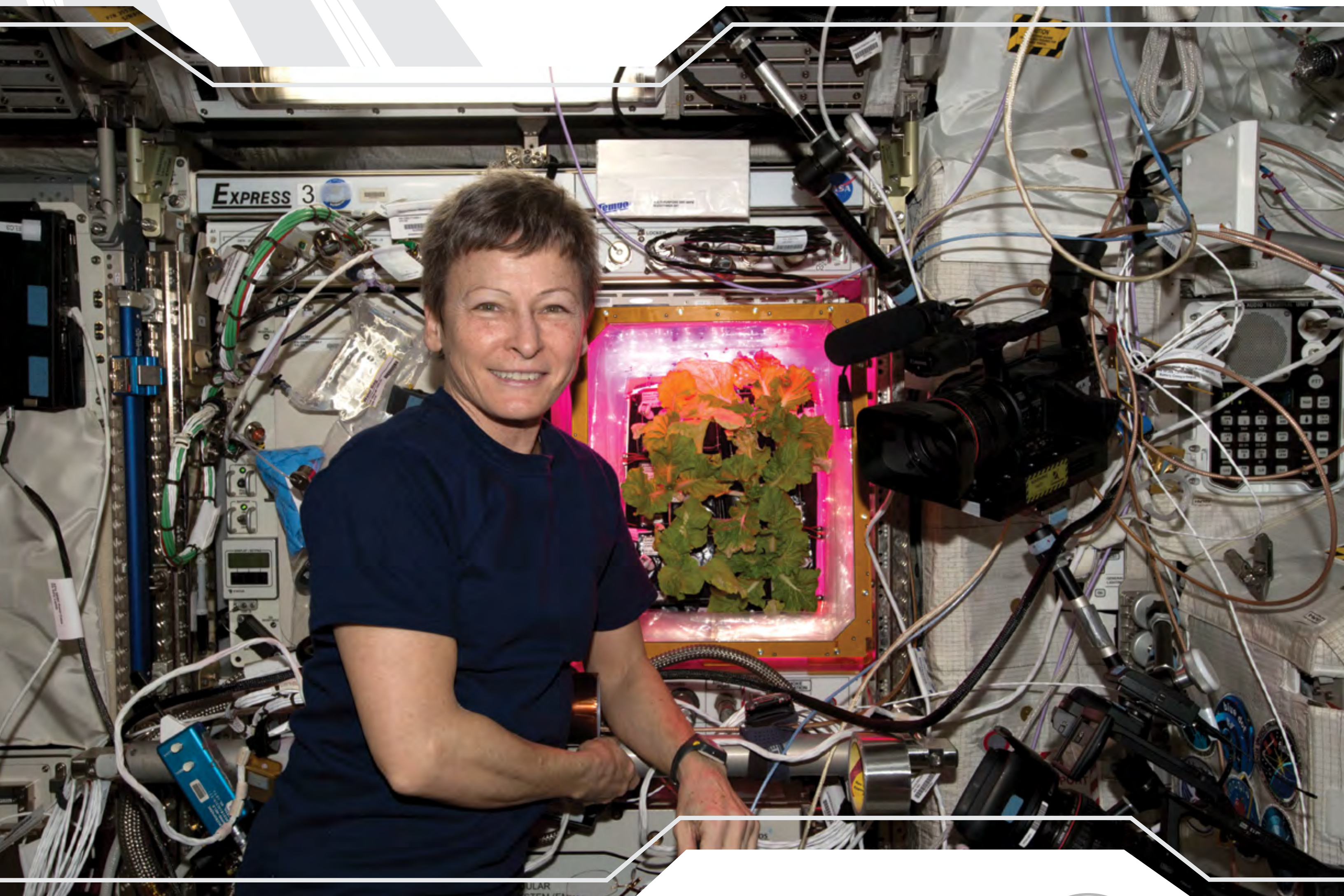
National Aeronautics and Space Administration

NASA

ANNUAL HIGHLIGHTS of RESULTS from the INTERNATIONAL SPACE STATION

October 1, 2016 – October 1, 2017



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ANNUAL HIGHLIGHTS of RESULTS from the INTERNATIONAL SPACE STATION

October 1, 2016 – October 1, 2017

Product of the International Space Station Program Science Forum

This report was developed collaboratively by the members of the Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), National Aeronautics and Space Administration (NASA), and the Roscosmos State Corporation for Space Activities (Roscosmos). The highlights and citations in this report, as well as all the International Space Station (ISS) results and citations collected to date can be found at: https://www.nasa.gov/stationresults.

Managing Editors

Tara Ruttley, NASA

Judy Tate-Brown, Barrios Technologies

Executive Editor

Julie Robinson, NASA

Cover:

ISS crewmember Peggy Whitson poses near Chinese cabbage plants growing in the Veggie facility.

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The night lights of cities in North and South America glow in this image captured by the Suomi National Polar-orbiting Partnership (NPP) satellite and mapped over existing imagery of Earth. The Suomi NPP satellite has a Visible Infrared Imaging Radiometer Suite that allows it to detect light in a range of wavelengths from green to near-infrared and uses filtering techniques to observe dim signals such as city lights, gas flares, auroras, wildfires, and reflected moonlight. This image provides new meaning to the Earth being a spaceship traveling through the darkness and overwhelming expanse of space.

Introduction

Research and Technology demonstration activities on the International Space Station (ISS) continue to progress, resulting in unprecedented scientific discoveries, benefits to Earth, and advancements in human exploration of space. From groundbreaking DNA amplification in space to understanding the sun's activity on Earth's climate, the ISS Program Science Office has identified 119 scientific publications that were collected between October 1, 2016, and October 1, 2017. Of the 119 publications, 113 were published in peer-reviewed journals, one was a book chapter and five were presented at conferences, reflecting an overall increase in publications by 6% since last year's 2016 Annual Highlights of Results from the International Space Station.[1] As of October 1, 2017, the ISS Program Science Office has identified a total of 2,031 publications since 1998 with sources in journals, conferences, and gray literature, representing the work of more than 3,500 scientists on Earth (Figure 1).

The results in this report represent the research and technology development activities sponsored by the National Aeronautics and Space Administration (NASA), the Roscosmos State Corporation for Space Activities (Roscosmos), the Japan Aerospace Exploration Agency (JAXA), the European Space Agency (ESA), and the Canadian Space Agency (CSA). This report will share some important highlights of the ISS results collected between October 1, 2016, and October 1, 2017, as well as the complete listings of the ISS results this year that benefit humanity, contribute to scientific knowledge, and advance the goals of space exploration for the world.

The ISS Program Science Office has a team of professionals dedicated to continuously collecting and archiving research results from all ISS utilization activities across the partnership at www.nasa.gov/iss-science. The database captures the ISS experiment summaries and results, and includes citations to the publications and patents as they become available. The team mines publications from the ISS research and technology development through many ways, including these examples:

- keyword searches with various tools and search engines
- databases such as AIAA, IEEE, IngentaConnect, JSTOR, J-STAGE, ScienceDirect, Wiley
- Web of Science
- conference proceedings
- science networks such as ResearchGate
- email alerts from systems such as Pubmed, Google Scholar, Nature Partner Journal-Microgravity
- NASA Taskbook and others
- ISS investigator and international partner websites
- personal email exchanges with ISS investigators and international partners

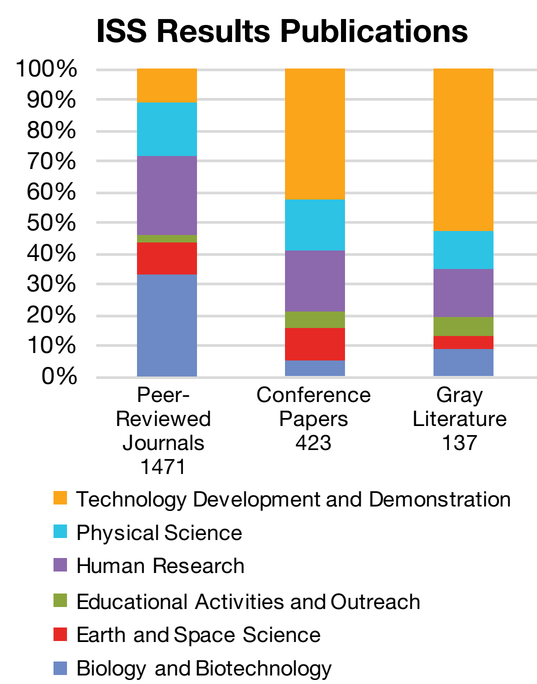


Figure 1: A total of 2,031 publications (through October 1, 2017) represent the work of scientists, worldwide. This chart illustrates the percentages for each area of research, per publication type.

1. Robinson, J, Ruttley, T, Tate-Brown, J. Annual Highlights of Results from the International Space Station: October 1, 2015-October 1, 2016. 2016;NASA/TP-2017-219791.

Because of the unique microgravity environment of the ISS laboratory, the multidisciplinary and international nature of the research, and the significance of the investment in its development, analyzing ISS scientific impacts is an exceptional challenge. As a result, the ISS Program Science Office uses different methods to describe the impacts of ISS Research activities.

Table 1: 2016-2017 ISS Publications In The Top 100 Global Journals, by Eigenfactor. From October 2016 to October 2017, 23 scientific publications from the ISS have been in the Top 100 journals ranked by Eigenfactor® as reported by 2016 Journal Citation Reports®, Clarivate Analytics.

	(Clarivate Analytics®) Ranks	Source (# of ISS articles)
ISS Publications In Top 100 Sources	1	PLOS ONE (6)
	2	Nature (1)*
	3	PNAS (1)
	6	Physical Review Letters (1)
	14	Scientific Reports (8)
	53	Geophysical Research Letters (1)
	70	Physical Review E (3)
	74	Langmuir (1)
	82	Biomaterials (1)

**This Nature publication was a MAXI paper published in January 2016 but discovered in 2017.*

One method used to evaluate scientific output from the ISS is to track the article citations and Eigenfactor rankings of journal importance across the ISS partnership. Because different disciplines have different standards for citation and different time spans across which citations occur, Eigenfactor uses an algorithm that uses the entire Web of Science citation network from Clarivate Analytics (formerly an analytical component of Thomson Reuters) spanning the previous 5 years, to create a metric that evaluates the importance of each journal (www.eigenfactor.org). The Eigenfactor Score counts citations to journals in both the sciences and social sciences, eliminates self-citations of journals, and is intended to reflect the amount of time researchers spend reading the journal. For the time period of October 1, 2016, to October 1, 2017, 23 ISS publications were published in the top 100 journals by Eigenfactor – nine of those ISS publications were in the top 10 journals as reported by Clarivate Analytics (Table 1).

To date, the most widely cited ISS articles that have been collected since 1998 are summarized as follows:

- The **AMS-02** investigation has collected and analyzed billions of cosmic ray events, and identified 9 million of these as electrons or positrons (antimatter), providing data that may lead to the solution of the origin of cosmic rays and antimatter, increasing the understanding of how our galaxy was formed. (Aguilar-Benitez M, et al., Physical Review Letters, 2013. Times Cited = 489)
- The **Subregional Bone** investigation found that the greatest space-induced bone loss occurs in pelvis, hip, and leg bones, which should be the focus of countermeasures and surface activities designed for space explorers on future missions beyond low-Earth orbit. (Lang TF, et al., Journal of Bone and Mineral Research, 2004. Times Cited = 381)
- The **Microbe** investigation implicated that the Hfq (RNA chaperone) protein acts as a major post-transcriptional regulator of Salmonella gene expression. (Sittka A, et al., Molecular Microbiology, 2007. Times Cited = 232)
- The **Astrovaktsina** investigation showed that the localization of the V-antigen in Yersinia plays a crucial role in the translocation process and its efficacy as the main protective antigen against plague. (Mueller CA, et al., Science, 2005. Times Cited = 231)
- The **MAXI** investigation revealed the existence of a hypernova remnant estimated to be 3 million years old, believed to be the first in our galaxy. (Burrows DN, et al., Nature, 2011. Times Cited = 228)

All information pertaining to ISS investigations across the ISS international partnership is continuously updated at http://www.nasa.gov/iss-science; in particular, publications of the ISS results can be found at http://www.nasa.gov/stationresults.

The ISS Program Science Office has developed an ISS Map of Science: a colorful visualization of the spread of knowledge gained from ISS research across the many different disciplines of science (Figure 2). The base map that underlies the ISS Map of Science is the widely used disciplinary classification system and layout algorithm known as the University of California, San Diego (UCSD) Map of Science.[2] The UCSD Map of Science is a reference-standard, disciplinary classification system derived from articles and citations contained in more than 25,000 journals carried by Thomson Reuters Web of Science and Scopus. In the UCSD visualization, each article is located within a network of 554 subdisciplines, which are then aggregated into 13 primary disciplinary classifications. Each colorful circle therefore represents a unique subdiscipline and is sized by how many scientific articles are present within that subdiscipline. The UCSD Map of Science was originally produced in 2005 at the request of UCSD, updated in 2012, and its map and classification system are distributed under the Creative Commons Attribution-Non Commercial-ShareAlike 3.0 Unported (CC BY-NC-SA 3.0) license (http://creativecommons.org/licenses/by-nc-sa/3.0/).

Overlaid on the standard UCSD Map of Science framework, and using its algorithm, the ISS Map of Science in Figure 2 displays the multidisciplinary nature of ISS research, given the significant presence of overlapping colors representing the different disciplines. Most importantly, this ISS Map of Science shows that the science conducted on the ISS has had an impact on 12 of the 13 primary disciplines that comprise the base map of all science (Humanities is excepted). These include both space-related and non-space-related scientific disciplines. Data used to develop this ISS Map of Science can be found in the Appendix.

ISS research results lead to benefits for human exploration of space, benefits to humanity, and the

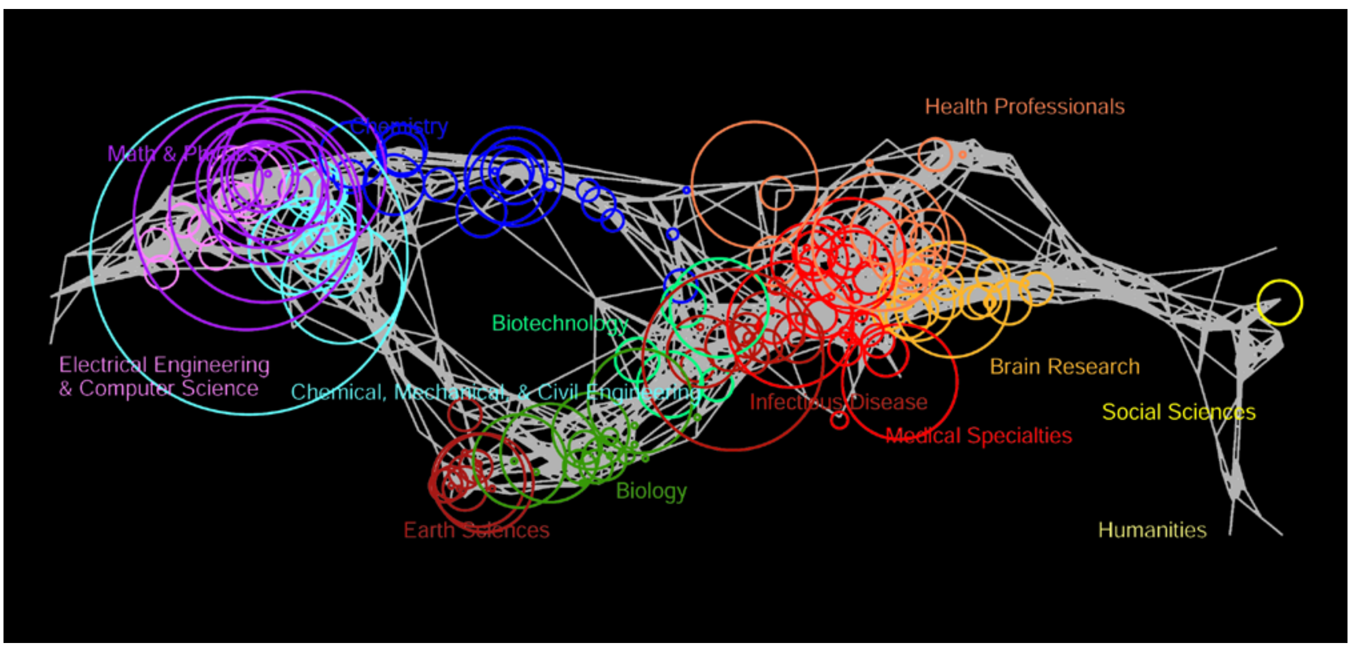


Figure 2: The ISS Map of Science for all ISS publications collected through October 1, 2017.

2. Borner, K, Kalvans R, Patek M, et al. Design and Update of a Classification System: The UCSD Map of Science. PLOS One. 2012 July; 7(7);e39464.

advancement of scientific discovery. This year's Annual Highlights of Results from the International Space Station includes comments on just a few of the results that were published in these areas from across the ISS partnership.

EXPLORATION

Results from the ISS have yielded updated insights into how to better live and work in space, such as addressing radiation effects on crew health, combating bone and muscle loss, improving designs of systems that handle fluids in microgravity, and how to most efficiently maintain environmental control.

BENEFITS FOR HUMANITY

Results from the ISS also have Earth-based applications, including understanding our climate, contributing to the treatments of disease, improving on existing materials, and inspiring the future generation of scientists, clinicians, engineers, technologists, mathematicians, explorers, and artists.

DISCOVERY

Results from the ISS can provide new contributions to the body of scientific knowledge in the areas of physical sciences, life sciences, and Earth and space sciences that advances scientific discoveries in multidisciplinary ways.

ISS crewmember Mike Hopkins, working with the Group Activation Pack (GAP) Experiment containing the Antibiotic Effectiveness in Space-1 (AES-1) investigation. AES-1 tests the hypothesis that antibiotics used to treat bacteria grown in space will exhibit reduced efficacy and will be associated with specific changes in bacterial gene expression that correlate with cell survival.

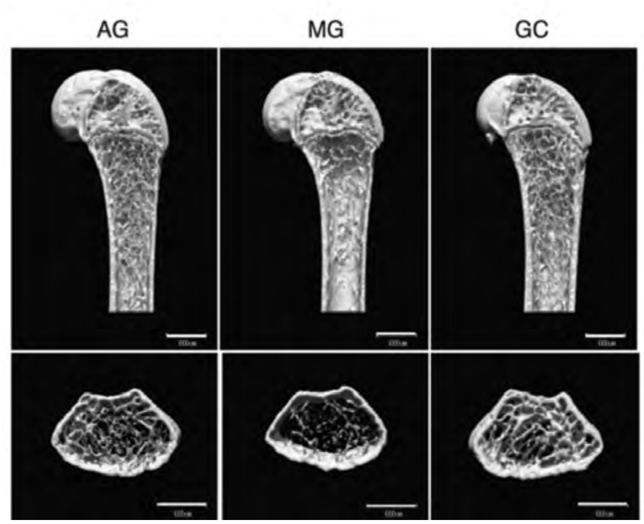
PUBLICATION HIGHLIGHTS:

BIOLOGY AND BIOTECHNOLOGY

The ISS laboratories enable scientific experiments in the biological sciences that explore the complex responses of living organisms to the microgravity environment. The lab facilities support the exploration of biological systems ranging from microorganisms and cellular biology to integrated functions of multicellular plants and animals. Several recent biological sciences experiments have facilitated new technology developments that allow growth and maintenance of living cells, tissues, and organisms.

EXPLORATION

JAXA's primary goal in the **Mouse Epigenetics** investigation is to study altered gene expression patterns in the organs of male mice that spend one month in space, as well as the changes in the DNA of their offspring. The first publication to arise from this study reports on the effects of artificial gravity from the on-orbit centrifuge on maintaining muscle and bone health of the ISS mice. Over an ISS duration of 35 days, mice that underwent artificial gravity exposure via regular continuous centrifugation at a 1-g (Earth-simulated) level did not display a significant decrease in soleus and gastrocnemius muscle weight and bone loss, unlike mice on the ISS that received no centrifugation. Both mice in artificial gravity and microgravity ate about the same during spaceflight; however, the microgravity mice showed higher water consumption. Upon return to Earth, the mice underwent a rotarod test, which is a standard laboratory test used to determine physical fitness of the mice. Both mouse groups exposed to spaceflight displayed less physical fitness than ground control mice, suggesting that despite the muscle and bone maintenance, spaceflight impaired motor coordination in both artificial gravity and microgravity mice. Overall, these findings provide results that will contribute to an understanding of physiological changes associated with artificial gravity exposure when considering it as a potential tool to maintain human health for long-duration spaceflight.



The representative vertical (upper) and horizontal (lower) sectional microCT photos of the proximal region of the femur. Scale bars = 1 mm. (Image courtesy of Shiba et al, Scientific Reports, 2017).

Shiba D, Mizuno H, Yumoto A, Shimomura M, Kobayashi H, et al. Development of new experimental platform 'MARS'—Multiple Artificial-gravity Research System—to elucidate the impacts of micro/partial gravity on mice. Scientific Reports. *2017 September 7; 7(1): 10837. DOI: 10.1038/s41598-017-10998-4. PMID: 28883615.*

DISCOVERY

ESA's **TripleLux-A** investigation studies the effects of microgravity on macrophage function. Macrophages are immune cells that engulf and break down microorganisms, cellular debris, and foreign particles. Macrophages are essential for cellular repair and overall healthy immune function, mainly due to their ability to perform a process called oxidative burst reaction, which causes chemical degradation of internalized particles, such as bacteria, that are a threat to the immune system. Results of this study showed that during the transition from a 1-g centrifuge to microgravity on the space station, the macrophages ability to generate oxidative burst reactions was reduced immediately, but subsequently recovered to their normal capabilities in less than a minute.

The "ultra-fast" adaptation indicates that mammalian macrophages are highly adaptive to a low-gravity environment; therefore, key cellular functions of multicellular life could adapt to and exist in a low-gravity environment, enabling long-duration space exploration beyond low-Earth orbit.

Thiel CS, de Zelicourt D, Tauber S, Adrian A, Franz M, et al. Rapid adaptation to microgravity in mammalian macrophage cells. Scientific Reports*. 2017 February 27; 7(1): 13 pp. DOI: 10.1038/s41598-017-00119-6.*

ISS crewmember Samantha Cristoforetti prepares the TripleLux-A experiment for return on SpaceX's Dragon cargo craft (ISS043E181043).

ISS crewmember Steve Swanson prepares to set up the Portable Pulmonary Function System hardware for Sprint VO2max sessions in the Destiny laboratory of the ISS (ISS040E123259).

PUBLICATION HIGHLIGHTS:

HUMAN RESEARCH

The ISS is being used to study the risks to human health that are inherent in space exploration. Many research investigations address the mechanisms of the risks—the relationship to the microgravity and radiation environments—and other aspects of living in space, including nutrition, sleep, and interpersonal relationships. Other experiments are used to develop and test countermeasures to reduce these risks. Results from this body of research are critical enablers for missions to the lunar surface and future Mars exploration missions.

EXPLORATION

Understanding how living in space affects human perception is critical for the development of safe, long-duration space travel. On the ground, humans perceive "up" and "down" from visual, gravity, and body orientation cues, but research has shown that perception is indeed altered by long-term weightlessness.

ISS crewmember Robert Thirsk uses the Neurospat hardware to perform the BISE investigation (ISS020E010314).

CSA's **Bodies In the Space Environment (BISE)** investigation studies how our multisensory system is affected in a microgravity environment. Visual reorientation illusions, inversion illusions, and motion sickness are regularly reported by space crew, and scientists suspect that long-term exposure to microgravity may cause significant changes in their perceived orientation. The BISE results showed a decrease in visual influence in flight subjects that was maintained throughout 6 months on the ISS and persisted several months after returning to Earth. Such a persistence of reduced visual dependency upon return to normal gravity is a concern for interplanetary missions in which astronauts landing on other planets must function without support of a ground-based recovery team. To deal with this effect, BISE investigators suggest that "visual gravity" should be introduced into spacecraft where visual cues to body orientation are generally not obvious.

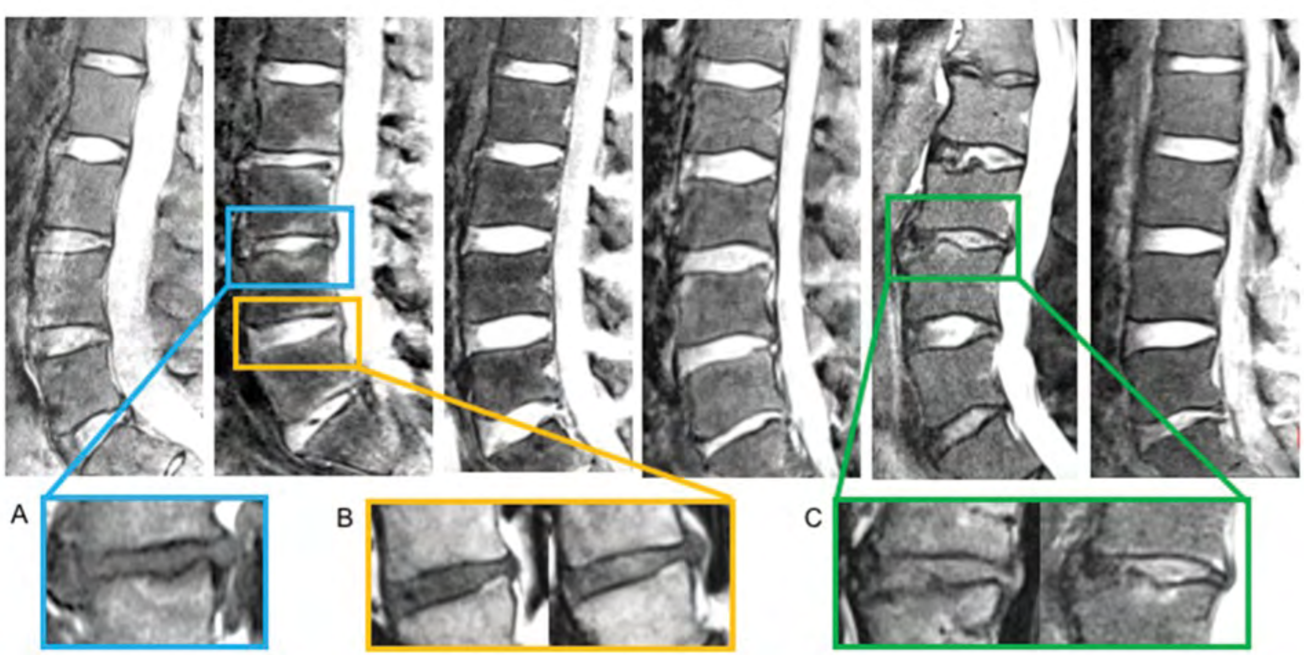
Harris LR, Jenkin MR, Jenkin HL, Zacher JE, Dyde RT. The effect of long-term exposure to microgravity on the perception of upright. npj Microgravity. *2017 January 12; 3(1): 3. DOI: 10.1038/s41526-016-0005-5. PMID: 28649625.*

BENEFITS FOR HUMANITY

EXPLORATION

NASA's **Risk of Intervertebral Disc Damage after Prolonged Space Flight (Intervertebral Disc Damage)** investigation aims to determine the impact of microgravity on the intervertebral discs of astronauts during and after long-duration stays in microgravity. Astronauts have reported back pain during long-duration microgravity missions and have experienced an increased likelihood of back injuries, such as herniated discs, after return to Earth. The discs create a cushion between vertebrae in a person's spine, and changes to their shape and size can affect the spinal column and back. Crewmembers participating in the Intervertebral Disc Damage experiment complete a battery of six tests before and after spaceflight so doctors can determine how the discs change, and whether this correlates to the pain those crewmembers experience. Results have shown that rather than intervertebral disc swelling, there was no change in water content of the discs, but a significant amount of muscle atrophy of the spine-stabilizing multifidus muscle. This atrophy was also associated with lumbar flattening and increased stiffness. Because these changes have been associated with harmful spine biomechanics and pain in populations on Earth, when combined with evidence of pre-flight spinal pathologies, they may elevate injury risk for astronauts upon return to gravity loading. These results contribute to new astronaut countermeasures that target the health of the multifidus muscles, and to research on the role of muscular stability in relation to chronic low back pain and disc injury.

Bailey JF, Miller SL, Khieu K, O'Neill CW, Healey RM, et al. From the international space station to the clinic: How prolonged unloading may disrupt lumbar spine stability. Spine Journal*. 2017 September 26; epub: 22 pp. DOI: 10.1016/j.spinee.2017.08.261. PMID: 28962911.*



Investigators found no systematic relationship between prolonged microgravity and disc water content (Bailey, Spine Journal, 2017).

BENEFITS FOR HUMANITY

Cosmic radiation represents one of the main health issues for space explorers during missions. To evaluate the impact of space radiation on human health and to reduce the uncertainty of related cancer risk, it is important to determine the exposure level as accurately as possible. Due to complexity of radiation environment in space and behind the shielding, accurate data must be obtained using calculations in conjunction with experimental measurements in real flight conditions.

ISS crewmember Koichi Wakata as he works with the Matroshka-R radiation suite phantom during Expedition 18 (ISS018E40993).

Roscosmos' **Matryoshka–R** from 2012 – 2013 examined packages with thermoluminescent and plastic nuclear track detectors at various locations onboard the ISS. Dose characteristics differed by a factor of about 2, depending on the location. Inside the ISS the maximal value of measured dose equivalent rate was about 1 mSv/day. Data obtained provides additional information about the radiation situation in space, helps to estimate the radiation risk of crewmembers, and can be used for the benchmarking of various codes and models for radiation risks.

Ambrozova I, Brabcova KP, Kubancak J, Slegl J, Tolochek RV, Ivanova OA, Shurshakov VA. Cosmic radiation monitoring at low-Earth orbit by means of thermoluminescence and plastic nuclear track detectors. Radiation Measurements. *2017; epub. DOI: 10.1016/j.radmeas.2016.12.004.*

EXPLORATION

DISCOVERY

ESA's **Effect of Gravitational Context on EEG Dynamics: A Study of Spatial Cognition, Novelty Processing and Sensorimotor Integration (Neurospat)** investigation examined how microgravity impacted the neural and cognitive processes of visual attention. Astronauts observed a virtual environment displayed on a computer screen simulating one of two scenarios: one piloting a spaceship toward the ISS (i.e., a period of visuo-attentional engagement) or one piloting a spaceship away from the ISS (i.e., a period of visuo-motor engagement). Neurospat results showed that there is increased electromagnetic brain activity in regions associated with motor processing throughout the period of visuo-attentional engagement. This indicates that the regions typically involved in motor control are also responsive during passive visuo-attentional tasks, most likely as a result of continuous readjustment of body posture in microgravity.

Neurospat results highlight discrepancies between a behavioral task (i.e., visuo-attentional) and the expected brain areas involved (i.e., primary motor). These findings contribute to the scientific advancement of neurocognition in astronauts who correct error signals for postural stabilization while free floating on the ISS even though the task at hand does not require movement. These Neurospat results contribute to the understanding of brain function in microgravity, which is crucial for the neurological health of astronauts on long-duration spaceflights.

Cebolla AM, Petieau M, Dan B, Balazs L, McIntyre J, et al. Cerebellar contribution to visuo-attentional alpha rhythm: insights from weightlessness. Scientific Reports. *2016 November 24; 6: 37824. DOI: 10.1038/srep37824. PMID: 27883068.*

ISS crewmember Andre Kuipers performs a NeuroSpat science session in the Columbus laboratory of the ISS (ISS030E116907).

Image taken during BASS-II flame test session with reduced oxygen partial pressure. BASS-II results contribute to the combustion computational models used in the design of fire detection and suppression systems in microgravity and on Earth (ISS040E023784).

PUBLICATION HIGHLIGHTS:
PHYSICAL SCIENCES

Much of our understanding of physics is based on the inclusion of gravity in fundamental equations. Using a laboratory environment found nowhere else, the ISS provides the only place to study long-term physical effects in the absence of gravity, without the complications of gravity-related processes such as convection and sedimentation. This unique microgravity environment allows different physical properties to dominate systems, and these have been harnessed for a wide variety of investigations in the physical sciences.

DISCOVERY

JAXA's **Crystal growth mechanisms associated with the macromolecules adsorbed at a growing interface – microgravity effect for oscillatory growth – 2 (Ice Crystal 2)** investigation analyzed images to measure the changes in growth of ice crystals in super-cooled water that contained an antifreeze glycoprotein impurity (AFGP). Researchers observed that ice morphology in the antifreeze solution changed to a polyhedral shape whereas pure water growth took on a circular disk shape on the ISS. Minimum values of growth rates obtained in microgravity were smaller than those for pure water due to the known effect of convection of crystal growth.

Researchers also observed that growth rates increased with temperature and higher concentrations of AFGP. These results indicated an important feature of AFGP molecules in that they greatly enhanced the growth rate of basal faces of the ice crystals. This is a significant observation that showed AFGP molecules absorbed on the basal faces promoted growth, counter to the previously believed effect that AFGP inhibited growth. Biological AFGP is found in several species of polar fish, where it prevents the formation of ice crystals even in freezing water, thus protecting the fish from freezing. Understanding how AFGP works could lead to new research in the fundamental physics of crystal growth, and how biological molecules can affect crystal formation.

ISS crewmember Koichi Wakata displays Ice Crystal 2 during preparations for its installation into the Solution Crystallization Observation Facility (ISS039E015633).

Furukawa Y, Nagashima K, Nakatsubo S, Yoshizaki I, Tamaru H, et al. Oscillations and accelerations of ice crystal growth rates in microgravity in presence of antifreeze glycoprotein impurity in supercooled water. Scientific Reports*. 2017 March 6;7:43157. DOI: 10.1038/srep43157. PMID: 28262787.*

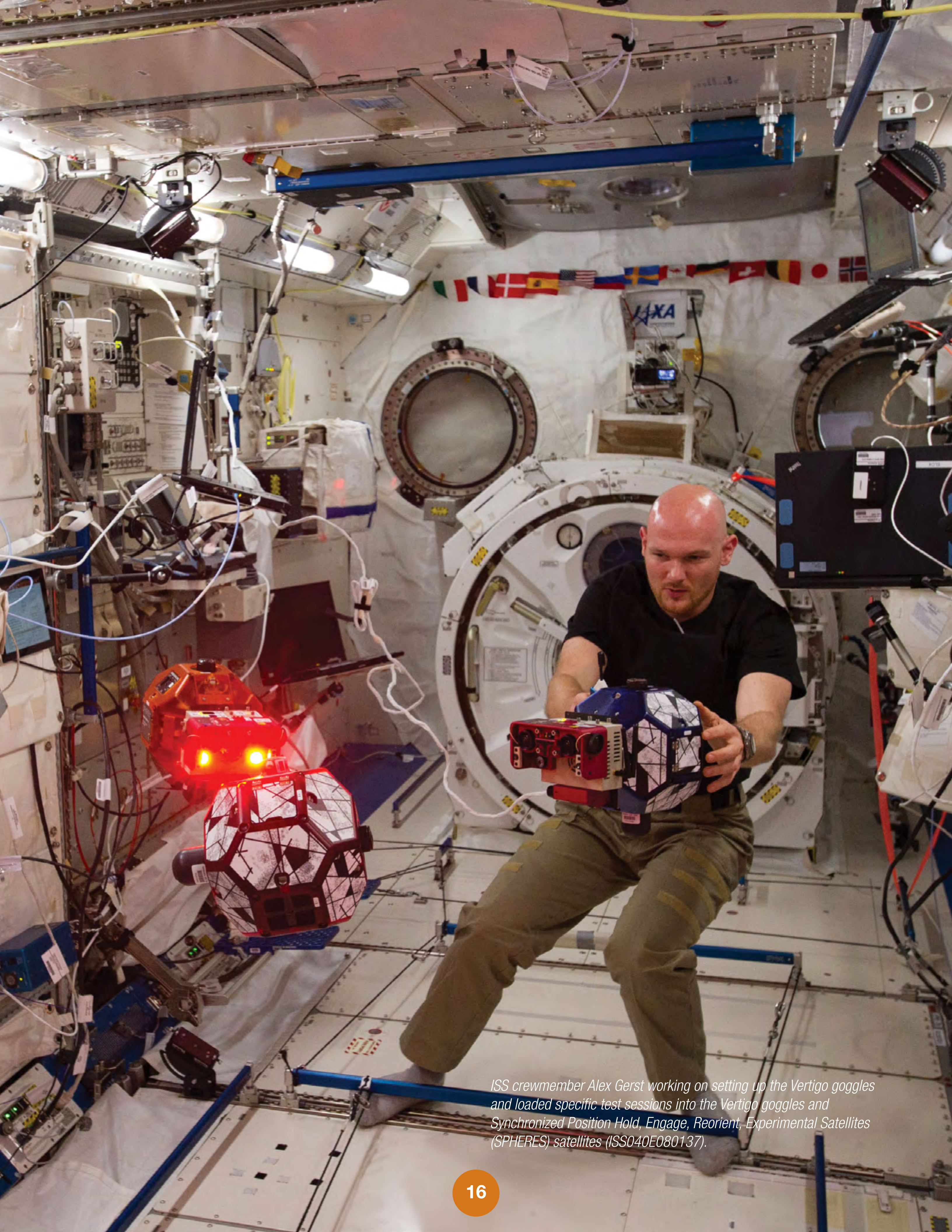
DISCOVERY

Roscosmos' **PK-3 Plus** laboratory was designed to study complex or "dusty" plasmas, which get their name from the presence of small, solid particles mixed into the plasma's charged gases. These particles can dramatically change the behavior of a plasma, and sometimes the particles even form crystalline structures. Dusty plasmas are found near artificial satellites, occur in Earth's upper atmosphere, and can be produced in lab settings. Physicist's favor them because they are relatively easy to control and provide a unique view of physics at the single-particle level. Dusty plasmas can be difficult to study on Earth because the planet's gravity affects the way dust particles settle and how they crystallize; hence, investigations in microgravity can be beneficial.

PK-3 Plus showed that the 'void' in the center of the complex plasma cloud could be easily closed under certain conditions, thus providing a much better homogeneity of the complex plasma – a feature unachievable on Earth. This is very promising as it is leads to new research areas around dusty plasmas. Instabilities in the plasma appear at high microparticle densities and are strongly related to changes in the plasma glow. However, even though homogeneous and void-free plasma is advantageous for modelling solid (crystalline), fluid, and gas phases and transitions between different phases, the reason for the void appearance in the neon distribution has created a new and interesting field of future study.

ISS crewmember Oleg Kononenko installing and preparing equipment for another run of the new PK-3 Plus investigation during Expedition 30. (ISS030E016793).

Naumkin VN, Zhukhovitskii DI, Molotkov VI, Lipaev AM, Fortov VE, Thomas HM, Huber P, Morfill GE. Density distribution of a dust cloud in three-dimensional complex plasmas. Physical Review E*. 2016 September 7; 94(3): 033204. DOI: 10.1103/PhysRevE.94.033204.*



ISS crewmember Alex Gerst working on setting up the Vertigo goggles and loaded specific test sessions into the Vertigo goggles and Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) satellites (ISS040E080137).

PUBLICATION HIGHLIGHTS:

TECHNOLOGY DEVELOPMENT AND DEMONSTRATION

Future exploration—the return to the moon and human exploration of Mars—presents many technological challenges. Studies on the ISS can test a variety of technologies, systems, and materials that will be needed for future Exploration missions. Some of the technology development experiments have been so successful that the hardware has been transitioned to operational status. Other experimental results feed new technology developments.

EXPLORATION

Agenzia Spaziale Italiana's **Anomalous Long Term Effects in Astronauts' Central Nervous System – Shield (ALTEA-Shield)** investigation used the ALTEA detectors set up to measure two different materials. The hardware monitored radiation levels in Express Rack 3 Columbus module for Polyethylene and Kevlar materials. An extensive amount of data was gathered to be applied to develop improved radiation and atmospheric models.

ISS crewmember Paolo Nespoli works with ALTEA Shield isotropic equipment in the Destiny laboratory of the ISS (ISS027E017236).

Radiation data was collected on the silicon detectors that were covered with tiles of different materials. Polyethylene is a well-known shielding material as it is extremely lightweight and contains large amounts of hydrogen (hydrogen atoms are efficient at absorbing and dispersing radiation). Kevlar is of great interest for spacecraft radiation shielding as it also has a known ability to protect human space infrastructures from meteoroids and debris. Successful accelerator-based tests have clearly demonstrated that Kevlar is an excellent shield for heavy ions, close to polyethylene. Results from this ISS study showed that the Kevlar material had comparable shielding properties with the polyethylene material, suggesting that the impact resistance and flexibility (also being a fabric) make it an optimal candidate as a performing element in an integrated shielding approach.

Narici L, Casolino M, Di Fino L, Larosa M, Picozza P, et al. Performances of Kevlar and Polyethylene as radiation shielding on-board the International Space Station in high latitude radiation environment. Scientific Reports*. 2017 May 10;7(1):1644. DOI: 10.1038/s41598-017-01707-2. PMID: 28490795.*

EXPLORATION

DISCOVERY

NASA's **Wet Lab RNA SmartCycler** is a new suite of tools on the ISS designed to process biological samples for real-time gene expression analysis. WetLab-2 includes a fluidic Ribonucleic (RNA) Sample Preparation Module, fluid transfer devices, lyophilized (freeze-dried) substances and enzymes for Polymerase Chain Reaction (PCR) assays, a centrifuge, and a real-time PCR thermal cycler. The system intakes diverse biological samples (e.g., cells, tissue, surface swabs, blood, etc.), uses temperature-stable substances, and allows for the isolation, purification, and reverse transcription of nucleic acids, such as RNA, for molecular biology analysis. Ground-based and on-orbit tests were conducted to validate the use of WetLab-2, and included *E. coli* primer assays, lyophilized components tests, sample preparation module tests, hardware tests, quantitative PCR (qPCR) efficiency tests of pre-prepared DNA concentrations (low, mid, high), as well as RNA extraction from *E. coli* and mouse liver tissue.

ISS crewmember Kate Rubins working with WetLab-2 RNA SmartCycler tubes for Session 3 (ISS049E040146).

Validation testing demonstrated that qPCR, RNA extraction, and gene expression analysis by Reverse Transcriptase-quantitative PCR (RT-qPCR) work well under microgravity conditions. Additionally, when problems such as gases accumulating in PCR tubes interfered with data uniformity, the system adapted to changes and iterations in real-time. Results showed that qPCR Cycle threshold (Ct) values and PCR efficiencies obtained on-orbit from DNA standards were similar to Earth (1g) controls. On-orbit analyses of gene expression of RNA extractions were successfully completed within 3 hours, thereby allowing researchers to receive results from multiple biological samples promptly. The WetLab-2 facility provides novel capabilities for the conduction of molecular biology research on-orbit, permitting the design, modification, and repetitions of experiments in space. WetLab-2 is publicly available to investigators for research on the ISS and may be used to analyze other types of samples or for medical diagnostics.

Parra MP, Jung J, Boone TD, Tran L, Blaber EA, et al. Microgravity validation of a novel system for RNA isolation and multiplex quantitative real time PCR analysis of gene expression on the International Space Station. PLOS ONE. *2017 September 6;12(9):e0183480. DOI: 10.1371/journal.pone.0183480. PMID: 28877184.*

View of Special Purpose Dextrous Manipulator (SPDM) DEXTRE carrying the Rapidscat instrument assembly (ISS041E049097).

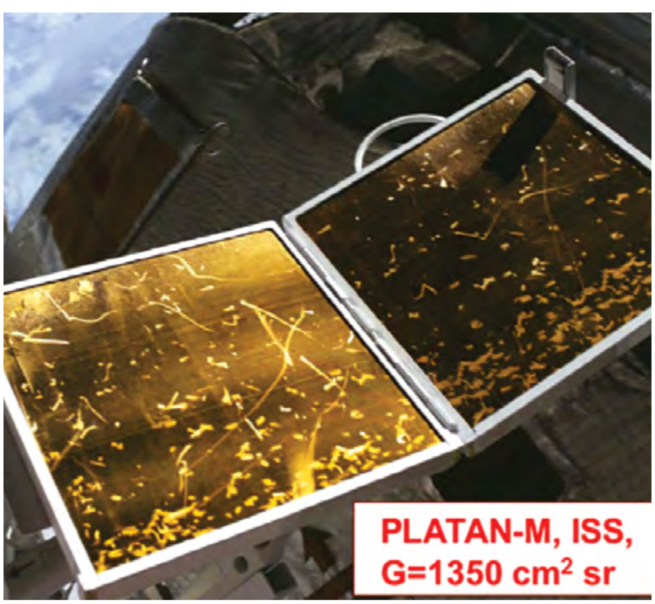
PUBLICATION HIGHLIGHTS:

EARTH AND SPACE SCIENCE

The presence of the space station in low-Earth orbit provides a unique vantage point for collecting Earth and space science data. From an average altitude of about 400 km, details in such features as glaciers, agricultural fields, cities, and coral reefs taken from the ISS can be layered with other sources of data, such as orbiting satellites, to compile the most comprehensive information available. Even with the many satellites now orbiting in space, the ISS continues to provide unique views of our planet and the universe.

EXPLORATION

Roscosmos' **Platan-Ferrum Galactic Cosmic Rays** investigation examined high-velocity microparticles such as micrometeoroids, orbital debris, and heavy nuclei of cosmic rays whose high likelihood of collision has threatened space stations over the years. This study analyzed the number and size of holes as well as craters that resulted from microparticle collisions against thermal control systems, the surface of a specimen container, and other materials.



View of the Platan-M experiment unit installed on the Zvezda.

The measurements conducted included the space stations Salyut-6, Salyut-7, Mir, and the ISS. Images of the space stations showed dents, cracks, and holes of circular shape with swellings around them. A different number of impacts were recorded depending on the detector and the length of the experiment. Relative to model predictions, investigators concluded that the diameter of a crater or a hole depends on the particle's size and velocity. These findings highlight the importance of studying space microparticles to protect spacecraft materials used in future exploration vehicles that will journey beyond low-Earth orbit.

Baranov DG, Dergachev VA, Nymmik RA, Panasyuk MI. Spectra of Fe ions in powerful SCR events. Bulletin of the Russian Academy of Sciences: Physics*. 2017 February 1;81(2):128-131. DOI: 10.3103/S1062873817020058.*

BENEFITS FOR HUMANITY

NASA's **Cloud-Aerosol Transport System (CATS)** investigation uses a light detection and ranging (LiDAR) system to measure the location, composition, and distribution of pollution, dust, smoke, aerosols, and other particulates in the atmosphere. CATS results have provided direct evidence that space-based LiDAR layer detection at 1064 nm is more representative of the true above-cloud aerosols scene compared to 532 nm. More accurate measurement of the vertical distribution of aerosols in the future will improve understanding of the semidirect effects of smoke plumes from biomass burning in Africa across the SE Atlantic. By gaining a better understanding of cloud and aerosol coverage, scientists can create a better model of the Earth's climate feedback processes.

Rajapakshe C, Zhang Z, Yorks JE, Yu H, Tan Q, et al. Seasonally transported aerosol layers over southeast Atlantic are closer to underlying clouds than previously reported. Geophysical Research Letters*. 2017 June 16; 44(11): 5818-5825. DOI: 10.1002/2017GL073559.*

View of CATS on the Japanese Experiment Module Exposed Facility (ISS049E006036).

BENEFITS FOR HUMANITY

DISCOVERY

ESA's **Sun Monitoring on the External Payload Facility of Columbus – SOLar SPECtral Irradiance Measurements (Solar-SOLSPEC)** is an instrument mounted externally on the ISS designed to acquire and analyze solar irradiance data. Examining the variability of solar irradiance broadens our understanding of the Earth's atmospheric photochemical processes and climate changes. SOLSPEC contains redundant optical devices that select a narrow band of light wavelengths. Results have shown that the spectral resolution of SOLSPEC changes as a function of the wavelength, agreement between thermal models, uncertainty associated with the absolute response of the instrument, and a wavelength-dependent uncertainty. Characterizing these parameters enables optimal SOLSPEC performance while on the ISS.

Multiple versions of SOLSPEC have been developed over the years to overcome the challenges presented by the space environment, including cosmic rays and outgassing. The most recent version of SOLSPEC covers 96% of the total solar spectrum and measures solar irradiance with high accuracy by correcting changes to the instrument's responsivity. Accurate and continuous solar irradiance measurements from space not only contribute to our understanding of Earth's climate, but can also inform the development of solar energy inventions to convert sunlight into electricity.

Bolsée D, Pereira N, Gillotay D, Pandey P, Cessateur G, et al. SOLAR/SOLSPEC mission on ISS: In-flight performance for SSI measurements in the UV. Astronomy & Astrophysics*. 2017 April 1; 600: A21. DOI: 10.1051/0004-6361/201628234.*

SOLSPEC mounted on the Columbus module (S128E009569).

ISS Research Results Publications

October 1, 2016 - October 1, 2017

(Listed by category and alphabetically by investigation.)

BIOLOGY AND BIOTECHNOLOGY

Antibiotic Effectiveness in Space-1 (AES-1) – Zea L, Prasad N, Levy SE, Stodieck LS, Jones A, Shrestha S, Klaus DM. A molecular genetic basis explaining altered bacterial behavior in space. *PLOS ONE*. 2016 November 2;11(11):e0164359. DOI: 10.1371/journal.pone.0164359.

Antibiotic Effectiveness in Space-1 (AES-1) – Zea L, Larsen M, Estante F, Qvortrup K, Moeller R, Dias de Oliveira S, Stodieck LS, Klaus DM. Phenotypic changes exhibited by E. coli cultured in space. *Frontiers in Microbiology*. 2017 August 28;8:1598-1610. DOI: 10.3389/fmicb.2017.01598.

Biorisk-MSN – Sugimoto M, Oono Y, Kawahara Y, Gusev OA, Maekawa M, Matsumoto T, Levinskikh MA, Sychev VN, Novikova ND, Grigoriev AI. Gene expression of rice seeds surviving 13- and 20-month exposure to space environment. *Life Sciences in Space Research*. 2016 November;11:10-17. DOI: 10.1016/j.lssr.2016.10.001. PMID: 27993188.

Biological Research In Canisters-17-1: Undifferentiated Cell development in Arabidopsis plants in Microgravity (BRIC-17-1) – Zupanska AK, Schultz ER, Yao J, Sng NJ, Zhou M, Callaham JB, Ferl RJ, Paul AL. ARG1 Functions in the Physiological Adaptation of Undifferentiated Plant Cells to Spaceflight. *Astrobiology*. 2017;epub. DOI: 10.1089/ast.2016.1538. PMID: 29088549.

Molecular Biology of Plant Development in the Space Flight Environment (CARA) – Paul AL, Sng NJ, Zupanska AK, Krishnamurthy A, Schultz ER, Ferl RJ. Genetic dissection of the Arabidopsis spaceflight transcriptome: Are some responses dispensable for the physiological adaptation of plants to spaceflight? *PLOS ONE*. 2017 June 29;12(6):e0180186. DOI: 10.1371/journal.pone.0180186. PMID: 28662188.

Crystallization of Huntingtin Exon 1 Using Microgravity (CASIS PCG HDPCG-1) – Owens GE, New DM, Olvera AI, Manzella JA, Macon BL, Dunn JC, Cooper DA, Rouleau RL, Connor DS, Bjorkman PJ. Comparative analysis of anti-polyglutamine Fab crystals grown on Earth and in microgravity. *Acta Crystallographica Section F: Structural Biology Communications*. 2016 October;72(10):762-771. DOI: 10.1107/S2053230X16014011. PMID: 27710941.

Dynamism of Auxin Efflux Facilitators, CsPINs, Responsible for Gravity-regulated Growth and Development in Cucumber (CsPINs) – Morohashi K, Okamoto M, Yamazaki C, Fujii N, Miyazawa Y, Kamada M, Kasahara H, Osada I, Shimazu T, Fusejima Y, Higashibata A, Yamazaki TQ, Ishioka N, Kobayashi A, Takahashi H. Gravitropism interferes with hydrotropism via counteracting auxin dynamics in cucumber roots: clinorotation and spaceflight experiments. *New Phytologist*. 2017;215(4):1476-1489. DOI: 10.1111/nph.14689.

ESA-Haptics-1 – Schiele A, Aiple M, Krueger T, Van Den Hulst F, Kimmer S, Smisek J, den Exter E. Haptics-1: Preliminary results from the first stiffness JND identification experiment in space. In: *Haptics: Perception, Devices, Control, and Applications*. 2016;9744:13-22. DOI: 10.1007/978-3-319-42321-0_2.***

European Technology Exposure Facility-Expose-Seeds (EuTEF-Expose-Seeds) – Tepfer D, Leach S. Survival and DNA damage in plant seeds exposed for 558 and 682 days outside the International Space Station. *Astrobiology*. 2017 March 6;17(3):205-215. DOI: 10.1089/ast.2015.1457. PMID: 28263676.

Regulation by Gravity of Ferulate Formation in Cell Walls of Rice Seedlings (Ferulate) – Wakabayashi K, Soga K, Hoson T, Kotake T, Kojima M, Sakakibara H, Yamazaki TQ, Higashibata A, Ishioka N, Shimazu T, Kamada M. Persistence of plant hormone levels in rice shoots grown under microgravity conditions in space: Its relationship to maintenance of shoot growth. *Physiologia Plantarum*. 2017 July 5;161(2):285-293. DOI: 10.1111/ppl.12591. PMID: 28573759.

KS5: Role of Gravity and Geomagnetic Field in Flatworm Regeneration (Flatworm Regeneration) – Morokuma J, Durant FR, Williams KB, Finkelstein JM, Blackiston DJ, Clements TS, Reed DW, Roberts MS, Jain M, Kimel K, Trauger SA, Wolfe BE, Levin M. Planarian regeneration in space: persistent anatomical, behavioral, and bacteriological changes induced by space travel. *Regeneration*. 2017 April 1;4(2):85-102. DOI: 10.1002/reg2.79.

International Space Station Internal Environments (ISS Internal Environments) – Green RD, Agui J, Berger GM, Vijayakumar R, Perry JL. Filter efficiency and pressure testing of returned ISS bacterial filter elements (BFEs). *47th International Conference on Environmental Systems*, Charleston, South Carolina July 16-20, 2017;7 pp.*

International Space Station Internal Environments (ISS Internal Environments) – Romoser AA, Scully RR, Limero TF, De Vera V, Cheng PF, Hand JJ, James JT, Ryder VE. Predicting air quality at first ingress into vehicles visiting the International Space Station. A*erospace Medicine and Human Performance*. 2017 February 1;88(2):104-113. DOI: 10.3357/AMHP.4702.2017.

International Space Station Internal Environments (ISS Internal Environments) – Mora M, Mahnert A, Koskinen K, Pausan MR, Oberauner-Wappis L, Krause R, Perras AK, Gorkiewicz G, Berg G, Moissl-Eichinger C. Microorganisms in confined habitats: Microbial monitoring and control of intensive care units, operating rooms, cleanrooms and the International Space Station. *Frontiers in Microbiology*. 2016 October 13;7:1573. DOI: 10.3389/fmicb.2016.01573. PMID: 27790191.**

Extremophiles – Mora M, Perras AK, Alekhova TA, Wink L, Krause R, Aleksandrova A, Novozhilova T, Moissl-Eichinger C. Resilient microorganisms in dust samples of the International Space Station-survival of the adaptation specialists. *Microbiome*. 2016 December 20;4(65). DOI: 10.1186/s40168-016-0217-7. PMID: 27998314.

Japan Aerospace Exploration Agency Protein Crystallization Growth (JAXA PCG) – Itoh T, Hibi T, Suzuki F, Sugimoto I, Fujiwara A, Inaka K, Tanaka H, Ohta K, Fujii Y, Taketo A, Kimoto H. Crystal structure of chitinase ChiW from Paenibacillus sp. str. FPU-7 reveals a novel type of bacterial cell-surface-expressed multi-modular enzyme machinery. *PLOS ONE*. 2016 December 1;11(12):e0167310. DOI: 10.1371/journal.pone.0167310.

Kennedy Space Center Fixation Tube (KFT) – LeFrois CE, Zhou M, Amador DM, Sng NJ, Paul AL, Ferl RJ. Enabling the spaceflight methylome: DNA isolated from plant tissues preserved in RNAlater™ is suitable for Bisulfite PCR assay of genome methylation. *Gravitational and Space Research*. 2016 December;4(2):28-37.

Crystalization of Biological Macromolecules and Generation of Biocrystal Film in the Conditions of Microgravity (Kristallizator-Modul-1) – Boyko KM, Timofeev VI, Samygina VR, Kuranova IP, Popov VO, Koval'chuk MV. Protein crystallization under microgravity conditions. Analysis of the results of Russian experiments performed on the International Space Station in 2005–2015. *Crystallography Reports*. 2016 ;61(5):718-729. DOI: 10.1134/S1063774516050059.

Crystalization of Biological Macromolecules and Generation of Biocrystal Film in the Conditions of Microgravity (Kristallizator-Modul-1) – Smirnova EA, Kislitsyn YA, Sosfenov NI, Lyashenko AV, Popov AN, Baidus AN, Timofeev VI, Kuranova IP. Protein crystal growth on the Russian segment of the International Space Station. *Crystallography Reports*. 2009 September; 54(5): 901-911. DOI: 10.1134/S106377450905023X.**

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Medaka Osteoclast – Chatani M, Morimoto H, Takeyama K, Mantoku A, Tanigawa N, Kubota K, Suzuki H, Uchida S, Tanigaki F, Shirakawa M, Gusev OA, Sychev VN, Takano Y, Itoh T, Kudo A. Acute transcriptional up-regulation specific to osteoblasts/osteoclasts in medaka fish immediately after exposure to microgravity. *Scientific Reports*. 2016 December 22;6:39545. DOI: 10.1038/srep39545. PMID: 28004797.

MicroRNA Expression Profiles in Cultured Human Fibroblasts in Space (Micro-7) – Lu T, Zhang Y, Wong M, Feiveson AH, Gaza R, Stoffle NN, Wang H, Wilson B, Rohde L, Stodieck LS, Karouia F, Wu H. Detection of DNA damage by space radiation in human fibroblasts flown on the International Space Station. *Life Sciences in Space Research*. 2017 February;12:24-31. DOI: 10.1016/j.lssr.2016.12.004.

MicroRNA Expression Profiles in Cultured Human Fibroblasts in Space (Micro-7) – Lu T, Zhang Y, Kidane Y, Feiveson AH, Stodieck LS, Karouia F, Ramesh GT, Rohde L, Wu H. Cellular responses and gene expression profile changes due to bleomycin-induced DNA damage in human fibroblasts in space. *PLOS ONE*. 2017 March 1;12(3):e0170358. DOI: 10.1371/journal.pone.0170358.

Microbial Tracking Payload Series (Microbial Observatory-1) – Knox BP, Blachowicz A, Palmer JM, Romsdahl J, Huttenlocher A, Wang CC, Keller NP, Venkateswaran KJ. Characterization of Aspergillus fumigatus isolates from air and surfaces of the International Space Station. *mSphere*. 2016 October 26;1(5):e00227-16. DOI: 10.1128/mSphere.00227-16. PMID: 27830189.

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Microbial Tracking Payload Series (Microbial Observatory-1) – Venkateswaran KJ, Singh NK, Checinska Sielaff A, Pope RK, Bergman NH, Van Tongeren SP, Patel NB, Lawson PA, Satomi M, Williamson CH, Sahl JW, Keim P, Pierson DL, Perry JL. Non-toxin-producing Bacillus cereus strains belonging to the B. anthracis clade isolated from the International Space Station. *mSystems*. 2017 May-June; 2(3): 16 pp. DOI: 10.1128/mSystems.00021-17. PMID: 28680972.

Microbial Tracking Payload Series (Microbial Observatory-1) – Be NA, Avila-Herrera A, Allen JE, Singh NK, Checinska Sielaff A, Jaing C, Venkateswaran KJ. Whole metagenome profiles of particulates collected from the International Space Station. *Microbiome*. 2017 July 17;5(1):81. DOI: 10.1186/s40168-017-0292-4. PMID: 28716113.

Microbial Tracking Payload Series (Microbial Observatory-1) – Venkateswaran KJ, Checinska Sielaff A, Ratnayake S, Pope RK, Blank TE, Stepanov VG, Fox GE, Van Tongeren SP, Torres C, Allen JE, Jaing C, Pierson DL, Perry JL, Koren S, Phillippy A, Klubnik J, Treangen TJ, Rosovitz MJ, Bergman NH. Draft genome sequences from a novel clade of *Bacillus cereus sensu lato* strains, isolated from the International Space Station. *Genome Announcements*. 2017 August 10;5(32):3. DOI: 10.1128/genomeA.00680-17. PMID: 28798168.

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Transcriptome Analysis and Germ-Cell Development Analysis of Mice in Space (Mouse Epigenetics) – Shiba D, Mizuno H, Yumoto A, Shimomura M, Kobayashi H, Morita H, Shimbo M, Hamada M, Kudo T, Shinohara M, Asahara H, Shirakawa M, Takahashi S. Development of new experimental platform 'MARS'—Multiple Artificial-gravity Research System—to elucidate the impacts of micro/partial gravity on mice. *Scientific Reports*. 2017 September 7;7(1):10837. DOI: 10.1038/s41598-017-10998-4. PMID: 28883615.

NanoRacks-CellBox-Primary Human Macrophages in Microgravity Environment (NanoRacks-CellBox-PRIME) – Tauber S, Lauber BA, Paulsen K, Layer LE, Lehmann M, Hauschild S, Shepherd NR, Polzer J, Segerer J, Thiel CS, Ullrich O. Cytoskeletal stability and metabolic alterations in primary human macrophages in long-term microgravity. *PLOS ONE*. 2017 April 18;12(4):e0175599. DOI: 10.1371/journal.pone.0175599. PMID: 28419128.

NanoRacks-The Investigation of Countermeasures to Modulate and Augment the Immune System (NanoRacks-ISS University Research (UR) - 1) – Okoro E, Mann V, Ellis I, Mansoor E, Olamigoke L, Marriott KC, Denkins P, Williams W, Sundaresan A. Immune modulation in normal human peripheral blood mononuclear cells (PBMCs) (Lymphocytes) in response to benzofuran-2-carboxylic acid derivative KMEG during spaceflight. *Microgravity Science and Technology*. 2017 August;29(4):331-336. DOI: 10.1007/s12217-017-9551-z.

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SPHEROIDS – Pietsch J, Gass S, Nebuloni S, Echegoyen D, Riwaldt S, Baake C, Bauer J, Corydon TJ, Egli M, Infanger M, Grimm DG. Three-dimensional growth of human endothelial cells in an automated cell culture experiment container during the SpaceX CRS-8 ISS space mission – The SPHEROIDS project. *Biomaterials*. 2017 April;124:126-156. DOI: 10.1016/j.biomaterials.2017.02.005. PMID: 28199884.

Gene, Immune and Cellular Responses to Single and Combined Space Flight Conditions – A (TripleLux-A) – Thiel CS, de Zelicourt D, Tauber S, Adrian A, Franz M, Simmet DM, Schoppmann K, Hauschild S, Krammer S, Christen M, Bradacs G, Paulsen K, Wolf SA, Braun M, Hatton JP, Kurtcuoglu V, Franke S, Tanner S, Cristoforetti S, Sick B, Hock B, Ullrich O. Rapid adaptation to microgravity in mammalian macrophage cells. *Scientific Reports*. 2017 February 27;7(1):13 pp. DOI: 10.1038/s41598-017-00119-6.

HUMAN RESEARCH

Advanced Resistive Exercise Device (ARED) – Petersen N, Lambrecht G, Scott J, Hirsch N, Stokes M, Mester J. Postflight reconditioning for European astronauts – A case report of recovery after six months in space. *Musculoskeletal Science and Practice*. 2017 January; 27(Suppl 1):S23-S31. DOI: 10.1016/j.msksp.2016.12.010. PMID: 28173929.

The Effect of Long-term Microgravity Exposure on Cardiac Autonomic Function by Analyzing 24-hours Electrocardiogram (Biological Rhythms) – Otsuka K, Cornelissen G, Furukawa S, Kubo Y, Hayashi M, Shibata K, Mizuno K, Aiba T, Ohshima H, Mukai C. Long-term exposure to space's microgravity alters the time structure of heart rate variability of astronauts. *Heliyon*. 2016 December;2(12):e00211. DOI: 10.1016/j.heliyon.2016.e00211. PMID: 28050606.

Bodies In the Space Environment: Relative Contributions of Internal and External Cues to Self - Orientation, During and After Zero Gravity Exposure (BISE) – Harris LR, Jenkin MR, Jenkin HL, Zacher JE, Dyde RT. The effect of long-term exposure to microgravity on the perception of upright. *npj Microgravity*. 2017 January 12;3(1):3. DOI: 10.1038/s41526-016-0005-5. PMID: 28649625.

A Simple In-flight Method to Test the Risk of Fainting on Return to Earth After Long-Duration Spaceflights (BP Reg) – Hughson RL, Yee NJ, Greaves DK. Elevated end-tidal Pco2 during long-duration spaceflight. *Aerospace Medicine and Human Performance*. 2016 October; 87(10): 894-897. DOI: 10.3357/AMHP.4598.2016. PMID: 27662353.**

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Validation of Procedures for Monitoring Crewmember Immune Function (Integrated Immune) – Crucian BE, Babiak-Vazquez A, Johnston SL, Pierson DL, Ott CM, Sams CF. Incidence of clinical symptoms during long-duration orbital spaceflight. *International Journal of General Medicine*. 2016 November 3;9:383-391. DOI: 10.2147/IJGM.S114188. PMID: 27843335.

Validation of Procedures for Monitoring Crewmember Immune Function (Integrated Immune) – Kunz HE, Quiriarte HD, Simpson RJ, Ploutz-Snyder RJ, McMonigal KA, Sams CF, Crucian BE. Alterations in hematologic indices during long-duration spaceflight. *BMC Hematology*. 2017 September 8;17:12. DOI: 10.1186/s12878-017-0083-y.

Risk of Intervertebral Disc Damage after Prolonged Space Flight (Intervertebral Disc Damage) – Chang DG, Healey RM, Snyder AJ, Sayson JV, Macias BR, Coughlin DG, Bailey JF, Parazynski SE, Lotz JC, Hargens AR. Lumbar spine paraspinal muscle and intervertebral disc height changes in astronauts after long-duration spaceflight on the International Space Station. *Spine*. 2016 December 15;41(24):1917-1924. DOI: 10.1097/BRS.0000000000001873.

Risk of Intervertebral Disc Damage after Prolonged Space Flight (Intervertebral Disc Damage) – Bailey JF, Miller SL, Khieu K, O'Neill CW, Healey RM, Coughlin DG, Sayson JV, Chang DG, Hargens AR, Lotz JC. From the international space station to the clinic: How prolonged unloading may disrupt lumbar spine stability. *The Spine Journal*. 2017 September 28;S1529-9430(17):30978-30986. DOI: 10.1016/j.spinee.2017.08.261. PMID: 28962911.

International Space Station Medical Monitoring (ISS Medical Monitoring) – Lambrecht G, Petersen N, Weerts G, Pruett CJ, Evetts SN, Stokes M, Hides JA. The role of physiotherapy in the European Space Agency strategy for preparation and reconditioning of astronauts before and after long duration space flight. *Musculoskeletal Science and Practice*. 2017 January; 27(Suppl 1):S15-S22. DOI: 10.1016/j.math.2016.10.009. PMID: 28173928.

International Space Station Medical Monitoring (ISS Medical Monitoring) – Koppelmans V, Bloomberg JJ, Mulavara AP, Seidler RD. Brain structural plasticity with spaceflight. *npj Microgravity*. 2016 December 19;2(1):2. DOI: 10.1038/s41526-016-0001-9. PMID: 28649622.

International Space Station Medical Monitoring (ISS Medical Monitoring) – Larina IM, Percy AJ, Yang J, Borchers CH, Nosovsky AM, Grigoriev AI, Nikolaev EN. Protein expression changes caused by spaceflight as measured for 18 Russian cosmonauts. *Scientific Reports*. 2017 August 15;7(1):8142. DOI: 10.1038/s41598-017-08432-w. PMID: 28811532.

Incidence of Latent Virus Shedding During Space Flight (Latent Virus) – Mehta SK, Laudenslager ML, Stowe RP, Crucian BE, Feiveson AH, Sams CF, Pierson DL. Latent virus reactivation in astronauts on the International Space Station. *npj Microgravity*. 2017 April 12;3(1):11. DOI: 10.1038/s41526-017-0015-y. PMID: 28649633.

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Effect of Gravitational Context on EEG Dynamics: A Study of Spatial Cognition, Novelty Processing and Sensorimotor Integration (Neurospat) – Cebolla AM, Petieau M, Dan B, Balazs L, McIntyre J, Cheron G. Cerebellar contribution to visuo-attentional alpha rhythm: insights from weightlessness. *Scientific Reports*. 2016 November 24;6:37824. DOI: 10.1038/srep37824. PMID: 27883068.

The Effects of Long-Term Exposure to Microgravity on Salivary Markers of Innate Immunity (Salivary Markers) – Kunz HE, Quiriarte HD, Simpson RJ, Ploutz-Snyder RJ, McMonigal KA, Sams CF, Crucian BE. Alterations in hematologic indices during long-duration spaceflight. *BMC Hematology*. 2017 September 8;17:12. DOI: 10.1186/s12878-017-0083-y.

Space Headaches – Vein AA, Koppen H, Haan J, Terwindt GM, Ferrari MD. Space headache: A new secondary headache. *Cephalalgia*. 2009 June 1;29(6): 683-686. DOI: 10.1111/j.1468-2982.2008.01775.x.**

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*Conference
**Published previous year
***Book chapter

APPENDIX

Below is the listing of each journal represented in the ISS Map of Science (Figure 2) and the discipline with respective citation counts archived in the ISS PST.

BIOLOGY

3 American Journal of Botany
2 BMC Plant Biology
1 Environmental Microbiology
1 Fungal Ecology
1 International Journal of Plant Sciences
2 ISME Journal
1 Journal of Experimental Biology
1 Journal of Microbiological Methods
1 Journal of Plant Physiology
3 Journal of Plant Research
4 Microbes and Environments
2 Microbial Ecology
1 Molecular Ecology
4 New Phytologist
1 Physiologia Plantarum
1 Plant and Cell Physiology
7 Plant Biology
1 Plant Cell and Environment
1 Plant Physiology
1 Plant Science
6 Planta
1 Protoplasma
2 Zoological Science

BIOTECHNOLOGY

3 Acta Crystallographica Section D–Biological Crystallography
5 Acta Crystallographica Section F–Structural Biology and Crystallization Communication
1 Antonie van Leeuwenhoek International Journal of General and Molecular Microbiology
2 Applied Microbiology and Biotechnology
1 Biochemistry–Moscow
2 Biochimica et Biophysica Acta–Proteins and Proteomics
2 Bioscience Biotechnology and Biochemistry
1 BMC Genomics
1 FEBS Letters
1 International Journal of Systematic and Evolutionary Microbiology
1 Journal of Proteome Research
1 Medical Mycology
1 Proteomics

BRAIN RESEARCH

1 Acta Physiologica
1 Archives Italiennes de Biologie
1 Brain Behavior and Immunity
1 Brain Research
1 Brain Structure & Function
1 Bulletin of Experimental Biology and Medicine
1 Cephalalgia
2 Doklady Biochemistry and Biophysics
1 European Archives of Oto–rhino–laryngology
3 Experimental Brain Research
1 Gerontology
1 International Journal of Endocrinology
1 Journal of Magnetic Resonance Imaging
2 Journal of Neurophysiology
1 Journal of Neurosurgery
2 Journal of Physiology–London
7 Journal of Vestibular Research–Equilibrium & Orientation
1 Lancet Neurology
1 Neuroreport
2 Neuroscience Letters
1 Radiology
1 Reviews in the Neurosciences
1 Stroke
1 Vision Research

CHEMICAL, MECHANICAL, & CIVIL ENGINEERING

72 Acta Astronautica
4 Acta Materialia
1 Acta Mechanica
3 Applied Thermal Engineering
26 Aviation Space and Environmental Medicine
5 Combustion and Flame
1 Combustion Science and Technology
1 Combustion Theory and Modelling
1 Comptes Rendus Mecanique
1 European Journal of Mechanics B–Fluids
2 Experimental Thermal and Fluid Science
2 Experiments in Fluids
2 Fire Safety Journal
6 International Journal of Heat and Mass Transfer
2 International Journal of Multiphase Flow
1 ISIJ International
3 JOM
2 Journal of Fluid Mechanics
2 Journal of Guidance Control and Dynamics
2 Journal of Heat Transfer–Transactions of the ASME
1 Journal of Materials Science
1 Journal of Nuclear Science and Technology
7 Journal of Spacecraft and Rockets
3 Journal of Thermophysics and Heat Transfer
25 Microgravity Science and Technology
5 Physics of Fluids
8 Proceedings of the Combustion Institute
2 Russian Journal of Physical Chemistry B
7 Solar Physics

CHEMISTRY

1 Biosensors & Bioelectronics
1 Chemical Communications
2 Chemistry Letters
3 Colloids and Surfaces A–Physicochemical and Engineering Aspects
4 Crystal Growth & Design
8 Crystallography Reports
7 European Physical Journal E
2 High Performance Polymers
1 Inorganic Materials
1 International Journal of Molecular Sciences
3 Journal of Chemical Physics
1 Journal of Colloid and Interface Science
1 Journal of Food Science
1 Journal of Pharmaceutical and Biomedical Analysis
1 Journal of Photochemistry and Photobiology A–Chemistry
1 Journal of Physical Chemistry B
2 Journal of Quantitative Spectroscopy & Radiative Transfer
3 Langmuir
2 Molecules
1 MRS Bulletin
1 Polymer Degradation and Stability

EARTH SCIENCES

2 Aerosol Science and Technology
4 Atmospheric Chemistry and Physics
1 Earth and Planetary Science Letters
1 Environmental Research Letters
2 GIScience & Remote Sensing
2 IEEE Geoscience and Remote Sensing Letters
1 IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing
3 IEEE Transactions on Geoscience and Remote Sensing
2 International Journal of Remote Sensing
6 Journal of Geophysical Research–Atmospheres
1 Journal of the Atmospheric Sciences
1 Meteoritics & Planetary Science
2 Remote Sensing of Environment
1 Terrestrial Atmospheric and Oceanic Sciences

ELECTRICAL ENGINEERING & COMPUTER SCIENCE

4 Applied Optics
1 Electronics and Communications in Japan
1 Human Factors
1 Japanese Journal of Applied Physics
1 Journal of Field Robotics

1 Journal of Real–time Image Processing
2 Optics Express
1 Photonics Spectra
1 Technology in Cancer Research & Treatment
1 Ultrasound in Medicine and Biology

HEALTH PROFESSIONALS

2 AAPS Journal
1 American Journal of Clinical Nutrition
1 Biomaterials
1 British Journal of Nutrition
1 Canadian Medical Association Journal
4 European Journal of Applied Physiology
1 European Spine Journal
2 Free Radical Research
1 IEEE Transactions on Biomedical Engineering
2 International Journal of Radiation Biology
23 Journal of Applied Physiology
4 Journal of Biomechanics
1 Journal of Emergency Medicine
1 Journal of Nutrition
1 Journal of Occupational and Environmental Medicine
1 Journal of Orthopaedic Research
2 Journal of Pineal Research
3 Journal of Radiation Research
1 Journal of Strength and Conditioning Research
2 Journal of the Royal Society Interface
1 Journal of Tissue Engineering and Regenerative Medicine
1 Journal of Trauma–Injury Infection and Critical Care
1 Medicine and Science in Sports and Exercise
1 Muscle & Nerve
3 Mutation Research–Genetic Toxicology and Environmental Mutagenesis
6 Radiation Research
1 Spine
1 Tissue Engineering Part A
1 Tissue Engineering Part B–Reviews

INFECTIOUS DISEASES

1 BMC Immunology
1 BMC Microbiology
1 Clinical and Vaccine Immunology
1 Cytokine
1 Cytoskeleton
1 European Journal of Clinical Microbiology & Infectious Diseases
1 FEMS Immunology and Medical Microbiology
1 Journal of Bacteriology
1 Journal of Clinical Immunology
1 Journal of Interferon and Cytokine Research
1 Journal of Leukocyte Biology
1 Journal of Medical Virology
2 Microbiology and Immunology
1 Microbiology and Molecular Biology Reviews
1 Molecular Biology
1 Molecular Immunology
1 Molecular Microbiology
1 Mutation Research–Fundamental and Molecular Mechanisms of Mutagenesis
41 PLOS One
1 Research in Microbiology
1 Russian Journal of Genetics
1 Stem Cell Research
1 Stem Cells and Development

MATH & PHYSICS

44 Advances in Space Research
29 Astrobiology
1 Astrophysical Journal
1 Astrophysical Journal Supplement Series
1 Contributions to Plasma Physics
12 Cosmic Research
5 Europhysics Letters (EPL)
1 General Relativity and Gravitation
1 Geomagnetism and Aeronomy
1 IEEE Transactions on Nuclear Science
6 IEEE Transactions on Plasma Science
15 International Journal of Astrobiology
2 Journal of Atmospheric and Solar–Terrestrial Physics
2 Journal of Cosmology and Astroparticle Physics

8 Journal of Crystal Growth
5 Journal of Geophysical Research–Space Physics
1 Journal of Physics G–Nuclear and Particle Physics
1 Journal of Physics–Condensed Matter
2 Journal of Synchrotron Radiation
1 Nanoscale Research Letters
6 New Journal of Physics
1 Nuclear Instruments & Methods in Physics Research Section A– Accelerators, Spectrometers, Detectors and Associated Equipment
2 Nuclear Instruments & Methods in Physics Research Section B– Beam Interactions with Materials and Atoms
1 Physical Review D
22 Physical Review Letters
6 Physics of Plasmas
3 Planetary and Space Science
3 Plasma Physics and Controlled Fusion
1 Plasma Sources Science & Technology
16 Publications of the Astronomical Society of Japan
14 Radiation Measurements
3 Review of Scientific Instruments

MEDICAL SPECIALTIES

1 American Journal of Pathology
5 American Journal of Physiology–Heart and Circulatory Physiology
3 American Journal of Physiology–Regulatory Integrative and Comparative Physiology
1 American Journal of Surgery
1 Australasian Physical & Engineering Sciences in Medicine
1 Biochemical and Biophysical Research Communications
8 Bone
1 Diabetes
1 Echocardiography–A Journal of Cardiovascular Ultrasound and Allied Techniques
11 Federation of American Societies for Experimental Biology (FASEB) Journal
2 In Vitro Cellular & Developmental Biology–Animal
1 In Vivo
1 International Journal of Radiation Oncology Biology Physics
5 Journal of Bone and Mineral Research
1 Journal of Cataract and Refractive Surgery
3 Journal of Cellular Biochemistry
1 Journal of Musculoskeletal & Neuronal Interactions
2 Journal of Neuro–ophthalmology
1 Journal of Urology
7 Journal of Women's Health
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1 Oncogene
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1 PLOS Biology
3 Radiation and Environmental Biophysics
13 Radiation Protection Dosimetry
5 Respiratory Physiology & Neurobiology
1 Skin Pharmacology and Physiology
1 Zeitschrift fur Medizinische Physik

SOCIAL SCIENCES

2 Atmospheric Measurement Techniques

MULTIPLE CATEGORIES

1 Analytical and Bioanalytical Chemistry
2 Applied and Environmental Microbiology
1 Geophysical Research Letters
1 Journal of Biological Chemistry
2 Nature
1 Neuroimage
10 Physical Review E
4 PNAS
1 Science

UNCLASSIFIED

1 ACM Transactions on Intelligent Systems and Technology
1 Acta Crystallographica Section F–Structural Biology Communications
1 Advances in Astronomy
1 Advances in Physical Ergonomics and Human Factors
16 Aerospace Medicine and Human Performance
1 Applications in Plant Sciences
1 Astronomy & Astrophysics
4 Biomed Research International
1 Catalysts
1 Comparative Biochemistry and Physiology A–Molecular & Integrative Physiology
1 Cytometry Part A
3 Diffusion in Materials
1 Extreme Physiology & Medicine
3 Frontiers in Microbiology
1 Frontiers in Oncology
1 Haptics: Perception, Devices, Control, and Applications, Eurohaptics 2016, Part I
1 IEEE Transactions on Circuits and Systems II–Express Briefs
1 Imaging Spectrometry XVIII
1 Infection and Drug Resistance
1 Interdisciplinary Transport Phenomena: Fluid, Thermal, Biological, Materials
1 International Journal of General Medicine
3 International Journal of Microgravity Science and Application
6 International Symposium on Physical Sciences in Space
2 International Symposium: Nanoscience and Quantum Physics 2011
1 JCI Insight
1 Journal of Allergy and Clinical Immunology–In Practice
1 Journal of Clinical Endocrinology & Metabolism
1 Journal of Experimental Zoology Part A–Ecological and Integrative Physiology
1 Journal of Experimental Zoology part A–Ecological Genetics and Physiology
3 Journal of Space Weather and Space Climate
5 Life Sciences in Space Research
1 Malaysian Journal of Pathology
1 MCWASP XIV: International Conference on Modelling of Casting, Welding and Advanced Solidification Processes
3 Microbiome
1 mSphere
1 mSystems
1 Multiphoton Microscopy in the Biomedical Sciences XV
17 npj Microgravity
1 Nutrients
1 Ocean Sensing and Monitoring III
5 Origins of Life and Evolution of Biospheres
1 PeerJ
1 Progress of Theoretical and Experimental Physics
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2 Remote Sensing
1 Remote Sensing Letters
1 Remote Sensing System Engineering III
1 RSC Advances
1 Science Advances
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1 Scientific World Journal
1 Solar Physics and Space Weather Instrumentation IV
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1 Stereoscopic Displays and Virtual Reality Systems XIV

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