually replace the operational Sentinel-2A and -2B at their end of their scheduled lives, will undergo Satellite Production Review from May to July.

Sentinel-3

Completion of Sentinel-3B AIT activities is planned for September, leading to readiness for launch by the end of the year. On the instrument side, the Sea and Land Surface Temperature Radiometer (SLSTR) has completed its acceptance test campaign including the instrument calibration in vacuum. The Ocean and Land Colour Instrument cameras have all completed their refurbishment and the instrument is now being integrated, after which the instrument acceptance testing will be

Vega VV09 carrying
Sentinel-2B, in its mobile
gantry at Europe's
Spaceport in Kourou,
French Guiana, on 6 March



conducted. At satellite level, after completion of the integrated system tests part 1, dealing with the platform and the topographic payload, the SLSTR instrument was integrated. Once the functional tests are complete, the EMC test campaign will start, which will be followed by the satellite thermal/vacuum testing in May.

For Sentinel-3C and -3D, lower-level equipment qualification status reviews were closed and the Satellite Production Review (SPR) took place, confirming the level of design maturity reached and allowing manufacturing of the overall satellite hardware to start.

Sentinel-4

The system CDR was completed. The STM of the optical instrument module has been delivered to the MTG prime contractor (OHB Bremen). This is the first formal Sentinel-4 hardware delivery to the MTG project. Airbus Defence & Space (DE) completed the Mandatory Inspection Point of the Instrument Control Unit FM1. Its functional testing is progressing. The instrument simulator passed the Test Review Board and was delivered to Airbus Defence & Space (DE).

Sentinel-5

All subsystem equipment requirement reviews have been completed and most of their PDRs have taken place. The focus is now on completing the identified actions to allow formal closure of these reviews. The first subsystem CDRs have started. The detailed design of the instrument optical module structure and radiators for the instrument STM is complete, and manufacturing of the parts is progressing. Parts for the instrument EM are being manufactured. This model will be used for a first verification at system level of optical performance, and will allow exercise of the calibration procedures.

Following interface checks between a UVN detector and the front-end electronics, these will now be interfaced with the demonstration model of the Detector Support Electronics unit.

Sentinel-5 Precursor

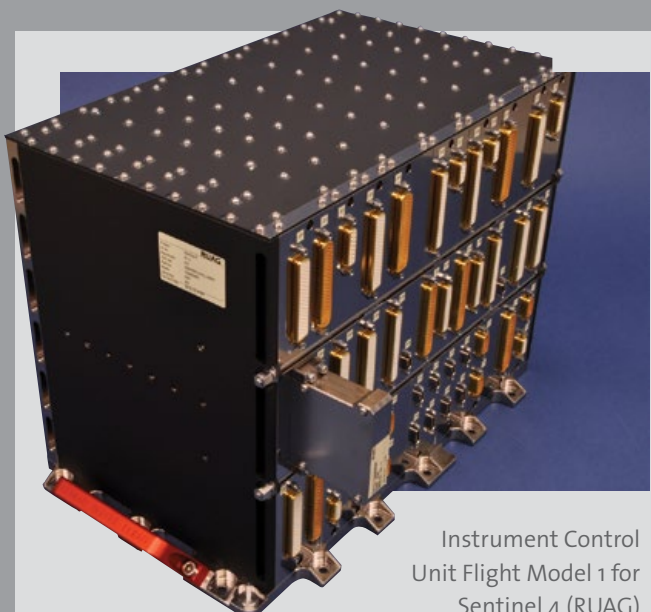
The satellite was returned to storage in Stevenage, UK, in January after a six-week maintenance programme. The Overall Ground Segment is ready. LEOP rehearsals at ESOC will start three months before launch. For the Rocket launcher, the launcher authority announced a further launch delay. The earliest possible launch date is mid-August.

Sentinel-6/Jason-CS

The mission PDR took place and the findings will be presented to the steering committee in April with the participation of all partners (NASA, NOAA, ESA and Eumetsat). The mission performance working group formed among the partners contributed to the mission PDR, and established a work plan to further consolidate the mission performance budgets under the joint responsibility of the partners.



Sentinel-2B lift-off



Instrument Control
Unit Flight Model 1 for
Sentinel 4 (RUAG)



Launch of Soyuz VS16 carrying Hispasat 36W-1, the first
telecommunication satellite using a SmallGEO platform,
27 January (ESA/CNES/Arianespace)

The NASA JPL project PDR took place and the upcoming key decision will be entering development Phase-C for the US-provided Customer Furnished Item payload elements. NASA will complete the launch service competitive procurement by October. The satellite detailed design activities are complete and the satellite CDR process will start in March.

→ NEOSAT

This programme will develop and qualify the next-generation platforms allowing two European satellite prime integrators, Airbus Defence & Space and Thales Alenia Space to deliver competitive satellites for the commercial satellite market. This includes development and in-orbit validation of the new platform product lines for both prime contractors, Eurostar Neo for Airbus and Spacebus Neo for Thales Alenia Space. Neosat is part of ESA's Advanced Research in Telecommunications Systems (ARTES) programme and is a cooperative endeavour between ESA and CNES.

Thales Alenia Space has already sold three full electric Spacebus Neo satellites: Eutelsat Broadband for Africa (BB4A), Comsat-NG for the French DGA (Ministry of Defence) and the high-power SES-17 satellite for aeronautical communications. The Spacebus Neo PFM platform will be used for the Eutelsat Broadband for Africa (BB4A) mission to validate the new platform in orbit. The system Intermediate Design Review (IDR) was completed, and subsystem CDRs are ongoing to prepare for the system CDR later this year.

Airbus Defence & Space expects a first Eurostar Neo mission selection during the second quarter of the year. Some platform procurement activities have been initiated in view of this first application under an internal Airbus initiative known as the 'white tail' programme.

The additional subscriptions obtained at the ESA Ministerial Council 2016 will allow the completion of the current technical baseline and address the platform extension in answer to the recent market needs for Very High Throughput Satellites (VHTS) in the 25 kW range. The associated workplan for Neosat activities has been defined with both prime contractors.

→ SMALLGEO/HISPASAT 36W-1

Hispasat 36W-1, the first telecommunication satellite using a SmallGEO platform, was launched on 27 January on Soyuz VS16. Immediately after separation from the Soyuz upper stage Fregat, the LEOP operations started at the German Space Operations Centre in Ottobrun, Germany. A team of engineers from ESA, Hispasat, OHB and DLR initiated the planned sequence of manoeuvres to put the



View of ELA-4 at Kourou, French Guiana, the new launch pad area for Ariane 6, in July 2016 (ESA/CNES/Arianespace)

satellite in its test orbital position and prepare it for in-orbit tests. All platform tests have been completed, and most of the Ka and Ku band payload tests have been achieved. The satellite is now ready to reach its final orbital position at 36 degrees west. Once at its destination, Hispasat will commence its commercial activities and will provide Europe, the Canary Islands and the Americas with conventional and advanced multimedia services.

→ ARIANE 6 AND P120C

Maturity Gate 6.1 (MG6.1) took place in March and was concluded with the Steering Board on 20 April. The documentation submitted includes a strong focus on the industrialisation (facilities, jigs and tools, manufacturing process and cycles). The end objective of the MG6.1 is to authorise, at launcher system level, the start of QM manufacturing. Maturity Gate 6.2 to be held by the end of the year will authorise the start of the manufacturing of the maiden flight FMs. For the launch base, contracts for Launcher Ground Interface Cryogenic arms, Communication Optic Video (COV) and A6 transfer means (upper composite trailer and dollies) have been signed.

Reviews of industrial activities are progressing, in particular the RDPi (Revue de Définition Préliminaire industrielle) for low current and safety, for fluids, for control bench family and the RCDi (Revue Critique de Définition industrielle) for infrastructure, power supply and air conditioning. In Kourou, the stabilisation of the rock faces of the flame pit

is close to completion, the concrete piles under the mobile gantry rolling ways are complete. The first End-to-End Optimisation Key Point (E2EOKP#1) took place in February, with the steering board at the beginning of March checking the launch system consistency in view of Launch Base and Launcher System Development milestones, notably Launcher System MG 6.1.

For P120C, the convergence process for the technical requirements specifications of the Solid Rocket Motor (SRM) is ongoing. Industrial meetings have been held on mechanical tolerances, cutting charge, multifunction connection ring/snap ring. The next major event on SRM is the Manufacturing Readiness Review of the Inert Loaded Motor.

→ VEGA C

The Tender Evaluation Board (TEB) for the Launcher System and Ground Proximity Means activities up to completion was held. Following authorisation, ESA and ELV have been negotiating for the start of Phase-C/D/E in mid-2017. VEnUS is a 10-kW Electric Upper Stage to be launched on Vega-C. Phase-B1 is ongoing. Business models assessment and actions will be consolidated for an ASI-requested milestone in June. Phase-o/A/B1 activities are completed for the Small Spacecraft Mission Service (SSMS), with a preliminary authorisation to proceed granted to industrial contractors to ensure activities continuity for the Phase-B2/C/D/E1. The proposal for Phase-B2/C/D/E1 was received and authorised to proceed.



Thomas Pesquet seen talking to friends and family after returning to Earth on 2 June after 196 days in space

→ FUTURE LAUNCHERS PREPARATORY PROGRAMME

System activities are in preparation in particular for Microlauncher. A workshop will take place in May and a work plan for implementation will be presented during the following Programme Board. Design activities for the Nucleus rocket were completed with the Manufacturing Readiness Review on 6 December. The Nucleus flight is scheduled for late 2017. For the Prometheus ultra-low cost engine demonstrator, the steering committee for Concept Review of the LOx/hydrocarbon combustion chamber was performed in March. RFQ for the complete activity was issued in March, and the offer received in April.

The P3.2 test bench reconfiguration for the Expander Technology Integrated Demonstrator (ETID-1) hot-firing test campaign is complete. The vacuum cell has been installed. The base plate injector head, based on additive manufacturing, was delivered in April. The valve control unit passed its MRR in April. The ETID-2 propulsion system concept phase began on 14 December.

→ HUMAN SPACEFLIGHT

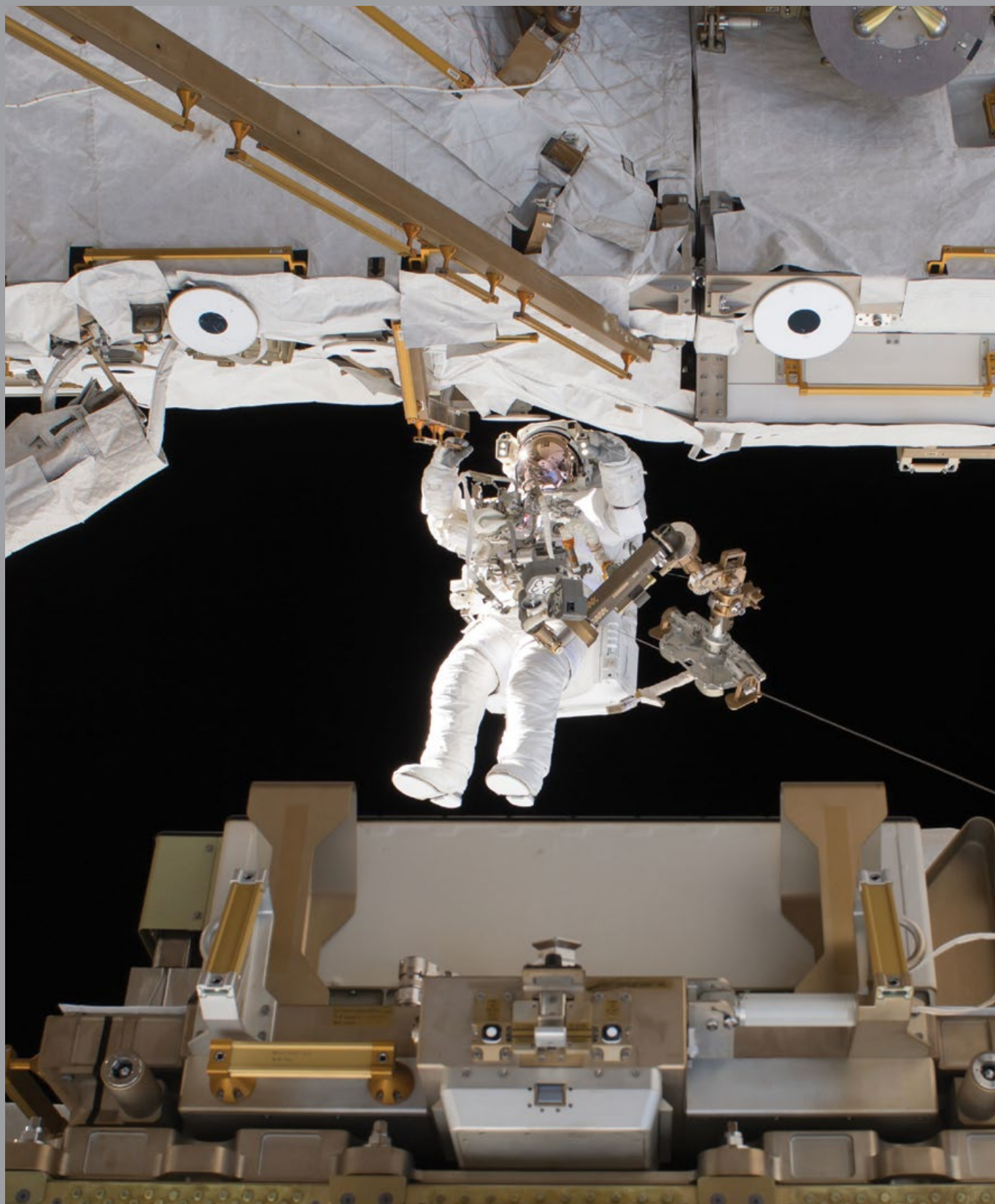
ISS

Thomas Pesquet (FR) completed spacewalks with NASA astronaut Shane Kimbrough on 13 January to complete a battery upgrade to the ISS, and on 24 March to relocate a docking adapter and to install a new computer relay box. Thomas landed back on Earth on 2 June with Russian commander Oleg Novitsky in their Soyuz MS-03 spacecraft after six months in space. Touchdown was at 14:10 GMT after a four-hour flight from the International Space Station. Thomas took part in more than 60 experiments during his Proxima mission and set a new record for the number of hours spent on science in a week as part of an Expedition crew.



ESA astronaut Tim Peake checking out the NASA Orion spacecraft with fellow ESA astronaut Matthias Maurer at Johnson Space Center, Houston, in April





↑ Thomas Pesquet on his second spacewalk of the Proxima mission, when he worked for six hours and 34 minutes outside the Space Station on 24 March (NASA/ESA)

← ESA astronaut Thomas Pesquet during his first EVA on 13 January 2017 (NASA/ESA)



Matthias Maurer joined the European Astronaut Corps in February

Astronauts

Following the decision at the ESA Ministerial Council 2016 to extend European participation in the ISS Programme until 2024, Matthias Maurer (DE) joined ESA's astronaut corps and was officially announced to the press on 2 February.

European Robotic Arm (ERA)

The Russian 2017 flight plan was signed by RSCE and Roscosmos for the Multipurpose Laboratory Module (MLM) and ERA launch, now scheduled for December. Because of additional technical issues with the cleanliness of the MLM propellant tanks and lines, Roscosmos is reviewing the launch date again.

Atomic Clock Ensemble in Space (ACES)

The MicroWave Link (MWL) flight segment delivery will take place no earlier than September and the ground terminal electronic unit delivery not before the end of the year, with impacts on the ACES system testing. The updated Space Hydrogen Maser (SHM) schedule from Spectratime (CH) is under discussion, considering the need to conclude all repairs after the latest failures. Because of these delays, the SHM and MWL integration readiness will not happen before the end of September, moving the launch readiness to no earlier than September 2018. The SpaceX CRS-15 launch is foreseen in August 2018. ESA and NASA have to establish the most realistic launch date and agree on the planning.

Atmosphere-Space Interactions Monitor (ASIM)

ASIM is undergoing final long-duration functional testing before going to the Columbus simulator in May. The ASIM schedule is still compatible with a handover to NASA on 31 July. However, an ISS planning issue emerged, which could mean moving ASIM to SpaceX CRS-14 (February 2018). The final decision will be confirmed at an ISS Programme Managers meeting in April.

→ ISS UTILISATION

The European ISS utilisation programme has been continuing with the assistance of the Expedition 50 crew on orbit. Highlights of the three months until 31 March:

Human research

Different test subjects completed in-flight activities for ESA's Energy experiment, studying changes in energy balance related to long-term spaceflight to help derive an equation for the energy requirements of crewmembers. There were also continued sessions of ESA's Space Headaches experiment studying headache incidence/characteristics and two ESA experiments (EDOS-2 and Immuno-2) with Russian cooperation studying post re-entry bone loss and recovery, and integrative immune system mechanisms. Hardware was launched for the Grip/Grasp neuromuscular control experiments.

Materials/fluids/complex plasma research

The Batch 2b alloy solidification experiments continued processing in the Materials Science Laboratory and a chamber of new samples arrived at the ISS for processing in the Electromagnetic Levitator (EML). The EML also underwent an upgrade. All of the experiments in these facilities are studying different aspects of the solidification process in metal alloys, which will help to optimise industrial casting processes. The Geoflow experiment series that started in 2008 came to a conclusion following the final runs of Geoflow-II in the Fluid Science Laboratory. GeoFlow-II is a fundamental study into spherical flow phenomena with links to astrophysical and geophysical problems. The Plasma Kristall-4 (PK-4) experiment completed its fourth campaign in February, investigating the liquid phase and flow phenomena of complex plasmas for which PK-4 is especially suited.

Solar/radiation research

Research with ESA's SOLAR facility concluded in February. In total, 110 (two-week) Sun observation windows were performed during nine years in orbit, taking measurements of solar spectral irradiance, including five extended periods to monitor solar activity during a full Sun rotation cycle (which lasts up to 36 days at the solar poles). The solar facility by far exceeded expectations, substantially surpassing its originally planned mission of 18–24 months in orbit. Monitoring of the radiation environment in Columbus also continued within the DOSIS-3D and ESA Active Dosimeter projects. The ESA Active Dosimeter project included a personal astronaut monitoring campaign.

Non-ISS platforms

The 2017 Concordia Antarctic over winter season started with four ESA-selected experiments, covering immunology, musculoskeletal and neuroscience research. A 60-day 'Cocktail' bed rest study started at MEDES in Toulouse in January with the implementation of 15 science proposals. The bed rest period started on 1 February.

→ EXPLORATION

Multi-Purpose Crew Vehicle/European Service Module 1 (MPCV/ESM1)

The shipment of the ESM1 to the US is scheduled in December. Close surveillance of suppliers and schedule acceleration measures are implemented since there are no margins left in the ESM schedule. The propulsion QM arrived at White Sands (US) in February. Integration into the test stand and subsequent acceptance testing started, targeting a first hot test in May.

ESM2

The rider for the industrial contract of the ESM2 FM was signed with Airbus Defence & Space in Bremen on 16 February. The needed dates and the subcontractor committed delivery dates of equipment do not correspond and will be resolved. The procurement and manufacturing of the ESM hardware must be authorised to maintain the ESM2 schedule, while the qualification of the design is not complete and waivers are not all processed. The risk is controlled by the project through participating as far as possible in all manufacturing release reviews.

ExoMars 2016

Trace Gas Orbiter (TGO) aerobraking operations started as planned on 15 March. A series of five pericentre-lowering manoeuvres spread over the month gradually brought down the pericentre height from the initial 208 km to 122 km. Aerobraking will continue with the objective to achieve the final two hours data relay orbit in April 2018. Publication of the report and recommendations of the Schiaparelli independent Inquiry Board headed by the ESA Inspector General is planned

for late April. NASA JPL, which supported the investigations, presented its entry, descent and landing dynamic analysis that confirmed that no parachute anomalies occurred. First mitigation actions applicable to ExoMars 2020, like an additional radar test, are already under implementation.

ExoMars 2020

Progress was made on the Lavochkin/Thales Alenia Space Italy 'European AIT contract' that was decided at the end of December 2016 to optimise the project schedule for the execution of Descent Module (DM), spacecraft composite and landing platform avionics test bed AIT activities. The technical definition of the AIT activities is now mature, allowing the production of a consolidated end-to-end ExoMars 2020 detailed schedule. Contractual negotiations should be finalised before the CPR Board on 21 April.

After the DM delta PDR, the ExoMars 2020 CPR collocation was held at the end of March. Some areas should be underlined as being schedule critical, like the onboard software, DM propulsion system and thermal protection shield. A worst-case schedule for all project activities showed a worst-case contingency of 42 working days (with single shift, normal working) that will require close control for the critical path. ESA and Roscosmos requested Lavochkin and Thales to preserve this contingency until at least one year prior to launch in July 2020, using AIT optimisation and shift/weekend work if required.

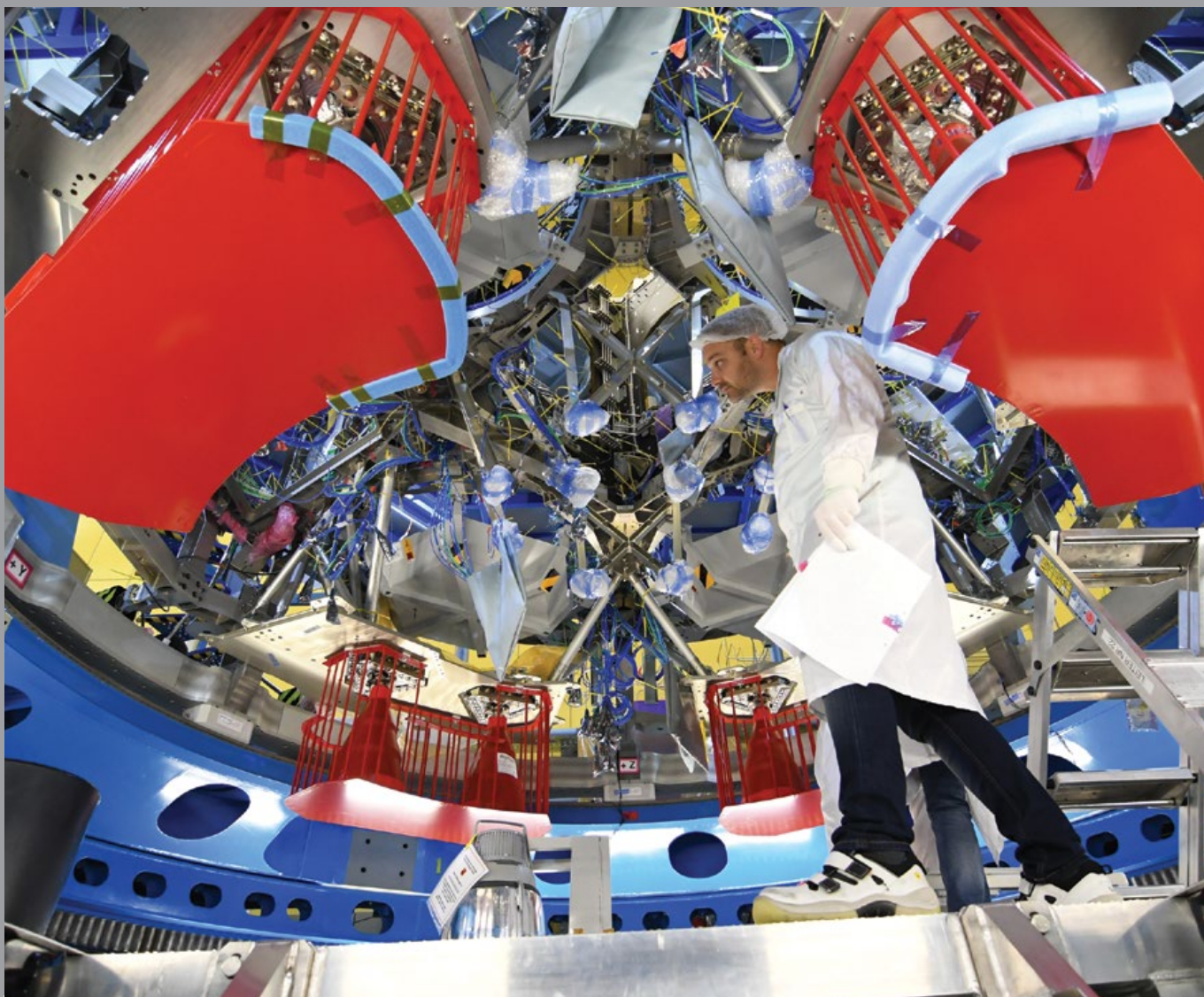
The Russian Kaliazin ground segment completed its requirements review, including the upgrade of its uplink chain and resolution of pointing issues.

The rover mobility confidence test that was completed at RUAG (CH) did not show full compliance to all the locomotion requirements and confirmed that a 'light walking mode' capability should be analysed in the allowable extent for implementation, taking advantage of the existing design to avoid unacceptable impacts. Further actions have been coordinated with Thales Alenia Space Italy and Airbus Defence & Space (UK) to converge towards a final decision in May.

The Rover Instrument Steering Committee (RISC) meeting of the Pasteur payload was held on 25 January to discuss instrument progress and adherence to the industrial schedule. Most of the instruments reported further delays. CLUPI in particular is in a critical situation. The Swiss Space Office is preparing a decision for the required instrument funding to avoid de-scoping of CLUPI from the Rover Payload complement, dependent on the cost at completion to be confirmed.

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

New sessions of the Haptics-2 experiment testing bilateral tele-operation between space and ground with force



The European Service Module flight model ESM1 taking shape in Bremen (ESA/Airbus D&S)

feedback were performed as part of the METERON experiments involving technologies and procedures for future human exploration missions with robotics elements. The remote control of the EAC Jackal rover from ESOC was demonstrated.

International Berthing Docking Mechanism (IBDM)

The ESA/SNC/QinetiQ agreement on IBDM for Dream Chaser was finalised with Sierra Nevada Corporation (SNC), European industrial partners and participating states. The possible application of IBDM for Orion is under active investigation. Discussions were held with NASA, Lockheed Martin and QinetiQ, identifying a possible schedule and assessing technical interface differences between the IBDM for SNC and for Orion.

European contributions to the Luna-Resource Lander Mission

The PILOT and PROSPECT SRR Board meetings were

held on 20 February and the close-out actions are being completed for end of April. The next model of PILOT-D (Camera Demonstrator as payload on board Luna-Glob), an interface emulator, is ready to be shipped to the Russian Space Research Institute, IKI. The text for the updated ESA/Roscosmos Agreement on Lunar Exploration is being iterated by the parties, with a view to signing it by the end of 2017.

Architecture and mission definition studies

The AO for co-funded studies on user-driven research platforms in low Earth orbit (LEO) is in preparation for issue in May.

Spaceship EAC

Low Technology Readiness Level activities are ongoing and performed by the Spaceship EAC student teams in particular in the areas of in situ resource utilisation, 3D printing/recycling, radiation simulations and virtual/augmented reality.

Commercial partnerships

Following the completion of the IceCubes business plan/programmatic review of the pilot partnership on 29 March, the initial partnership negotiation activity with Space Application Services began on 31 March. An ESA Integrated Project Review is being conducted in parallel, to begin on 15 March and with formal review by the Director General on 25 April. The MoU and Project Implementation Plan for two new commercial partnership projects were developed: one on private lunar lander surface missions with PTScientists (DE) and the other on ISS utilisation with TELDASAT with SAT42M (DE).

International cooperation

ESA's Director of Human Spaceflight and Robotic Exploration David Parker visited the Chinese Manned Space Agency (CMSA) and the Chinese National Space Agency (CNSA) in Beijing in January. A plan was confirmed with CNSA to set up a working group for advancing cooperation in three areas: scientific analysis of lunar samples, formulation of future polar missions and Mars exploration. The potential future collaboration with CMSA on the Chinese Space Station (CSS) was also discussed. The status and plan of activities for 2017 of the three working groups (Utilisation, Astronauts and Infrastructure) were discussed with the perspective of identifying a dedicated ESA contribution in exchange for an ESA astronaut flight to the CSS around 2022–23, subject to approval at the ESA Ministerial Council 2019.

On 31 March, ESA Director David Parker met the NASA Associate Administrator for Human Exploration and Operations William Gerstenmaier in Washington DC. NASA provided an update of their plans for the deployment of the 'Deep Space Gateway', based on the assumption of the NASA budget available and continuation of ISS to 2028. The important role of ESA on the critical path of Orion was also emphasised in light of its future contribution to the Deep Space Gateway.

→ SPACE SITUATIONAL AWARENESS (SSA)

Space Weather (SWE)

SWE Portal release 2.5.0 was deployed on 28 February, including new products and services from all Expert Service Centres in the SSA SWE Network. A training course was held at ESOC on 22 March for the Mars Express Flight Control Team. There are more than 500 registered users for SWE Services, and the SWE Service Portal has about 350 000 hits monthly for services that do not require registration.

The PFM of the Next Generation Radiation Monitor has been delivered to OHB GmbH for integration to the EDRS-C satellite. This is the first hosted payload mission implemented by the SSA Programme. Following

Programme Board and Industrial Policy Committee approval, preparations are ongoing for the release of the ITTs related to the SWE L5 mission (Phases-A/B1).

Near Earth Objects (NEO)

A number of contracts to support the operation of the NEO coordination centre came to an end and were presented at ESRIN. The software to calculate the impact risk and impact corridors of potentially threatening asteroids is now integrated in our web portal.

Observations with the Optical Ground Station in Tenerife, the Klet observatory in the Czech Republic, the VLT in Chile and the telescope on Calar Alto have produced important NEO observations.

Space Surveillance and Tracking (SST)

SST Core Software and space-based options were discussed at the SSA industry day. The activity looking at radar observations with the European Incoherent Scatter Scientific Association has been completed. The activity for the establishment of an expert centre for federated laser and optical systems has passed Factory Acceptance Test. Integration, testing and validation of the data processing, planning, scheduling, catalogue querying and event detection software is progressing and has passed PDR. The activity on support observations and sensor qualification is nearing completion with preliminary sensor characterisation available for the tested assets. International standardisation activities are continuing within CCSDS and the CEN/CENELEC.

Radars and telescopes

A parallel radar measurement campaign was performed with the mono- and bistatic radar, with improved results in accuracy of orbit determination due to a longer observation arc.

The project for the development of the fly-eye telescope (NEO-X) continued with the manufacturing readiness review. OHB Italy has been given a Contract Change Notice to cover procurement of the long-lead items for the completion of the telescope with 16 cameras in total. The notice also covers the definition of the infrastructure (size of telescope foundation, dome size, overall site layout). Investigations are proceeding for the selection of the site for NEO-X. Monte Mufara, Sicily (IT) could be a possibility, subject to satisfactory test results.

The General Support Technology Programme project 'Demonstration Test-Bed for the Remote Control of an Automated Follow-Up Telescope' is nearing completion. Both telescopes have been built. One is already deployed in Cebreros (ES), and the second is expected to be deployed at the ESO La Silla site in Chile.

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