esa

→ SPACE FOR LIFE

human spaceflight science newsletter

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NASA–Bill Ingalls

↑ ISS Expedition 42/43 crewmembers Terry Virts (NASA) left, Anton Shkaplerov (Roscosmos) middle, and Samantha Cristoforetti (ESA) right post-landing on June 11, 2015

In this issue:

→ A GLIMPSE INTO THE 'FUTURA':

ESA astronaut completes successful mission on the ISS

ESA astronaut Samantha Cristoforetti completed the European Futura mission to the ISS after landing in Kazakhstan on 11 June 2015. The Italian becomes the third of ESA's 'Astronaut Class of 2009' to complete a mission, spending 199 days in orbit. In this time she completed numerous experiments in the life and physical sciences and technology including being the subject of numerous human research experiments for ESA and the ISS International Partners. Cristoforetti additionally performed a host of education activities on top of her duties as an ISS Expedition 42/43 Flight Engineer. Her return marks the conclusion of the first half of a busy year for ESA with two additional ESA astronauts set to fly to the ISS in 2015.

Cristoforetti's mission was as a flight opportunity from the Italian Space Agency (ASI) as part of a barter agreement with NASA. She launched to the ISS in the early morning of 24 November from the Baikonur Cosmodrome in Kazakhstan, docking just under six hours later together with fellow Expedition 42/43 crew members Terry Virts (NASA) and Anton Shkaplerov (Roscosmos). The biggest focus of her time in orbit was an extensive programme of research activities.

↑ ESA astronaut Samantha Cristoforetti with a thermal sensor on her head as part of the Circadian Rhythms experiment

Human Research

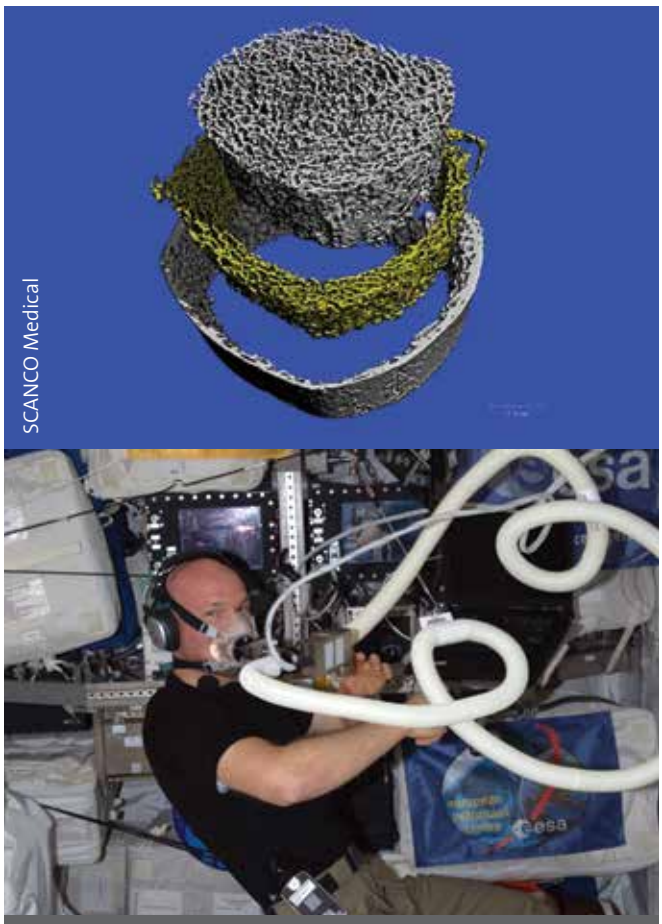
Cristoforetti successfully completed a number of ESA human research experiments on the ISS. She followed in the footsteps of her 'Class of 2009' astronaut colleagues Luca Parmitano and Alexander Gerst as a test subject of the Circadian Rhythms and Skin-B experiments. This included approximately monthly sessions of both experiments.

The first is studying alterations in circadian rhythms in humans during long-duration spaceflight to provide insights into the adaptation of the human autonomic nervous system in space over time. The second is helping to develop a mathematical model of aging skin (and other tissues in the body) to improve our understanding of skin-aging mechanisms, which are accelerated in weightlessness.

With Cristoforetti now back on Earth she will participate in post-flight data collection for the on-orbit experiments for which she was a test subject. This will include sessions for ESA's Cartilage experiment for which Cristoforetti is a test subject and only involves pre- and post-flight measurements to determine occurrence of cartilage degeneration in weightlessness and any biological markers thereof.

Outside of Samantha's activities, two Russian cosmonauts (Gennady Padalka and Mikhail Kornienko), who arrived at the ISS in March started as test subjects of the new joint ESA/Russian experiments Immuno-2 and EDOS-2. However some measurements could not be taken due to lost consumables on the Progress 59P mishap. These experiments follow up previous ISS experiments. Immuno-2 aims to improve our understanding of the interactions of cognition, stress and immunity to help develop suitable countermeasures to impaired immune response in space as well as on earth. EDOS-2 (Early Detection of Osteoporosis in Space 2) aims to describe the existence, extent and mechanisms of post re-entry bone losses and long-term failure to recover space-flight induced bone losses. Kornienko is a significant test subject for human research experiments as he will be on the ISS for a whole year meaning data provided will provide more of a link to future human exploration mission astronauts.

↑ ESA astronaut Samantha Cristoforetti performing a session of the Skin-B experiment on the ISS



↑ Top: Xtreme CT scan of the distal radius. Participants of the EDOS-2 experiment have scans pre- and post-flight
Bottom: ESA astronaut and Expedition 40/41 Flight Engineer Alexander Gerst performing measurements during the Energy experiment in September 2014

Finally in human research samples for ESA's Energy experiment, from Expedition 40/41 crew members, were returned on SpaceX-5. This experiment will help in deriving an equation for energy requirements of astronauts in weightlessness. This will contribute to planning adequate, but not excessive crew supplies for food, which also has a strong link with future human exploration missions.

Biology

Four biology experiments were completed during the Futura mission. The Seedling Growth 2 experiment concluded its final (of four) experiment run in December 2014, each experiment run undertaken with different light/gravity parameters. The processed samples were returned on SpaceX-5 in February 2015. Seedling Growth is a joint ESA/NASA series of experiments using the European Modular Cultivation System (EMCS) in Columbus and is set to conclude with Seedling Growth 3 in 2016. The experiments build on previous space experiments with *Arabidopsis thaliana* seeds studying the effects of various gravity levels on the growth responses of plant seedlings, in combination with light stimuli. The research will provide insight into the cultivation of plants during space flight on long-term missions.

↑ NASA astronaut Tom Marshburn relocating experiment containers for the first Seedling Growth experiment in the European Modular Cultivation System in May 2013

The weightless and 1g runs of ESA's TripleLux-B experiment took place in the Biolab facility in Columbus in the second half of March followed at the end of April/beginning of May by similar runs of the TripleLux-A experiment. These two experiments are comparing mechanisms which cause impairment in vertebrate and invertebrate immune cells in weightlessness.

Between the two TripleLux experiments the Stem Cell Differentiation experiment was performed in one of ESA's Kubik incubators. The samples for the two-week experiment were returned on Soyuz 41S. This experiment is examining the effect of weightlessness and spaceflight on the proliferation and differentiation of stem cells, which play an important role in maintenance of bone.

The latter three biology experiments are discussed in detail in separate articles in this newsletter.

↑ The new Kubik-5 Incubator on the ISS following installation in April 2015 with two ASI experiments ('Nanoparticles' and 'Cell Shape and Expression')

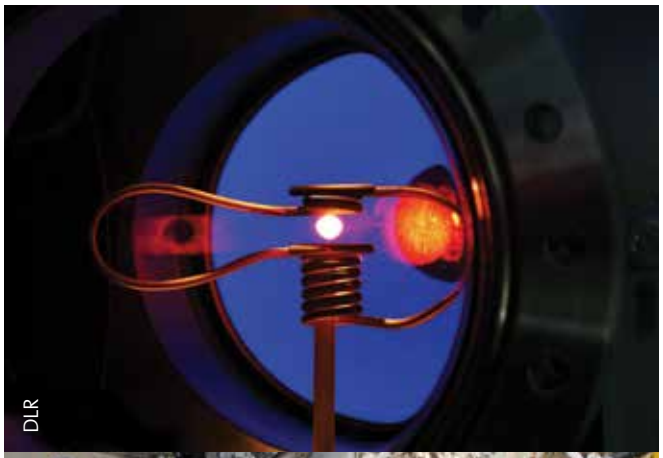
In support of future biology experiments a new Kubik incubator was also delivered to the ISS on SpaceX-6 in April and used immediately for performing two ASI experiments.

Turning outside the ISS ESA's astrobiology research continued during the Futura mission with the Expose-R2 astrobiology payload collecting data since October 2014 on the external surface of the Russian Service Module. Expose-R2 is carrying three ESA and one IBMP experiments, which could help understand how life originated on Earth and survivability of samples to conditions on for example Mars, the Moon and in other astrophysical environments. Detailed articles on Expose-R research and results appear in the two previous newsletters.

Material Science

A set of samples for the CETSOL/MICAST/SETA alloy solidification experiments completed processing on orbit. Samantha Cristoforetti removed the final sample from the Materials Science Laboratory (MSL) in December before it was returned to Earth on SpaceX-5 in February 2015. CETSOL, MICAST and SETA are all studying different aspects of the solidification process in metal alloys which will help to optimise industrial casting processes.

↑ ESA astronaut Samantha Cristoforetti during procedures for removal of a CETSOL experiment sample from the Materials Science Laboratory on the ISS in December 2014



↑ Top: Core element of the Electromagnetic Levitator
Bottom: ESA astronaut Alexander Gerst during final commissioning activities for the Electromagnetic Levitator (EML) seen protruding from the European Drawer Rack (by Gerst's right hand) in Europe's ISS Columbus laboratory

Following a successful checkout in February, research activities started in the Electromagnetic Levitator (EML) which has also become a key element of ESA's materials research on the ISS. The Electromagnetic Levitator is performing container-less materials processing involving melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and/or high gas purity conditions. Located in the European Drawer Rack in Columbus, samples were processed for three of the five first batch experiments (THERMOLAB, METCOMP and COOLCOP) during the Futura mission. THERMOLAB investigates the temperature and physical properties of industrial alloys in weightlessness in their liquid state. METCOMP investigates how weightlessness affects the metallic structure of a nickel–titanium alloy. COOLCOP aims at determining the surface tension and interfacial tension properties of Cobalt-Copper based immiscible alloys.

Complex Plasma Physics

Plasma Kristall-4 (PK-4) experiment hardware was installed inside the European Physiology Modules rack in Columbus on 27/28 November 2014 by ISS Flight Engineers Alexander Samokutyaev and Elena Serova under a cooperation agreement between ESA and Roscosmos, with successful checkout activities early in December, and a subsequent commissioning experiment successfully concluded in early June. PK-4 is investigating complex or dusty plasmas, which are plasmas (ionized gases produced by high temperatures) which contain micro-particles, e.g., dust grains, besides electrons, ions, and neutral gas. A detailed article on PK-4 appears in this newsletter.

Astrophysics Research

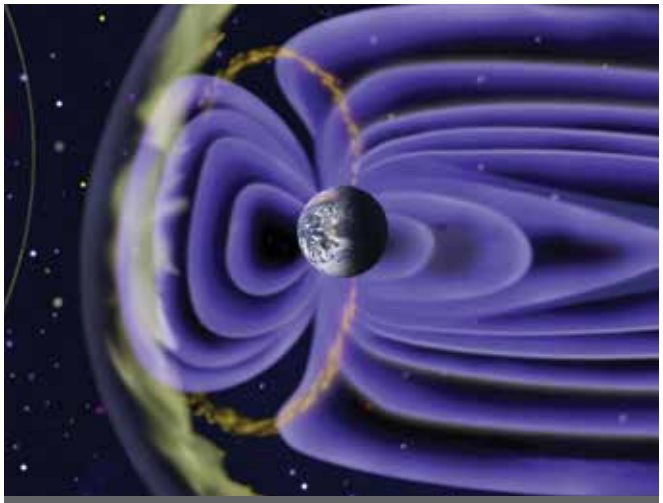
Radiation research continued during the Futura mission with the DOSIS-3D experiment monitoring the radiation environment inside Columbus with active and passive radiation sensors. The set of passive sensors (situated in numerous locations around Columbus in order to measure the spatial radiation gradients) were swapped out in March 2015. The set returned on Soyuz 40S are currently undergoing analysis. An extension to the experiment will see data acquisition continue for a few more years. A detailed article on DOSIS 3D also appears in this newsletter.

The Solar platform with its two SOLSPEC and SOLACES instruments took measurements of the Sun's irradiation during seven different Sun Visibility Windows of 11-14 days during the Futura mission. This included extra measurements in connection with the solar eclipse in March 2015.

↑ Solar eclipse photographed from the ISS by Expedition 43 crew member Samantha Cristoforetti on 20 March 2015

Technology

The first four science runs for ESA's Magvector experiment were completed inside the European Drawer Rack in Columbus by 17 December 2014 following the first successful science run in October. The MagVector experiment from DLR qualitatively investigates the interaction between a moving magnetic field (of Earth origin) and an electrical conductor. Using extremely sensitive magnetic sensors placed around and above the conductor, researchers will gain insight into how the magnetic field influences how conductors work. The expected changes in the magnetic field structure on different sides of the electrical conductor are of interest for technical applications as well as for astrophysical research.



↑ Artist's impression of Earth's magnetic field, compressed on the Sun-facing side and extended on Earth's dark side

The MagVector instrument is also acting as a dedicated wireless hub to receive signals from the Wireless-Sensor NETwork (WiSe-NET) sensors which were deployed in the Columbus laboratory by Samantha Cristoforetti on 31 December. WiseNET continued running for a few weeks and was deactivated on 13 March following battery depletion. WiSe-NET is a wireless mesh networking system consisting of easy-to-use and low power consumption sensors enabling monitoring of physical or environmental conditions like temperature, pressure, humidity, accelerations etc. and micro-controllers. With the WiSe-Net technology demonstrator it is intended to use this technology on the ISS in a space environment. The aim is to measure e.g. temperature gradients and light sources, with the objective to evaluate the possibility of "energy harvesting"

In February Cristoforetti swapped the receiver of the Vessel ID System for an upgraded version. This had been transported to the ISS on SpaceX-5 the previous month. This was followed by a successful commissioning phase. The science programme of VESSEL ID is continuing as planned, monitoring global maritime traffic from space by picking up signals from standard AIS transponders carried by all international ships over 300 tonnes, cargo vessels over 500 tonnes and all types of passenger carriers.

ESA's Multi-Purpose End-To-End Robotic Operations Network (METERON) project also took a step forward with the HAPTICS-1 investigation at the end of December and beginning of January, performed on orbit by NASA astronaut Barry Wilmore. HAPTICS-1 is the first part of a suite of Exoskeleton experiments

↑ View of WISENET wireless sensor (bottom) located by a DC to AC power inverter in the Columbus laboratory

to demonstrate a full bilateral control interaction between ground and space. The objective is to optimize the design for the mechatronic drive systems of the later Exoskeleton as well as identifying changes in human perception/performance in such tasks when exposed for long duration to weightlessness. ESA's METERON project is aiming to demonstrate communications and operations concepts and technologies for future human exploration missions with human robotic elements. At the start of June, the project also successfully demonstrated the full bi-directional hand-shake between ISS and ground, paving the way for more complex ISS crew and ground robotic interaction in the upcoming months.

↑ NASA astronaut Barry Wilmore performing the Haptics-1 protocol in Columbus in January 2015

↑ In-flight call with ESA astronaut Samantha Cristoforetti in March 2015 as part of the 'Mission X: Train Like An Astronaut' project

Education

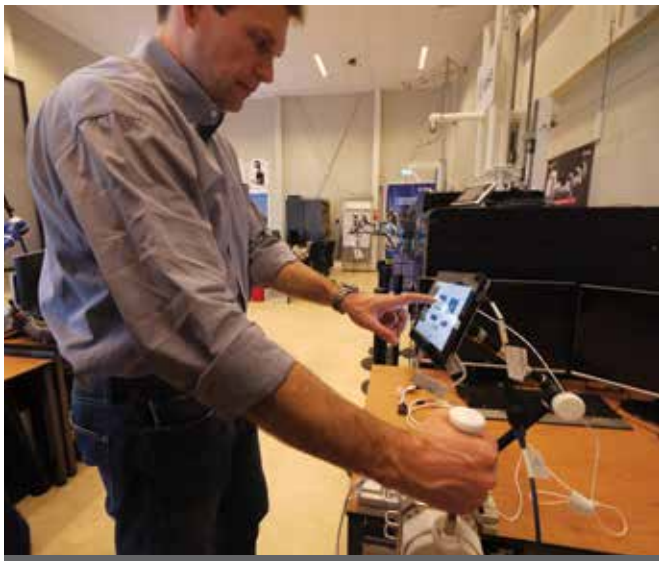
Education is another important area for ESA. Cristoforetti undertook numerous education activities on the ISS to inspire the scientists and engineers of tomorrow and promote a healthy lifestyle. This included recording numerous scripts on the ISS related to such topics as Food and Recycling, Gravity, and Biological Life Support Systems. Cristoforetti also had an in-flight call and recorded messages as part of the 'Mission X: Train Like An Astronaut' project. Mission X is a worldwide educational initiative supported by ESA and national space agencies to encourage healthy and active lifestyles among children aged 8-12 years. As a focus of the programme, astronauts inspire children to eat healthily and exercise regularly.

Future

With the Futura mission coming to conclusion in June we can look forward to two more ESA astronauts being launched to the ISS in 2015.

The first of these is astronaut Andreas Mogensen who will undertake a short-duration (just under two weeks) mission that will include numerous experiments. By far most of these are in the area of technology/biotechnology including tests on hardware/operations related to human robotic interaction on future exploration missions, biological life support systems, crew efficiency and on-board training technologies. There are further experiments and activities in human research biology and education.

Mogensen will be followed by Tim Peake in November who will serve as a Flight Engineer for Expeditions 46/47. Peake's mission will also include an extensive programme of activities in human research, materials science, radiation research, and technology as well as programme of education activities.



↑ ESA astronaut Andreas Mogensen training with a force feedback joystick related to a human/robotic experiment as part of his mission

↑ ESA astronaut Tim Peake during robotics training in 2014

→ IMMUNE SYSTEM RESPONSE IN THE BIOLAB FACILITY:

TripleLux experiments completed

The two TripleLux experiments were launched to the ISS and successfully performed in ESA's Biolab facility in the first half of 2015. These biology experiments are studying different aspects of immune system function in space focussing on specific cells which function by engulfing and digesting immune system 'intruders', a process known as phagocytosis. The TripleLux experiments will compare this type of immune response in vertebrate and invertebrate organisms and determine if any immune response impairment is due to weightlessness, radiation, or a combination of both. Increasing our understanding in this area is not only key for maintaining and improving the health of astronauts in orbit but could also lead to new treatments on Earth for those with impaired immune systems.

↑ ESA astronaut Samantha Cristoforetti preparing the Biolab facility for the start of the TripleLux-B experiment in March 2015

The immune systems of astronauts are impaired in space. Understanding which environmental conditions, or combination of conditions, are responsible for this impairment is one part of the problem. We also need to determine where in the complex chain of immune response this impairment occurs.

After physical barriers like the skin, the next line of defence in the human immune system against infection is the assortment of white blood cells. These have different functions in order to deal with incoming 'intruders' in different ways in different parts of the body. A selection of these white blood cells (neutrophils, monocytes and macrophages) perform an immune system response called phagocytosis whereby they engulf foreign bodies and produce a burst of reactive oxygen that helps destroy these 'invaders'. Though highly developed, this mechanism is not isolated to humans or even vertebrates.

↑ Blue mussel (*Mytilus edulis*) hemocytes: Left – Immune response not active. Right – Immune response active. Pseudopodia extended to engulf/destroy invading microbes (phagocytosis)

It is important throughout the animal kingdom and may have needed the presence of gravity to evolve and its continued presence to function. Conducting experiments on the space station provides the prolonged exposure to weightlessness, and opportunity necessary, to observe the oxygen-burst reactions in different immune cells.

Triplelux–B* is investigating immune system response in the hemocytes of blue mussels (*Mytilus edulis*). Hemocytes are the equivalent phagocytic immune response cells in invertebrates. The subsequent experiment, TripleLux-A**, is studying macrophages from mammalian cell cultures, which are more highly evolved and have more of a direct link with human immune response. The two experiments are investigating changes at a cellular level including genetic mechanisms such as DNA repair and separating out the specific effects of weightlessness from other spaceflight factors like radiation. Each experiment will provide valuable independent data on immune function in both vertebrates and invertebrates and also provide valuable data for cross-comparison purposes.

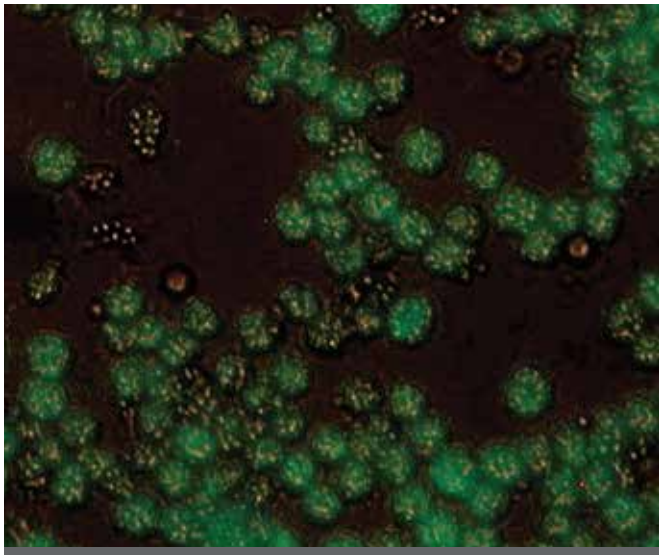
The goal is to find out whether the cells of the immune system of the mussel, which is older in an evolutionary sense, are affected in the same way as those in the immune system of an astronaut, or in this case simulated by using mammalian cell cultures. If there are differences, these experiments are aiming on determining what they are.

With respect to cell choice, cells from blue mussels were chosen as they are considered model organisms. They have characteristics making them easy to maintain, reproduce and study in a laboratory. Mussels can generate large numbers of immune system cells that are easy to collect without harming the animal. The mammalian cells were grown in cell cultures.

The TripleLux-B experiment was launched to the ISS on SpaceX-5 mission in January 2015 and successfully performed in the second half of March. This was followed shortly after by the launch of TripleLux-A on SpaceX-6 in April, being performed from the end of April until the middle of May. On-orbit activities were undertaken by ESA astronaut Samantha Cristoforetti with the principal measurements undertaken in the Biolab facility in ESA's Columbus laboratory on the ISS.

↑ Video still of ESA astronaut Samantha Cristoforetti undertaking procedures for the TripleLux-B experiment in March 2015

For both TripleLux experiments dormant cells were transferred to one of the Biolab facility centrifuges from where the experiment could be monitored and controlled from the Microgravity User Support Center (MUSC) in Cologne, Germany. Environmental conditions were kept stable during the experiment runs with the mussel cells processed at a temperature of 20 deg C and the cultured mammalian cells at 37 deg C. To clarify whether weightlessness, radiation or a combination is responsible for immune system changes during spaceflight, the mussel and mammalian immune cells were first exposed to weightlessness (centrifuge off) during the first run of each experiment then to simulated Earth gravity on the ISS (centrifuge on) during the second with accumulated radiation dose recorded. Equivalent ground reference experiments were also undertaken.



↑ Hemocytes after phagocytosis of yeast cells stained with a fluorescence dye (200 x).

To stimulate the immune response the mussel and cultured mammalian cells were mixed with a safe substitute for bacteria called zymosan, which is produced from yeast cells. In order to make the reactive oxygen production (phagocytosis) process 'visible' and hence quantify the immune response the immune cells were mixed with a chemical which emits a luminescent glow when mixed with an oxidizing agent. A highly sensitive

photomultiplier/photon counter was used to measure the associated light flashes. The strength of the light flashes is a direct indicator of the amount of formed reactive oxygen which gives an insight into the degree of phagocytosis and hence the degree to which the immune system is compromised.

Finally determination of how many living cells produced the luminescence was undertaken (i.e. how many cells in each sample remained viable). All this data generated is now being processed to determine the results which will be published in the future.

Previous and Expected Results

Previous studies have shown that gravity changes affect immune system cells. Preliminary clinostat studies have shown that active phagocytes can react within seconds to changes in gravity levels. In addition during parabolic flight campaigns, which were also testing the TripleLux hardware prior to flight, the fluorescence data could easily be correlated with gravity levels for the mammalian cell culture macrophages.

It is expected that the space experiments will allow a clear discrimination between the effects of weightlessness and radiation on phagocytosis by vertebrate and invertebrate immune cells by comparing the weightless samples against the 1g on-orbit and ground control experiments plus factoring in the accumulated radiation dose. Furthermore it will be possible to assess whether the effects of weightlessness and radiation are synergistic (i.e. does weightlessness enhance the damaging effects of radiation by negatively influencing cellular repair mechanisms). This study will provide useful information on how the spaceflight environment affects cellular processes which are of importance for long-term human space missions.

Future

This important research could help scientists develop ways to manage or prevent changes in immune system function both in space and on Earth, through for example pharmaceutical intervention, especially in light of future long-duration human exploration missions outside of Low-Earth orbit.

The photomultiplier measurement device developed by Airbus Defence and Space could potentially be adapted into a tool for monitoring astronauts' immune systems during long-duration spaceflights. The investigations also act as an opportunity to test this device.

*The TripleLux-B experiment is under the scientific lead of Prof. Dr. Peter-Diedrich Hansen from the Berlin Institute for Technology in Germany.
**The TripleLux-A experiment is under the scientific lead of Prof. Dr. Oliver Ullrich, from the Universities of Zurich in Switzerland and Magdeburg in Germany.

→ STEM CELL RESEARCH INTO BONE MASS REDUCTION:

Successful conclusion of the Stem Cell Differentiation experiment on the ISS

↑ ESA astronaut Samantha Cristoforetti preparing for the Stem Cell Differentiation experiment in the Kubik-6 Incubator (bottom/centre)

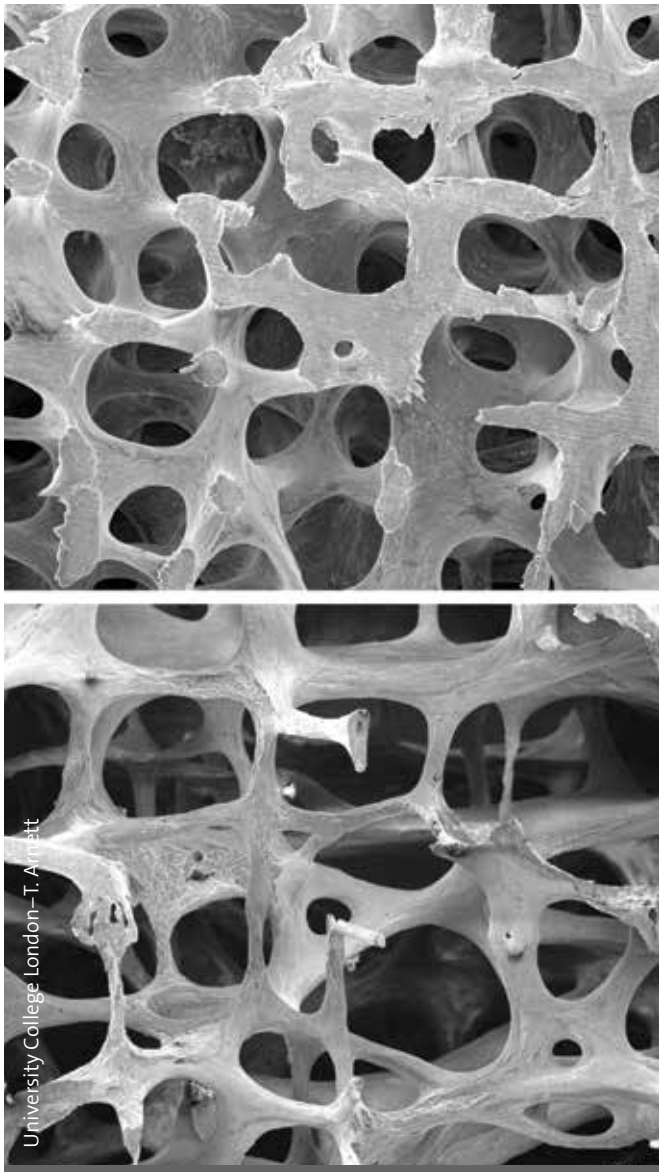
There is increasing evidence that most of the diseases related to aging are associated with a progressive decline in the number and/or function of stem cells: the precursor cells which develop into the variety of different cells around the body. With astronauts experiencing temporary bone mass loss similar to osteoporosis, this area of research is very important for the development of, for example, pharmaceutical countermeasures within human spaceflight as well the further implications this could have for improvements in terrestrial medicine. This is especially significant considering the vast cost that diseases such as osteoporosis have on society. ESA's Stem Cell Differentiation experiment aims to provide increased knowledge into the mechanisms of bone mass reduction in space related to stem cell activity, and was recently concluded on the ISS.

The yearly cost of osteoporosis is staggering. In the EU in 2010 alone the treatment cost, including pharmacological intervention, was estimated at €37 billion with additional costs to society estimated to bring this total up to €98 billion. This is set to rise to an estimated €120 billion in 2025 with an associated increase in the number of men and women with osteoporosis rising from 27.5 million to 33.9 million based on World Health Organisation criteria.

↑ Following physical deconditioning, including bone mass reduction, and return to gravity after a long-duration mission, ESA astronaut Luca Parmitano is carried to a medical tent minutes after landing

Understanding the mechanisms of bone mass reduction is fundamental to developing necessary countermeasures and treatments in order to reduce the financial and social burden. Long-term exposure to weightlessness induces what might be termed as typical age-related conditions in astronauts of which loss of bone mass is one of the most critical. In astronauts the bone density decrease is about 1 – 2% per month in weight bearing bones, compared to the 2 – 3% decrease per year in postmenopausal females (one of the highest risk groups with ~80% of osteoporosis sufferers over 50 being female). With the symptoms developing much more rapidly in space than on Earth, the ISS is a perfect test bed for observing/determining bone loss mechanisms and testing different countermeasures which could develop into preventative treatments on Earth.

During the past decade researchers considered whether loss of bone mass was related to under-activity in bone-forming cells (osteoblasts) or over-activity in bone-resorption cells (osteoclasts). The focus has now switched to stem cells which develop (differentiate) into osteoblasts.

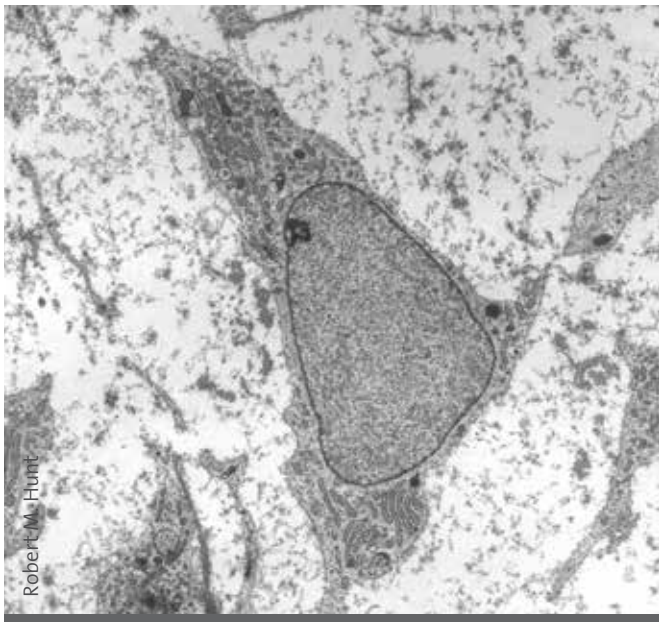


↑ Comparison of normal (top) and osteoporotic (bottom) bone architecture

Previous Research and Results

Bone loss in astronauts was first documented in the early 1960s spaceflight missions and research has been refining investigations in this area ever since. Research undertaken first on Mir and thereafter on the ISS also provided the possibility for undertaking research for long-duration missions of six months or longer.

It has been observed in astronauts that space conditions induces an increase in urinary calcium (due to reduced intestinal absorption of calcium and increased calcium excretion) up to twice the normal levels along with increases in other markers of bone degradation together with a decrease in bone mineral density. In ESA's Sodium Loading in Microgravity (SOLO) experiment it was found that higher salt intake additionally increases calcium excretion and acidity in the body, which can accelerate bone loss. This suggests that negative effects could be avoided by reducing sodium intake or by using a simple alkalizing agent like bicarbonate to counter the acid imbalance.



↑ Mesenchymal stem cell

With a more direct link to the Stem Cell Differentiation experiment recent papers investigated the behaviour of stem cells in simulated weightlessness using a Rotating Wall Vessel and a Random Positioning Machine. This showed that simulated weightlessness profoundly affects stem cell behaviour in terms of proliferation, differentiation, and senescence (i.e. the process by which cells cease to divide). The availability of adequate numbers stem cells (human Mesenchymal Stem Cells) and their proper growth, differentiation, and response to chemical signalling is a pre-requisite for producing an adequate number of osteoblasts and hence maintain bone mass.

The Stem Cell Differentiation experiment will help confirm these results and determine the molecular mechanisms for reversing bone loss that may be translated to treatment scenarios for human osteoporosis in the future.

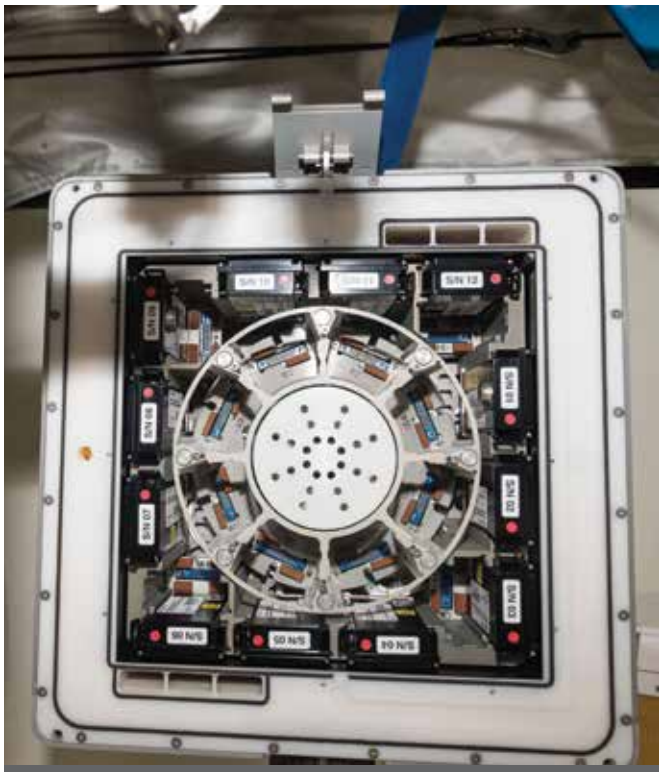
The experiment, arrived at the ISS on Soyuz 42S in March 2015 and was successfully undertaken in one of ESA's Kubik incubators for approximately two weeks. For comparison purposes a standard growth medium was used for one set of

↑ 3D Clinostat or Random Positioning Device

samples while a growth medium containing Vitamin D3 was used for the other set of samples. At the end of processing the samples were chemically fixed before being placed by ESA astronaut Samantha Cristoforetti in one of the ESA-developed MELFI freezers on the ISS. The samples are due for return on Soyuz 41S in June.

↑ Soyuz TMA-16M/42S approaching the ISS prior to docking, with the Stem Cell Differentiation experiment as part of its cargo

Vitamin D3 is the most biologically active form of Vitamin D and has been shown to directly promote osteoblast function to lay down new bone material so it will be intriguing to see the effect that the space environment has on this process. Vitamin D in general is of particular importance to bone health, increasing calcium uptake in the bowel, playing a critical role in bone development in children and recommended as a supplement in all adults age 60 years and older for its proven reduction in



↑ Stem Cell Differentiation Experiment in a KUBIK Incubator on the ISS

osteoporosis-related falls and fractures. In fact ground studies have shown that Vitamin D3 treatment prior to the onset of bone formation, rather than during bone formation leads to accelerated and enhanced bone formation.

Vitamin D is one of the major factors involved in calcium balance in the body through actions on the intestine, kidney, parathyroid gland, and bone. Most of its biological activities occur through binding to the vitamin D receptor which is also present in osteoblasts. In addition, Vitamin D3 can directly affect osteoblasts. This has been demonstrated by stimulating in vitro mineralization in osteoblast cultures.

Expected Results

If the experiment proceeds as expected the benefits of this experiment will range from a better understanding of the molecular mechanisms governing growth and differentiation of stem cells into osteoblasts to the possibility of outlining new countermeasures against astronaut bone loss. This could feed into ground-based fields such as tissue engineering and age-related bone pathology.

This will not only help maintain the well-being of astronauts in space on longer-duration missions in the future, it will also help to alleviate the burden that conditions such as osteoporosis have to society. Even if the data deriving from ESA's research should help in the future in simply delaying the onset of such conditions as osteoporosis this should cause a significant saving to society.

→ A NEW HORIZON IN PARABOLIC FLIGHT RESEARCH:

First joint Parabolic Flight Campaign with the A310 aircraft

DLR/ESA/CNES/Novespace

↑ Participants of the first Parabolic Flight Campaign with the Airbus A310 Zero-G aircraft at the Bordeaux airport in France in May 2015

ESA's first Parabolic Flight Campaign in 2015 was a very significant milestone with the new Airbus A310 aircraft performing its first campaign since replacing the now retired A300. This first successful campaign was a joint ESA, CNES, DLR campaign which included 12 experiments in the life and physical sciences and technology. Some of these are related to current and future ISS experiments or have a link with future human exploration or satellite missions. We take a look at the campaign just finished and a successful 17 years of research undertaken on the A300. We also take a look ahead to the next A310 campaign which is due to take place in June.

Parabolic Flights: Their Purpose

Aircraft parabolic flights repetitively provide approximately 23 - 30 seconds of weightlessness or partial gravity during ballistic flight manoeuvres. Parabolic flights are used to conduct investigations in science and technology, to test instrumentation prior to space flight and to train astronauts before a space mission. The use of parabolic flights is complementary to other weightless research platforms (drop towers, sounding rockets), and preparatory to human space missions on board the International Space Station and other human spacecraft. They provide a means to undertake research or test technologies and techniques for future human exploration missions beyond Earth orbit. They are also the only flight opportunity outside of orbital flight during which research with human test subjects can be performed in weightlessness or partial gravity.

A Change of Aircraft

ESA has been undertaking parabolic flight campaigns for more than 30 years. From 1984 -1996 utilising four different aircraft, NASA's KC-135, CNES' Caravelle, the Russian Ilyushin IL-76 MDK and the Dutch Cessna Citation II and from 1997 – 2014 using the Airbus A300 aircraft. However after all these successful campaigns, and after 17 years of service, in October 2014 it was time for the A300 to be retired.

The aircraft that has now taken over from the A300 is an Airbus A310 which is 16 years younger than the A300 zero-g aircraft. The A310 is a former German government aircraft that was used for journeys and state visits by German Federal Chancellors and government ministers between 1993 and 2011.

↑ Tim Peake, ESA's next astronaut scheduled to fly to the International Space Station (ISS), and EAC Instructor Gail Iles during parabolic flight training in May 2010

↑ Former ESA astronauts Wubbo Okkels (left) and Dirk Frimout (middle) together with ESA'S current parabolic flight campaign manager Vladimir Pletser during a parabolic flight on a NASA KC-135 aircraft in 1987

↑ Airbus A300 during descent phase as part of a parabolic flight campaign

In 2014 the aircraft was purchased by Novespace (a subsidiary of CNES who organise the Parabolic Flight Campaigns) and converted to a research aircraft by Lufthansa Technik AG in Hamburg. This included an approximately 100 square metre, windowless experiment zone fully clad with white synthetic leather padding equipped with handles, special lighting and flooring. An accelerometer was also added to the cockpit along with a system that enables the parabolic trajectories to be flown precisely.

The A310 is a perfect choice for such a research aircraft having performed limited flight cycles (take-off/landing) compared to a commercial aircraft and keeping costs down with Novespace acquiring the plane for approximately 2.5 million euros.

Following an initial set of test flights the first joint campaign with the A310 was undertaken in April/May and included 12 experiments. In the first week of the campaign the science teams set up their experiments inside the aircraft cabin. The flights themselves took place over three days (5-7 May) with 31 parabolas during each flight. As usual the campaign flew out from the Mérignac-Bordeaux airport in France.

↑ A310 cockpit

↑ The A310 experiment zone

The flights provide gravity levels which change repetitively, giving successive periods of approximately 20 s of weightlessness in between periods of about 20 s of 1.8 g's during each parabola cycle.

Each day's flight is helpful, not only in gathering important data, but also in highlighting where tweaks in instrumentation need to take place and possible issues that could occur to avoid an occurrence of such an issue during a human spaceflight mission where reconfiguration or replacement of hardware might be difficult or impossible.

Research on the first A310 campaign

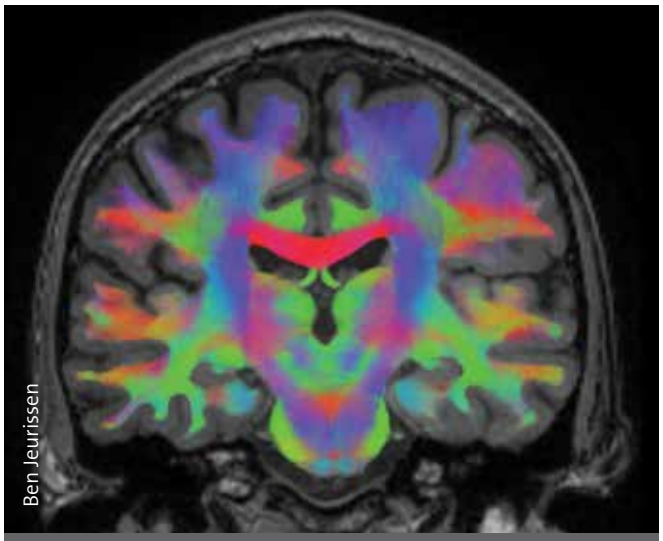
In total 12 experiments were undertaken during the first cooperative parabolic flight campaign with the A310, six from ESA, four from DLR and two from CNES.

Human Research: Neuroscience

With the nature of human spaceflight, human research was the predominant area in which experiments were undertaken covering five of the 12 experiments. Three of the experiments were in neuroscience, one from each participating agency.

The ESA-funded experiment is under the scientific lead of Floris Wuyts of the University of Antwerp in Belgium. The experiment is studying if transition into and out of short-duration weightlessness induces adaptation (neuroplasticity) in different areas of the human central nervous system involved in the integration of neuro-sensory information, provided by the vestibular organs in the inner ear, vision and a network of receptors (proprioceptors) located in muscles, tendons and joints. Using advanced MRI techniques, this data will be compared against similar (pre-/post-flight) data coming from an equivalent study of ISS astronauts (Brain-DTI experiment). This will determine any difference between the groups and determine biomarkers of this adaptation, which will help identify specific neural processes related to balance and orientation. This could in turn feed into research into certain neurological conditions on earth.

↑ Experiment setup inside the aircraft



↑ Whole brain tractography

The DLR-sponsored experiment is validating a neurocognitive test battery using a Soyuz docking training system coupled to an EEG to test mental load and cognitive performance. This is due to the fact that factors such as confinement, weightlessness, and lack of sunlight can have a negative effect on mental performance and, as such, could impair the chance of mission success and safety.

The CNES-sponsored experiment aims to determine if distortions in visual perception of 3D objects observed in weightlessness also extends to perception of 3D objects through haptic (tactile) feedback systems.

↑ Setup of the DLR-sponsored neuroscience experiment 'Microgravity effect on the haptic perception of geometric shapes'

Human Research: Musculoskeletal and Cardiovascular Research

The other two experiments in human research are in the areas of cardiovascular and musculoskeletal research. One ESA experiment is under the scientific lead of Dr. Daniel Belavy of the Charité University Hospital in Berlin, Germany, and Dr Kirsten Albracht of the German Sports University Cologne. The experiment is testing whether muscle force generation capacity is impeded in weightlessness with a focus on the muscles in the lower limbs which are most affected during long-duration spaceflight.

↑ Experiment procedures for the ESA-sponsored experiment 'Is muscle force generation capacity impeded in microgravity?'

If it is not possible to generate the necessary force in these muscles in weightlessness then it might not be possible to exercise at the necessary loads to maintain muscle mass, which has significant consequences especially for countermeasure development for future long-duration exploration missions.

↑ Experiment procedures for the DLR-sponsored experiment 'Interactions of the human heart and the aorta in parabolic flight'

The cardiovascular experiment from DLR is testing a modified upper arm device for determining the central aortic pressure and a measure of aortic stiffness on the ISS (as part of the Cardiovector experiment). It will compare pressure measurements against similar measurements using a finger cuff device as well as measuring cardiac performance with different techniques. The hypothesis is that central aortic pressure is lower and cardiac output higher in weightlessness compared to normal gravity conditions. This could have implications for astronaut health monitoring during long-duration space missions.

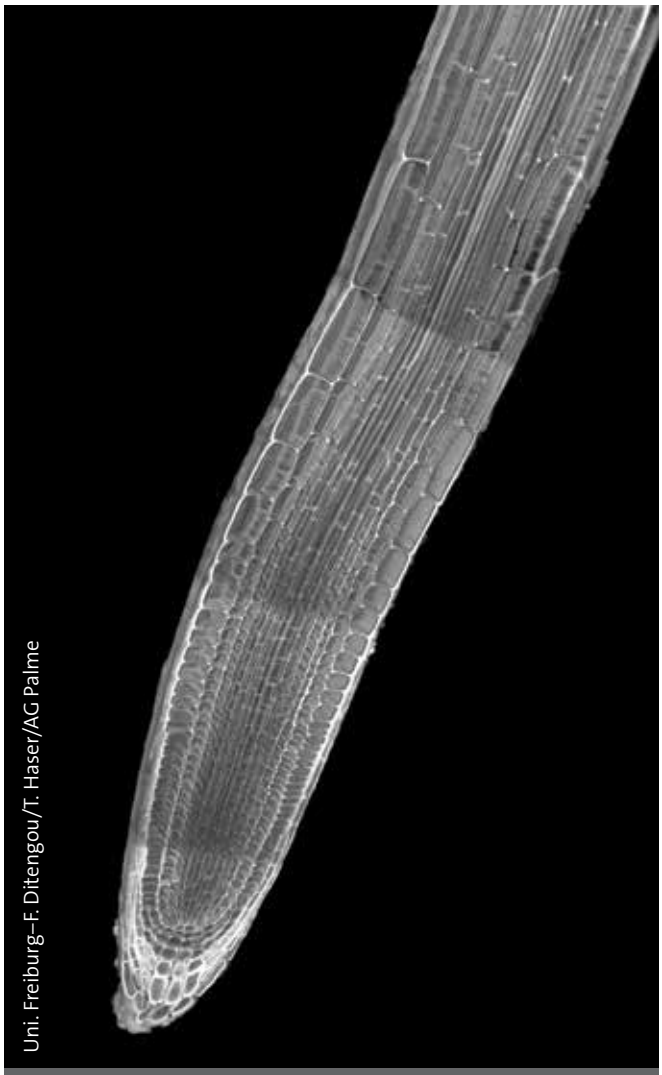
Biology

Two biology experiments were performed during the parabolic flight campaign one from ESA, one from DLR. The ESA-sponsored experiment from the University of Freiburg in the area of plant biology is studying a certain aspect of gravitational response in the roots of the model plant species *Arabidopsis thaliana*, focussing on auxin distribution and root growth at a tissue and cellular level. Auxin is a plant hormone, the distribution of which in plant roots causes curvature/growth in a specific direction. Advanced imaging techniques will be used to quantify changes in cell geometry and growth of *Arabidopsis* roots in 3D.

The DLR-sponsored experiment will aim at determining if pharmacologically relevant substances may need the presence of gravity to function properly. The experiment will study the interaction between ligands and specific biological receptors. Ligands are substances that form complexes with biomolecules to serve a biological purpose. One family of receptors studied are the G protein–coupled receptors which are involved in many diseases, and are also the target of approximately 40% of all modern medicinal drugs. Results will provide a better understanding of the modified action of a variety of pharmacologically relevant drugs under weightlessness as well as holding importance for the pharmacological welfare of astronauts on long-duration space missions.

Physical Sciences

In the Physical Sciences four experiments were performed, three from ESA and one from CNES.



Uni. Freiburg–F. Ditengou/T. Haser/AG Palme

↑ Microscope image of *Arabidopsis thaliana* root showing individual cells

↑ Dusty disk around a young star: Left: from the Hubble Space Telescope. Right: artist's impression

One of the ESA experiments is testing the Weak Equivalence Principle, which states that two different masses in a gravitational field fall with the same acceleration. To clarify this statement at a microscopic and quantum level, an atom interferometer was successfully used to measure differential acceleration between two atoms of different mass and structure (rubidium and potassium). This experiment is an important step in the frame of the Space-Time Explorer and QUantum Equivalence Principle Space Test (STE-QUEST) which is a candidate ESA mission aiming at putting an atomic clock and a double species interferometer on a satellite to test the weak equivalence principle and gravitational redshifts, and could be used for measurement of on-board gravity gradients. This research also has application with respect to atomic gravimeters or gyroscopes which can be used for inertial navigation, geophysics or metrology.

The second ESA experiment (MEDEA 2) is studying the early stages of planetary formation from dust grains in circumstellar gas disks around young stars. While the formation of bodies up to a size of about one millimetre is well understood, the collision physics of millimeter-sized dust aggregates and their further growth is still an active field of research. This experiment studies collisions between cm-sized dust agglomerates and the gain in mass that occurs when one agglomerate stays intact and the other fragments. An ensemble of agglomerates will be used and tested in a quasi-two-dimensional high-vacuum experiment container. The experiment is also testing hardware for flight on a sounding rocket.

The third ESA experiment is studying aspects of the use of thermally driven pumps created from thermal gradients in

↑ DLR-sponsored technology test of satellite separation system

dust beds. Thermal gradients lead to gas flow within pores in dust beds from the colder to the warmer part. This is most efficient in the pressure range around 1 mbar, depending on the kind of gas and the pore sizes. The goal of this project is to investigate the gas flow and velocities. A potential application of this mechanism is a thermally driven pump, which could be used as a thrust module for airborne systems in the Martian atmosphere. Airborne instruments can cover more terrain than surface rovers and are ideal platforms for studying atmospheric processes. However, the Martian atmosphere is rather thin (few mbar), so classical aircraft do not work efficiently. Thermally induced gas flow can therefore provide a propulsion method for thin atmospheres which doesn't involve moving parts, which makes it inherently more reliable. The research may also provide additional insights into early phases of planet formation.

The PROGRA2 experiment from CNES also has links to planetary formation. The experiment is performing measurements of light scattered by different dust particle samples simulating dust clouds found in different areas of space such as agglomeration processes in proto-stellar clouds, evolution of dust particles in the coma of comets, and the atmospheres of e.g. Titan, Earth. This campaign is partly the continuation of works in the frame of ESA's ICAPS experiment. A second objective is the study of carbonaceous particles that can be found in the different places of the solar system. The PROGRA2 project which has been on-going since 1994 has already developed a new concept and instrument used in routine air quality monitoring and for the study of aerosols from ground up to the middle stratosphere.

Technology

One DLR-sponsored technology experiment was tested during the parabolic flight campaign, though this did consist of two separate experiments both of which are testing small satellite separation systems, which not only ensure a stable fixation between a satellite and the launch vehicle/structure but also a reliable and controlled separation. The SEMENA-2 experiment was testing a mechanism with a 20kg dummy satellite that was released into a safety net. Success is determined by the quality of separation with respect to the velocity and rotational speed of the dummy satellite. The TUPEX-5 experiment is testing the deployment of a four 330 gram picosatellites.

The dummy satellites used acquire their own accelerations and rotational rates. From the measurements made and the video recordings, the current design of the picosatellites will be verified.

End of the A300

The retirement of the A300 zero-g aircraft in 2014 brought the end to a successful 17 years of service. The European Space Agency (ESA), and the German and French national space agencies (DLR and CNES) used the A300 for research experiments in weightlessness, and at Moon and Mars gravity levels, from 1997 until October 2014. A total of 104 parabolic flight campaigns were organised by ESA, CNES and DLR with the A300, including 38 ESA, 34 CNES and 23 DLR weightless campaigns, two Joint European ESA-CNES-DLR Partial-g Parabolic Flight Campaigns, and seven ESA Student campaigns.

During the 38 ESA weightless campaigns and the two partial-g campaigns with the A300, 475 ESA experiments were successfully performed by 275 teams from Germany, France, Belgium, Italy, ESA, The Netherlands, Switzerland, United Kingdom, USA, Canada, Spain, Sweden, Japan, Denmark, Ireland, Austria, Greece, Norway, Estonia, Finland, Hungary, Luxembourg, Brazil and China.

Across the ESA, DLR and CNES campaigns this has produced more than 700 articles in peer-reviewed scientific journals, 15 book chapters, 268 conference proceeding articles and abstracts, 539 doctoral, master's and bachelor's theses', and 59 technical reports and patents.

Future

With the first campaign with the A310 complete, we can look forward to the second campaign, which will be an ESA campaign starting in June 2015. This will cover 12 experiments in the areas of life and physical sciences. Five of the experiments are reflights from the first A310 campaign in April/May 2015 including the three neuroscience experiments, the ESA-sponsored experiment 'Is muscle force generation capacity impeded in microgravity?', and the CNES-sponsored PROGRA2 experiment. The June campaign will also include a reflight of an experiment which flew on three previous ESA parabolic flight campaigns between 2012 and 2014. The (Probing the direct effects of gravity on cavitation bubbles) experiment is studying the effects of gravity on cavitation bubbles (appearance of vapour bubbles in a liquid as the pressure drops) which has implications and applications in hydraulics.

One new ESA experiment from the University of Edinburgh will be testing experiment procedures in advance of the Biorock astrobiology experiment on the ISS. Biorock will study of the role of gravity and microgravity on the formation of biofilms, which are communities of bacteria found commonly in nature, and which can be utilised by humans. The other new experiment from CNRS in Nice, France is studying the characteristics of certain polymers without the detrimental influence of sedimentation. The experiment has application in improving the performance of concrete.

If the campaigns with the A310 follow the same successful pattern as 17 years with the A300, we can look forward to a very prosperous research return with many experiments finding their way into orbit.

↑ Airbus A300 and A310 aircraft prior to the start of the final A300 campaign in September 2014

→ COMPLEX PLASMA RESEARCH ON THE ISS

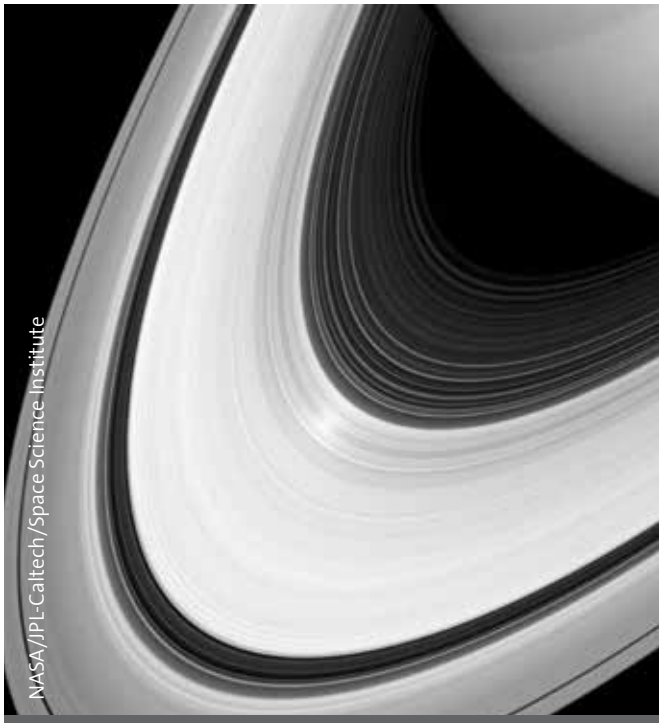
PK-4: The Latest Line in ESA's Complex Plasma Research

ESA-funded research into complex plasmas has been expanded recently with installation and commissioning of the PK-4 (Plasma Kristall 4) experiment on the ISS. The experiment is part of one of the longest running series of experiments in human spaceflight. The PK-4 experiment will provide valuable fundamental information into the mechanisms of how complex plasmas react and can be manipulated under certain conditions, without the disturbing influence of gravity, as well as providing a means of modelling and observing fluid physics phenomenon. By improving our understanding in plasma research, this could improve our knowledge of fluid behaviour at an atomic level, indirectly feed into improved knowledge of planetary formation and feed into Earth-based applications such as in semiconductor production.

↑ Roscosmos cosmonaut Elena Serova with the PK-4 experiment unit in ESA's Columbus laboratory on the ISS

Plasmas are ionized gases consisting of electrons and ions (positive or negatively charged particles) and more than 99% of the visible matter in our universe is in the plasma state. 'Complex' (dusty) plasmas include an additional component of micro-particles or 'dust' and also exist in space, such as in the interstellar medium, the rings of Saturn or the dusty tail of comets.

Plasma is also used in many industries. The field of plasma health care equipment is developing. Plasma is utilised in making many microelectronic or electronic devices such as semiconductors. It can help make features on chips for computers. Plasma is used in making transmitters for microwaves, high temperature films, and can even be used in work with minerals such as diamond, and in extracting economically valuable metals from rock. We also see plasmas on a daily basis with plasma displays and in the lighting industry with High Intensity Discharge (HID) lamps, commonly used in places such as football stadiums and large public areas. Understanding how plasmas behave and can be controlled therefore has significant economic potential.

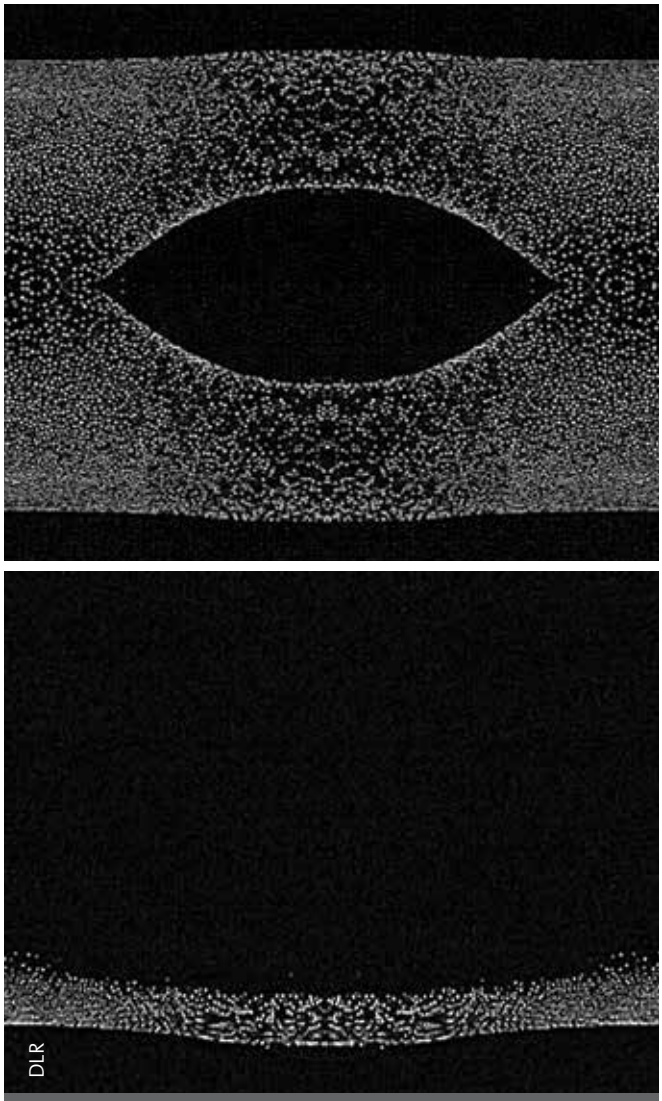


↑ Infrared image of Saturn taken from Cassini spacecraft in August 2013. Saturn's rings are composed of complex/dusty plasmas

Due to the strong influence of gravity on the micro-particles, most experiments on complex plasmas are strongly distorted or even impossible on earth and require weightless conditions such as on the ISS.

The Start of Plasma Manipulation

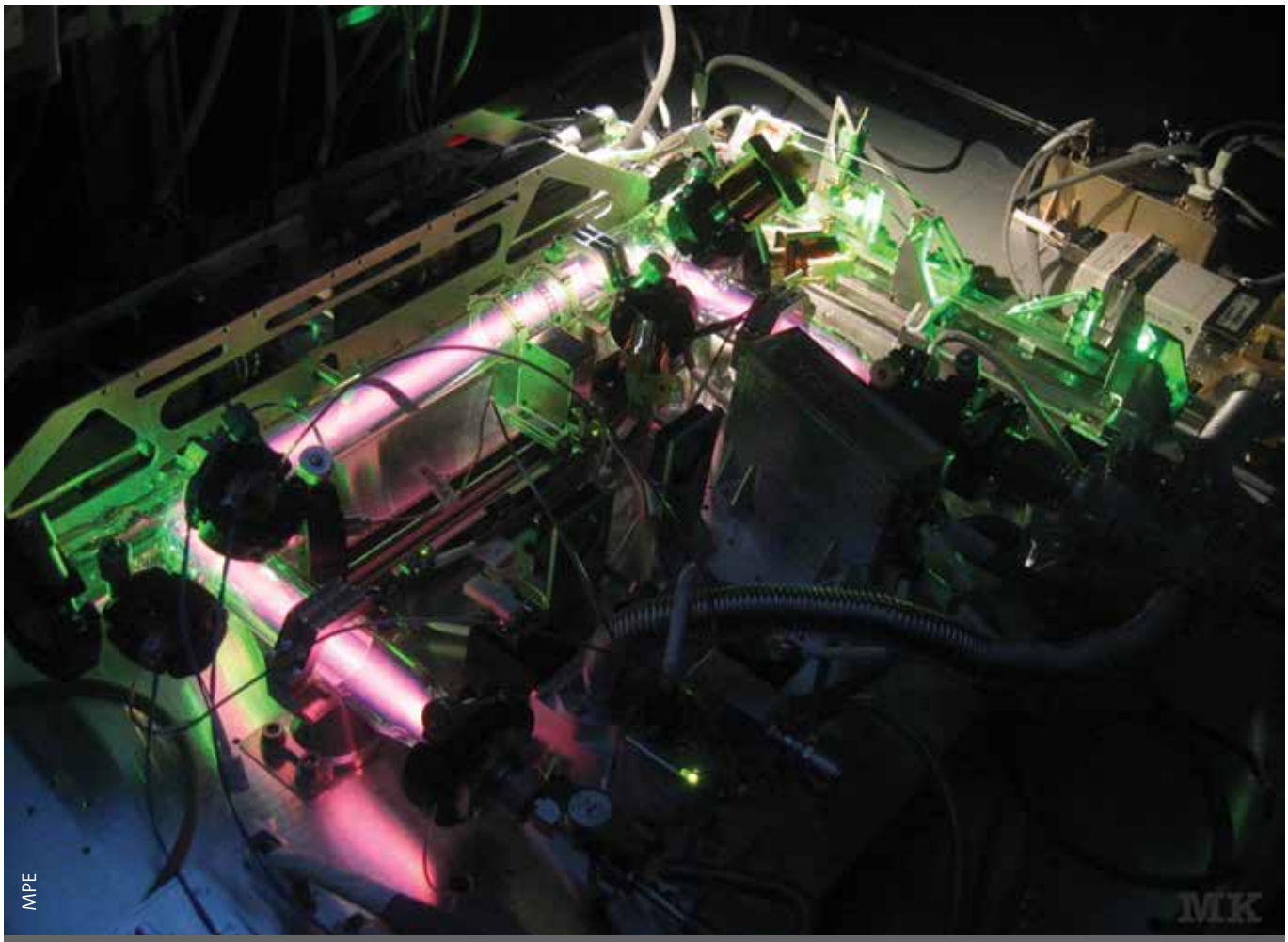
A plasma is the most disordered state of matter. It came as a major surprise in 1994 when scientists from the Max Planck Institute of Extraterrestrial Physics in Garching, Germany discovered that plasmas can be manipulated to resemble liquids, and may even spontaneously crystallise when micro-particles are added to the plasma. These dust particles charge automatically upon injection into a plasma. When particles of micrometer-size are used, it is possible to observe the individual particles. Their movement is slow enough, and the particles large enough, to be observed with ordinary cameras, and the kinetics of the system can be studied. This research therefore provides a unique model for observing the dynamics of regular liquids and solids at an atomic level though with unprecedented resolution and in slow motion, as if one could see atoms individually. This could include research in thermodynamics at the critical point where for example liquid and vapour coexist in thermodynamic equilibrium and at the triple point where the three phases of a substance (gas, liquid, and solid) can coexist in thermodynamic equilibrium under specific temperature and pressure conditions.



↑ Effect of gravity on complex plasmas: (Top) Electrically charged plasma in an experiment chamber in weightlessness, with a 'void' in its centre. (Bottom) Electrically charged plasma in an experiment chamber under gravity conditions

The PK-4 Experiment

The PK-4 experiment is furthering this research of investigating the behaviour of micro-particles in complex plasmas mainly related to the liquid state. Contrary to previous space-based research PK-4 studies a plasma generated in a high voltage direct current chamber.



↑ First light in PK-4 ground tests in 2010

The research focuses on areas such as understanding the origins of instabilities and the development of turbulence in hydrodynamics, phase transitions, and compression-freezing. Measurements of particle charge and ion drag force will also be undertaken. Ion drag force is the force imparted on a micro-particle in a complex plasma by streaming ions. This has an influence on micro-particle organisation and interesting phenomena such as void formation in weightlessness (see image on page 21). These different experiments will help to determine how different factors such as current, pressure, particle charge and velocity etc. help to shape and influence organisation within complex plasmas.

Also technical aspects can be addressed, e.g. particle growth in plasma chambers used for microchip production as well as indirect applications in astrophysics, such as the formation of planets.

The PK-4 experiment unit, mainly consisting of a glass plasma tube, electronics, optics, gas, and vacuum modules as well as cameras and a laser manipulation system was launched to the ISS in October 2014 on Progress 57P. The unit was installed inside the European Physiology Modules facility in Columbus in November 2014 by Russian cosmonauts Alexander Samokutyaev and Elena Serova under the guidance of the CADMOS control centre in Toulouse, France with a

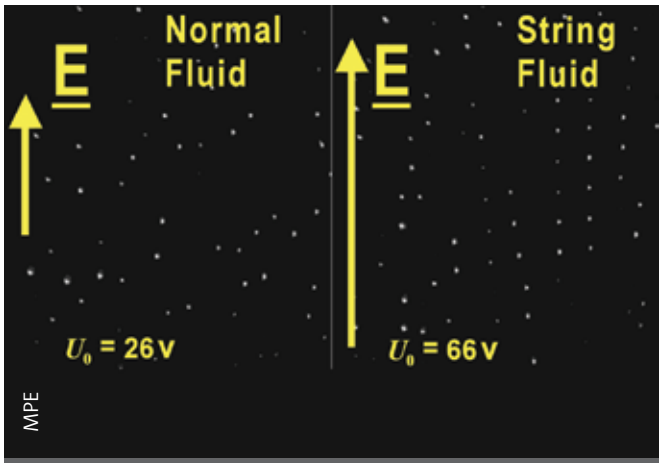
↑ PK-4 experiment unit

successful checkout in December. This was the first time that Russian cosmonauts have performed a reconfiguration of the Columbus module.

↑ Progress 57P during rendezvous and docking with the International Space Station

↑ Ground tests in 2003. Top: Alterations in pressure (from left) 0.25, 0.5, 1.0, 1.5 mbar, and with constant power. Middle: Nozzle experiment, two discharges create a nozzle where the particle flow is compressed. Bottom: Particles flowing through the nozzle. Their velocity increases (from right to left) inside the nozzle

The PK-4 experiment is under the scientific lead of the DLR complex plasma team in Oberpfaffenhoffen, just outside Munich, Germany, together with the Russian Joint Institute for High Temperatures (JIHT) in Moscow with a large and international PK-4 science team located in various other institutes around the world. The launch of PK-4 concluded an extensive campaign of testing and improvements on ground as well as during numerous ESA and DLR parabolic flight campaigns since 2002. This helped to test and define the different experiments to be undertaken on orbit principally with changes to the internal pressure environment and electric field as well as making improvements to the PK-4 hardware with the hardware developer OHB System AG (previously Kayser-Threde GmbH).



↑ Micro-particles lining up along electric field with increased voltage (left to right)

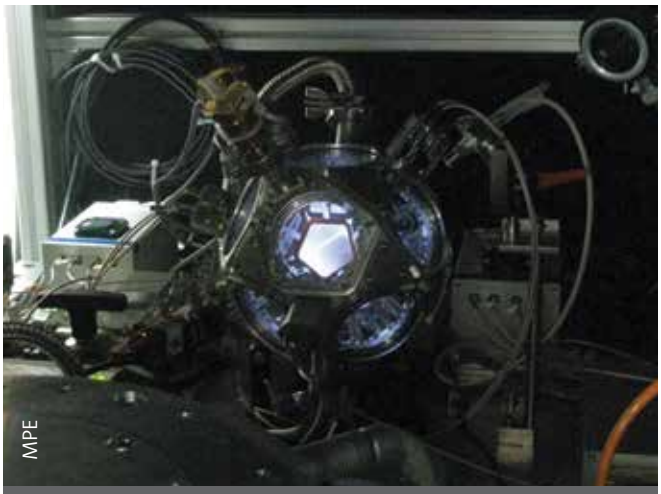
History and Selected Results

PK-4 is part of one of the longest running series of experiments in human spaceflight preceded by PK-1 and PK-2, performed on the Russian Mir space station ''PKE-Nefedov" (2001-2005), and then ''PK-3 Plus" (2006-2013) on the ISS. In PK-3 Plus so-called electro-rheological plasmas and the behaviour of binary mixtures (just like water and oil) could be studied for the first time. PK-3 Plus also enabled the creation and investigation of huge 3-dimensional plasma crystals, transitions to the liquid phase and re-crystallisation in detail. Compared to the PK instruments previously used on board the ISS, the DC chamber of PK-4 allows greater optical access for observation as well as laser manipulation for accelerating the micro-particles in the plasma.

In certain colloidal fluids (fluids containing micron sized particles) the rheological properties can be changed dramatically by applying an external electric field. The micro-particles line up along the electric field lines leading to a change in e.g. the viscosity by many orders of magnitude. This allows to tune the properties of this fluid between 'normal' liquid and elastic solid just by changing the applied voltage.

Complex plasmas are very similar to colloidal fluids. We see the same electro-rheological effect using an alternating electric field and microgravity conditions. PK-3 Plus managed to create an electro-rheological plasma for the first time. By increasing the voltage the transition from a homogeneous fluid to a so-called string fluid with different properties could be initiated.

↑ Russian cosmonaut Oleg Kotov working with the PK-3 Plus experiment payload on the ISS in January 2010



↑ PlasmaLab dodecahedral chamber during 2012 Parabolic Flight Campaign

Moving onto the PK-4 experiment, ground experiments in advance of on-orbit operations have already been undertaken that are generating interesting results.

This includes accurate estimates of dust particle charge in a DC plasma chamber using different methods with both a stable and turbulent plasma flow. These estimates also agreed with molecular dynamics simulations. The estimates indicate that the ion-neutral collisions (collisions between ions and neutral particles) have a significant effect on particle charging in plasmas.

Future:
With PK-4 just starting the next generation complex plasma experiment is already in development. PlasmaLab, supported, by DLR, will expand the parameter range in the area of complex plasmas and has already taken part in a number of (DLR) parabolic flight campaigns. This has included testing a plasma chamber with cylindrical and flexible geometry and a dodecahedral plasma chamber for creating spherical and isotropical plasmas as well as testing high-frequency generators.

PlasmaLab will have the advantage of having a modular structure. During the lifetime of the project new experiment containers will be developed and deployed in space regularly. The system will be upgraded from previous research with improved electrode configuration, the selection of up to six different micro particle diameters, and significantly improved diagnostic facilities.

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→ RADIATION RESEARCH IN THE COLUMBUS LABORATORY

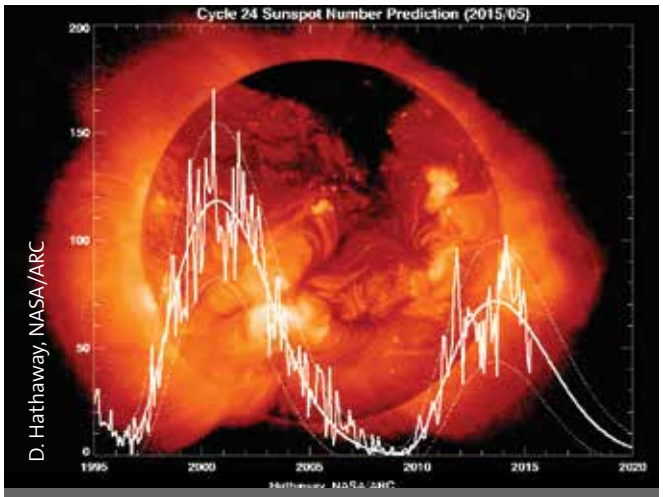
Extension for DOSIS-3D Experiment

In 2009 ESA's Dose Distribution Inside the ISS (DOSIS) experiment started, gathering data to help improve our knowledge of the radiation environment in low earth orbit and the effectiveness of radiation shielding at different points around the ISS. Now after six years of operations, and currently in the guise of the DOSIS 3D experiment, one of ESA's longest running experiments in orbit has received an extension in operations for another few years.

↑ One of the 11 passive detector packages (orange) of the DOSIS 3D experiment just after installation in the Columbus laboratory on 29 March 2015

Radiation Environment

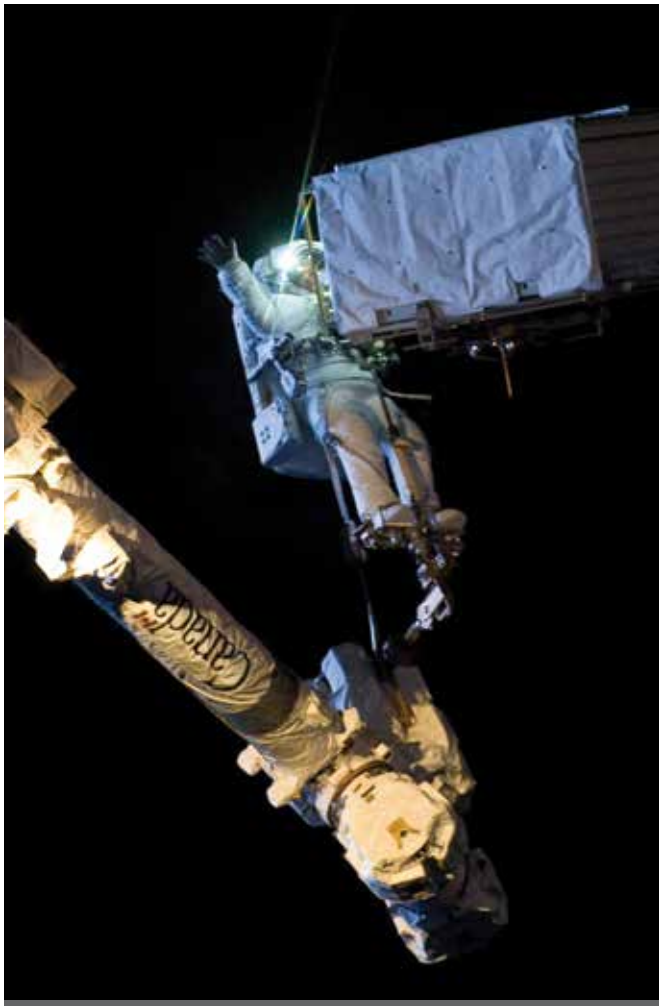
The radiation environment surrounding Earth is an extremely complex environment to assess with many different elements including UV, X-rays, and particles: electrons, neutrons, protons and heavy ions (cosmic rays). The levels of these different types of radiation can vary for a number of reasons. The 11-year solar cycle causes variations, for example with increased solar flare activity. Events such as galactic supernovas can have a similar influence in increasing high-energy radiation levels. Considering the orbit of the ISS, radiation levels vary with ISS altitude and there is the additional effect of increased radiation when the Station passes through the South Atlantic Anomaly during a few daily orbits, where Earth's magnetic field is weaker and the ISS encounters increased radiation doses for a short period of time. There are even variations in the radiation field through the ISS due to different shielding qualities in different modules.



↑ Graph showing variation in solar activity during two solar cycles, cycle 23 which ran from May 1996 – January 2008 and the much weaker cycle 24, which has been on-going since January 2008

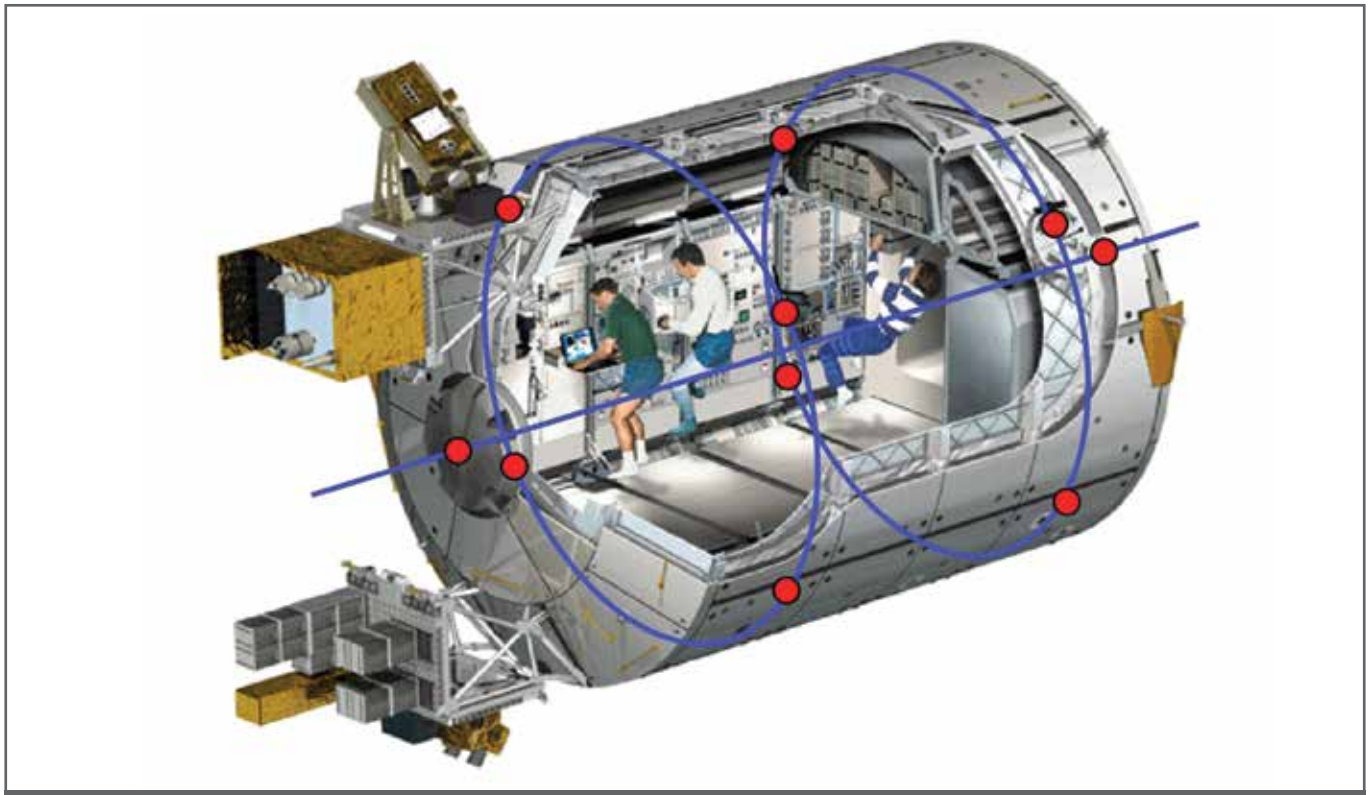
With its inherent complexity, it is clear to see why the process of monitoring and analysing the space radiation environment is an on-going one involving generation of extensive amounts of data from different experiments and collaboration with International Partners.

A more precise determination of (variations in) the radiation field in Low-Earth orbit is of great importance on many levels. On a basic level it is obviously of vital importance in monitoring and securing the safety of our astronauts in orbit now and in the future. The data can also be used to determine the shielding qualities of different areas of the ISS and be used to improve our understanding of how the radiation environment has an influence on the upper atmosphere. This can influence climatology, and thus help to improve current climate models.



↑ ESA astronaut Alexander Gerst during an ISS spacewalk. One important element of ESA's radiation research is to maintain an as-safe-as-possible environment for our astronauts to work in

ESA's broad spectrum of research touching on Earth's climatology is also supported by data coming from additional research payloads such as the Solar facility, which has been studying the Sun's irradiation since 2008, and will include projects in the future such as the Atmospheric Space Interactions Monitoring Instrument (ASIM), which will study giant electrical discharges (lightning) in the high-altitude atmosphere above thunderstorms. Additional Earth Observation projects based from the ISS are currently in the planning process.



↑ Cutaway image of Columbus showing the approximate locations of the passive radiation detectors used in the DOSIS experiments

DOSIS Experiments

The DOSIS experiment, under the scientific lead of Dr. Günther Reitz of DLR, was the first long-duration radiation experiment to take place in the Columbus Laboratory following its attachment to the ISS. It follows in the footsteps of the first European radiation experiment on the ISS, DosMap in 2001, which was also under the scientific lead of Dr. Reitz.

DOSIS was also ESA's first radiation-related experiment to undertake area dosimetry, i.e. using multiple sensors spread around Columbus to build a picture of the distribution of the radiation field inside Columbus and the ISS. This is a valuable method in verifying the shielding qualities of the ISS in different areas. The sets of 11 passive radiation detector packages used in the DOSIS experiments are composed of 10 passive detector packages (locations shown on the diagram above) and one triple detector package (located with the active DOSIS radiation detectors). The passive detector packages are made up of different types of detector material, to measure the total absorbed radiation dose across a wide cross section of the radiation spectrum. The passive packages are swapped out and returned to earth for analysis approximately every six months.

In addition to the passive detectors, which provide the accumulated radiation dose for each pair of ISS Expeditions, the experiment gathers data from two active radiation detectors pointing in different directions, enabling the measurement of radiation directionality and fluctuations over time. These are located on the outer surface of the European Physiology Modules facility in ESA's Columbus laboratory from which data is downlinked on a monthly basis.

The first DOSIS experiment ran for two years in orbit from July 2009 to June 2011, and was hereafter succeeded by the DOSIS-3D experiment. DOSIS-3D started in May 2012 with ESA astronaut André Kuipers installing repaired active detector hardware and the first set of passive radiation dosimeters. Since the start of DOSIS 3D the passive radiation detectors have been swapped out six times, with the most recent swap out occurring at the end of March 2015. The DOSIS-3D experiment builds on the data gathered from the first DOSIS experiment by combing data gathered in Columbus with data gathered from a whole host of different passive and active detectors from NASA, JAXA and Roscosmos placed all around the ISS.

↑ The DOSIS Main Box (blue), containing the two active DOSTEL detectors, and the triple passive detector package (orange) in March 2014

DOSIS 3D provides vital radiation data in support of all biological experiments that are being conducted in Columbus. This is an important element for all scientific publications in the area of biology and an important reason for granting an extension to operations.

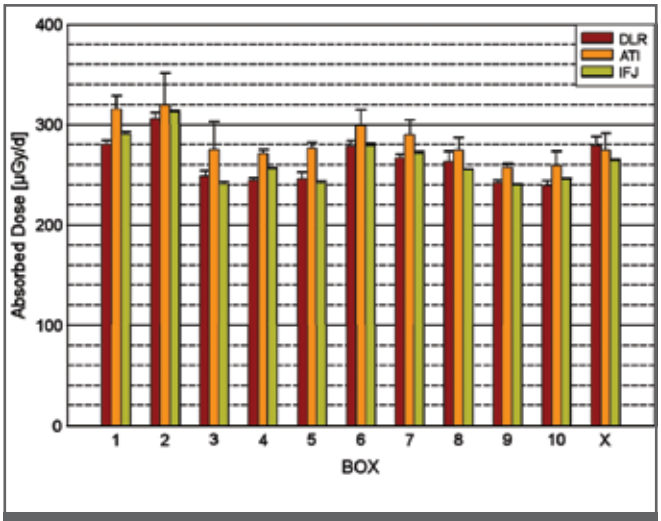
↑ ESA astronaut André Kuipers setting up the Tissue Equivalent Proportional Counter in the Zvezda Service Module of the ISS in March 2012. Data from this NASA radiation detector forms part of the DOSIS 3D experiment

Results

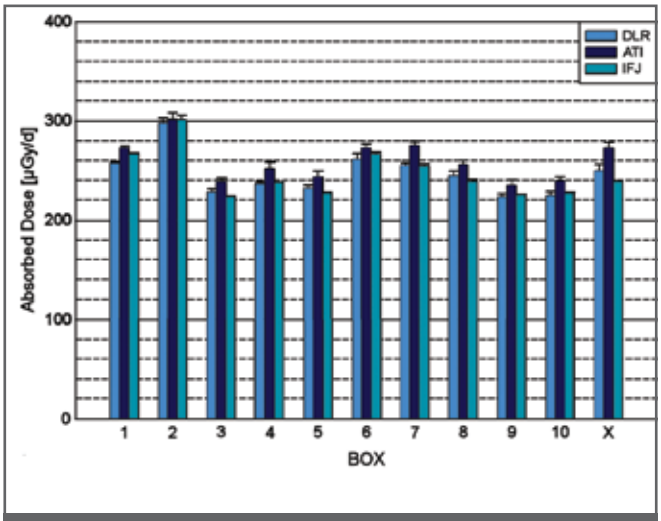
Initial Results of DOSIS 3D are scheduled to be presented at the Workshop on Radiation Measurements on the ISS in September 2015 at DLR in Cologne. However results of the first DOSIS experiment have already been published.

Two sets of passive radiation sensors were used as part of the first DOSIS experiment, one set which was installed in 11 different locations around the Columbus laboratory from July – November 2009 (set 1) and from November 2009 – May 2010 (set 2). These were analysed on ground following deinstallation and return on Shuttle while monthly data downlinks from the ISS were undertaken for the active detectors between July 2009 and June 2011.

One part of each of the 11 passive radiation detector packages was made up of thermoluminescence detectors composed of lithium fluoride with trace elements of magnesium and titanium (LiF: Mg, Ti). As an example of the results from the first set of passive thermoluminescence detectors the first figure in the next column shows the daily dose rate measured with neutron sensitive 6LiF: Mg, Ti thermoluminescence detectors originating from the three different investigator groups (DLR in Cologne, ATI in Vienna and IJF in Krakow) while the second figure shows the daily dose rate measured with non-neutron sensitive 7LiF: Mg, Ti thermoluminescence detectors. The absorbed dose rate inside Columbus can vary up to 30-40%



↑ DOSIS-I: Data for 6LiF:Mg, Ti Thermoluminescence Detectors



↑ DOSIS-I: Data for 7LiF:Mg, Ti Thermoluminescence Detectors

depending on the location of the detectors. The results from the three teams come very close together, partly as a result of a common pre-flight calibration approach.

Since the start of the DOSIS 3D experiment in May 2012, data acquisition has also included a period in May 2013 during an energetic solar particle event during which the active detectors were set to a higher data acquisition rate. A 2013 report and presentation of the scientists' analysis clearly showed how the radiation levels in the Columbus laboratory vary with the solar cycle, the altitude of the ISS and the location of the detectors inside Columbus.

Future

The DOSIS experiments have proven to be very successful exponents of ESA's radiation research on the ISS along with other experiments such as the Matroshka and ALTEA series of experiments and the TriTel experiment. With six successful years of research complete and results being published there is obviously a significant potential available to further extend the research with DOSIS to 2020 and possibly beyond and hence further improve our knowledge of the radiation environment surrounding our planet.

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