National Aeronautics and Space Administration

ANNUAL HIGHLIGHTS of RESULTS from the INTERNATIONAL SPACE STATION

October 1, 2017 – October 1, 2018

ROSCOSMOS

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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 State Space Corporation Roscosmos (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

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Cover:

View of the Kibo laboratory module as the ISS orbited over the southern Pacific Ocean east of New Zealand. Hardware seen in this photo: Japanese Experiment Module (JEM) Experiment Logistics Module Pressurized Section (ELM-PS), Japanese Experiment Module Remote Manipulator System (JEMRMS), Japanese Experiment Module - Exposed Facility (JEM-EF), Monitor of All-sky X-ray Image (MAXI), Cosmic-Ray Energetics and Mass for the International Space Station (ISS-CREAM), Nanoracks External Platform (NREP-2), Hyperspectral Imager for the Coastal Ocean (HICO), Remote Atmospheric and Ionospheric Detection System (RAIDS) Experiment Payload (HREP) Inter-orbit Communication System - Exposed Facility (ICS-EF), Cloud-Aerosol Transport System (CATS), and CALorimetric Electron Telescope (CALET) Space Environment Data Acquisition Equipment - Attached Payload (SEDA-AP) (ISS055E006395).

NP-2018-12-020-JSC

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Word cloud of keywords identified in ISS results publications collected from October 1, 2017 - October 1, 2018.

Introduction

The International Space Station (ISS) is a unique place – a convergence of science, technology and human innovation that demonstrates new technologies and makes research breakthroughs that cannot be accomplished on Earth. As an international laboratory for scientific research in microgravity, the space station's international crew lives and works while traveling at a speed of about five miles per second as they make new discoveries in the disciplines of biology and biotechnology, Earth and space science, human research, physical science, educational activities, and technology development and demonstrations.

This year, investigators published a wide range of ISS science results, from improved theories about the creation of stars to the outcome of data mining "omics" repositories of previously completed ISS investigations. The ISS Program Science Office collected 206 scientific publications between October 1, 2017 and October 1, 2018. Of these 206 publications, five were books, 173 were articles published in peer-reviewed journals, 19 were conference presentations, and nine were patents. Of the items collected, 60 were published prior to October 1, 2017, but not collected until after October 1, 2017.

The ISS is the springboard to the next great leap in exploration, enabling research and technology development that will benefit human exploration of destinations beyond low-Earth orbit. It is the blueprint for global cooperation – one that enables a multinational partnership and advances shared goals in space exploration.

Results represent research accomplishments sponsored by the National Aeronautics and Space Administration (NASA), the State Space Corporation Roscosmos (Roscosmos), the Japan Aerospace Exploration Agency (JAXA), the European Space Agency (ESA), and the Canadian Space Agency (CSA). This report includes highlights of collected ISS results as well as a complete listing of this year's ISS results that benefit humanity, contribute to scientific knowledge, and advance the goals of space exploration for the world.

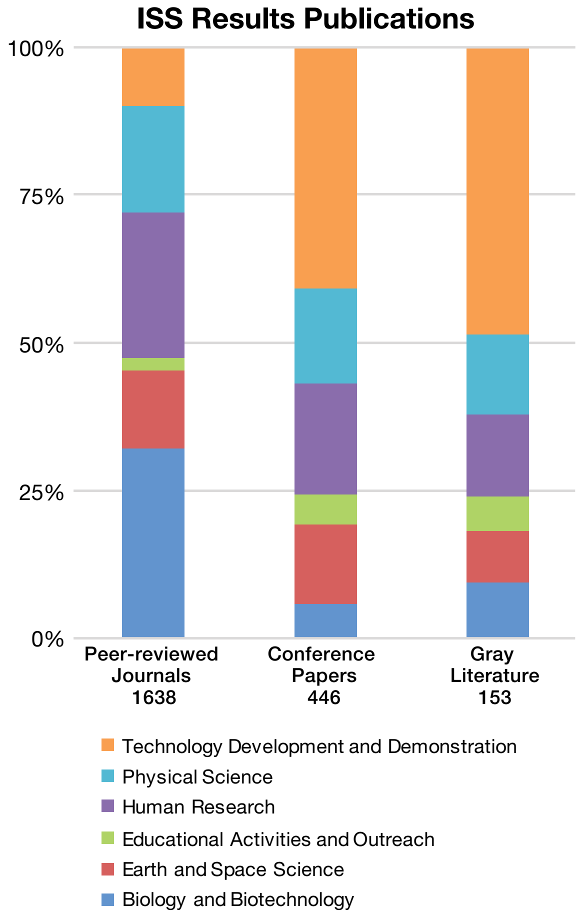

Figure 1: A total of 2237 publications (through October 1, 2018) represent scientist's worldwide. This chart illustrates the percentages for each discipline of research, per publication type.

Overall, the number of publications collected in 2017-2018 represents a year-over-year increase of 10% from the previous year of 2031 publications collected.[1] As of October 1, 2018, the ISS Program Science Office has identified a total of 2237 publications since 1999 with sources in peer-reviewed journals, conferences, and gray literature, representing the work of more than 5000 scientists worldwide (Figure 1).

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[1] *Robinson J, Ruttley T, Tate-Brown J. Annual Highlights of Results from the International Space Station: October 1, 2016 – October 1, 2017.2016; NP-2018-02-002-JSC.*

The ISS Program Science Office has a team of professionals dedicated to continuously collecting and archiving research results from all utilization activities across the ISS partnerships. The archive can be accessed at www.nasa.gov/iss-science. This database captures the ISS investigations summaries and results, providing citations to the publications and patents as they become available.

The team reviews various publications to locate articles detailing results from ISS research. Other methods to discover articles with ISS results include:

- email alerts from Pubmed, Google Scholar, Web of Science, and others
- ISS investigator websites
- Science networks such as ResearchGate

Measuring Space Station Impacts

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.

One method used to evaluate the significance of scientific output from the ISS is to track the article citations and the Eigenfactor of journal importance across the ISS partnership. Since different disciplines have different standards for citations and different time spans across which citations occur, Eigenfactor applies an algorithm that uses the entire Web of Science citation network from Clarivate Analytics® spanning the previous five years.[2]

This algorithm creates a metric that reflects the relative importance of each journal. Eigenfactor 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, 2017 to October 1, 2018, 42 ISS publications were published in the top 100 journals by Eigenfactor. Twenty-four of those ISS publications were in the Top 10 Global Journals as reported by Clarivate Analytics® (Table 1).

	(Clarivate Analytics®) Ranks	**Source (# of ISS articles)**
ISS Publications In Top 100 Sources	1	PLOS ONE (2)
	5	Nature Communications (1)
	7	Scientific Reports (13)
	8	New England Journal of Medicine (1)
	9	Physical Review Letters (7)
	16	The Astrophysical Journal (8)
	25	Monthly Notices of the Royal Astronomical Society (1)
	26	Applied Physics Letters (1)
	42	Astronomy and Astrophysics (1)
	67	The Journal of Chemical Physics (1)
	96	The Astrophysical Journal Letters (6)

Table 1: 2017-2018 ISS Publications collected in the Top 100 Global Journals, by Eigenfactor. From October 1, 2017 to October 1, 2018, as reported by 2017 Journal Citation Reports, Clarivate Analytics®.

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

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2. *West JD, Bergstrom TC, Bergstrom CT. The Eigenfactor Metrics™: A Network approach to assessing scholarly journals.* College and Research Libraries*. 2010;71(3). DOI: 10.5860/0710236.*

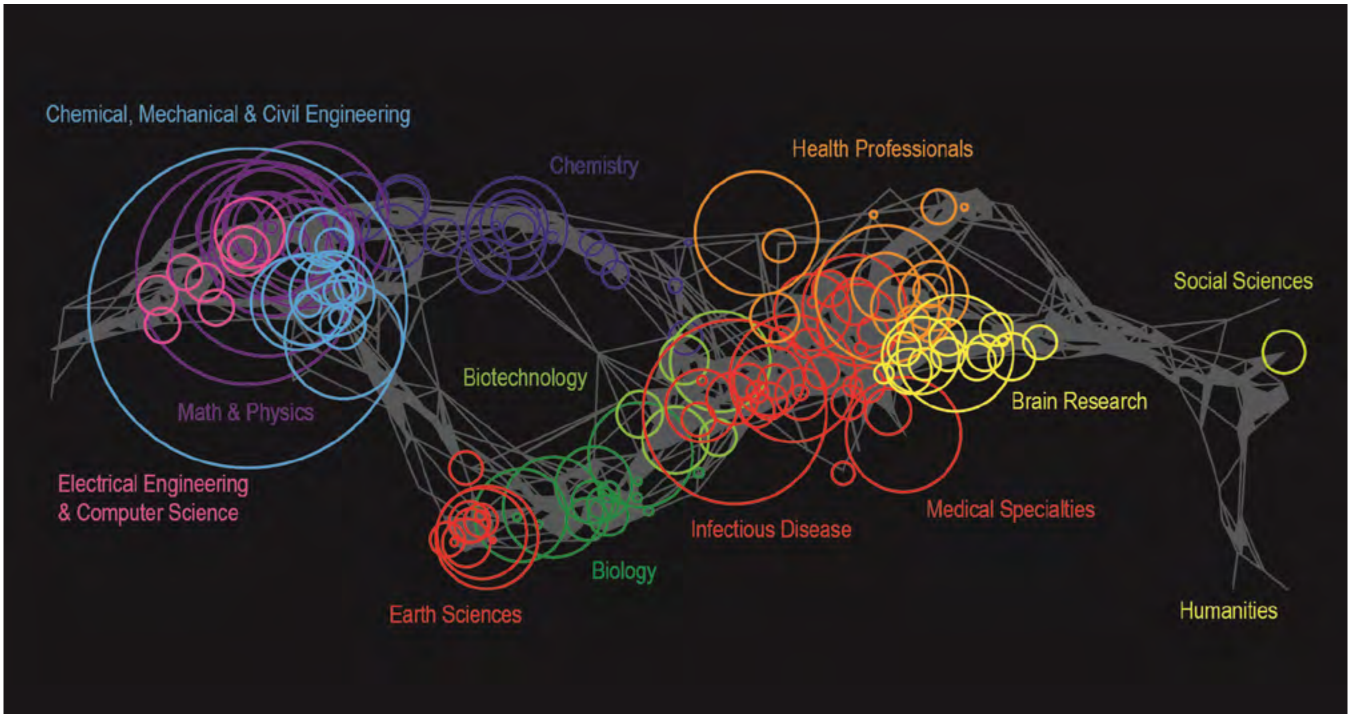

Figure 3.The ISS Map of Science for all ISS publications collected through October 1, 2018, overlaid on the UCSD Map of Science.

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 different science disciplines (Figure 3).

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.[3] The UCSD Map of Science is a reference-standard, disciplinary classification system derived from articles and citations published in the more than 25,000 journals indexed by Clarivate Analytics'® 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 color-coded circle represents a unique subdiscipline. The number of scientific articles published within that subdiscipline determines the size of each circle.

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-NonCommercial-ShareAlike 3.0 Unported (CC BY-NC-SA 3.0) license (https://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 3 reveals the multidisciplinary nature of ISS research, illustrated by the significant overlap between the circles representing the different disciplines. Most importantly, this ISS Map of Science indicates that the science conducted on the ISS impacts 12 of the 13 primary disciplines that comprise the base map of all science (Humanities is excepted). These disciplines include both space-related and non-space-related scientific disciplines.

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[3] *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. DOI: 10.1371/journal.pone.0039464.*

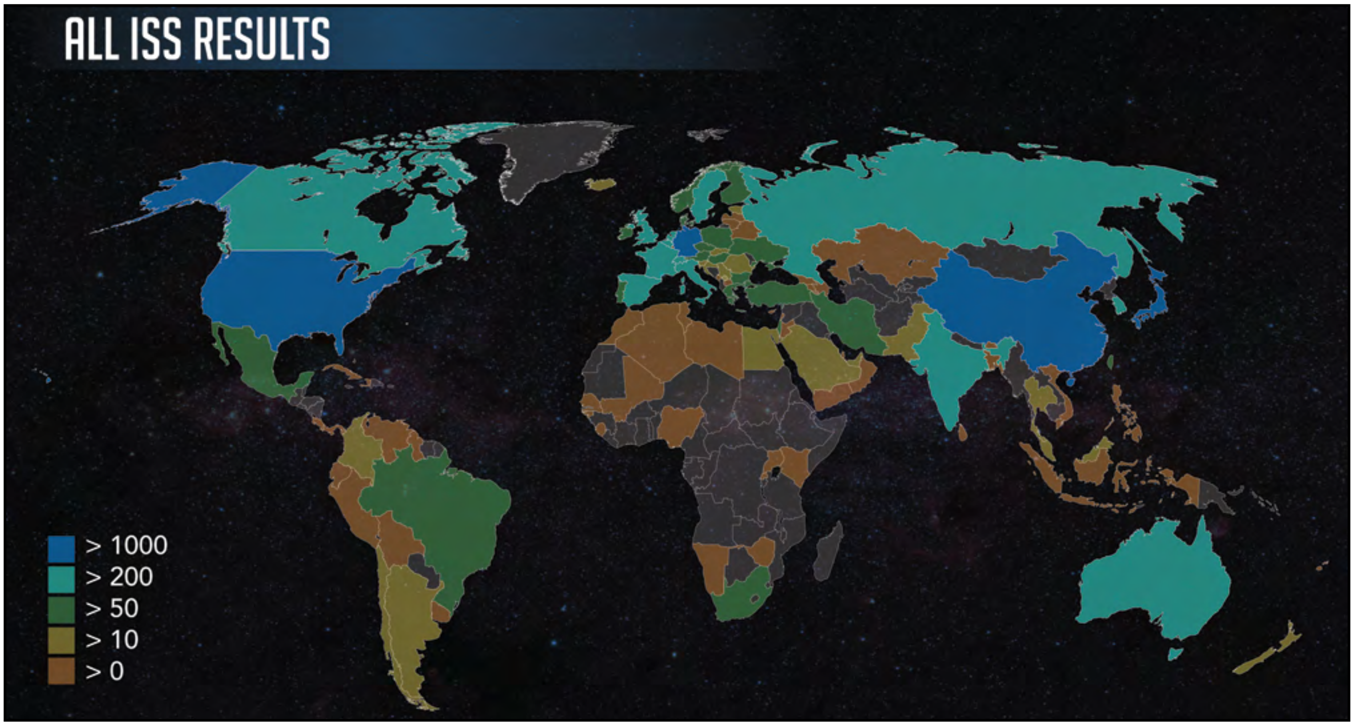


Figure 4. A heat map of all of the countries whose authors have cited scientific results publications from ISS Research through October 1, 2018.

Results from space station research reach beyond international borders and beyond the countries with research-sponsoring space agencies. Figure 4 depicts a heat map representing all of the countries of origin for authors that have cited ISS results published in scholarly journals since 1999. This global representation provides an indication of the international reach of ISS publications and their contributions to scientific literature.

Linking Space Station Benefits

ISS research results lead to benefits for human exploration of space, benefits to humanity, and the advancement of scientific discovery. This year's Annual Highlights of Results from the International Space Station includes descriptions of just a few of the results that have been published from across the ISS partnership.

EXPLORATION

ISS investigation results have yielded updated insights into how to live and work more effectively in space by addressing such topics as understanding radiation effects on crew health, combating bone and muscle loss, improving designs of systems that handle fluids in microgravity, and determining how to maintain environmental control efficiently.

BENEFITS FOR HUMANITY

Results from the ISS provide new contributions to the body of scientific knowledge in the physical sciences, life sciences, and Earth and space sciences to advance scientific discoveries in multi-disciplinary ways.

DISCOVERY

ISS science results have Earth-based applications, including understanding our climate, contributing to the treatment of disease, improving existing materials, and inspiring the future generation of scientists, clinicians, technologists, engineers, mathematicians, artists, and explorers.

ISS crewmember Samantha Cristoforetti activating the Biological Research in Canisters (BRIC) by injecting the growth medium into the samples (ISS043E127535).

PUBLICATION HIGHLIGHTS:

BIOLOGY AND BIOTECHNOLOGY

The ISS laboratory provides a platform for investigations in the biological sciences that explores the complex responses of living organisms to the microgravity environment. Lab facilities support the exploration of biological systems, from microorganisms and cellular biology to the integrated functions of multicellular plants and animals.

DISCOVERY

NASA's **GeneLab** database is an interactive, open-access resource where scientists can upload, download, store, search, share, transfer, and analyze omics data from spaceflight and corresponding analogue investigations. Omics is the field of research analyzing and integrating studies of many different "-omes," including the genome, proteome, and metabiome, using bioinformatics and computational biology. GeneLab allows users to explore GeneLab datasets in the Data Repository, analyze data using the Analysis Platform, and create collaborative projects using the Collaborative Workspace. Open access to GeneLab facilitates information sharing, fosters innovation, and increases the pace of scientific discovery from rare space biology investigations for researchers ranging from highly experienced in space research, to those who have never been involved in any NASA research.

Official NASA GeneLab patch (image credit: NASA).

Discoveries made using GeneLab have begun and will continue to deepen our understanding of biology, advance the field of genomics, help to determine cures for diseases, create better diagnostic tools, and ultimately allow space explorers to better withstand the rigors of spaceflight. This year, GeneLab data have yielded significant results:

- A research team examined how rodent cage architecture influences atmospheric carbon dioxide levels, and consequently, the physiological responses of animals in spaceflight. Through a systems biology approach, the authors concluded that variations in the type of rodent cage could influence metabolism, immune response, and potentially the activation of cancer-related pathways. Research insights shed light on study designs for rodent research and ultimately the biological risks for space explorers associated with long-term space missions.
- In another study, researchers used an unbiased systems biology approach to discover the existence of a potential master regulator, TGF-β1, that coordinates systemic responses to microgravity between multiple linked tissues, further predicting that the global response was driven by micro RNA (miRNA). The genes and miRNAs identified from these analyses can be targeted for future research involving efficient countermeasure design to combat health issues that can occur in space.

- Researchers performed the first normalized meta-analysis comparing all publicly available transcriptome profiles from both gram-negative and gram-positive bacteria exposed to the spaceflight environment. Findings suggest that gene variations in bacteria are not due to a shared response to space but instead are due to differences in methods. As a result of this meta-analysis, researchers observed that developing a clear understanding of how bacteria respond and adapt to microgravity requires that future investigations use standardized study conditions.

Beheshti A, Cekanaviciute E, Smith DJ, Costes SV. Global transcriptomic analysis suggests carbon dioxide as an environmental stressor in spaceflight: A systems biology GeneLab case study. Scientific Reports*. 2018 March 8;8:10 pp. DOI: 10.1038/s41598-018-22613-1. PMID: 29520055.*

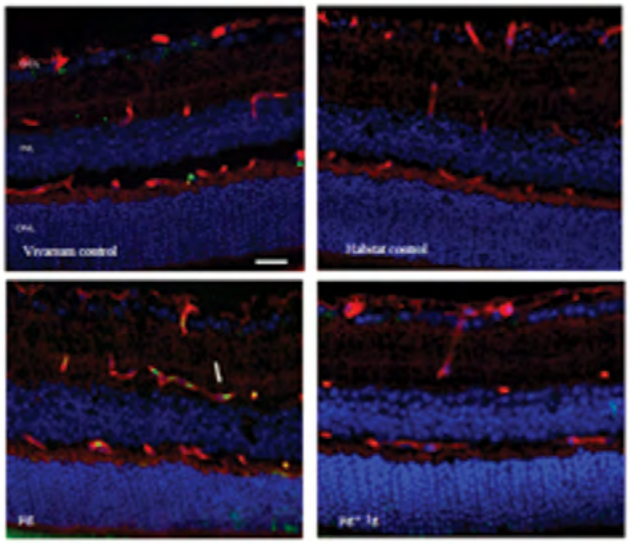
Beheshti A, Ray S, Fogle H, Berrios D, Coates SV. A microRNA signature and TGF-beta 1 response were identified as the key master regulators for spaceflight response. PLOS One*. 2018 July 25;13(7):19 pp. DOI: 10.1371/journal.pone.0199621. PMID: 30044882.*

Morrison MD, Nicholoson WL. Meta-analysis of data from spaceflight transcriptome experiments does not support the idea of a common bacterial "spaceflight response". Scientific Reports*. 2018 September 26;8:12 pp. DOI: 10.1038/s41598-018-32818-z. PMID: 30258082.*

The goal of JAXA's **Transcriptome Analysis and Germ-Cell Development Analysis of Mice in the Space (Mouse Epigenetics)** investigation was to investigate how different types of gravity exposure (i.e., earth gravity, microgravity, and artificial gravity) affect protein expression and oxidative stress-related cell death in the tissue of mice, in which a JAXA-NASA scientific collaboration under the Japan-U.S. Open Platform Partnership Program (JP-US OP3) focused on impact on the retinal tissue of mice. Protein synthesis and free-radical regulation are mechanisms involved in the structure and function of the retina. Uncovering the effects of microgravity on these mechanisms may clarify how visual impairments in crewmembers emerge.

While on the ISS for 35 days, mice were housed either in an ambient microgravity cage unit or in a centrifugal habitat that simulated Earth's gravity. Two additional control groups of mice, habitat and vivarium, remained on Earth for comparison purposes.

Immunocytochemical, immunohistochemical, and protein-expression profile analyses were performed on ocular tissue after spaceflight. Results showed significantly more cell death in the retinal vascular endothelial cells of mice exposed to microgravity compared to mice in all other conditions. Additionally, more changes in protein expression were identified in mice exposed to microgravity than mice exposed to artificial gravity. The affected proteins were primarily involved in inflammation, repair, and programmed cell death (apoptosis).



Apoptosis based on terminal deoxynucleotidyl transferase dUTP nick-end labeling (TUNEL) staining of 9-week-old male C57BL/6 mouse retinal tissue. Groups (n = 6): Vivarium control, habitat control, µg, and µg + 1 g. TUNEL-positive cells were identified with green fluorescence, the endothelium was stained with lectin (red). The nuclei of photoreceptors were counterstained with DAPI (blue). In the control retinal tissue, only sparse TUNEL-positive cells were found. In the retina from µg mice, TUNEL-positive labeling was apparent in the retinal endothelial cells. Arrow: TUNEL-positive endothelial cell. Outer nuclear layer; inner nuclear layer; ganglion cell layer. (Image courtesy of Mao XW, International Journal of Molecular Sciences, 2018.)

These findings suggest that changes to vascular endothelial cells in the mouse retina can lead to breaking the blood-retinal barrier, thereby increasing the risk for visual impairment. This is the first study to investigate the role of artificial gravity in spaceflight as a potential countermeasure for alleviating the negative effects of microgravity on the visual system.

Mao XW, Byrum S, Nishiyama NC, Pecaut MJ, Sridharan V, et al. Impact of spaceflight and artificial gravity on the mouse retina: Biochemical and proteomic analysis. International Journal of Molecular Sciences. *2018 August 28;19(9):2546. DOI: 10.3390/ijms19092546. PMID: 30154332.*

ISS crewmember Luca Parmitano performs an ocular health fundoscope exam in the Destiny laboratory of the ISS (ISS036E006423).

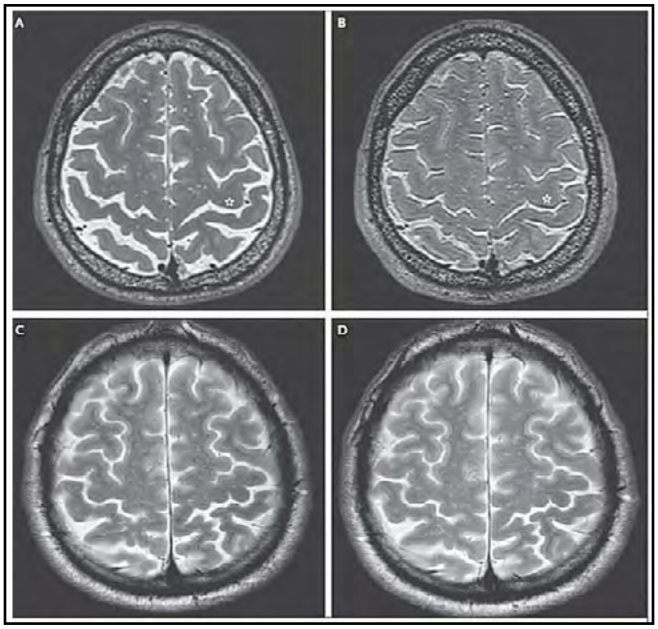
PUBLICATION HIGHLIGHTS:
HUMAN RESEARCH

ISS research includes the study of risks to human health that are inherent in space exploration. Many research investigations address the mechanisms of these risks — including the relationship to the microgravity and radiation environments — as well as other aspects of living in space, including nutrition, sleep, and interpersonal relationships. Other investigations are designed 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

NASA's **Cephalad Fluid Redistribution** investigation examined neuroanatomical changes in 34 crewmembers who participated in long-duration missions to the ISS and short-duration missions as part of the Space Shuttle Program.

Brain scans were acquired before and after spaceflight using three magnetic resonance-imaging machines in addition to an eye health assessment upon return from space. These scans revealed an upward shift of the brain, ventricular enlargement, and a narrowing of the central sulcus and cerebrospinal fluid spaces after long-duration space missions. Moreover, every crewmember who experienced optic-disk edema after long-duration missions also showed narrowing of the central sulcus.



Axial T2-weighted images of the brain obtained before (Panel A) and after (Panel B) this subject had undergone long-duration spaceflight on the ISS. Axial T2-weighted images of the brain obtained before (Panel C) and after (Panel D) this subject had undergone short-duration spaceflight on the space shuttle show no change in the appearance of the sulci at the vertex (Image courtesy of Roberts DR, New England Journal of Medicine, 2017).

The results of this study advocate for the incorporation of advanced methods into NASA's imaging protocol. Cutting-edge technology combined with a longitudinal design could reveal a relationship between neuroanatomical changes and visual impairments. Determining the cause of visual impairments resulting after spaceflight will help inform the development of countermeasures to better prepare the next generation of explorers for deep space interplanetary missions.

Roberts DR, Albrecht MH, Collins HR, Asemani D, Chatterjee AR, et al. Effects of spaceflight on astronaut brain structure as indicated on MRI. New England Journal of Medicine*. 2017 November 2;377(18):1746-1753. DOI: 10.1056/NEJMoa1705129. PMID: 29091569.*

EXPLORATION

Roscosmos' **Mechanism of Activity and Effectiveness of Various Countermeasures Intended to Prevent Disruptions to the Motor Apparatus in Microgravity (Profilaktika-1)** investigation recognizes that numerous conditions emerge in the human body as a result of exposure to weightlessness, from muscle atrophy to bone loss and decreased cardiac output. Scientists and physicians have developed different attempts to help crewmembers maintain good physical health while aboard the ISS. However, the current loading systems available on the ISS allow crewmembers to choose settings below the minimum recommended value of 70% of their body weight. The goal of Profilaktika-1 was to determine the loading value necessary to assure the effectiveness of the countermeasures currently used for motor training.

Results showed that for the training to have a positive effect and for crewmembers to maintain physical performance, 64% of the crewmember's body weight is the minimum loading target. The authors suggest that implementing heavier loads through more intense stimulation and stronger autonomic muscle activity would be useful to help prevent deconditioning related to weightlessness.

Fomina EV, Lysova NY, Savinkina AO. Axial load during the performance of locomotor training in microgravity as a factor of hypogravity countermeasure efficiency. Human Physiology. *2018 January 1;44(1):47-53. DOI: 10.1134/S0362119718010061.*

ISS crewmember Maxim Suraev, equipped with a bungee harness, exercises on the Combined Operational Load Bearing External Resistance Treadmill (ISS041E011475).

ESA's **Thermoregulation in Humans During Long-Term Spaceflight (ThermoLab)** investigation examined the effect of microgravity on ISS crewmembers' core body temperature (CBT) during periods of rest and exercise before launch, while on the ISS, and after return. Results showed that CBT gradually elevates during long-duration spaceflight, rising faster and higher during physical exercise compared to ground results. Additionally, researchers found that impairments in thermoregulation slowly return to normal once the ISS crewmembers are back on Earth. Additional analysis of interleukin-1 receptor antagonist, an anti-inflammatory protein, revealed that higher concentrations of the protein are positively correlated with elevated body temperature.

ISS crewmember Luca Parmitano wearing a ThermoLab double sensor on his forehead (ISS036E024483).

The researchers concluded that protein elevations could be related to pro-inflammatory responses to microgravity, vigorous exercise in space, radiation, stress-induced hyperthermia, or a combination of the factors. These findings demonstrate that there are significant challenges in understanding inflammation associated with spaceflight to enable space explorers to maintain their health and cognition on long-duration space missions.

Stahn AC, Werner A, Opatz O, Maggioni MA, Steinach M, et al. Increased core body temperature in astronauts during long-duration space missions. Scientific Reports. *2017 November 23;7(1):16180. DOI: 10.1038/s41598-017-15560-w. PMID: 29170507.*

EXPLORATION

BENEFITS FOR HUMANITY

CSA has supported several investigations examining **psychosocial aspects** of long-duration space exploration. One investigation surveyed veteran crewmembers who once flew on Mir, the ISS, or both provided information about their days in space through private semi-structured interviews, media interviews, memoirs, diaries, and debriefs. Using qualitative and quantitative methods in thematic content analysis, researchers measured the need for achievement, affiliation, and power of these retired crewmembers to understand how these values motivated their careers.

Crewmembers reported the need to achieve and be successful to be most important, followed by the need to be socially involved with like-minded peers, and finally followed by the need for power. Even though power was the least important value driving their careers, crewmembers did comment on the lack of autonomy experienced during space missions and their desire to have more control over what they did, how they did it, and when they did it. Despite their central role in space exploration, the crewmembers' thoughts and suggestions do not appear to be getting the necessary attention.

ISS Expedition 42 crewmembers pose for an inflight portrait in the Harmony Node 2. Clockwise from top center, are Barry Wilmore, Elena Serova, Samantha Cristoforetti, Terry Virts, Anton Shkaplerov, and Alexander Samoukutyaev (ISS042E306480).

Researchers recommend providing active and retired crewmembers opportunities to highlight their contributions to the world, remain involved with their peers, and have a voice in crew selection, training, schedules, and other space agency-related activities.

In another study, retired crewmembers' perceptions of actual and desired involvement with their children before, during, and after space missions were retrospectively examined. The Father Involvement Scale included items evaluating expressive involvement (e.g., intellectual, emotional, social, spiritual, and hobbies) and instrumental involvement (e.g., providing income, protection, discipline, responsibility, independence, and competence).

Responses from crewmembers indicated that actual instrumental and expressive involvement with their children was high. However, crewmembers still wished to have been more involved in the expressive domain. Several crewmembers expressed sentiments of regret by noting that lost time cannot be made up.

These results prompt the enhancement of family support programs provided by space agencies to further engage families and help strengthen father-child relationships.

Suedfeld P, Johnson PJ, Gushin VI, Brcic J. Motivational profiles of retired cosmonauts. Acta Astronautica. *2018 March 2;146:202-205.* *DOI: 10.1016/j.actaastro.2018.02.038.*

Johnson PJ, Suedfeld P, Gushin VI. Being a father during the space career: retired cosmonauts' involvement. Acta Astronautica. *2018 May 15;149:106-110.* *DOI: 10.1016/j.actaastro.2018.05.028.*

ISS crewmember Mike Hopkins preparing to install and activate the Selectable Optics Diagnostic Instrument-Diffusion Coefficient in Mixtures 2 cell array in the Microgravity Science Glovebox for operations (ISS038E009256).

PUBLICATION HIGHLIGHTS:

PHYSICAL SCIENCES

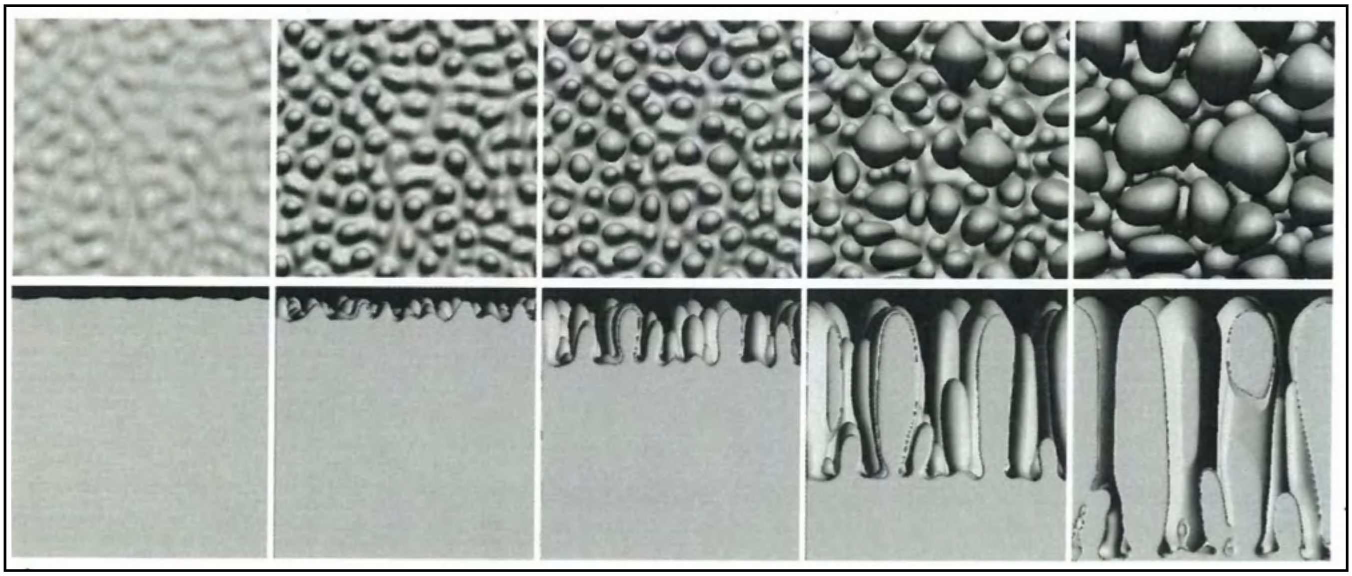
The presence of gravity greatly influences our understanding of physics and the development of fundamental mathematical models that reflect how matter behaves. The ISS provides the only laboratory where scientists can study long-term physical effects in the absence of gravity and without the complications of gravity-related processes such as convection and sedimentation. This unique microgravity environment allows different physical properties to dominate systems, and scientists are harnessing these properties for a wide variety of investigations in the physical sciences.

DISCOVERY

BENEFITS FOR HUMANITY

NASA's **DEvice for the study of Critical LIquids and Crystallization - Directional Solidification Insert (DECLIC-DSI)** has enabled the verification of three-dimensional (3-D) models that simulate microstructure solidification of organic liquid compounds in microgravity based on actual results aboard the ISS. The structures form in a homogeneous array that researchers can analyze for growth properties and development. Results allow scientists to understand the effects of a thermal gradient on the solidification processes for the solid structures formed and the spacing between these structures. Such studies are important to pharmaceutical research by furthering the understanding of crystallization formation in microgravity. These studies also contribute to an understanding of how liquids may behave in critical systems that are a part of spacecraft hardware. The results will also help refine the accuracy of 3-D simulation models to predict the behavior of other media for future applications.

Song Y, Tourret D, Mota FL, Pereda J, Billia B, et al. Thermal-field effects on interface dynamics and microstructure selection during alloy directional solidification. Acta Materialia*. 2018 May 15;150:139-152. DOI: 10.1016/j.actamat.2018.03.012.*



Microstructures at different time steps (left to right) in the TFC simulation at V = 4μm/s, seen from the top (top row) and from the side (bottom row) (Image courtesy of Song Y, Acta Materialia, 2018).

DISCOVERY

JAXA's **Electrostatic Levitation Furnace (ELF)** takes advantage of the microgravity environment to melt a variety of materials without the introduction of impurities from a container.

On Earth, making glass requires placing a mixture of raw materials into a container called a crucible. The crucible is heated to melt the materials, and the melted materials are cooled to become a solid. In the process of melting raw materials at high temperature, a chemical reaction between the liquid mixture and the crucible occurs, resulting in the introduction of impurities from the crucible into the melted materials. Scientists have hypothesized that heating materials while levitating them would avoid contamination from the crucible. The ELF enables this capability.

To date, crewmembers have processed several oxide and zirconium materials, levitating and heating them to temperatures as high as 3000 K to become molten in microgravity. Density, surface tension, and viscosity measurement capabilities have been confirmed. Understanding the thermophysical properties data of materials at high temperature is useful for the study of liquid states and improvement of numerical simulation by modeling the manufacturing process using the liquid state on Earth. Many more investigations are planned for the ELF.

Tamaru H, Koyama C, Saruwatari H, Nakamura Y, Ishikawa T, Takada T. Status of the Electrostatic Levitation Furnace (ELF) in the ISS-KIBO. Microgravity Science and Technology. *2018 October;30(5):643-651. DOI: 10.1007/s12217-018-9631-8.*

ISS crewmember Takuya Onishi functional-checking the Electrostatic Levitation Furnace (ELF) facility (ISS049E002367).

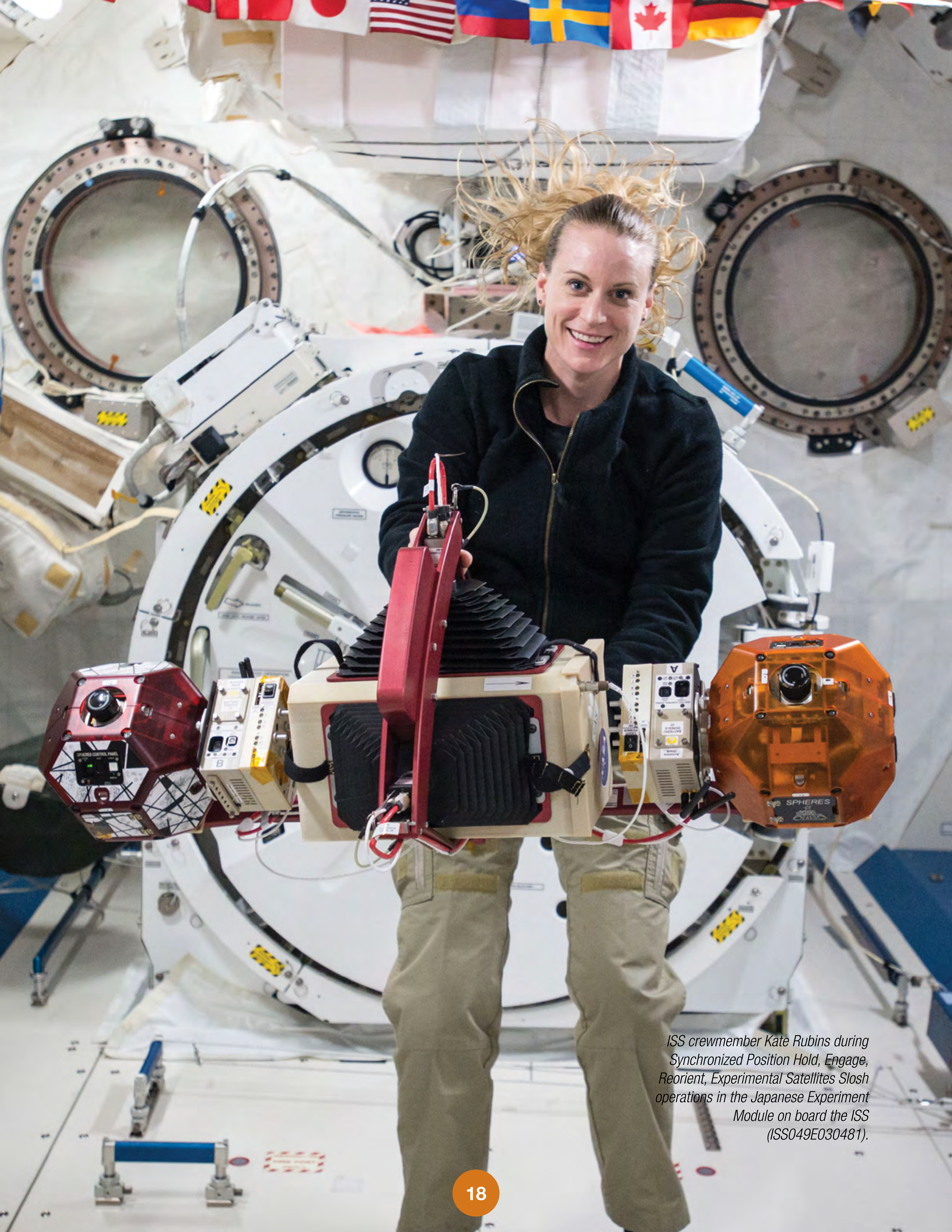
EXPLORATION

DISCOVERY

ESA's **Electro-Magnetic Levitator (EML) Batch 1 - Thermolab** investigation provides oscillation data that will enhance methods for frequency analysis and validation by estimating correction factors that identify how frequency shifts can be correlated with observed material deformations. These data will also improve our understanding of surface tension accuracy and precision. A 150 Hz camera measured surface movements during the solidification process of a nickel-based super-alloy droplet sample. This sample provided critical information when timed heater pulses were introduced to initiate a deformation of the material, creating an oscillation. The resulting data on frequency versus deformation amplitude for various cases in microgravity enable the validation of correction factors to the Rayleigh equation, which mathematically models the deformation behavior of melted materials. This information is critical for predicting the deformation behavior and eliminates the impact of deformations observed in surface tension data of molten metals during microgravity manufacturing processes, thereby improving accuracy and precision of the processes.

Xiao X, Hyers RW, Wunderlich RK, Fecht HJ. Deformation induced frequency shifts of oscillating droplets during molten metal surface tension measurement. Applied Physics Letters*. 2018 July 5;113(1):011903. DOI: 10.1063/1.5039336.*

ISS crewmember Alex Gerst working with the Electromagnetic Levitation hardware on board ISS (ISS041E000184).



ISS crewmember Kate Rubins during Synchronized Position Hold, Engage, Reorient, Experimental Satellites Slosh operations in the Japanese Experiment Module on board the ISS (ISS049E030481).

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 are needed for future exploration missions. Some technology development investigations have been so successful that the test hardware has been transitioned to operational status. Other results feed new technology development.

DISCOVERY

NASA's initial **Biomolecule Sequencer** investigations with genomic DNA extracted from a virus (*Enterobacteria phage lambda*), a bacterium (*Escherichia coli*), and a model organism, the mouse (*Mus musculus*), are complete, generating important sequencing datasets for making comparisons between biomolecule sequencing during spaceflight and on Earth. No decrease in sequencing performance was observed in microgravity results compared to samples on Earth. Additionally, the quantity and quality of the spaceflight data permitted assembly of bacterial and viral genomes.

ISS crewmember Ricky Arnold, swabbing designated surfaces used to collect samples. He then used the Miniature Polymerase Chain Reaction (miniPCR) device to extract DNA from the samples (ISS056E097419).

Importantly for microbiome and metagenomic applications, results demonstrate that a *de novo* assembly of microbial genomes from raw data corresponding to a complex metagenomic mixture is feasible in microgravity. Furthermore, lightweight sequencing platforms coupled with sufficient local computing power can be directly applied to terrestrial research applications in remote environments. The ability to analyze a subset of samples to assess sampling diversity and quality while in field locations such as the Arctic or on deep-sea drilling expeditions could greatly improve the overall yield of science from these campaigns.

The similarity in the results from sequencing in conjunction with the demonstrated robustness of the hardware and consumables sets the stage for the first time for use of this technology in infectious disease diagnostics, environmental monitoring, a wide array of space-based research, and potentially the detection of life beyond Earth during deep space exploration missions.

Castro-Wallace SL, Chiu C, John KK, Stahl SE, Rubins K, et al. Nanopore DNA Sequencing and Genome Assembly on the International Space Station. Scientific Reports. *2017;7:18022.* DOI: 10.1038/s41598-017-18364-0.

DISCOVERY

Roscosmos' **Development of a System of Supervisory Control over the Internet of the Robotic Manipulator in the Russian Segment of ISS (Kontur)** tested the remote control capabilities of the force-feedback joystick (RJo) on ground-based robots from aboard the ISS.

As part of the German Aerospace Center (DLR) study, two ISS crewmembers maneuvered the RJo, which moved the robotic arm ROKVISS on the ground via S-Band radio signals. The software created by DLR was designed to allow users to modify the controller features of the joystick for different robots. This software permitted testing on the Russian State Scientific Center for Robotics and Technical Cybernetics (RTC) investigation, consisting of the Surikat robot, a stylus surrounded by lighted targets. An ISS crewmember used the visual stream of the Surikat to apply force feedback on the joystick and extinguish the lighted targets.

Unlike the DLR investigation, RTC was conducted via S-Band radio signals and the internet. The sessions conducted in 2015 provided the necessary tactile and visual feedback for the creation of a second RTC mobile robot in 2016, in which a crewmember's interface appears as a three-dimensional model with a polygon map. Crewmembers controlled the display, similar to a video game, with a joystick that moved the on-ground robot. Live stream of the robot was also provided to crewmembers for visual reference. Despite observed delays in data exchange for all sessions, the communication channel between on-Earth robots and the joystick aboard the ISS was a success.

Muliukha V, Zaborovsky V, Ilyashenko A, Podgurski Y. Communication Technologies in the Space Experiment "Kontur-2". In: Galinina O, Andreev S, Balandin S, Koucheryavy Y. (eds) Internet of Things, Smart Spaces, and Next Generation Networks and Systems. *ruSMART 2017, NsCC 2017, NEW2AN 2017.* Lecture Notes in Computer Science, 10531. Springer, Cham.

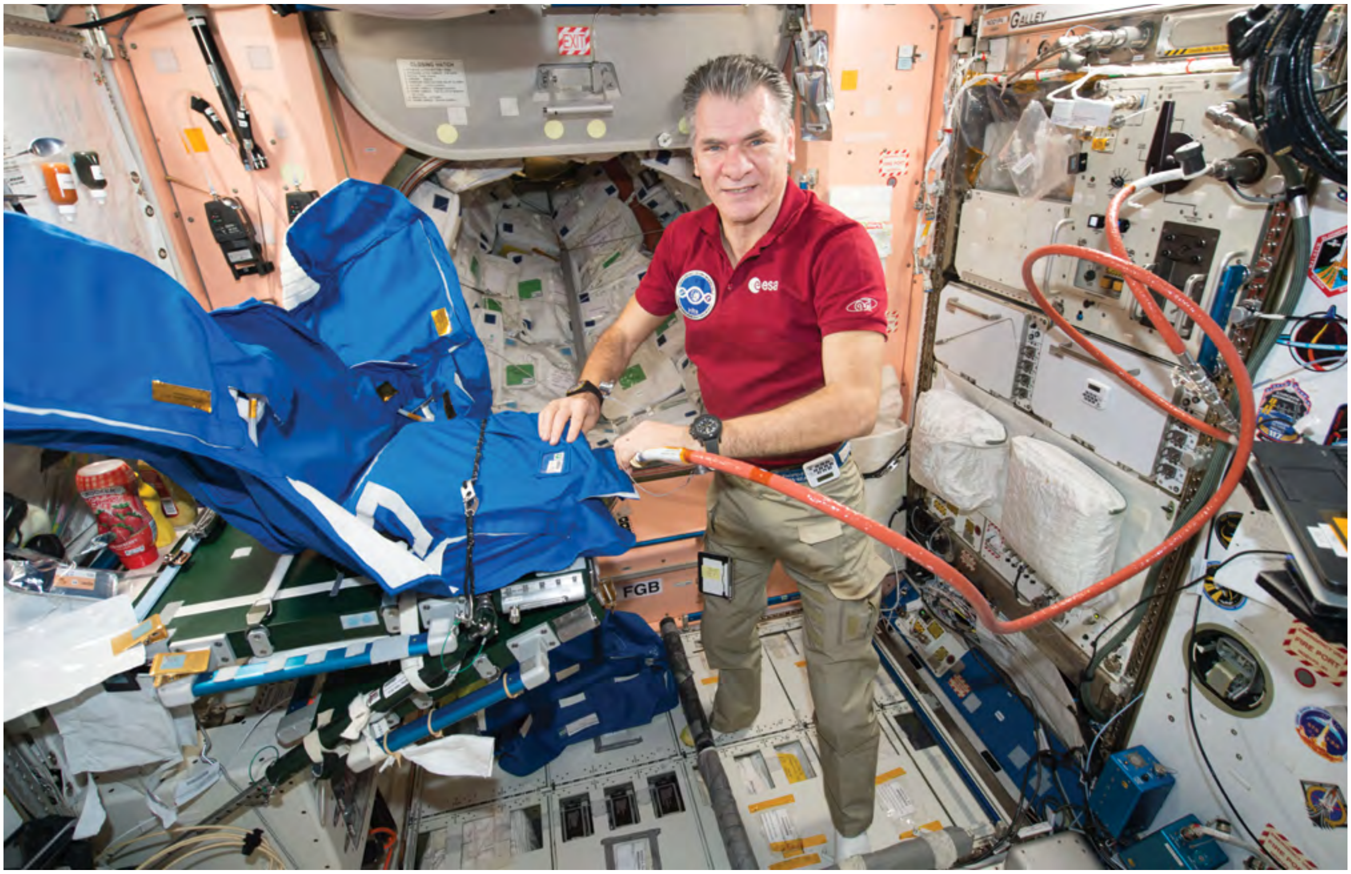
ISS crewmember Andrei Borisenko setting up the Kontur-2 on board the ISS (ISS050E075422).

EXPLORATION

ASI's **Personal Radiation Shielding for Interplanetary Missions (PERSEO)** explored strategies complementary to habitat shielding in view of future space exploration missions. Concerns related to space radiation exposure of the crew are still without conclusive solutions. The risk of long-term detrimental health effects needs to be kept below acceptable limits, and emergency countermeasures must be developed to avoid the short-term consequences of exposure to high particle fluxes during solar events that can be difficult to predict.

The design, manufacturing, and testing of the first prototype of a water-filled garment on board the ISS offers the validation of a personal radiation shielding strategy, complementary to habitat shielding and to other possible innovative countermeasures to be developed, to ensure the safety of the crew for future human exploration of deep space. PERSEO demonstrated the option of using a personal radiation-shielding device during time periods ranging from a fraction of an hour to a full day. PERSEO represents an important breakthrough in the field of radiation shielding in space.

Baiocco G, Giraudo M, Bocchini L, Barbieri S, Locantore I, et al. A water-filled garment to protect astronauts during interplanetary missions tested on board the ISS. Life Sciences in Space Research. *2018 April 26;18:1-11.* [DOI: 10.1016/j.lssr.2018.04.002. PMID: 30100142](https://doi.org/10.1016/j.lssr.2018.04.002).



ISS crewmember Paolo Nespoli filling a personal radiation shielding garment with water (ISS053E238877).

The Alpha Magnetic Spectrometer - 02 (AMS-02) is visible in the right foreground and a Soyuz spacecraft is visible docked to the ISS (ISS028E016135).

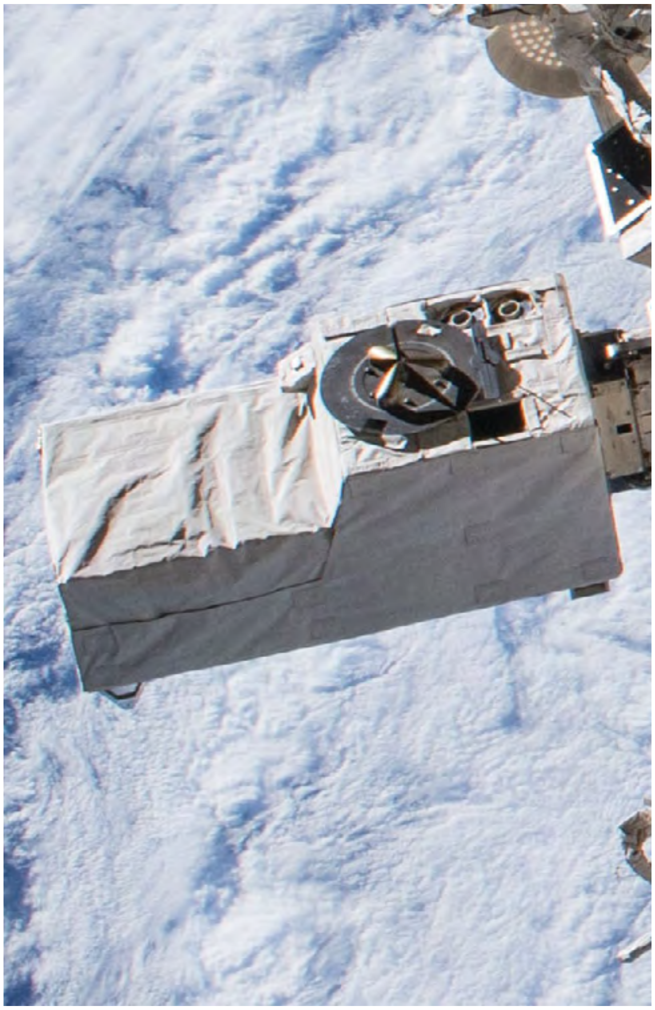
PUBLICATION HIGHLIGHTS:

EARTH AND SPACE SCIENCE

The position 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 combined with data from orbiting satellites and other sources 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

The Japanese-Italian-US **Calorimetric Electron Telescope (CALET)** has provided an enormous amount of data by registering and analyzing the spectra of high-energy cosmic-ray electrons and positrons. The primary science goal of CALET is to perform high-precision measurements of the cosmic-ray total electron spectrum into the TeV region to observe the signatures of possible sources of high-energy particle acceleration in our local region of the galaxy and, in addition, to search for evidence of dark matter. Since the start of operation in mid-October 2015, continuous observation has been maintained mainly by collecting data on high-energy (>10 GeV) showers. The number of these triggered events over 10 GeV is nearly 20 million per month. The electron energy spectrum has already extended to the TeV region, up to 5 TeV, and studies on dark matter and nearby cosmic-ray sources are being carried out. Cosmic-ray nuclei up to Z=40 are identified with high resolution, and the energy spectra for the major cosmic-ray elements up to iron have been obtained up to 100 TeV. Because the energy reach of CALET extends beyond that of previous space experiments, the new observations will provide valuable information on the acceleration and propagation mechanism of the high-energy cosmic rays. In addition, the gamma-ray capabilities of CALET provide an opportunity to look for the signal from counterparts to Gravitational Wave events in coordination with LIGO-Virgo. CALET also provides MeV electron profiles with applications for future spacecraft design (i.e., providing data to



Close-up of CALET attached to the ISS (ISS055E006395).

protect critical systems and crewmembers from high fluxes of gamma and cosmic radiation) as well as providing information on relativistic electron precipitation events.

Adriani O, Akaike Y, et al. Energy Spectrum of Cosmic-Ray Electron and Positron from 10 GeV to 3 TeV Observed with the Calorimetric Electron Telescope on the International Space Station. Physical Review Letters*. 2017 November 3;119(18).* [DOI: 10.1103/PhysRevLett.119.181101](https://doi.org/10.1103/PhysRevLett.119.181101).

Asaoka Y, Ozawa S, Torii S, et al. On-orbit Operations and Offline Data Processing of CALET onboard the ISS. Astroparticle Physics*. 2018 February 27;100:29-37.* [DOI: 10.1016/j.astropartphys.2018.02.010](https://doi.org/10.1016/j.astropartphys.2018.02.010).

Adriani O, Akaike Y, Asano K, Asaoka Y, Bagliesi MG, et al. Extended measurement of the cosmic-ray electron and positron spectrum from 11 GeV to 4.8 TeV with the calorimetric electron telescope on the International Space Station. Physical Review Letters*. 2018 June 29;120(26):261102.* [DOI: 10.1103/PhysRevLett.120.261102](https://doi.org/10.1103/PhysRevLett.120.261102)*. PMID: 30004739.*

Adriani O, Akaike Y, Asano K, Asaoka Y, Bagliesi MG, et al. Search for GeV gamma-ray counterparts of gravitational wave events by CALET. The Astrophysical Journal*. 2018 August 20;863(2):160.* [DOI: 10.3847/1538-4357/aad18f](https://doi.org/10.3847/1538-4357/aad18f).

DISCOVERY

BENEFITS FOR HUMANITY

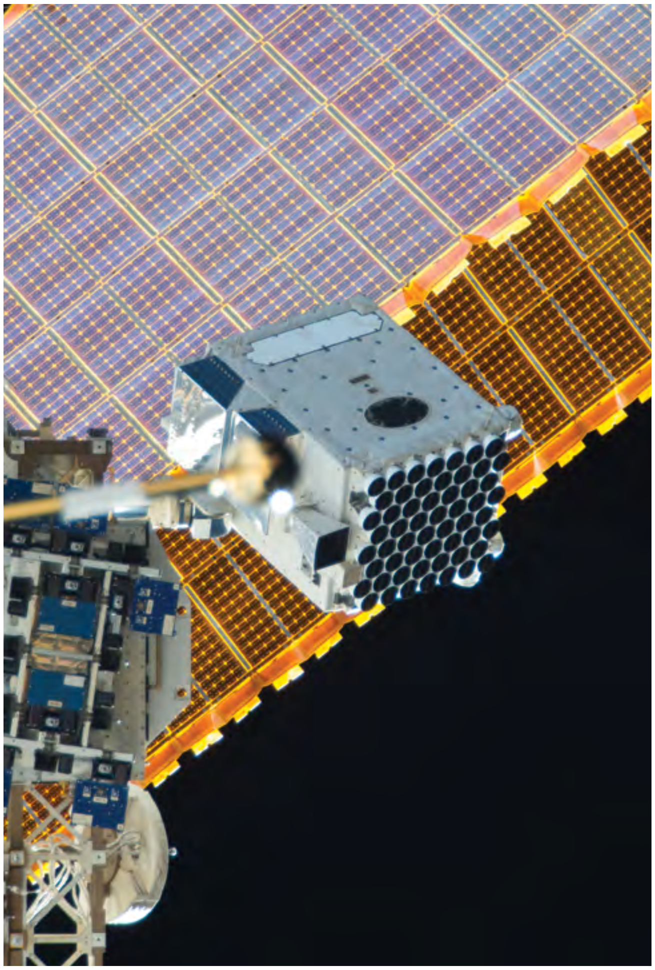
Roscosmos' **Study of Physical Processes Associated with Atmospheric Lightning Discharges Using the Chibis-M Microsatellite and Progress Cargo Vehicle (Microsputnik)** investigates the physical mechanisms of electrical discharges in the atmosphere in the broadest energy spectrum, specifically from radio frequency (RF) to gamma rays. The extremely powerful gamma radiation at altitudes of 10-20 km is a potential hazard for airline crews and passengers. Gamma radiation, which reaches Earth, covers wide areas and can be important both from an ecological perspective and in terms of human safety. Single supercharged RF pulses carry high radiation energy in virtually the entire radio useful wave range (up to and exceeding 3 GHz) and can serve as a convenient natural radiation source to create a global monitoring system for radio communications. Microsputnik obtained new data about the nature of atmospheric lightning discharges that is important for developing a kinetic theory on the breakdown of runaway electrons and for understanding other complicated phenomena of atmospheric electricity.

Solov'ev AV, Markov AV, Sorokin IV, Lyubinskii VE. Applied Scientific Research on the International Space Station and New Flight-Control Technologies. Herald of the Russian Academy of Sciences. *2017;87(3):229-236. DOI: 10.1134/S1019331617030091.*

ISS crewmember Anton SHkaplerov, posing with Mikrosputnik (ISS030E041537).

DISCOVERY

NASA's **Neutron Star Interior Composition Explorer (NICER)** is devoted to the study of neutron stars through soft X-ray timing. Neutron stars are the core left behind when massive stars explode. NICER probes the properties and behaviors of neutron stars: the dense-matter physics of their interiors and the electromagnetic environments of their magnetospheres. NICER's findings have implications for a broad array of studies in the areas of physics and astrophysics. By seeking a better understanding of the nature of neutron stars, NICER challenges nuclear physics theories by providing unique measurements by exploring the exotic states of matter within neutron stars through rotation-resolved X-ray spectroscopy.
The nature of matter under these conditions is a decades-old unsolved problem, one most directly addressed with measurements of the masses and radii of neutron stars to high precision (i.e., to better than 10 percent uncertainty). With few such constraints forthcoming from observations, theory has advanced a host of models to describe the physics governing neutron star interiors. These models can now be tested with astrophysical observations from NICER.



View of NICER attached to ExPRESS (Expedite the Processing of Experiments to Space Station) Logistics Carrier-2 (ELC-2) on the S3 Truss of space station (ISS057E055500).

Early data collected from NICER has borne some compelling results for neutron-star systems, black-hole binaries, active stars, and other cosmic X-ray sources. Some highlights are as follows:

- NICER observed that the accreting millisecond X-ray pulsar Swift J1756.9-2508 was consistent with previous outbursts. Accretion is the accumulation of particles over time into a massive object by gravitational attraction. Data confirmed that the X-ray pulsations have energy-dependent amplitudes (i.e., the fractional amplitude of the fundamental increases with energy), whereas the fractional amplitude of the harmonic shows a slight decline with energy.
- The NICER dataset presented evidence that Swift J0243.6+6124 underwent a transition between two accretion regimes at a critical luminosity of 10^{38} erg/s. This is the highest observed critical luminosity in any accretion-power pulsar, suggesting that the magnetic field for Swift J0243.6+6124 is unusually high, 10^{13} G. These observations of Swift J0243.6+6124 suggest that the ULX pulsars in other galaxies may also be accreting neutron stars with strong magnetic fields.
- NICER enabled a robust measurement of the spin of a black hole, which appears to be near maximal, using iron emission lines. NICER's spectral resolution revealed the existence of a black hole spinning near the speed of light. Whereas the overall shape of the broadened line provides information about the black hole spin and mass parameters, the existence of the narrow spectral feature reveals that the

accretion disk feeding the black hole is warped. (An accretion disk is the group of matter rotating around a massive body such as a black hole or star.)

- NICER allowed the characterization of deep and regular intensity variations (on timescales of a few minutes) from the black-hole binary GRS 1915+105, demonstrating that the energetic wind outflow from its accretion disk is constant in density over several months and that it effectively switches on and off with the black hole's short-term intensity modulations, within seconds.
- NICER detected a kilohertz Quasi-Periodic Oscillation (QPO). The subsequent measurement of the QPO amplitude below 2 keV favors those theories in which variations in accretion rate occur at the inner edge of the accretion disk. This measurement is likely due to strong gravity effects related to the neutron star's spin, resulting in luminosity variations.
- NICER confirmed IGR J17062-6143 is an accreting millisecond pulsar and measures its orbital period, 38 minutes, as the shortest known for this class of object.
- NICER enabled detection and modeling of relativistically broadened fluorescence lines from the accretion disk in Serpens X-1, including both the known high-ionization (K-shell) iron emission near 6.4 keV and the previously undistinguished lines from L-shell iron and lower-atomic-number elements near 1 keV.
- NICER tracked the full spectral and time evolution of a strong photospheric radius expansion Type I X-ray burst – the short-lived flash from thermonuclear fusion of accreted material on the surface of the neutron star – in the X-ray binary 4U 1820–30.
- NICER provided the first detection of a short sub-Eddington burst, demonstrating that bursts have a substantial impact on their accretion environment and allowing the study of burst-disk interaction across multiple sources and spectral states.
- NICER's observations of the black hole X-ray binary MAXI J1535-571 resulted in a count rate of >16,000 s^{-1} with minimal spectral distortion. Such large count rates combined with good energy resolution and soft X-ray response is revolutionary, growing our understanding of the innermost regions of accreting compact objects.

Gendreau KC, Arzoumanian Z. Searching for a pulse. Nature Astronomy. *2017 December 1; 1: 895.* DOI: 10.1038/s41550-017-0301-3.

Keek L, Arzoumanian Z, Bult PM, Cackett EM, Chakrabarty D, et al. NICER observes the effects of an X-Ray burst on the accretion environment in Aql X-1. The Astrophysical Journal. *2018 March 1;855(4):L4.* DOI: 10.3847/2041-8213/aab104.

Keek L, Arzoumanian Z, Chakrabarty D, Chenevez J, Gendreau KC, et al. NICER detection of strong photospheric expansion during a thermonuclear X-Ray burst from 4U 1820–30. The Astrophysical Journal. *2018 April 1;856(2):L37.* DOI: 10.3847/2041-8213/aab904.

Ludlam RM, Miller JM, Arzoumanian Z, Bult PM, Cackett EM, et al. Detection of reflection features in the neutron star low-mass X-Ray binary Serpens X-1 with NICER. The Astrophysical Journal. *2018 May 1;858(1): L5.* DOI: 10.3847/2041-8213/aabee6.

Bult PM, Altamirano D, Arzoumanian Z, Chakrabarty D, Gendreau KC, et al. NICER Discovers the Ultracompact Orbit of the Accreting Millisecond Pulsar IGR J17062–6143. The Astrophysical Journal Letters. *2018 May 9;858(2):L13.* DOI: 10.3847/2041-8213/aabf44.

Bult PM, Arzoumanian Z, Cackett EM, Chakrabarty D, Gendreau KC, et al. A NICER look at the Aql X-1 hard state. The Astrophysical Journal. *2018 May 20;859(1):L1.* DOI: 10.3847/2041-8213/aac2e2.

Bult PM, Altamirano D, Arzoumanian Z, Cackett EM, Chakrabarty D, et al. NICER detects a soft x-ray kilohertz quasi-periodic oscillation in 4U 0614+09. The Astrophysical Journal Letters. *2018 June 11;860(1):L9.* DOI: 10.3847/2041-8213/aac893.

Neilsen J, Cackett EM, Remillard RA, Homan J, Steiner JF, et al. A persistent disk wind in GRS 1915+105 with NICER. The Astrophysical Journal Letters. *2018 June 18;860(2):L19.* DOI: 10.3847/2041-8213/aaca96.

Miller JM, Gendreau KC, Ludlam RM, Fabian AC, Altamirano D, et al. A NICER spectrum of MAXI J1535–571: Near-maximal black hole spin and potential disk warping. The Astrophysical Journal Letters. *2018 June 25;860(2):L28.* DOI: 10.3847/2041-8213/aacc61.

Wilson-Hodge CA, Malacaria C, Jenke PA, Jaisawal GK, Kerr M, et al. NICER and Fermi GBM observations of the first galactic ultraluminous X-Ray pulsar Swift J0243.6+6124. The Astrophysical Journal. *2018 August 6;863(1):9.* DOI: 10.3847/1538-4357/aace60.

Bult PM, Altamirano D, Arzoumanian Z, Chakrabarty D, Gendreau KC, et al. On the 2018 outburst of the accreting millisecond X-ray pulsar Swift J1756.9-2508 as seen with NICER. The Astrophysical Journal. *2018 August 27;864(1):14.* DOI: 10.3847/1538-4357/aad5e5.

Stevens AL, Uttley P, Altamirano D, Arzoumanian Z, Bult PM, et al. A NICER discovery of a low-frequency quasi-periodic oscillation in the soft-intermediate state of MAXI J1535–571. The Astrophysical Journal Letters. *2018 September 26;865(2):L15.* DOI: 10.3847/2041-8213/aae1a4.

Word cloud of sources which contained ISS Results publications from October 1, 2017 - October 1, 2018.

ISS Research Results Publications

October 1, 2017 - October 1, 2018

(Listed by category and alphabetically by investigation.)

BIOLOGY AND BIOTECHNOLOGY

Alterations of C. elegans muscle fibers by microgravity (Nematode Muscles) – Sudevan S, Hashizume T, Yano S, Kuriyama K, Momma K, et al. Nematode Muscles project in spaceflight experiment. *Biological Sciences in Space*. 2018;32:6-10. DOI: 10.2187/bss.32.6.

Antibiotic Effectiveness in Space-1 (AES-1) – Aunins TR, Erickson KE, Prasad N, Levy SE, Jones A, et al. Spaceflight modifies Escherichia coli gene expression in response to antibiotic exposure and reveals role of oxidative stress response. *Frontiers in Microbiology*. 2018;9:310. DOI: 10.3389/fmicb.2018.00310.

Biological Research In Canisters (BRIC) – Fajardo-Cavazos P, Nicholson WL. Establishing Standard Protocols for Bacterial Culture in Biological Research in Canisters (BRIC) Hardware. *Gravitational and Space Research*. 2016 December 19;4(2):58-69.*

Biological Research In Canisters (BRIC) – Basu P, Kruse CP, Luesse D, Wyatt SE. Growth in spaceflight hardware results in alterations to the transcriptome and proteome. *Life Sciences in Space Research*. 2017 November;15:88-96. DOI: 10.1016/j.lssr.2017.09.001.

Biological Research in Canisters-21 (BRIC-21) – Morrison MD, Fajardo-Cavazos P, Nicholson WL. Cultivation in space flight produces minimal alterations in the susceptibility of Bacillus subtilis cells to 72 different antibiotics and growth-inhibiting compounds. *Applied and Environmental Microbiology*. 2017 November; 83(21):e01584-17. DOI: 10.1128/AEM.01584-17.

Caenorhabditis elegans to Assess Radiation Damage on Long-Duration Flights (Elerad) – Jamal RA, Nurul-Faizah J, Then SM, Szewczyk NJ, Stodieck LS, Harun R. Gene Expression Changes in Space Flown *Caenorhabditis Elegans* Exposed to a Long Period of Microgravity. *Gravitational and Space Biology*. 2010;23(2): 85-86.*

Commercial Biomedical Testing Module-3: Assessment of sclerostin antibody as a novel bone forming agent for prevention of spaceflight-induced skeletal fragility in mice (CBTM-3-Sclerostin Antibody) – Blaber EA, Pecaut MJ, Jonscher KR. Spaceflight activates autophagy programs and the proteasome in mouse liver. *International Journal of Molecular Sciences*. 2017 September 27;18(10):2062. DOI: 10.3390/ijms18102062.*

Crystallization of Medically Relevant Proteins Using Microgravity (Protein Crystallography) – Malley KR, Koroleva O, Miller I, Sanishvili R, Jenkins CM, Gross RW, Korolev S. The structure of iPLA2β reveals dimeric active sites and suggests mechanisms of regulation and localization. *Nature Communications*. 2018 February 22;9(765). DOI: 10.1038/s41467-018-03193-0.

Effect of Space Flight on Innate Immunity to Respiratory Viral Infections (Mouse Immunology-2) – Dagdeviren D, Beallias J, Khan I, Mednieks M, Hand AR. Response of the mouse sublingual gland to spaceflight. *European Journal of Oral Sciences*. 2018 October;126(5):373-381. DOI: 10.1111/eos.12541.

eValuatIon And monitoring of microBiofiLms insidE International Space Station (VIABLE ISS) – Perrin E, Bacci G, Garrelly L, Canganella F, Bianconi G, et al. Furnishing spaceship environment: evaluation of bacterial biofilms on different materials used inside International Space Station. *Research in Microbiology*. 2018 July-August;169(6):289-295. DOI: 10.1016/j.resmic.2018.04.001.

Functional Effects of Spaceflight on Cardiovascular Stem Cells (Cardiac Stem Cells) – Baio J, Martinez AF, Bailey L, Hasaniya N, Pecaut MJ, Kearns-Jonker M. Spaceflight activates protein kinase C alpha signaling and modifies the developmental stage of human neonatal cardiovascular progenitor cell. *Stem Cells and Development*. 2018 June 15;27(12):805-818. DOI: 10.1089/scd.2017.026.

Functional Effects of Spaceflight on Cardiovascular Stem Cells (Cardiac Stem Cells) – Baio J, Martinez AF, Silva I, Hoehn CV, Countryman S, et al. Cardiovascular progenitor cells cultured aboard the International Space Station exhibit altered developmental and functional properties. *npj Microgravity*. 2018 July 26;4(13):13 pp. DOI: 10.1038/s41526-018-0048-x.

GeneLab – Beheshti A, Cekanaviciute E, Smith DJ, Costes SV. Global transcriptomic analysis suggests carbon dioxide as an environmental stressor in spaceflight: A systems biology GeneLab case study. *Scientific Reports*. 2018 March 8;8(1):10 pp. DOI: 10.1038/s41598-018-22613-1.

GeneLab – Beheshti A, Ray S, Fogle H, Berrios D, Coates SV. A microRNA signature and TGF-beta 1 response were identified as the key master regulators for spaceflight response. *PLOS One*. 2018 July 25;13(7):19 pp. DOI: 10.1371/journal.pone.0199621.

GeneLab – Morrison MD, Nicholson WL. Meta-analysis of data from spaceflight transcriptome experiments does not support the idea of a common bacterial “spaceflight response.” *Scientific Reports*. 2018 September 26;8(1):14403. DOI: 10.1038/s41598-018-32818-z.

Genes in Space-1 – Boguraev A, Christensen HC, Bonneau AR, Pezza JA, Nichols NM, et al. Successful amplification of DNA aboard the International Space Station. *npj Microgravity*. 2017 November 16;3(1):26 pp. DOI: 10.1038/s41526-017-0033-9.

Gravity Related Genes in Arabidopsis - A (Genara-A) – Bizet F, Pereda-Loth V, Chauvet H, Gerard J, Eche B, et al. Both gravistimulation onset and removal trigger an increase of cytoplasmic free calcium in statocytes of roots grown in microgravity - document. *Scientific Reports*. 2018 July 30;8(1): 11442. DOI: 10.1038/s41598-018-29788-7.

International Space Station Internal Environments (ISS Internal Environments) – Wong W, Oubre C, Mehta SK, Ott CM, Pierson DL. Preventing infectious diseases in spacecraft and space habitats. *Modeling the Transmission and Prevention of Infectious Disease*. 2017.

International Space Station Internal Environments (ISS Internal Environments) – Salmela A, Kokkonen E, Kulmala I, Veijalainen A, Van Houdt R, et al. Production and characterization of bioaerosols for model validation in spacecraft environment. *Journal of Environmental Sciences*. 2018 July;69:227-238. DOI: 10.1016/j.jes.2017.10.016.

International Space Station Medical Monitoring (ISS Medical Monitoring) – Brzhozovskiy AG, Kononikhin AS, Indeykina M, Pastushkova LK, Popov IA, et al. Label-free study of cosmonaut’s urinary proteome changes after long-duration spaceflights. *European Journal of Mass Spectrometry*. 2017 August;23(4):225-229. DOI: 10.1177/1469066717717610.

International Space Station Medical Monitoring (ISS Medical Monitoring) – Pastushkova LK, Kashirina DN, Kononikhin AS, Brzhozovskiy AG, Ivanisenko VA, et al. The effect of long-term space flights on human urine proteins functionally related to endothelium. *Human Physiology*. 2018 January 1;44(1):60-67. DOI: 10.1134/S0362119718010139.

Japan Aerospace and Exploration Agency - Granada Crystallization Facility High Quality Protein Crystallization Project (JAXA-GCF) – Kinoshita T, Hashimoto T, Sogabe Y, Fukada H, Matsumoto T, Sawa M. High-resolution structure discloses the potential for allosteric regulation of mitogen-activated protein kinase kinase 7. *Biochemical and Biophysical Research Communications*. 2017 November 4;493(1):313-317. DOI: 10.1016/j.bbrc.2017.09.025.

Japan Aerospace Exploration Agency Protein Crystallization Growth (JAXA PCG) – Sakamoto Y, Suzuki Y, Iizuka I, Tateoka C, Roppongi S, et al. S46 peptidases are the first exopeptidases to be members of clan PA. *Scientific Reports*. 2014 May 15; 4:4977. DOI: 10.1038/srep04977.*

Japan Aerospace Exploration Agency Protein Crystallization Growth (JAXA PCG) – Yokomaku K, Akiyama M, Morita Y, Kihira K, Komatsu T. Core–shell protein cluster comprising haemoglobin and recombinant feline serum albumin as an artificial O_2 carrier for cats. *Journal of Materials Chemistry B*. 2018 April 28;6(16):2417-2425. DOI: 10.1039/C8TB00211H.

Microbial Tracking Payload Series (Microbial Observatory-1) – Urbaniak C, Checinska Sielaff A, Frey KG, Allen JE, Singh NK, et al. Detection of antimicrobial resistance genes associated with the International Space Station environmental surfaces. *Scientific Reports*. 2018 January 16;8(1):814. DOI: 10.1038/s41598-017-18506-4.

Molecular and Plant Physiological Analyses of the Microgravity Effects on Multigeneration Studies of *Arabidopsis thaliana* (Multigen) – Fisahn J. Control of plant leaf movements by the lunisolar tidal force. *Annals of Botany*. 2018 June 8;121(7):e1-e6. DOI: 10.1093/aob/mcx214.

Molecular Mechanism of Microgravity-Induced Skeletal Muscle Atrophy - Physiological Relevance of Cbl-b Ubiquitin Ligase (MyoLab) – Uchida T, Sakashita Y, Kitahata K, Yamashita Y, Tomida C, et al. Reactive oxygen species up-regulate expression of muscle atrophy-associated ubiquitin ligase Cbl-b in rat L6 skeletal muscle cells. *American Journal of Physiology-Cell Physiology*. 2018 June 4;314(6):C721-C731. DOI: 10.1152/ajpcell.00184.2017.

NanoRacks-Comparison of the Growth Rate and DNA Characterization of Microgravity Exposed Microbial Community Samples (NanoRacks-Project MERCCURI) – Lang JM, Coil DA, Neches RY, Brown WE, Cavalier D, et al. A microbial survey of the International Space Station (ISS). *PeerJ*. 2017 December 5;5:e4029. DOI: 10.7717/peerj.4029.

NanoRacks-National Center for Earth and Space Science-Kitty Hawk (NanoRacks-NCESSE-Kitty Hawk) – Gravely AK, Vlasov A, Freeman A, Wu K, Szewczyk NJ, et al. Levels of Acid Sphingomyelinase (ASM) in Caenorhabditis elegans in Microgravity. *Gravitational and Space Research*. 2018 July 26;6(1): 27-36.

NanoRacks-Self-Assembly in Biology and the Origin of Life (NanoRacks-SABOL) – Bell D, Durrance S, Kirk DR, Gutierrez HM, Woodard D, et al. Self-Assembly of Protein Fibrils in Microgravity. *Gravitational and Space Research*. 2018 July 26;6(1):10-26.

Rodent Research Hardware and Operations Validation (Rodent Research-1) – Ward C, Rettig TA, Hlavacek S, Bye BA, Pecaut MJ, Chapes SK. Effects of spaceflight on the immunoglobulin repertoire of unimmunized C57BL/6 mice. *Life Sciences in Space Research*. February 2018;16:63-75. DOI: 10.1016/j.lssr.2017.11.003.

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