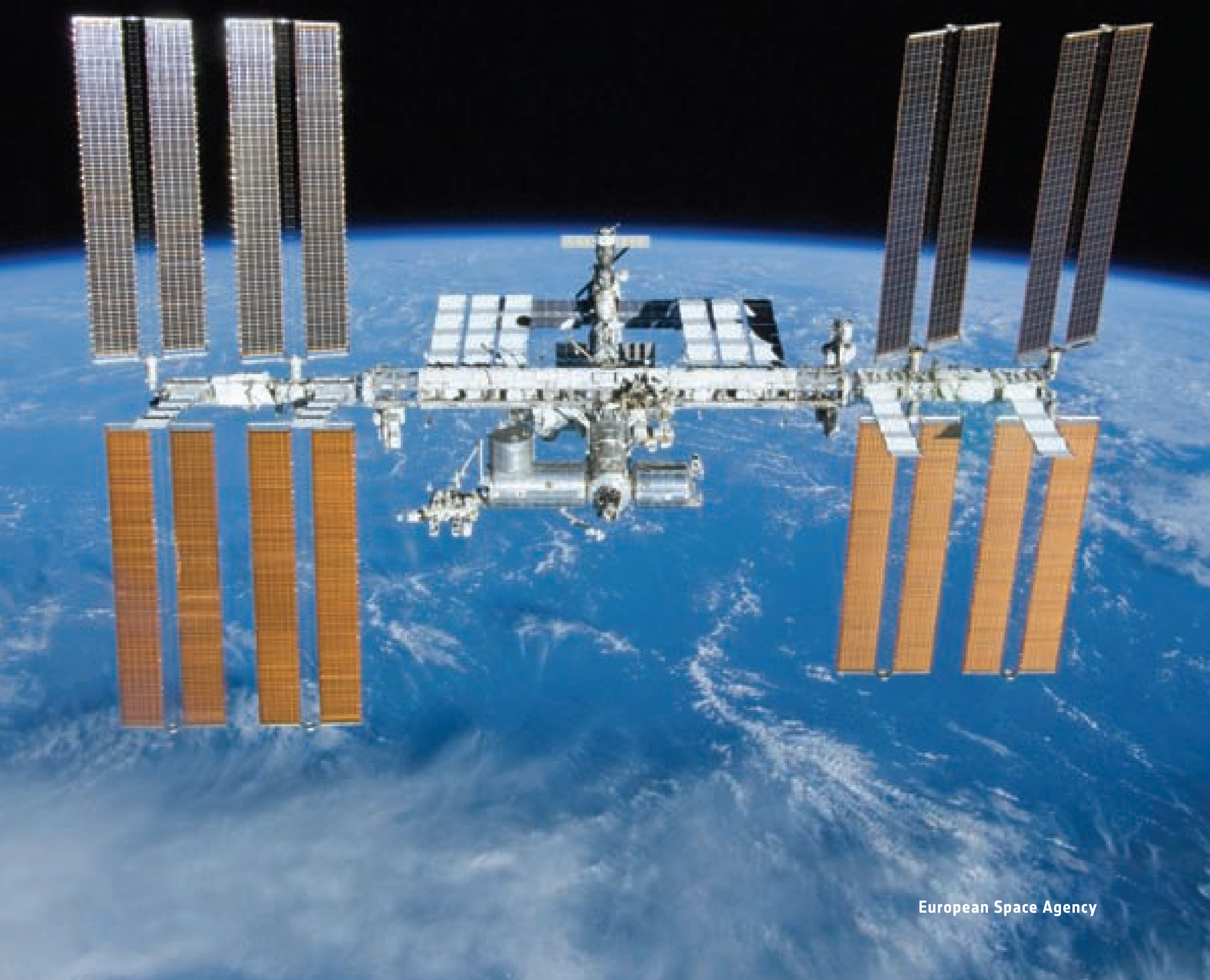
elips

→ RESEARCH IN SPACE FOR THE FUTURE



European Space Agency

→ RESEARCH IN SPACE TO PREPARE FOR THE FUTURE

Welcome to the exciting world of microgravity, science in space and preparing for the future of human exploration

This brochure gives an overview of the wide range of research the European Space Agency is performing under the unique conditions found in space. The cornerstone is the International Space Station and its European Columbus laboratory, but several other mission platforms are also available. The areas of scientific interest are many and diverse: from fundamental physics to human physiology, from new alloys to plant roots.

ELIPS – European Programme for LIfe and Physical Sciences in Space – is ESA's research programme for science and applications in microgravity, helping to improve our life on Earth and enable humankind's long-term presence in space. The examples presented here are all part of ELIPS. However, with a programme that involves some 1500 scientists in hundreds of experiments, as well as a large and diverse group of industrial research and development users, only a small but representative sample of the whole portfolio can be presented.

The first chapters describe the various ways in which ESA offers weightlessness (the formal term is microgravity) and other space conditions to scientists, lasting from a few seconds to years. A few seconds of free-fall already allows many important and interesting phenomena to be studied without the interference of gravity. After introducing the Space Station, the brochure highlights a few of the multitude of ELIPS experiments being performed in orbit.

The Station also offers a fantastic vantage point for studying Earth and its climate, the Sun and its varying characteristics, and all the particles and radiation coming from the whole Universe. For example, the Expose experiment series (page 18) literally exposes organic samples to the vacuum and extreme temperatures of open space for years.

The curiosity and the drive to explore are deeply rooted in humans and a hallmark of our culture. Many problems, though, have to be solved before we can leave low orbit again and eventually begin the much-anticipated journey to Mars. How humans fare on long interplanetary voyages is critical, both physiologically and psychologically. For example, how can our bodies cope with weightlessness for years at a time? Read about our early research on this, both on the International Space Station and on Earth, on page 10. This research will also help us on Earth to a better life.

I hope you will enjoy reading about our ELIPS endeavours and share a part of our universe!

Thomas Reiter
Director of Human Spaceflight & Operations

If you would like to know more, please take a look at **www.esa.int/esaHS/research.html**
Descriptions and results of around a hundred investigations on the International Space Station can be found at **eea.spaceflight.esa.int**

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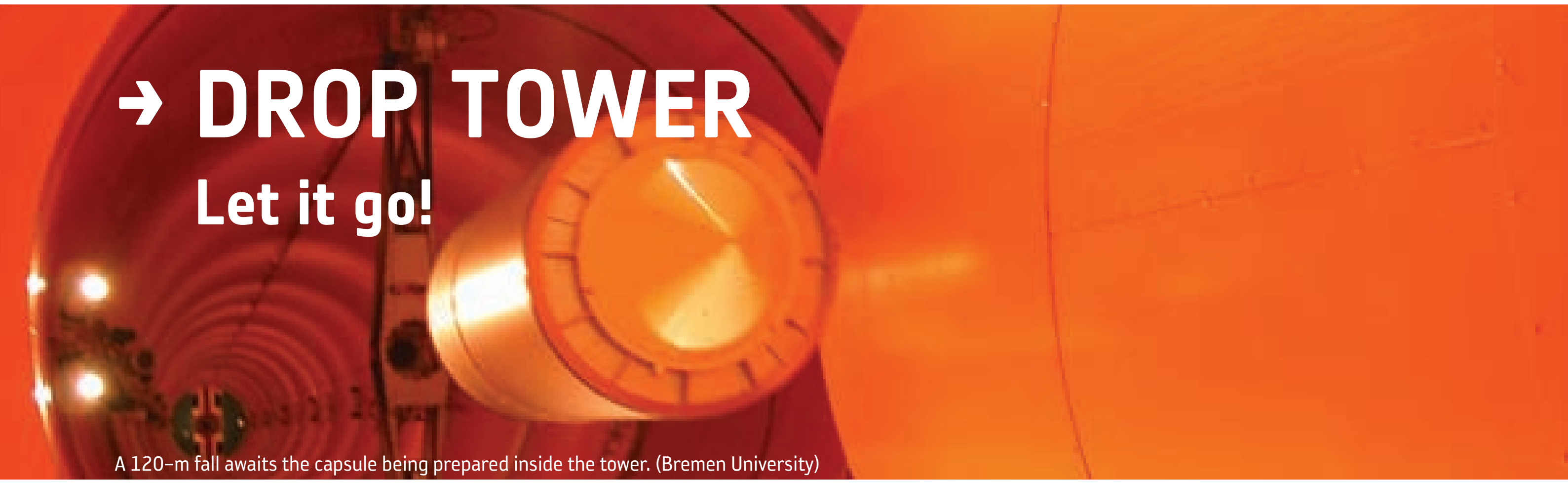
→ DROP TOWER

Let it go!



A 120-m fall awaits the capsule being prepared inside the tower. (Bremen University)

Drop towers are a very attractive way of creating microgravity on Earth: capsules carrying experiments are dropped inside a closed vacuum tower to experience a few seconds of free-fall.

ZARM (Zentrum für Angewandte Raumfahrt Microgravitation) is one of the best and attracts scientists from around the world to Bremen in Germany. It features a 146 m-high tower surrounded by numerous facilities and laboratories. The experiment is housed in a capsule that is allowed to fall freely, attaining low microgravity levels for up to nine seconds.

The quality of microgravity is better than that achieved in parabolic aircraft flights, or even on orbital platforms like the International Space Station. Drop towers are extremely versatile and the most flexible platforms for many scientific experiments.

ZARM is available for 300 working days every year and it allows the experiment hardware to be changed at short notice and the experiment set-up to be adjusted or improved between consecutive drops.

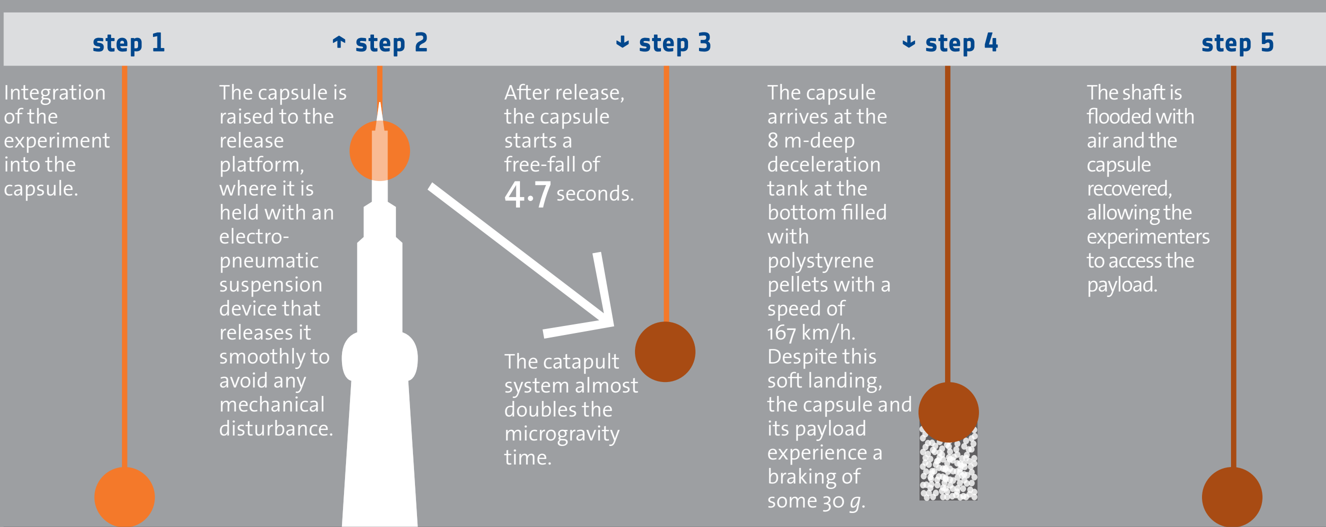
Drop towers also offer reliable and accurate monitoring of experiments, allowing both data upload and download during the experiment.

The ZARM drop tower

The ZARM drop capsule, pulled up to the height of a 40-storey building, is designed to withstand extreme accelerations. This microgravity laboratory performs around 300 drops a year, and it has been running now for two decades. On average, ESA funds 70–100 drops per year, spread between four or five campaigns.

What can be learned during those precious few seconds? The set up has become highly sophisticated over the years and allows quite exotic observations. For example, studying the combustion

How does it work?



of droplets, sprays, solid fuel and gas mixtures is helping to build computer models that will improve industrial processes.

The drop height in the tower is 100 m, providing an undisturbed free fall of slightly less than five seconds. Two to three drops can be performed in a day.

The chamber is free-standing inside a concrete building, which protects it from the wind. Inside the wide tower, a 4 m-diameter drop tube is the 'real' facility. The experiments are accommodated in a pressurised capsule and firmly attached to its structure.

A catapult almost doubles the microgravity time. Capsules up to as much as 400 kg can be launched up into the evacuated shaft from the bottom, accelerated by a pneumatic piston elegantly exploiting the difference in pressure between the airless tube and pressurised air tanks.

The enormous acceleration – leaving any Ferrari or Porsche in the dust – is controlled via a brake on the piston.

Cameras, temperature control and combustion chambers are available to researchers. A laser, installed at the top of the tower, can shine its beam into the capsule if needed. If the super-microgravity quality of up to $10^{-9}\,g$ is necessary – that's a mere billionth of Earth's gravity – then there is a capsule with an evacuated inner chamber for the experiment to float freely during the drop.

What do you gain by dropping your experiment?

- Up to nine seconds of high-quality weightless conditions.
- Real-time monitoring and control of experiments during the drop.
- Direct intervention by researchers to make modifications between drops.
- Low-cost access.
- Preparation for long-duration missions in space.
- A platform for new ideas in microgravity research.

ZARM drop tower in Bremen. (Bremen University)

→ PARABOLIC FLIGHTS

Don't fasten your seatbelt

The Airbus A300 Zero-G is the world's largest aircraft for parabolic flights. It has been used by ESA since 1997 to provide repeated microgravity or partial gravity periods. (ESA/Novespace)

Parabolic flights offer tickets to weightlessness without leaving Earth. ESA conducts scientific and technological investigations in microgravity and reduced gravity to test hardware before use in space, to finalise procedures, and to train astronauts for future spaceflights.

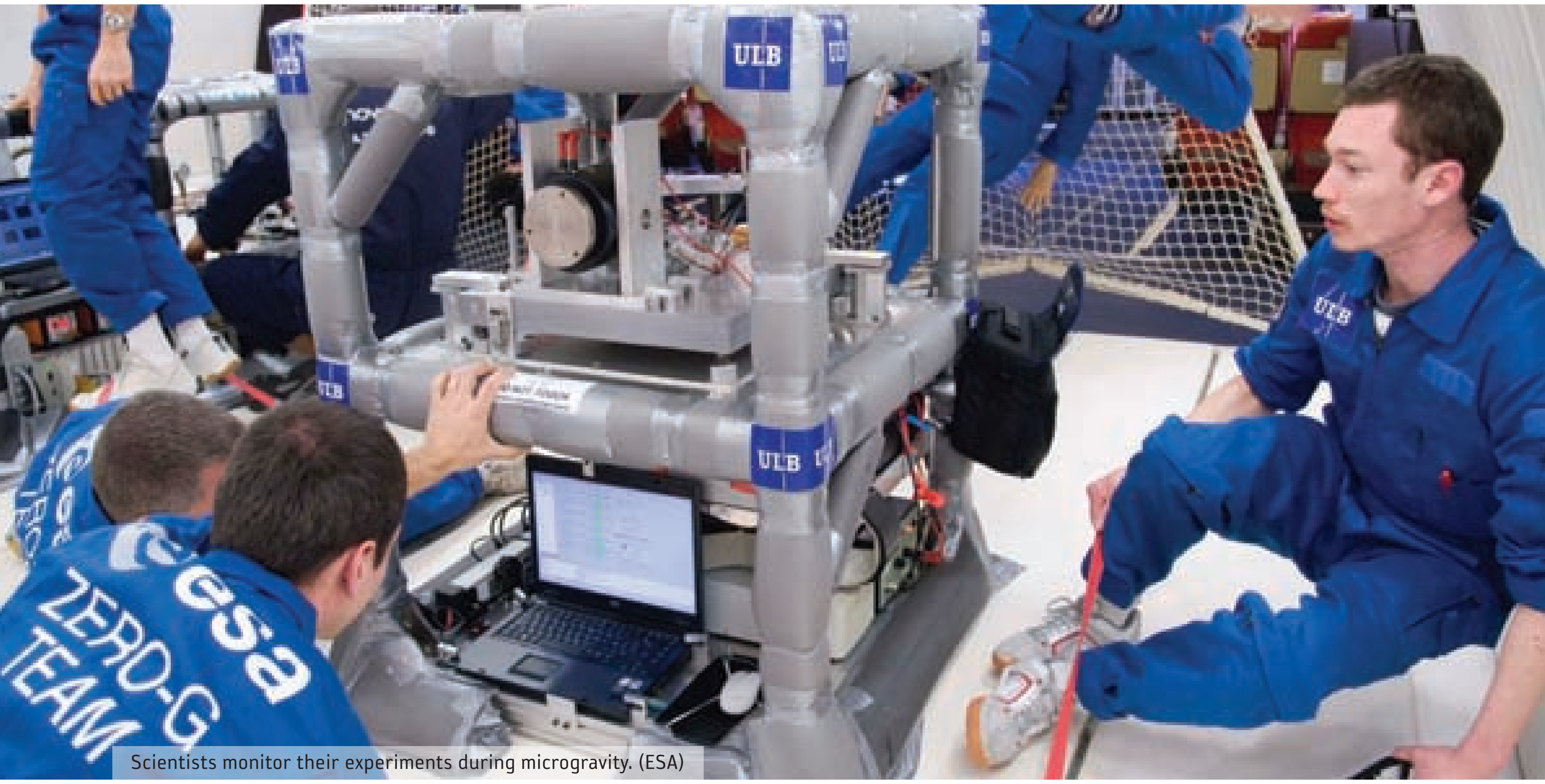
These flights are made on the converted 'Zero-G' Airbus, sponsored by ESA and France's CNES space agency, providing repeated periods of weightlessness.

One parabolic manoeuvre offers about 20 seconds of microgravity. Around 30 single parabolas are flown in this way each day of a three-day campaign, typically five in a row.

Each parabola has a period of increased gravity (1.8–2 *g*) that lasts for about 20 seconds immediately before and after the 20-second phase of reduced gravity.

Parabola after parabola, the total weightlessness accumulated during one of these flights can be as much as 10 minutes. The parabolas are separated by a few minutes to give time to experimenters to adjust settings or modify their experiment.

The high-tech aircraft can also imitate gravity conditions on the Moon and Mars. It is certified for flying parabolas that provide 0.16 *g* (Moon) for 23 seconds and 0.38 *g* (Mars) for 30 seconds.



Scientists monitor their experiments during microgravity. (ESA)

Since 1984 ESA has organised more than 50 campaigns, as part of ELIPS since 2001. Thanks to thorough technical, operational and safety preparations, there has never been an accident during flight.

What can you learn in 20 seconds?

Researchers can squeeze an enormous amount of scientific data out of 20 seconds of microgravity, with up to 15 experiments being performed at a time.

Advantages

- **Short lead-time** Typically a few months between research proposal and flight.
- **Low cost** ESA covers the cost of the flight opportunity.
- **Flexible research approach** Laboratory-type, hands-on instrumentation is most commonly used.
- **Direct intervention** Investigators aboard the aircraft can interact with their experiments between and even during parabolas.
- **Experiment modification** The experiment set-up can be modified or adapted between flights, since the three flights of a campaign usually occur on consecutive days.

Parabolic flights are the only suborbital means of carrying out medical and physiological experiments on human subjects under microgravity or reduced gravity, complementing space and ground studies.

Those precious 20 seconds helped to determine, for example, the influence of gravity on the coordination of human movements, and how much time is needed when adapting to weightlessness.

Physicists have the opportunity for hands-on investigations into processes at short time scales. Heat transfer when a liquid is boiling, for example, is better understood thanks to parabolic flights. They also helped to confirm the universality of free fall with atoms for the first time – or why a feather on the Moon falls as fast as a hammer.

Along with drop-tower experiments, these are often a step towards more elaborate experiments on longer-duration carriers such as sounding rockets or the International Space Station.

Before and after the experiments fly in space, parabolic flights can help to improve their quality and success rate, as well as to confirm or invalidate the results. Preparatory tests can contribute valuable results and provide experience for longer experiments.

Parabolic figures

- Two to three ESA campaigns a year.
- Over 90 parabolas per campaign (usually 3 flight days).
- About 10 minutes of total weightlessness per flight.
- About 20 seconds per parabola.
- Up to 15 simultaneous experiments.

→ SOUNDING ROCKETS

This is rocket science

Sounding rockets boost payloads of a few hundred kilograms into almost vertical ascent and descent trajectories. Their flights provide valuable vibration-free microgravity.

Originally conceived to sound the physical properties of the upper atmosphere (hence the name), their use has been extended to provide weightlessness conditions for research in physical and life sciences.

Since 1982, ESA has been using sounding rockets as carriers for its microgravity research. They can reach altitudes of 150–750 km. Maxus, for example, can be launched to twice the altitude of the International Space Station.

Flexible, reusable and ideal platforms for pioneering science, they are used to test scientific ideas and instruments that need only a few minutes of microgravity. The duration of weightlessness, 6–13 minutes, is determined by the apogee reached by the rocket.

Launched from Esrange next to Kiruna in northern Sweden, European payloads experience weightlessness during their free-fall once their rocket has stopped firing and detached.

Telescience, late access to experiments and quick retrieval of samples benefits a wide range of experiments, such as crystal growth, heat flow, flame propagation, dust aggregation and perception of gravity by living cells.

One Maser flight, for example, improved our insight into how gravity drives liquid drainage from propellant tanks.

State-of-the-art laboratories are available to the scientific teams at the Esrange premises, providing clean benches, laminar flow benches, microscopes, centrifuges, autoclaves and incubators.

The modular sounding rocket

The experiments are accommodated on circular and stackable decks. The resulting cylindrical assembly, which includes batteries, control electronics and data interfaces, constitutes an experiment module.

Support modules include the service module for telemetry, video streams and telecommands, and the recovery module that deploys a parachute shortly before touchdown.

Most of the support modules are refurbished and upgraded for reuse. The experiment modules can also be reused.

What do the rockets carry?

- The Biology in Microgravity module is a multi-user module, equipped with an incubator, for small biology experiments. Tens of experiment vials can be accommodated either in static positions or on a centrifuge.
- The XRMON facility provides X-ray monitoring of advanced metallurgical processes in medium-temperature alloys. Their solidification can be observed *in situ* and give hints on how to strengthen their properties in production plants.

This combination of standard and modular blocks gives the sounding rocket programme strong reliability and unique flexibility.

The ESA sounding rocket family

Texus

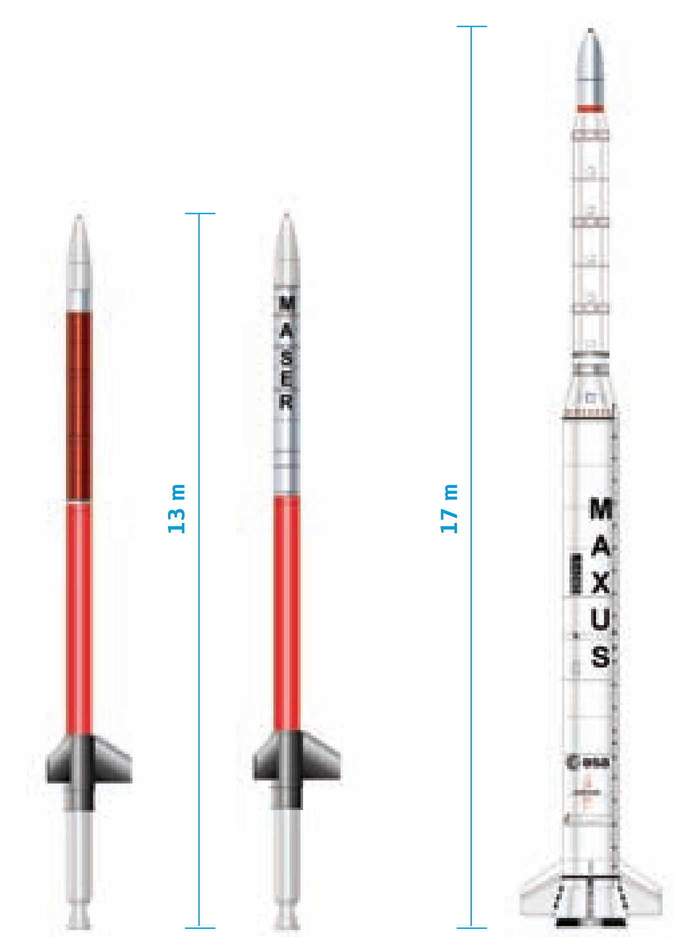
Microgravity time 7 minutes | **Scientific payload** 280 kg | **Apogee** 250km

Maser

Microgravity time 7 minutes | **Scientific payload** 285 kg | **Apogee** 250km

Maxus

Microgravity time 13 minutes | **Scientific payload** 485 kg | **Apogee** 750km



Three types of rocket provide microgravity lasting 6–13 minutes. (ESA)

Why perform experiments using the sounding rockets?

- Extended microgravity duration: up to 13 minutes.
- Late access to some experiments up to 30 minutes before launch.
- Fast retrieval of sensitive samples: scientists can receive their payloads back within a few hours of landing (within an hour for some samples).
- No human-safety restrictions.
- Low-cost and fast-track precursor to longer research in space.
- Interactive experiment operation (telescience, remote control).
- Regular flight opportunities.

Maxus ascends from Esrange, reaching an altitude of 750 km. (ESA/Esrange)

→ INTERNATIONAL SPACE STATION

The brightest man-made star

Space Station, with ATV *Johannes Kepler* attached. (NASA)

The International Space Station is a shining example of global cooperation, uniting Europe, the USA, Russia, Japan and Canada in one of the largest partnerships in the history of science. This human outpost in Earth orbit is a stepping stone for further space exploration.

The endeavour has brought humanity together to live and work in space uninterrupted for a decade. The 400-tonne complex has more than 1200 cubic metres of pressurised volume – enough room for the crew and a vast array of scientific experiments.

There is probably no single place on Earth where you can find such a laboratory – the size of a football field – with facilities to conduct the breadth of research.

Europe's involvement in this partnership through ESA continues to be a story of major technological and scientific achievement. It has been a great stimulus for European industry, which has taken huge strides in the development and manufacture of cutting-edge space systems and hardware.

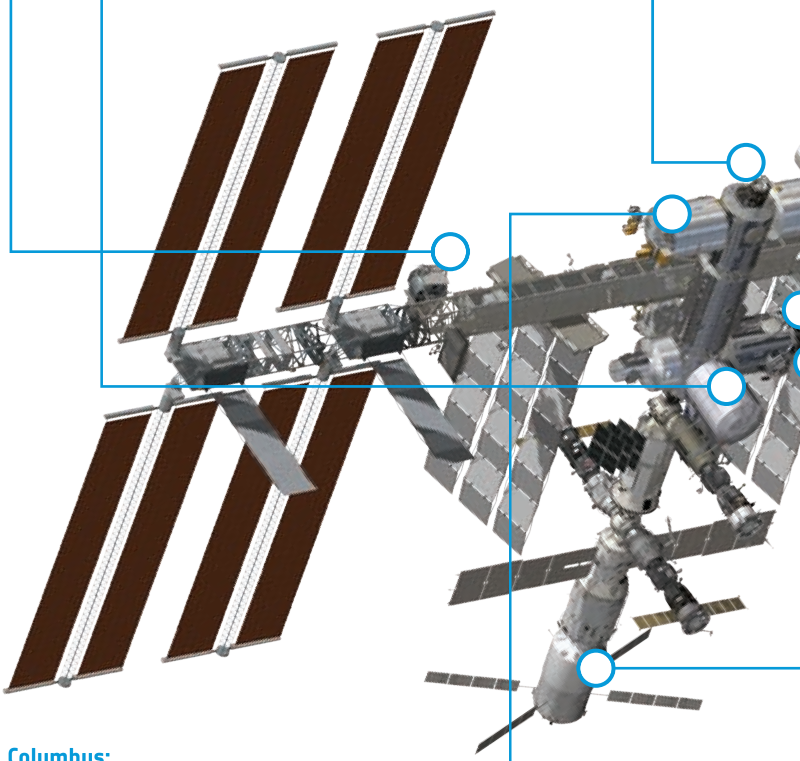
The Station will be in orbit until at least 2020. Supported by a crew of six, a new era of research and technology has begun.

A floating research laboratory in space

The main scientific purpose of the International Space Station is to do research in an environment free from the unwanted effects of gravity. Its stunning views of Earth and space are valuable for other research.

This high-flying international laboratory is packed with some of the most technologically sophisticated facilities to support a wide range of scientific inquiry in human physiology, biology, fundamental physics, fluid and materials sciences, Earth observation and space science.

Astronauts are working from an altitude of about 400 kilometres above our heads conducting world-class experiments in this unique research environment. Europe's latest boost to scientific research is the Columbus module, a multifunction laboratory that



specialises in fluid physics, materials science, biology and human research. External platforms are supporting solar, cosmic radiation and astrobiology, space physics and fundamental physics studies.

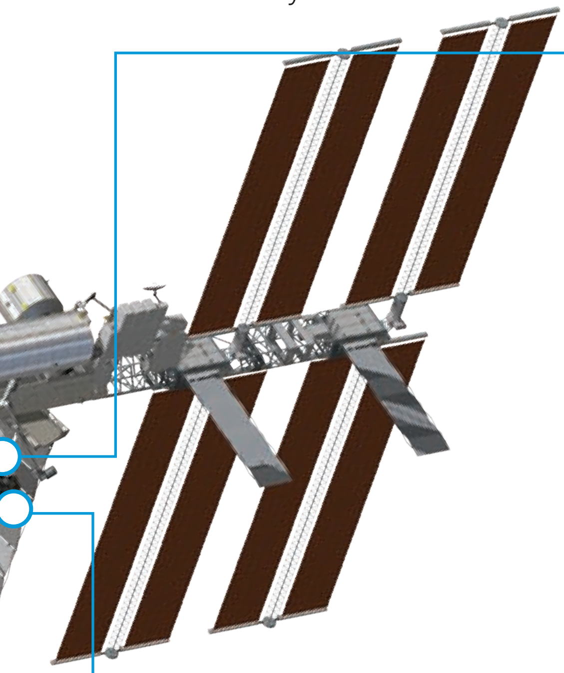
The Station is a unique vantage point for collecting Earth and space science data. Observation of such features as glaciers, agricultural fields, cities and coral reefs can be layered with other sources of data, such as specialised satellites, to compile the most comprehensive information available.

It is a prominent Earth observation platform. It has the potential to support competitive technology, and to foster scientific research and education.

Technology also has its place in space. The Station is testing and demonstrating a wide range of state-of-the-art technologies. Using Columbus as a testbed, for example, the ESA Vessel Identification System is bringing global sea traffic tracking within reach. The receiver is pinpointing more than 300 000 vessels every day. It is like the marine equivalent of the air traffic control system.

The European Technology Exposure Facility (EuTEF) hosted several tribology and materials degradation experiments for 1.5 years in open space before its return to Earth.

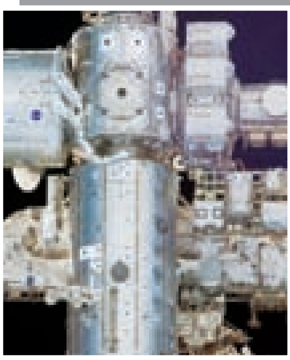
Future space exploration will not be possible without the Station. From it, Europe is envisaging how the future adventure beyond low Earth orbit will be.



European elements

Columbus

The Columbus laboratory, as the first permanent European research facility in space, is the cornerstone of European innovation and research in space. Since being attached to the Station in 2008, it has been consistently building scientific data across a multitude of disciplines. An external payload facility hosts experiments and applications in space science, Earth observation and technology.



Nodes

Node-2 serves as a connecting passage between the Columbus, the US Destiny laboratory and Japan's Kibo laboratory. It also provides three docking ports for visiting vessels.

Node-3 houses life-support and exercise equipment for the crew of six, and accommodates Cupola and docking ports.

Cupola

The Cupola observation module is the most modern element made-in-Europe attached to the Station. The seven-window dome is the crew's panoramic window onto Earth, as well as a working area for astronauts to control remote equipment outside the Station.

ATV

The Automated Transfer Vehicle is Europe's unmanned ferry that docks and undocks autonomously, delivering food, propellant and other essential supplies to the Station. ATV helps the Station to maintain its position and orientation, and departs with rubbish for incineration on reentry into Earth's atmosphere.

→ ACES

What atomic time is it?

The measurement of time has progressed spectacularly over the centuries. When Christiaan Huygens invented the pendulum clock in 1657, it had typical errors of tens of seconds per day. With high-precision manufacturing, mechanical clocks later reached accuracies of tens of milliseconds per day, sufficient for navigation across the Atlantic Ocean.

In the middle of the 20th century, the invention of the quartz oscillator and the first atomic clocks opened a new era for timekeeping. Atomic clocks provide the best accuracy on this planet.

The Atomic Clock Ensemble in Space (ACES) is an ESA flagship experiment in fundamental physics based on a new generation of atomic clocks operated on the International Space Station.

ACES will take advantage of the Station's continuous microgravity environment to maintain an ultra-stable onboard timescale. In the quest to define how time and space are related, this complex set of space clocks will be used to perform space-to-ground and worldwide ground-to-ground comparisons of clocks with unprecedented precision.

Space and time

Attempts to define how time and space are related have been going on for centuries.

According to Einstein's theory of general relativity, identical clocks placed at different positions in stationary gravitational fields experience a frequency shift. ACES will measure this shift by comparing the space clocks with clocks on the ground.

ACES measurements will also verify the constancy of the speed of light and search for possible time variations in the Universe's fundamental constants.

The mission will precisely test the fundamental laws of physics, thus challenging Einstein's and alternative theories of gravitation.

Clocks for the Station. ACES will be mounted outside Columbus in 2016. (ESA–D. Ducros)

Why be on time?

High-performance atomic clocks are used to test the fundamental laws of physics and to challenge our knowledge of the Universe.

ACES will benefit metrology – the science of measurement – because highly accurate clocks in space will help in the comparison of atomic frequency standards, in the synchronisation of clocks and in the realisation of global time scales such as the International Atomic Time.

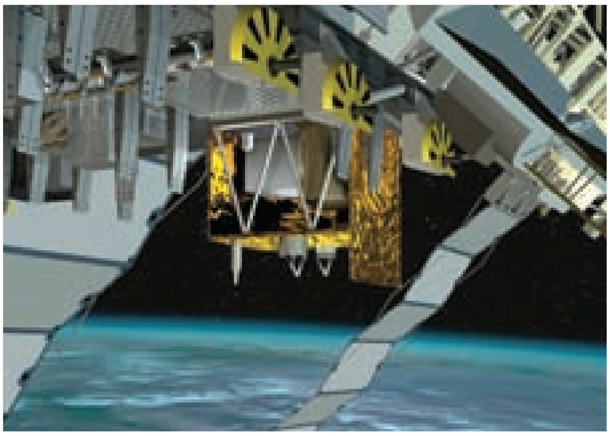
The space clock will also demonstrate a new type of 'relativistic geodesy' which, based on a precise measurement of the Einstein gravitational redshift, will resolve differences in Earth's gravitational potential to the level of tens of centimetres.

GPS enables users with a small receiver or modern cell phone to locate their positions on the globe with metre accuracy. GPS receivers are widely used in geodesy and Earth monitoring. ACES will contribute to the evolution of the global navigation satellite network and support the use of precision clocks in major Earth science activities.

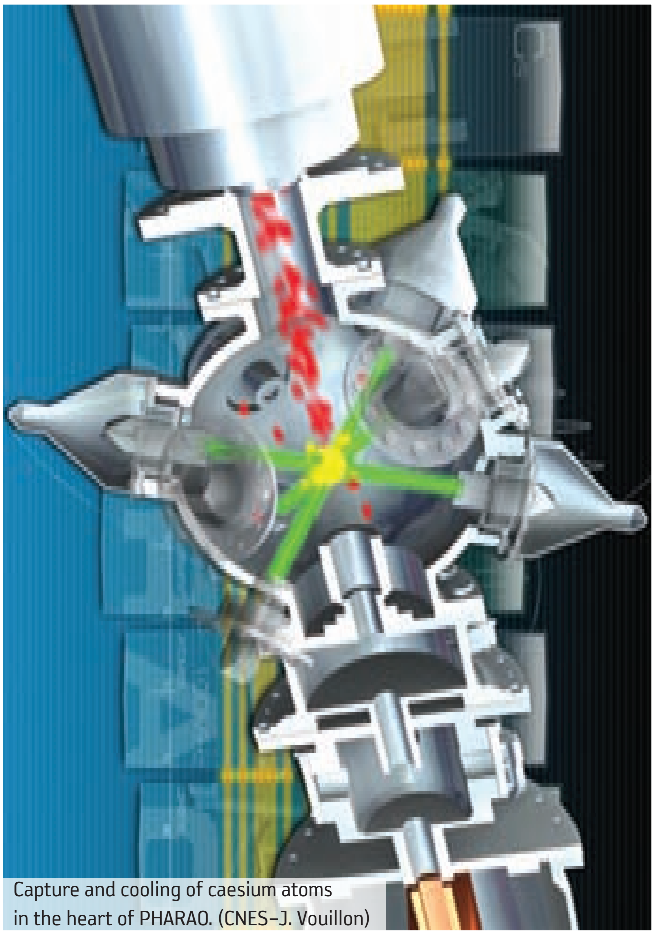
Why in space?

- Space provides weightless conditions. Within ACES, the PHARAO laser-cooled atomic clock will take advantage of the microgravity environment to operate a clock based on ultra-slow caesium atoms.

- Orbital motion around our planet provides global coverage. This is commonly used in Earth observation satellites as well as in the GPS system. The worldwide reach of ACES will establish a global network of clocks that can be compared to high accuracy.



The entrails of the clock



Capture and cooling of caesium atoms in the heart of PHARAO. (CNES–J. Vouillon)

ACES is deceptively simple but it carries two high-performance clocks, one of which is using laser-cooled atoms. Together, they are accurate to about one second over 300 million years.

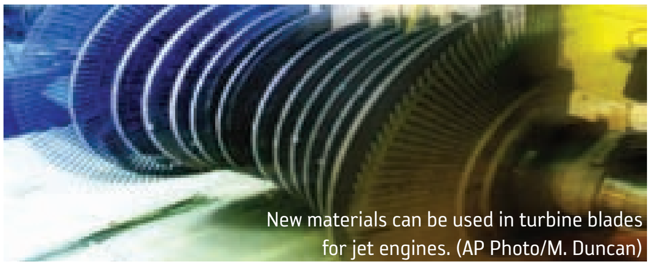
- **PHARAO** (Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbit) is a primary frequency standard based on samples of laser-cooled caesium atoms.

- **SHM** (Space Hydrogen Maser) is an active hydrogen maser for space applications.

The performances of the two clocks are combined to generate an onboard timescale with the short-term stability of SHM and the long-term stability and accuracy of the caesium clock.

→ IMPRESS

Let me impress you


New materials can be used in turbine blades for jet engines. (AP Photo/M. Duncan)

Despite much effort over the past decades, the effects of gravity during industrial casting are not yet fully understood. Various experiments performed on the ground and in space have tried to unravel the influence of gravity on the formation of materials from the liquid state but much remains to be learnt.

Closely related to ELIPS, Impress (Intermetallic Materials Processing in Relation to Earth and Space Solidification) was a flagship research project in materials science and applications. A large multidisciplinary European consortium probed the links between the processing, structure and properties of 'intermetallic' alloys.

Intermetallics are chemical compounds of two or more metallic elements. They have gained considerable interest in recent years through a wide range of potential applications in aeronautics, automotive engineering, hydrogen fuel cells and even biomedicine.

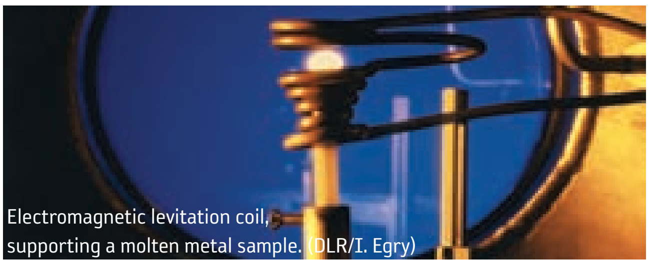
Impress investigated the solidification of intermetallics aboard sounding rockets and parabolic flights to establish their basic properties.

Materials of the future

Lightweight and high-strength intermetallic alloys can help to improve efficiency, reduce fuel consumption and lower exhaust emissions in aero-engines. They are also important for producing advanced catalytic powders, which speed up chemical reactions, saving both time and energy for the pharmaceutical, chemical and food industries.

Titanium aluminides, for example, have remarkable mechanical and physical properties at temperatures up to 800°C. The combination of high melting point, high strength and low density make them ideal for high-performance turbine blades.

These blades, produced by advanced casting techniques, will be used in the next generation of turbines for modern power stations and aero-engines. Using titanium aluminides would halve the weight of turbine components.


Electromagnetic levitation coil, supporting a molten metal sample. (DLR/I. Egry)

Impress explored new routes, such as gas atomisation and nanoparticles, as a way of producing spherical fine catalytic powders. After further processing, these powders and their outstanding properties are being exploited by industry to speed up hydrogenation reactions, which are vital for the production of certain chemicals and plastics.

Materials research toolbox

The International Space Station is being used for benchmarking experiments on different types of molten alloys, confirming theories, validating computer models and helping to optimise industrial processes.

European facilities on the Space Station are ideal places to explore materials and their processing. Under the near-absence of gravity's effects, terrestrial processes like solidification and casting can be studied in ways unattainable on Earth.

The Station facilities include:
- the **Materials Science Laboratory** (MSL) can run solidification experiments on high-temperature intermetallic alloy samples and crystallisation of semiconductors.
- the **Electromagnetic Levitator** (EML) will allow containerless melt processing and non-contact measurement of thermophysical properties.

A good impression

By combining the industrial and academic expertise of more than 200 leading scientists from 15 countries, Impress made Europe the world-leader in this strategically important area of materials science.

Numerous flight experiments were performed. The project, supported by the European Commission, comprised a large consortium of 40 research groups and companies. The close relationship with ELIPS is allowing the results to be fully exploited.

Impress not only greatly strengthened the global competitiveness of the European industries involved, but it also led to major environmental and energy-efficiency benefits thanks to new pollution-free power generation systems. It is hoped that the results are making a valuable contribution to the Kyoto Protocol on Climate Change.

→ GRAVI

The gravitational instinct of roots

On Earth, plants are strongly sensitive to gravity, with stems growing upwards and roots downwards. And when a seedling growing in the vertical position is placed horizontally, its extremities start bending in order to follow gravity. How this happens is still being debated.

Experiments on lentil seedlings confirm that the orientation of their roots strongly depends on gravity. When grown in orbit, their tips show pronounced curvatures.

The GRAVI series of experiments is looking at the minimum level of artificial gravity needed to start lentil seedling roots growing in a new direction.

Why lentils? Seeds of *Arabidopsis lens culinaris* were chosen because of their small size, their uniform germination and, in particular, because they are very sensitive to gravity.

Lentils in space

GRAVI is part of a long series of experiments addressing gravity perception in lentil roots, flying on Spacelab, Shuttle and the Mir station since 1985.

The International Space Station provides a unique platform for biological experiments. Columbus houses ESA's European Modular Cultivation System, originally installed in 2006 in the US Destiny laboratory. This unit is dedicated to experiments on plants – especially on seeds – to study gravity effects on early development and growth. The incubator provides a controlled atmosphere and two centrifuges provide microgravity, partial gravity and Earth gravity conditions.

The GRAVI-1 experiment was the second ESA experiment to use the EMCS, in 2007.

Earth's gravity has played a major role in plant evolution.

It demonstrated that lentil roots grown without the help of gravity behave differently: some of them even curve into hook shapes. The experiment showed the minimum gravity level required to change a root's direction, which is a clue to how a plant physically senses gravity.

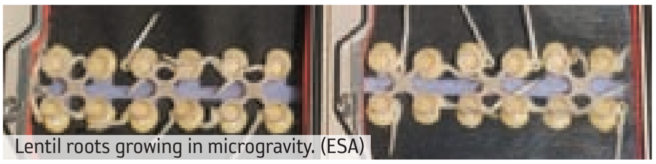
Back in space

Now the lentils will return to space thanks to GRAVI-2 observing the effects of centrifuging the seedlings. The goal is to pinpoint the threshold acceleration where the root responds with a significant curvature.

The roots will be stimulated in a centrifuge and the root curvature followed by time-lapse photography or video. During a 30-hour germination, different gravity levels between 0.01 g and 2 g will be applied for different durations.

The experiment will measure the movement of dense starch grains in the root cells and the redistribution of calcium in the root with different gravity levels. It is believed that both are important in how plant roots perceive and respond to gravity.

Earth and space applications



Lentil roots growing in microgravity. (ESA)

Although this is primarily basic research, understanding how plants respond to partial gravity may be useful for growing crops on long missions on the Moon and Mars.

Back on Earth, it provides insight into the fundamental organisation and operation of gravity response in plants. It will also show if other parts of the plant require cues for directional growth.

→ SOFT MATTER

May the force be with you

Foam is a mixture of a gas and a liquid. (SSC)

Emulsions

Bubbles, foams, emulsions – fickle and changing, important in our daily lives, but still a puzzle. How they are structured and which forces control them are a fundamental problem in physics and chemistry.

The study of the behaviour of foams and emulsions under weightless conditions has wide practical applications. Solid foams, for example, are as strong as pure metal but much lighter, and they are used in advanced aerospace technology and manufacturing.

Foams and emulsions are important for personal care products and waste treatment, and for food and oil companies. Food companies, for example, are interested in the properties of champagne bubbles and chocolate mousse in space to create improved and tastier products on Earth.

In some cases, a stable foam emulsion is desirable, like shaving foam, moisturiser, vinaigrette or beer. However, the instability between gas and liquid is welcomed when it comes to filling bottles of fizzy drinks.

Mix it!

Scientists have been always intrigued by how matter becomes mixed. Materials created with two or more components that blend without chemical changes are called a mixture. Milk, soap and glue are common examples.

ESA astronaut Frank De Winne works with the Microgravity Science Glovebox. (ESA)

However, the physical and chemical properties of a mixture may differ from those of its components. This is why the research on mixtures is as complex as it is interesting.

An interesting example of mixtures in space comes from foams. Foam cells do not drain because there is no longer gravity pulling the liquid downwards. Instead, other effects dominate the size of the bubbles and the way they collapse.

Colloids

Aggregation is one of the clues that tell us how atoms get along and make up our world. European scientists have become real-time voyeurs of this fascinating process with the SODI-Colloid experiment.

Colloids are mixtures of fluid and solid: particles are evenly distributed in the fluid. But gravity interferes when particles aggregate.

Sedimentation causes the particles to sink and growing structures to break, greatly modifying their shape. To study how colloids aggregate and uncover promising applications, some samples have been sent to the International Space Station.

SODI-Colloid focuses on the very small forces of attraction and repulsion between nano-scale objects (a nanometre is a billionth of a metre). Scientists play with a suspension of tiny particles, turning the temperature up and down, and observing when they start to cluster.

The aggregation can be easily tuned and reversed by varying the temperature. Standard aggregation techniques are not reversible and difficult to control, but the process under investigation is completely reversible: you go up in temperature and particles aggregate, you decrease it and the structures disappear.

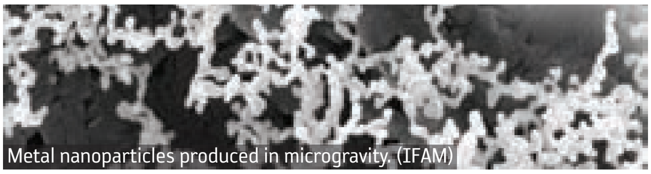
One of the most promising applications of colloidal engineering is the fabrication of photonic devices. Photonic crystals offer appealing properties for new types of optical components. They could be made of dielectric materials like plastic, glass or a metal oxide, and have the peculiar property of acting as a filter for light just like a transistor is a filter for electrons.

Three reasons

1. Solve a fundamental puzzle in physics: how structures are formed and which forces contribute to their formation. It would shed light on the critical Casimir effect – very weak forces predicted in 1978.

2. Learning how colloids aggregate tells us a lot about how smaller objects like atoms aggregate and form familiar objects like gases, liquids or solids.

3. Controlling aggregation is a very important technical and industrial issue. We all want uniform paints and clear glasses. These experiments are solving aggregation problems for the food, pharmaceutical and cosmetics industries.



Metal nanoparticles produced in microgravity. (IFAM)

Three experiments

Colloid is the second in a series of SODI (Selectable Optical Diagnostics Instrument) experiments. With a sealed and controlled environment, the European-built Microgravity Science Glovebox on the International Space Station provides the ideal research facility.

The glovebox has reached 10 000 hours of operation after almost 10 years in orbit, hosting a wide range of microgravity research, including fluid physics, combustion science, materials science, biotechnology and fundamental physics, seeking to understand the role of gravity in basic physical and chemical interactions.

- Influence of Vibrations on Diffusion in Liquids, completed in January 2010.
- SODI-Colloid, completed in October 2010.
- Diffusion and Soret Coefficient Measurements for Improvement of Oil Recovery (DSC). The third SODI experiment will be carried out in late 2011. Further batches of DSC experiments and additional runs of the Colloid experiment are planned for 2012.

Inside the Microgravity Science Glovebox:
SODI-Colloid shows how colloids aggregate. (ESA)

→ EXPOSE

Terrestrial life in open space

It was in the 19th century when prominent European scientists started to think that the simple, common ancestor of terrestrial life might have come from space. Pursuing that idea, astrobiologists have long been interested in exposing organic molecules and small organisms to the hostile space environment.

Out there, there are fascinating conditions such as full-spectrum solar ultraviolet light, high vacuum and ionising radiation – a whole 'package' that cannot be simulated on Earth. Now European scientists can test the survival skills of terrestrial organisms in outer space thanks to Expose.

Two Expose units have been built so far: Expose-E completed an 18-month run in 2008–09 mounted outside of Columbus, while Expose-R in 2011 ended its 22 months outside the Station's Russian segment. Both units exposed hundreds of samples to space for about as long as a single trip from Earth to Mars would take.

With the size of a suitcase, Expose houses a variety of organic samples outside of the International Space Station. Special windows allow the Sun's ultraviolet light to reach the test samples.

The returned samples showed that the variety of organisms able to cope with the hostile space conditions is larger than expected. Among them, healthy tobacco plants are now growing back on Earth, sprouting from seeds that were exposed for one and a half years to the 'five space factors'.

Back from space

Terrestrial organisms have proved to be tougher than we thought. Expose-E subjected biological samples to the hazards of open space and – against all odds – some survived for 1.5 years.

Certain lichens are the most complex form of life known to endure prolonged exposure, but some fungi, bacteria and seeds also survived. These specimens entered a dormant state and some of them came back to Earth in the same shape as before flight.

The initial results add weight to the theory of panspermia: that life could somehow be transported between planets by hitching a ride on an asteroid.

Expose-R was returned to Earth in 2011 after complementing the exobiology science package of its precursor Expose-E. Among the samples, spores of *Bacillus subtilis* spent 22 months exposed outside the Station.

For the first time on a long mission, living microorganisms were mixed with artificial meteorite dust and exposed to the harsh conditions of space. Scientists are now determining precisely how many of these spores have survived their ordeal.

If it turns out that the meteorite dust shielded them from the ultraviolet, some microorganisms may be capable of surviving within meteoroids for long periods and travelling from one planet to another.

The five space factors

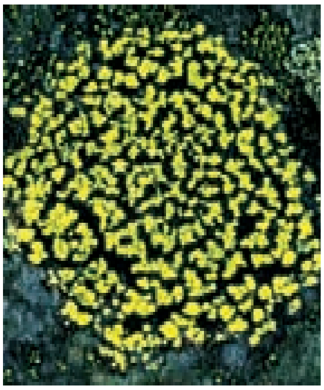
- Full-spectrum solar light
- Cosmic and ultraviolet radiation
- Vacuum
- Freezing/thawing cycles
- Microgravity

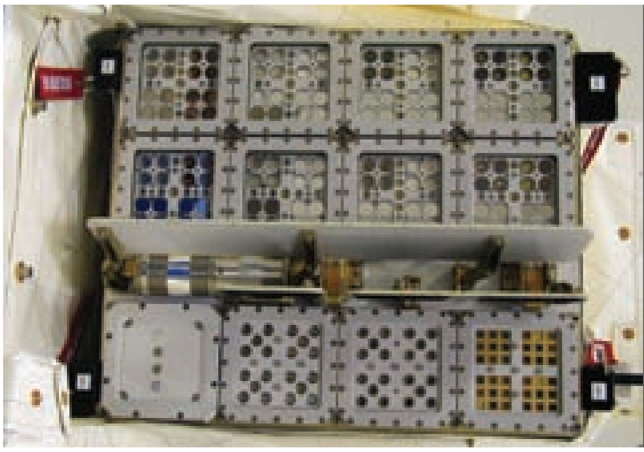
Expose attached to Columbus in the EuTEF European Technology Exposure Facility. (NASA)

Exposed to the future

The results obtained by the Expose experiments are helping us to understand the boundaries of terrestrial life, and support the need for planetary protection. The fact that life can endure periods of extreme conditions makes it more plausible that life could exist on some of the exoplanets detected in recent years.

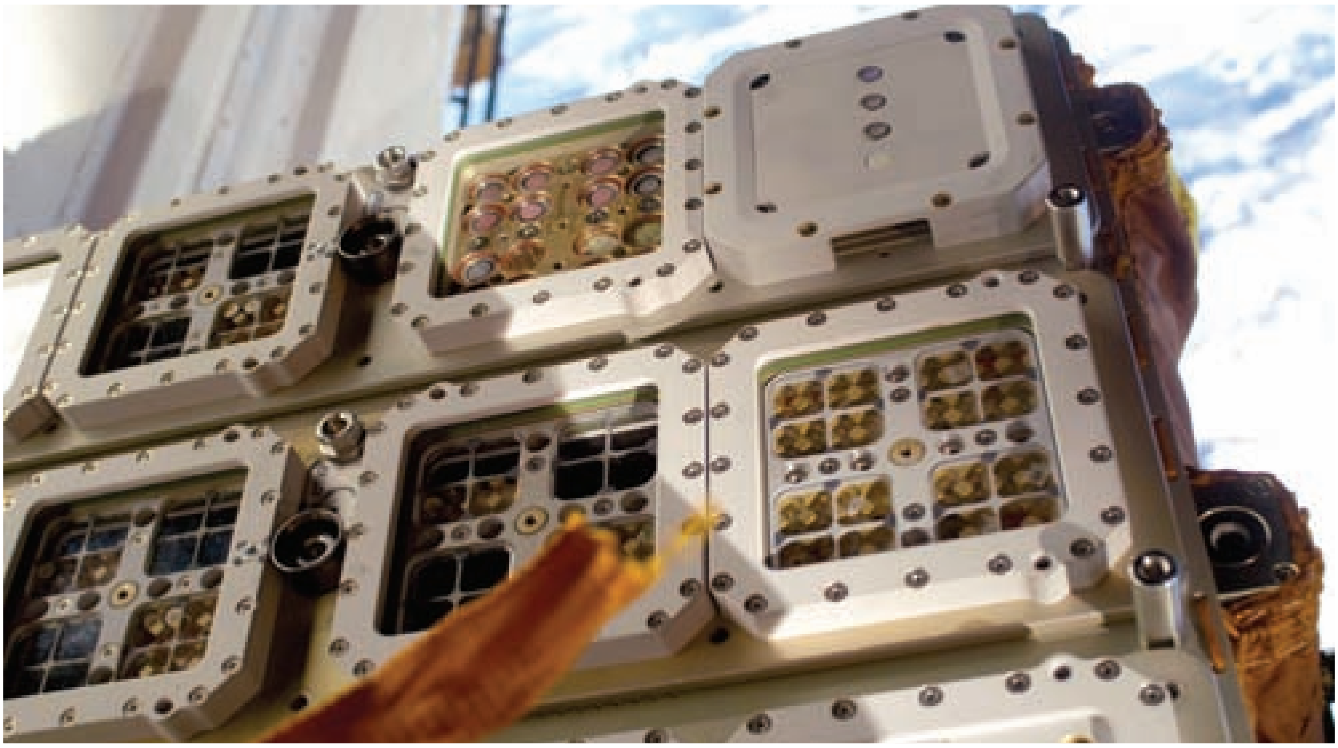
Expose-R2 is the next in line: a set of new sample trays comprising four experiments will be mounted outside the Station for 1.5 years in open space.





The experiments

Left: Expose-E ready for mounting outside Columbus.
Right: Expose-R was retrieved in January 2011; cosmonaut Dmitri Kondratyev removes the three trays of samples for return to Earth. (NASA)



→ SOLO

Less salt, please

Nutrition, preservation, size and preparation are important factors for space food. (NASA)

Astronauts lose bone mass in space, but the reasons are complex and largely unknown. Special diets are being tested under normal gravity conditions to see if they are an effective therapy against bone loss.

Research on the International Space Station will help significantly, because there are solid reasons to suspect that nutrition plays a key role in weightlessness. The central theme of SOLO – the SOdium LOading in Microgravity experiment – is keeping a very accurate account of the diet, particularly salt intake and excretion.

Salt and sodium are not exactly the same thing, but table salt is around 40% sodium – there are 2 grams of sodium in each teaspoonful. European scientists are investigating salt retention and related physiology to understand bone absorption in space and on Earth.

A sodium issue

It is well known that bone density falls when the human body is exposed to microgravity, most likely owing to the lack of weight stresses on the skeleton. In space, bones do not need to support our bodies.

Calcium is the main mineral in bone. Normal sodium intake on Earth is in balance but in space the sodium is retained. So does average sodium intake exacerbate calcium excretion? If

ESA astronaut Paolo Nespoli showing food items during his 2007 mission. (NASA) this is true, bone loss in microgravity may worsen owing to sodium retention – weakening bones further.

In this sense, salt could be a trigger for bone decay. According to classical theories on our response to excessive salt intake, the body should retain large amounts of water in order to keep the salt concentration in the circulation constant.

The hypothesis of increased urine flow as the main cause for body mass loss has also been questioned in several recent missions. Surprisingly, urine output following the water load with high sodium intakes was always low in space compared to Earth. But where does the salt go, if not to the bones or to the urine? This is what the SOLO scientists are probing.

The SOLO diet

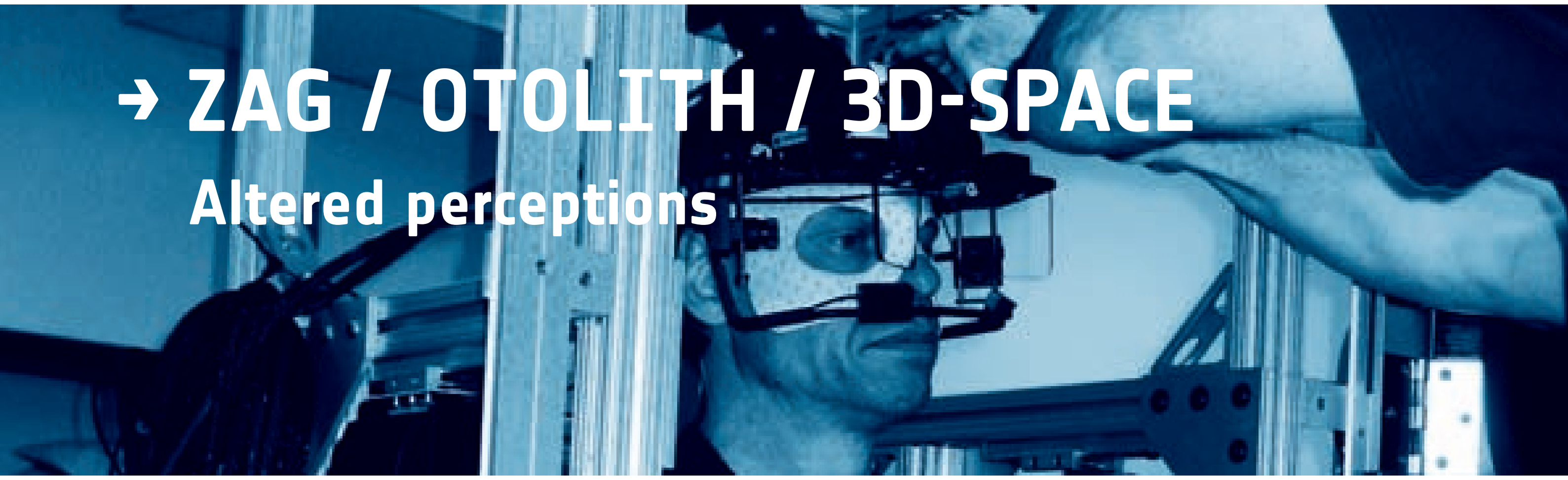
Astronauts participating in the SOLO study on long missions are following a special diet of constant low or normal sodium intake for five days at a time. The researchers can then compare the changes.

Samples of urine and blood are frozen and dispatched to Earth for analysis. Single drops of fingertip blood are analysed onboard using the Portable Clinical Blood Analyzer, which is part of the European Physiology Modules in Columbus.

SOLO is looking to answer several questions. What is the effect of the stored sodium? Does this affect the health of astronauts or bedridden patients on Earth?

Does retained sodium affect the bones of astronauts or patients on Earth? (Istockphoto/S. Kaulitzki)

NASA astronaut Greg Chamitoff participated in SOLO to study fluid and salt retention during spaceflight. (NASA)



→ ZAG / OTOLITH / 3D-SPACE

Altered perceptions

Human perception is complex. We create mental representations of our surroundings based on sensory information and experience. Our eyes, the vestibular organs and nerve cells in our skin, muscles and joints continuously send information to our brain, which uses the cues to determine spatial orientation.

During our daily life on Earth we usually walk on horizontal surfaces, thus evolving mainly in a two-dimensional world. But in weightlessness astronauts experience a true three-dimensional environment.

While vertical and horizontal are no longer relevant, the free-floating astronauts are confronted with up and down, right and left, and pitch and roll changes of attitudes. They start to rely much more on visual cues and their own body as a reference to determine up and down.

Spatial orientation is critical for posture, movement and maintenance of gaze in three-dimensional space. Weightlessness is a totally new experience – the nervous system receives conflicting or partial information from its sensory organs. When working in the spacecraft and seeing another crewmember 'upside down', astronauts can feel suddenly 'upside down' themselves.

The brain can be tricked when it has no gravitational frame of reference for extended periods. Weightlessness offers a unique opportunity to study not only the spatial orientation of astronauts, but also their posture, locomotion and eye–hand coordination.

How does gravity contribute to sensory and motor functions? European researchers are studying how the brain,

Paolo Nespoli performs the 3D-Space experiment. (ESA/NASA) inner ear and eyes interact in space through the Otolith and ZAG experiments, and the neural basis for spatial orientation in the 3D-Space experiment.

Understanding the space around us

Astronauts commonly report spatial orientation illusions in orbit, especially when they are floating free with their eyes closed. The lack of an intermediate distance range in the International Space Station doesn't help: objects inside are within a few metres, whereas the stars and Earth are far away.

3D-Space is probing the effects of microgravity on the mental representation of near and intermediate space by astronauts during and after flight. Astronauts were tested using simple experiments on a laptop, a digitising tablet and a head-mounted display.

Preliminary results indicate that perception of the perceived space surrounding astronauts is altered during flight, especially in the vertical and depth dimensions. Scientists believe that the absence of gravitational input may disorganise the brain structures commonly involved in building our spatial maps of the environment.

Virtual reality may be a way to compensate for the altered spatial perception in astronauts, as well as in patients with balance problems on Earth.

Which way is up?

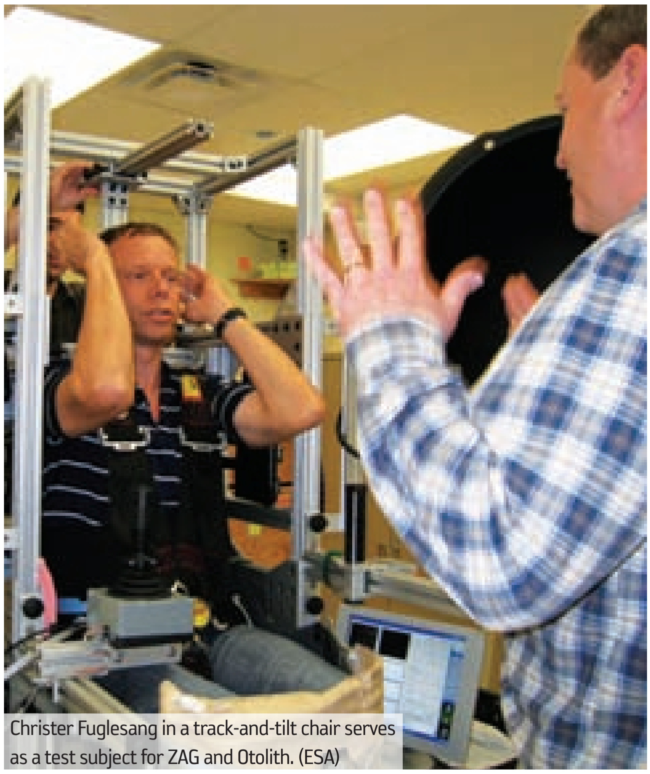
Our daily activities, such as looking around and walking, involve tilting and moving our heads. To maintain accurate spatial orientation, the gravity-sensing organs in our inner ear, the otoliths, act as tiny sensors that detect head movements.

Changes during spaceflight in how the brain interprets tilt or translation can lead to impaired movement coordination, vertigo and perceptual illusions. The resulting spatial disorientation can impair performance during critical mission phases, such as launch and landing.

The **ZAG** experiment (Z-axis Aligned Gravito-inertial force) uses a sled and a small centrifuge that spins the astronauts forwards, backwards or sideways while tilting them in pitch or roll.

The astronauts reported on their perceived motion in response to different combinations of body tilt and translation in darkness. Their ability to control their own orientation manually was also evaluated using a joystick to cancel the perceived tilt while the sled and centrifuge are in motion.

The results are helping us to understand the physiological basis for these illusions and develop potential countermeasures for spatial disorientation following adaptation to spaceflight. They could also have direct implications in the field of human neurology on Earth.



Christer Fuglesang in a track-and-tilt chair serves as a test subject for ZAG and Otolith. (ESA)

Inner-ear reactions to space travel

The otolith organs in the inner ear play an important role in our balance system as sensors of vertical and horizontal acceleration, and – most essentially – gravity. The **Otolith** experiment is examining how human balance, together with the eye-movement and visual systems, interact during and after spaceflight. This interplay is essential for maintaining spatial orientation.

Throughout evolution under Earth's gravity, these systems have remained closely coupled. In weightlessness, the otolith organs respond only to linear acceleration. This radical 'loss' of gravity can result in considerable disorientation, endangering an astronaut's capacity to work in space.

The experiment assesses the sensitivity of inner-ear organs to gravity before and after long- and short-duration spaceflight. Several astronauts who spent up to 16 days in space and on regular six-month stays on the International Space Station have taken part.

It is the first comprehensive assessment of the otolith organs in the inner ear. Using a track-and-tilt-chair allows separate stimulation of the right or left ear. Tests include estimation of 'up and down' on Earth and precise measurement of binocular, three-dimensional eye movement responses to the stimulation.

The results shed light on how the otolithic system adapts to novel gravity conditions, a crucial insight for recovering after flight in space.

→ CONVECTION & FOAM-S

Space for education

Since the installation of the Columbus module on the International Space Station, European astronauts have carried out educational programmes with a twist. Science activities are transmitted from space to students across Europe, with in-orbit demonstrations of curriculum-based experiments dubbed 'Take Your Classroom into Space'.

Thousands of young students can participate in space experiments and realise that seemingly simple phenomena such as foam formation or convection are actually very complex and differ under the influence of gravity compared to the Station's weightless environment.

For ESA astronaut André Kuipers' PromISSe mission on the Space Station, ESA developed two payloads to engage schoolchildren aged 10–14 as part of the 'Spaceship Earth' educational programme.

Using good scientific practice, students on the ground will compare their results with André's identical space experiments, by means of recorded and live links. The astronaut acts as our reporter in space, sharing his pictures and posing questions to the students on planet Earth.

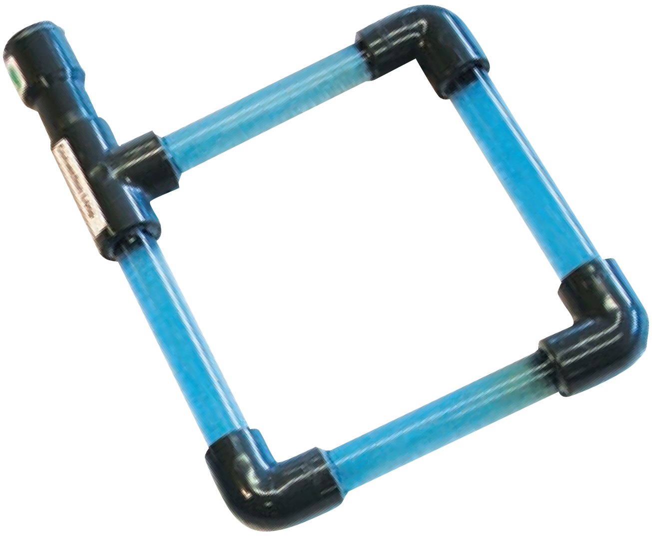
Convection illustrates how thermal gradients drive convective currents and thus, on the large scale of a planet, how temperature gradients influence density-driven convection and create atmospheric and oceanic currents.

A simple yet effective device shows how heat affects the density of liquids and the role that gravity plays in heat distribution. The rectangular tube is a liquid-filled, see-through closed loop with small particle tracers to visualise the movement of the liquid. By grasping the convection loop on one side, heat from the hand is sufficient to drive a convective current within the loop on Earth, with 1 *g* conditions. On the Space Station, there is no convective flow, demonstrating that convection depends on gravity.

There are direct links to the importance of large convective atmospheric and oceanic currents on Earth, and how these affect our climate. The experiment links these themes to the curricula of physics, biology and geography.

FOAM-Stability. Foams – mixtures of gas pockets within liquids – are strongly affected by gravity draining the liquid and by density differences.

André Kuipers and the Convection experiment. (ESA)



This experiment demonstrates the physical properties of wet foams and how gravity influences their stability. On the Space Station, foams and emulsions are not subject to gravitational forces. Up there, it is possible to form very stable foams from liquids such as pure water – rarely seen on Earth.

André will show how foam is made from pure water in weightlessness, helping children to understand how foam formation and stability can help us to make cutting-edge materials – see the 'Soft Matter' story on p16.

The astronaut will also play with soapy water, a beer-like sample and oils. Young scientists on Earth will operate their own identical experiment and make their observations, while André does his in space.


André and the FOAM-S experiment (ESA)

Stay connected

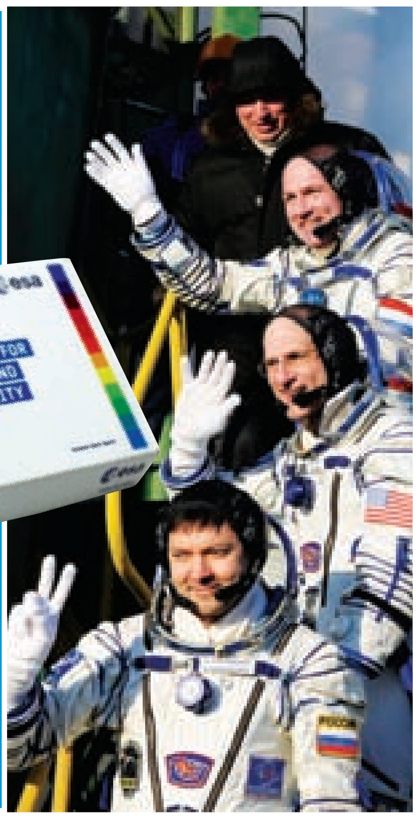
The school kits with the 'Take Your Classroom into Space' experiments can be ordered at:

www.esa.int/education

as well as visiting the PromISSe website:

www.esa.int/promisse

The kits are shipped free of charge to ESA member state schools on a first-come, first-served basis. All educational material remains on ESA's webpages and can be used at any time by teachers.



→ BEDREST

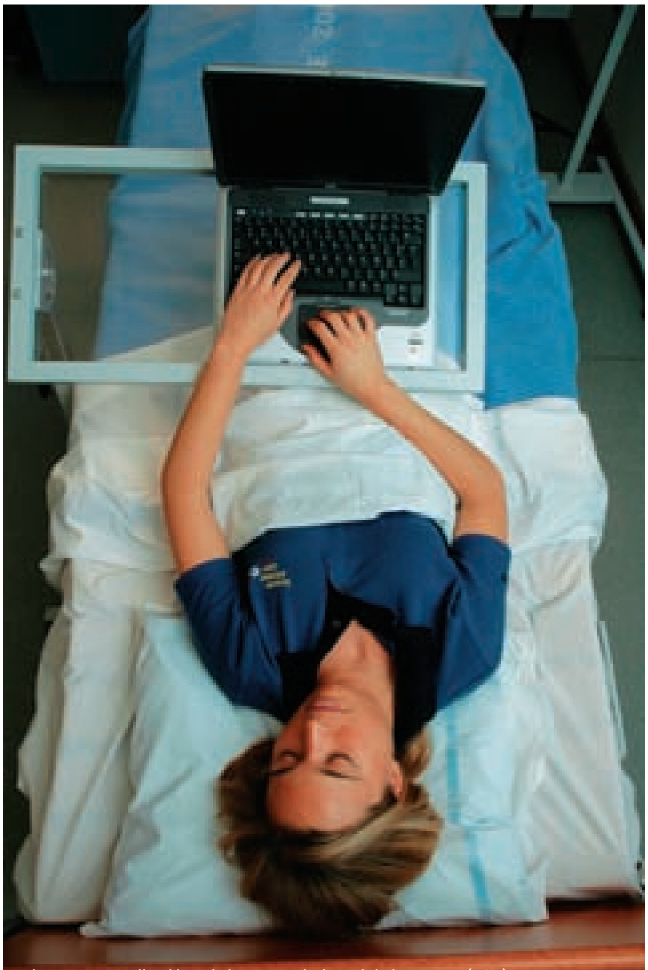
Stay in bed!

When everything is weightless, like on the International Space Station, strange things happen to the human body. And the longer it lasts, the more pronounced these changes appear to be.

With a reasonably active life on Earth, there are no great changes to our muscles and bones over time. But this static appearance is misleading – our bodies are continuously adapting to daily stresses. When we exercise or have a broken arm in a cast, our bodies adapt to the increased or reduced stresses by raising or lowering bone and muscle mass.

In space, muscles and bones have no need to work constantly against gravity as they do on ground. Astronauts flying long missions on the Space Station exercise and take various measures to stay fit for their return. Despite the two hours of daily exercises, these countermeasures are still not enough, especially for future and longer missions to other planets.

Bedrest experiments last up to 90 days. (ESA)



Volunteers are tilted head-down to mimic weightlessness. (ESA)

Volunteer on the tilt table: the angle can be varied from horizontal to vertical to test orthostatic tolerance. (ESA)

Bedrest studies are an important way of uncovering the mechanisms of these physiological changes, as well as of improving the countermeasures.

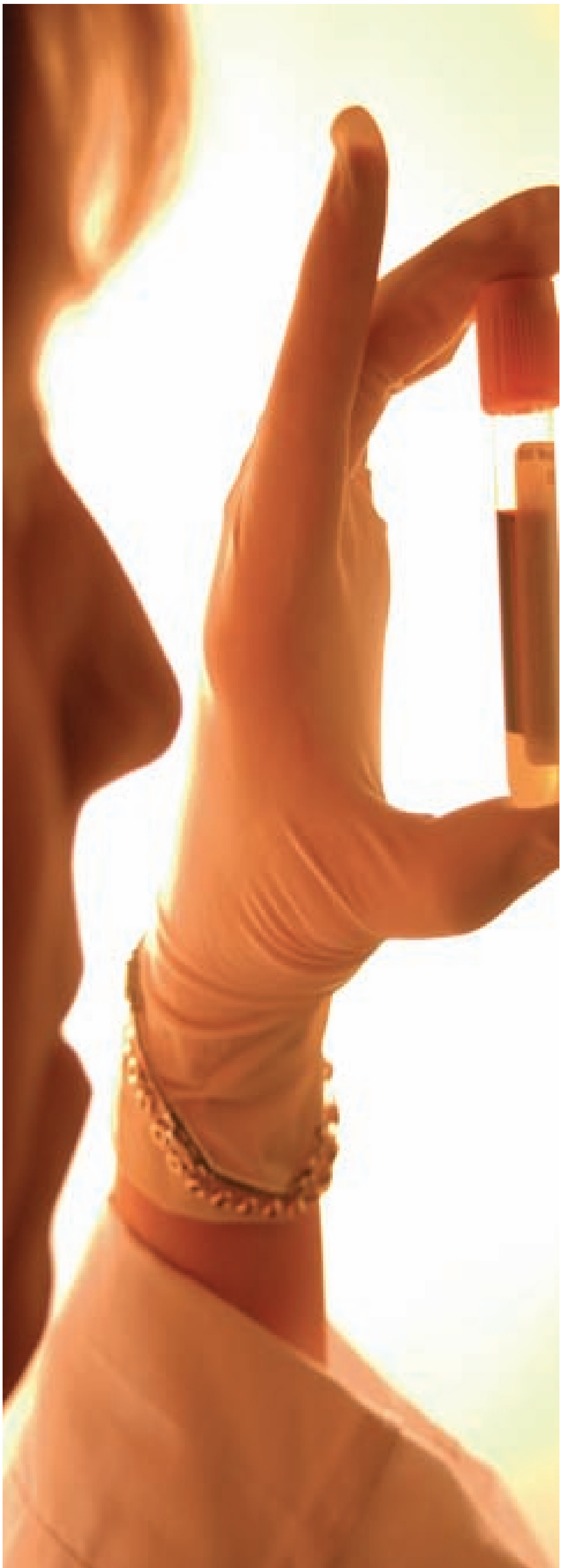
ESA has performed a number of bedrest studies over the last decade as a model for what happens in space. Volunteers from all over Europe spend between five days and three months lying down for the sake of science. They have to stay in bed all the time, tilted so that their heads are six degrees lower than their feet.

In this position, where the body no longer has to work against the pull of gravity from head to feet, there are many of the same changes to bones, muscles and the cardiovascular system as seen in spaceflight.

The benefits

Using bedrest, ESA is investigating three countermeasure concepts: nutritional supplements in combination with exercise, centrifugation and 'resistive vibration' exercise.

The research is also benefiting us on Earth. The obvious links to bed-ridden hospital patients and the lives of the aged and sedentary, are important for some of the challenges faced by society today.



Blood samples monitor physiological changes in the volunteers. (ESA)

→ CENTRIFUGE

Make it spin

We can simulate periods of weightlessness on Earth, and hypergravity can also be reproduced. A broad gravity spectrum has to be explored to complete the scientific picture of how gravity affects our bodies. This is where artificial gravity comes in, via the centrifuge.

ESA centrifuges can accelerate test subjects up to 20 times their weight. The samples – not only human – are exposed to a variety of levels beyond 1 *g*, where *g* is the normal gravitational acceleration on Earth's surface.

The idea to use centrifugation in space has been around for some time. Centrifuging plants and animals is primarily for research but, for humans, ESA's research is looking at how effective artificial gravity could be as a countermeasure on long spaceflights.

Typical countermeasures used today act primarily on one physiological aspect at a time, like on muscles or the cardiovascular system. The hope is that centrifugation, by recreating the normal pull of gravity on the whole body at the same time, can be more effective, especially when combined with exercise.

But what would be the ideal duration of each session to make it effective? Should we recreate Earth's 1 *g* or go to higher levels for the best results?

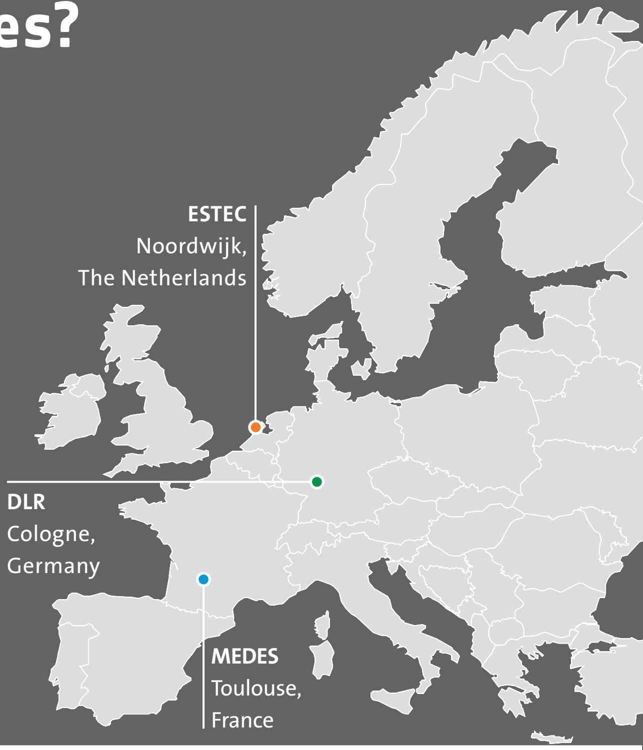
ESA is relying on a number of centrifuges in Europe for tests with humans, animals and all sorts of experiment samples.

Scientific and clinical applications

- Development of countermeasures against cardio-vascular and musculoskeletal degeneration of astronauts.
- Testing orthostatic and neurovestibular tolerance.
- Balance disorders.
- Development of rehabilitation measures.

Short-Arm Human Centrifuge. 'Dark environments' eliminate visual stimuli to avoid motion sickness. (ESA/DLR)

Where are the centrifuges?



Short-Arm Human Centrifuge Test subjects sit or lie flat in the compact centrifuge, experiencing a maximum acceleration of 5 *g*. The focus is on combining centrifuging with bedrest studies to test artificial gravity to combat the effects of weightlessness on humans.

ESA's **Large Diameter Centrifuge** provides hypergravity for cells, plants and small animals, as well as for physical science and technology experiments.

The diameter of the four-armed centrifuge is 8 m and it can run experiments from one minute up to six months, without stopping.

Large-Diameter Human Centrifuges are also used for astronaut flight training.


Large Diameter Centrifuge. (ESA)

→ CONCORDIA

Welcome to the science paradise

Half a century ago, Antarctica was officially declared to be a continent devoted to science. Since then, Earth's southernmost continent has been one of the most fascinating places for research.

Studies in glaciology, atmospheric sciences, astronomy, Earth sciences, technology, human biology and medicine all benefit from the isolated and extreme environment in the middle of the Antarctic continent. This is the exotic location of the Concordia station, a permanent international research facility high on the ice cap.

Since 2004, ESA has followed an ambitious programme in cooperation with the French Polar Institute and the Italian Antarctic Programme, the builders and operators of the station.

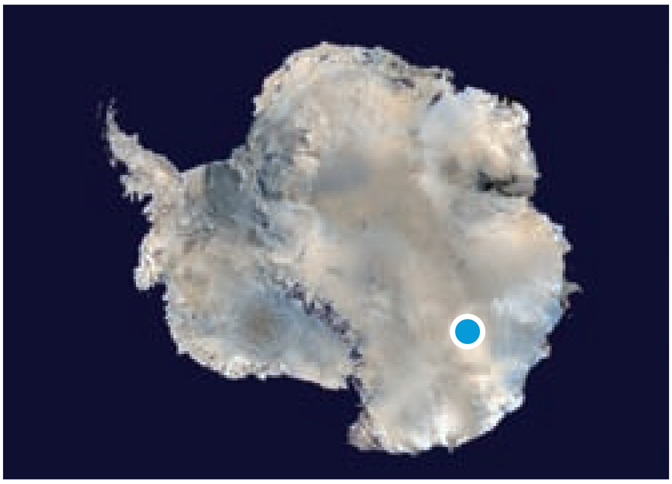
However, access to one of the most hostile places on Earth is only possible during the three-month summer season. The rest of the year, no aircraft can land and snow tractors are unable to reach it.

The last planeload of summer visitors departs in mid-February, leaving the crew to their own devices. For nine winter months they live in extreme isolation.

Concordia accommodates a crew of typically 12 to 14 scientists and technical staff. Only 200 kilowatts of electrical power is available, with a good fraction of it used for heating the two 3-storey buildings. Telecommunications are also very limited, so analysis of scientific data is largely done on site – unless it can wait for the next plane.

The flat landscape around Concordia is almost inaccessible from February to November.

Concordia environment



- An **altitude** of 3200 m.
- **Access** to the station is possible only during the Antarctic summer, from mid-November to mid-February.
- Overall mean **temperature** is –51°C, with a mean value of –30°C during summer and –60°C in winter. The lowest temperature ever recorded was –85°C in 2002.
- It has the driest desert **climate** on Earth.
- Exceptionally cold, clear and stable **atmosphere**.
- The **landscape** is an almost unending snow plain.

The crew is more cut off than on the International Space Station. The extreme isolation, confinement, self-reliance and limited resources make it a very useful testbed for future human space missions.

ESA uses Concordia as a laboratory for fundamental research into many subjects important for human missions to the Moon or Mars, like coping with stress, changes in the immune system, and alterations in circadian rhythms.

European scientists are also looking at how this environment can affect the crew's thinking, mood and sleep quality, and whether exercise could be a good countermeasure.

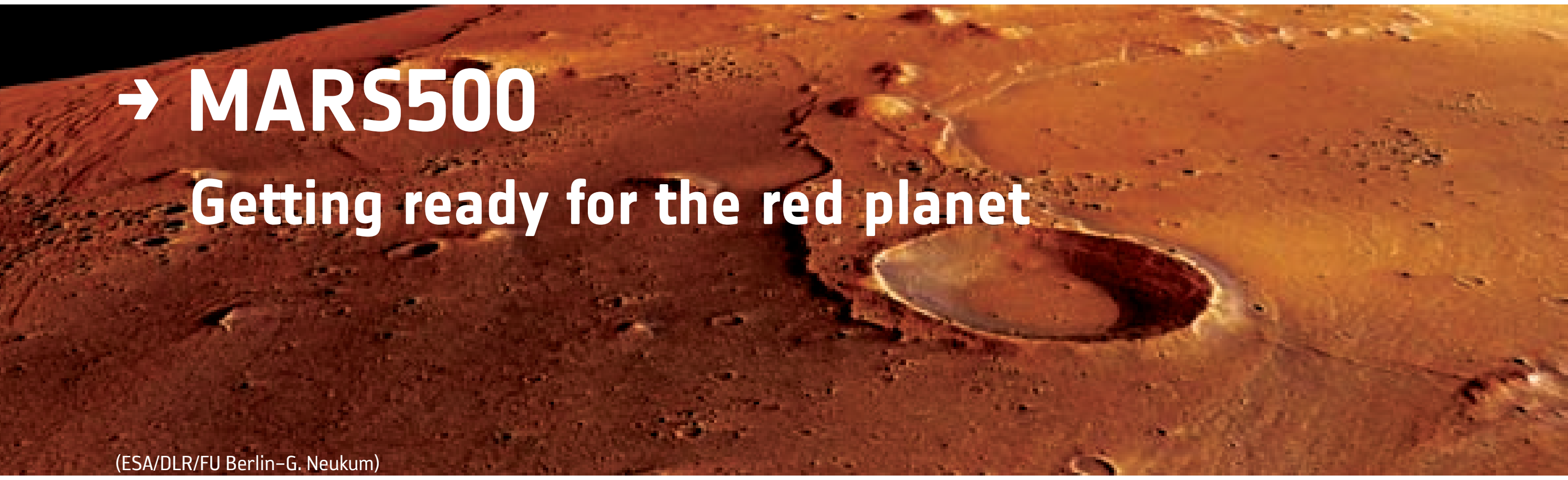
ESA is also cooperating with the Italian and French institutes on using Concordia for testing water recycling technology, which ESA is developing for space life support, and on long-term medical, psychological and microbial monitoring.

Far from light pollution: observing the southern sky, with a bright Milky Way. (ESA/E. Macdonald-Nethercott)

Extreme challenges

- **Prolonged isolation and confinement.** Typical duration of a stay in Concordia is one year.
- **Fascinating, but hostile natural environment.** Extreme low temperatures, chronic low air pressure and oxygen-poor atmosphere.
- **Autonomy.** The crew is self-dependent from February to November, when there is no access to the station, even in emergencies.
- **Life in a small multicultural setting.** More than a dozen crewmembers with different languages and behavioural customs coexist in two 3-storey towers.
- **Limited mobility outside the buildings.**
- **Night/daylight variations.** Very long polar nights and days. The light is continuous during the Antarctic summer, but darkness prevails during winter.
- **Limited resources.**
- **Consideration for the environment.**

Concordia at dusk. The outpost is one of the few permanent stations in Antarctica. (ESA)



→ MARS500

Getting ready for the red planet

(ESA/DLR/FU Berlin–G. Neukum)

More than 40 years after humans first landed on the Moon, a European has set foot on Mars. ESA's Italian crewmember Diego Urbina walked on the 'martian surface' for three hours and saluted the explorers of tomorrow.

Mars500 was a simulated mission to the Red Planet with six international crewmembers sealed in an isolation chamber for 520 days. It is the forerunner for a real human mission to Mars and back.

ESA is cooperating with the Russian Institute for Biomedical Problems (IBMP) to make sure that our astronauts are mentally and physically prepared for the demands of long exploration missions.

Being a 'marsonaut'

- The crew was hermetically isolated.
- The crew temporarily divided after 250 days: three moved to the martian surface simulator and three remained in the orbiting 'spacecraft'.
- Crew lived and worked like astronauts on the International Space Station.
- Maintenance, scientific experiments and daily exercise.
- A seven-day week, with two days off, except when special and emergency situations were simulated.
- Crew monitored and their psychological, medical and physical behaviour recorded.
- Limited consumables.
- Connection disrupted and with realistic delays: communication delay varied from 8 seconds to 12 minutes, with maximum delay on flight day 351.

Three Russians, two Europeans and one Chinese remained on Earth, in a purpose-built isolation facility at IBMP in Moscow. The volunteers virtually travelled to Mars, orbited the planet, landed and returned to Earth.

Psychology and operations are important on long missions. With Mars as far away as 380 million kilometres, real-time communication with Earth gradually becomes impossible because of the travel time for radio waves – up to 20 minutes.

In addition, the living space was cramped, food was packaged and stored, and the daily routine was unavoidably monotonous. There is no experience yet of the apprehension in facing a dangerous interplanetary journey, not to mention the long trip back.

Obviously, the weightlessness and radiation cannot be reproduced, but the Mars500 study provided useful insights into how a crew reacts to the stresses of a long flight, especially the isolation and confinement. The crew was under constant observation – more than 40 cameras monitored their lives in the spaceship and a team of psychologists was available around the clock.

Mars500 also provided lots of other results, particularly medical, all with benefits for Earth. Researchers can study how isolation affects the immune system. There are already indications that point towards a modulation and inhibition of some cellular responses that are important in the immune system.

Changes in biological rhythms have been found. Scientists confirmed that the circadian rhythm remains but the range of fluctuations in body temperature is substantially reduced.

The study is providing invaluable knowledge for developing countermeasures against unwanted side effects of such missions. It will also help in selecting future astronauts.

On the European side, Mars500 was financed by ELIPS and involved scientists from across Europe.

The isolation facility

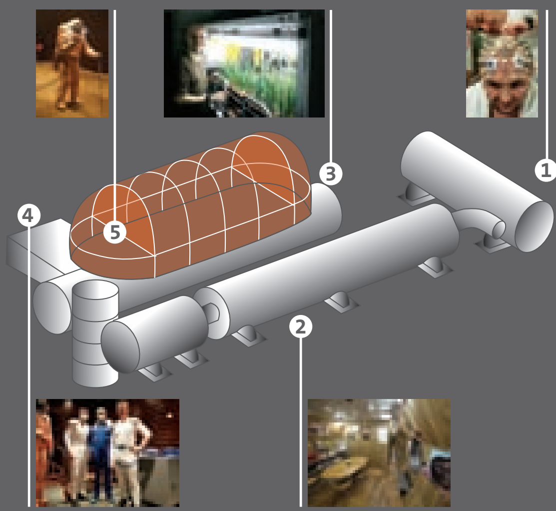
❶ Medical module
Two medical berths, a toilet and equipment for routine medical examinations and telemedical, laboratory and diagnostic investigations. Should a crewmember become ill, he could be isolated and treated here.

❷ Habitation module
Six individual compartments, kitchen/dining room, living room, main control room and toilet.

❸ Storage module
Four compartments: fridge, storage for non-perishable food, greenhouse, toilet, shower and gym.

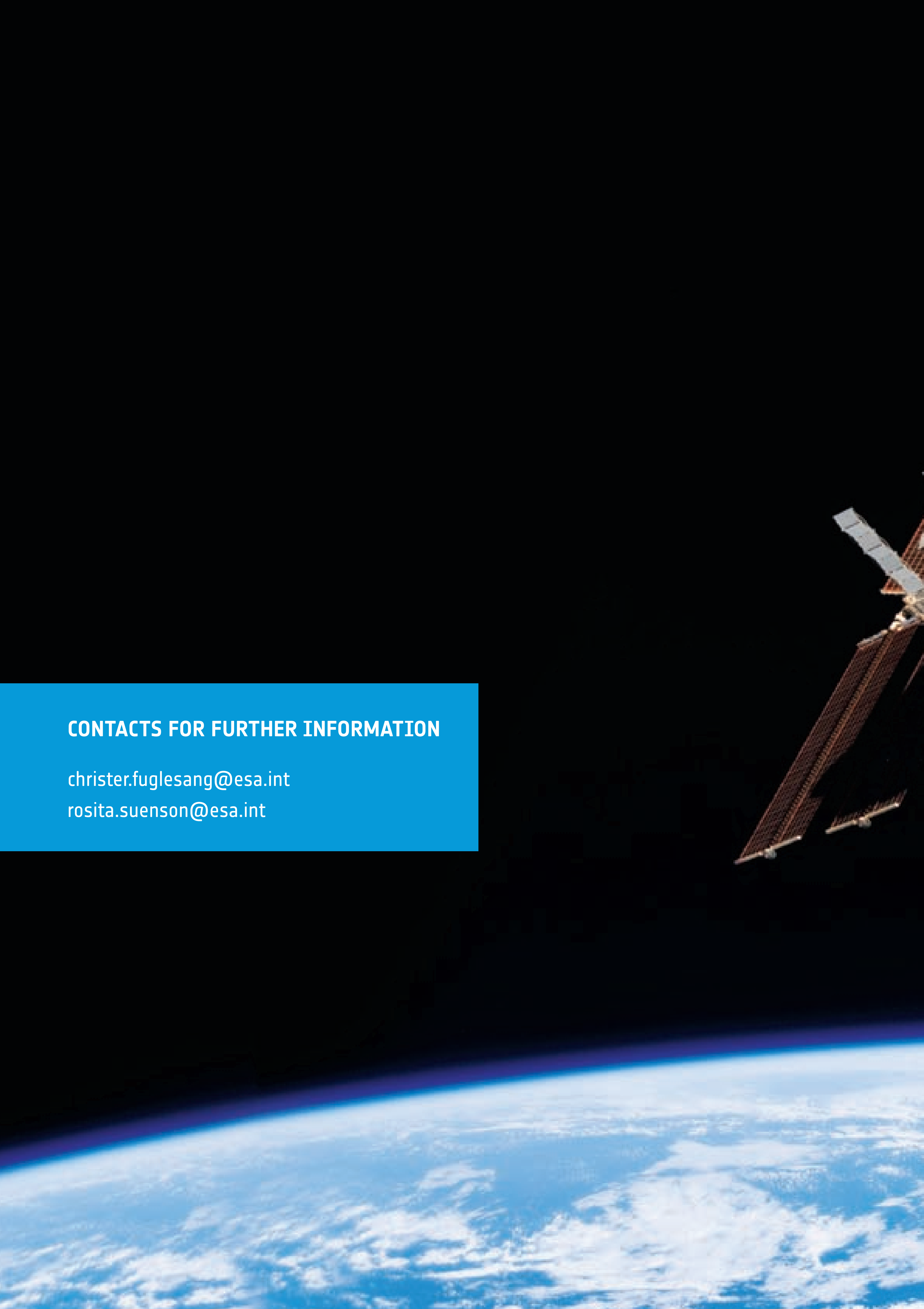
❹ Landing module
The Mars lander simulator was used only during the 30-day surface phase.

❺ Surface module
To walk across the soil and rocks of Mars, crewmembers wore Russian Orlan spacesuits.



Layout of the Mars500 'spaceship' at the Institute for Biomedical Problems, Moscow. Total habitable volume is 550 cubic metres. (ESA)

Mars500 crew. In clockwise order: Wang Yue, China; Alexandr Smoleevskiy, Russia; Diego Urbina, Italy; Romain Charles, France; Alexey Sitev, Russia; Sukhrob Kamolov, Russia. (ESA)



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