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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

- → 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
- space programme, in purceusal satellites;

  → by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.





# bulletin

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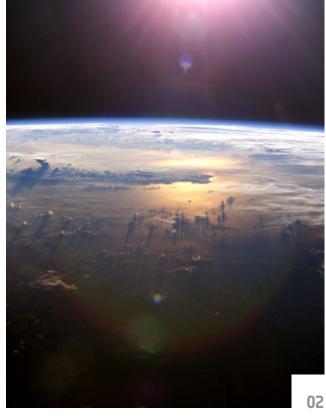
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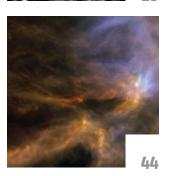


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# → ASTROBIOLOGY The search for life



Life: how do we define it and how did it begin on Earth? This is the subject of astrobiology, the study of the origin, evolution, distribution and future of life in the Universe.

Astrobiology improves our fundamental knowledge about our own existence, addressing primarily scientific and philosophical questions, as well as the more prosaic benefits of helping to advance applications of biological processes in industry and other activities on Earth. The study also helps our preparations for future missions — robotic exploration and human exploration — and enhances our activities in planetary protection.

ESA works with scientists from around Europe and beyond in defining and preparing to answer the key questions about extraterrestrial life and what forms it might take. Did life start on early Earth or was it brought to Earth 'ready-made' on a meteoroid? Are there signs of life on other planetary bodies in our Solar System and, if so, how will we recognise them if they look different from life on Earth? Can life on Earth adapt to conditions on other planets? What sequence of events produced the organic building blocks from which life sprang into existence and what is the process by which life emerges from non-life?

Astrobiology makes use of knowledge from many scientific disciplines, such as biology (including microbiology, botany, cellular biology and radiation biology), chemistry (including biochemistry, photochemistry and organic chemistry) palaeontology, geology, atmospheric physics, planetary physics, astronomy, meteoritics and stellar physics, to try to find out how and why life originates. Up until now, we know only one place where it exists – on our own Earth.

Our understanding of the resilience of life from Earth has been transformed by astrobiology experiments. We have been testing the ability for terrestrial organisms to adapt to and survive conditions in space – if a desiccated terrestrial organism can survive in open space to once again flourish under better conditions, it's possible that life could travel through space from one planet to another. But so far, the only proof we have of transport of life between celestial bodies are the Apollo missions to the Moon!

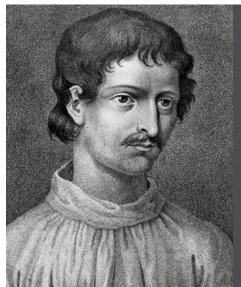
### How did life start on Earth?

There are different theories as to how life started on early Earth when the atmosphere was very different to now, temperatures were more extreme, the atmosphere had no oxygen, and levels of deep ultraviolet solar radiation were about 1000 times stronger than today.

One theory assumes that the earliest life did not originate on Earth at all but elsewhere in the cosmos, under different conditions — although nobody knows which conditions exactly are necessary to turn 'non-life' into 'life'. Called 'panspermia', this theory says that life can be distributed throughout the Universe by meteoroids, asteroids and comets. This could be, for example, by an impactor sending debris hosting microorganisms, seeds or spores into space from one planet to another, such as Earth.

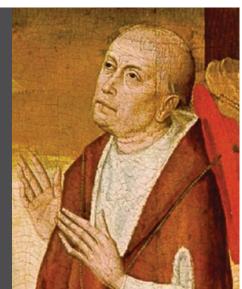
So far, no extraterrestrial organisms have been found in any meteorite that landed on Earth. However, prebiotic material (complex organic molecules that pre-date living organisms) in the shape of amino acids has been detected in several meteorites, including one of the most chemically primitive ones (the Murchison meteorite) that fell to Earth in 1969.





Italian friar and mathematician Giordano Bruno (1548–1600), known for his cosmological theories and proposing that other stars might also be surrounded by planets able to support life of their own (Wellcome Library)

German philosopher Nicholas of Cusa (1401–1464) theorised on the possibility of extraterrestrial life



The Murchison example even contains two of the 21 amino acids associated with life on Earth.

Some meteorites on Earth have also been used to study Mars, as they can be proven to have come from our neighbouring planet. The record of meteorites from Mars is missing a crucial component of the martian surface: all the martian meteorites examined are igneous rock. By comparison, around half of the surface of Mars consists of sedimentary rock. Since fossils are mostly found in sedimentary rock, it would be helpful to have such a sample from Mars.

The ESA STONE experiment suggests that such a sample could survive the journey through space and through Earth's atmosphere but it would be difficult to recognise on the ground because of normal weathering and erosion.

Exposing samples and organisms to the space environment provides an indication of the conditions under which an interplanetary transfer can occur, since conditions such as full spectrum solar ultraviolet radiation cannot properly be mimicked on Earth. For example, would compounds or organisms need protection under the surface of a meteoroid to remain viable/survive or could they remain viable even on the surface of a meteoroid in the glare of solar ultraviolet? And if they could endure such conditions, for how long could they endure them?

# Old theories, newly tested

Europe has a long history of interest in astrobiology – before the discipline even existed. The possibility of life on other planets was both a philosophical and scientific question, and sometimes even a religious one. In the fifteenth century, Cardinal Nicholas of Cusa debated life on other planets, while at the end of the sixteenth century Giordano Bruno also

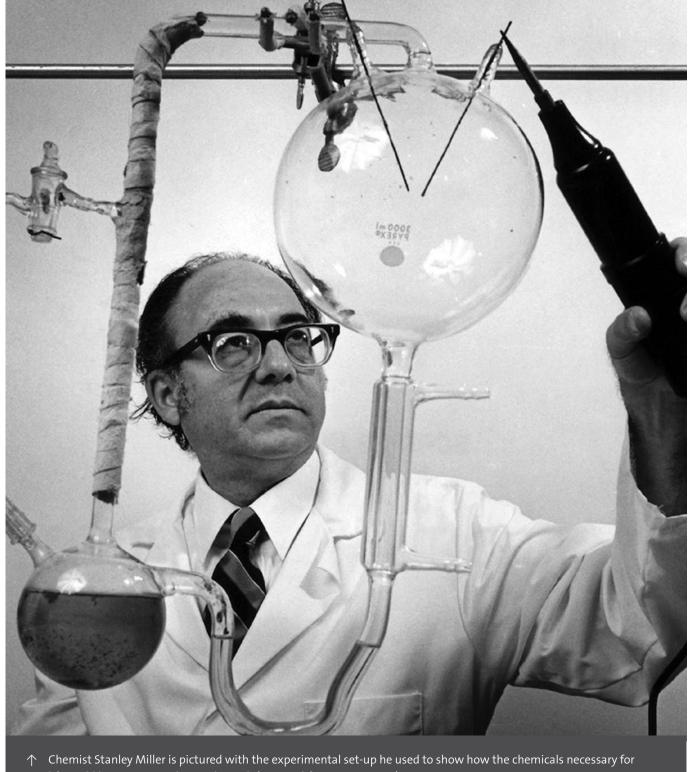
discussed life beyond Earth but his opinions and theories eventually saw him denounced as a heretic and he was burned at the stake.

In the early seventeenth century, Johannes Kepler expanded his interest in the cosmos to speculating about life off Earth. His novel Somnium talks about life on the Moon and is often considered the first work of science fiction. At the end of the seventeenth century, Christiaan Huygens wrote his Cosmotheoros, discussing the requirements for life and the possibilities of life on other planets in the Solar System. The work was published in Latin after his death before being translated into other languages. It was clear to Huygens that water was necessary for life, while on the topic of energy he mused that the inhabitants of Mercury would likely think Earth too cold for life in the same way as we considered the outer planets to be too far from the Sun and too cold.

At the end of the nineteenth century, several eminent scientists were engaged with ideas related to extraterrestrial life and the theory of panspermia. Hermann Richter, Hermann von Helmholtz, the microbiologist Ferdinand Cohn and Lord Kelvin himself all wrote or spoke about the idea.

The Swedish chemist Svente Arrhenius suggested that spores could be propelled away from Earth by electrical forces linked with auroras. In his 1908 book, Worlds in the making; the evolution of the universe, Arrhenius examined the potential for life on different planets according to their chemical make-up and considered how the future of Earth might improve with a continuing greenhouse effect. He disagreed with Lord Kelvin's suggestion that life could travel through the Solar System inside meteors saying he believed that the impact events that created them as well as reentry friction would be too hostile. He preferred the idea that spores, not reliant on water and resistant to cold and sunlight, could travel independently.





life could have originated on early Earth (Univ. California, San Diego)

The idea of life on multiple planets was a popular one, but outside the creation stories, there was no explanation for how life began on Earth. Even Charles Darwin, as he clarified how primitive life became more complex, could not explain the starting point. Alfred Russel Wallace, considered by many, including Darwin, to be the codiscoverer of the principle of natural selection, studied the other planets for evidence of habitability but equally could not say how life began.

Darwin speculated in a personal letter about the possible ingredients of life and its development on the early Earth

while Russian scientist Alexander Oparin also wrote about how the water and atmosphere on Earth might have given rise to life. Oparin was a biochemist and developed experiments to investigate how membranes might form from the primordial mix of chemicals on Earth. Testing theories of the origin of life was difficult and was also limited by knowledge of the early Earth's atmosphere.

A famous experiment by Stanley Miller in the 1950s demonstrated that amino acids could form from nonorganic matter in a sealed analogue of the early Earth. Since then, many laboratories have addressed prebiotic chemistry,



Comet 67P/Churyumov-Gerasimenko seen by ESA's Rosetta mission: experiments in organic chemistry have been studying compounds detected on comets or in the atmosphere of Titan, for example (ESA/ Rosetta/MPS)

producing various amino acids. Although amino acids are essential for life, they do not directly indicate life.

We know that amino acids can be formed in a lifeless, sterile environment and they are omnipresent interstellar space. The missing piece of information about how biology develops from chemistry may be found in physics or in a better understanding of our planet's environment 4.6 billion years ago, around when life emerged on Earth.

Building on the theories of the past, but using spacecraft earlier biologists could not have dreamed of, we are now in a better position to study whether life might exist on other planets, and how it might travel from one planet to another. It is only with the start of the space age that we have been able to test the resilience of life in open space. Europe has been leading the way in testing old ideas with modern methods.

# Forming the molecules that form life

Life as we know it is based, without exception, on complex carbon-based compounds such as proteins and nucleic acids (including DNA and RNA) with some organic molecules consisting of hundreds or thousands of atoms ordered in a specific way. There are 21 amino acids found in life on Earth, and they display left-handed chirality.

Right-handed amino acids emerge just as abundantly as lefthanded ones in Miller-type physico-chemical experiments, but do not occur in terrestrial life.

Cells, plants and animals are all assembled from the same molecular building blocks and have apparently evolved over time in Darwinian style from some simple, common ancestor. The chances of life starting from non-living material is staggering in its unlikelihood and must have been the end

product of a long process of chemical evolution. How can all these molecules assemble themselves into a sophisticated, functional ensemble capable of growth and reproduction? This may have started with carbon-based molecules being formed in the core of giant red stars that were ejected into space. The processes that brought us from these simple compounds to proteins and nucleic acids is still a mystery, though we know that ultraviolet radiation has a significant effect on breaking down chemical bonds and catalysing reactions in space and in the atmospheres of planets. Unravelling this mystery is a key element of ESA research in astrobiology.

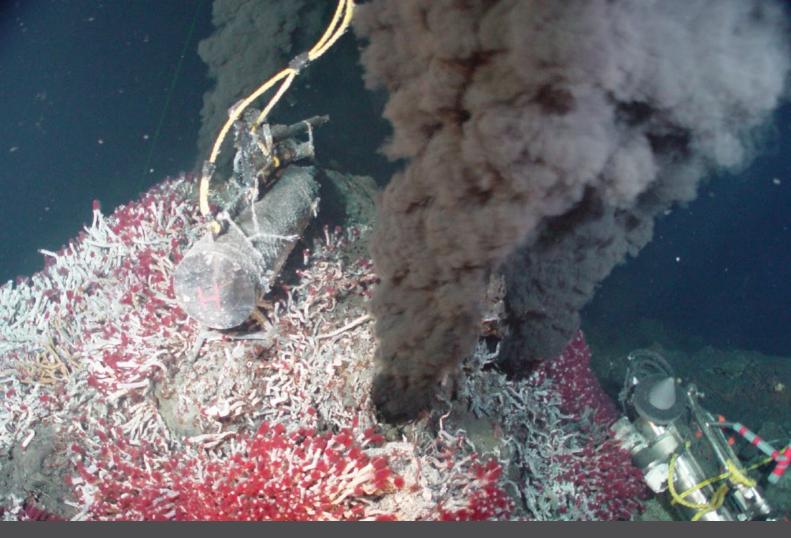
This research has been exposing to open space different organic compounds that can be found in interstellar space, or in the atmospheres of planetary bodies - we can tell the constituents of different gases in space using spectroscopy once light passes through them. This may one day help scientists to discover the key to where, and how, chemistry turned into biology and help to look for the signatures of current and previous life on other planets.

# Biochemistry and alternative biochemistries

Defining what is 'life' is notoriously difficult – and tracing the evidence of past life in fossils can be even trickier. However, life as we know it on Earth shares a number of traits in common:

**Energy:** living cells need energy. Life on Earth needs energy. Some organisms – autotrophs – make food directly from sunlight. Others, including humans, are heterotrophic meaning they search for food in their environments. **Transfer of information**: another important property of life as we know it is the transfer of information, for example through DNA.

A solvent: all evidence suggests that a solvent, specifically liquid water on Earth, is needed to host chemical interactions.



↑ Discovered only in 1977, hydrothermal vents ('black smokers') on the deep ocean floors are home to dozens of previously unknown species. How is life possible here without sunlight? In a process called chemosynthesis, microbes at the base of the foodchain convert chemicals from the vents into usable energy (NOAA/PMALE)

ESA's ExoMars 2020 mission that will look for signs of life on Mars (Airbus Defence & Space)





Radiation protection: life forms must either be resistant to radiation or protected from it to thrive.

**Common essential elements**: all of the life we know uses the same set of elements – carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur. Our biochemistry, and that of all other living things we know, is based on carbon. Carbon forms large molecules with itself and many other elements, and forms bonds that are very stable in the presence of water and oxygen.

Organic chemistry deals with carbon compounds, which used to be seen as a key marker of life. But science fiction has often postulated silicon-based life, because silicon has some chemical properties similar to carbon. For example, it is able to form stable bonds with itself and the other known ingredients for life (carbon, nitrogen, phosphorus and oxygen).

Plants and algae on Earth use silicon in the form of silicon dioxide for their cell walls, which suggests that it could be used by other life forms, at least for external structures. The chemical environment of other planets – particularly newly discovered exoplanets – may suggest other factors that are more or less favourable for silicon-based life. Though many within the astrobiology community still believe that liquid water is essential for life, some astrobiologists debate

whether an alternative solvent to liquid water may exist for other life forms. Possibilities include sulphuric acid, ammonia, methane, ethane and nitrogen, which could imply a different range of habitable zones at different stars.

### Life in extreme environments

As we examine how life originated on Earth, we have discovered life in unexpected places and in unexpected guises. When we research the survival of life in open space, some of the experiments involve plants or animals that are suited to surviving in extreme conditions on Earth – either through natural resilience or a dormant phase that allows them to avoid conditions that would inhibit or end the normal life cycle.

Open space conditions can be used to simulate conditions on or beneath the surface of a meteoroid in interstellar space, on early Earth before an oxygenated atmosphere existed, on the surface of a planet such as Mars, or conditions in the atmosphere of a planetary body such as Titan. Identifying organisms and compounds that remain viable in such conditions can provide an insight into looking for life elsewhere.



# Searching for extraterrestrial life

Life on Earth evolved under very specific conditions. This evolution changed the chemical make-up of our planet dramatically, for example through photosynthesis. The composition of the atmosphere changed to have a greater percentage of oxygen, leading to the ozone layer and its associated ultraviolet protection, and changing the chemical composition of the land we walk on to help sustain life.

This presence of oxygen is in itself one biological signature of life existing here on Earth. But how would we spot life on another planet if it evolved under different conditions? Or how could we spot the signs of life on a planet where life may have thrived in the past may now be extinct?

Studying and discovering organisms that can survive the extreme conditions on Earth provides an insight into the characteristics that extraterrestrial life would need to survive on another planetary body. These characteristics, whether it is able to protect itself against ultraviolet radiation, to survive extended periods without water or under extremely low pressure conditions, creates a biological fingerprint that could be used to find similar organisms on other planets. Traces of compounds produced when microorganisms interact with surface minerals can, for example, provide a biological signature of both existing and extinct life.

As a database of biological signatures grows, this

will provide an increased chance of finding signs of extraterrestrial organisms. Data from NASA's Kepler space mission suggest that there could be as many 40 billion Earth-sized planets orbiting in the habitable zones of Sun-like stars and red dwarf stars within the Milky Way, hinting at the possibility of finding other places where life has arisen. More than 3500 exoplanets have already been identified, with over 30 in their stars' 'habitable zones'.

Indeed, in its search for exoplanets, the CNES/ESA COROT mission pioneered exploration of smaller planets with the discovery of the first confirmed Earth-like exoplanet orbiting a star similar to our own Sun. Between 2006 and 2012, it has since revealed 32 planets with 100 more awaiting confirmation.

# **Protecting other planets**

Planetary protection is a very significant issue, especially when searching for life in extraterrestrial environments. When we send probes to different planetary bodies in search of signs of life, for example the ExoMars rover, we need to make sure that we are not contaminating that body with microorganisms from Earth and are able to study this new environment in its pristine state.

Determining which organisms could survive such a space journey is a key element in making sure that this does not take place and needs to be taken into account with



# → Planetary protection

sterilisation techniques of surface rovers, for example. This principle also applies in reverse. If signs of life are detected elsewhere in our Solar System we need to take precautions to protect Earth's biosphere.

# Future human exploration of the Solar System

Earth provides a hugely complex life support system for many millions of species, and microorganisms are at the very root of the chain of life, crucial to nutrient recycling and soil formation. Microorganisms are also used in biotechnology, in traditional and modern food preparation techniques.

Organisms that can survive extreme space conditions could prove a vital element of future human exploration missions forming the basis of biological life support systems to assist in oxygen production, carbon dioxide recycling and as decomposers and recyclers of waste. They could form the basis of future agricultural techniques in space, being used to create soil in situ on surface bases in order to assist in crop production.

# Biotechnology

In uncovering the secrets of life's survival on the Earth, astrobiology has found some remarkable applications. For example, the powder that you put in your washing machine at high temperatures works because it contains proteins extracted from microbes that grow in volcanic hot springs. The nature of this field of study could also help in uncovering organisms that can survive extreme conditions that could play a role in areas such as bioremediation (the use of organisms to remove or neutralise pollutants from a contaminated site) on Earth.

### What if?

Recent studies have indicated that life arose on the very early Earth, and once it existed, it proved extremely tough. This suggests that life could form and persist on other planets, although we are working with an example of only one. Perhaps life on other planets arose late or was not as durable. We know now that there are many 'exoplanets', or planets revolving around other stars, where it might be possible for microbial life to exist.

The actual discovery of microbes, or any other form of life, on other worlds would be one of the biggest discoveries of all time, and conclusive evidence of extraterrestrial life would forever change how we, as humans, approach all facets of our lives.

Jon Weems is an Ajilon Technology Aerospace writer for ESA Ruth McAvinia is an ATG Europe editor for ESA



# → EXTREMOPHILES

# Choosing organisms to study

René Demets and Jon Weems Directorate of Human & Robotic Exploration, ESTEC, Noordwijk, the Netherlands

Looking for life throughout the Universe means understanding the characteristics that organisms need to have to survive and adapt. Some Earthbased creatures can survive, and even thrive, in environments that would kill humans - whether at extremes of temperature, radiation and pressure or even in a vacuum.

On Earth, there are several environments that resemble conditions in space such as extreme heat and extreme

cold, highly desiccating conditions (such as in deserts and high salt plains), lack of oxygen, poisonous arsenic lakes, and so on. Investigating organisms that survive in these extreme conditions on Earth, organism called 'extremophiles', could help us to identify organisms that can survive in open space or on another planetary body with a hostile environment such as the Moon or Mars. These extremophiles cover different classes of organisms from bacteria and archaea to lichens, fungi and micro-animals.

# → BACTERIA

Bacteria were among the first life forms to appear on the early Earth. Bacteria have adapted to survive in most Earth habitats living in soil, water, acidic hot springs, radioactive waste, arsenic lakes, and the deep portions of Earth's crust.

Scientists have reported finding bacteria living in the cold and dark in Lake Whillans some 800 m under the ice in Antarctica, and bacteria that displayed robust cellular growth under conditions of thousands of times the gravity experienced on Earth, which is usually found only in cosmic environments, such as on very massive stars or in the shock waves of supernovas.

The *Thermus* genus of bacteria was first identified towards the end of the 1960s in a hot spring at Yellowstone National Park in USA. Since then, more than a dozen species have been defined. *Thermus* was the first extremophile reported that could live in temperature above 70 °C. The bacterium *Deinococcus radiodurans* can withstand exceptionally high doses of ultraviolet and gamma radiation, apparently by rebuilding its DNA even if it is fragmented by radiation.

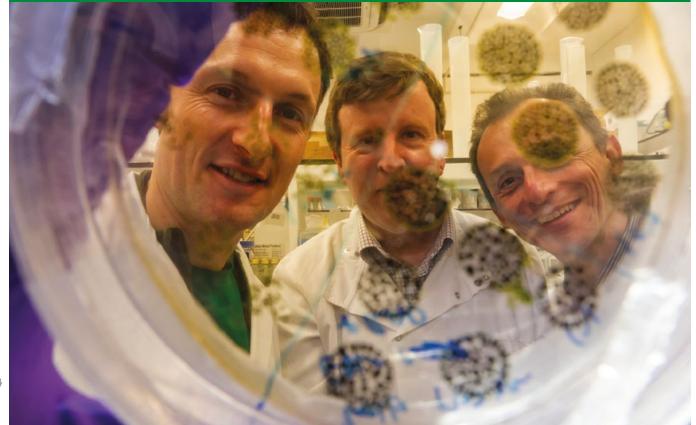
Bacteria compose the largest selection of species that have undergone astrobiological research.



↑ A photomicrograph of *Chroococcidiopsis* (A. Donner/Uni. Rostock)

Chroococcidiopsis, for example, is one of the most primitive blue-green algae (cyanobacteria) known. Some members of the genus are known for their ability to survive harsh environmental conditions, including extreme high and low temperatures, ionising radiation and high salinity. Chroococcidiopsis is able to thrive in

↓ ESA astronauts Pedro Duque and Matthias Maurer with Prof. Charles Cockell, head of the UK Centre of Astrobiology, studying colonies of *Chroococcidiopsis* from the Negev desert in Israel. The bacteria were flown to the International Space Station and returned for analysis after a year in space (S. Sechi)



Cesa



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The Concordia Station in Antarctica: scientists have reported finding bacteria living in the cold and dark some 800 m under the ice in Antarctica (ESA/ IPEV/PNRA—B. Healey)

extreme environments on Earth like the Atacama desert in Chile and the Dry Valleys in Antarctica. It can survive in a low moisture environment, but not totally without water. Its characteristics have made it a candidate for being capable of living on Mars and possibly aid in the formation of an aerobic environment and soil production.

Bacillus subtilis is another bacterial species, found in the gastrointestinal tract of humans and in soil. The model organism can tolerate extreme environmental conditions and is capable of switching to anaerobic respiration if oxygen is absent. B. subtilis is also used on an industrial scale by biotechnology companies.

↓ The Great Salt Lake in Utah, seen here from space, is 3–5 times saltier than the ocean. The northern arm of the lake (red) typically has twice the salinity of the rest of the lake because the railroad causeway crossing the lake restricts water flow. Each half of the lake hence accommodates different algal and bacterial species that cause the colour difference (NASA/ESA)



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# → FUNGI

Fungi are more advanced organisms on the evolutionary scale compared with bacteria or archaea. The fungus kingdom is diverse with varied ecologies, life cycle strategies and morphologies ranging from unicellular aquatic fungi to yeast to large mushrooms.

Fungi have a worldwide distribution and grow in a wide range of habitats, including extreme environments such as deserts or areas with high salt concentrations, as well as in deep-sea sediments and hydrothermal areas of the ocean.

One example of a fungus used in space research is Aspergillus niger, which causes a disease called black mould on certain fruits and vegetables and is a common contaminant of food. Members of the Aspergillus genus possess the ability to grow in areas of high osmotic concentration (high sugar, salt, etc.).

Another example used in astrobiology is Trichoderma longibrachiatum, a fast-growing soil fungus occurring commonly on decaying plant material with industrial applications because of its capacity to secrete large amounts of protein and metabolites.

It has potential benefits as a biocontrol agent in agriculture, or use within waste management for cleaning polluted sites associated with hydrocarbons and heavy metals, as well as the generation of biofuels.

↓ Microscopic image of lichen showing fungal and algal cells (L. Sancho)



# **→ LICHENS**

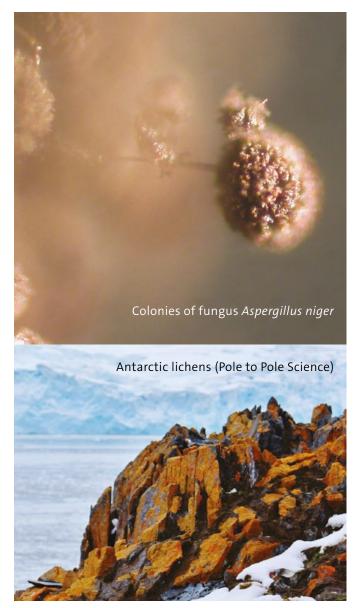


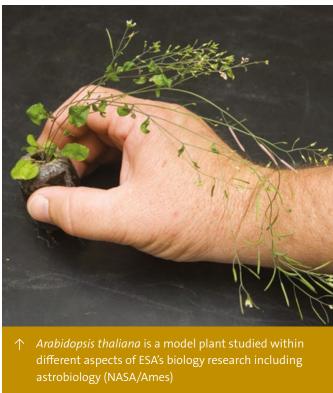
There are thousands of species of lichen, but they function as an association of millions of algal cells, which cooperate in photosynthesis and are held in a fungal mesh. Species take their names from the fungal part. The algal cells and the fungus have a symbiotic relationship, with the algal cells providing the fungus with food and the fungus providing the algae with a suitable living environment for growth.

In fact, lichens can be considered as very simple ecosystems. Lichens occur from sea level to high alpine elevations, in a wide range of environmental conditions, and can grow on almost any surface. Different kinds of lichens are adapted to survive in some of the most extreme environments on Earth: arctic tundra, hot dry deserts, rocky coasts and toxic slag heaps. They can even live inside solid rock, growing between the grains.

Certain lichens have already shown a remarkable resistance to the space environment, including the ability to survive exposure to full solar ultraviolet radiation. For example, ESA proved that lichens from two different species could survive in open space. During the Foton-M2 mission, launched into low Earth orbit in May 2005, Rhizocarpon geographicum and Xanthoria elegans were exposed for 14.6 days in total before being returned to Earth. Analysis after the flight showed a full rate of survival and an unchanged ability for photosynthesis. Xanthoria elegans is found on all continents except Australia and is widespread in Antarctic regions.

Other research has focused on Circinaria gyrosa and Buellia frigida. Circinaria gyrosa naturally grows in steppelike and continental deserts of the northern hemisphere and Buellia frigida is a maritime lichen found especially in continental Antarctica.





# **→ VIRUSES**

Though not classed as a 'life form' per se, viruses do have an important impact on it and are also the subject of ESA's astrobiological research. This not only provides information about whether infectious agents could survive extreme conditions (with application to planetary protection issues for example), it can also have additional applications. The bacteriophage T7 virus for example has been tested as a biological radiation dosimeter in space, as it has a stable relationship with ultraviolet radiation exposure for determination of the effective radiation dose.

# → PLANT SEEDS

Plants have also been the subject of astrobiology research through the testing of the viability of plant seeds to germinate after exposure to space conditions. One plant species that has undergone such astrobiological research is Arabidopsis thaliana, which is a model plant organism and the first plant to have its genome sequenced. A. thaliana is a popular tool for understanding the molecular biology of many plant traits, including flower development and light sensitivity. In fact many common, non-exotic plant seeds can cope with exposure to open space. For instance lettuce seeds (Lactuca sativa), as was shown in one of the Biopan experiments.

# → CHEMICAL COMPOUNDS

To determine steps in organic chemistry that led to the origin of life, different species of organic compounds have been exposed to open space and simulated planetary conditions. This includes several hydrocarbons that have been identified by spectroscopy in space environments like polycyclic aromatic hydrocarbons (PAHs), which are estimated to make up approximately 15% of the cosmic carbon as well as being present in meteorites, moons and possibly in comets. Other stable carbon molecules known to exist in planetary nebula are being studied along with a selection of organic molecules such as different amino acids and RNA.

# → MICRO ANIMALS



The micro-animals tested in space have included the cysts of brine shrimp (Artemia salina) and the tardigrade, or 'water bear'.

When temperatures drop and food is scarce, the females of the brine shrimp release dormant cysts. Inside the cysts, the embryos are arrested in development. The surrounding shell protects them from the elements. When conditions improve, the embryo resumes development, and the life cycle continues. The cysts are desiccation-resistant and able to survive in high-saline environments.

Tardigrades are even tougher. They are water-dwelling, segmented micro-animals, with eight legs. More than 1150 different tardigrade species have been identified.

Tardigrades can survive in extreme environments, withstanding temperatures from just above absolute zero (oK, -273.15 °C) to well above the boiling point of water, and pressures about six times greater than those found in the deepest ocean trenches, as well as ionising radiation at doses hundreds of times higher than the lethal dose for humans and the vacuum of outer space. They can go without food or water for more than 10 years, drying out to the point where they are 3% or less water. Usually, tardigrades are about 0.5 mm long when they are fully grown.

# **→ ARCHAEA**

Initially classified as bacteria, archaea constitute a domain of single-celled microorganisms with no cell nucleus (like bacteria) though possessing certain genetic characteristics more closely related to organisms with cells containing a nucleus (Eukaryotes).

Archaea are found in many extreme environments on Earth such as in high temperatures, even above 100 °C, like geysers, undersea hydrothermal vents (where seawater meets magma) and oil wells, as well as very cold habitats and highly saline, acidic, or alkaline water.

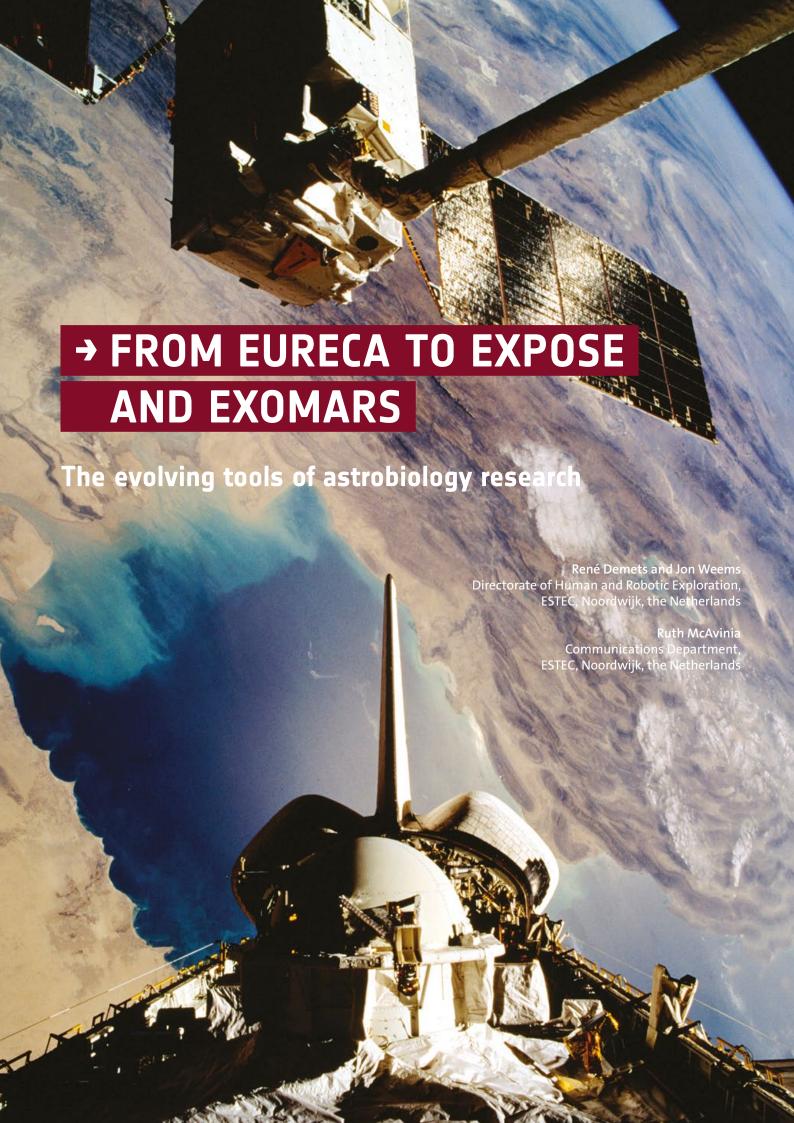
The archaea Sulfolobus are known as 'hyperthermophiles' and can survive temperatures of 80 °C, particularly around volcanic springs. The pH is also very low in these areas so Sulfolobus are also 'acidophiles', liking acidic conditions. Methanopyrus kandleri, meanwhile, can tolerate temperatures of up to 110 °C and are also 'halophiles', thriving in a salty environment.

Not restricted to extreme environments as we know them. archaea are also found in soils, oceans, marshlands and the human colon.

Archaea are particularly numerous in the oceans, and the archaea in plankton may be one of the most abundant groups of organisms on the planet, playing roles in both the carbon and nitrogen cycles.

As a major part of global ecosystems, archaea may contribute up to 20% of Earth's biomass. Examples of archaea used in astrobiology research include different halophilic archaea (such as Halococcus dombrowskii and Halorubrum chaoviator), which survive in high-saline environments such as salt plains and salt lakes.

Jon Weems is an Ajilon Technology Aerospace writer for ESA



For more than 25 years, ESA has shared in astrobiology research. Experiments have included studies of the compatibility, or incompatibility, of terrestrial life exposed to open space, leading to ambitious landers and the possibility of finding life native to other environments in space.

Astrobiology has been a cornerstone of ESA research from the earliest Russian-flown experiments through the development of the Exobiology and Radiation Assembly (ERA) for the EURECA platform flown on the US Space Shuttle in the early 1990s, to the upcoming ExoMars rover.

ESA's life sciences activities cover every aspect of space life sciences, including biology, physiology, biotechnology, biomedical applications, biological life-support systems, astrobiology, animal research and access to ground facilities. ESA flew its first biological samples in open space on the Russian retrievable capsules Bion-8 (1987), Bion-9 (1989) and Bion-10 (1992/93).

In 1992, the ERA experiment flew on the EURECA mission. At the same time, Biopan had been in development and flew its qualification flight in October 1992. Thirty-five twoweek Biopan experiments were flown on six Russian Foton missions between 1992 and 2007.

For longer missions, 'Expose' was installed externally on the International Space Station – the first on the Columbus module and its successors on the Russian segment Zvezda. These facilities were developed to explore the survivability and damage/repair mechanisms of organics, plants, fungi, spores, microorganisms and invertebrates in space conditions.

# **Exobiology and Radiation Assembly**

The European Retrievable Carrier (EURECA) housed 15 different experiments. Most were focused on non-biological microgravity experiments, but two were in the domain of astrobiology, accommodated in the Exobiology and Radiation Assembly. At the time, EURECA was the largest spacecraft to be built and flown by ESA, weighing 4500 kg

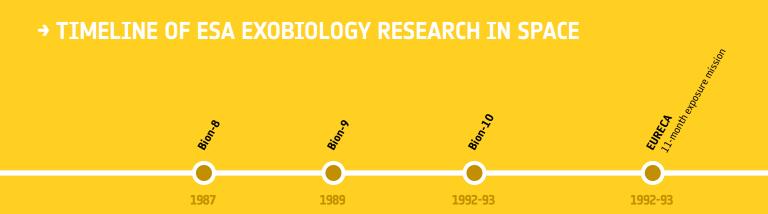
and measuring 20 m across. It was the first ESA spacecraft to be returned to Earth – on board the space shuttle – for sample access and potential reflight.

EURECA was placed into orbit in August 1992 by Space Shuttle Atlantis and returned in July 1993 by Space Shuttle Endeavour. EURECA had its own propulsion capabilities attaining and adjusting orbital altitude and subsequent retrieval as well as telemetry and command subsystems. ERA provided information on the long-term exposure of microorganisms and organic molecules to outer space conditions including bacterial spores of Bacillus subtilis and Escherichia coli, cells of Deinococcus radiodurans. Halobacterium salinarum membranes and conidia of the fungus Aspergillus sp.

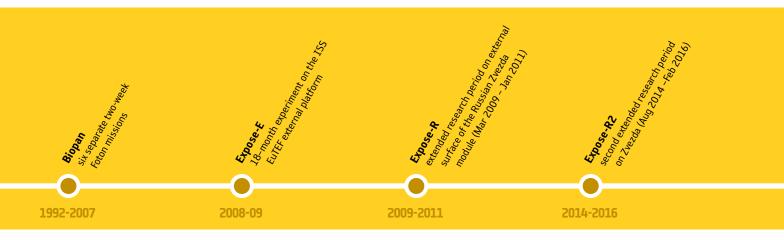
## Biopan

Biopan was being developed around the same time – in the early 1990s – and functioned for more than a decade on different flights to reach ESA's astrobiology investigation goals. Biopan was an exposure facility, shaped like a large clamshell, which was installed on the external surface of a Russian Foton descent capsule in a series of flights.









The facility had a motor-driven hinged lid, which opened 180° in Earth orbit to expose the experiment samples to the harsh space environment. Biopan was equipped with sensors measuring temperature, pressure, cosmic radiation and solar ultraviolet light and had an ablative heat shield for protecting the closed facility during reentry. The sensors delivered critical information about the exact environmental conditions the samples experienced in open space.

These missions included 35 experiments in total, covering the viability and survivability of a much more diverse set of organisms compared with the EURECA astrobiology experiments, and incorporated associated radiation dosimetry experiments. The different organisms included brine shrimp, tardigrades, lichens, fungi (including yeast), algae, bacteria, archaea and different plant seeds, as well as simple organic molecules such as amino acids and peptides.



Removal of the Biopan facility from Foton-11 Descent Module after landing in Kazakhstan on 23 October 1997

# **Expose-E and Expose-R**

While the Biopan missions were still running, planning was already under way for longer-duration astrobiology experiments on the International Space Station. This series of experiments became collectively known as 'Expose', the name of instrument platform used to host the experiments on the exterior of the station.

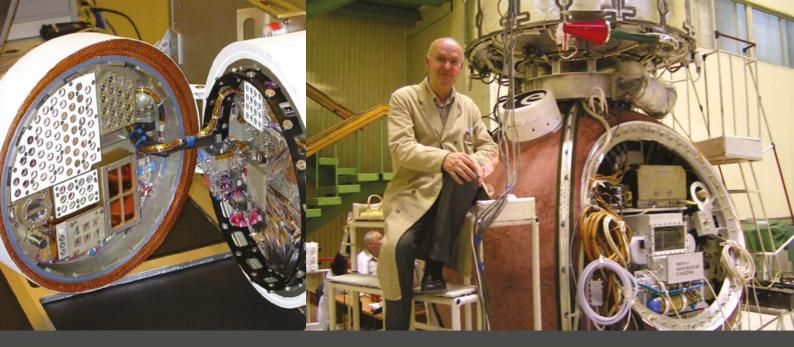
Two models of the Expose facility were built for multiple experiments. Each Expose unit was equipped with three sample trays with sensors delivering extra information

about the space environment in low Earth orbit. Cosmic radiation was measured with detectors provided by the scientists for their experiments. Solar radiation was measured by in-built sensors in Expose as well as by investigator-provided detectors.

The Expose-E payload was a sub-assembly of the EuTEF

facility and was exposed outside the

Columbus laboratory for more than 18 months. Artist impression of Foton capsule in orbit with Biopan facility, the white feature at top right of the brown re-entry capsule (AOES/Medialab)

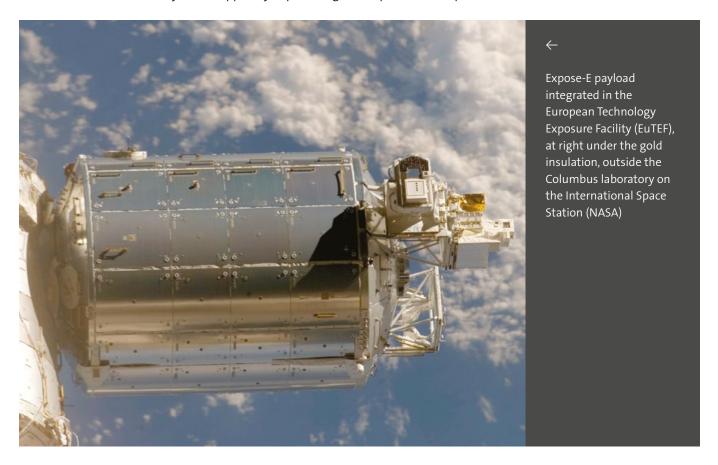


- ↑ Biopan facility open with clear view of exposure experiments inside
- ESA astrobiologist and article co-author René Demets with Biopan container at the surface of Foton-M3 capsule during payload and spacecraft interface tests in 2007

Expose-E incorporated five astrobiology experiments covering exposure of different lichen and fungi samples, plant seeds, microorganisms, spores and organic molecules. Two of the three sample trays were exposed to open space conditions while the third tray was modified to offer the samples simulated martian conditions; these were low pressure, atmosphere mainly of CO<sub>2</sub> and an altered ultraviolet spectrum. The samples were typically distributed over different layers: an upper layer, providing

full exposure to solar radiation, and lower layers in darkness, for reference.

The Expose-R facility completed 22 months of exposure on its first set of experiments. This was the second longest astrobiology mission in low Earth orbit. In August 2014, the same facility was mounted outside the Space Station, loaded with a follow-up collection of experiments and samples. This second trip, known as Expose-R2, was to continue for 16 months in orbit.







Expose-R hosted a suite of nine astrobiology experiments, while Expose-R2 hosted four. This does not mean that less science was produced on Expose-R2, it just indicates that the experiments individually covered a wider scientific scope and occupied more space. Three of the Expose-R2 experiments were from ESA and one came from the Russian Institute of Biomedical Problems (IBMP) in Moscow.

The experiments studied biological processes in the simulated climate of Mars and the probabilities and limitations for life to be distributed among the bodies of our Solar System. The experiments put a variety of organisms to the test such as lichens, archaea, bacteria, cyanobacteria, algae, black fungi, and bryophytes (a division of green flowerless plants comprising mosses and liverworts) as well as biomolecules like pigments, specific cellular components, different amino acids, and DNA and RNA nucleobases.



The research also included biochemistry experiments aiming to study processes of chemical evolution in space including stability of biomolecules and a wide range of non-gaseous and gaseous organic compounds detected in, for example, interstellar space, comets, and the atmosphere of Titan.

The results of the research will help determine which organisms, or the organic components thereof, can survive space conditions. It will help to find out which characteristics aid the survival process and create a biosignature database to help in the search of extant or extinct life off our planet.

The samples exposed to 'open space' conditions were placed behind magnesium fluoride windows to allow all wavelengths from deep ultraviolet to far infrared to pass through. For simulated Mars conditions, the samples were placed behind quartz windows along with cut-off filters to mimic the solar wavelength spectrum that arrives at the surface of Mars. Additional neutral density filters are also used for some samples to reduce the quantity of ultraviolet getting through for comparative purposes.

The samples were arranged in layers (Sun-exposed and darkness) with the experiment environment monitored by temperature, solar and radiation sensors. Many of the samples were exposed to a vacuum by venting the sample compartments at the start of the exposure period, while others were kept in an inert (argon) atmosphere to stop sample metabolism and to maintain pressure (Expose-R) or kept in a simulated martian atmosphere (Expose-R2). Several results from Expose-R2 have already been published, but there will be much more to come in 2018.

# Astrobiology experiments in the future

ESA is also working on a new facility for astrobiology to fly on the International Space Station. Building on the experience of the Expose experiments, it will also travel on the exterior of the Station, but with the extra capacity for automated in situ monitoring during flight, so that we can learn how the samples change over time during space exposure. Seven different experiments will be hosted in the facility, which will undergo its preliminary design review next year with a view to flying in late 2019 or early 2020.

The seven experiments that have been selected have slightly different requirements: three require a spectrometer in the ultraviolet/visible and the infrared light range. These experiments will operate concurrently. When completed, the astrobiology facility will be transferred back inside the space station for reconfiguration before the remaining four experiments are deployed outside.

The first scientific goal is to investigate to what extent specific biological organisms, tolerant to extreme environments on Earth, are able to cope with the even



The Expose-R2 payload with sunshield still on top before the start of the full exposure period (NASA/ESA/ Roscosmos)



The Expose-R2 facility photographed during the Russian spacewalk in October 2014 (NASA/ESA/Roscosmos)



Close-up of Expose-R facility outside the Zvezda (NASA/ESA/Roscosmos)





harder conditions in open space, on Mars or on Jupiter's moon Europa. The second goal is to measure how particular biochemical reactions, fuelled by unfiltered, full-spectrum solar ultraviolet light, proceed over time.

### **ExoMars**

The 'Exo' in 'ExoMars' refers to the study of exobiology, another term for astrobiology. The primary goal of the ExoMars programme is to search for signs of past and extant life on Mars. Mars shows evidence for having had suitable temperatures and liquid water capable of supporting primitive life early in its history, some 3.5 billion years ago.

The discovery of methane in the martian atmosphere suggested the possibility of life on the planet even to the present day – especially because it is difficult for methane to persist in the atmosphere. Methane is broken down over time by ultraviolet radiation, oxidising it through chemical reactions into carbon dioxide, the primary ingredient of the martian atmosphere. In addition, winds on Mars can redistribute the methane from its original source, reducing localised concentrations.

The two main potential sources of methane on Mars are biological and geological. Subsurface microbes could be generating methane directly every day. But methane could also have been produced millions of years in the past and become trapped in clathrate hydrates (a crystal-like structure of water, similar to ice), only to be released today.

Methane can also be produced by non-biological reactions between water and a mineral called olivine, a process called 'serpentinisation'. On Mars, this may occur

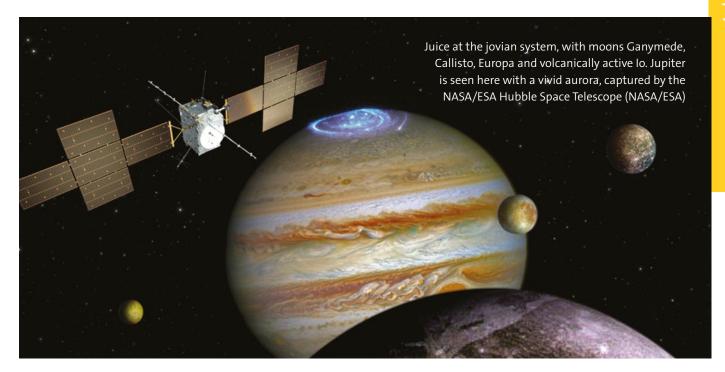
underground, perhaps in combination with warmer, volcanic environments.

The ExoMars Trace Gas Orbiter (TGO) can detect important isotopologues of methane and water. Isotopologues are molecules in which at least one atom has a different number of neutrons than in the parent molecule: for example, HDO is an 'isotopologue' of H<sub>2</sub>O, where one hydrogen atom has been replaced by an isotope atom, deuterium. Measurements of methane on Earth suggest that methane originating from biological and geological processes have distinctive isotopic signatures, so TGO's measurements should help narrow down the origin and history of these species on Mars.

The next ExoMars mission will send a lander to drill into the surface of Mars, in 2020. Tests, models and simulations have been used to characterise a landing site. To recover wellpreserved chemical biosignatures from the very early history of Mars, some four billion years ago, we need to collect samples from a depth of 1.5–2.0 m at a site that has been relatively recently uncovered by wind erosion. The site needs to have deposits where sediments were laid down in a long-lasting water environment.

# Juice

The Jupiter Icy Moons Explorer, or 'Juice', will be used to identify potential for life around the gas giants. The mission will look at how these worlds evolved as the Solar System formed, as well as their current potential for habitability. Juice is scheduled for launch in 2022 and will reach Jupiter in 2030. Its tour will include a dedicated orbit phase of Jupiter, targeted flybys of Europa, Ganymede and Callisto, and finally nine months orbiting Ganymede – the first time any



moon beyond our own has been orbited by a spacecraft. The spacecraft has a laboratory of instruments to study Jupiter's atmosphere and magnetosphere, as well as the three planet-sized moons. All three moons are thought to have oceans of liquid water beneath their icy crusts and should provide clues about whether such moons could sustain habitable environments.

It will carry cameras, spectrometers, a radar, an altimeter, radio science experiments and sensors to monitor the plasma environment in the jovian system. Juice's cameras will capture details of the moons' features, as well as identifying the ices and minerals on their surfaces.

Other instruments will sound the subsurface and interior of the moons to characterise the location and nature of their buried oceans. It will look for essential elements and chemical indications of biological activity. The mission will also explore the tenuous atmosphere around the moons.

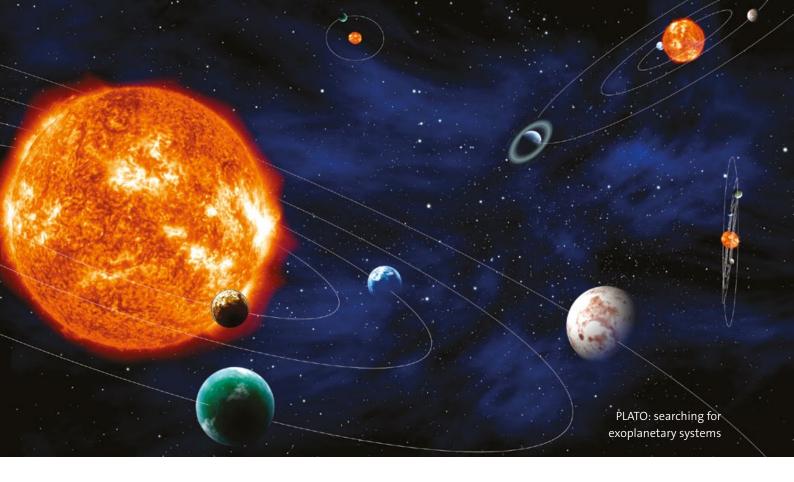
Ganymede is interesting in part as an example of the nature, evolution and potential habitability of icy worlds, and also because of the role it plays within the system of Galilean satellites, and its unique magnetic and plasma interactions with the surrounding jovian environment. It is the only moon in the Solar System to generate its own internal magnetic field, and Juice will document its behaviour and explore its interaction with Jupiter's own magnetosphere.

# Cheops

The Cheops mission will examine the conditions for planet formation and the emergence of life. Studying exoplanets – planets outside our Solar System – will help us to understand the architecture of planetary systems, and the main processes driving their evolution. The goal of the Cheops mission is to measure the bulk density of super-Earths and Neptunes orbiting bright stars and provide good targets for subsequent, in-depth characterisation studies of exoplanets in these mass and size ranges.

The mission will perform first-step characterisation of super-Earths – measuring the radius and density, and inferring the presence or absence of a significant atmospheric envelope for super-Earths in a wide range of environmental





conditions. Cheops will obtain new insights into the physics and formation processes of Neptunes, such as measuring accurate radii for Neptunes, determining precise densities, deriving minimum values of their gas mass fractions, and inferring possible evolution paths.

Thirdly, the mission will assemble a collection of 'golden targets' for exoplanetology, meaning it will identify the small-mass exoplanets transiting bright stars that will be the best suited targets for in-depth atmospheric characterisation by spectroscopic facilities during or after the mission – for example, by the James Webb Space Telescope.

### **PLATO**

PLATO will look for other planets similar to Earth. The mission will investigate how planets and planetary systems form and evolve, and ask whether our Solar System is special or if there are other systems like ours. From an astrobiology perspective, it will also look for potentially habitable planets.

PLATO will characterise rocky planets in the habitable zone of Sun-like stars. 'Habitability' is defined as the potential of an environment to sustain life of any kind. The mission team is considering all the possible variables for habitability, including alternative atmospheric planets. The existence of liquid water for long periods of time on the surface of terrestrial planets is considered as one of the prerequisites for life.

From the prerequisite of liquid water comes the concept of the habitable zone around a star, where liquid water on the surface is possible in principle. The liquid water reservoir should also be small enough to avoid the formation of highpressure ice at the bottom of the ocean, which is expected for ocean planets and suspected to prevent the functioning of the carbonate-silicate cycle. The width of what is defined as the habitable zone normally includes assumptions about the carbonate-silicate cycle but if these are not correct, the habitable zone may be smaller.

It is challenging to find small planets, similar to Earth, around stars similar to our Sun and orbiting at distances such that liquid water can exist for long periods of time to potentially sustain life on the planetary surface. The detection of these planets will be a breakthrough for our understanding of the conditions that led to the emergence of life on Earth. The investigation of these small planets with long-period orbits will be complemented studies of planets of all sizes, in all kinds of systems, on all kind of orbits.

Current detection limits have prevented the discovery of more than a few rocky exoplanets, although low-mass planets around other stars are most likely abundant. PLATO will accurately measure the radii, masses and ages of Earth-like planets in the habitable zones of stars similar to our own, filling that gap in our knowledge of extrasolar planets and laying the foundations for exoplanetary research in the coming decades.

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ESA's short-duration Biopan flights between 1992 and 2007 delivered some unexpected and unique results: particular terrestrial organisms could happily survive in open space over a period of two weeks — without a spacesuit!

Of course, most biological species that we know, be they microbes, fungi, plants and animals, including humans, will be killed rapidly in open space without protection, through desiccation, freezing, suffocating, choking, sunburn and so on. But some organisms won't. Among the survivors of these experiments, some were unicellular but others were macroscopic and multicellular, including specific types of microbes but also plant seeds, lichens and tardigrades ('water bears').

This robustness of terrestrial life was somewhat unexpected and provided food for thought for biologists — what is the biological explanation? These results also provided worries for planetary protectionists, and impetus for advocates of the panspermia theory. Since 2008, this path has been further explored by ESA on Biopan's

successor experiment facility, Expose, which can stay in orbit up to two years.

Of the five major space factors that astrobiological samples are exposed to (solar ultraviolet radiation, vacuum, weightlessness, wide-temperature variations and cosmic radiation), the solar ultraviolet was found to be the most deadly.

A significant amount of organisms have shown that they can survive the open space environment, but only if shielded from solar ultraviolet – as would be the case just below the surface of a meteoroid, early Earth or a planet like Mars. Some types of plants seeds and full-grown lichens are even able to cope with direct solar ultraviolet irradiation, and some cluster-forming micro-organisms can also survive long-duration exposure to solar ultraviolet with the outer cell layers acting a shield for the inner layers.

One of the most durable organisms in astrobiology, the yellow-coloured lichen *Xanthoria elegans*, showed ability to survive open space conditions including vacuum and solar ultraviolet radiation following more than 18 months of exposure.

√ Xanthoria elegans one of the most durable organisms in astrobiology, showed ability to survive open space conditions following more than 18 months of exposure (D. Molter)





# Surviving solar ultraviolet radiation: lichens and fungi

As direct successors to earlier short-duration studies on Biopan, the Lichens and Fungi (LIFE) experiments on Expose-E demonstrated that one lichen (Xanthoria elegans) and one black fungus (Cryomyces antarcticus) resisted full solar irradiation for 18 months, whereas almost all other samples only survived if partly or fully shielded from ultraviolet light. This was a significant step forward in astrobiology research because these organisms were far more advanced on an evolutionary scale than bacteria or archaea used in previous ESA experiments. As a symbiotic relationship between algal cells, which cooperate in photosynthesis within in a fungal mesh, lichens can, in fact, be considered as very simple ecosystems.

This type of research continued on Expose-R. Spores of the fungus Trichoderma longibrachiatum survived exposure to the full spectrum of solar ultraviolet irradiation or the martian-equivalent spectrum during the 22 months Expose-R was in space. Aspergillus fungal spores (from the IBMP experiments) also remained viable after ultraviolet exposure. This was probably due to the fact that the spores form clusters, and the outer layers of spores may have shielded the inner cells.

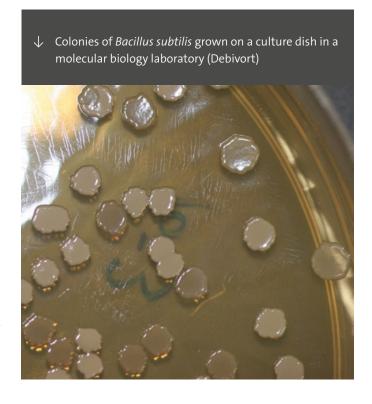
### Bacteria and archaea

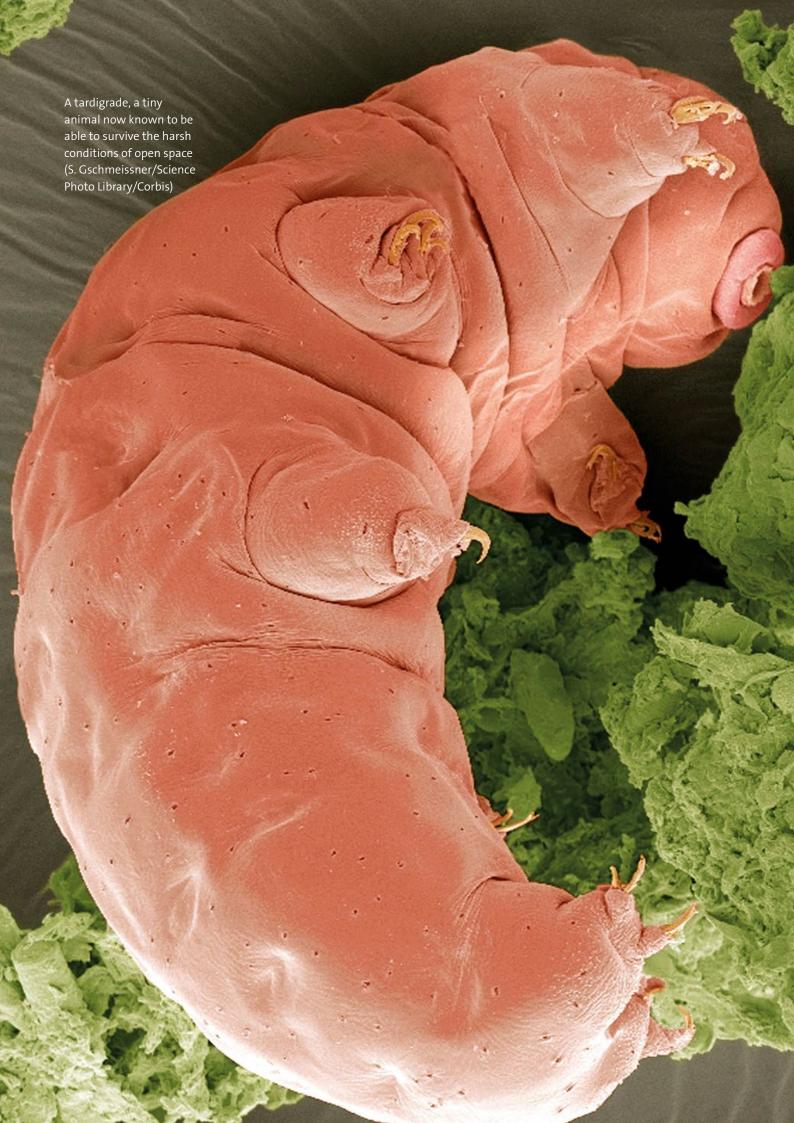
As the first organisms to populate the early Earth, bacteria and archaea have been a dominant presence in astrobiology research. Different species of bacteria and archaea have shown good survival rates during long-duration exposure to the space environment (18 months on Expose-E or 22

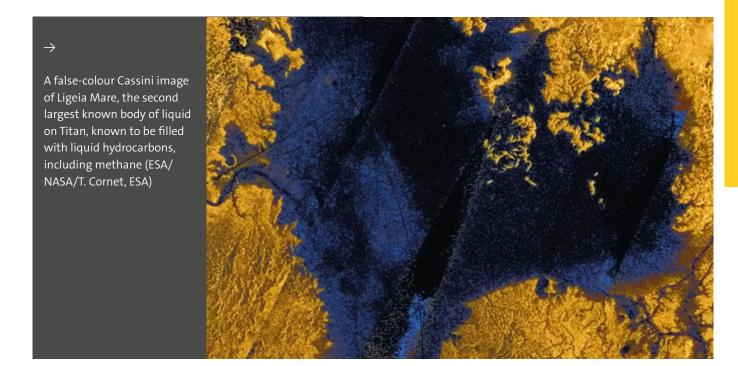
months on Expose-R) if shielded from solar ultraviolet. This includes the extreme-tolerant bacteria Bacillus subtilis and Bacillus pumilus, the halophilic Halococcus dombrowskii and Halorubrum chaoviator archaea, and blue-green algae species of the genera Synechococcus and Chroococcidiopsis, which are also salt-tolerant. For the salt-tolerant/halophilic species, their extreme desiccation resistance in space is most likely related to their salt tolerance, which protects them from dehydration and desiccation on Earth.

The results of the associated experiments suggest that the protection afforded by meteorite material or within impact-shocked rocks is adequate to preserve the viability of different micro-organisms during interplanetary travel, or beneath the surface or in impact craters on, for example, early Earth or Mars.

For the two *Bacillus* species, this has additional implications for planetary protection, for example the issue of not contaminating other planetary bodies on future missions such as ExoMars. Results of ESA research also provide credibility to the idea that microorganisms which use solar light as a primary energy source (phototrophic organisms) could have colonised early land masses if just under the surface, or as multicellular layers, where enough light could penetrate for photosynthesis to occur. Such organisms may also be as part of surface habitats for future human exploration missions, for example, to Mars as part of biological ecosystems within life-support systems for oxygen production or food production to aid in the formation of soil, as long as the balance between light and ultraviolet protection can be struck.







### Micro-animals

Other complex lifeforms have shown that they can survive space conditions. This includes the tiny microscopic animals called tardigrades that survived a two-week exposure to the vacuum of space very well, though with significantly reduced survival when exposed to the combined effect of vacuum and solar ultraviolet light.

### Seeds

A remarkable quantity of survivors was found in both Arabidopsis (thale cress) seeds and tobacco seeds exposed to open space conditions. Seeds that had been shielded against solar ultraviolet, but exposed to the other conditions of space survived at even higher rates.

# Organic chemistry results

The Expose-R experiment ORGANIC concentrated on the evolution of carbon polymers relevant to the processes occurring in interstellar space and in circumstellar clouds. The experiment confirmed our understanding of how ultraviolet light interacts with organic molecules, such as 'fullerenes' (carbon molecules in specific formations of multiple carbon atoms) or polycyclic aromatic hydrocarbons (PAHs, specific compounds of carbon and hydrogen) in space. The greatest stability was found in the different fullerenes and the compact PAHs, followed by non-compact PAHs and thereafter PAHs with an additional non-hydrogen/carbon element.

Another Expose-R experiment, AMINO, confirmed that some ultraviolet-exposed amino acids could survive transport through interstellar space when exposed to ultraviolet, even

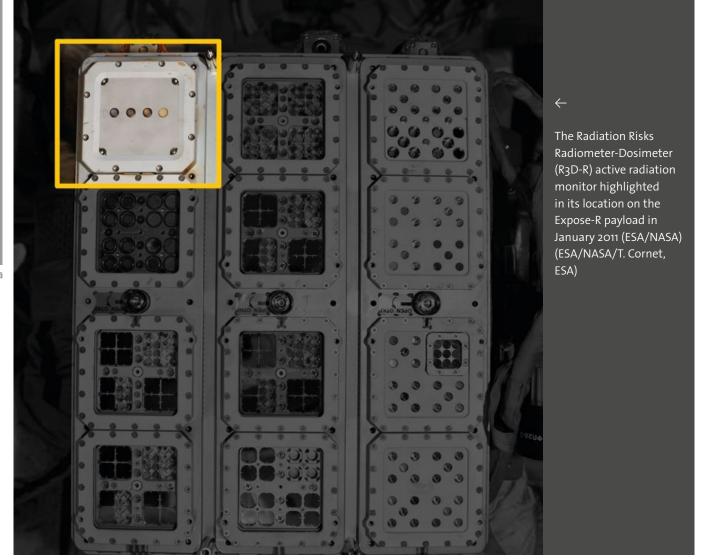
more so if not fully exposed but embedded in appropriate mineral matter. A further part of the experiment determined that RNA would not survive exposure in open space unless shielded from solar ultraviolet and would most likely not have survived on the surface of the early Earth. However, with life on Earth probably starting in seawater, which acts as a filter against ultraviolet, if there was RNA in the seas and oceans it would have been safely protected.

A final part of the experiment exposed Titan-equivalent atmosphere samples (nitrogen and methane) to open space. This led to the formation of saturated hydrocarbons (i.e. hydrocarbons saturated with hydrogen), which included ethane and propane, which have been detected in Titan's and Saturn's atmospheres, as well as isobutene and n-pentane.

# Recent ground tests

Expose-R2 delivered results from preflight ground experiments before it was taken to the International Space Station. Survivability of the lichen species Circinaria gyrosa and Buellia frigida was increased when exposed to ultraviolet and vacuum compared with samples exposed to ultraviolet without vacuum due to desiccation. Freezing also protected the lichens against the damaging effect of solar ultraviolet compared with room temperature samples. It therefore seems that the mechanisms that these organisms employ to go into a dormant state for protection against extreme stressors on Earth also inadvertently protect them from ultraviolet in space. Circinaria gyrosa naturally grows in steppe-like and continental deserts of the northern hemisphere and Buellia frigida is a maritime lichen found especially in continental Antarctica.





### Radiation research results

This research is improving our knowledge of the radiation environment in low Earth orbit as well as providing reference data for the biology and organic chemistry experiments. As part of the Expose-E, -R and -R2 mission, measurements were taken with an active (time-dependent) radiation detector as well as sets of passive detectors to measure the overall radiation dose. From March 2009 to January 2010, there was a period of very low solar activity connected with an unusual deep minimum of solar cycle 23. From January to August 2010, solar and geomagnetic activities increased as solar cycle 24 progressed and the electron flux and dose rate changed. The more active the Sun is, the fewer protons are recorded in low Earth orbit.

Compared with measurements taken during the Expose-E mission, the hourly and daily average dose rates during the Expose-R mission were higher for proton and electron measurements because of reduced shielding in the vicinity of the active instrument but lower for Galactic Cosmic Radiation. The Galactic Cosmic Radiation average daily-absorbed dose rates were actually lower than readings taken inside the Space Station (March–June 2009), which can be attributed to secondary particles generated when primary particles pass through the walls of the Station.

From 1 April to 20 August 2010, increased activity was observed (significantly on 6 and 7 April with further high measurements afterwards) with the highest dose rate of 21.13 mGy (Gy = gray, the SI unit for ionising radiation dose) per hour obtained from a single measurement. This was connected with the second largest fluence of electrons recorded in the history of the Geostationary Operational Environmental Satellites (GOES) that have been taking measurements since the 1970s.

### More results coming

These are the experiments featured on the Expose-R2 facility, with results from its stay in space soon to be published:

# **BIOlogy and Mars Experiment (BIOMEX)**

The BIOMEX experiment was designed to measure how resistant biomolecules like pigments and cellular components are to space and Mars-like conditions, and how well they maintain their stability. BIOMEX also examined how well terrestrial extremophiles are able to survive in space and which interaction between biological samples and selected minerals (including terrestrial, Moon and Mars analogue varieties) can be observed under space and Mars-like conditions. The samples included bacteria, cyanobacteria, algae and archaea, as well as fungi and lichens.

#### **BIODIVERSITY**

This experiment is to evaluate the impact of prolonged exposure (from 12-18 months) of the space environment on the survival of evolutionarily separated dormant forms of living creatures (bacteria, fungi, plants and animals). The results will help us to understand more about the limits of biological systems and inform our decisions about quarantine and protection in interplanetary flight.

#### Biofilm Organisms Surfing Space (BOSS)

BOSS used bacteria including extremophiles to examine the behaviour of biofilms in space. In their natural environment, most bacteria live on surfaces as slime-encased biofilms and microbial mat communities. On Earth this makes them more resistant to environmental stresses like chemical pollution, antibiotics and predation. This experiment tests whether the same is true in space, with samples exposed to open space and Mars-like conditions.

#### Photochemistry in the Space Station (PSS)

Solar ultraviolet photons are a major source of energy to initiate chemical reactions in the Solar System. The solar spectrum below 200 nm is hard to reproduce in the laboratory, so photochemical studies of the evolution of organic molecules are missing some crucial information with respect to extraterrestrial environments. PSS tested a range of organic compounds to help us to understand chemical evolution in organic-rich astrophysical environments (comets, meteorites, Titan, the interstellar medium) and where organic matter is being looked for (martian surface and subsurface).

#### Where are we now?

The quantity and diversity of different organisms that we know can survive in the environment of open space environment are growing, and the conditions under which they can survive are being studied in more depth.

This research is already providing information that will improve our chances of detecting life on other planetary bodies whether extant or extinct. This may also feed into strategies for planetary protection. The findings will also help with follow-on geobiological studies on the Moon and as preparation and support for future Mars exploration missions. Indeed, with the future of human spaceflight looking towards exploration beyond low-Earth orbit, the potential for expanding this type of research to the more demanding radiation environment outside Earth's magnetic field is growing.

This area of research can also have an impact in many different areas. Biotechnology is an obvious choice, with the potential for using extremophiles within life-support systems for human space exploration and in situ resource utilisation on the Moon and Mars.

These results are moving us closer to answering the important questions of astrobiology posed at the beginning of this Bulletin: on the origin and evolution of life, whether there is any other life in the Universe, and what could be the future of life on Earth?

Domagal-Goldman and Wright discuss this in Astrobiology: whether life beyond Earth will be detected and is this separate from the question of whether such life exists? It is unlikely we will be able to investigate most of the candidate planetary bodies in our galaxy, let alone those that are farther away. It is also possible that any signs of life will be missed, because we are not looking at the right time, since we know from our own Solar System that the environments of planetary bodies change over geological timescales.

We know of only one planet with life: Earth. The response of humankind to the detection of life beyond Earth would depend on the nature of the extraterrestrial life itself. Some scientists hope that discovering another type of life form would allow us to develop a broader theory of life, and the existence of this second form of life would also strongly suggest that life is commonplace throughout our galaxy. However, this raises another important ethical question: if we do find another form of life, what do we do with it? Do we have an obligation to preserve it?

Another example of the wider implications of astrobiology research is the definition of life itself. The ongoing debate among astrobiologists is also relevant to research in synthetic biology and artificial intelligence, with some thinkers asking whether computers may reach the point of being considered 'living'.

The well-known astronomer Carl Sagan noted in his 1980 book Cosmos, that 'astrobiological research is, therefore, not simply investigation of the possibility of life beyond Earth but includes extensive and ongoing debate about issues that help us have a glance at different possibilities for our own future'.

Jon Weems is an Ajilon Technology Aerospace writer for ESA

#### **Further reading**

- Space for Life, ESA Human Spaceflight Newsletter, Issue 7, April 2015
- The Astrobiology Primer v2.o, Domagal-Goldman, SD, and Wright, SD (eds), Astrobiology, Vol. 16, Number 8, 2016
- Cosmos, Sagan, C, Random House, New York, 1980





The story of Europe's Spaceport at Kourou, French Guiana

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Carl Walker Communications Department, ESTEC, Noordwijk, the Netherlands

Liftoff of Ariane 5 flight VA233 carrying Galileo satellites in 2016 (ESA/CNES/Arianespace) Cesa

As a byword for excellence and reliability, Europe's Spaceport in French Guiana ranks among the most modern space facilities in the world. A 'pearl' of the European space adventure, this facility allows independent European access to space.

The spaceport, technically called the Centre Spatial Guyanais (CSG) or Guiana Space Centre, lies just above the equator in South America, and hosts facilities for Ariane, Soyuz and Vega launchers.

Of more than one hundred launches performed by the present Ariane 5, Soyuz and Vega vehicles, around 30% have been dedicated to European payload programmes. Among the most important launches from Europe's Spaceport, we can include the Automated Transfer Vehicles that supplied the International Space Station, the Galileo satellite navigation system and the Copernicus Earth Observation programme's Sentinels, as well as science missions such as XMM-Newton. Rosetta and LISA Pathfinder.

Coming soon will be the launches of the ESA/JAXA BepiColombo mission and the NASA/ESA/CSA James Webb Telescope. But as impressive as each launch is, they all result from a colourful history of successful European cooperation.

#### History

At the beginning of the 'Space Race' between the the USA and the USSR, several European countries also set access to space as a priority, so as not depend on those powers for space utilisation. In 1964, France decided to build a new launch facility in order to move the nascent Diamant launch operations of the French space agency, CNES, from Algeria. French Guiana,

an overseas department of France situated in the northeast of South America, was chosen from a shortlist of 14 sites.

On the recommendations of CNES, the French government formally opened the site for international cooperation. While taking the responsibility for the development, France was guaranteeing unrestricted access to the future space centre. In parallel, France was also taking the heaviest burden in the development of the European launcher.

In 1966, the launch organisation ELDO (the European Launcher Development Organisation, one of ESA's predecessors) decided to move its operations from Australia and chose the Kourou site as the base for its Europa II launcher. In 1968, with the launch of a sounding rocket from the Veronique series, the Guiana Space Centre became operational: 'Europe's Spaceport' was born.

The first launch into orbit from Kourou was the Franco-German satellite DIAL-WIKA on a French Diamant-B rocket in 1970. In 1971, Europa II's first launch was unsuccessful and this launcher programme was cancelled two years later. Shortly after, in 1973, ELDO was reorganised and became part of the new European Space Agency, with European Member States deciding to develop a new launcher, thus starting the Ariane programme. Europa II's launch complex was recycled and adapted for Ariane 1.

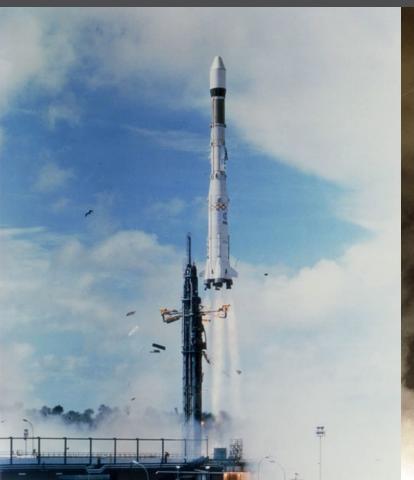
On Christmas Eve 1979, the first Ariane was launched from the Guiana Space Centre, marking the beginning of Europe's independent adventure in space. Four more Ariane versions were developed. And while Ariane 5 has been flying, the Guiana Space Centre has also become a multi-launcher base with the arrival of Vega and Soyuz.





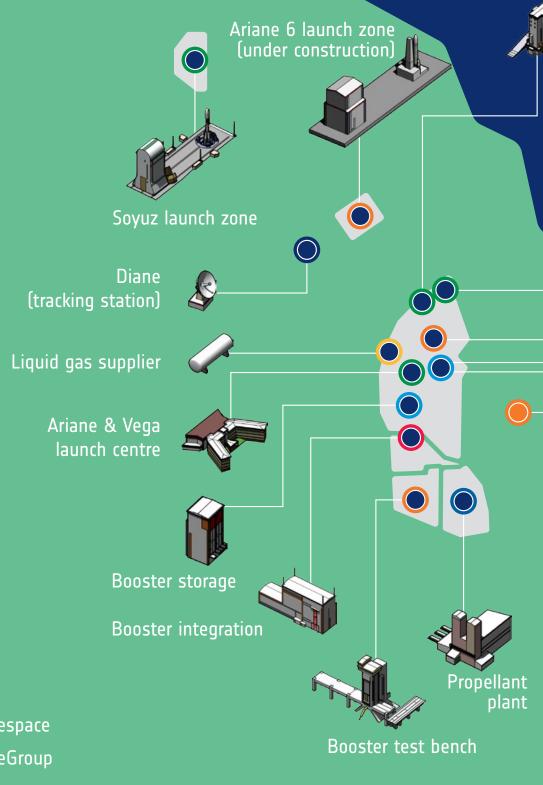


- ↑ Europa II launch complex in 1971 (ESA/CNES)
- The first Ariane 1 launch, 24 December 1979. Ariane 1
   was designed to put two telecommunications satellites
   at a time into orbit. As the size of the satellites grew
   Ariane 1 gave way to the more powerful Ariane 2, 3 and 4
   launchers. Altogether, 11 successful Ariane 1 launches took
   place between 1979 and 1986
- ↑ The original ELA 1 launch complex, the original launch site of Europa II, Ariane 1 and Ariane 3, now repurposed for Vega
- The last Ariane 4 launch, 15 February 2003. Ariane 4 entered service in 1988 and made 113 successful launches. During its working life, Ariane 4 captured 50% of the world market in commercial satellite launches





#### → EUROPE'S SPACEPORT



- Operated by ESA
- Operated by CNES
- Operated by Arianespace
- Operated by ArianeGroup
- Operated by Regulus
- Operated by Europropulsion
- Operated by Air Liquide
- Owned by ESA
- Owned by CNES
- \*Ensemble de Préparation Charge Utile



#### → Key dates for Kourou Creation of French space agency CNES Signature of the ESA Convention to establish Creation of European Launcher Development new European Space Agency 1979 Inaugural flight of first ESA-developed launcher, France decides to relocate CNES launch 1964 Ariane 1 from ELA 1 launch pad operations from Algeria Arianespace is created to commercialise services 1965 Establishment of a CNES centre in Kourou, called of ESA-developed launchers 1984 First flight of Ariane 3 from ELA 1 1966 ELDO Council decides to move Europa II launcher 1986 First flight of Ariane 2 from ELA 1 activities to CSG First flight of Ariane 4 from ELA 2 1968 CSG enters into service with the first flight of a 1996 First flight of Ariane 5 from ELA 3 sounding rocket First flight of the Soyuz at CSG from the El 1970 First satellite launched from Kourou launch pad 1971 First Europa II launch unsuccessful 2012 First flight of Vega from the ZLV launch pad 1973 Europa II programme is cancelled. Ariane recycled from ELA 1 programme begins

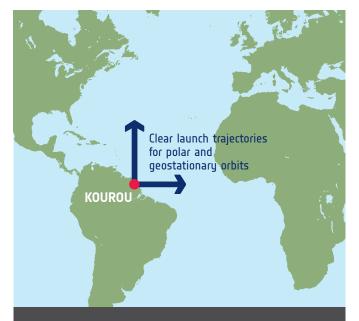
Today, the spaceport is an industrial site with 37 companies, representing nine European nationalities. The facility has helped to bring jobs and wealth to French Guiana, where space activities constitute 15% of the GDP. Industry is centred on the spaceport and an estimated 15% of the population work directly or indirectly in jobs connected with the space industry. The spaceport itself has around 1700 permanent staff. About 200 additional experts join for launch days. The construction of new launch complexes can bring in hundreds of extra workers, which was the case for Soyuz and Vega with up to 600 more people on site in 2006.

#### Reason for siting

Europe's Spaceport is located just over 500 km north of the equator. Surrounded by South American forest, its 50 km-long coastline borders the Atlantic Ocean from the city of Kourou to the town of Sinnamary. Its total area comes close to 700 km², which is about the same size as the island of Madeira.

These geographical features make for an ideal launch site. First, the wide opening on the Atlantic Ocean allows for launch amplitudes of 102° without flying over inhabited





land. Launchers from the spaceport can then achieve all

orbiting and geostationary satellites

kinds of missions towards any orbit.

With a clear trajectory over the oceans to the north and east, Kourou is in an ideal place to launch polar-

Second, the proximity to the equator gives a free boost of 460 m/s to eastward launches thanks to Earth's rotation. This reduces the energy required for orbit change manoeuvres. Saving fuel and money, satellites can be heavier and their operational lifetimes increased, which improves the return on investment for spacecraft operators. Finally, the climate and landscape are favourable

for the spaceport's operations: the region is not prone to extreme weather events, the surrounding hills facilitate the installation of tracking systems and the underlying granite shield is perfect for structural foundations for launch pads.

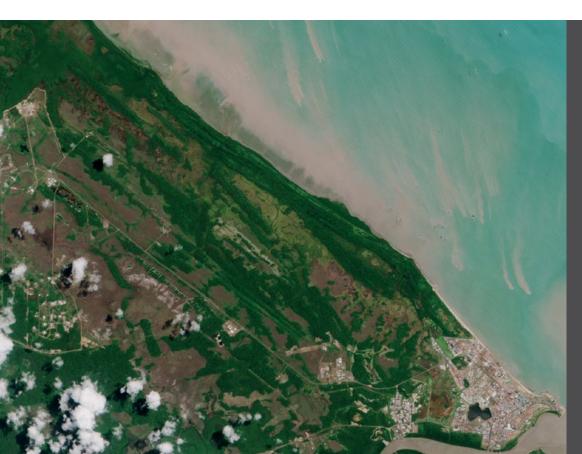
#### **Current facilities**

Since the Guiana Space Centre became Europe's Spaceport, ESA and its predecessor ELDO have invested more than €2 billion in upgrading ground facilities for European launchers. ESA owns the infrastructure related to the launches, which can be divided in three areas: the launch complexes, the launch range and propellant manufacturing facilities.

When ESA qualifies a launch development programme, it entrusts Arianespace with the commercialisation of the launch services and the operation of the launch complexes. In return, Arianespace maintains the facilities with the support of European industry.

ESA also contributes partially with Arianespace in the fixed cost of the launch complexes of Ariane 5, Soyuz and Vega. Indeed, ESA continues to monitor its launchers in exploitation via its Launchers Exploitation and Accompaniment Programme (LEAP), which aims to improve their competitiveness in the launch market.

Launch complexes include the facilities necessary for the integration of the launcher elements, as well as the launch operations. A launch complex is composed of a vehicle preparation zone, a launch pad and a control centre. The launch control centre is the remote brain of a launcher system. It links every installation at the complex, ensuring the live control of the operations for the launcher and



 $\leftarrow$ 

Europe's Spaceport from space: seen by the Copernicus Sentinel-2A satellite (contains modified Copernicus Sentinel data (2016)/ESA)



↑ The Ariane 5 ELA 3 launch complex

its facilities. By analogy with an aircraft, a launch control centre could be seen as a remote cockpit. The layout of the preparation zone and the launch pads depends on the launcher vehicle.

For Ariane 5, the ELA 3 launch complex includes a vehicle integration building, a final assembly building for fitting the fairing and the satellite, and then a launch pad to which Ariane is transferred the day before the launch.

A launch table on a rail line system allows the Ariane 5 to move between its different preparation phases, and operations are configured for an average of six launches per year.

The ZLV launch pad for Vega is located inside the Ariane ELA 1 launch complex, the original launch site of Europa II, Ariane 1 and Ariane 3. For Vega, the launch pad, mobile gantry and infrastructure have been updated and adapted to meet the operational requirements of the new lightweight vehicle.

The launch pad retains its pair of original flame ducts, which channel Vega's exhaust gases during ignition and liftoff. A new fixed umbilical mast provides power and environmental control connections to the launcher and its payloads from mission preparations through the countdown and liftoff. Four tall towers are positioned around the launch table to provide protection against lightning strikes.

During launch vehicle assembly and payload integration, the ZLV's refurbished mobile gantry offers protection from the weather and provides proper working conditions for launch team personnel. Once a Vega launcher is complete, the gantry is rolled back to its parked position, clear of the launch pad, usually a few hours before launch.

Its launch control room is inside the same building as the Ariane 5 control centre. Vega operations are configured for an average rhythm of three launches per year. This launch complex is to be adapted soon to accommodate the future version of the rocket, Vega-C.

The ELS launch complex for Soyuz is similar to those at Baikonur Cosmodrome in Kazakhstan. The integration building enables the Soyuz rocket to be assembled horizontally up to the fairing part. The only difference is that, once Soyuz is erected on its launch pad four days before launch, a European mobile gantry moves into place for vertical fairing and payload integration. Soyuz operations are configured for an average of three launches per year.



The ELA 4 launch complex for Ariane 6 is under construction. Its launch campaigns will evolve in two phases. First, the Ariane 6 elements will be integrated horizontally in the launcher assembly building, then the launcher will be erected on its launch pad. A mobile gantry will be used to finalise integration of the launcher with the fairing and its payload. The mobile gantry will be moved away just before launch. Ariane 6 operations are expected to perform an average of 11 launches per year.

The launch range includes the facilities that provide the necessary services to carry out a launch campaign safely. Indeed, a launch complex alone is not sufficient for a launch to happen. Using the aircraft analogy again, a launcher is like a plane operated by a private company at an airport. In

order to take off, it needs a representative of the airport to tell them it is safe to operate.

Following an agreement between ESA and France, ESA has been financing two-thirds of the fixed costs of the launch range, with France paying the remaining third. In return, the French space agency CNES operates services such as the maintenance of the general infrastructure, satellite support from arrival at the airport up to integration, launcher tracking and flight data acquisition, as well as general coordination of the launch campaign.

Because CNES represents France in space activities, it has responsibility for ensuring safety and security of people and property, and protecting the environment, on its territory.



Aerial view of Vega and Ariane 5 launch pads. An Ariane 5 is in the background, during its transfer from the Final Assembly Building to the ELA-3 launch zone in March 2012

Artist's view of the Ariane 6 four boosters configuration



↑ The Ariane 6 launch complex at ELA 4 under construction in 2017 (ESA/CNES/Arianespace)

The Diane Ground Station located a few kilometres from the Ariane 5 launch pad

Cesa

#### Propellant manufacturing

While satellites arrive by plane, launcher elements produced in Europe are transported to Kourou by sea. Some manufacturing operations take place in French Guiana because either it is too dangerous to transport the final product, or it is more practical to do it locally. For this purpose, ESA has invested in relocating manufacturing facilities so that industries can operate in French Guiana.

First, the Guiana propellant plant (UPG) was created for the production of propellant used for the Ariane and Vega solid boosters. Raw materials are brought safely to French Guiana where hazardous operations are conducted on site at the spaceport by the French/Italian company Regulus. At the same time, the boosters are integrated so that they can be later filled by another French/Italian company Europropulsion.

A booster engine test stand (BEAP) has also been set up so that powerful booster engines can be tested to ensure they work correctly. With the arrival of Ariane 6 and Vega-C, the UPG plant is being adapted to accommodate the new P12OC motor.

Secondly, a dedicated infrastructure was built for the local production of gas solutions for launch operations and fuels. This facilitated the transport of gas solutions at the spaceport and also enabled the French company AirLiquide to supply the rest of the territory.

#### **ESA Kourou Office**

ESA maintains a small team at the spaceport to act as its representatives in French Guiana. As well as representing the Agency and its Member States at the spaceport, the ESA Kourou Office is also responsible for monitoring the implementation of the contract between ESA and CNES for the running of the spaceport, managing the inventory of ESA assets at the spaceport, participating in strategic decision-making processes, monitoring the participation of European industry and highlighting the European dimension of the centre.

Noémi Brousmiche is a SERCO communications manager for ESA







#### → Charlotte Beskow Head of ESA's Kourou Office

Charlotte Beskow became Head of ESA's Kourou office on 1 January 2018. Having worked at Europe's Spaceport 20 years ago, as tracking coordinator, and then more recently as deputy launch campaign manager for several of ESA's Automated Transfer Vehicles she is familiar with operations in Kourou, but also sees exciting challenges ahead.

"I am looking forward to working on a launch base – I can't deny it's great fun. In the past, I have seen the two biggest sides of what goes on in Kourou, as a CNES operation and as a customer.

"My challenge is to make all interactions as smooth as possible. Our role is to make everything easy for all sides -Arianespace, Arianegroup, CNES and ESA. It's a big challenge for us all. Many ESA projects are due to be launched from Kourou during the coming years, including the project I worked on just before moving here, EarthCARE and I will be delighted to receive them. I'll be happy to see every ESA launch! There are many ESA launches coming up, and if we are able to help with anything, that will be one of our objectives.

"ESA has an important role to play in French Guiana in terms of providing new infrastructure. Not as attention-grabbing as a launch, but we need good infrastructures and have challenges ahead with a new launcher and an upgraded Vega.

"The spaceport is amazing, but it's such an out-of-the-way place, so it becomes important to see your own representation there – to see a little bit of Europe there. My role is also to show that it's a European facility. I hope to be able to promote that side of the activity. I want people to feel proud of it.



"I will miss ESTEC. It is more than a workplace, it is like a university campus. I will miss my friends and colleagues, the four seasons and the changing weather of the Netherlands. There are many advantages with French Guiana, the Sun, the beach, the interesting environment, and I'll still be working for ESA and I'll still have appointments to come to Europe, and I'll need to keep up with what's going on there to represent ESA.

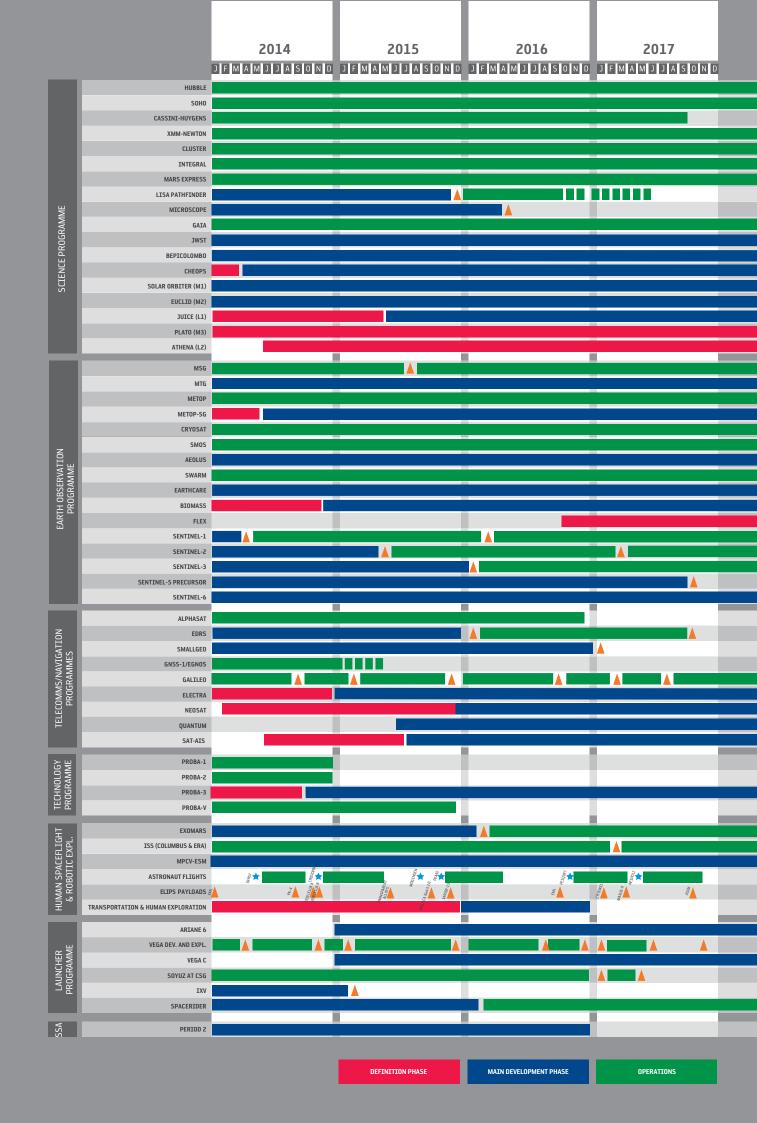
"I know never to go out without mosquito spray and always have your flashlight handy. I never really learned the night sky's constellations before, but with a new app you can do it and I'm really looking forward to it. The last time I was based there we had no Internet, so that will be different. Life in Kourou is a lot simpler, and that has all sorts of advantages. I have lots of big books to read in my spare time. And it will be nice to be in the Sun."

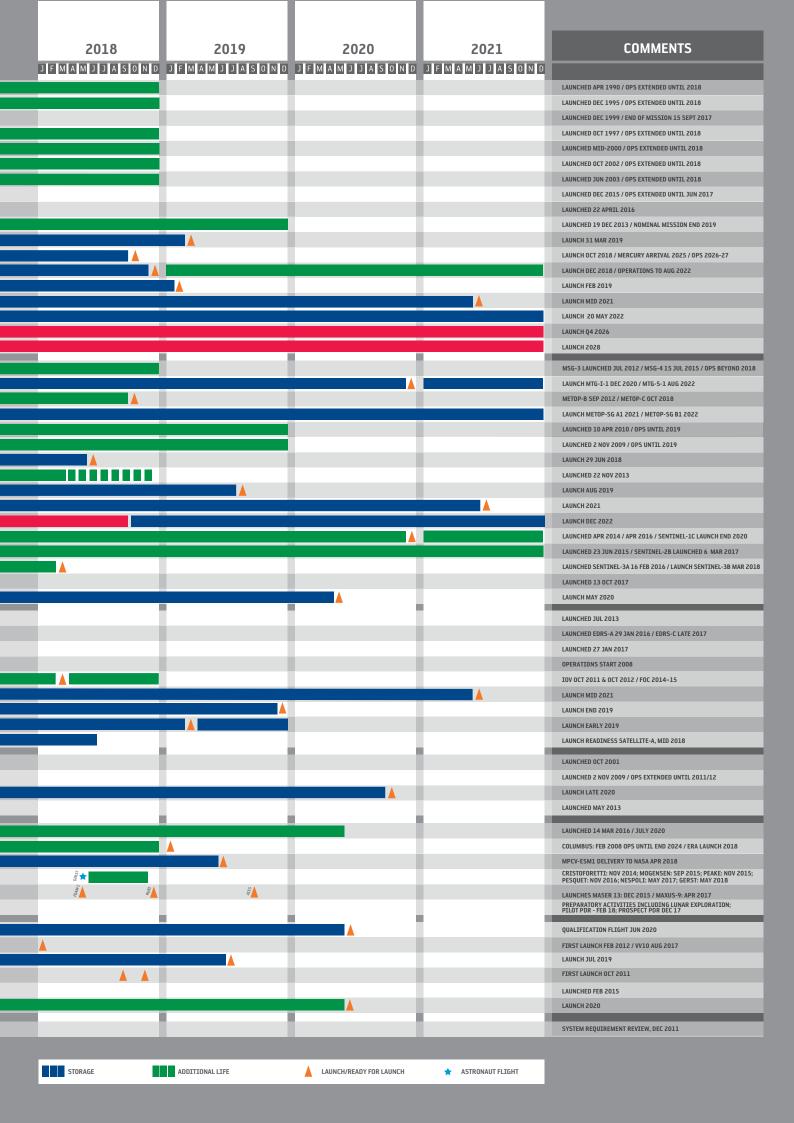
# → PROGRAMMES IN PROGRESS

Status at October 2017

Rho Ophiuchi, one of the nearest star-forming regions to Earth where new stars take shape from billowing clouds of gas. Located about 440 light-years from us, in the constellation Ophiuchus, the Serpent Bearer. This three-colour image combines Herschel observations at 70  $\mu$ m (blue), 160  $\mu$ m (green) and 250  $\mu$ m (red)(ESA/Herschel/NASA/JPL-Caltech, CC BY-SA 3.0 IGO; R. Hurt)







esa

#### **KEY TO ACRONYMS**

AM - Avionics Model

**AO** - Announcement of Opportunity

**AIT** - Assembly, integration and test

AU - Astronomical Unit

CDR - Critical Design Review

**CSG** - Centre Spatial Guyanais

**EFM** - Engineering Functional Model

**ELM** - Electrical Model

EM - Engineering Model

**EMC** - Electromagnetic Compatibility

**EQM -** Electrical Qualification Model

**EQSR-** Equipment Qualification Status Review

FAR - Flight Acceptance Review

FM - Flight Model

FQR - Flight Qualification Review

**GEO** - Geostationary Earth orbit

IPC - Industrial Policy Committee

ITT - Invitation to Tender

LEO - Low Earth orbit

LEOP-Launch and Early Orbit Phase

**MoU -** Memorandum of Understanding

NEO - Near Earth object

PDR - Preliminary Design Review

**PFM** - Proto-flight Model

**PLM** - Payload Module

**PPP** - Public-private partnership

**PRR** - Preliminary Requirements Review

**OM** - Qualification Model

SM - Structural Model

**SRR** - System Requirement Review

STM - Structural/Thermal Model

SVM - Service Module

SVT - System Validation Testing

SWE-Space Weather

TM - Thermal Model

thrusters, until the gas drag torques resulted in an off-pointing and loss of signal, marking the end of mission. The loss of signal was at an altitude of 1231 km above the 1-bar level, and a latitude of 8 degrees. Telemetry was transmitted and received up to the mission end, with the lon and Neutral Mass Spectrometer, the Magnetometer, the Radio and Plasma Wave Science instrument, and the Cosmic Dust Analyzer working at full capacity.

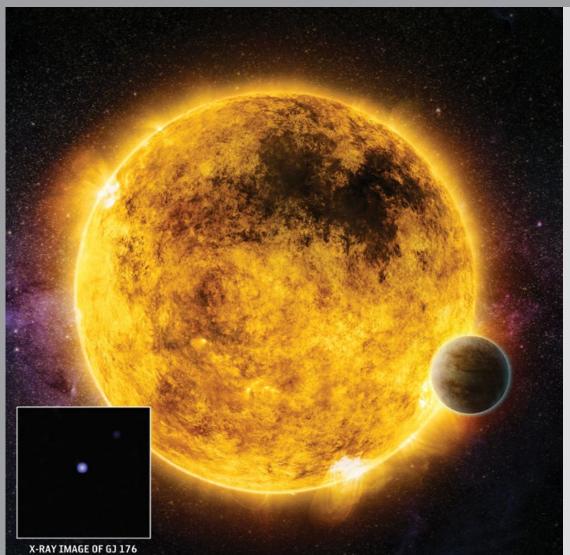
A preliminary analysis indicates a lower than expected ring mass. The size of Saturn's core was determined and input of material from the rings to Saturn's atmosphere was detected. The magnetic field appears nearly perfectly aligned with the planetary rotation axis within 0.06 degrees, a deep weather layer in the interior of Saturn was inferred from gravity measurements, and for the first time, *in situ* sampling of main ring particles and their composition analysis was performed, revealing a significant silicate fraction.

#### → CASSINI

Cassini's last signal was received on 15 September after the spacecraft entered Saturn's atmosphere. It kept its highgain antenna pointed towards Earth using its attitude

#### → XMM-NEWTON

Stellar X-ray emissions mirror the magnetic activity of stars, so X-ray observations can tell us about the high-energy environment around stars. Data from XMM-Newton and NASA's Chandra X-ray observatory were used to see how



Artist impression depicting an older Sun-like star with a planet in orbit around it: such stars which were found to be relatively calm compared with younger stars (X-ray: NASA/ CXC/Queens Univ. Belfast/R. Booth et al./illustration: NASA/CXC/M. Weiss)



The site of Cassini's atmospheric entry in a view taken on 14 September in visible light using the Cassini spacecraft wide-angle camera at a distance of 634 000 km from Saturn (NASA/JPL/SSI)

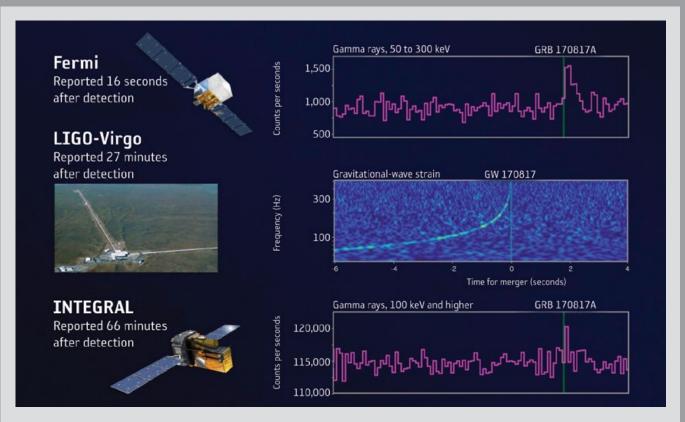
the X-ray brightness of stars behaves over time. Stars like the Sun and their less massive counterparts calm down surprisingly quickly after a turbulent youth. This result has positive implications for the long-term habitability of planets orbiting such stars.

#### → CLUSTER

Magnetic reconnection in Earth's magnetotail occurs in association with expanded enhancements in the aurora known as 'auroral substorms'. However, the exact relationship is still under investigation. Previous studies have directly linked reconnection and associated fast flows in the magnetotail to enhancements in the aurora, but the difficulty in finding reconnection events has meant that most were individual case studies. A recent comprehensive investigation used an automated signature detection routine to find reconnection events in the magnetotail and auroral counterparts observed in whole auroral oval images to examine the relationship. The study used magnetospheric data from the ESA Cluster, CNSA/ESA Double Star and the JAXA/NASA Geotail missions, along with auroral images from the NASA IMAGE and Polar missions. Among the 59 reconnection events detected, 43 of them show a clear coincidence of reconnection and auroral enhancement.



Impact of a magnetic substorm on Earth's night side in the form of colourful aurora (NASA)



Gamma-ray light curves and gravitational wave signal from six seconds before the merger time (T=o). Top to bottom, NASA Fermi/GBM lightcurve, LIGO/Virgo gravitational wave signal, Integral/SPI-ACS light curve (J. McEnery/NASA), Fermi/LIGO-Virgo/Integral)

See: An analysis of magnetic reconnection events and their associated auroral enhancements, *J. Geophys. Res. Space Physics*, 122, 2922–35, 2017.

#### → INTEGRAL

On 17 August, a binary neutron star merger (GW170817) was observed through gravitational waves by the Advanced LIGO and Advanced Virgo detectors. Both ESA's gamma-ray observatory Integral and NASA's Fermi Gamma-ray Burst (GRB) Monitor independently detected a short gamma-ray burst (GRB 170817A) with a time delay of about 1.7 seconds with respect to the merger time. This confirms binary neutron star mergers as a progenitor of short GRBs. The association of GW170817 and GRB 170817A provides new insight into fundamental physics and the origin of short GRBs.

The observed time delay provides vital information: it constrains the difference between the speed of gravity and the speed of light to be between  $-3 \times 10^{-15}$  and  $7 \times 10^{-16}$  times the speed of light; it places new bounds on the violation of Lorentz invariance; and it presents a new test of the equivalence principle by constraining the Shapiro delay between gravitational and electromagnetic radiation.

GRB 170817A is the closest short GRB with a known distance, but is between two and six orders of magnitude less energetic than other bursts with measured redshift. A new generation of gamma-ray detectors, and sub-threshold searches in existing detectors, will be essential to detect similar short bursts at greater distances. An observation campaign was launched across the electromagnetic spectrum leading to the discovery of a bright optical transient in NGC 4993 (at about 40 Mpc) less than 11 hours after the merger. Subsequent observations targeted the object and its environment. Early ultraviolet observations revealed a blue transient that faded within 48 hours.

Following early non-detections, X-ray and radio emission were discovered at the transient's position about 9 and 16 days, respectively, following the merger. The X-ray and radio emission likely arise from a physical process that is distinct from the one that generates the UV/optical/near-infrared emission. No ultra-high energy gamma-rays and no neutrino candidates consistent with the source were found in follow-up searches. These observations support the hypothesis that GW170817 was produced by the merger of two neutron stars in NGC 4993 followed by a short gamma-ray burst (GRB 170817A) and a 'kilonova'/'macronova' powered by the radioactive decay of r-process nuclei synthesised in the ejecta.

#### → HUBBLE SPACE TELESCOPE

In the night following the initial discovery of a neutron star merger, telescopes searched for the source of the event, which was found in the galaxy NGC 4993. A point of light was shining where nothing had been visible before, prompting one of the largest multi-telescope observing campaigns ever – among these telescopes was Hubble. Different teams of scientists used Hubble in the two weeks following the gravitational wave event alert to observe NGC 4993. Using Hubble's high-resolution imaging capabilities they got the first observational proof for a 'kilonova', the visible counterpart remaining after the merging of the two neutron stars.

Hubble captured images of the galaxy in visible and infrared light, witnessing a new bright object within NGC 4993 that was brighter than a nova but fainter than a supernova. The images showed that the object faded noticeably over the six days of the Hubble observations. Using Hubble's spectroscopic capabilities the teams also found indications

The source of the 17 August event within the lenticular galaxy NGC 4993, shown in this image taken by the Hubble Space Telescope. The associated stellar flare, a kilonova, is clearly visible. This is the first time the optical counterpart of a gravitational wave event was observed. Hubble observed the kilonova gradually fading over the course of six days between 22 and 28 August in the insets (NASA/ESA/AJ Levan (Univ. Warwick)/ NR Tanvir (Univ. Leics)/A. Fruchter & O. Fox (STScI))

of material being ejected by the kilonova as fast as one-fifth of the speed of light.

The spectrum of the kilonova was exactly as theoretical physicists had predicted for the outcome of the merger of two neutron stars. The infrared spectra taken with Hubble also showed several signatures that indicate the formation of some of the heaviest elements in nature. These observations may help solve another long-standing question in astronomy: the origin of heavy chemical elements, like gold and platinum. The conditions in the merger of two neutron stars appear just right for their production.

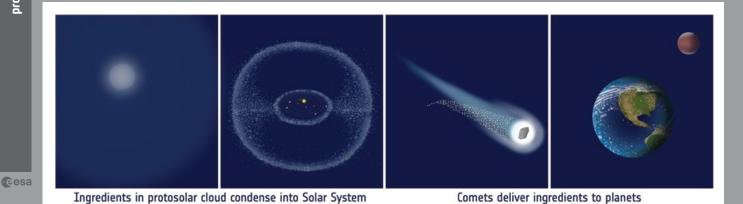
This discovery has opened up a new approach to astronomical research, where information is combined both from electromagnetic light and from gravitational waves. The combination will help astronomers understand some of the most extreme events in the Universe. Gravitational waves provide information from objects that are very hard to study using only electromagnetic waves. The dream of multi-messenger astronomy is finally a reality.

#### → ROSETTA

A scientific study was published using data from Rosetta and the ground-based Atacama Large Millimetre/submillimetre Array (ALMA) in Chile. The work focuses on the detection of the organohalogen methyl chloride. This molecule is also found on Earth, produced by industry, and by biological and geological activity. As such, it has been identified as a useful marker for life, a biomarker, in the search for life at exoplanets.

The ALMA observations were made of the young star IRAS 16293-2422, a low-mass binary system in the Rho Ophiuchi star-forming region about 400 light-years from Earth. The system was already known to have a wealth of organic molecules distributed around it, but ALMA makes it possible to zoom in to scales equivalent to the outer planets in our own Solar System, making it an ideal target for comparative studies with comets.

The methyl chloride was found in comparable abundances in both the young star system and the comet, suggesting these chemicals are part of the 'primordial soup' of a young solar system. Rocky planets like Earth could directly inherit these ingredients during the planet-building phase, but comets could also act as a vessel to deliver them through the high rate of impacts occurring in the early years of a forming solar system. Understanding this initial chemistry on planets is an important step toward the origins of life and is also a crucial aspect for the search for life outside our Solar System. However, the apparent prevalence of organohalogens in space calls into question their use as a biomarker when interpreting any future detections of the molecule in the atmospheres of rocky exoplanets.



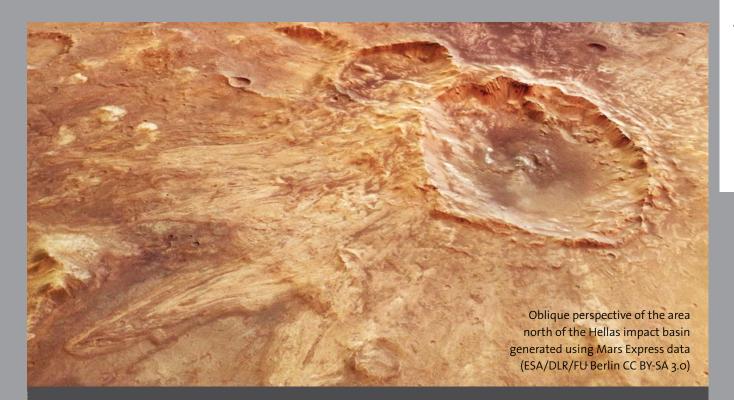
As well as inheriting ingredients during the planet-forming process itself, comets are also believed to have delivered some of the basic ingredients for life to Earth, leading to life as we know it today

#### → HERSCHEL

Herschel is progressing towards the end of the final year of its post-operations phase. The Herschel Science Archive has been improved and Highly Processed Data Products, User Provided Data Products and Ancillary Data Products are served in addition to the standard 'pipeline' products. To extend the lifetime of the Herschel HIPE and HSpot software, virtual machines providing the legacy versions have been produced and are being tested. In September, 'Herschel Week' highlighted science achievements with new images and videos. All material is available at http://sci.esa.int/herschel/59492-herschel-week/



The W3/W4/W5 complex of molecular clouds and star-forming regions. Located over 6000 light-years away, in Cassiopeia, it is one of the best regions in which to study the life and death of massive stars in the Milky Way. This two-colour image combines Herschel observations at 70  $\mu$ m (cyan) and 100  $\mu$ m (orange) (ESA/Herschel/NASA/JPL-Caltech, CC BY-SA 3.0 IGO; R. Hurt)



Impacts of comets and asteroids have shaped the surfaces of rocky planets and moons over the Solar System's 4.6 billion year history. Impact craters can reveal environmental conditions at the time of their formation. For example, an impactor smashing into an ice-rich surface gave rise to the complex flow features around this ancient crater on Mars. The 32 km-wide crater, seen in this Mars Express image, clearly formed at a time when water or ice was present near the surface. The energy of the impact heated up the water-rich sub-surface, allowing it to flow more easily, leading to the 'fluidised' nature of the ejecta blanket. The periphery of the lobes of excavated material often displays a raised ridge: as the flow slowed, the debris

behind it piled up, pushing up the material at its periphery into ramparts. Many craters on Mars show this pattern, sometimes with multiple layers of ejecta. Here, up to three layers of ejecta lobes can be identified, some of them terminating in ramparts. Multi-layer ejecta deposits can result from a combination of an impact into a buried layer of water-rich ground, and interaction of ejected material with the atmosphere. The scene is located north of the Hellas impact basin, one of the largest in the entire Solar System at 2300 km. The region is in an area that is suspected to be the former drainage basin of a lake. Small channels can also be seen to the south, providing more evidence of water in the region's past.

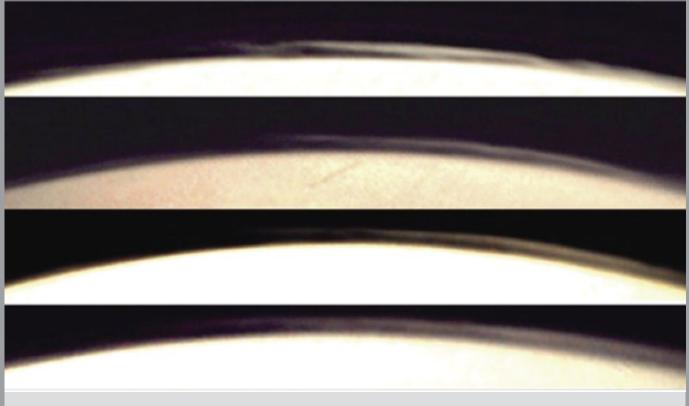
#### → PLANCK

The next Planck ('Legacy') data release has been delayed and will not take place before December. It will contain products with improved quality, allowing Planck's polarisation data to be fully exploited for cosmology. A life-size model of Planck has been loaned to the NEMO Science Museum of Amsterdam, for a long-term exhibition named 'Life in the Universe'.

#### **→ MARS EXPRESS**

The first paper describing the Mars Express Visual Monitoring Camera (VMC) employed as a scientific instrument was published in a scientific journal. The camera is a simple engineering imager originally aimed to monitor the release of the Beagle-2 lander and for public outreach. The paper presents the properties of highaltitude aerosol layers observed by VMC. More than 21 000 images taken between 2007 and 2016 were examined to detect and characterise elevated layers of dust at the limb, as well as dust storms and clouds. Their main properties were determined for 18 events. The upper altitudes of the detached layers ranged from 40 to 85 km extending horizontally from 120 to 2000 km. They mostly occurred at equatorial and tropical latitudes at morning and afternoon local times in the southern autumn and northern winter seasons. Three of these events were studied in detail





Example of a sequence of images taken by ESA's Mars Express Visual Monitoring Camera as a limb cloud came into view on 7 March 2013. Top to bottom, the images were taken at 22:48, 22:49, 22:51 and 22:53 GMT (ESA CC BY-SA 3.0)

using simultaneous images taken by the MARCI/Mars Reconnaissance Orbiter and the predictions from the Mars Climate Database General Circulation Model. This allowed determination of three-dimensional structure and nature of these events. One was a regional dust storm and the two others were water-ice clouds. Similar analyses for the other cases studied indicate that the rest of the events correspond most probably to water ice clouds.

#### → SOHO

On 21 August, there was a total solar eclipse in parts of North America revealing the Sun's outer atmosphere (corona). An uncommon phenomenon on Earth, solar eclipses are regularly observed from space by the Large Angle Spectrometric Coronagraph (LASCO) instrument, which is a coronagraph telescope that creates a perpetual total solar eclipse by blocking sunlight with a solid central 'occulting' disc, revealing the Sun's corona. The image shows the combination of two eclipses: SOHO/LASCO's perpetual eclipse, and the total solar eclipse of 21 August.

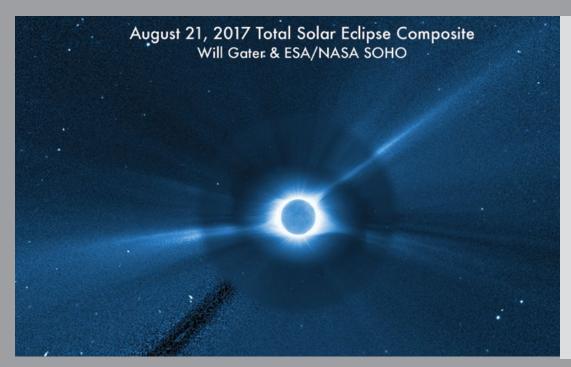
The inner-most image is a ground-based shot taken during totality, where the detail of the Sun's corona close to the solar disc is visible as well as the face of the Moon partially illuminated by 'Earthshine' (sunlight reflected by Earth on

to the Moon). This inner image was combined with two images recorded by SOHO/LASCO, which is able to see solar structures extending far from the Sun, but unable to see fine structure close to the Sun.

The ability to combine concurrent ground and space-based observations of the Sun's corona is a valuable scientific tool that enables solar physicists to better understand how the extended solar corona connects to the features seen near the disc of the Sun, and helps in understanding the extremely complex magnetic fields that control the structure of the Sun's corona.

#### → GAIA

The second Gaia Data Release (Gaia DR2) is in production, progressing towards the April 2018 release date. After scientific assessment and recommendation by the Gaia Science Team, a Gaia DR2 pre-release was made for a field including Triton. This moon of Neptune occulted a star on 5 October. To place the ground-based telescopes on the occultation path, it was necessary not only to know the position of the star, but also determine the position of Triton with the help of Gaia stars in the field. The Gaia astrometry was also used to plan the flight path of SOFIA to catch the occultation. The observations in several places were successful, also with respect to recording



Composite image, from Earth and from space, of the 21 August total solar eclipse (K. Battams/W. Gater/ SOHO/LASCO, ESA/ NASA)

the central flash, to provide information about the deepest layers of the atmosphere of Triton.

#### → BEPICOLOMBO

Spacecraft system integration and test activities continued. The small schedule contingency that was still available prior to shipment of the spacecraft to Kourou has been depleted because of technical issues. A margin during the launch campaign of three weeks with respect to the opening of the launch window in October 2018 remains. After the mechanical testing of the FM stack and the full electrical/functional verification in the stack configuration, the proper functioning of the spacecraft mechanisms was demonstrated through a set of deployments, i.e. of the solar arrays, the antennas, the magnetometer boom and also the steering test of the ion thrusters, confirming the health of the system.

An issue was observed during the deployment of the highgain antenna that is being followed up to ensure a flawless deployment process for the FM. Problems with the Mercury Transfer Module (MTM) battery recharge when exiting from an eclipse are being investigated and may be mitigated with the inclusion of corrective circuitry into a dedicated box. The activity is scheduled during the first two weeks in ESTEC in January 2018, not affecting the critical path.

In light of the MTM thermal balance/thermal vacuum (TB/TV) test on the Mercury Planetary Orbiter (MPO), a further unit will be implemented with the modifications needed to avoid disturbances of the MPO power control and distribution unit that are caused by reflections from the spacecraft towards the

solar array when tracking a secondary power point. After separation into module configuration, the MPO alignment campaign was completed, while the TB/TV test preparations are ongoing on the MTM. The MTM will enter the test chamber in early November.

The solar-electric thruster life test, running offline on the thruster QM of the Solar Electric Propulsion System (SEPS), had to be stopped because of technical issues but was restarted on the QM to accumulate as many test hours as possible before the Qualification and Acceptance Review in March 2018.

#### → SOLAR ORBITER

The optical and electronic units of the scientific instruments have been mechanically integrated onto the spacecraft by Airbus Defence & Space UK in Stevenage. The payload electrical integration and functional tests are continuing with active, *in situ* participation of the scientists in the instrument teams.

Mechanical integration of all flight units inside the spacecraft body is also complete, and electrical integration and testing is in progress. With both the instrument panel and the spacecraft equipment panels fitted onto the core structure, the reference alignment was measured for the first time. Functional testing continues on the two spacecraft engineering test benches and on the FM avionics already installed on the spacecraft.

The heat shield environmental testing is complete, and the shield is now under final functional testing. The solar



Solar Orbiter core structure (centre), the instrument panel (right) and the spacecraft equipment panels before they were mated together for the first time (Airbus D&S)

generator FM wings that had been completed in their original configuration are now being fitted with mirror-like elements to prevent straylight entering the instrument apertures. The highgain antenna is undergoing final acceptance tests.

The ground segment implementation review of the Mission Operations Centre and of the Science Operations Centre developments is under way.

Interface work with NASA's Goddard Space Flight Center and NASA Kennedy Space Center, and United Launch Alliance for the baseline Atlas V-411 launcher services, is progressing well.

# → JAMES WEBB SPACE TELESCOPE (JWST)

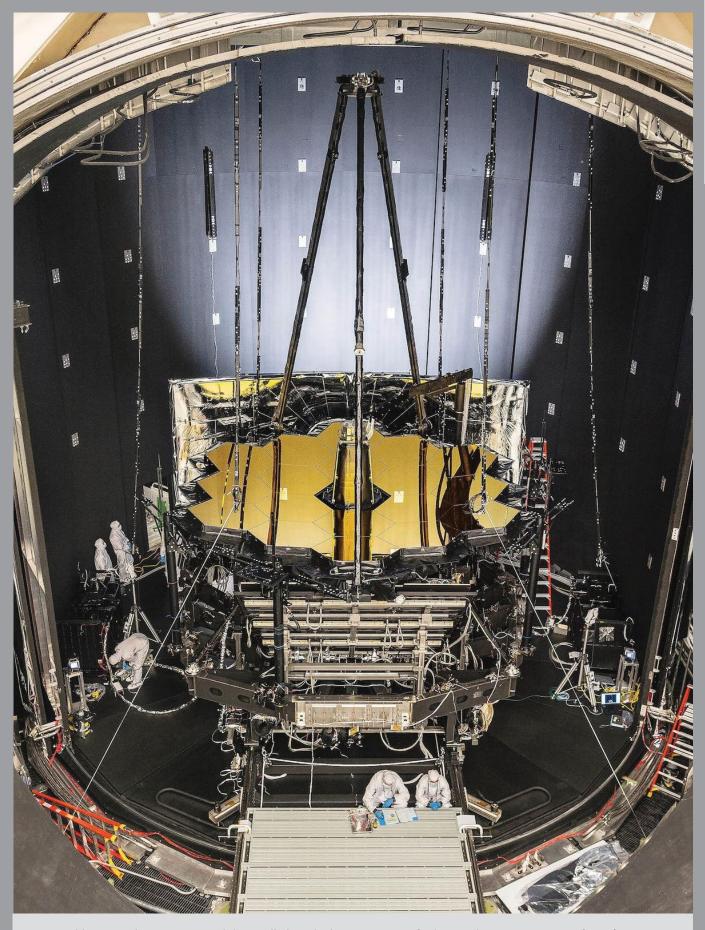
The programme has faced some delays during the complex integration of the sunshield. The launch is now foreseen in the period between March and June 2019.

The OTIS (Integrated Science Instrument Module/Optical Telescope/Electronics Module/Thermal Hardware) cryogenic functional and optical end-to-end test has been completed. The telescope, the instruments and the thermal system performed as expected. Integration of the spacecraft and the sunshield has been completed. The first deployment test of the sunshield is continuing.

#### → EUCLID

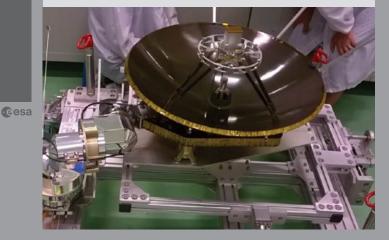
The system design is being consolidated for the system CDR. The PLM CDR was held in June and July. The PLM met demanding requirements in terms of image quality and stray light in dedicated optical, structural and thermal analyses.

Many STM and EM and some flight components have been manufactured and tested. All the SiC reflectors optics, FM and STM, have been manufactured. The FM optics were mechanically polished and are now under ion beam figuring.



James Webb Space Telescope OTIS module installed inside the cryo-vacuum facility at Johnson Space Center (NASA)

The Euclid Structural/Thermal Model high-gain antenna assembly, with K-band dish, Antenna Pointing Mechanism and the Hold-Down and Release Mechanism (Thales Alenia Space)



All eight SiC baseplate pieces (four each for STM and FM) have been manufactured.

The Visible Imager (VIS) instrument has suffered delay. The instrument EM tests have not been completed. The instrument-level CDR was held in January but not completed. The technical issues identified at the CDR have been resolved. An independent review of the schedule that was requested at the CDR has been carried out by the lead funding agency, confirming that the FM VIS delivery has slipped by more than one year.

The ESA contract with e2v for the development, qualification and FM production of the CCD detectors is proceeding and 55 FM devices, enough to complete the entire focal plane (36) and spares, passed acceptance testing.

The Near Infrared Spectro-Photometer (NISP) has completed the instrument CDR and is proceeding with the flight hardware manufacture and integration. The NISP STM was delivered for the PLM STM campaign. The EM units have incurred delays partially recovered by a schedule readjustment and model reshuffling. The cold part of the FM instrument – mounted in the PLM – proceeds on schedule but significant delays were incurred for the warm electronics, mounted in the SVM.

The procurement of the NISP HgCdTe FM is delayed. Following serious anomalies in the front-end electronics during cold restart tests, NASA decided to discard as unworthy for flight all the units produced and has started working on design solutions. The impact on the instrument delivery and spacecraft schedule will depend on the time needed to solve these issues.

Ground segment development is progressing. Preparation for the next review, the ground segment design review, is

complete. This review will begin in November. The Euclid Consortium is also performing the third of the science challenges to test the processing functions pipelines and an infrastructure challenge to stress the system made of nine Science Data Centres under large data traffic.

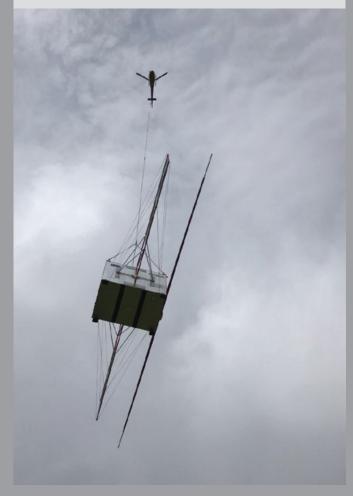
Launch readiness has moved between mid-2021 to mid-2022 depending on the actual delay of the instruments.

#### **→ JUICE**

The spacecraft PDR was completed in March and the 10 instrument PDRs in July. The industrial consortium is complete and the detailed design is progressing. Mass increases were reported for the structure shield and thermal subsystem requiring local redesigns.

The manufacture of EMs and QMs of the equipment and instruments has started. The focus at system level is on the preparation of the EM test campaign, which will begin in mid-2018.

The JUICE spacecraft mock-up with the RIME antenna hanging below the helicopter during the field test (Airbus D&S GmbH/STI)



The tests of the solar array coupons (technology validation) progressed in the new thermal test facility at the Centre Spatial Liège. A second test facility, large enough to test two solar panels at a time, is under production. The work on the TM continues. The model will test key elements of the thermal design of the spacecraft, specifically the multi-layer insulation, at the Sun intensities ranging from the Venus flyby to Jupiter orbit insertion.

A helicopter test was used to test the characteristics of the long radar boom (RIME antenna) to probe below the surface of Jupiter's icy moons. The antenna was mounted on a simplified mock-up of the spacecraft and hung 150 m below the helicopter as it hovered about 300 m above the ground.

The programmatic status of the instruments is not satisfactory. Funding for the Phase-C/D of a few instruments is not secured, with knock-on effects on activities and the schedule. The planned launch date is 20 May 2022 on an Ariane 5 ECA (with a launch window that closes on 10 June 2022).

#### → PLATO

The Science Programme Committee adopted the PLATO mission on 26 June. The ITT for the implementation phase was published on 7 July, the proposals being expected by 8 December. The formation of the industrial team is planned in spring 2018. The target launch date is in 2026. The contract with Teledyne e2v for the development, qualification and FM production of the (ESA-procured) CCD detectors for the scientific payload is proceeding.

#### → CHEOPS

Spacecraft development continues towards launch readiness at the end of 2018. The platform is fully integrated and system AIT activities are progressing at Airbus Defence & Space in Spain. In September, interface tests between the flight platform and the instrument EM were completed, including tests dedicated to the role of the payload in the anti-coincidence subsystem loop. Preparation for the second part of the SVT 1 (focused on instrument functionality) has started.

Instrument development continues, although the schedule is critical. In July the Focal Plane Module (FPM) EQM was delivered by DLR to the University of Bern and integrated with the flight telescope (thus replacing the FPM EM). This configuration allowed a series of mechanical and thermal tests to be conducted, significantly de-risking the final instrument AIT and calibration activities. The flight FPM, the last missing instrument unit, is undergoing acceptance testing at DLR and delivery is expected by the end of October. Preliminary mission analysis began in July, targeting the launch for late 2018/early 2019, as passenger on a Soyuz.



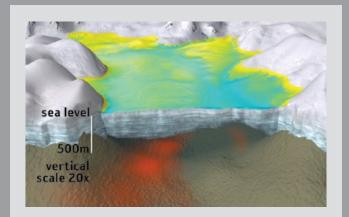
The Cheops instrument at the University of Bern before the start of thermal tests (Univ. Bern)

#### → SMOS

Operations have been extended to 2019 and beyond, pending an extension review in 2018. CNES has also extended its support to 2019 and potentially beyond. Future data products include severe wind speed over oceans and freeze/thaw information over land.

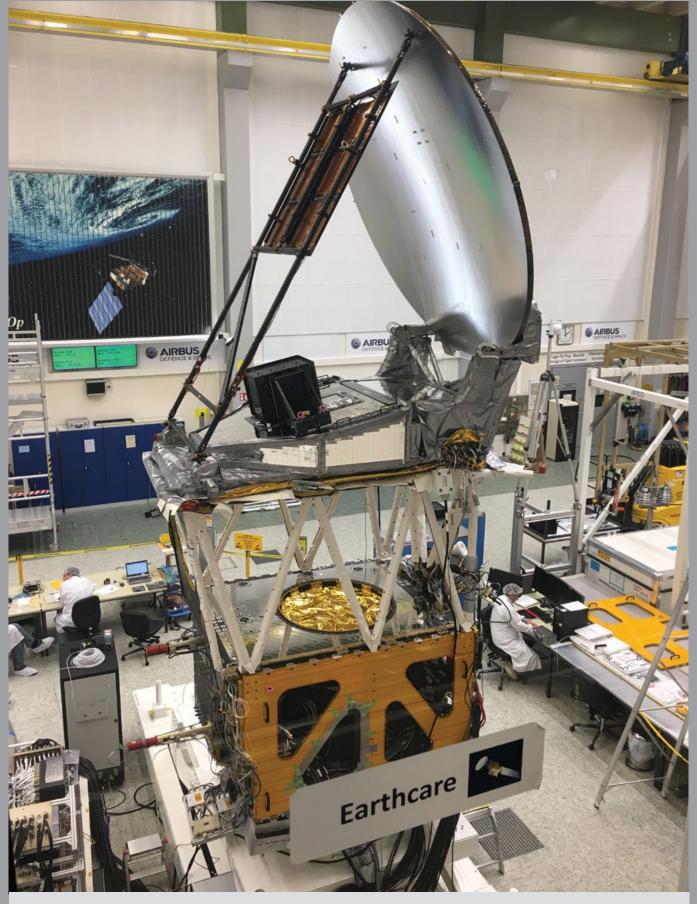
#### **→ CRYOSAT**

An improved version of CryoSat Ocean is now available to users. The mission has been extended until the end of 2019. Preparation for the January 2018 Antarctic campaign is under way and will be carried out in close collaboration with national and international institutions. Like the previous



Antarctica's Dotson ice shelf: warm bottom ocean water is entering the cavity under the ice shelf and is stirred by Earth's rotation causing one side of the ice shelf to melt (ESA/Univ. Edinburgh—N. Gourmelen/Planetary Visions)





EarthCARE Cloud Profiling Radar to spacecraft pre-integration configuration

campaign, the focus will be to explore the role of dual frequency altimetry in reducing the error in retrieving seaice freeboard due to snow load.

Using CryoSat and Sentinel-1 data, scientists have measured subtle changes in the elevation and flow of ice shelves in Antarctica's Dotson ice shelf that, in turn, reveal how huge canyons are forming underneath. Warmer water from the bottom of the ocean enters the cavity under the ice shelf and is stirred by Earth's rotation causing one side of the ice shelf to melt. The canyon, which has formed over 25 years, is now 200 m deep in places and the ice just above it is heavily crevassed, affecting the shelf's future ability to buttress the ice on land.

#### → SWARM

The readiness and feasibility of the three Swarm spacecraft and their ground segment to support an extended mission has been demonstrated through a series of technical reviews. Supporting resolutions adopted by the participants at the Fourth Swarm Science Meeting, by the International Association of Geomagnetism and Aeronomy and its umbrella organisation, the International Union of Geodesy and Geophysics, indicate that Swarm either already has, or by the end of its mission will have, met all of its requirements. The resolutions also recommend that the ESA and its Member States provide the Swarm mission with a clear long-term perspective, ideally as long as possible, but at least covering one full solar cycle (i.e. until 2024). A decision on the mission extension by Member States is expected in late November.

ESA is defining – jointly with the stakeholders and the user community – a series of broader objectives and related R&D plans that build on the experience gained in the mission, but also add new topics. A key issue is widening the context of Swarm by addressing broader Earth system science topics rather than issues that can be addressed by the Swarm mission in isolation. Physics-based modelling is becoming important.

#### → AEOLUS

Preparations for the complex satellite thermal/vacuum test campaign are ongoing in the Centre Spatial de Liège. The test includes a full performance test of the Aladin lidar instrument and is expected to start at the end of October. The ground segment acceptance activities are complete, including validation of the planning and calibration facilities.

Part 1 of the satellite Qualification and Acceptance Review has been completed with a collocation in Airbus Defence & Space at the end of September. Part 2 and completion of the review is planned for the first quarter of 2018.

A new launch period for Aeolus has been agreed with Arianespace, June to August 2018 on Vega VV-13.

#### **→ EARTHCARE**

The Base Platform integration is complete following the delivery of the PFM mass memory and formatting unit by SYDERAL-CH. The payload data handling integrated system tests will proceed interleaved with the AOCS subsystem at Airbus Defence & Space in Friedrichshafen.

ATLID PFM electrical integration continues at Airbus Defence & Space in France. Following the coupling of the laser transmitter (TxA) with the instrument electronics, the UV beam performance as established by Leonardo (IT) has been confirmed and the mechanical integration of the pressurised laser head onto the stable structure assembly is being prepared. Meanwhile, the second TxA FM has completed its acceptance campaign and has been delivered.

The Broad-Band Radiometer (BBR) PFM test campaign is nearing completion at RAL (UK). Preparation for the instrument shipment is ongoing along with the remaining part of the BBR calibration and characterisation campaign.

The JAXA Cloud Profiling Radar PFM instrument preintegration onto the PFM satellite and subsequent test campaign took place at Airbus Defence & Space in Germany from June to August. The instrument was shipped back to JAXA for refurbishment and testing.

#### → BIOMASS

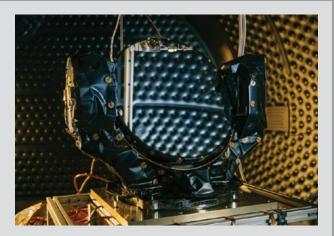
The major procurements for the satellite's units are being completed and subcontractors are starting to build hardware. Fifty-two individual procurements are required and decisions on the suppliers for the most important and schedule-critical items have already been made. With 80% of the related budget having been allocated to European industries, the build-up of the full industrial consortium is advanced and the transition to the development phase is under way.

#### → METEOSAT

#### Meteosat Third Generation (MTG)

The Platform CDR is ongoing. The Flexible Combined Imager and the Lightning Imager instrument CDRs are planned during 2018. The MTG-I spacecraft CDR will begin at the end of 2018. The Infrared Sounder instruments and MTG-S spacecraft CDRs will follow in 2019.

The mechanical integration of the first flight platform (for MTG-I-1) has begun with the propulsion module structure



MTG Flexible Combined Imager Structural/Thermal ModelScan Mechanism (SENER)

at Airbus Defence & Space, Lampoldshausen, for the integration of the first flight propulsion subsystem. At instrument level, STM and EM development model manufacturing is progressing.

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

#### → METOP

#### MetOp-C

MetOp-C testing is proceeding at Airbus Defence & Space, Toulouse. The antenna and radio frequency compatibility tests have been completed. The satellite is being prepared for the mechanical tests that should be completed by the end of the year.

The GOME-2 instrument calibration and Microwave Humidity Sounder instrument reacceptance after repair are on schedule and both instruments should be ready in January 2018 for reintegration on MetOp-C in time for the SVT. Launch on a Soyuz from French Guiana is planned in October 2018.

#### MetOp Second Generation

The cycle of lower level subsystem/equipment CDRs continues. The satellite ELM AIT programme is progressing. Manufacture of the STMs for the satellites and instruments is under way, with the STM for the microwave sounder instrument having completed all its environmental testing. The Preliminary Mission Analysis Review for Satellite A, for a Soyuz launch from Kourou, has begun with Arianespace. The overall schedule is being driven by the availability of the instruments and, in particular, the complex Customer Furnished Item instruments (METimage, IASI-NG and Sentinel-5). The launch dates remain as September 2021 for the first Satellite A and December 2022 for the first Satellite B.

#### → COPERNICUS

#### Sentinel-1

Sentinel-1A and -1B remain stable and data downlink is routinely performed. Image Mode data are systematically acquired over land and coastal areas and Wave Mode data are acquired over open oceans.

By the end of September, more than 101 000 users had self-registered on the Sentinels Scientific Data Hub where 1.75 million Sentinel-1 products are available for download, representing about 2.7 PB of data.

Development of the new Sentinel-1C and -1D models is continuing according to the plan of completing them in 2020 and 2021. The satellite production review in September authorised the production of the flight units. These new Sentinel-1 models are mostly recurrent to the -1A and -1B models. However, their service will be improved with a new automatic identification system payload to augment maritime applications, a new GNSS receiver compatible with the Galileo navigation system, and improvement of the data radiometric quality.

#### Sentinel-2

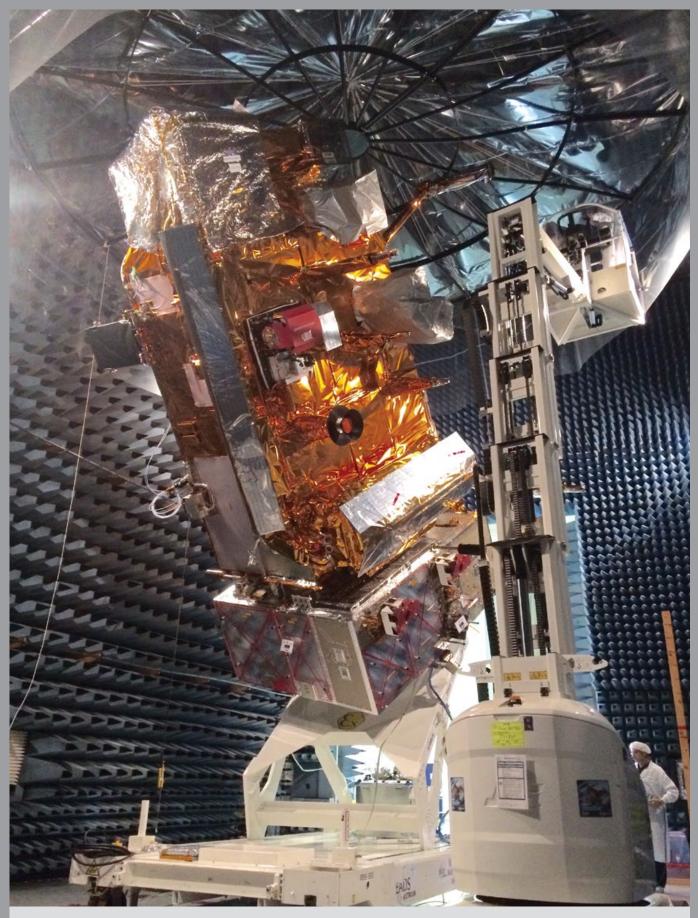
The mission constellation was completed by the launch of Sentinel-2B in March. The constellation has acquired more than one petabyte of images, serving a large community of users that has already downloaded 10 times this volume for their applications. Because of the additional download capability offered by EDRS optical communication link, the Sentinel-2 constellation will shortly reach its full capacity, mapping the land surface worldwide within five days. Extension of the nominal coverage is being contemplated in response to a growing number of potential applications.

Progress is being made for the procurement of the Sentinel-2C and -2D models. Following the completion of the satellite production review, the procurement of the different satellite units advances, with some flight equipment already delivered to the satellite prime contractor. Their integration into the platform will start next year.

#### Sentinel-3

The final thermal/vacuum test of the satellite in flight configuration was completed and is now starting the final functional tests performed at the end of the environmental test campaign. The completion of Sentinel-3B AIT activities is confirmed for November, leading to a readiness for the start of the launch campaign at the end of the year. The launch date is under discussion with the launch service provider(s), but likely March 2018.

Manufacture of the various Sentinel-3C and -3D units is ongoing, with some flight units (e.g. thrusters, reaction wheels, magnetometer, etc.) already delivered. The



 ${\sf MetOp-C}\ in\ the\ Coulomb\ B\ Anechoic\ Chamber\ of\ ITS\ Toulouse\ during\ antenna\ test$ 

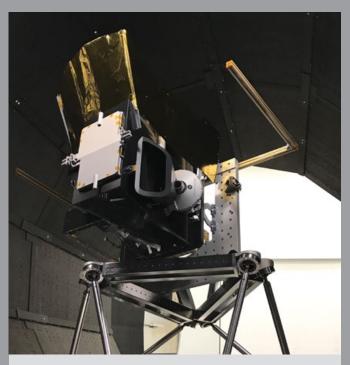
Sentinel-3C primary structure has been delivered and the start of the platform integration is being prepared. The central software has also passed CDR.

#### Sentinel-4

Integration of the instrument EM at Airbus Defence & Space in Munich is progressing: the integration and alignment of the telescope-spectrographs-assemblies was completed while the nadir baffle was integrated onto the instrument structure baseplate.

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The qualification testing of all the three mechanisms (calibration assembly mechanism, aperture cover mechanism and scanner mechanism) has been completed.



Sentinel 4 rotapod and mock-up (CEMEC/Airbus D&S)

#### Sentinel-5

All subsystem equipment requirement reviews have been closed. One subsystem PDR remains. The focus is now on completing the identified actions to allow formal closure of these reviews. Subsystem CDRs have started. An ultravioletvisible-near-infrared focal plane assembly EM has been manufactured, and has completed environmental testing. The detailed design of the instrument optical module structure and radiators for the instrument STM is complete and manufacture and assembly is progressing.

#### Sentinel-5 Precursor

Sentinel-5 Precursor was launched on a Rockot from Plesetsk on 13 October into a near-perfect orbit. After separation from the Breeze-KM launcher upper stage, the solar arrays were deployed and the S-Band transmitter switched on in time for acquisition of signal at Kiruna and the start of LEOP.



During a record next 30 hours with no anomalies, the AS 250 platform from Airbus Defence & Space was fully checked out and the spacecraft placed in Earth-pointing mode. The TROPOMI instrument electronics will be checked and the satellite manoeuvred to rendezvous with Suomi-NPP by 7 November when the TROPOMI Radiant Cooler Door will be deployed, cooling down the instrument in readiness for the measurement performance of TROPOMI to be assessed. An event to publish the first TROPOMI data ('First Light') is planned for November.

#### Sentinel-6/Jason-CS

Following the satellite CDR, the AIT is in preparation. Most of the flight hardware is under manufacture and satellite integration will be initiated in November.

The NASA equipment project CDR will take place at the end of October while the Poseidon-4 altimeter instrument CDR is planned in December.

The project mission advisory group will report the status of Sentinel-6/Jason-CS at the Ocean Surface Topography Science Team annual meeting as jointly agreed with NASA, NOAA and Eumetsat mission partners.

#### → PROBA-3

The two Proba-3 satellites will demonstrate high-precision formation flying in the context of a large-scale instrument. The pair will form a 150 m long solar coronagraph to study the Sun's corona closer to the solar rim than has been achieved before. They will maintain a fixed configuration as a 'large rigid structure'.

The coronagraph is called ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun). A secondary payload called DARA (Digital Absolute Radiometer) will provide complementary information.

Both the mission and ASPIICS payload activities are progressing in Phase-C/D with the reviews of units and subsystems. The system CDR of the ASPIICS payload started in October. The system CDR will start at the end of November.

#### → EDRS-C

The second EDRS node will be launched on an Ariane 5 launcher into its geostationary slot at 31°E in the first half of 2018. Following the initial functional test at OHB in Bremen, the satellite will be readied for its shipment to the environmental test facility at IABG.

The GlobeNet programme will add a third node – EDRS-D – in the Asia/Pacific region to complement EDRS-A and EDRS-C.

Phase-B activities started with the User Requirements Review, which concluded in October. The initial system design along with the definition of the system requirements is ongoing and will lead up to the SRR in February 2018. This will be followed by the preliminary design phase, which will conclude with the PDR at the end of 2018.

#### → NEOSAT

The CDR of the new Spacebus Neo platform product line has started with a first review cycle in July covering the features of the first application programmes. Airbus Defence & Space is marketing the new Eurostar Neo platform and has started the procurement and build of a mechanical platform, in anticipation of a satellite sale.

#### → ARIANE 6

#### Launcher system

A Vulcain 2.1 engine has arrived in Germany for its first test firing in December to demonstrate new capabilities and technologies developed for Ariane 6. The engine delivers 135 tonnes of thrust in vacuum. Vulcain parts from around Europe were assembled at the Vernon test centre in France and a demonstration model was sent to the DLR German Aerospace Center test facility in Lampoldshausen for functional tests. Over 15 months, three Vulcain test campaigns will provide information to help engineers decide whether adjustments are needed to optimise functional and mechanical behaviour before combined tests start.



Test facility P5 at the DLR German Aerospace Center test facility in Lampoldshausen



esa



French President Emmanuel Macron and European Commission President Jean-Claude Juncker visited Europe's spaceport in Kourou with ESA Director General Jan Wörner on 27 October (ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

#### Launch base

Construction work is under way for the new Ariane 6 facilities. Assembly of the mobile gantry will begin in November.

#### P120C

The first full-scale model of the rocket motor has been cast and filled with inert propellant to safely test new equipment and procedures. The model casing took about 36 hours to fill with inert propellant blended at Europe's Spaceport. Further tests on the motor will confirm that it is ready to be integrated with other structures in January.

These tests are a step towards casting active propellant in November on another P120C development motor that will be static fired in April.

Concerning the Second Production Line, the industrial proposal from the two launcher prime contractors was evaluated by the Tender Evaluation Board (TEB) in September. A way forward has been agreed, and a revised industry proposal is expected around mid-November.

#### → VEGA-C

A review of the Integrated Master Schedule is continuing. The objective is to set the conditions to meet both the needs of the Development and of the Exploitation activities.

#### → SPACE RIDER

Space Rider activities are progressing according to the planning, including the following milestones:

- Phase-B1 activities, redirected to account for the integration of Vega-C/AVUM as Orbital Service Module with the SRR planned in November;
- Phase-B2/C activities industrial proposal evaluation, of which TEB was held on 22 September, up to completion of system CDR.

### → FUTURE LAUNCHERS PREPARATORY PROGRAMME

An authorisation to proceed initiating the Ultra-Low Cost Engine Demonstrator (Prometheus) activity was signed at the Paris Air Show on 21 June. The TEB and negotiations are finalised in view of submission of the contract proposal at the November Industrial Policy Committee. The contract will be signed in December.

Consultations on Cryogenic Metallic and Composite tank demonstration projects are ongoing in view of the Request for Ouotation issue.

The Fibre-reinforced Optimised Rocket Case (FORC) Solid Rocket Motor (SRM) Casing Demonstrator, will be finalised for transfer in the P120C environment in mid-October

following the test campaign and project completion. The release of the manufacturing of the additively manufactured Berta engine is planned for mid-October. The demonstration flight of the Nammo Nucleus using a hybrid propulsion demonstrator is planned for between March and June 2018.

#### → HUMAN SPACEFLIGHT

ESA astronaut Paolo Nespoli (IT), NASA astronaut Randy Bresnik and Roscosmos commander Sergei Ryazansky were launched into space on 28 July from the Baikonur cosmodrome in Kazakhstan. Paolo's mission name is 'Vita', which stands for vitality, innovation, technology and ability. Italy's space agency ASI is providing this long-duration mission through a barter agreement with NASA.

#### ACES/ASIM

The Space Hydrogen Maser FM is completing functional tests before delivery to the prime contractor at the end of January 2018. The MicroWave Link hardware and software finalisation is still not proceeding as planned. A possible option to complete the development of ACES by mid-2019 was defined with Airbus, implying a cost increase. The impacts will be presented to the European Utilisation Board/Programme Board for Human Spaceflight, Microgravity and Exploration in November.



The Soyuz MS-05 carrying ESA astronaut Paolo Nespoli, NASA astronaut Randy Bresnik and cosmonaut Sergei Ryazansky docked with the International Space Station at 22:00 GMT on 28 July (NASA)

The ASIM FM was completely reintegrated during the summer and testing is completed. The consent to ship to Kennedy Space Center will be given after conclusion of the Qualification Acceptance Review at the end of November. Launch will be on SpaceX CRS-14 in February 2018.



The Expedition 52/53 crew: ESA astronaut Paolo Nespoli, NASA astronauts Jack Fischer and Peggy Whitson, Roscosmos cosmonaut Sergei Ryazansky, NASA astronaut Randy Bresnik and Roscosmos cosmonaut Fyodor Yurchikhin pose for a photo in the Russian section of the International Space Station (NASA/ESA)

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#### → ISS UTILISATION

The European ISS utilisation programme has been continuing with the assistance of the Expedition 52/53 crew members on orbit. Highlights of recent activities are as follows:

New test subjects started on-orbit activities for ESA's Sarcolab-3, Circadian Rhythms and Space Headaches experiments. Sarcolab-3 is studying the effect of weightlessness on loss of muscle mass, function and motor control, by determining the contractile characteristics of muscles particularly affected. The Circadian Rhythms experiment is studying alterations in circadian rhythms during long-duration spaceflight. Space Headaches is looking into headache incidence/characteristics during (long-duration) spaceflight. In addition a number of pre-/ post-flight experiments were performed looking into the effect of (long-duration) spaceflight exposure on human central nervous system adaptation, cartilage health, bone demineralisation, and straight ahead perception.

#### Biology research

Final samples for the Extremophiles experiment were returned from orbit on the SpaceX CRS-12 flight in September for post-flight analysis. The Extremophiles experiment aims to acquire new information on the identity and variability of microbial communities inhabiting the ISS. Samples will be analysed for the suspected presence of Archaea and extremophile bacteria. The species detected on



Paolo Nespoli, visible on screen, operates a rover in Germany from the International Space Station as part of ESA's METERON project (DLR, CC BY-SA 3.0 IGO)



Paolo Nespoli wears the Drager Double Sensor, which measures core temperature and body chemistry for the Circadian Rhythms experiment, during amateur radio contacts with students in Ireland, Sweden and Italy (ESA/ NASA)



Reading during a bedrest campaign

the ISS will be compared with those identified in spacecraft clean rooms and visiting vehicles. Paolo Nespoli also assisted in the performance of ASI-sponsored biology research within the ASI Biomission experiments.

#### Materials research

The final sample of the Solidification along a Eutectic path in Ternary Alloys 2 (SETA-2) experiment (one of the two Batch 2b experiments) was processed in the Materials Science Laboratory. The SETA experiment is looking into a specific type of eutectic growth in ternary alloys of aluminium, copper and silver. Research performed in the laboratory supports both basic and industrial research and will help to optimise industrial casting processes.

#### Radiation research

Radiation research continued within the Dose Distribution inside the ISS 3D (DOSIS-3D) experiment, which undertook continuous data acquisition of the radiation environment inside Columbus. This included a week of high-resolution monitoring in relation to increased solar activity.

#### Technology demonstrations

Science runs of the SUPVIS-JUSTIN experiment were performed. Paolo Nespoli on the ISS commanded a robot on ground (on a simulated extra-terrestrial solar farm). This experiment aims to validate such extraterrestrial robotic command protocols using of a simple device such as a tablet PC. SUPVIS-JUSTIN is part of the METERON series of experiments investigating various robotics and operations strategies for future exploration missions with human/ robotic elements.

#### Non-ISS platforms

A second 60-day bedrest campaign started at MEDES (FR) in September testing a nutritional countermeasure consisting of a 'cocktail' of anti-inflammatory, anti-oxidant substances.

A Research AO was released covering Investigations into Biological Effects of Radiation on 15 August, for which 20 letters of intent were received. A Continuously Open Research Announcement for radiation activities was also released in September making available five European radiation facilities.

The results of the PERWAVES, GRADECET and XRMON-DIF experiments, launched on Maxus-9 in April, were presented to the scientific community at the ISPS-7/ELGRA-25 joint conference in October.

#### → EXPLORATION

Multi-Purpose Crew Vehicle/European Service Modules (ESMs)

Shipment of ESM1 to the US is scheduled for April 2018 despite issues with supplier deliveries. The propulsion qualification test campaign was interrupted by the damage of the test article (two reaction control thrusters). The anomaly is being investigated and a recovery plan developed. There is no impact to the FM integration activity schedule.

A challenge to the delivery of equipment for ESM2 by dates committed to by the subcontractor is being resolved. NASA moved the ESM2 on-dock at Kennedy Space Center to September 2019.

The Phase-A for the design upgrades began on 1 September. The design consolidation review is planned for early 2018.

Studies to inform the identification of the Complementary Barter and the potential ESA contributions to the NASA Deep Space Gateway are continuing.

#### ExoMars 2016

The Trace Gas Orbiter aerobraking operations are progressing and the spacecraft should reach its science and data relay quasi-circular orbit (410/270 km) at the end of April 2018. A large reserve of fuel is secured for routine and contingency operations.

#### ExoMars 2020

The CDRs of the Carrier, Rover and Descent Modules (DM) are ending. Some equipment belonging to the Carrier and Rover Modules encountered difficult development that required close monitoring, lengthy tests and adjustments of design. The second phase of the DM CDR jointly conducted by Roscosmos/TsNIIMash and ESA is ongoing with emphasis on hardware design readiness, specification of software requirements and final analysis of the braking engine/Radar Doppler altimeter plume interference risk.

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The system CDR is planned for 26 October. An updated ExoMars 2020 project schedule is being created to reflect a full-fledged DM and spacecraft test campaign, introducing 60 working days of contingencies, and assuming a realistic 66-day launch campaign.

European contributions to the Luna-Resource lander

A PROSPECT operational workshop was organised at ESTEC in mid-July, with the participation of the PROSPECT User Group, the PROSPECT industrial consortium and IKI. The PROSPECT Phase-C/D approach is being prepared with Leonardo and the Open University, with a programmatic and planning review conducted on 30 June.

The overall PILOT-D schedule for Luna-Glob remains critical. The interface unit EM could not be shipped in mid-August as requested by IKI, but in mid-October instead. A significant delay of the camera unit FM is expected in 2018, because of lead times from US and European component suppliers. The PILOT Phase-B2 activities are ongoing, including simulations and prototype assembly and testing at the subcontractors.

Exploration Preparation, Research and Technology (ExPeRT) An ITT was opened in September for a definition study for an ESA-led, commercially enabled mission of opportunity to demonstrate In Situ Resource Utilisation (ISRU) on the Moon. The mission objectives focus on the demonstration of selected ISRU technologies (e.g. building on PROSPECT)

and processes. The activity includes the identification of commercial providers for lunar surface delivery and communications services.

The Call for Research Ideas for the Deep Space Gateway (DSG) closed on 6 October after receiving 100 submissions. The research ideas are now under review by a science advisory team.

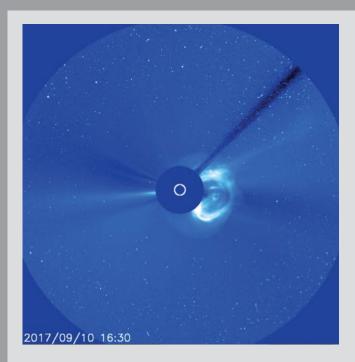
The first Life Support Systems Working Group with Member States representatives took place at ESTEC on 7 September. The working group plans to establish a consistent European Life Support roadmap, in line with possible missions and associated programmatic framework (technical and financial).

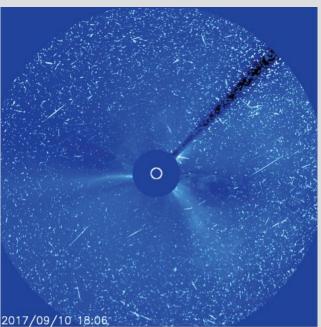
#### Commercial partnerships

Pending resolution of open points with NASA on ISS resource use, the Bartolomeo Partnership Agreement should be submitted in November for decision. Bartolomeo is an unpressurised platform on the outside of the ISS to host external payloads.

#### Lunar Services Pathfinder

This partnership with SSTL and GES (UK) is to demonstrate services in support of Moon exploration. These include the transport of payloads to Moon orbit, navigation, provision of lunar communications relay. It provides a dedicated ground infrastructure with antennas and global





The coronal mass ejection (CME) of 10 September 2017 observed by the LASCO C3 coronagraph on SOHO. Left, the onset of the CME; right, the CME is just about the leave the coronagraph field of view, with the image corrupted by the energetic solar protons hitting the CCD imager (ESA/NASA)

connectivity of commercial users. The business review was initiated in August to identify scenarios for possible ESA contributions and to work towards a proposed staged Partnership Agreement in 2018.

#### Activities carried out in ETHEPA or GSTP

The contract between ESA and QinetiQ for the full development and production of the first International Berthing and Docking Mechanism flight unit was signed on 29 September.

#### International cooperation

Joint sea survival training of European and Chinese astronauts took place for the first time in August, with Samantha Cristoforetti (IT) and Matthias Maurer (DE). A workshop on lunar samples analysis and future lunar missions was held in Beijing at the end of August.

A delegation from the United Arab Emirates visited EAC in September to start exploring potential for ESA support in selecting and training a future UAE astronaut corps.

Technical exchanges with NASA on possible European contributions to Mars Sample Return (MSR) architectural concepts are ongoing. The objective is to converge on a single reference architecture for the overall MSR campaign early next year. The Ministerial Council in 2019 will decide on the implementation Phase-B2/C/D.

## → SPACE SITUATIONAL AWARENESS

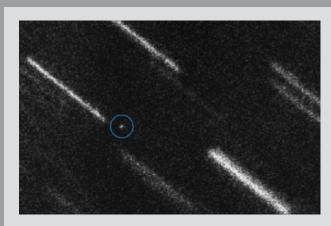
#### Space Weather (SWE)

The SWE System provided and coordinated space weather services during the high solar activity period in September. The image shows the onset of the coronal mass ejection (CME) on 10 September. The solar particle event associated with this CME produced the first ground-level enhancement since 2012 and the increased solar energetic proton flux caused loss of scientific measurement data in many satellite missions on 11-12 September.

Development of the Lagrange space weather mission to the Earth-Sun Lagrangian point L5 situated at a distance of 150 million km is progressing with the Phase-A/B1 mission studies and the instrument pre-developments expected to start in November.

#### Near Earth objects (NEOs)

On 12 October, asteroid 2012 TC4 made a close flyby of Earth, at a distance of only 44 000 km above the surface. While it was a small object (only about 10-15 m in diameter), it was used as a 'test case' for dealing with a real impact threat in a campaign coordinated by the University of Maryland in which ESA participated. In collaboration



Recovery image of 2012 TC4 (ESO/ESA NEOCC/O. Hainaut (ESO), M. Micheli (ESA) & D. Koschny (ESA))

with the European Southern Observatory (ESO), we were the first team to recover the object, using ESO's Very Large Telescope in Chile, on 27 July. It was the faintest NEO ever observed. The object attracted considerable media attention. It was used to test observational capabilities, interaction between the different relevant parties, and communication with emergency response agencies.

The topic of NEOs, dubbed 'Planetary Defence', is also on the agenda of the United Nations. From 10-12 October, CNES hosted the 9th meeting of the UN-endorsed Space Mission Planning Advisory Group (SMPAG). SMPAG is a group of space agency representatives working on asteroid impact threat mitigation. ESA currently chairs this group. During the meeting, a roadmap was finalised and a paper and brochure describing the work of the group was prepared.

#### Space Surveillance & Tracking (SST)

Activities for the SST Core Software are progressing after consultation with the SSA Programme Board. An SST User Forum is being formed. The first phase to establish an expert centre for federated laser and optical systems has been completed. The activity on integration, testing and validation of the data processing, planning, scheduling, catalogue querying, and event detection software is progressing. A supporting observation campaign is ongoing to collect test input. Final results from an activity on sensor qualification and characterisation have been discussed with sensor operators.

#### Radars and telescopes

Integration and assembly of the Fly-Eye telescope system has started. The progress of the camera system remains a concern. A seismic load study was performed to analyse placement of the telescope in Monte Mufara, Sicily. Discussions on this potential site are progressing with ASI.

#### → ESA PUBLICATIONS

#### **Brochures**

Space Situational Awareness: Detecting Space Hazards

(December 2017) BR-338 // 18 pp E-book online

Sentinel-5P: Global Air Monitoring for Copernicus (June 2017)

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SmallGEO: Small Geostationary Platform (December 2016)

BR-334 // 6 pp E-book online

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BR-327 // 12 pp E-book online

Sentinel-3: A Bigger Picture for Copernicus (September 2017)

BR-326 (2nd ed.) // 8 pp

E-book online

Sentinel-2: Colour Vision for Copernicus (June 2015)

BR-325 // 8 pp E-book online

Our Future in the Space Age (September 2017)

BR-324 (2nd ed.) // 64 pp

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LISA Pathfinder: First Steps to Observing Gravitational Waves from

**Space** (September 2015) BR-323 // 12 pp

EDRS: The European Data Relay System (May 2015)

BR-322 EN/DE // 8 pp E-book online

#### **Special Publications**

Corporate Responsibility and Sustainability, 2015–16 Report

(August 2017) SP-1335 // 76 pp E-book online

Sentinel-4: ESA's Geostationary Atmospheric Mission for Copernicus

Operational Services (December 2017)

SP-1334 (2nd ed.) // 88 pp

Price: €20

ESA's Report to the 41st COSPAR Meeting (June 2016)

SP-1333 // 236 pp Price: €30

#### Other Publications

Product Assurance Guidelines for CubeSat Projects (January 2018)

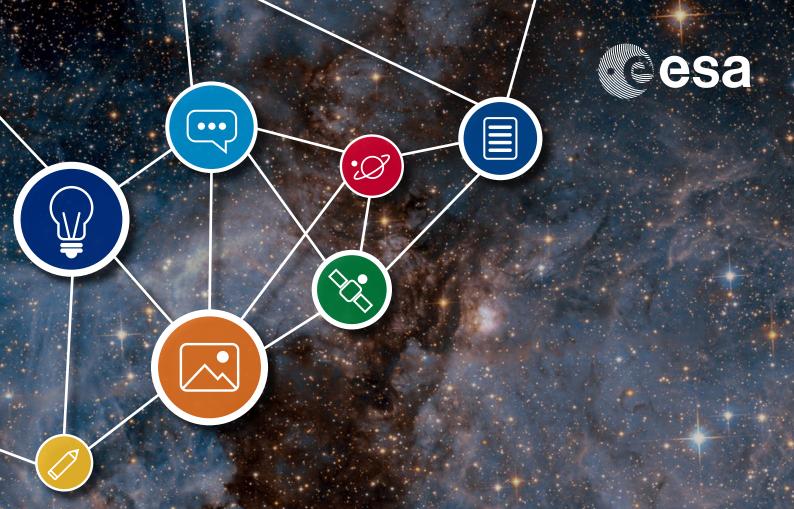
STM-283 // 54 pp Price: €20

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