National Aeronautics and
Space Administration

ANNUAL HIGHLIGHTS of RESULTS from the INTERNATIONAL SPACE STATION

October 1, 2019 – October 1, 2020

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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 www.nasa.gov/stationresults.

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Cover:

Image of NASA Astronaut Andrew Morgan, whose spacesuit is outfitted with a variety of tools and cameras, holds on to a handrail during a spacewalk to repair the International Space Station's cosmic particle detector, the Alpha Magnetic Spectrometer (iss061e058254).

NP-2020-11-021-JSC

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20 Years on the International Space Station

Introduction

This year, we celebrate the 20th anniversary of continuous human presence on board the International Space Station (ISS), a momentous milestone for the low-Earth orbiting laboratory.

The ISS has been a reliable testbed for microgravity research that cannot be accomplished on Earth. This lab is where some of the most innovative concepts are tested in the fields of technology development and demonstration, educational activities, biology and biotechnology, Earth and space science, human research, and physical science.

With the accomplishment of 20 uninterrupted years of humans living and working in space, we also commemorate the successful cooperation among member nations to understand and address the challenges in our quest for long-term exploration and to sustain human life on the Moon and Mars in the coming decades.

Far more than simply preparing us for life in in the extreme environment of space[1], microgravity research on board the ISS also has served to provide breakthrough discoveries for improving the quality of human lives here on Earth. Disciplines as varied as health care (e.g., pharmaceuticals, imaging, medical) and physical sciences are represented, while the space station itself serves as an observation platform that captures environmental changes and weather events.

In this year's Annual Research Highlights, we report ISS science results from a wide range of fields, from investigating ways to sustain human life in space, such as plant seedling growth and early detection of osteoporosis in space, to better understanding the electrostatic levitation processes and Bose-Einstein Condensate (BEC) Bubble Dynamics. The ISS Program Science Office (PSO) collected 312 scientific publications between October 1, 2019, and October 1, 2020. Of these, 286 were articles published in peer-reviewed journals, 20 were conference papers, and 4 were gray literature publications such as technical reports or books. Out of the 312 items collected, 29 were published prior to October 1, 2019, but they were not identified until after October 1, 2019.

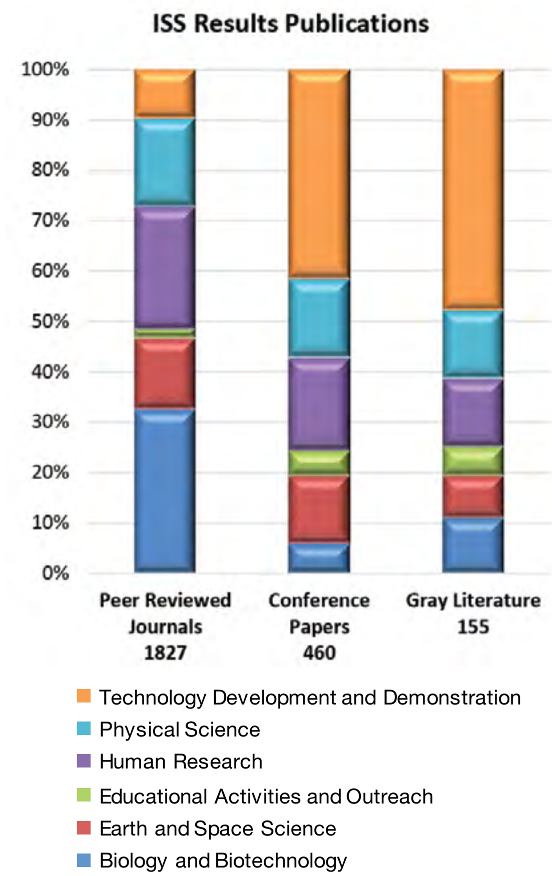


Figure 1. A total of 2850 publications (through October 1, 2020) represent scientists worldwide. This chart illustrates the percentages for each research discipline by publication type.

These results represent research activities 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), the Canadian Space Agency (CSA), and the Italian Space Agency (ASI). This report includes highlights of collected ISS results as well as a complete listing of the year's ISS results that benefit humanity, contribute to scientific knowledge, and advance the goals of space exploration for the world.

[1] *Diallo, O. N., Ruttley, T. M., Costello, K., Hasbrook, P., Cohen, L., Marcil, I., ... & Karabadzhak, G. (2019). Impact of the International Space Station Research Results. The 70th International Astronautical Congress. 2019*

As of October 1, 2020, the ISS PSO has identified a total of 2850 results publications since 1999, with sources in peer-reviewed journals, conferences, and gray literature representing the work of more than 5000 scientists worldwide (Figure 1). Overall, this number of results publications represents a 17% increase from a year ago.

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

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 PSO 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 article citations and the journal's Eigenfactor ranking 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 5 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. From October 1, 2019, to October 1, 2020, 56 ISS articles were published in the top 100 journals based on Eigenfactor. Ten of those ISS articles were in the top 10 journals based on Eigenfactor, as reported by Clarivate Analytics® (Table 1).

	Clarivate Analytics® Rank by Eigenfactor	Source (# of ISS publications)
ISS Publications In Top 100 Sources	1	PLOS ONE (3)
	3	Scientific Reports (4)
	4	Nature (1)
	5	Science (1)
	6	Proceedings of the National Academy of Sciences of the United States of America (1)
	11	Physical Review Letters (3)
	22	The Astrophysical Journal (19)
	28	Monthly Notices of the Royal Astronomical Society (10)
	37	Circulation (1)
	46	Astronomy and Astrophysics (2)
	49	Science Advances (2)
	58	Frontiers in Microbiology (3)
	67	Journal of Alloys and Compounds (1)
	95	Frontiers in Plant Science (5)

Table 1: 2019-2020 ISS Publications collected in the Top 100 Global Journals, by Eigenfactor. From October 1, 2019, to October 1, 2020, as reported by 2019 Journal Citation Reports, Clarivate Analytics®.

A stacked area chart in Figure 2 has been included in this year's edition of the Annual Highlights of Results (2020) to depict the growth of ISS publications over the years and its augmentation through citations. These data may imply that the dissemination of ISS science is now influencing other areas of investigation and contributing to the generation of new ideas.

[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.*

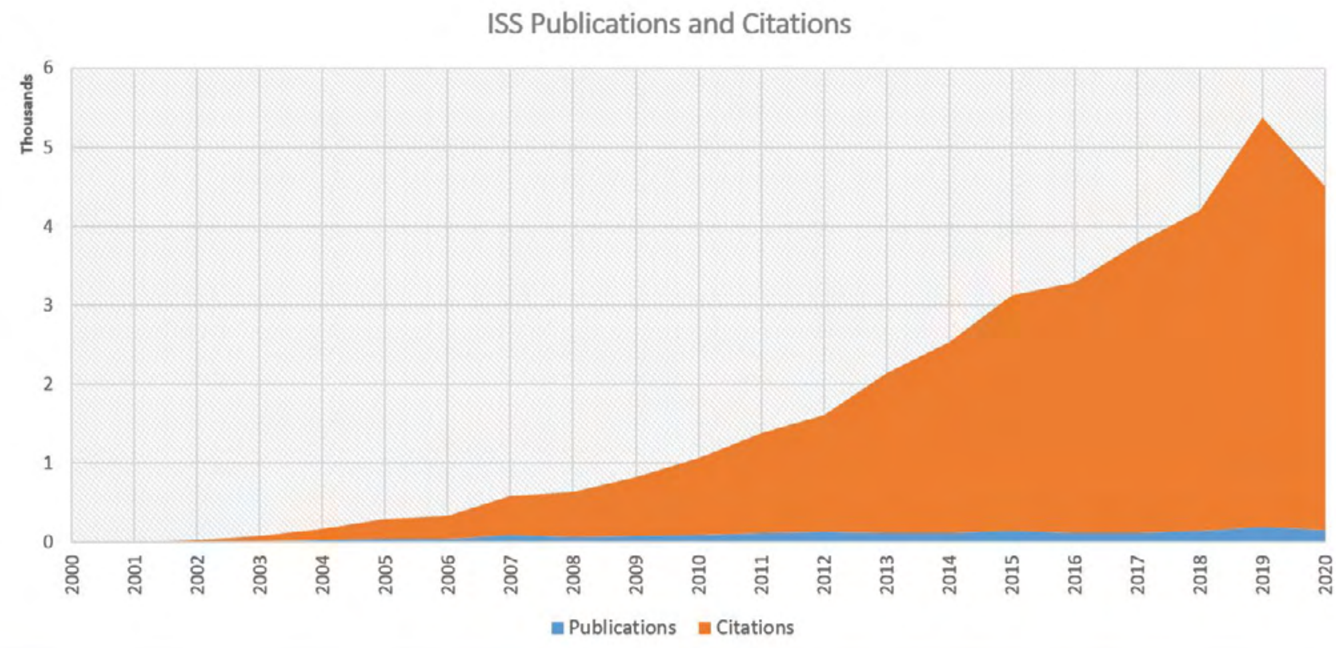


Figure 2. Stacked area chart depicts growth of publications and citations since the inception of the ISS.

ISS science continues to flourish even more rapidly today than 10 years ago, consequently affecting formal and public education, generating a new workforce of responsible and creative scientists, and inspiring young minds.

The ISS PSO has implemented the use of bibliometrics as an additional method to measure the impact of space station research. Bibliometrics is the quantitative analysis of written documents. It is frequently used to analyze scientific and scholarly publications. Researchers may use bibliometrics to get an overview of their research field and its connections with other areas of research. Bibliometrics can be used to address a broad range of challenges in research management and research evaluation. For instance, bibliometrics can be applied to support strategic decision making by the management of a research institution and to support the evaluation of research institutes and research groups.[3]

Bibliometric visualizations offer a powerful way to present detailed information in a way that improves understanding of the data. Visualizations can provide a network perspective; e.g., a representation of networks of research disciplines, co-authorship, or citations. When dealing with large numbers of publications, an overview of the publications' global reach can be obtained by presenting a visualization of the authors.

[3] *Van Eck NJ, Waltman L. Software survey:VOSviewer, a computer program for bibliometric mapping. Scientometrics. 2010;84(2):523-538. DOI: 10.1007/s11192-009-0146-3.*

INTERNATIONAL SPACE STATION RESEARCH GROWTH

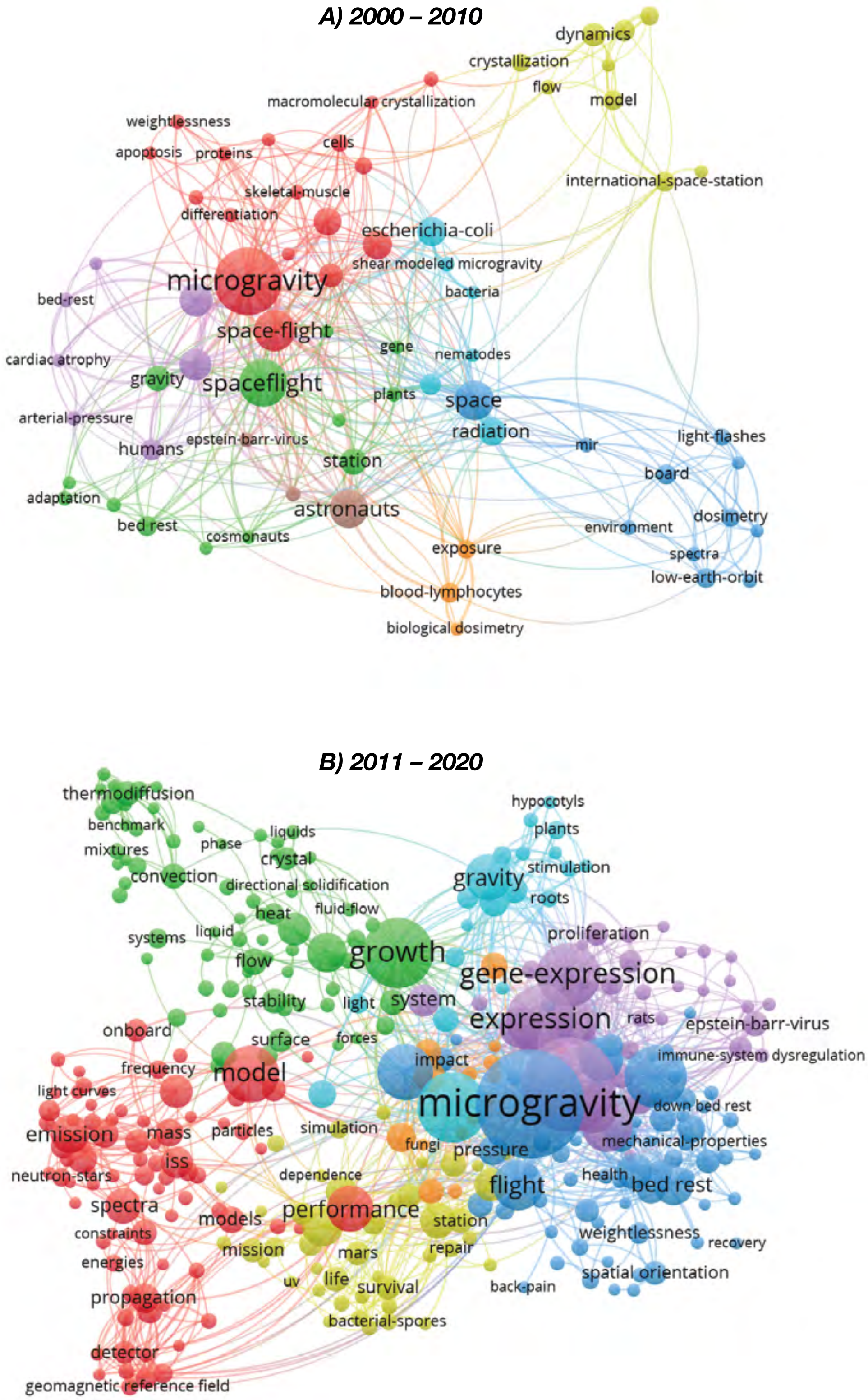


Figure 3. A) Network analysis of research topic keywords identified in ISS publications during the first decade (2000 – 2010) of the ISS. B) Network analysis of research topic keywords identified in ISS publications during the second decade (2011 – 2020) of the ISS.

EVOLUTION OF SPACE STATION COLLABORATION

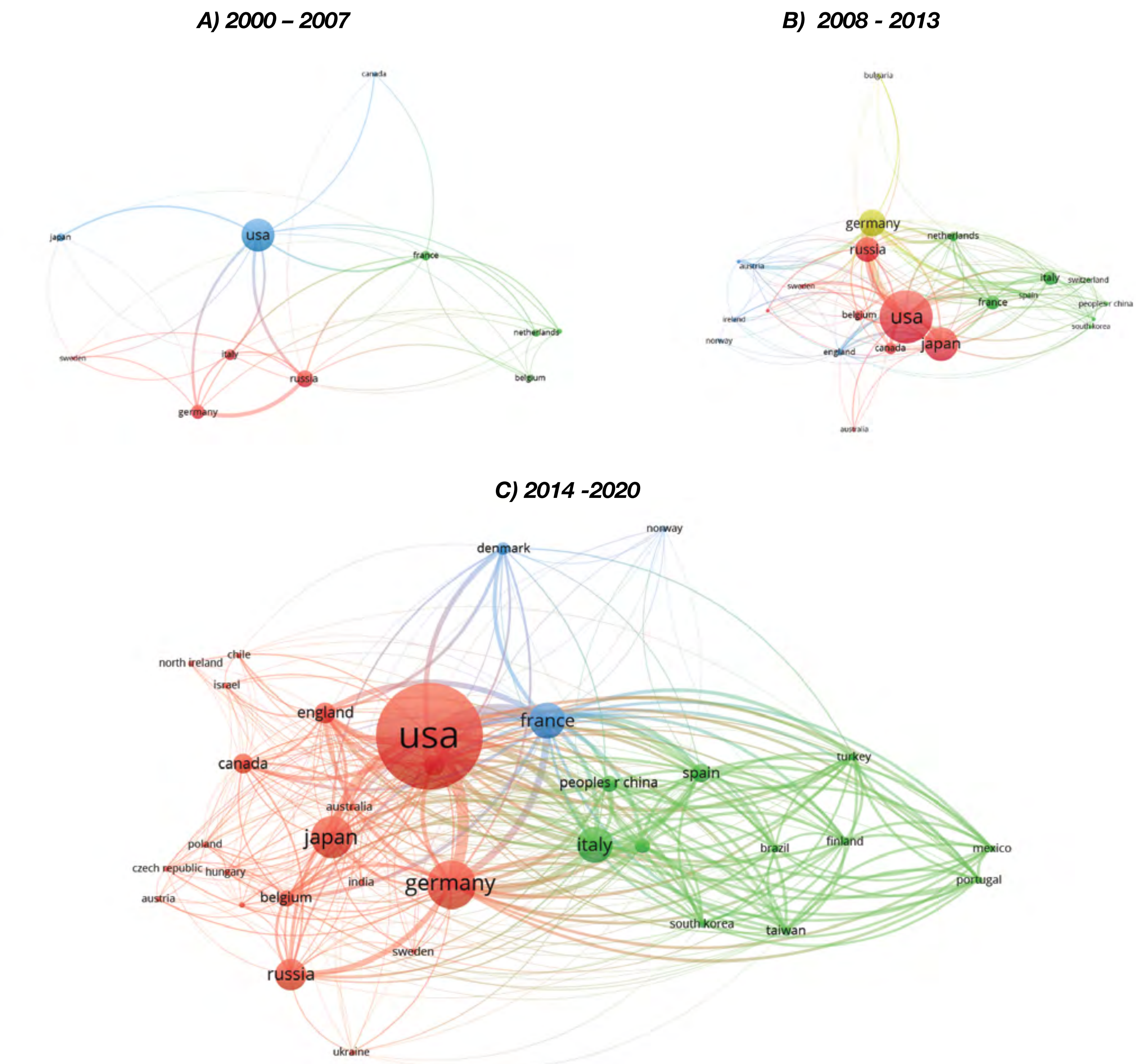


Figure 4. VOSviewer visualization of co-authorship by country. Growth of co-authorship is observed across the panels A, B, and C. A) Co-authorship data from 2000 – 2007. B) Co-authorship data from 2008 – 2013. C) Co-authorship data from 2014 – 2020. The sizes of the nodes indicate the number of publications of the country labeled. Links indicate co-authorship between countries.

Using all ISS research results articles collected through October 1, 2020, Figure 3 presents two VOSviewer network analyses of research topic keywords collected during the first half (2000 – 2010) and second half (2011 – 2020) of the 20 years of ISS operations to illustrate how research has grown and diversified since the inception of space station. The sizes of the nodes indicate the number of publications associated with the research topic labeled. As shown, for example, the topic of microgravity has grown and strengthened over the years. Additionally, the number of links within each colored category represent the variety of specific topics roughly captured by a research area on the ISS.

For instance, in the realm of physics, research topics expanded and diversified from 9 nodes in panel A (in yellow) to more than 60 nodes in panel B (in green). Another example involves the topics “gene” or “genetic expression”. The network in panel A shows a small node connected to other topics associated with Human Research as well as the Biology and Biotechnology areas of ISS research.

The network in panel B shows a large node that is highly interconnected, primarily with other Human Research topics. This interconnectivity tells us that genetic research on the space station has qualitatively changed from a topic typically associated with plants in the early days to a topic typically associated with humans and animal models today.

Figure 4 presents another VOSviewer analysis showing the network of co-authorship by country broken down by three time periods. The sizes of the nodes indicate the number of publications of the country labeled, and the links indicate co-authorship between countries.

In panel A, the beginning years of ISS, the graph shows that the United States was the epicenter that drove collaboration with other countries (i.e., Germany, Russia, Italy, France, Japan, and Canada). In panel B, the graph shows that the United States remained an important participant in collaborative research, yet Japan, Russia, and Germany also demonstrated their outstanding efforts in collaborating with other countries such as Spain and the Netherlands. In panel C, the current ISS activity, the graph shows that the United States continues to be fundamental to the development of new research collaborations, yet countries such as England, Denmark, Germany, and Russia keep pace, establishing collaborations with other countries. Overall, the graph demonstrates that the United States and other countries such as Germany, Japan, Russia, France, and Italy have multiplied their collaborative ties with other countries over the last 20 years to make breakthrough discoveries.

EVOLUTION OF SPACE STATION RESULTS

The archive of ISS investigations went online in 2004. Since that time, the PSO team has implemented many changes to how it tracks investigations. The team has separated research disciplines and added new research disciplines as more investigations have become active. The team has added or redefined many fields since the rollout of the archive. Initially, the PSO Research Results team collected only publications that were either related to an investigation or presented direct results from an investigation via a publication or patent. More recently, the Program Science Database (PSDB) included the following publication types:

- ISS Results – publications that provide information about the performance and results of the investigation, facility, or project as a direct implementation on the ISS or on a vehicle to the ISS
- Patents – applications filed based on the performance and results of the investigation, facility, or project on the ISS or on a vehicle to the ISS
- Related – publications that lead to the development of the investigation, facility, or project.

Through continual analysis of the database, the team has determined it is time for another change. We have implemented two new types of results publications to track: ISS Flight Preparation Results and Derived Results.

ISS Flight Preparation Results are articles about the development work performed for the investigation, facility, or project prior to operation on the ISS. Derived Results are articles that use data from an investigation that operated on the ISS; however, the authors of the article are not members of the original investigation team. Derived Results articles have emerged as a direct outcome of the open data initiative, which provides access to raw data to researchers from outside the investigation, enabling them to analyze and publish results, providing wider scientific benefits, and expanding global knowledge. As of October 1, 2020, the PSO Research Results team identified 78 publications as ISS Flight Preparation Results and 107 publications as Derived Results. Although the Annual Highlights of Results spotlights ISS Results publications, recognition of these additional publication types in the database will contribute to the spread of scientific knowledge from the ISS.

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 ISS includes descriptions of just a few of the results that were published from across the ISS partnership during the past year.

EXPLORATION

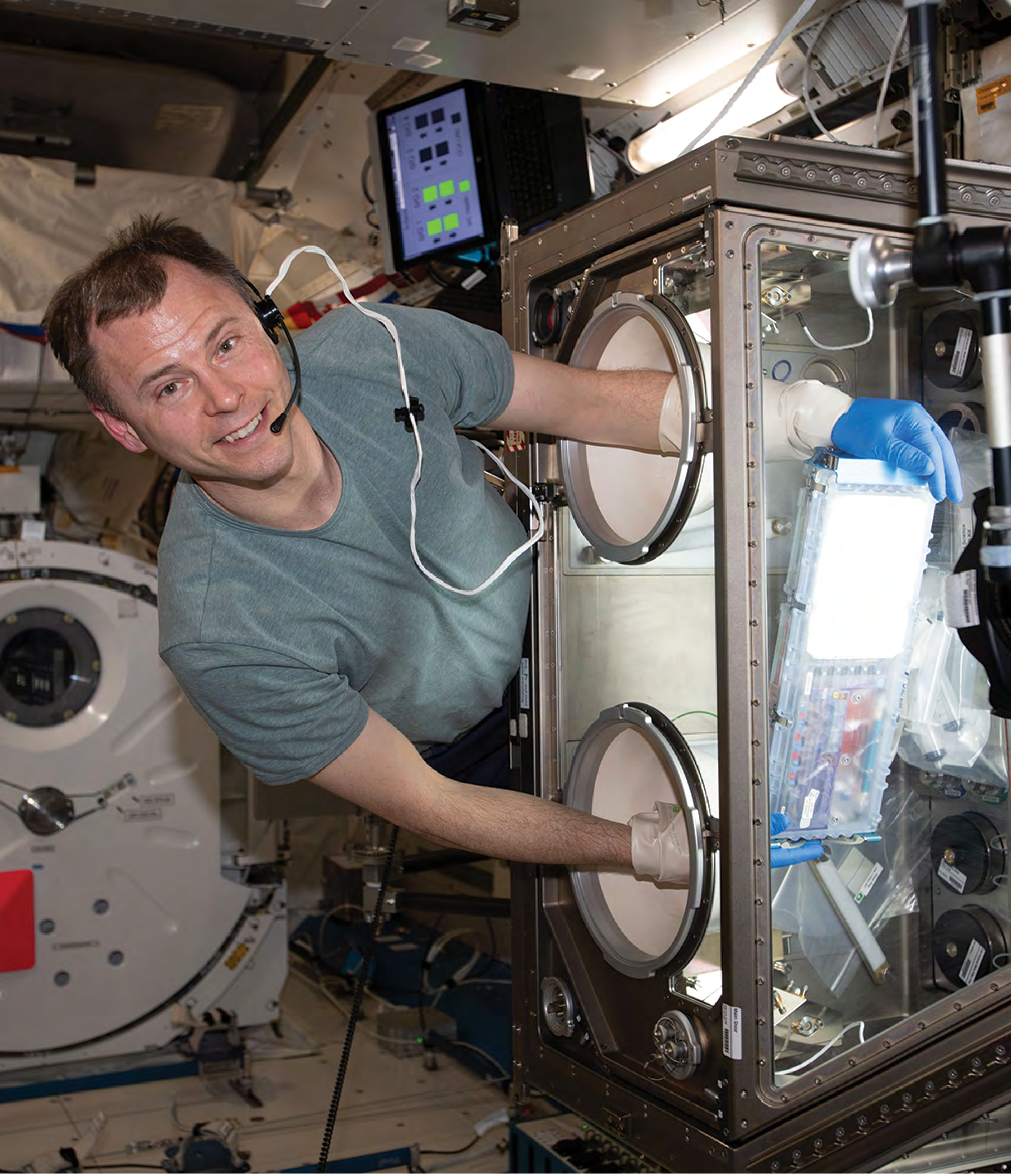
ISS investigation results have yielded updated insights into how to live and work more effectively in space by addressing such topics as understanding radiation effects on crew health, combating bone and muscle loss, improving designs of systems that handle fluids in microgravity, and determining how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

DISCOVERY

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 multidisciplinary ways.

BENEFITS FOR HUMANITY

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.



NASA astronaut Nick Hague works inside the Japanese Kibo laboratory module, supporting research activities with the Life Sciences Glovebox. Hague is conducting science operations for the Cell Science-02 bone healing and tissue regeneration experiment. (iss060e019982).

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

Plants can generate breathable air and be a source of food for crew members. ESA's investigation, **Seedling Growth-1**, sought to understand the effects of gravity and light on plant development. Gravity is thought to be the primary factor, followed by light, that drives plant root and stem growth orientation. The investigation used the European Module Cultivation System aboard the ISS to examine the adaptation of Arabidopsis thaliana seedlings grown under different gravity conditions, including microgravity, Moon, Mars, Earth, and reduced-Earth. Seedlings were then exposed to white light for 96 hours followed by blue light for 48 hours before they were frozen for further analyses on Earth. Seedling RNA was extracted and sequenced to identify all differentially expressed genes (DEGs).

Analyses revealed that only one gene was differentially expressed across all gravity conditions (Figure 5). In addition, the same 14 genes appeared to be expressed differentially in microgravity, Moon gravity, and reduced-Earth gravity. These DEGs were associated with light and photosynthesis, chemical and hormone responses, and cell membrane structure and function. Overall, the number of DEGs was reduced as the difference from Earth gravity decreased. Even though a blue light was provided, genes associated with photosynthesis were still reduced at fractional gravities, suggesting that shared pathways exist between gravity and light perception responses.

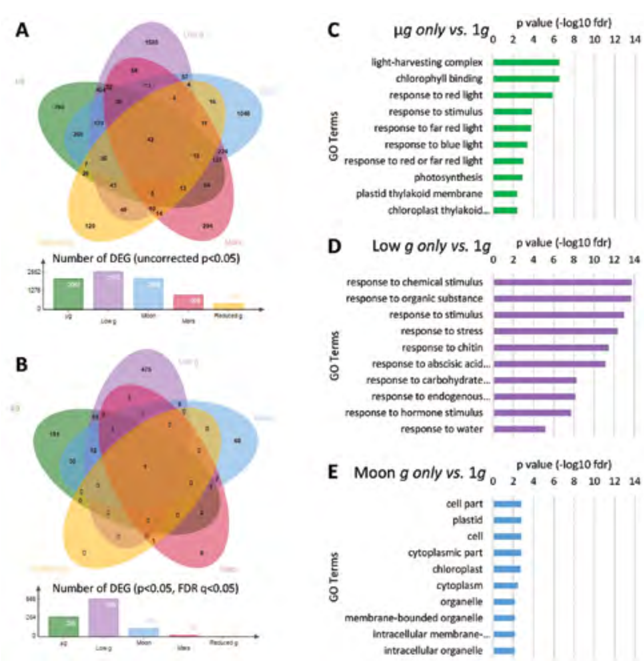


Figure 5. DEGs across the different gravity levels. Panels A and B show uncorrected and adjusted results. Panels C, D, and E show the most significant gene ontologies under different gravity levels. (Image courtesy of Herranz R, et al, Frontiers in Plant Science, 2019.)

These results guide the current use and future implementation of bioregenerative plant support systems in space.

Herranz R, Vandenbrink JP, Villacampa A, Manzano A, Poehlman WL, Feltus FA, Kiss JZ, Medina F. RNAseq Analysis of the Response of Arabidopsis thaliana to Fractional Gravity Under Blue-Light Stimulation During Spaceflight. Frontiers in Plant Science. 2019 November 26; 10: 11 pp. DOI: 10.3389/fpls.2019.01529.

JAXA's **Characterization of Amyloid Formation Under Microgravity Environment: Toward Understanding the Mechanisms of Neurodegenerative Diseases (Amyloid)** investigated the mechanisms behind amyloid fibril formation for the development of new treatments for diseases such as Parkinson's and Alzheimer's. Amyloid β (Aβ) fibrils are protein aggregates involved in the processes of neurodegenerative disorders. In a new study, researchers compared the growth of Aβ fibrils (i.e., nucleation and elongation) between microgravity and Earth conditions. Four samples of Aβ (1-40) solution were flown to the ISS. Samples were thawed and incubated at 37°C to allow the growth of the fibrils. Growth was stopped at 6 hours and 1, 3 and 9 days, and the samples were transferred to cold stowage. Control samples were independently processed under the same conditions on the ground.

Once the ISS samples were returned to Earth, the fibrils were analyzed using cryogenic electron microscopy, which allowed three-dimensional reconstruction of the different morphologies of Aβ fibrils grown in space (Figure 6). Overall, the results revealed two morphologies of Aβ fibrils that were more twisted and with a higher pitch than ground control samples. The two morphologies observed in microgravity were practically indistinguishable from one another. Space-grown Aβ fibrils also grew much more slowly than on Earth, similar to observations of crystal growth experiments.

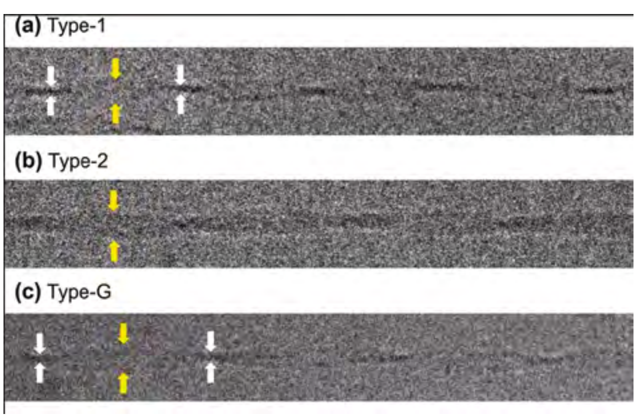


Figure 6. Aβ fibrils grown aboard the ISS (type-1 and type-2) and Aβ control fibrils grown on the ground (type-G). (Image courtesy of Yagi-Utsumi, M, et al, npj microgravity, 2020.)

Reduced convection effects may explain the slow growth of Aβ fibrils in space, and kinetic differences (i.e., lack of sedimentation) may explain the new fibril structure observed in microgravity.

The experimental environment of the ISS enables the search for the molecular mechanisms underlying amyloid formation and, more generally, the self-organization of biological macromolecules on Earth.

These promising findings could assist the development of new pharmaceuticals aimed at inhibiting amyloid fibril formation to prevent or treat neurodegenerative conditions.

Yagi-Utsumi M, Yanaka S, Song C, Satoh T, Yamazaki C, Kasahara H, Shimazu T, Murata K, Kato K. Characterization of amyloid ß fibril formation under microgravity conditions. npj Microgravity. 2020 June 12; 6(1): 17. DOI: 10.1038/s41526-020-0107-y.

NASA's **Assessment of Myostatin Inhibition to Prevent Skeletal Muscle Atrophy and Weakness in Mice Exposed to Long-Duration Spaceflight (Rodent Research-3-Eli Lilly)**, sponsored by pharmaceutical company Eli Lilly and Co. and ISS National Lab, studied molecular and physical changes in the musculoskeletal system of rodents in space. Mice exposed to spaceflight can be a valuable model to understand, target, and treat causes of muscle disuse atrophy and bone loss, including modeling grave muscle and bone diseases such as muscular dystrophy, osteoporosis, and musculoskeletal frailty with aging.

In a recent publication, researchers described results of their study of whether the inhibition of myostatin through the delivery of an antibody, YN41, could prevent the expected loss of skeletal muscle mass in a space environment. Mice were treated with YN41 one day before launching to the ISS, and at 2 and 4 weeks in space. Grip strength and body composition of the mice were measured at different time points during the 6-week experiment. At termination, mice were sacrificed and frozen in space, with the exception of the right hind leg, which was dissected and stored at room temperature.

On Earth, further hind leg dissections of the gastrocnemius, soleus, and plantaris were bisected and imaged to measure the area of the cross sections of the muscle fibers. Bones were stained and analyzed using quantitative microcomputed tomography.

Findings showed that the treatment with myostatin prevented all losses in lean mass, grip strength, and muscle weights (with the exception of the soleus) induced by microgravity (Figure 7). Mice treated with YN41 also prevented heart weight loss. Finally, myostatin inhibition did not have a detrimental effect on bone mineral density; however, it also did not prevent bone loss.

This research demonstrates that myostatin inhibition is an effective countermeasure to prevent muscle loss produced by the harsh environment of space.

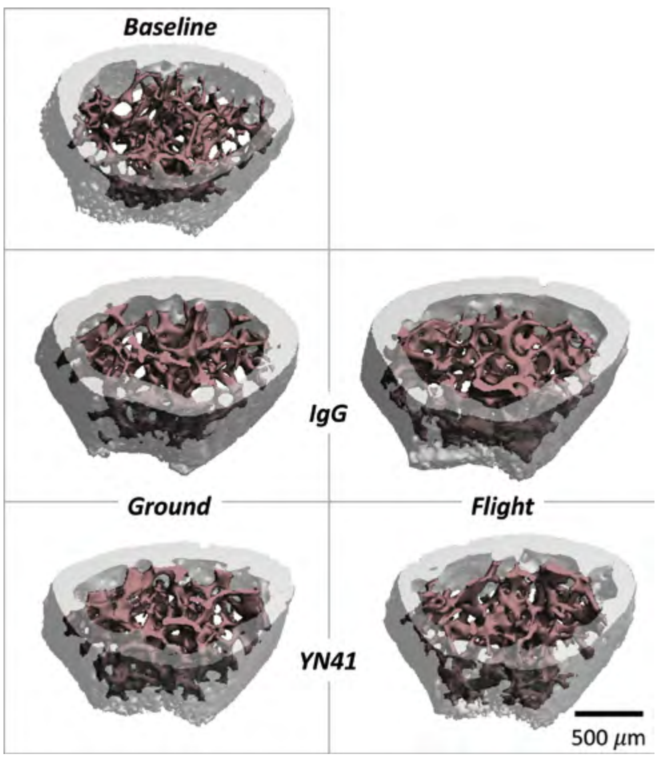


Figure 7. Baseline, ground, and flight micro-computed tomography images obtained from the distal femur of mice treated with either IgG or YN41. Relative to the IgG ground group, the flight group showed that the microarchitecture of both trabecular and cortical compartments were significantly reduced with microgravity exposure, but were unchanged by myostatin inhibition. (Image courtesy of Smith RC., et al, PLOS ONE, 2020.)

Smith RC, Cramer MS, Mitchell PJ, Lucchesi J, Ortega AM, Livingston EW, Ballard D, Zhang L, Hanson J, Barton K, Berens S, Credille KM, Bateman TA, Ferguson VL, Ma YL, Stodieck LS. Inhibition of myostatin prevents microgravity-induced loss of skeletal muscle mass and strength. PLOS ONE. 2020 April 21; 15(4): e0230818. DOI: 10.1371/journal.pone.0230818.

EXPLORATION

Roscosmos' investigation, **Studying the Features of the Growth and Development of Plants, and Technology for their Culturing in Spaceflight on the ISS RS (Rastenia-Pshenitsa (Plants-Wheat)**, aimed to optimize the way plants are cultivated aboard the ISS. The main objective was to study the impact of spaceflight on plant development, particularly examining the effect on phenology and genetic expression after long-term microgravity exposure.

In a new study, researchers flew seeds of a super dwarf form of wheat and grew them in the Lada space greenhouse aboard the Russian segment of the ISS. The plants grew for a span of 90 days to encompass a full cycle of the wheat plant. The dried wheat plants were returned to Earth, and the bran of the kernels underwent morphological analysis with a scanning electron microscope.

Space-grown wheat seeds were significantly larger and heavier than ground controls (Figure 8). There was also a significant decrease in the length of the hairs and their angle of inclination. The side surfaces of the seeds – or cheeks – had large and small creases, and there was a significant decrease in the distance between cross cells, which are cells that elongate transversely that are only found in grasses. There was also a decrease in the width of tube cells, which grow in the inner epidermis of the seed wall.

These results suggest that although a space environment causes various disturbances to the structural organization of cells on the kernel surface, these differences do not appear to affect the proper development of wheat plants in space.

Baranova EN, Levinskikh MA, Gulevich AA. Wheat Space Odyssey: "From Seed to Seed". Kernel Morphology. Life. 2019 October 25; 9(4): 81. DOI: 10.3390/life9040081.

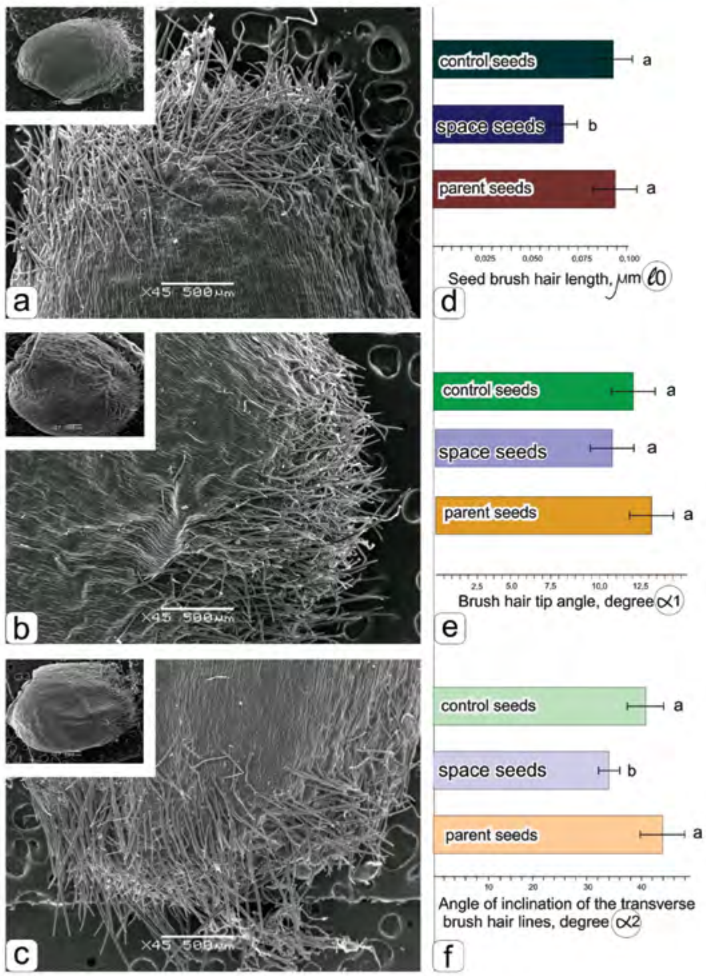


Figure 8. The surface of the kernels and brush hairs of the grains obtained: when cultivated aboard the ISS in the greenhouse "Lada" in a) ground conditions, b) in orbit, and c) parental seeds harvested. Histograms show d) brush hair length, e) the angle of the tip of the hair, and f) the angle of inclination of transverse brush hair lines. (Image courtesy of Baranova, EN et al., Life 2019.)

Expedition 27 flight engineer and cosmonaut Andrey Borisenko during his fourth session of the Russian MBI-21 Pnevmokard (Pneumocard) experiment. Image was taken in the Zvezda Service Module (iss027e015221).

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, such as 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 to enabling missions to the lunar surface and future Mars exploration missions.

EXPLORATION

Space anemia was identified from the first human presence in space. The suspected cause was a large-scale destruction of red blood cells (i.e., hemolysis) that rapidly adapts to fluid shifts. Recent long-duration mission data showed that astronauts were not anemic while on the ISS. The CSA investigation **MARROW** sought to characterize the problem of space anemia and develop methods to find its cause.

With more than 5 decades of astronaut data, MARROW revealed that space anemia occurs after landing after the reverse fluid shift is completed.

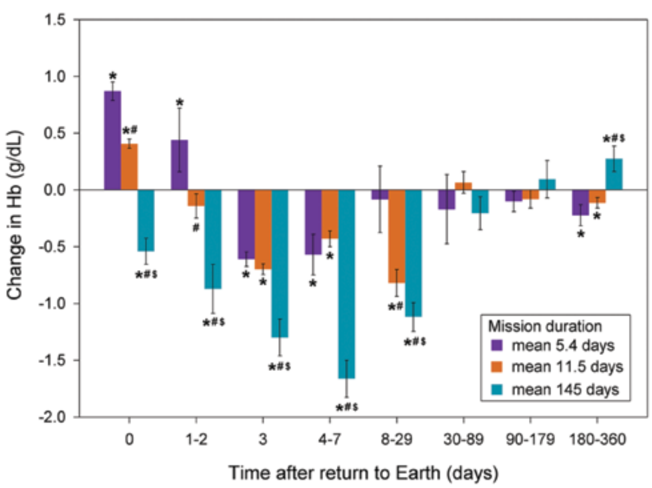


Figure 9. Changes in hemoglobin (Hb) concentration after return to Earth by mission duration. All astronauts showed reduced Hb levels after spaceflight,; however, astronauts participating in long-duration missions experienced the most pronounced drops. (Image courtesy of Trudel, G. et al., American Journal of Hematology, 2019.)

The study's statistically powerful epidemiologic approach demonstrated that red blood cell loss is proportional to the time spent in space, and the recovery from space anemia takes between 1 and 3 months, depending on mission duration (Figure 9).

An additional publication described methods to measure markers of human hemolysis in extreme environments. The elimination of endogenously produced carbon monoxide measured with a parts-per-billion precision constitutes a reliable marker of red blood cell destruction.

MARROW successfully tested methods to collect and transfer astronaut air samples to examine carbon monoxide and identify causes of space anemia. These novel results illuminate the problem of space anemia and prepare for more knowledge acquisition on its causes to guide countermeasures and monitoring post-landing.

Trudel G, Shafer J, Laneuville O, Ramsay T. Characterizing the effect of exposure to microgravity on anemia: more space is worse. American Journal of Hematology. 2019 December 2; 95(3): 267-273. [DOI: 10.1002/ajh.25699](https://doi.org/10.1002/ajh.25699). -- Shahin, N., Louati, H. & Trudel, G. Measuring Human Hemolysis Clinically and in Extreme Environments Using Endogenous Carbon Monoxide Elimination. Ann Biomed Eng 48, 1540–1550 (2020). https://doi.org/10.1007/s10439-020-02473-5

EXPLORATION

Previous research suggests that microgravity leads to activation of sodium-retaining hormones, even at normal sodium intake levels, causing positive sodium balances. An average- or high-sodium diet in microgravity may exacerbate bone resorption in space.

Microgravity may affect osmotically inactive sodium storage, a mechanism involved in volume regulation in the human body. This reaction can result in the retention of salt and fluid during spaceflight. ESA's investigation, **SOdium LOading in Microgravity (SOLO)**, examined astronauts' central blood volume in relation to their dietary sodium intake levels in space and on Earth (Figure 10). Astronauts were assigned to either a low-sodium or high-sodium diet group for 5 days. Water and other nutrients were the same for both diet groups. Blood samples were collected from the astronauts on the last day of the diet. Sodium, creatine, midregional proatrial natriuretic peptide, N-terminal Pro-B type natriuretic peptide, and aldosterone were analyzed.

Regardless of diet group, results revealed that astronauts tended to retain more sodium in space and excrete more sodium on Earth. Thoracic fluid content was reduced in space, and aldosterone regulation was practically identical in space and on Earth.

These results suggest that cardiac natriuretic peptide concentrations responsive to sodium changes, which facilitate pressure/volume homeostasis, are reset to lower levels in space. Researchers recommend further investigation into the role of sodium in blood volume regulation to determine whether the effects are temporary or permanent.

The exploratory nature of this study encourages the development of new investigations in the areas of fluid regulation and homeostasis, essential topics to the health of astronauts in space.

Frings-Meuthen P, Luchitskaya ES, Jordan J, Tank J, Lichtinghagen R, Smith SM, Heer MA. Natriuretic peptide resetting in astronauts. Circulation. 2020 May 12; 141(19): 1593-1595. DOI: 10.1161/CIRCULATIONAHA.119.044203.

Figure 10. In the Columbus laboratory of the ISS, NASA astronaut Dan Burbank, Expedition 30 commander, enters data for the High Salt Diet protocol of the Sodium Loading in Microgravity (SOLO) experiment (iss030e117431).

Skeletal muscles atrophy and weaken during spaceflight. Many crew members experience orthostatic intolerance immediately after returning to Earth. JAXA's investigation, **The Elucidation of the Re-adaptation on the Attitude Control After Return from Long Term Spaceflight (Synergy)**, measured crew members' blood flow in the legs, centers of gravity, and electrical activity in skeletal muscle to determine how the ability to stand upright can be recovered.

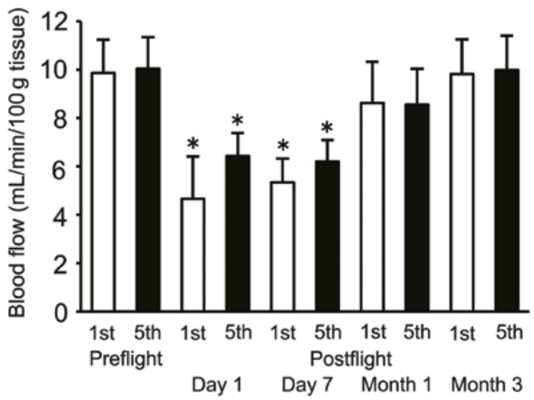


Figure 11. Bar chart depicting results of blood flow in the right lower limbs of astronauts at the first and fifth steps on the same spot at preflight, postflight day 1, postflight day 7, postflight month 1, and postflight month 3. (Image courtesy of Ishihara, A. Acta Astronautica, 2020.)

In a recent study, the blood flow of astronauts was examined before and after flight using a laser blood flow meter. The noninvasive blood flow monitoring technique uses near-infrared light and measures blood flow in the capillaries and small blood vessels close to the skin surface. Changes in wavelength and strength of the light were used to analyze blood flow. This powerful technique determines blood flow changes over time or over an area of the skin. Astronauts were asked to step five times on the same spot to take the measurements. A probe that measured blood flow was attached to the skin surface on the central region of the right calf muscle while the astronauts were tested.

Results showed reduced blood flow in the lower limbs, induced by long-duration spaceflight (3 – 6 months). This result was observed postflight on days 1 and 7. At postflight month 1, blood flow had recovered to preflight levels (Figure 11). Physical activities after return to Earth are known to improve muscle mass and pumping, which consequently increases blood flow in the lower limbs.

These results suggest that physical rehabilitation is fundamental for the improvement of blood flow during the first month postflight. Researchers hope to examine countermeasures using mild hyperbaric oxygen known to recover reduced blood flow due to injury, disease, old age, or weightlessness. Increased understanding of recovery duration is expected to assist rehabilitation schedules.

Ishihara A, Terada M, Hagio S, Higashibata A, Yamada S, Furukawa S, Mukai C, Ishioka N. Blood flow in astronauts on Earth after long space stay. Acta Astronautica. 2020 May 16; epub: 16 pp. DOI: 10.1016/j.actaastro.2020.05.017.

Metabolic changes associated with microgravity that produce calcium loss and are associated with microgravity can result in bone density reductions during spaceflight. The ASI investigation, **Nanoparticles-based countermeasures for Treatment of Microgravity-induced Osteoporosis (Nanoparticles and Osteoporosis)**, examines the role of nanoparticles in the development of bone loss countermeasures. Results from this investigation are expected to protect the health of astronauts and that of individuals on Earth who have bone conditions such as osteoporosis.

A groundbreaking study examined the effect of a new nanoparticle drug, with suspensions of calcium (nCa-HAP) and strontium (nSr-HAP), on human bone marrow stem cell differentiation across three conditions: Earth gravity, simulated gravity using a Random Positioning Machine, and microgravity on the ISS.

The human bone marrow mesenchymal stem cell (hBM-MSC) samples were isolated and phenotypically analyzed to assess their properties. The hBM-MSCs were cultured at 37°C in a humidified incubator with 5% CO_2 in a medium maintenance, low-glucose osteogenic medium to induce osteogenesis. The treatment lasted no more than 28 days and the medium was changed every 3 days. Immunofluorescent dyes identified cell death, cell structure changes, and bone extracellular matrix deposits.

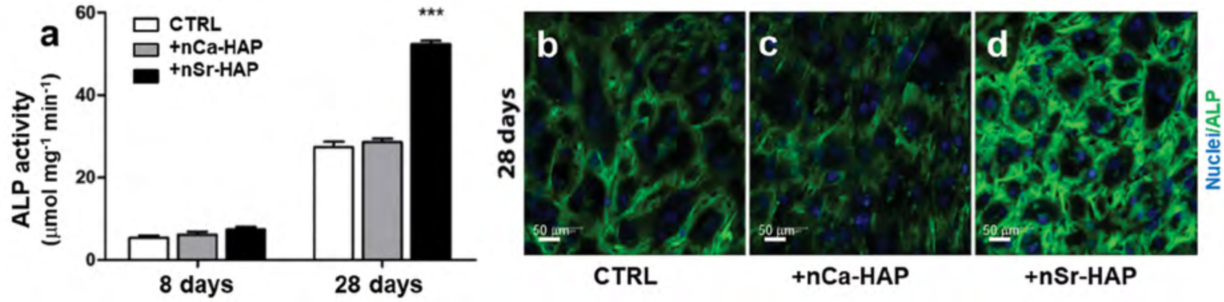


Figure 12. Effect of nanoparticles on alkaline phosphatase (ALP) activity and protein immunolocalization in gravity conditions. Panel a) ALP-specific activity of untreated, calcium- or strontium-treated cells for 8 and 28 days in an osteogenic medium. Panels b) – d) are representative images of ALP immunostaining of b) untreated, c) calcium-treated, or d) strontium-treated cells cultured for 28 days in an osteogenic medium. (Image courtesy of Cristofaro, F. Scientific Reports, 2019.)

Results showed positive effects of the drug on new bone regeneration. Depending on the condition, strontium-containing nanoparticles accelerated stem cell differentiation into osteoblasts, counteracted microgravity-induced osteoporosis, or improved the deposition of the nanoparticles (Figure 12).

Researchers believe that delivery of the drug for the promotion of bone remodeling can be implemented through pharmaceuticals or food supplements.

Cristofaro F, Pani G, Pascucci B, Mariani A, Balsamo M, Donati A, Mascetti G, Rizzo AM, Visai L, Rea G. The NATO project: nanoparticle based countermeasures for microgravity-induced osteoporosis. Scientific Reports. 2019 November 20; 9(1): 1-15. [DOI: 10.1038/s41598-019-53481-y](https://doi.org/10.1038/s41598-019-53481-y).

BENEFITS FOR HUMANITY

The Roscosmos' investigation, **Early Detection of Osteoporosis in Space (EDOS)**, examines bone loss using a high-resolution three-dimensional peripheral quantitative computed tomography (3DpQCT) technique for the early detection of bone impairment and bone microarchitectural changes to provide information about the biomechanics of bone. The goal is to demonstrate the viability and feasibility of 3DpQCT to provide accurate measurements of bone tissue following missions in microgravity.

A new study conducted an in-depth bone mineral analysis of the lower back before and after spaceflight using surveys to estimate bone density.

Results revealed that there were no significant differences in pre- and postflight values of projection area of the lumbar spine (Figure 13). This outcome indicates that no anatomical changes occurred. The known increase in height of the lumbar segment was not observed in this study.

Further analyses indicated that the lumbar vertebrae are marked by a negative pattern of bone mineral content changes. Additionally, mineral content examined for the first time showed that the reduced mineralization observed in the upper region of the lower back results from the significant functional load carried under Earth gravity in the region of the lower back. Researchers point out that this is exactly the opposite of how osteoporosis develops on Earth, where less-loaded vertebrae are more likely to deteriorate.

Since crew members exhibit bone loss characteristics similar to osteoporosis on Earth, this research could contribute to the development of medical devices that enable the early detection of osteoporosis. Improved early-stage diagnostics are expected to assist the conceptualization of future treatments to combat the effects of osteoporosis on Earth.

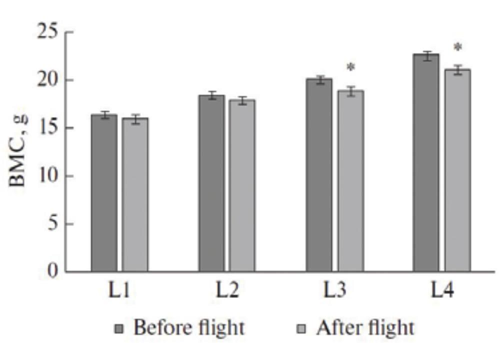


Figure 13. Bone mineral content at various locations of the lumbar spine before and after flight. Image courtesy of Gordienko, KV 2019.

Gordienko KV, Novikov V, Servuli E, Nosovsky AM, Vasilieva GY. Detailed Analysis of the Central Osteodensitometry Data from Cosmonauts Participating in the Mir and ISS Programs. Human Physiology. 2019 December 1; 45(7): 764-767. [DOI: 10.1134/S0362119719070065](https://doi.org/10.1134/S0362119719070065).

A view of the Zero Boil-Off Tank (ZBOT) experiment Vacuum Jacket Camera Window Cover hardware. ZBOT uses an experimental fluid to test active heat removal and forced jet mixing as an alternative means for controlling tank pressure for volatile fluids. Results from the investigation improve models used to design tanks for long-term cryogenic liquid storage, which are essential in biotechnology, medicine, industrial, and many other applications on Earth. (iss051e028301)

PUBLICATION HIGHLIGHTS:
PHYSICAL SCIENCE

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 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.

BENEFITS FOR HUMANITY

ESA's **EML Batch 1 - THERMOLAB Experiment** measures the thermophysical properties of industrial alloys to improve solidification processes. A recent study reports on a series of investigations that were performed using the Electro-Magnetic Levitator (EML) on board the ISS. In particular, the study documents the results gained regarding three commercial high-temperature alloys (nickel-based superalloys) that are widely used in turbines and other energy applications. These results include high-accuracy thermophysical property data (liquid surface tension, viscosity, mass density, specific heat capacity) that cannot be obtained on Earth and are essential for advancing manufacturing efficiency and product quality.

Results showed that the surface tension of the three superalloys was lower, the viscosity in the stable liquid phase was higher, and the overall density was dominated by the quantity of heavy elements (Figure 14). There were also no apparent signs of oxide formation on returned samples. Higher accuracy of specific heat capacities was obtained using the containerless processing method.

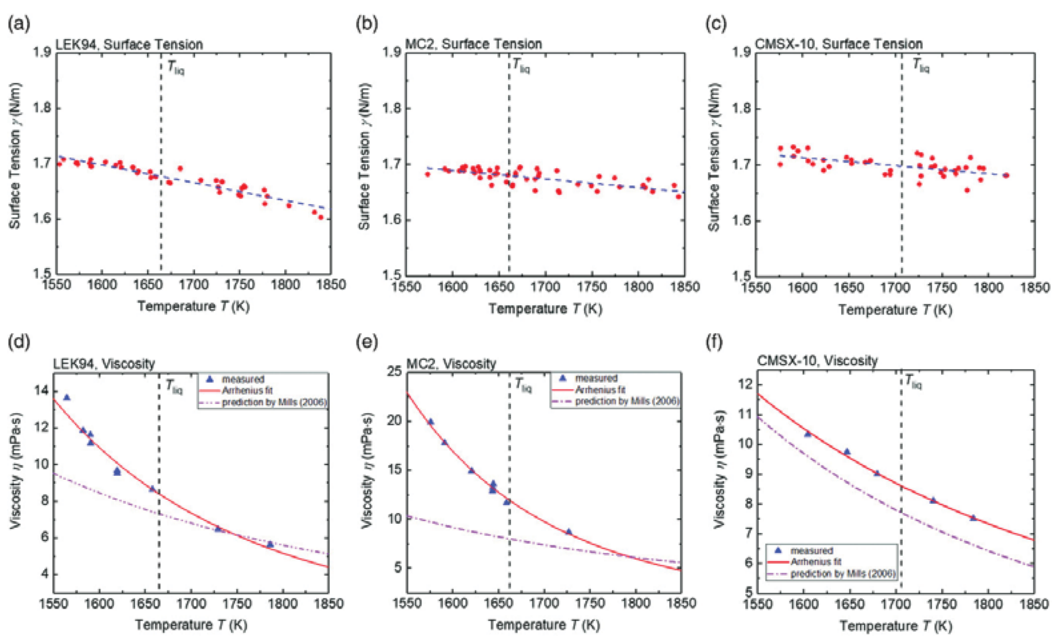


Figure 14. Panels a-c show surface tension of LEK94, MC2, and CMSX-10 in response to temperature. Panels d-f show viscosity of of LEK94, MC2, and CMSX-10 in response to temperature. (Image courtesy of Mohr, M. Advanced Engineering Materials, 2020.)

This study brings together longtime efforts on the ISS EML facility, the development of experimental techniques for high-accuracy measurement of melt properties, and the application of these techniques to a set of industrially relevant alloys. Of scientific as well as engineering significance, the manuscript is anticipated to become a reference work on the topic.

Mohr M., Wunderlich R., Dong Y., Furrer D., Fecht H.-J.; "Thermophysical properties of advanced Ni-based superalloys in the liquid state measured on board the International Space Station"; Advanced Engineering Materials 22/4 (2020): 1901228 ([DOI 10.1002/adem.201901228](https://doi.org/10.1002/adem.201901228))

DISCOVERY

The JAXA facility **Electrostatic Levitation Furnace (ELF)** uses containerless processing techniques to levitate, melt, and solidify materials. Researchers use this facility to measure the thermophysical properties of materials in high-temperature melts and to solidify materials from deeply undercooled melts. Using semiconductor lasers, ELF can heat samples above 2000 degrees Celsius and measure the density, surface tension, and viscosity of high-temperature materials. It is challenging to measure these properties on the ground. Other research objectives, such as the synthesis of new materials, can be accomplished using the ELF. The most typical materials used in the ELF are

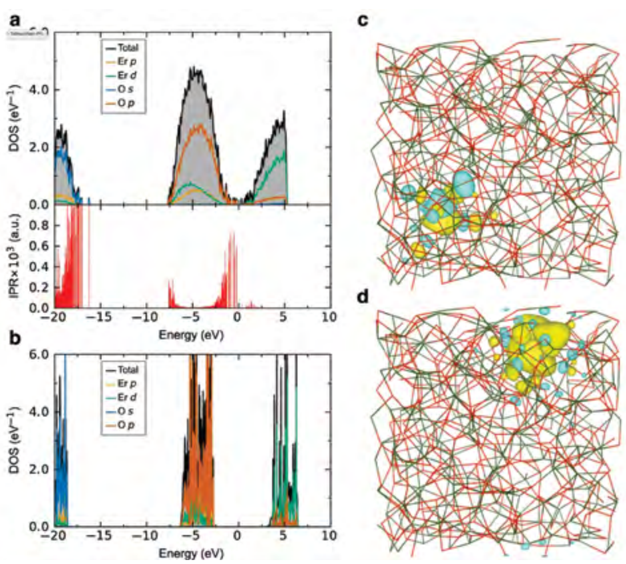


Figure 15. a) Calculated atom resolved of density and inverse participation rations for l-Er2O3. b) Calculated density of c-Er2O3 for comparison. c) Visualization of the highest occupied molecular band. d) Visualization of the lowest unoccupied molecular band. Er and O atoms are shown in green and red, respectively. Yellow and cyan correspond to different signs of the wavefunction. (Image courtesy of Koyama, C. NPG Asia Materials, 2020.)

oxides and insulators that cannot be handled in other levitation furnaces on the ISS.

A new ELF experiment discovered an unusual structure of liquid Erbium Oxide (Er_2O_3), combined with ground experiments using synchtron X-rays and supercomputer simulations. Researchers observed the formation of distorted tetraclusters and a very sharp principal peak in the diffraction pattern. Tetraclusters appeared to be coordinated in intermediate-range, thus hindering glass transition and leading to crystallization (Figure 15).

Notably, the arrangement of the tetraclusters was not observed in other oxide liquids. In addition, computer simulations determined that Er_2O_3 is a highly fragile liquid.

Taken together, these results suggest that a very sharp principal peak is a specific signature for the formation of a tetracluster network with long-range periodicity. This finding is a paradigm shift for condensed matter physics – in particular, for glass transition and the development of new materials.

Koyama C, Tahara S, Kohara S, Onodera Y, Smabraten DR, Selbach SM, Akola J, Ishikawa T, Masuno A, Mizuno A, Okada JT, Watanabe Y, Nakata Y, Ohara K, Tamaru H, Oda H, Obayashi I, Hiraoka Y, Sakata O. Very sharp diffraction peak in nonglass-forming liquid with the formation of distorted tetraclusters. NPG Asia Materials. 2020 June 2; 12(1): 1-11. [DOI: 10.1038/s41427-020-0220-0](https://doi.org/10.1038/s41427-020-0220-0).

DISCOVERY

NASA's **Cold Atom Lab - Bose-Einstein Condensate Bubble Dynamics** investigation examines ultracold states of matter by creating a quantum gas known as a BEC, which is kept in a bubble-like structure, to answer questions about quantum mechanics. Understanding the behavior of quantum gas bubbles will enhance next-generation quantum sensors and simulators. The study of the ultracold is a new frontier that has grown exponentially in the last 20 years since the first observation of Bose-Einstein condensation. Studying a quantum gas with a new confinement geometry enables the exploration of new areas of BEC physics and elucidates the nature of ultracold systems.

In a groundbreaking study, researchers examined the cooling and trapping of atomic gases to form a BEC, allowing quantum behavior to be inspected at a macroscopic scale for long durations in microgravity.

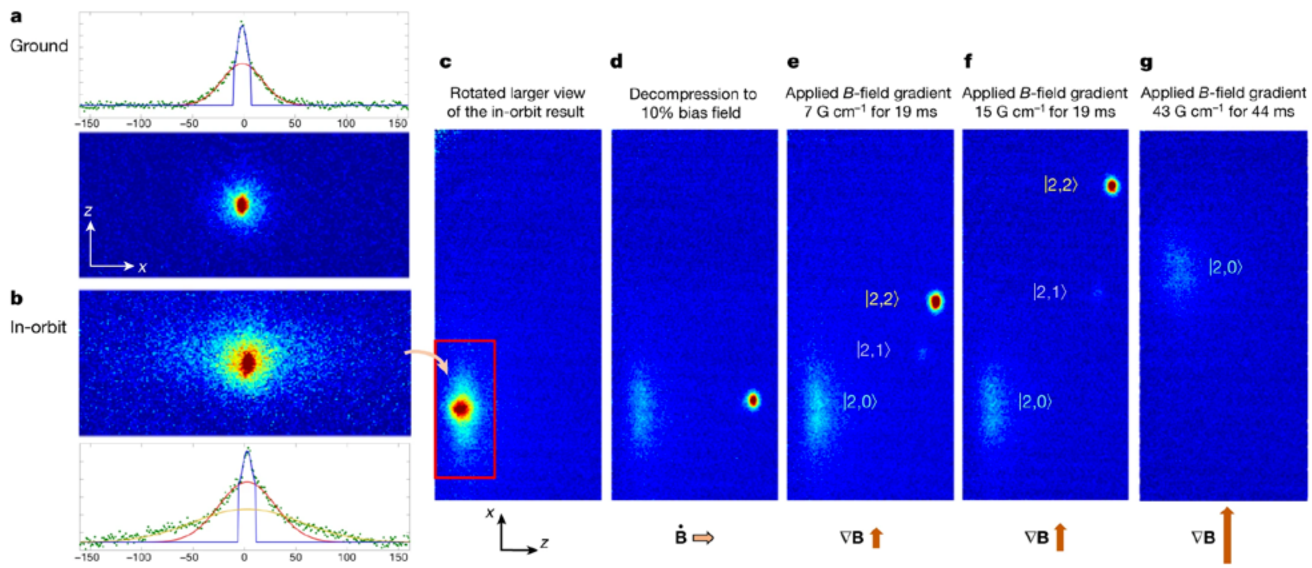


Figure 16. A false-color absorption image shows a BEC produced in the Cold Atom Lab on the ground. (Image courtesy of Aveline DC, Nature, 2020.)

Microgravity allowed the atoms to be manipulated by weaker magnetic fields, speeding cooling and allowing clearer imaging of BECs before diffusing (Figure 16). Scientists observed the fifth state of matter in microgravity for the first time, offering unprecedented insight into Einstein's theory of relativity.

Studying BECs in microgravity opens additional research arenas in gravitational waves, spacecraft navigation, and prospecting for subsurface minerals on the Moon and other planetary bodies.

The opportunity to study BEC's new geometry in space reinforces the need for the space station, as a facility, to conduct research in the field of ultracold atomic physics. Daily life applications on Earth include the development of quantum computers. Additionally, with routine BEC production, continued operations on the ISS will support new investigations of unique trap topologies, atom-laser sources, few-body systems, and trailblazing techniques for atom-wave interferometry.

Aveline DC, Williams JR, Elliott ER, Dutenhoffer CA, Kellogg JR, Kohel JM, Lay NE, Oudrhiri K, Shotwell RF, Yu N, Thompson RJ. Observation of Bose–Einstein condensates in an Earth-orbiting research lab. Nature. 2020 June 11; 582(7811): 193-197. DOI: 10.1038/s41586-020-2346-1.

NASA astronaut Serena Auñón-Chancellor works to insert a Microgravity Investigation of Cement Solidification (MICS) Module into the Multi-use Variable-g Platform (MVP) facility (iss057e106261).

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 **Biomolecule Sequencer** investigation tests the functionality of a permanent molecular biology capability that allows scientists to sequence DNA in space in real time. This new resource enables prompt genetic expression examinations of microorganisms, thereby rendering crew members more independent in their decision-making and problem-solving strategies.

A new study developed and tested an end-to-end sample-to-sequencer process that could be conducted entirely aboard the ISS (Figure 17). The identifications obtained by the unit on board the ISS — Staphylococcus hominis and Staphylococcus capitis — matched those determined on the ground down to the species level. This marks the first-ever identification of microbes entirely off Earth. This validated process could be used for in-flight microbial identification, diagnosis of infectious

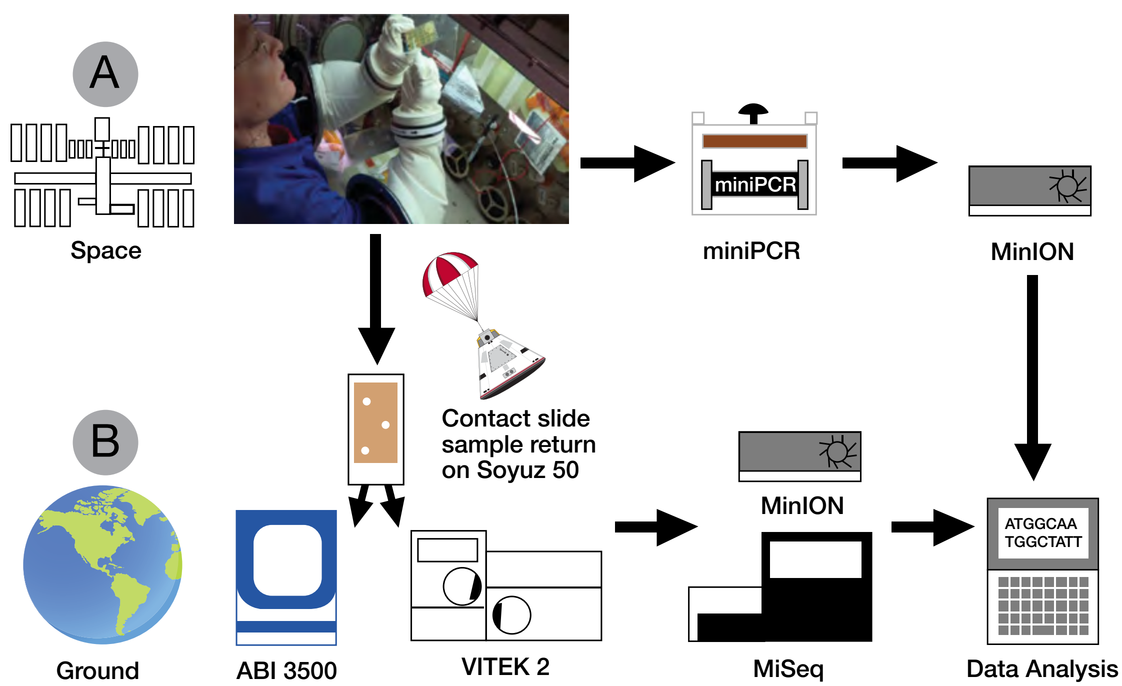


Figure 17. Workflow of the first on-orbit sequencing library preparation and in situ sequencing of bacterial colonies cultured from the ISS. (Image courtesy of Burton, A. Genes, 2020.)

disease in a crew member, and as a research platform for investigators around the world.

The sequencer could greatly improve and accelerate scientific research on the ISS by permitting microbe identification, disease diagnostics, and collection of real-time genomic data. This technology would also allow astronauts to examine and identify life based on DNA and DNA-like molecules during future missions to Mars.

Burton AS, Stahl SE, John KK, Jain M, Juul S, Turner DJ, Harrington ED, Stoddart D, Paten B, Akeson M, Castro-Wallace SL. Off Earth Identification of Bacterial Populations Using 16S rDNA Nanopore Sequencing. Genes. 2020 January 9; 76(11): 76. DOI: 10.3390/genes11010076.

The Roscomos' investigation, **Studying the Hydrodynamics and Heat Transfer of Monodisperse Droplet Streams in Microgravity (Kaplya-2)**, tests and validates the operation of droplet generators in microgravity and high-vaccum conditions by verifying the main parameters of monodisperse droplet streams. The investigation additionally confirms the continuous operation of a closed hydraulic circuit.

A new study provides a comprehensive analysis of possible designs of radiator coolers used to reject low-potential heat from spacecraft (Figure 18). As a result of conducting the set of computational and experimental investigations, droplet radiant cooler (DRC) units have been created and tested under ground conditions. The newly developed units were tested with a closed cycle of the operating process implemented during the ground investigations and tests. The conclusion of the ground tests indicates that DRCs substantially outperform all the existing designs of heat exchangers with regard to heat-rejection efficiency and weight-size characteristics, with the following confirmations:

- Stable droplet flow of the working medium in parallel jet flows at the outlets of the single-row and multi-row generators once the pressure reaches a stationary regime inside the droplet generators.
- Working capacity of elements of the passive collector.
- Fundamental possibility of creating an active droplet collector that ensures full collection of the working medium.

Figure 18. Russian cosmonaut Oleg Kotov, Expedition 38 commander, sets up the Particle Cooler/Generator Module for the Kaplya-2 experiment in the Rassvet Mini-Research Module 1 (MRM1) of the ISS (iss038e029764).

The scientific and technical results obtained during this investigation validate the workflow of droplet refrigerator radiators to assist the design and development of droplet radiator equipment for power units used in space. Minimal thermal resistance between the coolant and the radiating surface, protection to meteor breakdown, and low mass render these radiators beneficial in spacecraft.

Konyukhov GV, Bukharov AV, Konyukhov VG. On the problem of rejection of low-potential heat from high-power space systems. Journal of Engineering Physics and Thermophysics. 2020 February 27; 93: 16-27. DOI: 10.1007/s10891-020-02086-8.

The Roscosmos' investigation **Development of a System of Supervisory Control Over the Internet of the Robotic Manipulator in the Russian Segment of ISS (Kontur)** examined time delays in the development of visual control systems to operate the ISS robotic arm remotely via the internet.

An alternative to sending humans to Mars to build habitats is to use robots to build such habitats through

Figure 19. Roscosmos cosmonaut Oleg Novitsky during the Kontur-2 experiment. Image taken in the Zvezda Service Module (iss050e075473).

remote operations from space. A new feasibility study used the ISS as the orbiter and Earth as the location of the teleoperated robot to investigate whether the provision of force feedback at the joystick is as beneficial in microgravity as under terrestrial conditions (Figure 19). Using two tasks — a free motion task requiring rapid aimed robot motions and a contact task requiring minimal surface contact when moving the robot along a curved structure — researchers set out to determine whether touch and motion technology needs to be adjusted to the altered environmental conditions in space to support humans operating in weightlessness.

Results indicated that microgravity had an impact on motion control after 6 weeks. Motor control strategy shifted from speed to accuracy during aiming to avoid highly reactive forces on the human body and limbs, which are difficult to compensate for in a state of weightlessness. Adding touch and motion technology impaired performance in microgravity. Future studies could investigate how certain parameters hinder or facilitate performance during spaceflight.

Study results emphasize that force feedback is indispensable for space teleoperation missions. Researchers recommend the continued examination of teleoperations from space using larger samples, in different mission phases, and with a more extensive variety of tasks.

Weber B, Balachandran R, Riecke C, Stulp F, Stelzer M. Teleoperating robots from the International Space Station: Microgravity effects on performance with force feedback. IEEE International Conference on Intelligent Robots and Systems, IROS 2019, Macau, China; 2019 November 4. 8138-8144. [Webpage]

View of the External Payload Facility attached to the Columbus European Laboratory. The Atmosphere-Space Interactions Monitor and High Definition Earth Viewing payloads are in view. Photo was taken by the ground-controlled External High Definition Camera 3 (iss057e080463).

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 that can be seen in images 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.

DISCOVERY

The ESA investigation, **Atmosphere-Space Interactions Monitor (ASIM)**, is an Earth observation facility designed to study severe thunderstorms, atmosphere, and climate. ASIM studies high-altitude electrical discharges such as transient luminous events (TLEs) and terrestrial gamma-ray flashes (TGFs) from the external payload platform on the Columbus module of the ISS.

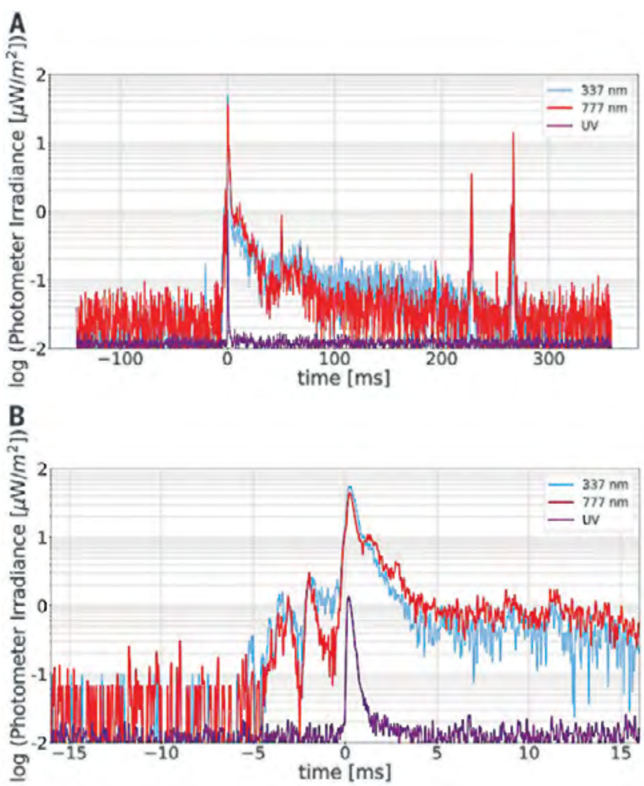


Figure 20. A lightning flash analysis. (Image courtesy of Neubert, T. Science, 2019.)

In a new study, researchers used data obtained by ASIM's three photometers to determine whether TLEs and TGFs are independent or somewhat related phenomena.

ASIM identified a TGF produced in the initial stage of a lightning flash. The TGF was observed close to the island of Sulawesi in Indonesia. Multiple parameters used in the optical and X-ray measurements consistently identified the convective cloud as the source of lightning associated with the TGF (Figure 20). A TLE (i.e., an elve) was also detected, but with a delay corresponding to the travel times of the electromagnetic pulse. TLE optical pulses were bright and rose out of pre-activity, suggesting that a delay resulted from the limitations of the sensor sensitivities; however, the optical pulses start at approximately the same time as the TGF.

These observations show the temporal sequence of emissions using various optical, ultraviolet, X-ray, and gamma-ray bands of a TGF, and demonstrate that TLEs and TGFs are related.

The ASIM investigation improves our knowledge of thunderstorms in relation to ionosphere and radiation belts, as well as meteor distribution that affects the Earth's atmosphere.

Neubert T, Ostgaard N, Reglero V, Chanrion O, Heumesser M, Dimitriadou K, Christiansen F, Budtz-Jorgensen C, Kuvvetli I, Rasmussen IL, Mezentsev A, Marisaldi M, Ullaland K, Genov G, Yang S, Kochkin P, Navarro-Gonzalez J, Connell PH, Eyles CJ. A terrestrial gamma-ray flash and ionospheric ultraviolet emissions powered by lightning. Science. 2019 December 10; epub: 8 pp. DOI: 10.1126/science.aax3872.

Three JAXA external payloads installed on the same module on the ISS — **Space Environment Data Acquisition Equipment - Attached Payload (SEDA), CALorimetric Electron Telescope (CALET)**, and **Monitor of All-sky X-ray Image (MAXI)** — were used collectively to estimate and quantify radiation dosage during relativistic electron precipitation (REP) events (Figure 21). The assessment of radiation dose rate during such events will allow researchers to determine whether the level of radiation poses a significant health risk to astronauts.

For more than 50 years, researchers have identified REP events using radio waves. These REPs are unusually enhanced ionization of the mesosphere, known to play a role in space weather forecasts and the Earth's atmosphere. In a new study, researchers quantified radiation dose data from the three instruments while considering the impact to astronauts who are sporadically exposed when participating in extravehicular activities.

During a 2.5-year period of overlapping operations of the three instruments, 762 REP events were detected on board the ISS, with 34 relatively strong REP events exceeding 1 mSv per event, including the largest event of 3 mSv (ionizing radiation dose). These radiation exposure dose rates were then evaluated through an astronaut helmet visor hypothetically encountering a REP event during an extravehicular activity. Researchers found that the electrons with larger energy have a larger effect on the lens of the eyes. However, the overall finding indicated that REP exposure dose to the lens of eye is lower than the recommended limit.

These data indicate that such low radiation rates are unlikely to affect astronauts' health, though cumulative radiation exposure over several months could produce a different outcome.

This study demonstrates the enhanced power of research and discovery when multiple resources are used together, as well as performance of the ISS to accommodate various payloads.

Ueno H, Nakahira S, Kataoka R, Asaoka Y, Torii S, Ozawa S, Matsumoto H, Bruno A, de Nolfo G, Collazuol G, Ricciarini SB. Radiation dose during relativistic electron precipitation events at the International Space Station. Space Weather. 2020 July; 18(7): 7 pp. DOI: 10.1029/2019SW002280.

The NASA investigation, **Arcsecond Space Telescope Enabling Research In Astrophysics (ASTERIA)**, is a six-unit small satellite deployed from the ISS. ASTERIA is designed to probe new technologies for astrophysical observations and complex measurements, including the detection of planets outside our solar system and the brightness of stars over time (Figure 22). The goal of this investigation is to use cutting-edge technologies such as arcsecond-level line of sight pointing error and focal plane temperature control to make precision photometry possible. Space-based photometric measurements are a powerful tool for astrophysics. Since the variable of time on existing large space telescopes is scarce, small satellite platforms are the logical alternative.

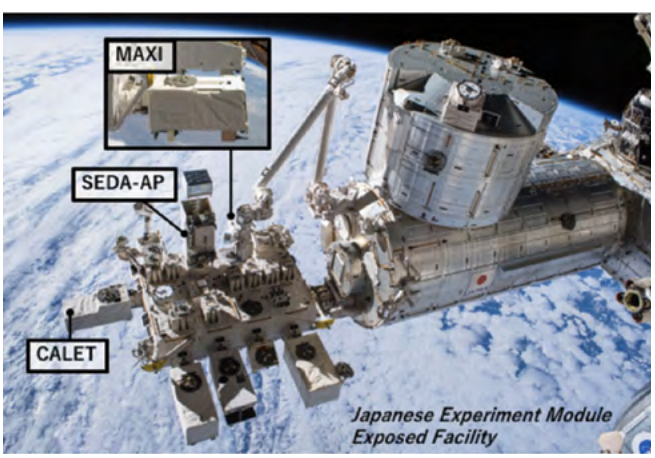


Figure 21. CEO images of Chicago, IL, USA at night on (A) January 19, 2008, (B) January 31, 2012 and (C) October 9, 2013 (ISS16E024220, ISS30E061820, ISSE037E008303).

Figure 22. A view of the ASTERIA satellite moments after deployment from the ISS. ASTERIA is a six-unit CubeSat, deployed from the ISS, that tests new technologies for astronomical observation such as the detection of planets outside our solar system (iss053e470644).

ASTERIA was used for opportunistic observations and photometric data of an exoplanetary system called 55 Cancri. Researchers implemented a routine workflow with advanced mathematical calculations to adjust the data and obtain reliable results. The analyses revealed the exoplanet 55 Cancri e — a known transiting super-Earth orbiting a Sun-like star.

The resulting data of the transit search demonstrated that a signal can be seen in ASTERIA data; however, not at a level that is significant enough to claim independent detection without prior knowledge of the planet orbit and transit. However, ASTERIA demonstrated the capability of sub-Arcsecond pointing and thermal control using passive cooling and active heating.

This is the first time an exoplanet transit has been detected by a small satellite. The successful identification of 55 Cancri e demonstrates that an inexpensive spacecraft designed with an adaptable model of science in mind can deliver groundbreaking results.

Ueno H, Nakahira S, Kataoka R, Asaoka Y, Torii S, Ozawa S, Knapp M, Seager S, Demory B, Krishnamurthy A, Smith MW, Pong CM, Bailey VP, Donner A, Di Pasquale P, Campuzano B, Smith C, Luu J, Babuscia A, Bocchino, Jr. RL, Loveland J, Colley C, Gedenk T, Kulkarni T, Hughes K, White M, Krajewski J, Fesq L. Demonstrating high-precision photometry with a CubeSat: ASTERIA observations of 55 Cancri e. The Astrophysical Journal. 2020 June; 160(1): 23. DOI: 10.3847/1538-3881/ab8bcc.

EXPLORATION

The NASA investigation, **Neutron star Interior Composition Explorer (NICER)**, analyzes neutron stars, which are bright star residues that remain after the explosion of massive stars, thus providing new insights into their nature and behavior (Figure 23). The Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) is included in this investigation. SEXTANT aims to demonstrate a GPS-like capability by detecting millisecond pulsars that enable autonomous navigation throughout the solar system and beyond.

A recent study analyzed a sample of NICER data to understand the periodicity of quiescent periods and flare-ups of black hole and X-ray binary MAXI J1535–571. Low mass X-ray binaries (LMXBs) spend most of their time in a calm and quiet state; however, they occasionally exhibit outbursts. To date, there is no explanation to these reflares. The brightness of the

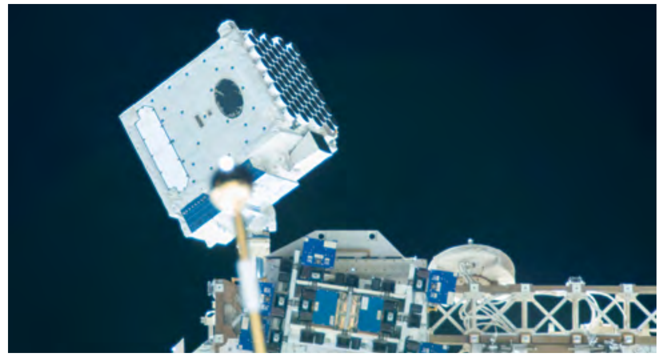
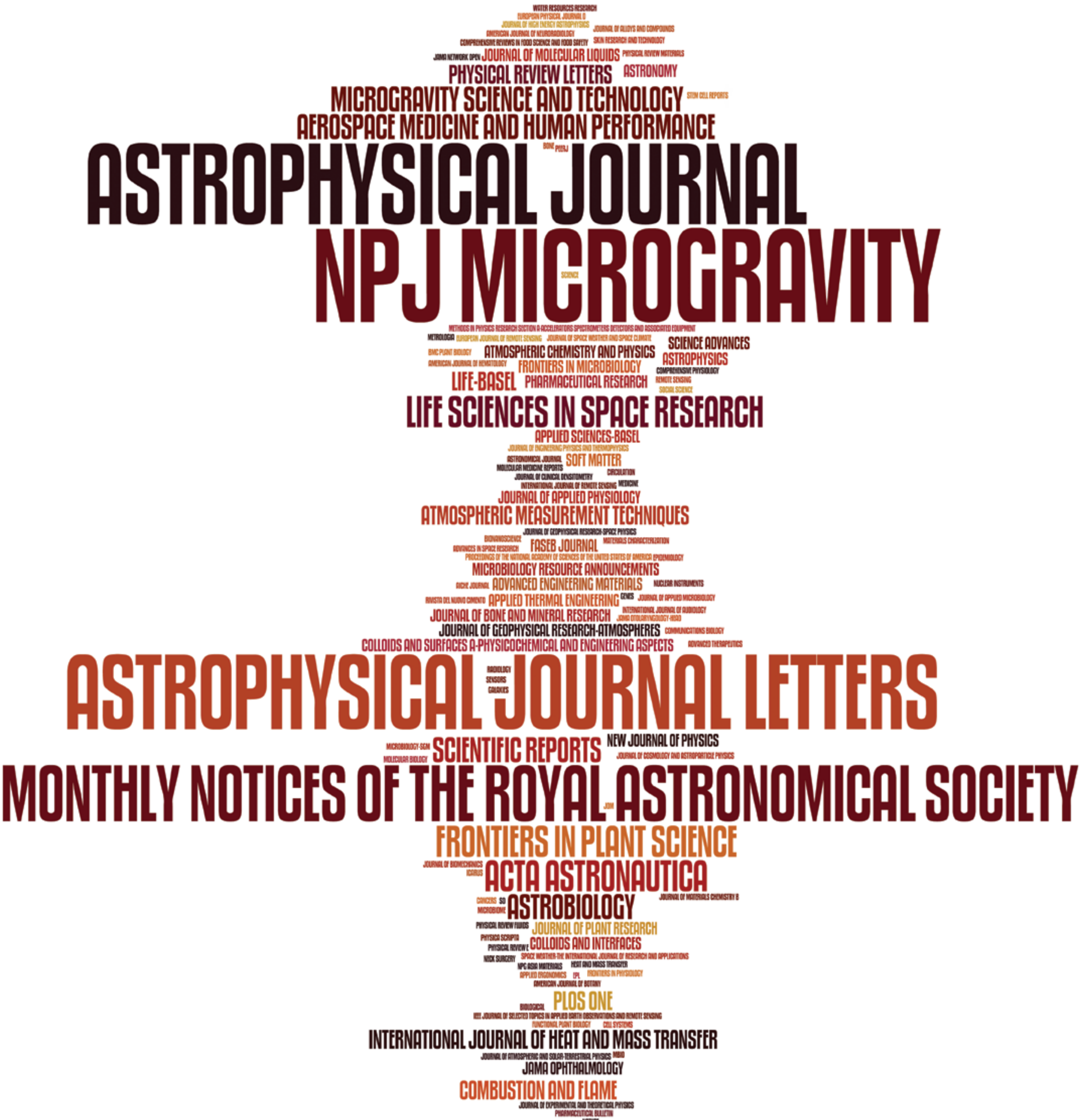


Figure 23. View of the Neutron Star Interior Composition ExploreR (NICER) payload, attached to Expedite the Processing of Experiments to Space Station (ExPRESS) Logistics Carrier-2 (ELC-2) on the S3 Truss. (iss057e055436)

reflares is very faint and only highly sensitive instruments can detect the necessary information. Processing of NICER data included the calculation of energy spectra, light curve and intensity, and timing analysis. Results showed that the brightness of the binary declined slowly for approximately 106 days before showing a slight increase. A sequence of four reflares was observed, with flares occurring approximately every 31 to 32 days. Researchers noticed that the reflares fluctuated between the hard area and a softer area of their analysis, demonstrating hysteresis. Additionally, researchers identified that temperature correlated with the light curve.

In conclusion, researchers found that reflares underwent state transitions, reaching softer states at the peak of the first flare and returning to the hard state during the valleys. These state transitions display a hysteresis loop that resembles the hysteresis of other LMXBs with both black hole and neutron star accretors. These results suggest that the same physical processes drive outbursts and reflares, even when the X-ray luminosity is different by two orders of magnitude.

Cuneo VA, Alabarta K, Zhang L, Altamirano D, Mendez M, Padilla MA, Remillard RA, Homan J, Steiner JF, Combi JA, Munoz-Darias T, Gendreau KC, Arzoumanian Z, Stevens AL, Loewenstein M, Tombesi F, Bult PM, Fabian AC, Buisson DJ, Neilsen J, Basak A. A NICER look at the state transitions of the black hole candidate MAXI J1535-571 during its reflares. Monthly Notices of the Royal Astronomical Society. 2020 June 9; epub: 12 pp. DOI: 10.1093/mnras/staa1606.



Word cloud of journal sources containing ISS results publications from October 1, 2019 – October 1, 2020.

ISS Research Results Publications

October 1, 2019 – October 1, 2020

(Listed by category and alphabetically by investigation.)

BIOLOGY AND BIOTECHNOLOGY

Advanced Plant Habitat (**Plant Habitat**) — Monje OA, Richards JT, Carver JA, Dimapilis DI, Levine HG, et al. Hardware validation of the Advanced Plant Habitat on ISS: Canopy photosynthesis in reduced gravity. *Frontiers in Plant Science*. 2020; 11: 15 pp. DOI: 10.3389/fpls.2020.00673.

Amyloid Aggregation (**Amyloid Aggregation**) — Berrone E, Cardone F, Corona C, Sbriccoli M, Favole A, et al. The Amyloid Aggregation study on board the International Space Station, an update. *Aerotecnica Missili & Spazio*. 2020 June 1; 99(2): 141-148. DOI: 10.1007/s42496-020-00049-z.

ARC ISS Drosophila Experiment (**Fruit Fly Lab-01 (FFL-01)**) — Gilbert R, Torres ML, Clemens R, Hateley S, Hosamani R, et al. Spaceflight and simulated microgravity conditions increase virulence of Serratia marcescens in the Drosophila melanogaster infection model. *npj Microgravity*. 2020 February 4; 6(1): 1-9. DOI: 10.1038/s41526-019-0091-2.

Arthrospira sp. Gene Expression and Mathematical Modelling on Cultures Grown in the International Space Station (**Arthrospira B**) — Poughon L, Laroche C, Creuly C, Dussap C, Paille C, et al. Limnospira indica PCC8005 growth in photobioreactor: model and simulation of the ISS and ground experiments. *Life Sciences in Space Research*. 2020 May; 25: 53-65. DOI: 10.1016/j.lssr.2020.03.002.

Assessment of myostatin inhibition to prevent skeletal muscle atrophy and weakness in mice exposed to long-duration spaceflight (**Rodent Research-3-Eli Lilly**) — Smith RC, Cramer MS, Mitchell PJ, Lucchesi J, Ortega AM, et al. Inhibition of myostatin prevents microgravity-induced loss of skeletal muscle mass and strength. *PLOS ONE*. 2020 April 21; 15(4): e0230818. DOI: 10.1371/journal.pone.0230818.

Biological Research in Canisters-20 (**BRIC-20**) — Kruse CP, Meyers AD, Basu P, Hutchinson S, Luesse D, et al. Spaceflight induces novel regulatory responses in Arabidopsis seedling as revealed by combined proteomic and transcriptomic analyses. *BMC Plant Biology*. 2020 May 27; 20(1): 237. DOI: 10.1186/s12870-020-02392-6.

BioScience-4 (**STaARS BioScience-4**) — Cepeda C, Vergnes L, Carpo N, Schibler MJ, Bentolila LA, et al. Human neural stem cells flown into space proliferate and generate young neurons. *Applied Sciences*. 2019 January; 9(19): 4042. DOI: 10.3390/app9194042.

BRIC - Natural Product under Microgravity (**BRIC-NP**) — Blachowicz A, Raffa N, Bok JW, Choera T, Knox BP, et al. Contributions of spore secondary metabolites to UV-C protection and virulence vary in different Aspergillus fumigatus strains. *mBio*. 2020 February 8; 11(1): e03415-19. DOI: 10.1128/mBio.03415-19.

Characterization of Amyloid Formation Under Microgravity Environment: Toward Understanding the Mechanisms of Neurodegenerative Diseases (**Amyloid**) — Yagi-Utsumi M, Yanaka S, Song C, Satoh T, Yamazaki C, Kasahara H, et al. Characterization of amyloid β fibril formation under microgravity conditions. *npj Microgravity*. 2020 June 12; 6(1): 17. DOI: 10.1038/s41526-020-0107-y.

E. coli AntiMicrobial Satellite (**EcAMSat**) — Padgen MR, Chinn T, Friedericks CR, Lera MP, Chin M, et al. The EcAMSat fluidic system to study antibiotic resistance in low Earth orbit: Development and lessons learned from space flight. *Acta Astronautica*. 2020 February 19; epub: 48 pp. DOI: 10.1016/j.actaastro.2020.02.031.

E. coli AntiMicrobial Satellite (**EcAMSat**) — Padgen MR, Lera MP, Ricco AJ, Chin M, Chinn T, et al. EcAMSat spaceflight measurements of the role of ss in antibiotic resistance of stationary phase Escherichia coli in microgravity. *Life Sciences in Space Research*. 2020 February 1; 24: 18-24. DOI: 10.1016/j.lssr.2019.10.007.

Effect of Microgravity at Bone Cell and Tissue Levels (**Invitrobone**) — Colucci S, Colaianni G, Brunetti G, Ferranti F, Mascetti G, et al. Irisin prevents microgravity-induced impairment of osteoblast differentiation in vitro during the space flight CRS-14 mission. *FASEB: Federation of American Societies for Experimental Biology Journa*l. 2020 June 15; epub: 11 pp. DOI: 10.1096/fj.202000216R.

Effect of Space Flight on Innate Immunity to Respiratory Viral Infections (**Mouse Immunology-2**) — Deymier AC, Schwartz AG, Lim C, Wingender B, Kotiya A, et al. Multiscale effects of spaceflight on murine tendon and bone. *Bone*. 2019 November 12; 131: 115152. DOI: 10.1016/j.bone.2019.115152.

Effects of Microgravity on Stem Cell-Derived Heart Cells (**Heart Cells**) — Wnorowski A, Sharma A, Chen H, Wu H, Shao N, et al. Effects of spaceflight on human induced pluripotent stem cell-derived cardiomyocyte structure and function. *Stem Cell Reports*. 2019 November 7; epub: 10 pp. DOI: 10.1016/j.stemcr.2019.10.006.

Exercise Countermeasures for Knee and Hip Joint Degeneration during Spaceflight (**Willey Gait**) — Kwok A, Rosas S, Bateman TA, Livingston EW, Smith TL, et al. Altered Rodent Gait Characteristics after ∼35 Days in Orbit aboard the International Space Station. *Life Sciences in Space Research*. 2020 February; 24: 9-17. DOI: 10.1016/j.lssr.2019.10.010.

GeneLAB — Fujita S, Rutter L, Ong Q, Muratani M. Integrated RNA-seq analysis indicates asynchrony in clock genes between tissues under spaceflight. *Life*. 2020 September; 10(9): 196. DOI: 10.3390/life10090196.

GeneLAB — Beheshti A, Chakravarty K, Fogle H, Fazelinia H, Silveira WA, et al. Multi-omics analysis of multiple missions to space reveal a theme of lipid dysregulation in mouse liver. *Scientific Reports*. 2019 December; 9(1): 19195. DOI: 10.1038/s41598-019-55869-2.

Influence of Factors of the Space Environment on the Condition of the System of Microorganisms-Hosts Relating to the Problem of Environmental Safety of Flight Techniques and Planetary Quarantine (**Biorisk-MSN**) — Sychev VN, Novikova ND, Poddubko SV, Deshevaya EA, Orlov OI. The biological threat: The threat of planetary quarantine failure as a result of outer space exploration by humans. *Doklady Biological Sciences*. 2020 January; 490(1): 28-30. DOI: 10.1134/S0012496620010093.

Influence of microgravity on the production of Aspergillus secondary metabolites (IMPAS) - a novel drug discovery approach with potential benefits to astronauts' health (**Micro-10**) — Romsdahl J, Blachowicz A, Chiang Y, Venkateswaran KJ, Wang CC. Metabolomic analysis of Aspergillus niger isolated from the International Space Station reveals enhanced production levels of the antioxidant pyranonigrin A. *Frontiers in Microbiology*. 2020 May 21; 11: 931. DOI: 10.3389/fmicb.2020.00931.

International Space Station Internal Environments (**ISS Internal Environments**) — Kamyshev NG, Besedina NG, Bragina JV, Danilenkova LV, Fedotov SA, et al. Behavioral changes in Drosophila males after travel to international space station. *Acta Astronautica*. 2020 June 30; epub: 15 pp. DOI: 10.1016/j.actaastro.2020.06.048.

International Space Station Internal Environments (**ISS Internal Environments**) — Ichijo T, Shimazu T, Nasu M. Microbial Monitoring in the International Space Station and Its Application on Earth. *Biological & Pharmaceutical Bulletin*. 2020; 43(2): 254-257. DOI: 10.1248/bpb.b19-00912.

International Space Station Internal Environments (ISS Internal Environments) — Thompson AF, English EL, Nock AM, Willsey GG, Eckstrom K, et al. Characterizing species interactions that contribute to biofilm formation in a multispecies model of a potable water bacterial community. *Microbiology-SGM*. 2019 October 4; 166(1): 34–43. DOI: 10.1099/mic.0.000849.

International Space Station Internal Environments (**ISS Internal Environments**) — Karpov DS, Domashin AI, Kotlov MI, Osipova PG, Kiseleva SV,

et al. Biotechnological potential of the Bacillus subtilis 20 strain. *Molecular Biology*. 2020 January 1; 54(1): 119-127. DOI: 10.1134/S0026893320010082.

International Space Station Internal Environments (**ISS Internal Environments**) — McGhee JJ, Rawson N, Bailey BA, Fernandez-Guerra A, Sisk-Hackworth L, et al. Meta-SourceTracker: application of Bayesian source tracking to shotgun metagenomics. *PeerJ*. 2020 March 24; 8: e8783. DOI: 10.7717/peerj.8783.

International Space Station Internal Environments (**ISS Internal Environments**) — O'Rourke A, Lee MD, Nierman WC, Everroad RC, Dupont CL. Genomic and phenotypic characterization of Burkholderia isolates from the potable water system of the International Space Station. *PLOS ONE*. 2020 February 19; 15(2): e0227152. DOI: 10.1371/journal.pone.0227152.

International Space Station-Microbial Observatory of Pathogenic Viruses, Bacteria, and Fungi (ISS-MOP) Project (**Microbial Tracking-2**) — Avila-Herrera A, Thissen J, Urbaniak C, Be NA, Smith DJ, et al. Crewmember microbiome may influence microbial composition of ISS habitable surfaces. *PLOS ONE*. 2020 April 29; 15(4): e0231838. DOI: 10.1371/journal.pone.0231838.

Investigation of the Osteoclastic and Osteoblastic Responses to Microgravity Using Goldfish Scales (**Fish Scales**) — Furusawa Y, Yamamoto T, Hattori A, Suzuki N, Hirayama J, et al. De novo transcriptome analysis and gene expression profiling of fish scales isolated from Carassius auratus during space flight: Impact of melatonin on gene expression in response to space radiation. *Molecular Medicine Reports*. 2020 July 28; 2627-2636. DOI: 10.3892/mmr.2020.11363.

Japan Aerospace Exploration Agency Protein Crystallization Growth (**JAXA PCG**) — Funaki R, Okamoto W, Endo C, Morita Y, Kihira K, et al. Genetically engineered haemoglobin wrapped covalently with human serum albumins as an artificial O2. *Journal of Materials Chemistry B*. 8(6): 1139-1145. DOI: 10.1039/C9TB02184A.

Japan Aerospace Exploration Agency Protein Crystallization Growth (**JAXA PCG**) — Negoro S, Shibata N, Lee Y, Takehara I, Kinugasa R, et al. Structural basis of the correct subunit assembly, aggregation, and intracellular degradation of nylon hydrolase. Scientific Reports. 2018 June 27; 8(1): 1-16. DOI: 10.1038/s41598-018-27860-w.*

Japan Aerospace Exploration Agency Protein Crystallization Growth (**JAXA PCG**) — Sakamoto Y, Suzuki Y, Iizuka I, Tateoka C, Roppongi S, et al. Structural and mutational analyses of dipeptidyl peptidase 11 from Porphyromonas gingivalis reveal the molecular basis for strict substrate specificity. *Scientific Reports*. 2015 June 9; 5(1): 11151. DOI: 10.1038/srep11151.*

JAXA Mouse Habitat Unit — Suzuki, Takafumi, Akira Uruno, Akane Yumoto, Keiko Taguchi, Mikiko Suzuki, Nobuhiko Harada, et al, 'Nrf2 Contributes to the Weight Gain of Mice during Space Travel', *Communications Biology*, 3.1 (2020), 496. DOI: 10.1038/s42003-020-01227-2

Life Cycles of Higher Plants Under Microgravity Conditions (SpaceSeed) — Karahara I, Suto T, Yamaguchi T, Yashiro U, Tamaoki D, et al. Vegetative and reproductive growth of Arabidopsis under microgravity conditions in space. *Journal of Plant Research*. 2020 July 1; 133(4): 571-585. DOI: 10.1007/s10265-020-01200-4.

Magnetic 3-D Bioprinter — Parfenov VA, Khesuani YD, Petrov SV, Karalkin PA, Koudan EV, et al. Magnetic levitational bioassembly of 3D tissue construct in space. *Science Advances*. 2020 July 15; 6(29): eaba4174. DOI: 10.1126/sciadv.aba4174.

MELiSSA ON board DAnish Utilisation flight (**MELONDAU**) — El_Nakhel C, Giordano M, Pannico A, Carillo P, Fusco GM, et al. Cultivar-specific performance and qualitative descriptors for butterhead salanova lettuce produced in closed soilless cultivation as a candidate salad crop for human life support in space. *Life*. 2019 September; 9(3): 61. DOI: 10.3390/life9030061.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Cao L, Gurevich AV, Alexander KL, Naman B, Leao T, Glukhov E, et al. MetaMiner: A Scalable Peptidogenomics Approach for Discovery of Ribosomal Peptide Natural Products with Blind

Modifications from Microbial Communities. *Cell Systems*. 2019 December 19; 9(6): 600-608.e4. DOI: 10.1016/j.cels.2019.09.004.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Bijlani S, Singh NK, Mason CE, Wang CC, Venkateswaran KJ. Draft genome sequences of Sphingomonas species associated with the International Space Station. *Microbiology Resource Announcements*. 2020 June 18; 9(25): e00578-20. DOI: 10.1128/MRA.00578-20.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Bijlani S, Singh NK, Mason CE, Wang CC, Venkateswaran KJ. Draft genome sequences of Tremellomycetes strains isolated from the International Space Station. *Microbiology Resource Announcements*. 2020 June 25; 9(26): e00504-20. DOI: 10.1128/MRA.00504-20.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Daudu R, Parker CW, Singh NK, Wood JM, Debieu M, et al. Draft Genome Sequences of Rhodotorula mucilaginosa Strains Isolated from the International Space Station. *Microbiology Resource Announcements*. 2020 July 30; 9(31): e00570-20. DOI: 10.1128/MRA.00570-20.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Bharadwaj AR, Daudu R, Singh NK, Wood JM, Debieu M, et al. Draft genome sequences of Enterobacteriales strains isolated from the International Space Station. *Microbiology Resource Announcements*. 2020 September 9; 9(37): e00817-20. DOI: 10.1128/MRA.00817-20.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Bharadwaj AR, Singh NK, Wood JM, Debieu M, O'Hara NB, et al. Draft genome sequences of Lactobacillales isolated from the International Space Station. *Microbiology Resource Announcements*. 2020 September 24; 9(39): e00942-20. DOI: 10.1128/MRA.00942-20.

Microbial Tracking Payload Series (**Microbial Observatory-1**) — Urbaniak C, Lorenzi HA, Thissen J, Jaing C, Crucian BE, et al. The influence of spaceflight on the astronaut salivary microbiome and the search for a microbiome biomarker for viral reactivation. *Microbiome*. 2020 April 20; 8(1): 56. DOI: 10.1186/s40168-020-00830-z.

Microgravity Effect on Entomopathogenic Nematodes' Ability to Find and Kill Insects (**Module-85 Pheronym**) — Kaplan F, Shapiro-Illan D, Schiller KC. Dynamics of entomopathogenic nematode foraging and infectivity in microgravity. *npj Microgravity*. 2020 August 10; 6(1): 20. DOI: 10.1038/s41526-020-00110-y.

Microgravity Expanded Stem Cells — Huang P, Russell AL, Lefavor R, Durand NC, James E, et al. Feasibility, potency, and safety of growing human mesenchymal stem cells in space for clinical application. *npj Microgravity*. 2020 June 1; 6(1): 1-12. DOI: 10.1038/s41526-020-0106-z.

Microgravity Growth of Crystalline Monoclonal Antibodies for Pharmaceutical Applications (**CASIS PCG 5**) — Reichert P, Prosise W, Fischmann TO, Scapin G, Narasimhan C, et al. Pembrolizumab microgravity crystallization experimentation. *npj Microgravity*. 2019 December 2; 5(1): 1-8. DOI: 10.1038/s41526-019-0090-3.

Mighty Mice in Space: Preclinical Evaluation of a Broad Spectrum Mysotatin Inhibitor to Prevent Muscle Loss and Bone Loss Due to Disuse (**Rodent Research-19**) — Lee S, Lehar A, Meir JU, Koch C, Morgan A, et al. Targeting myostatin/activin A protects against skeletal muscle and bone loss during spaceflight. *Proceedings of the National Academy of Sciences of the United States of America*. 2020 September 2; epub: 10 pp. DOI: 10.1073/pnas.2014716117.

Molecular Muscle (**Molecular Muscle**) — Pollard AK, Gaffney CJ, Deane CS, Balsamo M, Cooke M, et al. Molecular Muscle experiment: Hardware and operational lessons for future astrobiology space experiments. *Astrobiology*. 2020 April 8; 20(10): ast.2019.2181. DOI: 10.1089/ast.2019.2181.

Multiple-Tropism: Gravity, Nutrient and Water Interaction of Stimuli for Root Orientation in Microgravity (**MULTI-TROP**) — Izzo LG, Romano LE,

De Pascale S, Mele G, Gargiulo L, et al. Chemotropic vs hydrotropic stimuli for root growth orientation in microgravity. *Frontiers in Plant Science*. 2019 November 22; 10: 1547. DOI: 10.3389/fpls.2019.01547.

Multiple-Tropism: Gravity, Nutrient and Water Interaction of Stimuli for Root Orientation in Microgravity (MULTI-TROP) — Aronne G, Romano LE, Izzo LG. Subsequent inclusion/exclusion criteria to select the best species for an experiment performed on the ISS in a refurbished hardware. *Life Sciences in Space Research*. 2020 July 11; epub: 22 pp. DOI: 10.1016/j.lssr.2020.07.002.

Mycological Evaluation of Crew Exposure to ISS Ambient Air (Myco) — Sugita T, Yamazaki TQ, Cho O, Furukawa S, Mukai C. The skin mycobiome of an astronaut during a 1-year stay on the International Space Station. *Medical Mycology*. 2020 August 24; epub: 4 pp. DOI: 10.1093/mmy/myaa067.

Nanotechnology Solutions against Oxidative Stress in Muscle Tissue during Long-term Microgravity Exposure (NANOROS) — Genchi GG, Marino A, Tapeinos C, Ciofani G. Smart materials meet multifunctional biomedical devices: Current and prospective implications for nanomedicine. *Frontiers in Bioengineering and Biotechnology*. 2017 December 18; 5(80): 8 pp. DOI: 10.3389/fbioe.2017.00080.*

Organs-On-Chips as a Platform for Studying Effects of Microgravity on Human Physiology — Low LA, Giulianotti MA. Tissue chips in space: Modeling human diseases in microgravity. *Pharmaceutical Research*. 2020 January; 37(1): 8. DOI: 10.1007/s11095-019-2742-0.

Regulation by Gravity of Ferulate Formation in Cell Walls of Rice Seedlings (Ferulate) — Wakabayashi K, Soga K, Hoson T, Kotake T, Yamazaki TQ, et al. Microgravity Affects the Level of Matrix Polysaccharide 1,3:1,4-b-Glucans in Cell Walls of Rice Shoots by Increasing the Expression Level of a Gene Involved in Their Breakdown. *Astrobiology*. 2020 March 24; 20(7): 10 pp. DOI: 10.1089/ast.2019.2140.

Rodent Research Facility (Rodent Research Facility) — McDonald JT, Stainforth R, Miller J, Cahill T, da Silveira WA, et al. NASA GeneLab platform utilized for biological response to space radiation in animal models. *Cancers*. 2020 February; 12(2): 381. DOI: 10.3390/cancers12020381.

Rodent Research Hardware and Operations Validation (Rodent Research-1) — Choi SY, Saravia-Butler AM, Shirazi-Fard Y, Leveson-Gower D, Stodieck LS, et al. Validation of a New Rodent Experimental System to Investigate Consequences of Long Duration Space Habitation. *Scientific Reports*. 2020 February 11; 10(1): 2336. DOI: 10.1038/s41598-020-58898-4.

Rodent Research-6 (RR-6) — Ballerini A, Chua CY, Rhudy J, Susnjar A, Trani ND, et al. Counteracting muscle atrophy on Earth and in space via nanofluidics delivery of f ormoterol. *Advanced Therapeutics*. 2020 May 10; epub: 2000014. DOI: 10.1002/adtp.202000014.

Role of the Edocannabinoid System in Pluripotent Human Stem Cell Reprogramming under Microgravity Conditions (SERISM) — Maccarrone M, Fava M, Battista N, Piccirillo S, Valentini G, et al. Opening the gate to the Serism project: From Earth to space and back. *Aerotecnica Missili & Spazio*. 2020 May 9; 99: 87-91. DOI: 10.1007/s42496-020-00043-5.

Seedling Growth-1 — Vandenbrink JP, Herranz R, Poehlman WL, Feltus FA, Villacampa A, et al. RNA-seq analyses of Arabidopsis thaliana seedlings after exposure to blue-light phototropic stimuli in microgravity. *American Journal of Botany*. 2019 November 10; 106(11): 1466-1476. DOI: 10.1002/ajb2.1384.

Seedling Growth-1 — Herranz R, Vandenbrink JP, Villacampa A, Manzano A, Poehlman WL, et al. RNAseq Analysis of the Response of Arabidopsis thaliana to Fractional Gravity Under Blue-Light Stimulation During Spaceflight. *Frontiers in Plant Science*. 2019 November 26; 10: 11 pp. DOI: 10.3389/fpls.2019.01529.

Spaceflight Environment Induces Remodeling of Vascular Network and Glia-vascular Communication in Mouse Retina (Mao Eye) — Roque-Torres GD, Nishiyama NC, Stanbouly S, Mao XW. Assessment of global ocular structure following

spaceflight using a micro-computed tomography (micro-CT) imaging method. *JoVE (Journal of Visualized Experiments)*. 2020 September; e61227.

Studies on gravity-controlled growth and development in plants using true microgravity conditions (**Auxin Transport**) — Ueda J. Comprehensive report on the Auxin Transport space experiment: the analysis of gravity response and attitude control mechanisms of plants under microgravity conditions in space on the International Space Station. *Biological Sciences in Space*. 2020; 34: 12-33. DOI: 10.2187/bss.34.12.

Studies on gravity-controlled growth and development in plants using true microgravity conditions (**Auxin Transport**) — Oka M, Kamada M, Inoue R, Miyamoto K, Uheda E, et al. Altered localisation of ZmPIN1a proteins in plasma membranes responsible for enhanced-polar auxin transport in etiolated maize seedlings under microgravity conditions in space. *Functional Plant Biology*. 2020 July 8; epub: 11 pp. DOI: 10.1071/FP20133.

Studies on gravity-controlled growth and development in plants using true microgravity conditions (**Auxin Transport**) — Kamada M, Oka M, Miyamoto K, Uheda E, Yamazaki C, et al. Microarray profile of gene expression in etiolated Pisum sativum seedlings grown under microgravity conditions in space: Relevance to the International Space Station experiment "Auxin Transport". *Life Sciences in Space Research*. 2020 August 1; 26: 55-61. DOI: 10.1016/j.lssr.2020.04.005.

Studies on gravity-controlled growth and development in plants using true microgravity conditions (**Auxin Transport**) — Ueda J, Sakamoto-Kanetake M, Toda Y, Miyamoto K, Uheda E, et al. Auxin polar transport is essential for the early growth stage of etiolated maize (Zea mays L. cv. Honey Bantam) seedlings. *Plant Production Science*. 2014 January 1; 17(2): 144-151. DOI: 10.1626/pps.17.144.*

Studying the Features of the Growth and Development of Plants, and Technology for their Culturing in Spaceflight on the ISS RS (**Rastenia-Pshenitsa (Plants-Wheat)**) — Baranova EN, Levinskikh MA, Gulevich AA. Wheat Space Odyssey: "From Seed to Seed". *Kernel Morphology*. Life. 2019 October 25; 9(4): 81. DOI: 10.3390/life9040081.

Tissue Regeneration-Bone Defect (**Rodent Research-4 (CASIS)**) — Chakraborty NM, Waning DL, Gautam A, Hoke A, Sowe B, et al. Gene-metabolite network linked to inhibited bioenergetics in association with spaceflight-induced loss of male mouse quadriceps muscle. *Journal of Bone and Mineral Research*. 2020 June 8; epub: 26 pp. DOI: 10.1002/jbmr.4102.

Transcriptome analysis and germ-cell development analysis of mice in the space (**Mouse Epigenetics (MHU-1)**) — Horie K, Kato T, Kudo T, Sasanuma H, Miyauchi M, et al. Impact of spaceflight on the murine thymus and mitigation by exposure to artificial gravity during spaceflight. *Scientific Reports*. 2019 December 27; 9(1): 19866. DOI: 10.1038/s41598-019-56432-9.

Transgenic Arabidopsis Gene Expression System - Intracellular Signaling Architecture (**APEX-03-2 TAGES-Isa**) — Sng NJ, Kolaczkowski B, Ferl RJ, Paul AL. A member of the CONSTANS-Like protein family is a putative regulator of reactive oxygen species homeostasis and spaceflight physiological adaptation. *AoB Plants*. 2018 December 15; 11(1): 18 pp. DOI: 10.1093/aobpla/ply075.*

Transgenic Arabidopsis Gene Expression System - Intracellular Signaling Architecture (**APEX-03-2 TAGES-Isa**) — Califar B, Sng NJ, Zupanska AK, Paul AL, Ferl RJ. Root skewing-associated genes impact the spaceflight response of Arabidopsis thaliana. *Frontiers in Plant Science*. 2020 March 4; 11: 239. DOI: 10.3389/fpls.2020.00239.

Transgenic Arabidopsis Gene Expression System - Intracellular Signaling Architecture (**APEX-03-2 TAGES-Isa**) — Sng NJ, Callaham JB, Ferl RJ, Paul AL. Arabidopsis Thaliana for spaceflight applications – Preparing dormant biology for passive stowage and on orbit activation. *Gravitational and Space Research*. 2014 December 31; 2(2): 9 pp.*

Veg-03 J/K/L — Khodadad CL, Hummerick ME, Spencer LE, Dixit AR, Richards JT, et al. Microbiological and nutritional analysis of lettuce crops grown on the

International Space Station. *Frontiers in Plant Science*. 2020; 11: 199. DOI: 10.3389/fpls.2020.00199.

HUMAN RESEARCH

A Simple In-flight Method to Test the Risk of Fainting on Return to Earth After Long-Duration Spaceflights (BP Reg) — Wood KN, Murray KR, Greaves DK, Hughson RL. Inflight leg cuff test does not identify the risk for orthostatic hypotension after long-duration spaceflight. *npj Microgravity*. 2019 October 11; 5(1): 22. DOI: 10.1038/s41526-019-0082-3.

Acoustic Upgraded Diagnostics In-Orbit (Acoustic Diagnostics) — Moleti A, D'Amico A, Orlando MP, Pennazza G, Santonico M, et al. Mission beyond: The Acoustic Diagnostics Experiment on board the International Space Station. *Aerotecnica Missili & Spazio*. 2020 May 23; 99: 79-85. DOI: 10.1007/s42496-020-00042-6.

Biochemical Profile (Biochem Profile) — Lee SM, Ribeiro LC, Martin DS, Zwart SR, Feiveson AH, et al. Arterial structure and function during and after long-duration spaceflight. *Journal of Applied Physiology*. 2020 June 11; 129(1): 108-123. DOI: 10.1152/japplphysiol.00550.2019.

Brain-DTI — Jillings S, Van Ombergen A, Tomilovskaya ES, Rumshiskaya A, Litvinova L, et al. Macro- and microstructural changes in cosmonauts' brains after long-duration spaceflight. *Science Advances*. 2020 September 1; 6(36): eaaz9488. DOI: 10.1126/sciadv.aaz9488.

Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capability and Risk for Cardiac Arrhythmias (Integrated Cardiovascular) — Marshall-Goebel K, Laurie SS, Alferova IV, Arbeille P, Aunon-Chancellor SM, et al. Assessment of jugular venous blood flow stasis and thrombosis during spaceflight. *JAMA Network Open*. 2019 November 1; 2(11): e1915011-e1915011. DOI: 10.1001/jamanetworkopen.2019.15011.

Cardiovascular Health Consequences of Long-Duration Space Flight (Vascular) — Patel S. The effects of microgravity and space radiation on cardiovascular health: From low-Earth orbit and beyond. *IJC Heart & Vasculature*. 2020 October 1; 30: 100595. DOI: 10.1016/j.ijcha.2020.100595.

Dose Tracker Application for Monitoring Medication Usage, Symptoms, and Adverse Effects During Missions (Dose Tracker) — Wotring VE, Smith LK. Dose Tracker Application for Collecting Medication Use Data from International Space Station Crew. *Aerospace Medicine and Human Performance*. 2020 January 1; 91(1): 41-45. DOI: 10.3357/AMHP.5392.2020.

Early Detection of Osteoporosis in Space (EDOS) — Gordienko KV, Novikov V, Servuli E, Nosovsky AM, Vasilieva GY. Detailed Analysis of the Central Osteodensitometry Data from Cosmonauts Participating in the Mir and ISS Programs. *Human Physiology*. 2019 December 1; 45(7): 764-767. DOI: 10.1134/S0362119719070065.

Feasibility Study: QCT Modality for Risk Surveillance of Bone - Effects of In-flight Countermeasures on Sub-regions of the Hip Bone (Hip QCT) — Sibonga JD, Spector ER, Keyak JH, Zwart SR, Smith SM, et al. Use of quantitative computed tomography to assess for clinically-relevant skeletal effects of prolonged spaceflight on astronaut hips. *Journal of Clinical Densitometry*. 2020 April 1; 23(2): 155-164. DOI: 10.1016/j.jocd.2019.08.005.

Functional Immune Alterations, Latent Herpesvirus Reactivation, Physiological Stress and Clinical Incidence Onboard the International Space Station (Functional Immune) — Crucian BE, Makedonas G, Sams CF, Pierson DL, Simpson RJ, et al. Countermeasures-based improvements in stress, immune system dysregulation and latent herpesvirus reactivation onboard the International Space Station - Relevance for deep space missions and terrestrial medicine. *Neuroscience and Biobehavioral Reviews*. 2020 August; 115: 68-76. DOI: 10.1016/j.neubiorev.2020.05.007.

Human Cerebral Vascular Autoregulation and Venous Outflow In Response to Microgravity-Induced Cephalad Fluid Redistribution (**Cephalad Fluid Redistribution**) — Roberts DR, Brown TR, Nietert PJ, Eckert MA, Inglesby DC, et al. Prolonged microgravity affects human brain structure and function. *American Journal of Neuroradiology*. 2019 October 17; epub: 8 pp. DOI: 10.3174/ajnr.A6249.

Human Cerebral Vascular Autoregulation and Venous Outflow In Response to Microgravity-Induced Cephalad Fluid Redistribution (**Cephalad Fluid Redistribution**) — Inglesby DC, Antonucci MU, Spampinato MV, Collins HR, Meyer TA, et al. Spaceflight-associated changes in the opacification of the paranasal sinuses and mastoid air cells in astronauts. *JAMA Otolaryngology*. 2020 March 26; epub: 11 pp. DOI: 10.1001/jamaoto.2020.0228.

Human Exploration Research Opportunities - Differential Effects on Homozygous Twin Astronauts Associated with Differences in Exposure to Spaceflight Factors (**Twins Study**) — Welsh J, Bevelacqua JJ, Keshavarz M, Mortazavi SA, Mortazavi SM. Is telomere length a biomarker of adaptive response in space? Curious findings from NASA and residents of high background radiation areas. *Journal of Biomedical Physics & Engineering*. 2019 June; 9(3): 381-388. DOI: 10.31661/jbpe.v9i3Jun.1151.

Human Exploration Research Opportunities - Differential Effects on Homozygous Twin Astronauts Associated with Differences in Exposure to Spaceflight Factors (**Twins Study**) — Schmidt MA, Meydan C, Schmidt CM, Afshinnekoo E, Mason CE. The NASA Twins Study: The effect of one year in space on long-chain fatty acid desaturases and elongases. *Lifestyle Genomics*. 2020 May 6; epub: 1-15. DOI: 10.1159/000506769.

Inflight Pharmacokinetic and Pharmacodynamic Responses to Medications Commonly Used in Spaceflight (Rx Metabolism) — Berman E, Eyal S. Drug interactions in space: A cause for concern?. Pharmaceutical Research. 2019 May 31; 36(8): 114. DOI: 10.1007/s11095-019-2649-9.

Integrated Resistance and Aerobic Training Study (**Sprint**) — English KL, Downs ME, Goetchius EL, Buxton RE, Ryder JW, et al. High intensity training during spaceflight: results from the NASA Sprint Study. *npj Microgravity*. 2020 August 18; 6(1): 21. DOI: 10.1038/s41526-020-00111-x.

International Space Station Medical Monitoring (**ISS Medical Monitoring**) — Chu W, Glad W, Wever R. Embracing change while retaining the existing: Sustainable behaviour design insights from astronaut food consumption transitions. *International Association of Societies of Design Research Conference IASDR 2019*, Manchester, United Kingdom; 2019 September 2-5. 15 pp.

International Space Station Medical Monitoring (**ISS Medical Monitoring**) — Koryak YA. Isokinetic force and work capacity after long-duration space station Mir and short-term International Space Station missions. *Aerospace Medicine and Human Performance*. 2020 May 1; 91(5): 422-431. DOI: 10.3357/AMHP.5348.2020.

International Space Station Medical Monitoring (**ISS Medical Monitoring**) — Jain V, Ploutz-Snyder RJ, Young MH, Charvat JM, Wotring VE. Potential venous thromboembolism risk in female astronauts. *Aerospace Medicine and Human Performance*. 2020 May 1; 91(5): 432-439. DOI: 10.3357/AMHP.5458.2020.

International Space Station Medical Monitoring (**ISS Medical Monitoring**) — Trudel G, Shafer J, Laneuville O, Ramsay T. Characterizing the effect of exposure to microgravity on anemia: more space is worse. *American Journal of Hematology*. 2019 December 2; 95(3): 267-273. DOI: 10.1002/ajh.25699.

International Space Station Medical Monitoring (**ISS Medical Monitoring**) — Ilyin VC, Shumilina GA, Solovieva ZO, Nosovsky AM, Kaminskaya EV. Some characteristics of the oral cavity and teeth of cosmonauts on missions to the International Space Station. Aviakosmicheskaia i Ekologicheskaia Meditsina (*Aerospace and Environmental Medicine*). 2016; 50(6): 25-30. DOI: 10.21687/0233-528x-2016-50-6-25-30.*

International Space Station Medical Monitoring (ISS Medical Monitoring) — Pastushkova LK, Goncharova AG, Vasilyeva GY, Tagirova SK, Kashirina DN, et al. Search for Blood Proteome Proteins Involved in the Regulation of Bone Remodeling in Astronauts. *Human Physiology*. 2019 September 1; 45(5): 536-542. DOI: 10.1134/S0362119719050128.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Kotovskaya AR, Koloteva MI, Glebova TM. Tolerance of G-Loads by a Russian Cosmonaut and a NASA Astronaut during the Soyuz Space Vehicle De-Orbit after a 340-Day Mission to the International Space Station. *Human Physiology*. 2019 December 1; 45(7): 754-758. DOI: 10.1134/S0362119719070090.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Kukoba TB, Novikov VE, Babich DR, Lysova NY, Gordienko KV, et al. Preventive efficiency of resistive exercises for the bone system of cosmonauts in repeated long-duration space missions. *Human Physiology*. 2019 December 1; 45(7): 759-763. DOI: 10.1134/S0362119719070107.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Stepanova SI, Koroleva MV, Nesterov VF, Galichiy VA, Karpova OI. In-flight monitoring of cosmonauts' work and rest cycle: Retrospective data analysis and information sources. *Human Physiology*. 2019 December 1; 45(7): 768-772. DOI: 10.1134/S0362119719070168.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Koryak YA. Changes in human skeletal muscle architecture and function induced by extended spaceflight. *Journal of Biomechanics*. 2019 December 3; 97: 109408. DOI: 10.1016/j.jbiomech.2019.109408.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Burkhart K, Allaire B, Anderson D, Lee D, Keaveny TM, et al. Effects of long-duration spaceflight on vertebral strength and risk of spine fracture. *Journal of Bone and Mineral Research*. 2020 February; 35(2): 269-276. DOI: 10.1002/jbmr.3881.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Stavnichuk M, Mikolajewicz N, Corlett T, Morris M, Komarova SV. A systematic review and meta-analysis of bone loss in space travelers. *npj Microgravity*. 2020 May 5; 6(1): 1-9. DOI: 10.1038/s41526-020-0103-2.

International Space Station Medical Monitoring (ISS Medical Monitoring) — Larina IM, Pastushkova LK, Kononikhin AS, Nikolaev EN, Orlov OI. Piloted space flight and post-genomic technologies. *REACH*. 2020 July 11; 16: 100034. DOI: 10.1016/j.reach.2020.100034.

International Space Station Summary of Research Performed (ISS Summary of Research) — English KL, Bloomberg JJ, Mulavara AP, Ploutz-Snyder LL. Exercise countermeasures to neuromuscular deconditioning in spaceflight. *Comprehensive Physiology* (book); 2019. DOI: 10.1002/cphy.c190005.

International Space Station Summary of Research Performed (ISS Summary of Research) — Rcheulishvili N, Zhang Y, Papukashvili D, Deng Y. Survey and evaluation of spacecraft-associated aluminum-degrading microbes and their rapid identification methods. *Astrobiology*. 2020 August; 20(8): 925-934. DOI: 10.1089/ast.2019.2078.

International Space Station Summary of Research Performed (ISS Summary of Research) — Taylor AJ, Beauchamp JD, Briand L, Heer MA, Hummel T, et al. Factors affecting flavor perception in space: Does the spacecraft environment influence food intake by astronauts?. *Comprehensive Reviews in Food Science and Food Safety*. 2020 September 18; epub: 37 pp. DOI: 10.1111/1541-4337.12633.

International Space Station Summary of Research Performed (ISS Summary of Research) — Siddiqui R, Akbar N, Khan NA. Gut microbiome and human health under the space environment. *Journal of Applied Microbiology*. 2020 July 21; epub: 11 pp. DOI: 10.1111/jam.14789.

International Space Station Summary of Research Performed (ISS Summary of Research) — Ramkumar PN, Navarro SM, Becker J, Ahmad F, Minkara

AA, et al. The effects of space microgravity on hip and knee cartilage: A new frontier in orthopaedics. *Surgical Technology International*. 2019 November 1; 35: 421-425.

Invasive and Noninvasive ICP Monitoring and VIIP Biomarker Identification (**Direct ICP**) — Wahlin A, Holmlund P, Fellows AM, Malm J, Buckey, Jr. JC, et al. Optic nerve length before and after spaceflight. *Ophthalmology*. 2020 July 10; epub: 30 pp. DOI: 10.1016/j.ophtha.2020.07.007.

Mechanism of Activity and Effectiveness of Various Countermeasures Intended to Prevent Disruptions to the Motor Apparatus in Microgravity (**Profilaktika-1 (Prophylaxis-1)**)— Fomina EV, Savinkina AO, Chumachenko VV. Locomotion strategies and intensity of support reactions as an approach to individualization of countermeasures against the negative effects of microgravity. Aviakosmicheskaia i Ekologicheskaia Meditsina (*Aerospace and Environmental Medicine*). 2016; 50(6): 31-36. DOI: 10.21687/0233-528x-2016-50-6-31-36.*

Nanoparticles-based countermeasures for Treatment of Microgravity-induced Osteoporosis (**Nanoparticles and Osteoporosis**) — Cristofaro F, Pani G, Pascucci B, Mariani A, Balsamo M, et al. The NATO project: nanoparticle based countermeasures for microgravity-induced osteoporosis. *Scientific Reports*. 2019 November 20; 9(1): 1-15. DOI: 10.1038/s41598-019-53481-y.

Neuroendocrine and Immune Responses in Humans During and After Long Term Stay at ISS (**Immuno**) — Fava M, Leuti A, Maccarrone M. Lipid signalling in human immune response and bone remodelling under microgravity. *Applied Sciences*. 2020 January; 10(12): 4309. DOI: 10.3390/app10124309.

Content — Yusupova AK, Shved DM, Gushchin VI, Supolkina NS, Chekalkina AI. Preliminary results of “Content” space experiment. *Human Physiology*. 2019 December 1; 45(7): 710-717. DOI: 10.1134/S0362119719070181.

Nutritional Monitoring for the International Space Station (**NutrISS**) — Di Girolamo FG, Biolo G, Fiotti N, Situlin R, Piacenza C, et al. The Nutriss Study: A new approach to calibrate diet and exercise in long-term space missions to maintain body fat, muscle and fluid homeostasis. *Aerotecnica Missili & Spazio*. 2020 May 12; 99: 121-125. DOI: 10.1007/s42496-020-00044-4.

Physiological Factors Contributing to Postflight Changes in Functional Performance (**Functional Task Test**) — Deshpande N, Laurie SS, Lee SM, Miller CA, Mulavara AP, et al. Vestibular and cardiovascular responses after long-duration spaceflight. *Aerospace Medicine and Human Performance*. 2020 August 1; 91(8): 621-627. DOI: 10.3357/AMHP.5502.2020.

Prospective Observational Study of Ocular Health in ISS Crews (**Ocular Health**) — Macias BR, Patel NB, Gibson CR, Samuels BC, Laurie SS, et al. Association of long-duration spaceflight with anterior and posterior ocular structure changes in astronauts and their recovery. *JAMA Ophthalmology*. 2020 April 2; 138(5): 553-559. DOI: 10.1001/jamaophthalmol.2020.0673.

Prospective Observational Study of Ocular Health in ISS Crews (**Ocular Health**) — Kramer LA, Hasan KM, Stenger MB, Sargsyan AE, Laurie SS, et al. Intracranial effects of microgravity: A prospective longitudinal MRI study. *Radiology*. 2020 April 14; epub: 191413. DOI: 10.1148/radiol.2020191413.

Quantification of In-Flight Physical Changes - Anthropometry and Neutral Body Posture (**Body Measures**) — Young KS, Rajulu SL. Changes in seated height in microgravity. *Applied Ergonomics*. 2020 February 1; 83: 102995. DOI: 10.1016/j.apergo.2019.102995.

Quantification of In-Flight Physical Changes - Anthropometry and Neutral Body Posture (**Body Measures**) — Kim KH, Young KS, Rajulu SL. Neutral Body Posture in Spaceflight. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 2019 November 1; 63(1): 992-996. DOI: 10.1177/1071181319631129.

Recovery of Functional Sensorimotor Performance Following Long Duration Space Flight (**Field Test**) — Lee SM, Ribeiro LC, Laurie SS, Feiveson AH, Kitov VV, et al. Efficacy of gradient compression garments in the hours after long-duration spaceflight.

Frontiers in Physiology. 2020 July 17; 11: 784. DOI: 10.3389/fphys.2020.00784.

Risk of Intervertebral Disc Damage after Prolonged Space Flight (Intervertebral Disc Damage) — Sayson JV, Hargens AR. Exercise Countermeasures for the Spine in Microgravity (Contramedidas de los ejercicios para la columna vertebral en condiciones de microgravedad). *Revista Cubana de Investigaciones Biomédicas*. 2019 September; 38(3): e252.

Skin-B — Theek C, Tronnier H, Heinrich U, Braun N. Surface Evaluation of Living Skin (SELS) parameter correlation analysis using data taken from astronauts working under extreme conditions of microgravity. *Skin Research and Technology*. 2020 January; 26(1): 105-111. DOI: 10.1111/srt.12771.

SOdium LOading in Microgravity (SOLO) — Frings-Meuthen P, Luchitskaya ES, Jordan J, Tank J, Lichtinghagen R, et al. Natriuretic peptide resetting in astronauts. *Circulation*. 2020 May 12; 141(19): 1593-1595. DOI: 10.1161/CIRCULATIONAHA.119.044203.

Spaceflight Effects on Neurocognitive Performance: Extent, Longevity, and Neural Bases (NeuroMapping) — Hupfeld KE, McGregor HR, Lee JK, Beltran NE, Kofman IS, et al. The impact of six and twelve months in space on human brain structure and intracranial fluid shifts. *Cerebral Cortex Communications*. 2020 June 15; epub: 44 pp. DOI: 10.1093/texcom/tgaa023.

Study of the Impact of Spaceflight Factors on the Vegetative Regulation of Blood Circulation, Respiration, and Contractile Function of the Heart in Long-Term Spaceflight (Pnevmocard/Pneumocard) — Pastushkova LK, Rusanov VB, Orlov OI, Goncharova AG, Chernikova AG, et al. The variability of urine proteome and coupled biochemical blood indicators in cosmonauts with different preflight autonomic status. *Acta Astronautica*. 2020 March 1; 168: 204-210. DOI: 10.1016/j.actaastro.2019.12.015.

The Effects of Long-Term Exposure to Microgravity on Salivary Markers of Innate Immunity (Salivary Markers) — Agha NH, Mehta G, Rooney BV, Laughlin MS, Markofski et al. Exercise as a countermeasure for latent viral reactivation during long duration space flight. *FASEB: Federation of American Societies for Experimental Biology Journal*. 2020 February; 34(2): 2869-2881. DOI: 10.1096/fj.201902327R.

The Effects of Long-Term Exposure to Microgravity on Salivary Markers of Innate Immunity (Salivary Markers) — Agha NH, Baker FL, Kunz HE, Spielmann G, Mylabathula PL, et al. Salivary antimicrobial proteins and stress biomarkers are elevated during a 6-month mission to the International Space Station. *Journal of Applied Physiology*. 2019 November 21; epub: 45 pp. DOI: 10.1152/japplphysiol.00560.2019.

The elucidation of the re-adaptation on the attitude control after return from long term space flight (Synergy) — Ishihara A, Terada M, Hagio S, Higashibata A, Yamada S, et al. Blood flow in astronauts on Earth after long space stay. *Acta Astronautica*. 2020 May 16; epub: 16 pp. DOI: 10.1016/j.actaastro.2020.05.017.

Vision Impairment and Intracranial Pressure (VIIP) — Laurie SS, Lee SM, Macias BR, Patel NB, Stern C, et al. Optic disc edema and choroidal engorgement in astronauts during spaceflight and individuals exposed to bed rest. *JAMA Ophthalmology*. 2020 February 1; 138(2): 165-172. DOI: 10.1001/jamaophthalmol.2019.5261.

Vision Impairment and Intracranial Pressure (VIIP) — Lee AG, Mader TH, Gibson CR, Tarver WJ, Rabiei P, et al. Spaceflight associated neuro-ocular syndrome (SANS) and the neuro-ophthalmologic effects of microgravity: a review and an update. *npj Microgravity*. 2020 February 7; 6(1): 1-10. DOI: 10.1038/s41526-020-0097-9.

PHYSICAL SCIENCES

Asymmetric Sawtooth and Cavity-Enhanced Nucleation-Driven Transport (PFMI-ASCENT) — Sridhar K, Smith R, Narayanan V, Bhavnani S. Phase change cooling of spacecraft electronics: Terrestrial reference experiments prior to ISS microgravity experiments. *2020 19th IEEE Intersociety Conference*

on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Orlando, Florida; 2020 July 21. 315-322. DOI: 10.1109/ITherm45881.2020.9190438.

Atomic Clock Ensemble in Space (**ACES**) — Laurent P, Esnault F, Gibble K, Peterman P, Leveque T, et al. Qualification and frequency accuracy of the space based primary frequency standard PHARAO. *Metrologia*. 2020 May 19; epub: 36 pp. DOI: 10.1088/1681-7575/ab948b.

Atomic Clock Ensemble in Space (**ACES**) — Cacciapuoti L, Armano M, Much R, Sy O, Helm A, et al. Testing gravity with cold-atom clocks in space. *The European Physical Journal D*. 2020 August 4; 74(8): 164. DOI: 10.1140/epjd/e2020-10167-7.

Bose Einstein Condensate Cold Atom Lab (BECCAL) — Moller NS, A dos Santos FE, Bagnato VS, Pelster A. Bose–Einstein condensation on curved manifolds. *New Journal of Physics*. 2020 June; 22(6): 063059. DOI: 10.1088/1367-2630/ab91fb.

Bose Einstein Condensate Cold Atom Lab (BECCAL) — Lundblad N, Carollo RA, Lannert C, Gold MJ, Jiang X, et al. Shell potentials for microgravity Bose-Einstein condensates. *npj Microgravity*. 2019 December 4; 5(1): 1-6. DOI: 10.1038/s41526-019-0087-y.

Coarsening in Solid Liquid Mixtures-4 (CSLM-4) — Stan T, Thompson ZT, Voorhees PW. Optimizing convolutional neural networks to perform semantic segmentation on large materials imaging datasets: X-ray tomography and serial sectioning. *Materials Characterization*. 2020 February 1; 160: 110119. DOI: 10.1016/j.matchar.2020.110119.

Cold Atom Lab (**Cold Atom Lab**) — Aveline DC, Williams JR, Elliott ER, Dutenhoffer CA, Kellogg JR, et al. Observation of Bose–Einstein condensates in an Earth-orbiting research lab. *Nature*. 2020 June 11; 582(7811): 193-197. DOI: 10.1038/s41586-020-2346-1.

Columnar-to-Equiaxed Transition in Solidification Processing (**CETSOL**) — Li YZ, Mangelinck-Noel N, Zimmermann G, Sturz L, Nguyen-Thi H. Modification of the microstructure by rotating magnetic field during the solidification of Al-7 wt.% Si alloy under microgravity. *Journal of Alloys and Compounds*. 2020 September 25; 836: 155458. DOI: 10.1016/j.jallcom.2020.155458.

Constrained Vapor Bubble-2 (**CVB-2**) — Nguyen TT, Yu J, Wayner, Jr. PC, Plawsky JL, Kundan A, et al. Rip currents: A spontaneous heat transfer enhancement mechanism in a wickless heat pipe. International Journal of Heat and Mass Transfer. 2020 March 1; 149: 119170. DOI: 10.1016/j.ijheatmasstransfer.2019.119170.

Detailed validation of the new atomization concept derived from drop tower experiments--Aimed at developing a turbulent atomization simulator (**ATOMIZATION**) — Umemura A, Osaka J, Shinjo J, Nakamura Y, Matsumoto S, et al. Coherent capillary wave structure revealed by ISS experiments for spontaneous nozzle jet disintegration. *Microgravity Science and Technology*. 2020 January 1; epub: 29 pp. DOI: 10.1007/s12217-019-09756-0.

DEvice for the study of Critical LIquids and Crystallization - Directional Solidification Insert (**DECLIC-DSI**) — Mota FL, Ji K, Lyons T, Strutzenberg LL, Trivedi R, et al. In situ observation of growth dynamics in DECLIC directional solidification insert onboard ISS: DSI-R flight campaign. *70th International Astronautical Congress 2019*, Washington, DC; 2019 October 21. 8 pp.

DEvice for the study of Critical LIquids and Crystallization - High Temperature Insert-Reflight (**DECLIC HTI-R**) — Hicks MC, Hegde UG, Lecoutre C, Marre S, Garrabos Y. Supercritical water (SCW) investigations in the DECLIC and DECLIC-Evo: Past, present and future. *Acta Astronautica*. 2020 June 4; epub: 24 pp. DOI: 10.1016/j.actaastro.2020.06.006.

Dose Distribution Inside the International Space Station - 3D (**DOSIS-3D**) — Berger T, Matthia D, Burmeister S, Zeitlin C, Rios R, et al. Long term variations of galactic cosmic radiation on board the International Space Station, on the Moon and on the surface of Mars. *Journal of Space Weather and Space Climate*. 2020 July 28; 10: 34. DOI: 10.1051/swsc/2020028.

Electromagnetic Levitator (**EML**) — Diefenbach A, Schneider S, Volkmann T. Experiment preparation and performance for the Electromagnetic Levitator (EML) onboard the International Space Station. *Preparation of Space Experiments*; 2020.

Electromagnetic Levitator (**EML**) — Nawer J, Gosse S, Matson DM. Tracking evaporation during levitation processing of nickel-based superalloys on the ISS. *JOM Journal of the Minerals, Metals and Materials Society*. 2020 July 8; 72: 3132–3139. DOI: 10.1007/s11837-020-04256-8.

Electromagnetic Levitator Batch 2 - Investigation of Thermophysical Properties of Liquid Semiconductors in the Melt and in the Undercooled State under Microgravity Conditions (**EML Batch 2 - SEMITHERM**) — Luo Y, Damaschke B, Lohofer G, Samwer K. Thermophysical properties of a Si50Ge50 melt measured on board the International Space Station. *npj Microgravity*. 2020; 6: 10. DOI: 10.1038/s41526-020-0100-5.

Electrostatic Levitation Furnace (ELF) (**JAXA ELF**) — Ishikawa T, Koyama C, Saruwatari H, Tamaru H, Oda H, et al. Density of molten gadolinium oxide measured with the electrostatic levitation furnace in the International Space Station. *High Temperatures-High Pressures*. 2020 February 2; 49(1-2): 5-15.

Electrostatic Levitation Furnace (ELF) (**JAXA ELF**) — Oda H, Koyama C, Ohshio M, Saruwatari H, Ishikawa T. Density of Molten Zirconium-Oxygen System Measured with an Electrostatic Levitation Furnace in the International Space Station. *International Journal of Microgravity Science and Application*. 2020 July 31; 37(3): 370302. DOI: 10.15011/ijmsa.37.3.370302.

Electrostatic Levitation Furnace (ELF) (**JAXA ELF**) — Ohara K, Onodera Y, Kohara S, Koyama C, Masuno A, Mizuno A, Okada J. T, Tahara S, Watanabe Y, Oda H, Nakata Y, Tamaru H, Ishikawa T, Sakata O. Accurate synchrotron hard X-ray diffraction measurements on high-temperature liquid oxides, Int. *J. Microgravity Sci*. Appl. 2020 April 30; 37(2): 370202. DOI: 10.15011/jasma.37.2.370202

Electrostatic Levitation Furnace (ELF) (**JAXA ELF**) — Koyama C, Tahara S, Kohara S, Onodera Y, Smabraten DR, et al. Very sharp diffraction peak in nonglass-forming liquid with the formation of distorted tetraclusters. *NPG Asia Materials*. 2020 June 2; 12(1): 1-11. DOI: 10.1038/s41427-020-0220-0.

EML Batch 1 - NEQUISOL Experiment — Herlach DM, Burggraf S, Reinartz M, Galenko PK, Rettenmayr M, et al. Dendrite growth in undercooled Al-rich Al-Ni melts measured on Earth and in Space. *Physical Review Materials*. 2019 July 16; 3(7): 073402. DOI: 10.1103/PhysRevMaterials.3.073402.

EML Batch 1 - THERMOLAB Experiment — Mohr M, Wunderlich RK, Novakovic R, Ricci E, Fecht HJ. Precise measurements of thermophysical properties of liquid Ti–6Al-4V (Ti64) alloy on board the international space station (ISS). *Advanced Engineering Materials*. 2020 April 2; epub: 23 pp. DOI: 10.1002/adem.202000169.

EML Batch 1 - THERMOLAB Experiment — Mohr M, Wunderlich RK, Dong Y, Furrer D, Fecht HJ. Thermophysical properties of advanced Ni-based superalloys in the liquid state measured on board the International Space Station. *Advanced Engineering Materials*. 2020; 22(4): 1901228. DOI: 10.1002/adem.201901228.

EML Batch 1 - THERMOLAB Experiment — Chen LY, Mohr M, Wunderlich RK, Fecht HJ, Wang XD, et al. Correlation of viscosity with atomic packing in Cu50Zr50 melt. *Journal of Molecular Liquids*. 2019 November 1; 293: 111544. DOI: 10.1016/j.molliq.2019.111544.

EML Batch 1 - THERMOLAB Experiment — Su Y, Mohr M, Wunderlich RK, Wang X, Cao Q, et al. The relationship between viscosity and local structure in liquid zirconium via electromagnetic levitation and molecular dynamics simulations. *Journal of Molecular Liquids*. 2020 January 15; 298: 111992. DOI: 10.1016/j.molliq.2019.111992.

EML Batch 1 - THERMOLAB Experiment — Mohr M, Wunderlich RK, Hofmann DC, Fecht HJ. Thermophysical properties of liquid Zr52.5Cu17.9Ni14.6Al10Ti5-prospects for bulk metallic glass manufacturing in space. *npj Microgravity*. 2019 October 25; 5(1): 24. DOI: 10.1038/s41526-019-0084-1.

EML Batch 1 - THERMOLAB Experiment — Van Hoesen D, Gangopadhyay A, Lohofer G, Sellers M, Pueblo C, et al. Resistivity Saturation in Metallic Liquids Above a Dynamical Crossover Temperature Observed in Measurements Aboard the International Space Station. *Physical Review Letters*. 2019 November 29; 123(22): 226601. DOI: 10.1103/PhysRevLett.123.226601.

Experimental Assessment of Dynamic Surface Deformation Effects in Transition to Oscillatory Thermo capillary Flow in Liquid Bridge of High Prandtl Number Fluid (Dynamic Surf) — Fujimoto S, Ogasawara T, Ota A, Motegi K, Ueno I. Effect of Heat Loss on Hydrothermal wave Instability in Half-Zone Liquid Bridges of High Prandtl NumberFluid. *International Journal of Microgravity Science and Application*. 2019 April 30; 36(2): 360204. DOI: 10.15011//jasma.36.360204.

Facility for Absorption and Surface Tension (FASTER) — Kovalchuk VI, Loglio G, Bykov AG, Ferrari M, Kragel J, et al. Effect of temperature on the dynamic properties of mixed surfactant adsorbed layers at the water/hexane interface under low-gravity conditions. *Colloids and Interfaces*. 2020 September; 4(3): 27. DOI: 10.3390/colloids4030027.

Flame Extinguishment Experiment (FLEX) — Nayagam V, Dietrich DL, Williams FA. Radiative extinction of burner-supported spherical diffusion flames: A scaling analysis. *Combustion and Flame*. 2019 July 1; 205: 368-370. DOI: 10.1016/j.combustflame.2019.04.027.

Flame Extinguishment Experiment (FLEX) — Williams FA, Nayagam V. Cool-flame dodecane-droplet extinction diameters. *Combustion and Flame*. 2020 February 1; 212: 242-244. DOI: 10.1016/j.combustflame.2019.10.036.

Flame Extinguishment Experiment (FLEX) — Xi X, Torero JL, Jahn W. Data driven forecast of droplet combustion. *Proceedings of the Combustion Institute*. 2020 July 10; epub: 9 pp. DOI: 10.1016/j.proci.2020.05.012.

Flame Extinguishment Experiment - 2 (FLEX-2) — Xu Y, Farouk TI, Hicks MC, Avedisian CT. Initial diameter effects on combustion of unsupported equi-volume n-heptane/iso-octane mixture droplets and the transition to cool flame behavior: Experimental observations and detailed numerical modeling. *Combustion and Flame*. 2020 October 1; 220: 82-91. DOI: 10.1016/j.combustflame.2020.06.012.

Fluid Boiling Condensation Experiment (FBCE) — O'Neill LE, Mudawar I. Review of two-phase flow instabilities in macro- and micro-channel systems. *International Journal of Heat and Mass Transfer*. 2020 August 1; 157: 119738. DOI: 10.1016/j.ijheatmasstransfer.2020.119738.

Fluid Boiling Condensation Experiment (FBCE) — Lee J, O'Neill LE, Mudawar I. 3-D computational investigation and experimental validation of effect of shear-lift on two-phase flow and heat transfer characteristics of highly subcooled flow boiling in vertical upflow. *International Journal of Heat and Mass Transfer*. 2020 April 1; 150: 119291. DOI: 10.1016/j.ijheatmasstransfer.2019.119291.

Fluid Dynamics in Space (FLUIDICS) — Berhanu M, Falcon E, Michel G, Gissinger C, Fauve S. Capillary wave turbulence experiments in microgravity. *EPL (Europhysics Letters)*. 2020 January; 128(3): 34001. DOI: 10.1209/0295-5075/128/34001.

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (FSL Soft Matter Dynamics - PASTA) — Noskov BA, Yazhgur PA, Liggieri L, Lin SY, Loglio G, et al. Dilational rheology of spread and adsorbed layers of silica nanoparticles at the liquid-gas interface. *Colloid Journal*. 2014 March 1; 76(2): 127-138. DOI: 10.1134/S1061933X14020057.*

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (FSL Soft Matter Dynamics - PASTA) — Orsi D, Salerni F, Macaluso E, Santini E, Ravera F, et al. Diffusing wave spectroscopy for investigating emulsions: I. Instrumental aspects. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2019 November 5; 580: 123574. DOI: 10.1016/j.colsurfa.2019.123574.

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (FSL Soft Matter

Dynamics - PASTA)— Salerni F, Orsi D, Santini E, Liggieri L, Ravera F, et al. Diffusing wave spectroscopy for investigating emulsions: II. Characterization of a paradigmatic oil-in-water emulsion. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2019 November 5; 580: 123724. DOI: 10.1016/j.colsurfa.2019.123724.

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (**FSL Soft Matter Dynamics - PASTA**) — Zabiegaj D, Santini E, Ferrari M, Liggieri L, Ravera F. Carbon based porous materials from particle stabilized wet foams. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2015 May 20; 473: 24-31. DOI: 10.1016/j.colsurfa.2015.02.031.*

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (**FSL Soft Matter Dynamics - PASTA**)— Santini E, Guzman E, Ferrari M, Liggieri L. Emulsions stabilized by the interaction of silica nanoparticles and palmitic acid at the water–hexane interface. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2014 October 20; 460: 333-341. DOI: 10.1016/j.colsurfa.2014.02.054.*

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (**FSL Soft Matter Dynamics - PASTA**)— Zabiegaj D, Caccia M, Cascob ME, Ravera F, Narciso J. Synthesis of carbon monoliths with a tailored hierarchical pore structure for selective CO2 capture. *Journal of CO2 Utilization*. 2018 July 1; 26: 36-44. DOI: 10.1016/j.jcou.2018.04.020.*

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (**FSL Soft Matter Dynamics - PASTA**)— Guzman E, Santini E, Zabiegaj D, Ferrari M, Liggieri L, et al. Interaction of carbon black particles and dipalmitoylphosphatidylcholine at the water/air interface: thermodynamics and rheology. *Journal of Physical Chemistry C*. 2015 December 3; 119(48): 26937-26947. DOI: 10.1021/acs.jpcc.5b07187.*

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (**FSL Soft Matter Dynamics - PASTA**)— Llamas S, Santini E, Liggieri L, Salerni F, Orsi D, et al. Adsorption of sodium dodecyl sulfate at water–dodecane interface in relation to the oil in water emulsion properties. *Langmuir*. 2018 May 29; 34(21): 5978-5989. DOI: 10.1021/acs.langmuir.8b00358.*

FSL Soft Matter Dynamics - Particle STAbilised Emulsions and Foams (PASTA) (**FSL Soft Matter Dynamics - PASTA**)— Zabiegaj D, Buscaglia MT, Giuranno D, Liggieri L, Ravera F. Activated carbon monoliths from particle stabilized foams. *Microporous and Mesoporous Materials*. 2017 February 1; 239: 45-53. DOI: 10.1016/j.micromeso.2016.09.046.*

Fundamental and Applied Studies of Emulsion Stability (**FASES**) — Loglio G, Kovalchuk VI, Bykov AG, Ferrari M, Kragel J, et al. Interfacial Dilational Viscoelasticity of Adsorption Layers at the Hydrocarbon/Water Interface: The Fractional Maxwell Model. *Colloids and Interfaces*. 2019 December; 3(4): 66. DOI: 10.3390/colloids3040066.

Fundamental and Applied Studies of Emulsion Stability (**FASES**) — Pandolfini P, Loglio G, Ravera F, Liggieri L, Kovalchuk VI, et al. Dynamic properties of Span-80 adsorbed layers at paraffin-oil/water interface: Capillary pressure experiments under low gravity conditions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2017 November 5; 532: 228-243. DOI: 10.1016/j.colsurfa.2017.05.012.*

Inertial Spreading with Vibration and Water Coalescence (**Drop Vibration**) — Xia JY, Steen PH. Dissipation of oscillatory contact lines using resonant mode scanning. *npj Microgravity*. 2020 January 21; 6(1): 1-7. DOI: 10.1038/s41526-019-0093-0.

Observation and Analysis of Smectic Islands in Space (**OASIS**) — Pikina ES, Ostrovskii BI, Pikin SA. Coalescence of isotropic droplets in overheated free standing smectic films. Soft Matter. 2020 May 4; 16: 4591-4606. DOI: 10.1039/C9SM02292A.

Observation and Analysis of Smectic Islands in Space (**OASIS**) — Klopp C, Trittel T, Eremin A, Harth K, Stannarius R, et al. Structure and dynamics of a two-dimensional colloid of liquid droplets. *Soft Matter*. 2019 October 9; 15: 8156-8163. DOI: 10.1039/c9sm01433k.

Packed Bed Reactor Experiment (**PBRE**) — Motil BJ, Rame E, Salgi P, Taghavi M, Balakotaiah V. Gas–liquid flows through porous media in microgravity: The International Space Station Packed Bed Reactor Experiment. *AIChE Journal*. 2020 August 26; epub: e17031. DOI: 10.1002/aic.17031.

PK-3 Plus: Plasma Crystal Research on the ISS (**PK-3 Plus**) — Zhukhovitskii DI, Naumkin VN, Khusnulgatin AI, Molotkov VI, Lipaev AM. Propagation of the 3D crystallization front in a strongly nonideal dusty plasma. *Journal of Experimental and Theoretical Physics*. 2020 April 1; 130(4): 616-625. DOI: 10.1134/S1063776120020090.

Plant Water Management — Mungin RM, Weislogel MM, Hatch T, McQuillen JB. Omni-gravity Hydroponics for Space Exploration. *49th International Conference on Environmental Systems* (Boston, Massachusetts); 2019 July 7-11. 10.

Plasma Kristall-4 (**PK-4**) — Schwabe M, Khrapak SA, Zhdanov SK, Pustylnik MY, Rath C, et al. Slowing of acoustic waves in electrorheological and string-fluid complex plasmas. *New Journal of Physics*. 2020 July 24; epub: 29 pp. DOI: 10.1088/1367-2630/aba91b.

Plasma Kristall-4 (**PK-4**) — Pustylnik MY, Klumov BA, Rubin-Zuzic M, Lipaev AM, Nosenko V, et al. Three-dimensional structure of a string-fluid complex plasma. *Physical Review Research*. 2020 August 26; 2(3): 033314. DOI: 10.1103/PhysRevResearch.2.033314.

Plasma Kristall-4 (**PK-4**) — Nosenko V, Pustylnik MY, Rubin-Zuzic M, Lipaev AM, Zobnin AV, et al. Shear flow in a three-dimensional complex plasma in microgravity conditions. *Physical Review Research*. 2020 September 14; 2(3): 033404. DOI: 10.1103/PhysRevResearch.2.033404.

Ring Sheared Drop (**Ring Sheared Drop**) — McMackin PM, Griffin SR, Riley FP, Gulati S, Debono NE, et al. Simulated microgravity in the ring-sheared drop. *npj Microgravity*. 2020 January 3; 6(1): 1-7. DOI: 10.1038/s41526-019-0092-1.

Selectable Optical Diagnostics Instrument-Influence of VIbrations on DIffusion of Liquids (**SODI-IVIDIL**) — Dubert DC, Marin-Genesca M, Simon MJ, Gavalda J, Ruiz X. Complementary techniques for the accelerometric environment characterization of thermodiffusion experiments on the ISS. *Microgravity Science and Technology*. 2019 November 11; 11: 673-683. DOI: 10.1007/s12217-019-09739-1.

Simulation of Geophysical Fluid Flow Under Microgravity-1 (**Geoflow-1**) — Travnikov V, Zaussinger F, Haun P, Egbers C. Influence of dielectrical heating on convective flow in a radial force field. *Physical Review E.* 2020 May; 101(5-1): 053106. DOI: 10.1103/PhysRevE.101.053106.

Simulation of Geophysical Fluid Flow Under Microgravity-1 (**Geoflow-1**) — Zaussinger F, Haun P, Szabo PS, Travnikov V, Al Kawwas M, et al. Rotating spherical gap convection in the GeoFlow International Space Station (ISS) experiment. *Physical Review Fluids*. 2020 June 19; 5(6): 063502. DOI: 10.1103/PhysRevFluids.5.063502.

SODI-DCMIX— Mialdun A, Bou-Ali MM, Braibanti M, Croccolo F, Errarte A, et al. Data quality assessment of Diffusion Coefficient Measurements in ternary mIXtures 4 (DCMIX4) experiment. *Acta Astronautica*. 2020 June 17; epub: 38 pp. DOI: 10.1016/j.actaastro.2020.06.020.

SODI-DCMIX — Khlybov OA, Matveenko VP, Trusov PV, Yants AY, Faerman VA. Reconstruction of refractive index field of optically inhomogeneous medium by 2D Fourier filtering method. *AIP Conference Proceedings: 28th Russian Conference on Mathematical Modelling in Natural Sciences*, Perm, Russia. 2020 April 1; 2216(1): 050004. DOI: 10.1063/5.0003543.

SODI-DCMIX (**SODI-DCMIX**) — Errarte A, Bou-Ali MM, Aginagalde M, Santamaria C. Thermodiffusion coefficients of nanofluid binary mixtures. *Microgravity Science and Technology*. 2019 July 16; 31: 877-882. DOI: 10.1007/s12217-019-09725-7.

SODI-DCMIX (**SODI-DCMIX**) — Dubert DC, Marin-Genesca M, Simon MJ, Ezquerro Navarro JM, Massons J, et al. On the monitoring of the vibratory

environment of DCMIX4 campaign. Preliminary results. *Microgravity Science and Technology*. 2020 June 15; epub: 14 pp. DOI: 10.1007/s12217-020-09797-w.

Structure and Liftoff In Combustion Experiment (**SLICE**) — Smith L, Souza D, Takahashi F. Stabilization of laminar hydrocarbon jet diffusion flames in Earth's and micro-gravity. *27th International Colloquium on the Dynamics of Explosions and Reactive Systems (27th ICDERS)*, Beijing, China; 2019 July 28. 6 pp.

Toward Understanding Pore Formation and Mobility During Controlled Directional Solidification in a Microgravity Environment (**PFMI**) — Nabavizadeh SA, Lenart R, Eshraghi M, Felicelli SD, Tewari S, et al. Dendritic solidification of Succinonitrile -0.24 wt% water alloy: A comparison with microgravity experiments for validating dendrite tip velocity. *Acta Astronautica*. 2020 May 30; epub: 36 pp. DOI: 10.1016/j.actaastro.2020.05.059.

Toward Understanding Pore Formation and Mobility During Controlled Directional Solidification in a Microgravity Environment (**PFMI**) — Nabavizadeh SA, Eshraghi M, Felicelli SD, Tewari S, Grugel RN. The Marangoni convection effects on directional dendritic solidification. *Heat and Mass Transfer*. 2020; 56: 1329-1341. DOI: 10.1007/s00231-019-02799-4.

Zero Boil-Off Tank (**ZBOT**) — Kassemi M, Hylton S, Kartuzova O. 1G and microgravity tank self-pressurization: Experiments and CFD model validations across Ra and Bo regimes. *International Journal of Microgravity Science and Application*. 2020 January 31; 37(1): 370103. DOI: 10.15011/jasma.37.1.370103.

TECHNOLOGY DEVELOPMENT AND DEMONSTRATION

Alteino Long Term Cosmic Ray Measurements on board the International Space Station (**ALTCRISS**) — Larsson O, Benghin VV, Berger T, Casolino M, Di Fino L, et al. Measurements of heavy-ion anisotropy and dose rates in the Russian section of the International Space Station with the Sileye-3/Alteino detector. *Journal of Physics G: Nuclear and Particle Physics*. 2014 December; 42(2): 025002. DOI: 10.1088/0954-3899/42/2/025002.*

AQua Thruster-Demonstrator (**AQT-D**) — Y aginuma K, Asakawa J, Nakagawa Y, Tsuruda Y, Kakihara K, et al. AQT-D: CubeSat demonstration of a water propulsion system deployed from ISS. *Transactions of the Japan Society for Aeronautical and Space Sciences, Aerospace Technology Japan*. 2020 July; 18(4): 141-148. DOI: 10.2322/tastj.18.141.

Astrobee — Carlino R, Barlow J, Benavides J, Bualat M, Katterhagen AJ, et al. Astrobee free flyers: integrated and tested. Ready for launch!. *70th International Astronautical Congress 2019*, Washington, DC; 2019 October 21. 9 pp.

Biomolecule Sequencer — Burton AS, Stahl SE, John KK, Jain M, Juul S, et al. Off Earth Identification of Bacterial Populations Using 16S rDNA Nanopore Sequencing. *Genes*. 2020 January 9; 76(11): 76. DOI: 10.3390/genes11010076.

Development of a System of Supervisory Control Over the Internet of the Robotic Manipulator in the Russian Segment of ISS (**Kontur (Contour)**) — Weber B, Balachandran R, Riecke C, Stulp F, Stelzer M. Teleoperating robots from the International Space Station: Microgravity effects on performance with force feedback. *IEEE International Conference on Intelligent Robots and Systems*, IROS 2019, Macau, China; 2019 November 4. 8138-8144.

Exploration ECLSS: WPA Upgrades — Velez Justiniano Y, Carter L, Nur M, Angle G. Developing methods for biofilm control in microgravity for a water recovery system. 49th International Conference on Environmental Systems (Boston, Massachusetts); 2020 July 31. 9 pp.

Elucidating the Ammonia Electrochemical Oxidation Mechanism via Electrochemical Techniques at the ISS (Ammonia Electro-oxidation Lab at the ISS (**AELISS**)) — Nicolau E, Poventud-Estrada CM, Arroyo L, Fonseca J, Flynn MT, et al. Microgravity effects on the electrochemical oxidation of ammonia: A parabolic flight experiment. *Electrochimica Acta*. 2012 July 30; 75: 88-93. DOI: 10.1016/j.electacta.2012.04.079.*

Elucidating the Ammonia Electrochemical Oxidation Mechanism via Electrochemical Techniques at the ISS (Ammonia Electro-oxidation Lab at the ISS (AELISS)) — Poventud-Estrada CM, Acevedo R, Morales-Navas C, Betancourt L, Diaz DC, et al. Microgravity effects on chronoamperometric ammonia oxidation reaction at platinum nanoparticles on modified mesoporous carbon supports. *Microgravity Science and Technology*. 2017 October; 29(5): 381-389. DOI: 10.1007/s12217-017-9558-5.*

Elucidating the Ammonia Electrochemical Oxidation Mechanism via Electrochemical Techniques at the ISS (Ammonia Electro-oxidation Lab at the ISS (AELISS)) — Acevedo R, Poventud-Estrada CM, Morales-Navas C, Ortiz-Quiles E, Vidal-Iglesias FJ, et al. Chronoamperometric study of ammonia oxidation in a direct ammonia alkaline fuel cell under the Influence of microgravity. *Microgravity Science and Technology*. 2017 August; 29(4): 253-261. DOI: 10.1007/s12217-017-9543-z.*

Experimental Studies Of The Possible Development Of Microscopic Deterioration Of ISS RS Module Structural Elements When Impacted By The Components Of The Station's External Atmosphere And Conditions Promoting The Life Of Microflora On Pressure Hull Surfaces Under MLI (Test) — Deshevaya EA, Shubralova EV, Fialkina SV, Guridov AA, Novikova ND, et al. Microbiological investigation of the space dust collected from the external surfaces of the International Space Station. *BioNanoScience*. 2020 March 1; 10(1): 81-88. DOI: 10.1007/s12668-019-00712-1.

International Space Station Acoustic Measurement Program (ISS Acoustics) — Nakashima A, Limardo JG, Boone A, Danielson RW. Influence of impulse noise on noise dosimetry measurements on the International Space Station. International Journal of Audiology. 2020 January 31; 59(sup1): 540-547. DOI: 10.1080/14992027.2019.1698067.

ISS Non-invasive Sample Investigation and results Transmission to ground with the Utmost easiness (IN SITU) — Roda A, Zangheri M, Guardigli M, Di Nardo F, Anfossi L, et al. Chemiluminescence biosensor for non-invasive crew health monitoring at the International Space Station. *Aerotecnica Missili & Spazio*. 2020 May 30; 99: 103-109. DOI: 10.1007/s42496-020-00052-4.

Microgravity Investigation of Cement Solidification (MICS) — Neves JM, Grugel RN, Scheetz B, Radlinska A. Experimental investigation of cement hydration in gravity-free environment. *15th International Congress on the Chemistry of Cement* (Prague, Czechoslovakia); 2019 September 16. 9 pp.

Exploration ECLSS: UPA Upgrades — Eshima SP, Nabity JS. Failure mode and effects analysis for Environmental Control and Life Support System self-awareness. *49th International Conference on Environmental Systems* (Boston, Massachusetts); 2020 July 31. 13 pp.

Exploration ECLSS Technology Demonstrations Integrated Into Systems Racks — Shaw LA, Garr JD, Gavin LL, Matty CM, Ridley AH, et al. International Space Station as a Testbed for Exploration Environmental Control and Life Support Systems - 2020 Status. *50th International Conference on Environmental Systems -* ICES 2020, Lisbon, Portugal; 2020 July 31. 12 pp.

Photobioreactor — Helisch H, Keppler J, Detrell G, Belz S, Ewald R, et al. High density long-term cultivation of Chlorella vulgaris SAG 211-12 in a novel microgravity-capable membrane raceway photobioreactor for future bioregenerative life support in SPACE. *Life Sciences in Space Research*. 2020 February; 24: 91-107. DOI: 10.1016/j.lssr.2019.08.001.

Raven (STP-H5 Raven) — Lewis A, Drajeske D, Raiti J, Berens A, Rosen J, et al. RAVEN-S: Design and simulation of a robot for teleoperated microgravity rodent dissection under time delay. 2020 IEEE International Conference on Robotics and Automation (ICRA), Paris, France; 2020 May. 11332-11337. DOI: 10.1109/ICRA40945.2020.9196691.

Science for the Improvement of Future Space Exploration (ISS Exploration) — Borrego MA, Zaruba YG, Broyan, Jr. JL, McKinley MK, Baccus S. Exploration toilet integration challenges on the International Space Station. *49th International Conference on Environmental Systems* (Boston, Massachusetts); 2019 July 7-11. 14 pp.

Science for the Improvement of Future Space Exploration (ISS Exploration) — Truong V, Greco T, Kassam I, D'Silva O, Tan E. A cost effective methodology for building flight spares for robotic life extension on the International Space Station. *Acta Astronautica*. 2019 September 1; 405-408. DOI: 10.1016/j.actaastro.2019.06.025.

SEOPS-MakerSat (**SEOPS-MakerSat**) — Campbell B, Nogales C, Grim B, Kamstra M, Griffin J, et al. On-orbit polymer degradation results from MakerSat-1: First satellite designed to be additively manufactured in space. 2020 - *Space Mission Architectures: Infinite Possibilities*, Logan, UT; 2020 August 1. 9 pp.

Studying the Hydrodynamics and Heat Transfer of Monodisperse Droplet Streams in Microgravity (**Kaplya-2/Drop-2**) — Konyukhov GV, Bukharov AV, Konyukhov VG. On the problem of rejection of low-potential heat from high-power space systems. *Journal of Engineering Physics and Thermophysics*. 2020 February 27; 93: 16-27. DOI: 10.1007/s10891-020-02086-8.

EARTH AND SPACE SCIENCE

Alpha Magnetic Spectrometer - 02 (**AMS-02**) — Zheng C, Qi J, Fu J, Song J, Cheng L. Thermal analysis on Alpha Magnetic Spectrometer main radiators under the flight attitude adjustment of International Space Station. *Applied Thermal Engineering*. 2020 January 5; 164: 114457. DOI: 10.1016/j.applthermaleng.2019.114457.

Alpha Magnetic Spectrometer - 02 (**AMS-02**) — Zheng C, Qi J, Song J, Cheng L. Effects of the rotation of International Space Station main radiator on suppressing thermal anomaly of Alpha Magnetic Spectrometer caused by flight attitude adjustment. *Applied Thermal Engineering*. 2020 May 5; 171: 115100. DOI: 10.1016/j.applthermaleng.2020.115100.

Alpha Magnetic Spectrometer - 02 (**AMS-02**) — Pato M, Hooper D, Simet M. Pinpointing Cosmic Ray Propagation With The AMS-02 Experiment. *Journal of Crystal Growth*. 2020 June 23; 2010: DOI: 10.1088/1475-7516/2010/06/022.

Alpha Magnetic Spectrometer - 02 (**AMS-02**) — Battiston R. High precision cosmic ray physics with AMS-02 on the International Space Station. *La Rivista del Nuovo Cimento*. 2020 July 1; 43(7): 319-384. DOI: 10.1007/s40766-020-00007-2.

Alpha Magnetic Spectrometer - 02 (**AMS-02**) — Qi J, Zheng C, Song J. Numerical investigation on the impact of locking solar arrays of the International Space Station on the thermal system of Alpha Magnetic Spectrometer. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*. 2020 July 18; epub: 164443. DOI: 10.1016/j.nima.2020.164443.

Alpha Magnetic Spectrometer - 02 (AMS-02) — Aguilar-Benitez M, Cavasonza LA, Ambrosi G, Arruda MF, Attig N, et al. Properties of neon, magnesium, and silicon primary cosmic rays results from the Alpha Magnetic Spectrometer. *Physical Review Letters*. 2020 May 29; 124(21): 211102. DOI: 10.1103/PhysRevLett.124.211102.

Alpha Magnetic Spectrometer - 02 (**AMS-02**) — Aguilar-Benitez M, Cavasonza LA, Ambrosi G, Arruda MF, Attig N, et al. Properties of cosmic helium isotopes measured by the Alpha Magnetic Spectrometer. *Physical Review Letters*. 2019 November 1; 123(18): 181102. DOI: 10.1103/PhysRevLett.123.181102.

ASTERIA (**ASTERIA**) — Knapp M, Seager S, Demory B, Krishnamurthy A, Smith MW, et al. Demonstrating high-precision photometry with a CubeSat: ASTERIA observations of 55 Cancri e. *The Astrophysical Journal*. 2020 June; 160(1): 23. DOI: 10.3847/1538-3881/ab8bcc.

Astrobiology Exposure and Micrometeoroid Capture Experiments (**Tanpopo**) — Kawaguchi Y, Shibuya M, Kinoshita I, Yatabe J, Narumi I, et al. DNA damage and survival time course of deinococcal cell pellets during 3 years of exposure to outer space. *Frontiers in Microbiology*. 2020 August 26; 11: 2050. DOI: 10.3389/fmicb.2020.02050.

Atmosphere-Space Interactions Monitor (ASIM) — Neubert T, Ostgaard N, Reglero V, Chanrion O, Heumesser M, et al. A terrestrial gamma-ray flash and ionospheric ultraviolet emissions powered by lightning. *Science*. 2019 December 10; epub: 8 pp. DOI: 10.1126/science.aax3872.

Biology and Mars Experiment (Expose R2) — Alekseev VR, Levinskikh MA, Novikova ND, Sychev VN. Studying Dormancy in Space Conditions. Dormancy in Aquatic Organisms. *Theory, Human Use and Modeling*; 2019. DOI: 10.1007/978-3-030-21213-1_6.

CALorimetric Electron Telescope (CALET) — Torii S, Marrocchesi PS. The CALorimetric Electron Telescope (CALET) on the International Space Station. *Advances in Space Research*. 2019 December 15; 64(12): 2531-2537. DOI: 10.1016/j.asr.2019.04.013.

CALorimetric Electron Telescope (CALET) — Asaoka Y, Adriani O, Akaike Y, Asano K, Bagliesi MG, et al. CALET results after three years on the International Space Station. *Journal of Physics: Conference Series*. 2020 February; 1468: 012074. DOI: 10.1088/1742-6596/1468/1/012074.

CALorimetric Electron Telescope (CALET) — Brogi P, Adriani O, Akaike Y, Asano K, Asaoka Y, et al. CALET on the International Space Station: the first three years of observations. *Physica Scripta*. 2020 June; 95(7): 074012. DOI: 10.1088/1402-4896/ab957d.

Cloud-Aerosol Transport System (CATS) — Gogoi MM, Jayachandran VN, Vaishya A, Babu SN, Satheesh SK, et al. Airborne in situ measurements of aerosol size distributions and black carbon across the Indo-Gangetic Plain during SWAAMI–RAWEX. *Atmospheric Chemistry and Physics*. 2020 July 22; 20(14): 8593-8610. DOI: 10.5194/acp-20-8593-2020.

Crew Earth Observations (CEO) — Leake S. Reverse Geolocation of Images Taken from the International Space Station Utilizing Various Lightning Datasets. *2019 IEEE Aerospace Conference*, Big Sky, MT; 2019 June 20. 10 pp. DOI: 10.1109/AERO.2019.8741774.

Crew Earth Observations (CEO) — Rybnikova N, Portnov BA. Population-level study links short-wavelength nighttime illumination with breast cancer incidence in a major metropolitan area. *Chronobiology International*. 2018 May 16; 1-11. DOI: 10.1080/07420528.2018.1466802.*

Crew Earth Observations (CEO) — Garcia-Saenz A, Sanchez de Miguel A, Espinosa A, Costas L, Aragones N, et al. Association between outdoor light-at-night exposure and colorectal cancer in Spain (MCC-Spain study). *Epidemiology*. 2020 September; 31(5): 718-727. DOI: 10.1097/EDE.0000000000001226.

Crew Earth Observations (CEO) — Wicht M, Kuffer M. The continuous built-up area extracted from ISS night-time lights to compare the amount of urban green areas across European cities. *European Journal of Remote Sensing*. 2019 August 9; 52: 58-73. DOI: 10.1080/22797254.2019.1617642.

Crew Earth Observations (CEO) — Nanjo S, Hozumi Y, Hosokawa K, Kataoka R, Miyoshi Y, et al. Fine-scale visualization of aurora in a wide area using color digital camera images from the International Space Station. *Journal of Geophysical Research: Space Physics. 2020*; 125(3): e2019JA027729. DOI: 10.1029/2019JA027729.

Crew Earth Observations (CEO) — Li K, Chen Y, Li Y. The Random Forest-Based Method of Fine-Resolution Population Spatialization by Using the International Space Station Nighttime Photography and Social Sensing Data. *Remote Sensing Letters*. 2018 October 17; 10(10): 1650. DOI: 10.3390/rs10101650.*

Crew Earth Observations (CEO) — Cote-Lussier C, Knudby A, Barnett T. A novel low-cost method for assessing intra-urban variation in night time light and applications to public health. *Social Science & Medicine*. 2020 January 30; 248: 112820. DOI: 10.1016/j.socscimed.2020.112820.

CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT) — Johnson JT, Ball C, Chen C, McKelvey C, Smith GE, et al. Real-time detection and filtering of radio frequency interference onboard a spaceborne microwave radiometer: The CubeRRT Mission. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 2020 April 8; 13: 1610-1624. DOI: 10.1109/JSTARS.2020.2978016.

DLR Earth Sensing Imaging Spectrometer (DESIS) — Alonso K, Bachmann M, Burch K, Carmona E, Cerra D, et al. Data products, quality and validation of the DLR Earth Sensing Imaging Spectrometer (DESIS). *Sensors*. 2019 October 15; 19(20): 44 pp. DOI: 10.3390/s19204471.

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) — Fisher JB, Lee B, Purdy AJ, Halverson GH, Dohlen MB, et al. ECOSTRESS: NASA's next generation mission to measure evapotranspiration from the International Space Station. *Water Resources Research*. 2020 April 6; 56(4): e2019WR026058. DOI: 10.1029/2019WR026058.

Experimental Chondrule Formation at the International Space Station (EXCISS) — Spahr D, Koch T, Merges D, Beck A, Bohlender B, et al. A chondrule formation experiment aboard the ISS: Experimental set-up and test experiments. *Icarus*. 2020 June 6; epub: 113898. DOI: 10.1016/j.icarus.2020.113898.

EXPOSE R2- Photochemistry on the Space Station (EXPOSE-R2-P.S.S.) — Cottin H, Saiagh K, Nguyen D, Grand N, Benilan Y, et al. Photochemical studies in low Earth orbit for organic compounds related to small bodies, Titan and Mars. Current and future facilities. *Bulletin de la Société Royale des Sciences de Liège*. 2015; 84: 60-73.*

EXPOSE-R2-BIOlogy and Mars EXperiment (EXPOSE-R2-BIOMEX) — Baque M, de Vera JP, Rettberg P, Billi D. The BOSS and BIOMEX space experiments on the EXPOSE-R2 mission: Endurance of the desert cyanobacterium Chroococcidiopsis under simulated space vacuum, Martian atmosphere, UVC radiation and temperature extremes. *Acta Astronautica*. 2013 October 1; 91: 180-186. DOI: 10.1016/j.actaastro.2013.05.015.*

EXPOSE-R2-BIOlogy and Mars EXperiment (EXPOSE-R2-BIOMEX) — Billi D, Baque M, Smith HD, McKay CP. Cyanobacteria from extreme deserts to space. *Advances in Microbiology*. 2013 October 24; 3(6): 80-86. DOI: 10.4236/aim.2013.36A010.*

EXPOSE-R2-BIOlogy and Mars EXperiment (EXPOSE-R2-BIOMEX) — de la Torre Noetzel R, Ortega Garcia MV, Miller AZ, Bassy O, Granja C, et al. Lichen vitality after a space flight on board the EXPOSE-R2 facility outside the International Space Station: Results of the Biology and Mars Experiment. *Astrobiology*. 2020 May; 20(5): 583-600. DOI: 10.1089/ast.2018.1959.

EXPOSE-R2-BIOlogy and Mars EXperiment (EXPOSE-R2-BIOMEX) — Podolich O, Kukharenko O, Zaets I, Orlovska I, Palchikovska L, et al. Fitness of outer membrane vesicles from Komagataeibacter intermedius is altered under the impact of simulated Mars-like stressors outside the International Space Station. *Frontiers in Microbiology*. 2020 June; 11: 1268. DOI: 10.3389/fmicb.2020.01268.

EXPOSE-R2-BIOlogy and Mars EXperiment (EXPOSE-R2-BIOMEX) — Billi D, Mosca C, Fagliarone C, Napoli A, Verseux CN, et al. Exposure to low Earth orbit of an extreme-tolerant cyanobacterium as a contribution to lunar astrobiology activities. *International Journal of Astrobiology*. 2020 February; 19(1): 53-60. DOI: 10.1017/S1473550419000168.

EXPOSE-R2-BIOlogy and Mars EXperiment (EXPOSE-R2-BIOMEX) — Baque M, Scalzi G, Rabbow E, Rettberg P, Billi D. Biofilm and planktonic lifestyles differently support the resistance of the desert cyanobacterium Chroococcidiopsis under space and Martian simulations. Origins of life and evolution of the biosphere: *The Journal of the International Society for the Study of the Origin of Life*. 2013 October 1; 43(4): 377-389. DOI: 10.1007/s11084-013-9341-6.*

Neutron Star Interior Composition Explorer (NICER) — Yu WH, Semper SR, Mitchell J, Winternitz LB, Hassouneh MA, et al. NASA Sextant Mission Operations Architecture. *70th International Astronautical Congress 2019*, Washington, DC; 2019 October 12. 9 pp.

Neutron Star Interior Composition Explorer (NICER) — Rowan DM, Ghazi Z, Lugo L, Spano S, Lommen A, et al. A NICER view of spectral and profile evolution for three X-ray emitting millisecond pulsars. *Bulletin of the American Physical Society 2020*, Washington, DC; 2020 April 18-21. 16 pp.

Neutron Star Interior Composition Explorer (**NICER**) — Vivekanand M. NICER observations of the Crab pulsar glitch of 2017 November. *Astronomy & Astrophysics*. 2020 January 1; 633: A57. DOI: 10.1051/0004-6361/201936774.

Neutron Star Interior Composition Explorer (**NICER**) — Kuiper LM, Tsygankov SS, Falanga M, Mereminskiy IA, Galloway DK, et al. High-energy characteristics of the accretion-powered millisecond pulsar IGR J17591-2342 during its 2018 outburst - XMM-Newton, NICER, NuSTAR, and INTEGRAL view of the 0.3–300 keV X-ray band. *Astronomy & Astrophysics*. 2020 September 1; 641: A37. DOI: 10.1051/0004-6361/202037812.

Neutron Star Interior Composition Explorer (**NICER**) — Binder BA, Carpano S, Heida M, Lau R. From SN 2010da to NGC 300 ULX-1: Ten Years of Observations of an Unusual High Mass X-Ray Binary in NGC 300. *Galaxies*. 2020 March; 8(1): 17. DOI: 10.3390/galaxies8010017.

Neutron Star Interior Composition Explorer (**NICER**) — Xiao G, Lu Y, Ma X, Ge M, Yan L, et al. Timing analysis of Swift J1658.2-4242's outburst in 2018 with Insight-HXMT, NICER and AstroSat. *Journal of High Energy Astrophysics*. 2019 October 10; epub: 28 pp. DOI: 10.1016/j.jheap.2019.09.005.

Neutron Star Interior Composition Explorer (**NICER**) — Vasilopoulous G, Petropoulou M, Koliopanos F, Ray PS, Bailyn CD, et al. NGC 300 ULX1: spin evolution, super-Eddington accretion, and outflows. *Monthly Notices of the Royal Astronomical Society*. 2019 October 1; 488(4): 5225-5231. DOI: 10.1093/mnras/stz2045.

Neutron Star Interior Composition Explorer (**NICER**) — van den Eijnden J, Degenaar N, Ludlam RM, Parikh AS, Miller JM, et al. A strongly changing accretion morphology during the outburst decay of the neutron star X-ray binary 4U 1608-52. *Monthly Notices of the Royal Astronomical Society*. 2020 March 21; 493(1): 1318-1327. DOI: 10.1093/mnras/staa423.

Neutron Star Interior Composition Explorer (**NICER**) — Fabian AC, Buisson DJ, Kosec P, Reynolds CS, Wilkins DR, et al. The soft state of the black hole transient source MAXI J1820+070: Emission from the edge of the plunge region?. *Monthly Notices of the Royal Astronomical Society*. 2020 April 21; 493(4): 5389-5396. DOI: 10.1093/mnras/staa564.

Neutron Star Interior Composition Explorer (**NICER**) — Paice JA, Gandhi P, Shahbaz T, Uttley P, Arzoumanian Z, et al. Black Hole X-ray Binary at ~100 Hz: Multiwavelength Timing of MAXI J1820+070 with HiPERCAM and NICER. *Monthly Notices of the Royal Astronomical Society*. 2019 November; 490(1): L62-L66. DOI: 10.1093/mnrasl/slz148.

Neutron Star Interior Composition Explorer (**NICER**) — Cuneo VA, Alabarta K, Zhang L, Altamirano D, Mendez M, et al. A NICER look at the state transitions of the black hole candidate MAXI J1535-571 during its reflares. *Monthly Notices of the Royal Astronomical Society*. 2020 June 9; epub: 12 pp. DOI: 10.1093/mnras/staa1606.

Neutron Star Interior Composition Explorer (**NICER**) — Vasilopoulous G, Ray PS, Gendreau KC, Jenke PA, Jaisawal GK, et al. The 2019 super-Eddington outburst of RX J0209.6-7427: detection of pulsations and constraints on the magnetic field strength. *Monthly Notices of the Royal Astronomical Society*. 2020 June 1; 494(4): 5350-5359. DOI: 10.1093/mnras/staa991.

Neutron Star Interior Composition Explorer (**NICER**) — Belloni TM, Zhang L, Kylafis ND, Reig P, Altamirano D. Time lags of the type-B QPO in MAXI J1348-630. *Monthly Notices of the Royal Astronomical Society*. 2020 August; 496(4): 4366–4371. DOI: 10.1093/mnras/staa1843.

Neutron Star Interior Composition Explorer (**NICER**) — Sanna A, Burderi L, Gendreau KC, Di Salvo T, Ray PS, et al. Timing of the accreting millisecond pulsar IGR J17591–2342: evidence of spin-down during accretion. *Monthly Notices of the Royal Astronomical Society*. 2020 June 21; 495(2): 1641-1649. DOI: 10.1093/mnras/staa1253.

Neutron Star Interior Composition Explorer (**NICER**) — Wang LJ, Ge MY, Wang JS, Weng SS, Tong H, et al. The braking index of PSR B0540-69 and the associated pulsar wind nebula emission after spin-down rate transition. *Monthly Notices of the Royal Astronomical Society*. 2020 May 11; 494(2): 1865-1870. DOI: 10.1093/mnras/staa884.

Neutron Star Interior Composition Explorer (NICER) — Goodwin AJ, Russell DM, Galloway DK, Baglio MC, Parikh AS, et al. Enhanced optical activity 12 days before X-ray activity, and a 4 day X-ray delay during outburst rise, in a low-mass X-ray binary. *Monthly Notices of the Royal Astronomical Society*. 2020 August 26; epub: 12 pp. DOI: 10.1093/mnras/staa2588.

Neutron Star Interior Composition Explorer (NICER) — Davis MC, Stevens AL. Spectral variability of a soft-intermediate state QPO from MAXI J1820+070. *Research Notes of the AAS*. 2020 June; 4(6): 95. DOI: 10.3847/2515-5172/ab9f39.

Neutron Star Interior Composition Explorer (NICER) — Abbott BP, Abbott R, Abbott TD, Abraham S, Acernese F, et al. Searches for Gravitational Waves from Known Pulsars at Two Harmonics in 2015-2017 LIGO Data. *The Astrophysical Journal*. 2019; DOI: 10.3847/1538-4357/ab20cb.

Neutron Star Interior Composition Explorer (NICER) — Ludlam RM, Shishkovsky L, Bult PM, Miller JM, Zoghbi A, et al. Observations of the ultra-compact X-ray binary 4U 1543-624 in outburst with NICER, INTEGRAL, Swift, and ATCA. *The Astrophysical Journal*. 2019 September; 883(1): 39. DOI: 10.3847/1538-4357/ab3806.

Neutron Star Interior Composition Explorer (NICER) — Miller JM, Kammoun E, Ludlam RM, Gendreau KC, Arzoumanian Z, et al. A NICER Look at Strong X-Ray Obscuration in the Seyfert-2 Galaxy NGC 4388. *The Astrophysical Journal*. 2019 October; 884(2): 106. DOI: 10.3847/1538-4357/ab3e05.

Neutron Star Interior Composition Explorer (NICER) — Bult PM, Jaisawal GK, Guver T, Strohmayer TE, Altamirano D, et al. A NICER thermonuclear burst from the millisecond X-ray pulsar SAX J1808.4–3658. *The Astrophysical Journal*. 2019 October; 885(1): L1. DOI: 10.3847/2041-8213/ab4ae1.

Neutron Star Interior Composition Explorer (NICER) — Jaisawal GK, Chenevez J, Bult PM, in't Zand JJ, Galloway DK, et al. NICER observes a secondary peak in the decay of a thermonuclear burst from 4U 1608–52. *The Astrophysical Journal*. 2019 September; 883(1): 61. DOI: 10.3847/1538-4357/ab3a37.

Neutron Star Interior Composition Explorer (NICER) — Homan J, Bright J, Motta SE, Altamirano D, Arzoumanian Z, et al. A rapid change in X-ray variability and a jet ejection in the black hole transient MAXI J1820+070. *The Astrophysical Journal*. 2020 March 9; 891(2): L29. DOI: 10.3847/2041-8213/ab7932.

Neutron Star Interior Composition Explorer (NICER) — Jaisawal GK, Wilson-Hodge CA, Fabian AC, Naik S, Chakrabarty D, et al. An evolving broad iron line from the first Galactic ltraluminous X-ray pulsar Swift J0243.6+6124. *The Astrophysical Journal*. 2019 October; 885(1): 18. DOI: 10.3847/1538-4357/ab4595.

Neutron Star Interior Composition Explorer (NICER) — Gorgone NM, Kouveliotou C, Negoro H, Wijers RA, Bozzo E, et al. Discovery and identification of MAXI J1621–501 as a Type I X-Ray burster with a super-orbital period. *The Astrophysical Journal*. 2019 October; 884(2): 168. DOI: 10.3847/1538-4357/ab3e43.

Neutron Star Interior Composition Explorer (NICER) — Trakhtenbrot B, Arcavi I, MacLeod CL, Ricci C, Kara E, et al. 1ES 1927+654: An AGN Caught Changing Look on a Timescale of Months. *The Astrophysical Journal*. 2019 September; 883(1): 94. DOI: 10.3847/1538-4357/ab39e4.

Neutron Star Interior Composition Explorer (NICER) — Younes GA, Ray PS, Baring MG, Kouveliotou C, Fletcher C, et al. A radiatively quiet glitch and anti-glitch in the magnetar 1E 2259+586. *The Astrophysical Journal*. 2020 June; 896(2): L42. DOI: 10.3847/2041-8213/ab9a48.

Neutron Star Interior Composition Explorer (NICER) — Ludlam RM, Cackett EM, Garcia JA, Miller JM, Bult PM, et al. NICER–NuSTAR observations of the neutron star low-mass X-Ray binary 4U 1735–44. The Astrophysical Journal. 2020 May; 895(1): 45. DOI: 10.3847/1538-4357/ab89a6.

Neutron Star Interior Composition Explorer (**NICER**) — Pilia M, Burgay M, Possenti A, Ridolfi A, Gajjar V, et al. The lowest-frequency fast radio bursts: Sardinia radio telescope detection of the periodic FRB 180916 at 328 MHz. *The Astrophysical Journal*. 2020 June; 896(2): L40. DOI: 10.3847/2041-8213/ab96c0.

Neutron Star Interior Composition Explorer (**NICER**) — Ricci C, Kara E, Loewenstein M, Trakhtenbrot B, Arcavi I, et al. The destruction and recreation of the X-ray corona in a changing-look active galactic nucleus. *The Astrophysical Journal*. 2020 July 20; 898(1): L1. DOI: 10.3847/2041-8213/ab91a1.

Neutron Star Interior Composition Explorer (**NICER**) — Stiele H, Kong AK. A timing study of MAXI J1820+070 based on Swift/XRT and NICER monitoring in 2018/19. *The Astrophysical Journal*. 2020 February 3; 889(2): 142. DOI: 10.3847/1538-4357/ab64ef.

Neutron Star Interior Composition Explorer (**NICER**) — Abarr Q, Baring MG, Beheshtipour B, Beilicke M, de Geronimo G, et al. Observations of a GX 301–2 apastron flare with the X-Calibur hard X-Ray polarimeter supported by NICER, the Swift XRT and BAT, and Fermi GBM. *The Astrophysical Journal*. 2020 March; 891(1): 70. DOI: 10.3847/1538-4357/ab672c.

Neutron Star Interior Composition Explorer (**NICER**) — Hare J, Tomsick JA, Buisson DJ, Clavel M, Gandhi P, et al. NuSTAR observations of the transient galactic black hole binary candidate Swift J1858.6–0814: A new sibling of V404 Cyg and V4641 Sgr?. *The Astrophysical Journal*. 2020 February; 890(1): 57. DOI: 10.3847/1538-4357/ab6a12.

Neutron Star Interior Composition Explorer (**NICER**) — Tse K, Chou Y, Hsieh H. Updated spin and orbital parameters and energy dependent pulse behaviors of the accreting millisecond X-Ray pulsar IGR J17591–2342. *The Astrophysical Journal*. 2020 August; 899(2): 120. DOI: 10.3847/1538-4357/aba18f.

Neutron Star Interior Composition Explorer (**NICER**) — Gotthelf EV, Halpern JP. The timing behavior of the central compact object pulsar 1E 1207.4-5209. *The Astrophysical Journal*. 2020 September 11; 900(2): 159. DOI: 10.3847/1538-4357/aba7bc.

Neutron Star Interior Composition Explorer (**NICER**) — Bilous AV, Watts AL, Harding AK, Riley TE, Arzoumanian Z, et al. A NICER view of PSR J0030+0451: Evidence for a global-scale multipolar magnetic field. *The Astrophysical Journal Letters*. 2019 December; 887(1): L23. DOI: 10.3847/2041-8213/ab53e7.

Neutron Star Interior Composition Explorer (**NICER**) — Bogdanov S, Guillot S, Ray PS, Wolff MT, Chakrabarty D, et al. Constraining the neutron star mass–radius relation and dense matter equation of state with NICER. I. The millisecond pulsar X-ray data set. *The Astrophysical Journal Letters*. 2019 December; 887(1): L25. DOI: 10.3847/2041-8213/ab53eb.

Neutron Star Interior Composition Explorer (**NICER**) — Bogdanov S, Lamb FK, Mahmoodifar S, Miller MC, Morsink SM, et al. Constraining the neutron star mass–radius relation and dense matter equation of state with NICER. II. Emission from hot spots on a rapidly rotating neutron star. *The Astrophysical Journal Letters*. 2019 December; 887(1): L26. DOI: 10.3847/2041-8213/ab5968.

Neutron Star Interior Composition Explorer (**NICER**) — Guillot S, Kerr M, Ray PS, Bogdanov S, Ransom SM, et al. NICER X-Ray observations of seven nearby rotation-powered millisecond pulsars. *The Astrophysical Journal Letters*. 2019 December 12; 887(1): L27. DOI: 10.3847/2041-8213/ab511b.

Neutron Star Interior Composition Explorer (**NICER**) — Miller MC, Lamb FK, Dittmann AJ, Bogdanov S, Arzoumanian Z, et al. PSR J0030$\ mathplus$0451 Mass and Radius from NICER Data and Implications for the Properties of Neutron Star Matter. *The Astrophysical Journal Letters*. 2019 December; 887(1): L24. DOI: 10.3847/2041-8213/ab50c5.

Neutron Star Interior Composition Explorer (**NICER**) — Raaijmakers G, Riley TE, Watts AL, Greif SK, Morsink SM, et al. A NICER view of PSR J0030$\ mathplus$0451: Implications for the dense matter equation of state. *The Astrophysical Journal Letters*. 2019 December; 887(1): L22. DOI: 10.3847/2041-8213/ab451a.

Neutron Star Interior Composition Explorer (NICER) — Riley TE, Watts AL, Bogdanov S, Ray PS, Ludlam RM, et al. A NICER view of PSR J0030+0451: Millisecond pulsar parameter estimation. *The Astrophysical Journal Letters*. 2019 December; 887(1): L21. DOI: 10.3847/2041-8213/ab481c.

Space Environment Data Acquisition Equipment - Attached Payload (SEDA-AP) — Ueno H, Nakahira S, Kataoka R, Asaoka Y, Torii S, Ozawa S, Matsumoto H, Bruno A, de Nolfo G, Collazuol G, Ricciarini SB. Radiation dose during relativistic electron precipitation events at the International Space Station. *Space Weather*. 2020 July; 18(7): 7 pp. DOI: 10.1029/2019SW002280.

STP-H5-Lightning Imaging Sensor (STP-H5 LIS) — Poelman D, Schulz W. Comparing lightning observations of the ground-based European lightning location system EUCLID and the space-based Lightning Imaging Sensor (LIS) on the International Space Station (ISS). *Atmospheric Measurement Techniques*. 2020 June 5; 13(6): 2965-2977. DOI: 10.5194/amt-13-2965-2020.

STP-H5-Lightning Imaging Sensor (STP-H5 LIS) — Erdmann F, Defer E, Caumont O, Blakeslee RJ, Pedeboy S, et al. Concurrent satellite and ground-based lightning observations from the Optical Lightning Imaging Sensor (ISS-LIS), the low-frequency network Meteorage and the SAETTA Lightning Mapping Array (LMA) in the northwestern Mediterranean region. *Atmospheric Measurement Techniques*. 2020 February 20; 13(2): 853-875. DOI: https://doi.org/10.5194/amt-13-853-2020.

STP-H5-Lightning Imaging Sensor (STP-H5 LIS) — van der Velde OA, Montanya J, Neubert T, Chanrion O, Ostgaard N, et al. Comparison of high-speed optical observations of a lightning flash from space and the ground. *Earth and Space Science*. 2020 July 15; epub: e2020EA001249. DOI: 10.1029/2020EA001249.

STP-H5-Lightning Imaging Sensor (STP-H5 LIS) — Hui W, Huang F, Liu R. Characteristics of lightning signals over the Tibetan Plateau and the capability of FY-4A LMI lightning detection in the Plateau. *International Journal of Remote Sensin*g. 2020 June 17; 41(12): 4605-4625. DOI: 10.1080/01431161.2020.1723176.

STP-H5-Lightning Imaging Sensor (STP-H5 LIS) — Chatterjee C, Das S. On the association between lightning and precipitation microphysics. *Journal of Atmospheric and Solar-Terrestrial Physics*. 2020 October; 207: 105350. DOI: 10.1016/j.jastp.2020.105350.

STP-H5-Lightning Imaging Sensor (STP-H5 LIS) — Blakeslee RJ, Lang TJ, Koshak WJ, Buechler DE, Gatlin P, et al. Three years of the Lightning Imaging Sensor Onboard the International Space Station: Expanded global coverage and enhanced applications. *Journal of Geophysical Research: Atmospheres*. 2020 August 27; 125(16): 20 pp. DOI: 10.1029/2020JD032918.

Stratospheric Aerosol and Gas Experiment III-ISS (SAGE III-ISS) — Chouza F, Leblanc T, Barnes J, Brewer M, Wang P, et al. Long-term (1999–2019) variability of stratospheric aerosol over Mauna Loa, Hawaii, as seen by two co-located lidars and satellite measurements. *Atmospheric Chemistry and Physics*. 2020 June 10; 20(11): 6821-6839. DOI: 10.5194/acp-20-6821-2020.

Stratospheric Aerosol and Gas Experiment III-ISS (SAGE III-ISS) — McCormick MP, Lei L, Hill MT, Anderson J, Querel R, et al. Early results and validation of SAGE III-ISS ozone profile measurements from onboard the International Space Station. *Atmospheric Measurement Techniques*. 2020 March 18; 13(3): 1287-1297. DOI: 10.5194/amt-13-1287-2020.

Stratospheric Aerosol and Gas Experiment III-ISS (SAGE III-ISS) — Wang HJ, Damadeo R, Flittner DE, Kramarova NA, Taha G, et al. Validation of SAGE III/ISS solar occultation ozone products with correlative satellite and ground-based measurements. Journal of Geophysical Research: *Atmospheres*. 2020 May 16; 125(11): e2020JD032430. DOI: 10.1029/2020JD032430.

Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) — Kasai Y, Baron P, Ochiai S, Mendrok J, Urban J, et al. JEM/SMILES Observation Capability. *2009 SPIE: Sensors, Systems, and Next-Generation Satellites XIII, Berlin, Germany*; 2009 22 September. 6 pp.*

Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) — Ochiai S, Kikuchi

K, Nishibori T, Mizobuchi S, Manabe T, et al. Gain Nonlinearity Calibration of the SMILES Receiver. *2011 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Vancouver, BC; 2011. 1021-1024.*

Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) — Imai K, Suzuki M, Takahashi C. Evaluation of Voigt algorithms for the ISS/JEM/SMILES L2 data processing system. *Advances in Space Research*. 2010 November; 45: 669-675. DOI: 10.1016/j.asr.2009.11.005. *

Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) — Fujinawa T, Sato TO, Yamada T, Nara S, Uchiyama Y, et al. Validation of acetonitrile (CH₃CN) measurements in the stratosphere and lower mesosphere from the SMILES instrument on the International Space Station. *Atmospheric Measurement Techniques*. 2020 April 29; 13(4): 2119-2129. DOI: 10.5194/amt-13-2119-2020.

Total and Spectral Solar Irradiance Sensor (Total & Spectral Solar Irradiance Sensor (TSIS)) — Richard E, Harber D, Coddington O, Drake G, Rutkowski J, et al. SI-traceable spectral irradiance radiometric characterization and absolute calibration of the TSIS-1 Spectral Irradiance Monitor (SIM). *Remote Sensing*. 2020 January; 12(11): 1818. DOI: 10.3390/rs12111818.

EDUCATIONAL ACTIVITIES

Artery in Microgravity - Orbit Your Thesis! (Ice Cubes #7) — Drayson O, Bernardini N, Abderrahaman AB, Cerquetani L, Cipolletta A, et al. AIM (Artery In Microgravity): An ICE Cubes mission by university students. *3rd Symposium on Space Educational Activities*, Leicester, United Kingdom; 2020. 109-113. DOI: 10.29311/2020.27.

European Space Agency-Education Payload Operation-Peake (ESA-EPO-Peake) — Chandler JO, Haas FB, Khan S, Bowden L, Ignatz M, et al. Rocket Science: The effect of spaceflight on germination physiology, ageing, and transcriptome of Eruca sativa seeds. *Life*. 2020 April 24; 10(4): 49. DOI: 10.3390/life10040049.

European Space Agency-Education Payload Operation-Peake (ESA-EPO-Peake) — Bennett J, Airey J, Dunlop L, Turkenburg M. The impact of human spaceflight on young people's attitudes to STEM subjects. *Research in Science & Technological Education*. 2019 July 19; 0(0): 1-22. DOI: 10.1080/02635143.2019.1642865.

Genes in Space-1 — Rubinfien J, Atabay KD, Nichols NM, Tanner NA, Pezza JA, et al. Nucleic acid detection aboard the International Space Station by colorimetric loop-mediated isothermal amplification (LAMP). *FASEB BioAdvances*. 2019 March; 2(3): 160-165. DOI: 10.1096/fba.2019-00088.

Science off the Sphere — Pettit DR, Fontana P. Comparison of sodium chloride hopper cubes grown under microgravity and terrestrial conditions. *npj Microgravity*. 2019 November 11; 5(1): 25. DOI: 10.1038/s41526-019-0085-0.

Xenopus Growth and Regeneration on ISS (XENOGRISS) — Rizzo AM, Zava S, Galoforo G, Ferranti F, Pacelli C, et al. The educational experiment Xenogriss: Growth and regeneration of Xenopus laevis tadpoles on the ISS. *Aerotecnica Missili & Spazio*. 2020 May 11; 99: 115-120. DOI: 10.1007/s42496-020-00041-7.

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