esa

→ SPACE FOR LIFE

human spaceflight science newsletter

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NASA

ESA astronaut Hans Schlegel working on the outside of the Columbus laboratory in February 2008 two days after its installation on the International Space Station as part of the STS-122 mission

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→ COLUMBUS 5 YEARS IN ORBIT

In February 2013 the European Columbus laboratory, ESA and Europe's biggest single contribution to the ISS, reached the landmark of five years on orbit.

The arrival of Columbus marked a notable shift in European research potential with the variety of research facilities in Columbus providing the means to undertake longer-term European research activities on the Station and also providing Europe with its full quota of research rights on the ISS. This research potential has been further increased over the past few years with the increase to a six-member crew.

With this significant milestone in Columbus activities reached it is time to take a look back at the variety of successful research undertaken with Europe's permanent research laboratory in space over the past five years.

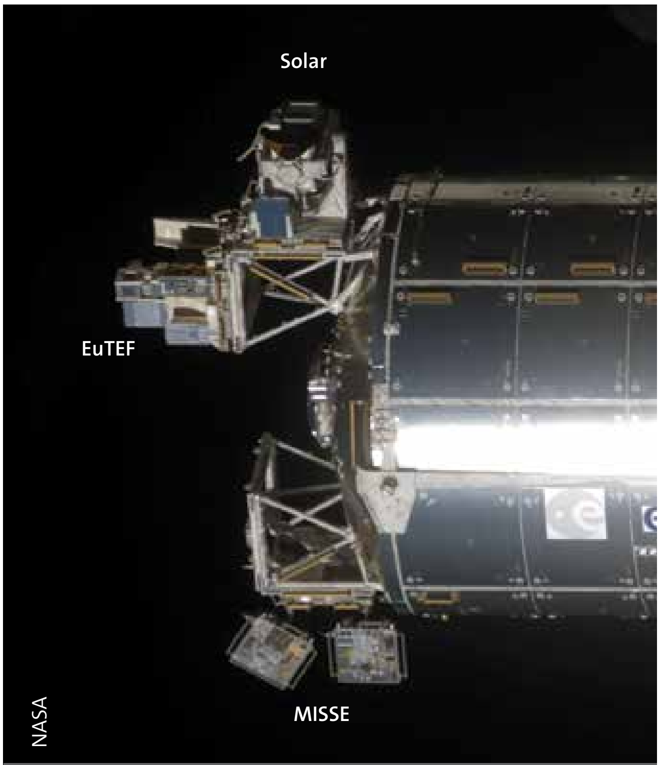

NASA

Launch of the Columbus laboratory on STS-122 Shuttle Atlantis on 7 February 2008 from the Kennedy Space Center

→ LIFE OUTSIDE THE STATION

Astrobiology and Exposure Research on EuTEF

Prior to the Columbus launch and becoming an ISS partner with its own on-orbit resources Europe had carried out about 100 experiments on the ISS since 2001, though these were mainly associated with short-duration Soyuz missions involving European astronauts. Since Columbus has been on orbit there have been many success stories, two of the most successful being located on the external surface of Columbus from the very beginning.



Columbus External Payload Facility showing locations of external payloads in June 2008 including ESA's Solar facility and European Technology Exposure Facility (EuTEF) as well as two panels from NASA's Materials ISS Experiment (MISSE)

A highlight of the Columbus assembly mission in 2008 was the installation of the first two external facilities on the Columbus External Payload Facility: Solar (covered in detail in a separate article), which is still undertaking successful Solar research in orbit and the European Technology Exposure Facility (EuTEF). EuTEF covered an extensive variety of Exposure research including materials research, radiation dosimetry, tribology (study of friction), and different types of environmental monitoring to name a few during 1.5 years from February 2008 – September 2009. However, one of the principal research areas undertaken on EuTEF which has definitely benefitted from the possibilities of the ISS and exposure to open space conditions is astrobiology. The ISS has proven to be a very successful platform for undertaking long-duration sample exposure in orbit and ESA's astrobiology research that was undertaken on EuTEF's Expose-E platform has made some very noticeable strides in this area.

Expose-E and Astrobiology

Built on previous research on such platforms as Foton (robotic orbital capsules), where exposure time was of relatively short duration (2 weeks) ESA astrobiology research on EuTEF pushed this to 18 months, which greatly increased the significance of the results in different areas of astrobiology.

Tardigrades or water bears, now known to survice the harsh conditions of open space

ESA research has shown the survivability of numerous complex organisms to the open space environment, where they are exposed to full solar UV, vacuum, cosmic rays and perpetual temperature variations as the Station continuously passes between areas of direct sunlight and the cold darkness of Earth's shadow.

Xanthoria elegans, a lichen known as one of the best known survivors in open space

De-integration of flight sample carrier of Expose-E in nitrogen atmosphere at DLR with support from the hardware developers RUAG and MUSC

Post-flight de-integration of lichens (from the experiment LIFE) at DLR

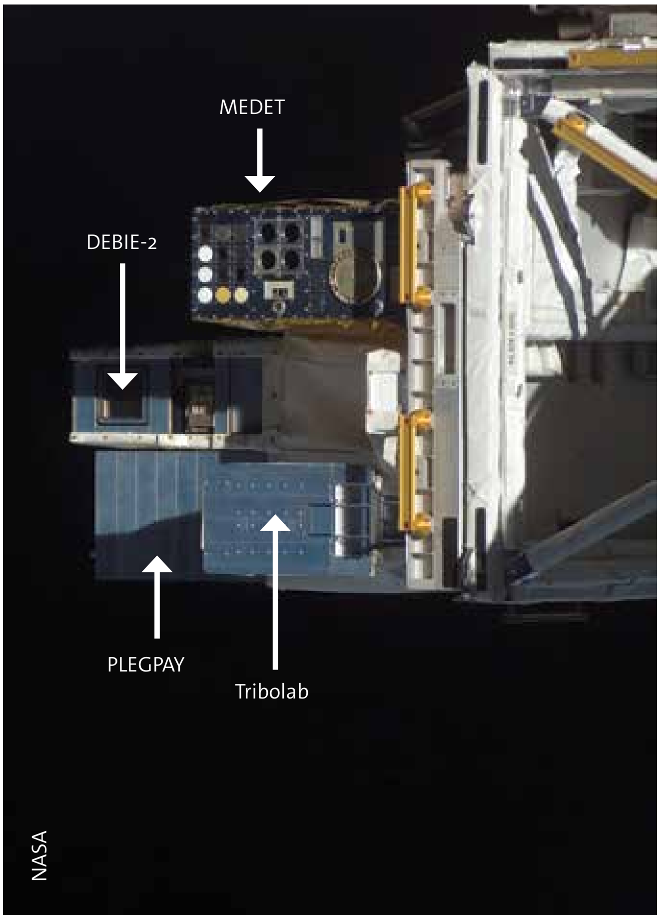
This kind of research can shed light on the survivability of different organisms on other planets, or during interplanetary travel, under conditions that we on Earth would call ultra-extreme, how they may possibly build resistance when exposed to such harsh conditions, and help determine planetary protection measures in order to restrict possible contamination of another planetary body by surface probes sent from Earth.

The Expose-E Payload incorporated five astrobiology experiments (SEEDS, ADAPT, PROCESS, PROTECT and LIFE). Post-flight analysis showed that the single-celled organism Halococcus dombrowskii (from ADAPT), one lichen and one black fungus (from LIFE) and seeds from Arabidopsis and tobacco (from SEEDS) survived open space conditions to varying degrees. There was an even greater level of survivability, and amongst more test organisms, with samples additionally shielded from solar UV radiation. In nature shielding against UV could be the case if, for example, an organism is shielded on a meteor or by surface debris, or beneath the surface on a planetary body. Further results from the PROTECT experiment showed that bacterial spores were able to survive a simulated journey to Mars if protected against solar UV-C, and may survive at the surface of that planet for several years if shielded against direct solar irradiation. This is significant for planetary protection issues and adequate decontamination procedures especially when considering the in situ search for extra-terrestrial life on other planets.

Physical Science and Technology Research on EuTEF

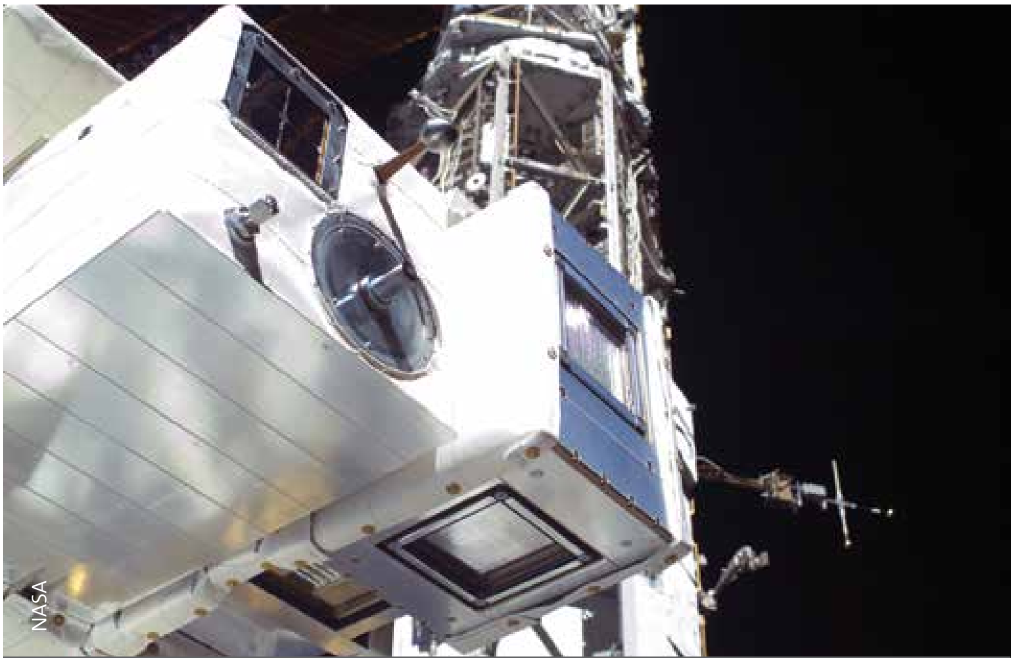
Materials Exposure Research

Outside of astrobiology a whole host of successful research was undertaken on the EuTEF facility. In materials exposure research, the Material Exposure and Degradation Experiment (MEDET) evaluated the effects of the complex low orbit space environment on material properties. The results could help utilise new/existing materials within future space applications and spacecraft design.



View of the front face of EuTEF showing the location of several of the experiment payloads

MEDET consisted of seven instruments, with active sensors and material samples. The material samples consisted of a selection of thermal control paints and foils, optical glasses, thin solar sail materials and metallic anodisations (anodised metals have increased corrosion/wear resistance). The results showed no significant degradation of the white paint samples, Plasmocer (a plasma chemical coating that improves wear and corrosion of underlying metallic layers), and black bodies; a complete erosion of the Upilex-S sample (an ultra-high heat-resistant polymide film); darkening of the Y100 polyimide sample followed by a decrease in its absorptance (a measure of the ability of an object to absorb radiation), and a small increase in absorptance of the RSR, MAP ATOX and RSF coatings.



An on-orbit close up of the DEBIE-2 and PLEGPAY payloads on EuTEF

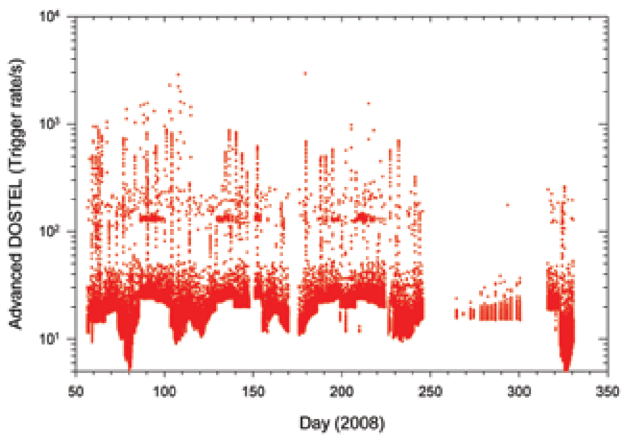
Within space environment monitoring research on the ISS, the DEBris In-orbit Evaluator-2 (DEBIE-2) measured impact energies and velocities of sub-millimetre micro-meteoroids and space debris hitting its three aluminium foil panels and thus provided an insight into this smaller type of orbital debris of which least is known. Around the same size as smoke particles, they may be tiny but their effect is still dramatic: impacting at hypersonic velocities, they briefly heat the aluminium foil locally to thousands of degrees Kelvin, hotter than the surface of the Sun.

931 events were identified as potential impact events in the period Jan-Sep. 2009. From this data a significant higher amount of impacts occurred on the upward (zenith) facing sensor than on the forward facing and starboard sensors. One of the surprising findings was that impact events came in clusters and were not randomly distributed. These peaks can be concentrated within the space of perhaps a minute to 80 seconds at a time, indicating the existence of clouds of dust along the ISS orbit.

The Advanced Dosimetric Telescope (DOSTEL) experiment monitored the radiation environment outside the ISS with data compared to measurements from inside the ISS. Preliminary results showed that the equivalent dose rates outside the ISS are a factor of around 2 times higher than inside. This data has been compared with the results obtained from previous similar experiments already sent to space such as DOSIS and MATROSHKA and used to build overall radiation models.

Additional space environment monitoring research showed variations in levels of Atomic Oxygen along the ISS orbit showing variations between day/night phases and between the Equator and high latitudes (FIPEX experiment); demonstrated the capability of the plasma contactor device to control electrostatic charging of a very large spacecraft (PLEGPAY experiment); showed that the behaviour of lubricants under microgravity and vacuum conditions in orbit is similar to their behaviour on Earth (Tribolab experiment); and successfully recorded temperature data throughout ascent into orbit, and transfer of EuTEF to and from the Shuttle cargo bay during installation/deinstallation on Columbus (EuTEMP experiment).

The success of the research coming from the external payload facility of Columbus bodes well for future exposure research and the arrival of the next two ESA external payloads: the Atomic Clock Ensemble in Space (ACES) and the Atmospheric Space Interactions Monitoring Instrument (ASIM). The ACES atomic clocks which will be the most precise measurement of time yet in space will test Einstein's general relativity theory and alternative theories of gravitation. ASIM will study giant electrical discharges (lightning) in the high-altitude atmosphere above thunderstorms and their role in the Earth's climate.

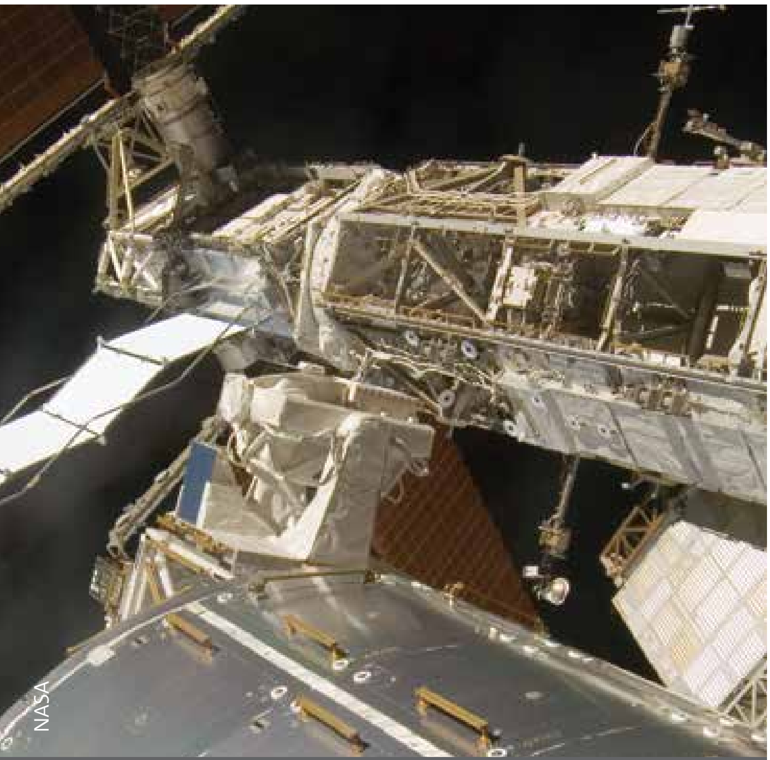


A graph showing dose rates of the DOSTEL radiation detector from February to December 2008

→ SOLAR FACILITY

2008 - 2013 and Beyond

When the Columbus Laboratory was attached to the International Space Station in February 2008, one of the first external payloads to be deployed outside of Columbus was the Solar facility which gathered its first data on 15 February 2008 and it is still going strong.



The SOLAR facility (centre) pictured on the International Space Station in June 2008 during an STS-124 mission spacewalk

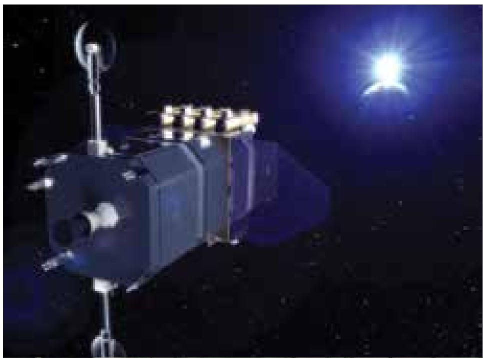
The originally foreseen lifespan of Solar was 18 months to 2 years with the facility originally deemed to return with the Space Shuttle, though now after five years in orbit, the facility is still studying the Sun's cycle and changing irradiation with unprecedented accuracy across most of its spectral range, acquiring extensive data on the Solar-UV environment from low-Earth orbit and recently carried out the most significant period of research to date.

Earth's atmosphere makes it difficult to study the wide range of solar electromagnetic emission spectra from the ground. This makes it necessary to undertake solar research in space and the ISS provides a valuable platform for observing the activity of the Sun for a long period of time.

Solar activity can have a significant effect, not only for our planet but also for the satellites surrounding it, which have an ever-increasing importance to communications and navigation on Earth. Solar Extreme UV (EUV) radiation, for instance, which is absorbed into the upper atmosphere, strongly influences the propagation of electromagnetic signals such as emitted from navigation satellites. It is also one of the main elements that have the effect of heating up the outer atmosphere of the Earth, causing it to expand during periods of increased solar activity, which increases the drag on satellites orbiting Earth and thus reducing their lifetime in orbit.

The Solar facility acquires scientific data when the ISS is in the correct profile in relation to the Sun. Even though the Solar facility can be rotated to a certain degree to face in the optimal direction with an automatic sun pointing device, orbital parameters and restrictions cause these data acquisition periods (called Sun Visibility Windows) to normally last around 10-12 days at a time. This has allowed the Solar facility to acquire an extensive amount of data in the past five years, though until recently not across a complete Sun rotation cycle which lasts around 27 days.

However recent high-level discussions led to an agreement with NASA to rotate the whole ISS slightly in order to undertake data acquisition with the Solar facility continuously in the period between two Sun Visibility Windows, known as the bridging period. This is a very significant occurrence. Aside from calculating the correct orbital profile to keep the Solar facility in view of the Sun, other factors need to be taken into account such as ensuring the solar panels that power the Station are not left in the dark, and communication antennas need to be reoriented to stay in contact with Earth. More complex research planning also needs to take place as rotating the ISS imparts small accelerations/vibrations on the Station and all of its equipment, which could interfere with any research being undertaken at the time (an obviously important factor for research that focuses on the effect of weightlessness). As such the complex planning process from its concept to its realisation took about two years.



Artist's impression of NASA's Solar Dynamics Observatory

Solar Dynamics Observatory on ground prior to launch

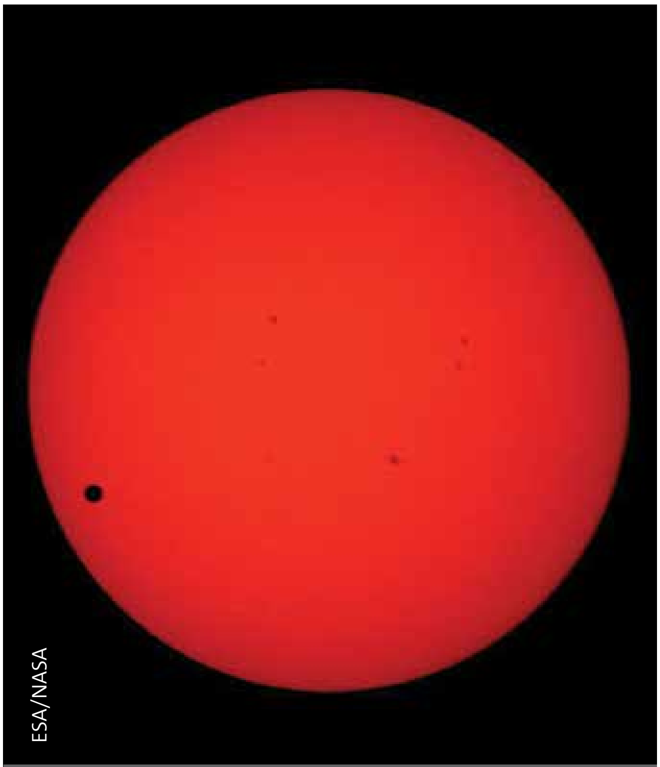
One important point of planning was that the bridging period would occur around the Summer or Winter solstice when the period between the Sun Visibility Windows is at a minimum. For this reason the bridging period took place from 30 November – 12 December 2012 with the ISS being rotated by about 7º. This was the first time that the ISS had undergone an attitude change for scientific reasons. Taking the Sun Visibility Windows before and after into account, this accounted for a continuous science acquisition period lasting around 35 days (18 November – 23 December 2012), thus incorporating a complete Sun rotation cycle. The science teams reported excellent scientific results from the data gathered during this period which will provide a fascinating picture of Sun's irradiation during a rotational cycle.

Comparison of data from the Solar Auto-Calibrating Extreme UV-Spectrometer (SolACES) instrument of Solar with those from NASA's Solar Dynamics Observatory/EUV Variability Experiment (SDO/EVE, launched in February 2010) is considered a breakthrough in EUV spectrophotometry in space. In the past the accuracy of EUV-Solar Spectral Irradiance data could only be estimated. Still in 2010 a key requirement for the SDO/EVE was "to measure the EUV radiation with an accuracy of 25 %". However the results as presented in the bridging period report suggest the best known agreement of data for two EUV space instruments of different optics and calibration methods: The direct inter-comparison of data from SDO/EVE and Solar/SolACES instruments during the period of 19 November through 23 December 2012 agree with each other to within 5 %.

Data gathered from the Solar facility has already far exceeded original expectations with a first extension to the mission until February 2013 (approved in July 2009 following a serious engineering/safety analysis). With the extension of the ISS lifetime until 2020 and possibly beyond, and the Solar facility receiving a second mission extension to continue gathering scientific data until February 2017 (approved in June 2012), this will also provide a great deal of data during the approximately 11-year solar cycle (during which time the Sun goes through varying degrees of increased/diminished solar activity). This was scheduled to encompass the expected maximum level of activity in the approximately 11-year solar cycle (due to occur in 2013, though refer to results below), when the occurrence of sunspots and solar flares will be at their maximum levels, and the Sun's magnetic field will be most powerful.

As such the Solar facility will acquire data that will provide a fascinating picture of the transition to the Solar maximum period and also the transition out of this period towards the solar minimum period. If the Solar facility continues in the same lines by 2017 this will be almost 10 years of data gathered and will surely encompass additional milestones on the way.

In 2012 alone the Solar facility completed its 50th Sun Visibility Window in January and undertook simultaneous measurements in coordination with ESA's Venus Express project in May, close to the transit of Venus across the Sun. These simultaneous measurements with Venus Express allowed an in-orbit calibration of a UV spectrometer (SPICAV) on Venus Express. The SPICAV spectrometer allows for atmospheric analysis (by measuring solar spectra passing through Venus' atmosphere) and will provide a complete map of the sun as seen from Venus, at all wavelengths between 180 and 300 nm.



Venus transit seen from ISS

During the simultaneous measurements both Venus (Venus Express spectrometer) and the Earth (SolACES instrument) were simultaneously looking at the same face of the sun. The measurements allowed for a good calibration of the SPICAV spectrometer. The data gathered will also help in solar activity prediction.

Monitoring Solar from the ground: Highs and Lows

The extensive amount of data gathered from the Solar facility has been monitored since the start of operations in 2008 from the Belgian User Support and Operations Centre (B-USOC) in Brussels, Belgium which has also reached the landmark of five years in operation.

Solar facility during installation on 15 February 2008

There have been a few challenges during Solar's five-year period in orbit. The Solar Variability and Irradiance Monitoring instrument (SOVIM) of Solar, designed to measure the total and the spectral irradiance of the Sun with high precision, high stability and high accuracy has not been active since the last quarter of 2008. However, in the time that it was active it was able to produce extensive scientific measurements, complementary to the measurements performed by the other two instruments.

The SolACES instrument from SOLAR also experienced some optical degradation from the start of 2010 which is suspected to be principally caused by external contamination (from thruster firings, ventings) leading to material deposition on the optics as well as by spectrometer degradation. However the SolACES team developed a successful work-around (started in April 2011) which involves heating the instrument up to 50-55 deg C during shadow periods, thruster-firing events (dockings, undockings, ISS reboosts, and debris-avoidance manoeuvres) and some venting activities to accelerate removal of deposited material and protect the instrument's optics from degradation. Outside of these events the SolACES instrument is able to acquire data during Sun Visibility Windows.

With all these challenges faced the SOLAR instruments still continue to successfully measure the solar spectral irradiance of the full disk from 17 to 150 nm at 0.5 to 1.6 nm spectral resolution using the SolACES instrument as well as measuring the solar spectrum irradiance from 180 nm to 3000 nm using the SOLar SPECctral irradiance (SOLSPEC) instrument.

Results from Solar

The length of the period of the solar Extreme-UV minimum between solar cycles 23 and 24 * continued over an unexpected long period (roughly two years instead of one) with SolACES showing a distinct minimum in Aug./Nov. 2009. During the beginning solar cycle 24 measurements are showing abnormally low characteristics of the EUV spectral irradiance.

The Maximum of the Solar Cycle was also previously predicted for late 2013. However, in SolACES measurements up to now, the maximum of the Solar cycle currently appears in late 2011. After that the Solar Cycle sank and is stagnating at a lower level though measurements continue which does not exclude another strong increase of solar activity within the near future. Data from the SOLAR facility has already helped to validate improved models of the upper atmosphere. Results from NASA's Solar Radiation and Climate Experiment (SORCE) have shown that standard assumptions on the variability of the solar spectrum are incorrect.

A new method has now been developed which describes the effect of solar EUV on the ionosphere and its variability, called the EUV-Total Electron Content proxy. Solar Extreme UV (EUV) radiation is completely absorbed at altitudes above 50 km, so that it does not reach the Earth's surface. As mentioned previously it has the effect of heating Earth's atmosphere. A principal cause of this is a process called photo-ionisation where the Solar EUV interacts with the upper atmosphere causing electrons to detach from atoms and molecules. (This process also creates the temperature increase).

This new proxy is determined from ionisation rates calculated from solar EUV measurements taken from satellites. Comparisons have shown this method to be an improvement on conventional solar indices and may make it useful for scientific research in describing the ionospheric effects on radio communications and navigation systems.

In particular, EUV-TEC is able to represent the seasonal global Total Electron Content cycle during the solar minimum, which is not present in other indices used to describe solar variability.

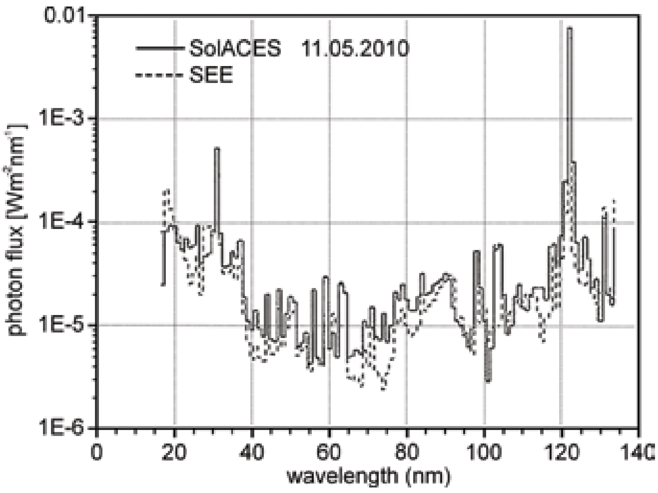


Fig.1 Example of a comparison of calibrated EUV spectra as measured by TIMED SEE and SolACES for solar minimum conditions

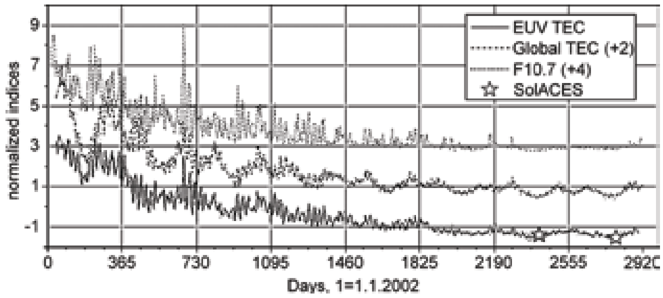


Fig.2 Time series of daily EUV-TEC indices, global mean TEC, and F10.7 solar radio flux during 2002–2009. Two data points based on SolACES measurements are shown as open stars in the upper panel

In particular, for representing ionospheric variability, the new proxy performs better than the frequently used F10.7 radio flux. It could be used to evaluate satellite navigation data (GNSS/GPS).

Data from the SOLAR facility (Fig. 1) on the ISS together with data from the Solar EUV Experiment (SEE) on board the NASA TIMED satellite (which measures Solar spectra in the wavelength range from 0.1 nm to about 200 nm) have helped to confirm the improvement in the EUV-TEC model.

SolACES has been measuring the short-wavelength solar EUV irradiance from 17 to 150 nm (Photo-ionisation occurs only at wavelengths up to 102 nm.) during the extended solar activity minimum.

Fig 2 shows the comparison of EUV-TEC and F10.7, together with global mean TEC, from 2002 to 2009. Two SolACES data points are shown on this graph, which correspond well with the TIMED-SEE data. The extension of this work is on-going.

A good correlation between EUV-TEC and F10.7 exists during high solar activity. Comparing EUV-TEC and the global TEC index, the seasonal pattern at low solar activity is visible in both. One may conclude that F10.7 does not represent ionospheric variability that well as the EUV-TEC proxy does, in particular during times of low solar activity.

Note that the majority of data points refer to low solar activity conditions, essentially because the last solar minimum was very extended, from 2007 to 2009. The F10.7 index approximately reaches a constant value during solar minimum conditions while the solar UV and EUV irradiance continues to decrease. This is one of the reasons that F10.7 is not a very good index for solar EUV variability during periods of low solar activity.

The Future

Continued monitoring of the current solar cycle 24 is of very special scientific interest, especially due to the abnormal behaviour already measured. It would also be the first time a full set of Solar Spectral Irradiance data would be provided and would answer open questions with respect to different solar cycle periods especially in the highly variable EUV spectral range.

The SOLAR facility will continue to serve the purpose of updating the measurements of the spectrum of solar radiation, which will provide important contributions for scientists to elaborate new and improved means to know and deal with all aspects (planetary climate, atmosphere, satellite telecommunications, medical, etc.), which are influenced by solar radiation. Providing the variability of solar Extreme UV radiation, SOLAR will contribute to improving the accuracy of navigation data, as well as the orbit forecasts of satellites and debris.

The data acquired by the science instruments of the SOLAR facility will help scientists in developing improved climate models, which could help us with future climate predictions. In addition the data coming from SOLAR can feed into future design of satellites to prolong their life in orbit and help preventing the effects of ultraviolet radiation on satellite communications.
On-going modelling of the EUV radiation will enable the definition of solar 'lead' emissions that could be monitored by a low-cost EUV sensor to provide real-time EUV data for near real-time application in satellite navigation data evaluation.

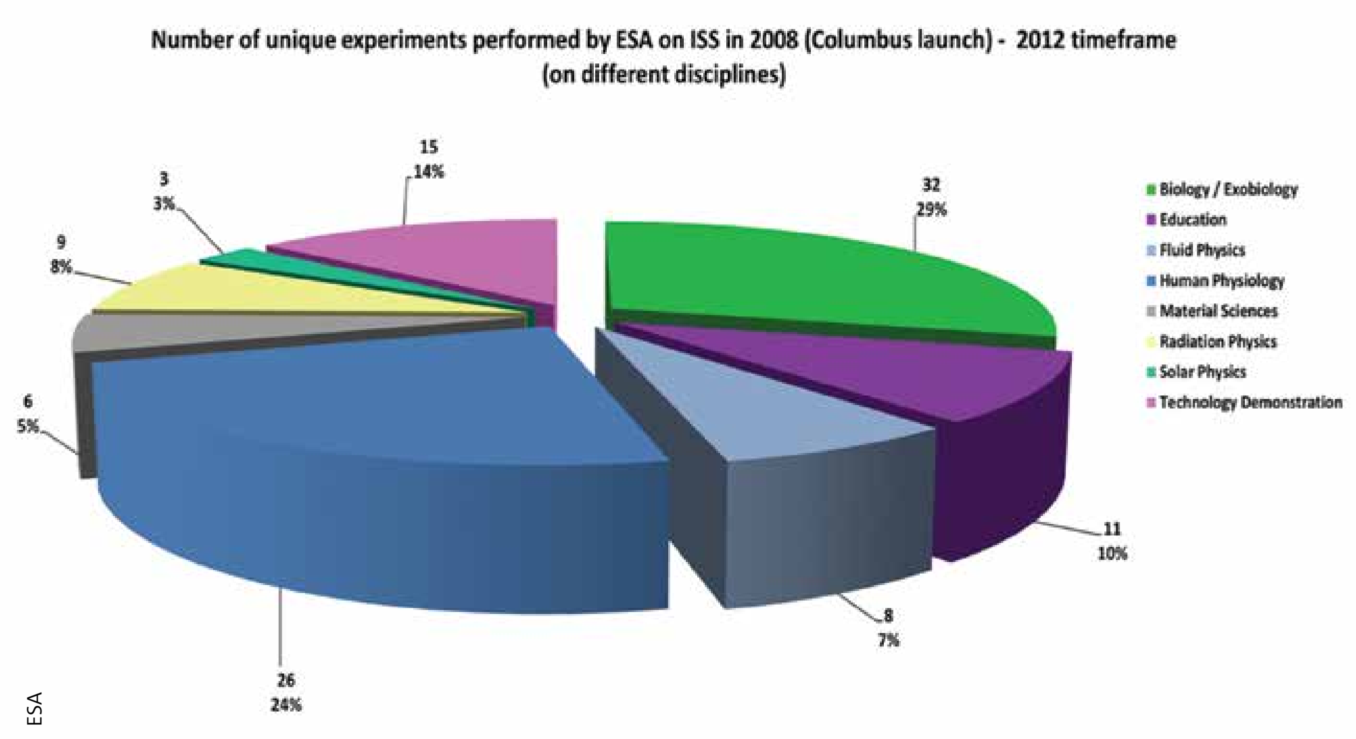
Only by studying solar activity in more detail can we hope to understand the physical mechanisms at work in the Sun. We can use this data to create models that better predict the solar activity, and therefore we can be more prepared for these effects and develop methods to help dealing with the negative effects of solar activity.

* *A Solar cycle is taken as the period between two solar minimum periods. From a historical measurement standpoint Solar cycle 1 is defined as the period between 1755 and 1766 with cycle 24 being the current cycle.*

➜ LIFE INSIDE THE STATION

Human Research in Columbus

The whole variety of human research activities have taken place in Europe's Columbus laboratory over the past five years, covering many areas from neuroscience to musculoskeletal research and cardiopulmonary research to immunology.



ESA Life Science research (Human Research, Biology, Exobiology) has accounted for more than 50% of the total amount of experiments that have taken place on the ISS since Columbus was launched

The mechanisms by which blood and nutrients are circulated around the body, how the human skeleton maintains its structure, and how we maintain balance and equilibrium are major areas within which gravity has a major influence. Previous research (and exposure to) space as well as simulated research campaigns on Earth have shown that weightlessness and the conditions in orbital spacecraft provide a unique burden to the human body. Understanding these effects and developing ways to counter them are beneficial for maintaining the health of our astronauts now and in the future, contribute to our understanding of many medical conditions prevalent on Earth and could help improve rehabilitation procedures.

The arrival of Columbus in 2008 enabled a significant enhancement of diagnostic capabilities in human research on the ISS with the European Physiology Modules Facility (and two NASA Human Research Facilities) installed inside Europe's ISS laboratory.

Neuroscience

ESA's neuroscience research on the ISS has been providing improved understanding of how the central nervous system is affected when adapting to and from weightlessness, providing an insight into such conditions as space adaptation syndrome or space sickness, improving diagnosis and treatment of patients with dizziness and equilibrium disorders on earth and with regard to aerospace technology, more refined design of flight simulator and virtual reality vision systems.

A number of long-duration neuroscience studies have taken place in Columbus focussing on various aspects of spatial orientation and visual perception, which is essential in order for astronauts to reliably perform their tasks in orbit. This is of especial significance when considering critical mission activities such as spacewalks.

NASA astronaut Greg Chamitoff undertaking the first ESA neuroscience experiment in Columbus, 3D Space, in July 2008

ESA's first two long-duration neuroscience experiments in Columbus were 3D-Space and NeuroSpat. 3D-Space started soon after Columbus arrived in orbit with NASA astronaut Greg Chamitoff as the first test subject. This research was investigating whether the absence of gravity is responsible for alterations in distance and depth perception in astronauts using 2D geometric illusions and 3D objects presented through a headset; distance estimation; and astronauts writing/drawing memorized objects following instructions.

Nine astronauts were test subjects for the experiment including ESA astronauts Frank De Winne (in 2009) and Paolo Nespoli (in 2011). From the data gathered the indications go in the same direction as earlier experiments. For example, a 3-D cube looks 'normal' when its height is smaller and width larger than a normal cube with the height effect being significant; hand drawn objects have greater width and smaller height than on the ground; words written vertically in 0g are shorter than pre-flight, but longer immediately after return; and the asymmetry between vertical and horizontal distance perception seen on Earth, where vertical distance is overestimated, disappears late in-flight. (Clément et al).

This process of quantifying altered perception in weightlessness and determining the mechanisms behind it continued with the NeuroSpat experiment, which was the first major neurological experiment to make full use of the European Physiology Modules facility and its Multi-Electrode Encephalogram Measurement Module (MEEMM). NeuroSpat started in June 2009, with ESA astronaut Frank De Winne and Canadian Space Agency astronaut Robert Thirsk as the first test subjects and is now just being completed with 5 subjects.

NeuroSpat has been investigating the ways in which crew members' perception of three-dimensional objects and space is affected by long-duration stays in weightlessness. It is too early to give any concrete results since CSA astronaut Chris Hadfield only completed the experiment as the final test subject in February 2013 so analysis is still on-going. However, NeuroSpat is a joint experiment protocol which includes the NeuroCog-2 and PreSpat experiments, with NeuroCog-2 itself being an extension of the earlier NeuroCog experiment which produced positive results from the research that was undertaken from 2002 to 2005 on the ISS.

ESA astronaut André Kuipers undertaking a session of the NeuroSpat experiment during the PromISSe mission in February 2012

If the positive results which came from NeuroCog are anything to go by then we should expect similarly significant results to come from NeuroSpat. NeuroCog revealed interesting results based on neural processes affecting angular perception by taking EEG measurements from astronauts while they traversed a virtual reality tunnel and provided feedback on angles turned. Interestingly on earth there is a greater error in angle perception when undertaking a forward nose down turn in a tunnel to a backward nose up turn. This difference surprisingly does not exist in weightlessness. The NeuroCog experiment revealed a disturbance in the 'higher' processes, that might involve memory, expectation, attention, or changes in the mental state, among others.

NASA astronaut and Expedition 25 commander Doug Wheelock, performing a session of the PASSAGES experiment in Columbus in October 2010

3D-Space and Neurospat laid the cornerstones of neuroscience in Columbus, which has subsequently been built upon with experiments such as the Passages experiment which also successfully concluded just over two years of research in March 2012 and the Reversible Figures experiment which started in July 2012. The Passages experiment was covered in detail in the previous newsletter and Reversible Figures will be covered in an upcoming issue.

Cardiopulmonary Research

With the effect that weightlessness has on cardiovascular deconditioning, cardiopulmo-nary research has always been a central focus of research activities for ESA within human spaceflight activities.

ISS Expedition 19 flight engineer and JAXA astronaut Koichi Wakata, preparing to use the Pulmonary Function System for a rebreathing session as part of the CARD experiment

There have been a couple of major ESA experiments in this area that have taken place in Columbus. The first of these, the CARD experiment, which concluded more than five years of research on the ISS in April 2012 was covered in detail in the previous newsletter. The experiment made use of the joint ESA/NASA Pulmonary Function System, located in NASA's Human Research Facility 2 in Columbus and followed on from ESA's first major cardiopulmonary experiment on the ISS: CardioCog.

One of ESA's major on-going research projects in Columbus which is adding to our improved knowledge of cardiovascular function is the Vessel Imaging experiment which started in June 2010. Vessel Imaging is providing information on blood vessel properties in weightlessness, by evaluating the changes in central and peripheral blood vessel wall properties and cross sectional areas in long-duration ISS crewmembers during and after long-term exposure to weightlessness using ultrasound scans of major arteries/veins combined with ECG and heart rate measurements. The experiment is borne from the suggestion that the long-term exposure to microgravity will induce changes in vessel wall properties as well as in the vessel size and flow, with similar effects as seen in bed rest studies.

NASA astronaut Dan Burbank setting up Human Research Facility 1 in Columbus for ultrasound scans on André Kuipers for the joint Vessel Imaging and Integrated Cardiovascular experiments in January 2012

If continued research determines that long-duration spaceflight increases cardiac output and induces dilation of peripheral arteries this suggests that long-duration spaceflight is actually healthy for the cardiovascular system. This will have an impact on how we prepare our astronauts and plan for future long-duration missions.

Establishing a better understanding of the influence that gravity plays in blood pressure control and the sympathetic nervous system over the course of a spaceflight mission will also shed light on certain cardiovascular conditions on Earth. This will in turn impact on the treatment and rehabilitation of patients suffering from hypertension and other cardiovascular diseases. The cost of cardiovascular disease was estimated at around €170 billion in the European Union in 2003. This indicates how important this area of research is, not only from a financial perspective, but also from the social perspective of the debilitating effects that such diseases can have.

ESA astronaut André Kuipers undertaking Body Mass Measurement for the SOLO experiment on 1 February 2012

Musculoskeletal

Within musculoskeletal research, undoubtedly the major ESA experiment which utilised equipment in Columbus was the Sodium Loading in Microgravity (SOLO) experiment. SOLO concluded on-orbit activities in April 2012 with the return of associated astronaut samples on Soyuz 28S including those for ESA astronaut André Kuipers. Data from the SOLO experiment, which builds on extensive research during previous bed rest studies and spaceflights, will help in determining the mechanisms and links between salt intake and bone metabolism and thus help in the development of countermeasures to bone mass reduction. This will not only be beneficial for maintaining the optimal health of astronauts in orbit, it will also shed light on conditions such as osteoporosis on earth. (An in-depth article on SOLO was published in the previous newsletter).

Immunology

ESA's immunology research in Columbus is built on a long line of ESA immunology research dating back decades. This includes numerous immunology experiments undertaken on the ISS including the on-going Immuno experiment since 2005 and numerous experiments in the Kubik incubators since 2006 which have been discovering more and more information concerning how the immune system adapts and is affected by weightlessness.

The PAthway DIfferent Activators (PADIAC) experiment followed in this line of research, taking place in Columbus in October 2010 using two of ESA's Kubik incubators, one of them situated in the European Drawer Rack. The goal of PADIAC is to study the possible inhibition of a certain receptor required for stimulation of T-lymphocytes.

A year later the ROALD-2 experiment in December 2011, was another major highlight of immunology research undertaken in Columbus. The ROALD-2 experiment (also covered in the previous newsletter) was undertaken in one of ESA's Kubik incubators during the PromISSe mission with André Kuipers.

MARES Commissioning

Most of the European research racks in Columbus were installed in Europe's laboratory prior to the Columbus launch in 2008. NASA's Human Research Facilities, EXPRESS Rack 3 containing the European Microgravity Cultivation System and the European-built Microgravity Science Glovebox were relocated to Columbus following its attachment to the ISS (though the Microgravity Science Glovebox was relocated back to the US laboratory in 2010). The final (ESA) rack facility to be installed in Columbus was the Muscle Atrophy Research and Exercise System (MARES) in April 2010 following its launch on the STS-131/19A Shuttle Flight. The facility was undergoing final commissioning steps during compilation of this report. MARES will be used for assessing the strength of isolated muscle groups around joints to provide a better understanding of the effects of weightlessness on the muscular system. ESA's facility's in Columbus such as the European Physiology Modules facility and MARES are complemented by NASA's Human Research Facilities in Columbus which have also been invaluable within ESA research for undertaking body mass measurements, ultrasound scans, and centrifuging blood samples.

CSA astronaut Chris Hadfield (left) and NASA astronaut Tom Marshburn working with the Muscle Atrophy Resistive Exercise System (MARES) in Columbus on 3 January 2013

→ FIVE YEARS OF BIOLOGY IN COLUMBUS

From Cells to Plants

ESA's life science activities in Columbus are supported by additional biology research looking into such mechanisms as gravitational response in plants and cells, with two of the principal facilities in Columbus for undertaking biology research being the European Modular Cultivation System and Biolab.

Arabidopsis thaliana or thale cress, a model plant studied in numerous ESA plant biology experiments such as Multigen and Genara

Exchange of Experiment Container in the European Modular Cultivation System on the ISS during Expedition 14

Plant Biology

Understanding the mechanisms behind which plants sense gravity and how these mechanisms are altered in weightlessness will be of vital importance for future human exploration missions where a greater deal of self- sufficiency with respect to food growth will positively impact on mission planning and cost.

The European Modular Cultivation System (EMCS) has had noticeable success stories from an ESA perspective including the Gravi-1 experiment, which produced very good results concerning gravity response in plant (lentil) seedlings and the (on-going) Multigen experiment, though these were undertaken in the facility prior to the relocation of the EMCS from the US laboratory to Columbus in 2008. However both of these projects have follow up experiments in the pipeline, related to gravity response in lentil roots and multi-generation plant growth processes in weightlessness.

Since the relocation of the EMCS to Columbus ESA subsequently undertook the Genara-A experiment in 2010, with the first samples returned on STS-133/ULF-5 in March 2011 for analysis. Undertaken in two parts Genara-A is aiming to identify gravity-regulated genes by assessing protein synthesis expression in Arabidopsis seedlings. The follow-up experiment is currently being defined prior to a future launch as a joint experiment protocol including the follow up to the Multigen experiment.

ESA astronaut Frank De Winne installing Yeast experiment containers into Biolab incubator in Columbus on 2 October 2009

Cell and Molecular Biology

Cell and molecular biology is the area of biology in which the majority of ESA experiments have taken place. Outside of the inherent immunology research, ESA has undertaken research on yeast cultures since 2001, with the most recent research in Columbus in 2009 with the Yeast In No Gravity experiment which was studying the effect of weightlessness on Flo proteins and its importance in the formation of organised cell structures (flocculation, biofilm, invasion) and the entire 'Flo processes' itself. This made use of functionality of the Biolab facility.

A year later the 'SPaceflight of Huvec: an Integrated Xperiment' (SPHINX) used the European Drawer Rack and the Kubik 6 incubator inside to carry out the experiment. The objective of the SPHINX experiment is to determine how HUVEC (Human Umbilical Vein Endothelial Cells) modify their behaviour when exposed to real weightlessness. This could provide better knowledge of endothelial function, which could be useful for clinical application. Endothelial cells, which line the interior of the heart and blood vessels, are important in many aspects of vascular function.

ESA's SPHINX (SPaceflight of Huvec: an Integrated eXperiment) Biobox kits floating between NASA astronaut Scott Kelly (left) and Russian cosmonaut Oleg Skripochka, both ISS Expedition 25 flight engineers, on 31 October 2010

→ RADIATION DOSIMETRY AND COLUMBUS

Monitoring the Space Weather Around Earth

ESA's radiation research is not only safeguarding our astronauts now and for future missions, it also helps test new shielding materials, can feed into applications in high-end technology and health care and helps us to better understand Earth's radiation 'weather' surrounding our planet and whether this has an impact on climatology.

Even before Columbus arrived at the ISS ESA has been a central figure in undertaking radiation research on the Station within the Alteino and ALTCRISS experiments from 2002, the Matroshka series of experiments since 2004 in addition to data gathered from European ISS crew members wearing European Crew Personal Dosimeters since 2006.

The Matroshka facility in its outer casing on the outside of the Russian Zvezda Module in September 2004

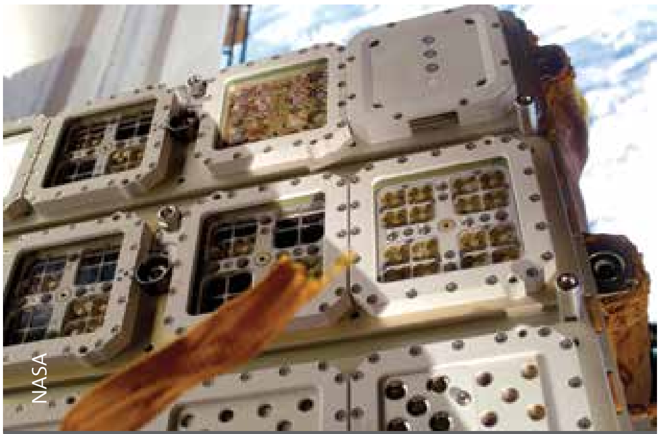
However, the attachment of Columbus heralded the start of four long-duration experiments that have taken place inside Europe's ISS laboratory to expand our knowledge of the radiation environment in low-Earth orbit. The first experiment to take place was the Dose Distribution inside the ISS (DOSIS) which was ESA's first radiation-related experiment to undertake area dosimetry, i.e. using multiple sensors spread around Columbus to build a picture of the nature and distribution of the radiation field inside the Space Station. This is valuable method in verifying the shielding qualities of the ISS in different areas.

An orange-packaged detector located on the front of ESA's European Physiology Modules Facility in the Columbus Laboratory as part of the DOSIS experiment

In addition to 11 sets of passive radiation detectors which were located around Columbus, which provide the accumulated radiation dose per increment, the experiment gathered data from two active radiation detectors, enabling the measurement of radiation fluctuations over time. These were located on the outer surface of the European Physiology Modules facility from which data was downlinked on a monthly basis. The set of passive detectors (which were swapped out for a new set after each increment) were analysed on return to earth. The experiment ran for two years in orbit from July 2009 to July 2011, and was hereafter succeeded by the very similar DOSIS-3D experiment, which has been active since 2012.

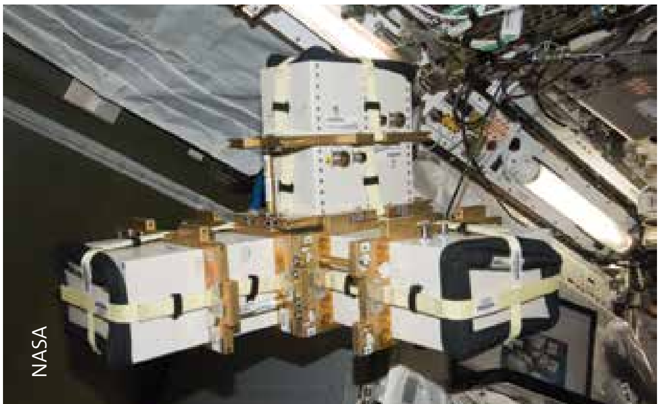
DOSIS included additional information from the Dosimetry for Biological Experiments in Space (DOBIES) experiment, which aims to develop a standard method to measure the radiation dosage experienced by biological samples in specific areas of the ISS using a combination of different dosimetric techniques. Similar radiation sensor packages were located on the outside of the ISS as part of ESA's EXPOSE-E payload (on ESA's EuTEF facility) and ESA's EXPOSE-R astrobiology payload.

Since May 2012 the DOSIS experiment has been built upon with the start of the DOSIS-3D experiment in Columbus (covered with an in-depth article in the previous newsletter). These two DOSIS experiments also support similar measurements by international ISS partners to map radiation across the whole station.



The Expose-R facility following installation on the outside of the Zvezda Service Module on the ISS in March 2009

The third long-duration radiation experiment to take place in Columbus was the ALTEA-Shield experiment, which follows in a long line of ALTEA (Anomalous Long Term Effects in Astronauts) experiments to take place on the Station. The ALTEA-Shield experiment is split into different parts. The first part of the experiment undertook a 3-dimensional survey of the radiation environment in the US laboratory (in three different locations) using the active ALTEA-silicon detectors. The three data acquisition periods were undertaken from September – November 2010, April – June 2011, and July – December 2011.



On-orbit hardware configured for the Survey part of ESA's ALTEA-Shield experiment

The next part of the experiment was undertaken in Columbus, testing two different materials (polyethylene and Kevlar), and different thicknesses of each material, for their shielding qualities against radiation. (An in depth article on this part of the experiment is also in the previous newsletter). André Kuipers set up and started this part of the experiment with the polyethylene tile samples in June 2012. These were swapped for the Kevlar tiles in August with this part of the experiment concluding on 13 November. The two sessions covered 54 days of cumulative data with the polyethylene tiles and 94 cumulative days of science acquisition with the Kevlar tiles. This surpassed the minimum requirement of 40 days.

André Kuipers setting up the ALTEA Shield hardware in the Shielding configuration on 8 June 2012

ESA's radiation research has been further expanded by the TriTel (Tri-Axis Telescope) experiment which is undertaking a 3D measurement of the radiation environment inside the Columbus laboratory using active and passive detector hardware. The active cosmic radiation detector hardware was installed in Columbus on 6 November 2012 following its transport to the ISS on Progress 49P. The active detector hardware includes three different detector types which are able to provide a 3-dimensional mapping of radiation entering Columbus i.e determining the time-dependent level of radiation and direction with which it travels into/through Columbus. After a successful checkout, an accompanying set of passive detectors were launched on Soyuz 33S which arrived at the ISS on 21 December 2012. These were installed the following day and the TriTel experiment has been continuing to acquire data since this date and is due to continue until mid-2013.

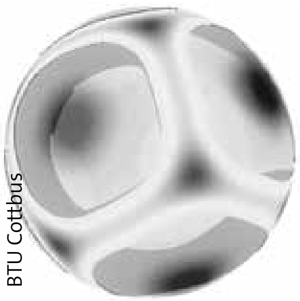
Continuing this type of research is a necessity. The spectrum of radiation to which an astronaut can be exposed is wide: UV, X-rays, and high energy particles: electrons, neutrons, protons and heavy ions (cosmic rays). The levels of these different types of radiation can vary for a number of reasons. 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 there is the additional daily effect of increased radiation when the Station passes through the South Atlantic Anomaly where Earth's magnetic field is weaker and the ISS encounters increased radiation doses for a short period of time. With all these different elements the radiation environment around our planet is therefore a complex environment to assess, though with each experiment undertaken in Columbus and on the ISS its complexities are becoming clearer step by step.

→ COLUMBUS AND FLUIDS RESEARCH

A Constant Flow of Data

ESA has had a successful history with fluids research in Columbus, utilising European-built facilities such as the Fluids Science Laboratory and the Microgravity Science Glovebox. This has encompassed extensive research goals within projects such as the SODI and Geoflow series of experiments

The Geoflow series of experiments (in-depth article in previous newsletter) have undertaken extensive research inside the Fluid Science Laboratory in Columbus with the first experiment runs from August 2008 to January 2009, Geoflow-2 concluding 14 months of on-orbit activities in May 2012, and the Geoflow-2b experiment starting in December 2012.



Graphic image generated from a Geoflow numerical model for spherical convective regimes. This octahedral pattern is generated in conditions of no rotation and a medium temperature gradient profile

Geoflow-2 and -2b (which follow on from the initial Geoflow experiment with new scientific objectives and a more complex experiment configuration) are investigating the flow of an incompressible viscous fluid held between two concentric spheres rotating about a common axis as a representation of a planet. This is of importance for astrophysical and geophysical problems such as global scale flow in the atmosphere, the oceans, and in the liquid nucleus of planets.

Some very important results have already come from the Geoflow experiment, which is helping to provide an insight into geophysical processes occurring inside planets.

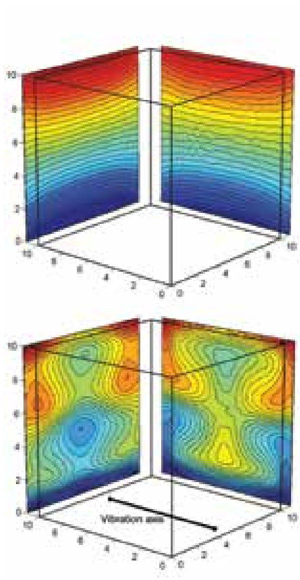
Outside of the Fluid Science Laboratory, ESA has undertaken some very successful fluids research inside the European-built Microgravity Science Glovebox in the period when it was installed inside Columbus before moving back to the US Laboratory in October 2010.

This was as part of the Selectable Optical Diagnostics Instrument (SODI) series of experiments (These are covered in detail in an article in the previous newsletter '10 Years of the MSG'). The first of these experiments was the SODI-IVIDIL (Influence of Vibrations on Diffusion in Liquids) experiment (Oct 2009 – Jan 2010) the results of which surpassed expectations with data received allowing the observation of flow patterns generated exclusively by controlled vibrations, for the first time. The experiment has been able to trace the variation of concentration of about 0.03% from the initial composition and made it possible to demonstrate vibrational effects and quantify their impact on the measurement of thermodiffusion coefficients.

September 2009 for the installation of the SODI-IVIDIL experiment hardware

IVIDIL was followed up by the SODI-Colloid experiment in September 2010 studying the growth of colloidal structures from solution in an aggregation process that can be easily controlled experimentally. The experiment may have interesting applications in photonics, with emphasis on nano-structured, periodic dielectric materials, known as photonic crystals, which possess appealing properties and make them promising candidates for new types of optical components.

Even though the analysis is still on-going, the set of images and data already studied are extremely promising as temperature controlled aggregation has already been evidenced for the first time.



Comparison between the convection flow without vibration (left) and with strong vibration (right) from the SODI-IVIDIL experiment

Following the conclusion of SODI-Colloid, the MSG was moved back to the US laboratory where the SODI experiments were completed with extensive runs of the SODI-Colloid 2 and DSC

(Diffusion and Soret Coefficient Measurements) experiments which took place at the end of 2011, start of 2012.

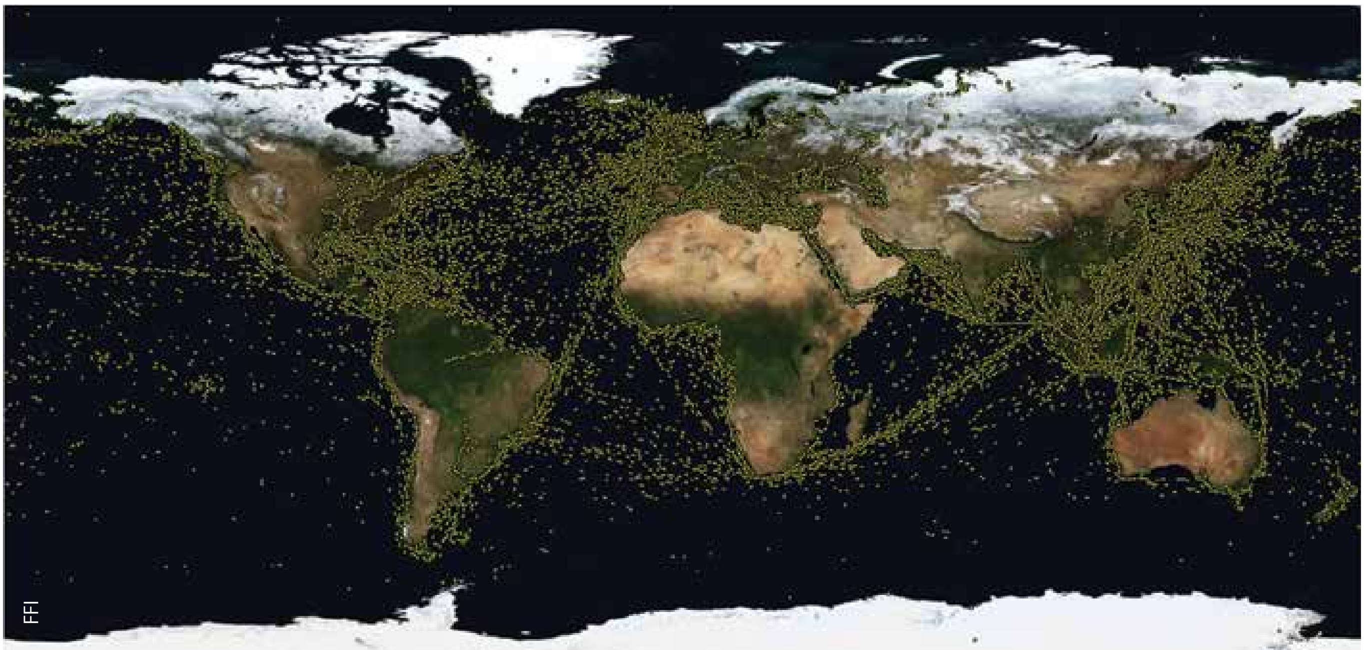
There are further positive expectations from ESA's fluids research in Columbus with the scheduled launches of the FASES (Fundamental and Applied Studies of Emulsion Stability) project on ATV-4 in April and FASTER (Facility for Adsorption and Surface Tension) project at the end of 2013 which are related to foams and emulsions research. FASES and FASTER will study the mechanisms of either stabilisation or destabilisation of emulsions using various combinations of surfactants, polymers and particles.

Emulsions (of which milk is a common example) commonly appear both in nature and man-made products aiming at specific properties for targeted applications. However, their production and stability pose problems of which only some are understood so far. The areas in which these have significance include: the physical chemistry of food, the hydrodynamics of complex fluids, the handling of crude oil and related instrumentation for process control. There are obvious applications of emulsions in the food industry, and therefore, industrial partners are interested in the role of proteins as natural surfactants.

→ TECHNOLOGY AND EUROPE'S ISS LABORATORY

Improving Processes in Space and on Earth

ESA has had a rich history of technology research on the ISS, even more so since the arrival of Columbus. This has covered an array of different areas from monitoring of maritime vessels at sea to testing technologies to improve astronaut health and performance.



Plot of global ship positions using AIS data from the Norwegian NORAIS Receiver. NORAIS forms part of ESA's Vessel Identification System for tracking global maritime traffic

One of the most successful technology demonstration has been the Vessel ID System which has been active since June 2010 (in depth article in the next newsletter). This technology has been verifying the capability to track global maritime traffic from space. It consists of two antenna assemblies that were mounted on the outside of Columbus during a spacewalk in November 2009, as well as data relay hardware and a receiver mounted inside Columbus. The system has undergone updates since activation to improve the system, especially with respect to improved decoding of signals in very busy shipping areas and undertaking near-real time data transfer. The current ground-based systems are only designed to monitor maritime vessels in coastal waters.

Outside of global tracking, The Wearable Augmented Reality (WEAR) hardware has shown great possibilities as a hands-free computer reference aid for assisting astronauts with undertaking on orbit activities. Combining multiple technologies such as object recognition, speech recognition, barcode reading, augmented reality and integration of multiple data sources, the system eradicates the need for manuals or other hand held media by providing the astronaut with a voice-controlled system that displays 3D graphics and data through a partially see-through viewing screen on a headset.

The AIS antenna following installation on the outside of the Columbus laboratory

Developed out of largely off-the-shelf space-qualified equipment to elicit a quick development time and keep budget considerations relatively low, ESA astronaut Frank De Winne successfully tested the system in Columbus in September 2009, using it to follow instructions to replace a filter. The success of the test has led to the consideration of the equipment for use in different sectors including non-space sectors such as fire fighting.

De Winne was also a central figure in successfully testing ESA's Flywheel Exercise in 2009, to determine its ability to conduct human physiology investigations in the area of advanced crew countermeasures.

ESA's next generation 3D video camera has gone through successful on-orbit commissioning and has already sent stunning 3D high definition images back to earth for use in outreach activities. This has included the first ever 3D high definition live streaming from space using the camera in August 2011. The camera uses the European Drawer Rack for downlinking data.

One of the latest technology devices which is being successfully tested on the ISS is the NightPod tracking device which supports a Nikon 3DS camera in taking high-definition pictures of the Earth, especially at night. The footage will be available for the public on the internet. The payload will also be used for education purposes in order to teach children and students about geography and demographic distribution on Earth.

ESA astronaut Frank De Winne's training session with the WEAR system

ESA astronaut and Expedition 26 Flight Engineer Paolo Nespoli, uses the ERB-2 3D video camera to film the ALTEA-Shield experiment on the International Space Station on 8 January 2011

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