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International Space Station research: hidden treasures in Open Data Portals

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Abstract

From fundamental scientific knowledge to medical treatments to pushing the frontiers of scientific knowledge, research on the International Space Station (ISS) is improving our understanding of the solar system. Over the past 25 years, the ISS has become a premier orbiting laboratory, enabling over 4,000 groundbreaking experiments from over 100 different nations. Research in the space environment and advanced technologies has produced a massive amount of data, resulting in more than 4,400 publications since the beginning of the station. These results are being delivered to humanity in the form of numerous breakthroughs, scientific publications and Earth applications, as described in the document "Benefits for Humanity". Over the years, ISS partners have strived to store and share this invaluable knowledge to maximize the scientific output of this remarkable international laboratory. Many data repositories were created to provide access to the information generated through ISS investigations, which are listed in this article. This paper will provide an overview of the Open Data Portals already available, as well as their purpose and instructions for access, to improve the visibility of these data repositories and inform the research community regarding the availability of this unique data. Challenges related to data sharing and its dissemination will be addressed and new initiatives to maximize the results of ISS research will be discussed. The purpose is to fully analyze this unique information, create collaboration opportunities, even between seemingly unrelated fields of research, and increase the visibility and access to this invaluable knowledge that will support human exploration of the solar system.
Keywords: International Space Station (ISS), microgravity research, benefits, humanity, human spaceflight, international collaboration.

Acronyms/Abbreviations
Digital Object Identifiers (DOI)
European Space Agency (ESA)
Informed Consent Briefing (ICB)
Inform Consent Form (ICF)
International Space Station (ISS)
Institutional Review Board (IRB)
Italian Space Agency (ASI)
National Aeronautics and Space Administration (NASA)
NASA Life Sciences Portal (NLSP)
NASA Open Science Data Repository (OSDR)
Program Science Forum (PSF)
Space Science Data Center (SSDC)
Utilisation ISS (UTISS)

1. ISS as a critical steppingstone for space exploration of the solar system

From basic scientific investigations to making medical breakthroughs, research conducted onboard the ISS has generated a vast amount of knowledge that is propelling humankind forward into the solar system. It has served as a foundation for multiple scientific discoveries and technology development where researchers studied phenomena and processes in various fields such as biomedical and life sciences, physical and material sciences, astronomy, climate change, as well as engineering. Scientific experimentation onboard the ISS played an important role in numerous discoveries contributing to solutions for important challenges on Earth and enabling further exploration into deep space [1]. Since November 2, 2000, when continuous human presence began on the ISS, the station has steadily evolved from a modest outpost into a vibrant research platform. Now, through the Moon to Mars Program, the ISS serves as an even more crucial resource for testing new exploration technologies.

Recently, ISS crews participated in many more investigations to average upwards of 300 during their time onboard [2]. This improvement is largely thanks to advancements in technology, increased international collaboration, and the establishment of the ISS as a fully operational and proven research platform in microgravity. Station research has seen a remarkable growth of international collaboration since its first days of assembly in 1999. Currently, about 40% of the research produced on the station is the result of a collaboration between two or more countries [3]. This high level of international collaboration contributes to the success of the ISS Utilization program and confirms that space exploration requires the involvement of the international research community to tackle the scientific and technical challenges characteristic of this unique environment.

Although results of ISS investigations have been analyzed in many scientific and technical publications, this data will enable the full potential of investigations conducted on the ISS. Several ISS partner agencies have created and maintained web portals to maximize the scientific output of ISS research. One of the purposes of this paper is to highlight the availability of open-access portals of scientific data from ISS experiments and outlines the processes involved in accessing them. These databases are expanding each year. For instance, the 2021 integration of the National Aeronautics and Space Administration (NASA) Ames Life Sciences Data Archive with GeneLab to establish the NASA Open Science Data Repository (OSDR) significantly enhanced access to a wide range of life sciences, biomedical-clinical and mission telemetry data alongside existing omics data from GeneLab. This repository is funded by the NASA Space Biology Program, part of the Biological and Physical Sciences Division within the Science Mission Directorate. The OSDR repository (https://www.nasa.gov/osdr/) is the focus of a recent review, which describes the database architecture and features that enable the submission, hosting, retrieval, and analysis of diverse data types [4]. The accessibility to these data varies depending on the source. Some datasets can be accessed with minimal login requirements, while others may require a more extensive approval process. This aspect is discussed in this article after a general description of ISS research results obtained so far.

2. Overview of ISS research results, publications, and Earth benefits

Research in the space environment and advanced technologies has produced a massive amount of data, resulting in more than 4,400 publications since 2000. Many of these publications stemming from ISS research continue to be cited across a wide range of scientific literature beyond space-related fields, serving as foundational references for subsequent studies, this illustrates the growing impact of ISS-based discoveries on Earth-bound benefits.

Over the past 20 years the ISS has evolved into a reliable laboratory with dozens of research facilities, capabilities for the autonomous monitoring and conduct of research, and a growing array of scientific tools and observational instruments [2]. The ISS has become the premier orbiting laboratory, enabling over 4,000 groundbreaking experiments representing over 100 different nations [3]. Between October 1, 2023, and September 30, 2024, ISS research experiments produced a total of **361** publications broken down by discipline and publication count in Table 1.

Table 1 : Breakdown of Space Station Experiments per Scientific Discipline [3]

Discipline	Publication Count
Biology and Biotechnology	52
Earth and Space	176
Educational and cultural activities	5
Human research	40
Physical science	56
Technology development and demonstration	32

In addition to scientific advancement, these experiments also generated emerging areas of research that mark a new era of innovation onboard the ISS. The past year brought groundbreaking achievements such as the first live 3D bioprinted human heart tissue in microgravity and the inaugural 3D print metal using liquefied stainless steel. Advancements in remote medicine were demonstrated through the successful operation of a compact robotic surgeon controlled from Earth. Furthermore, Earth observation also reached new heights, with over 300,000 images captured in the first half of 2024 alone, surpassing the total for all of 2023 and offering unparalleled insights of our planet [3]. These developments showcase how the ISS continues to expand the frontiers of science and technology.

The shared operation of the ISS enables participating nations to share costs, foster international collaboration, and promote the exchange of scientific expertise. This partnership provides a broader access to space for smaller countries. The breakdown of publications per agency is presented in Figure 1 [3]. Note that the NASA publications numbers include articles related to Italian Space Agency (ASI) experiments performed under the agreement between ASI and NASA.

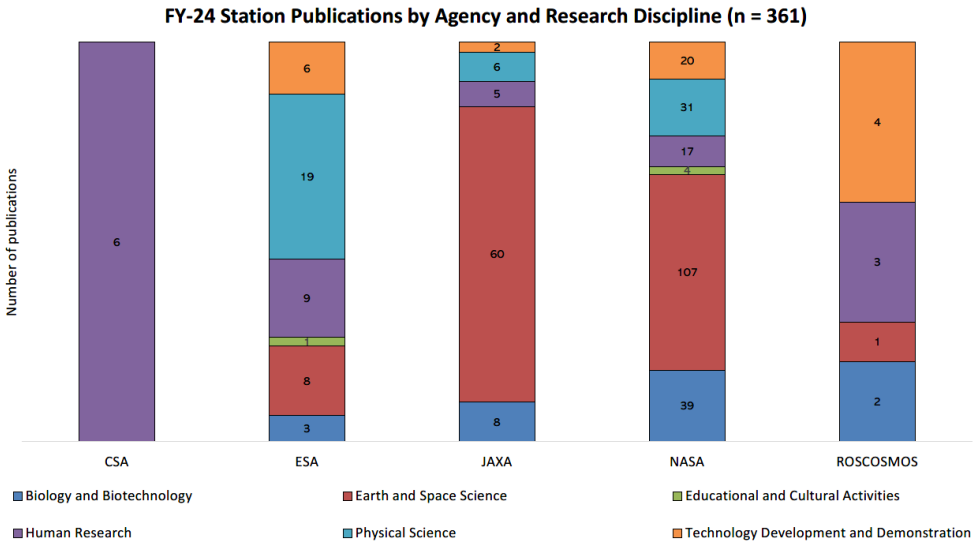
Beyond its scientific output, ISS research has had a direct impact on life on Earth through tangible societal benefits. For instance, medical research conducted onboard the station has led to advancements in areas such as neonatal care, robotic surgery, and disease treatment through a better understanding of protein structures. Space research has also generated solutions for a range of everyday challenges from healthcare innovations to environmental sustainability [1].

The ISS has collected observational earth imagery by the crew using handheld cameras since 2000. Starting in 2009, a succession of both internal and external sensor systems of increasing sophistication has enabled a variety of environmental monitoring objectives and science investigations in areas including atmospheric, geophysical and geochemical studies, coastal ocean processes, disaster response, land surface characterization, and plant responses to changing regional temperature regimes [5]. Individual sensor systems have been sponsored by their respective space agencies, and each agency also determines how and to what extent the individual datasets can be accessed.

Taking advantage of the microgravity environment, ISS investigations on colloids support improvements to commonly used products such as toothpaste or pharmaceuticals. Colloids are mixtures of tiny particles suspended in liquid, a structure commonly found in of natural products such as milk and muddy water, as well as a range of manufactured products from shampoo to salad dressing [6]. Microgravity studies of colloid and soft matter on the ISS help isolate fundamental self-organisation mechanisms—insights that can revolutionize applications like microrobotic swarms, targeted drug delivery systems, and smart environmental sensors on Earth [7]. By analyzing the behavior of these products without interference from gravity, manufacturing processes can be refined and improved. Materials science in space enables unique investigations of matter under microgravity, free from Earth's interfering forces like buoyancy and convection. Experiments onboard the ISS, especially using containerless techniques like electromagnetic levitation, reveal previously inaccessible thermophysical properties of high-temperature liquids. These insights are crucial not only for understanding the evolution of matter in the universe but also for advancing industrial processes on Earth [8]. Microgravity studies of dusty plasmas onboard the ISS have advanced our understanding of plasma–particle interactions, and also shed light on the

development of electrostatic dust-removal technologies and disinfect and healing applicable to both space and Earth environments [9]. Precision quantum sensors—such as cold-atom interferometers and atomic clocks—operating in space offer unprecedented sensitivity for mapping Earth's gravity and improving geodesy, navigation systems, and time-keeping technologies on the ground [10].

Figure 1: ISS research publications per space agency and scientific discipline [3]



The creation of the space station robot Robonaut led to the development of an industrial strength robotic glove. NASA and General Motors (GM) developed a Robonaut prototype and tested it on the station where it successfully performed simple tasks alongside astronauts. The team then reconfigured the hand-like portion of Robonaut into a wearable device to help both astronauts and auto workers avoid hand fatigue and injury. Initially called Robo-Glove, the device now is commercially available as Ironhand.

Core body temperature rises faster during exercise on the space station than it does on Earth. ESA's (European Space Agency's) ThermoLab experiment (*Space Station Research Explorer*) has investigated body temperature regulation and cardiovascular adaptations in crew members since 2009. The technology that measures body temperature developed for the study by German company Dräge has begun to make a difference on Earth. The devices are deployed in many clinics to monitor infant incubators and patients during surgery and have been used to study how extreme heat affects farmers in Kenya and Burkina Faso. Other applications of the device include monitoring for signs of fatigue in people working in extreme conditions, including firefighters and fighter pilots.

3. Available Open Data portals by disciplines

The research conducted onboard the ISS is vast and diverse, generating a substantial and growing body of data. The continuous flow of information from ISS investigations is steadily increasing, with new findings being collected, processed, and analyzed. These data are made available through a growing list of repositories, ensuring that the research community can access and build upon this expanding body of knowledge to address complex challenges, promote interdisciplinary collaboration, and drive future innovation.

Table 2 presents a summary of scientific experiment repositories from various portals including the NASA Open Science Data Portal, which catalogs space-based research conducted onboard the ISS by various international agencies. In this table, each repository is organized thematically by research discipline and includes a direct link to the corresponding database, along with a summary of its

content. The final two columns indicate whether the data are immediately accessible or if an application request is required for access.

Table 2 - Experiment Databases by Discipline and Access Status

Title	Link	Brief Summary	Agency	Access to Data	
				Direct retrieval	By Request
Life Sciences / Biological Sciences					
Open Science Data Repository	OSDR	Multi-level spaceflight data on biological and health responses of terrestrial life (including omics, physiology, behaviour, imaging, and environmental telemetry)	NASA	✓	
Open Science for Exploration	GeneLab	Molecular response of biology to ISS environment - Human data	NASA	✓	
RadLab	RadLab Portal	Radiation data from ISS and other multiple databases maintained by multiple space agencies, aimed at human protection	NASA	✓	
NASA Life Sciences Portal	NLSP	Spaceflight, flight analog and ground-based life sciences research investigations - Human data	NASA	✓	✓
NASA BPS Open Science Data Repository	BPS Data Repository	Repository of 2 databases (ALSDA and GeneLAb - Human & other types (microbes, plants, fruit flies, rodents)	NASA	✓	
JAXA Biorepository at Tsukuba Space Center – Integrated Biobank for Space Life Science	ibSLS	Multi-omics data, including transcriptome, metabolome, and phenotypes	JAXA	✓	
UTilisation ISS*	UTISS	ASI-funded or co-funded experiments covering a large number of scientific areas - human physiology and biology and biotechnology research	ASI-funded or co-funded		✓
Physical Sciences					
Physical Science Informatics	PSI	Physical science experiments (ISS and Space Shuttles)	NASA	✓	

Title	Link	Brief Summary	Agency	Access to Data	
				Direct retrieval	By Request
Materials In Space	Materials In Space	Data and analysis from research into materials in space	NASA		✓
ASIM Science Data Centre	ASIM	Lightning and bursts of gamma-rays from thunderstorm clouds	ESA		✓
Earth & Environmental Sciences					
EarthData	EarthData	Earth science data to users from satellite, airborne, and International Space Station (ISS)	NASA	✓	
Gateway to Astronaut Photography of Earth	GAPE	Database of handheld camera imagery from human spaceflight missions	NASA	✓	
NASA Ocean Color Database	HICO	Imager for the Coastal Ocean	NASA		✓
ASI Space Data Center (SSDC)	Mini-EUSO	Data from a UV telescope for Earth observation	ASI/ROSCOSMOS	✓	
	Cosmic Ray Database	Provides access to published data from missions dedicated to charged cosmic-rays measurements.	ASI	✓	
Multidisciplinary / Cross-Cutting Data Repositories					
NASA Task Book	NASA Task Book	Database information includes project descriptions, annual or final research results, Earth benefits and research impacts, and listings of publications resulting from the NASA-funded research.	NASA		No data – publications, experiments and facilities
NASA's Open Data Portal	NASA's Open Data Portal	Aerospace, applied science, earth science, management/operations, and space science	NASA	✓	
Erasmus Experiment Archive	EEA	Database of ESA-funded or co-funded experiments covering a wide range of scientific areas	ESA		✓
Human and Robotic Exploration Data	HREDA	Various space platforms and microgravity ground-based facilities.	ESA		✓

Title	Link	Brief Summary	Agency	Access to Data	
				Direct retrieval	By Request
Archive					
Data ARchives and Transmission System	DARTS	Multi-disciplinary space science data archive for astrophysics, solar physics, solar-terrestrial physics, lunar and planetary science, and microgravity science.	JAXA	✓	✓
Education / Outreach					
ASI Educational Resources	ASI Educational Resources	Resource based on science for Italian teachers and students.	ASI	✓	
European Space Education Resource Office	ESERO ESA	ESERO aims at training the community of teachers, who represent the main link to students.	ESA	✓	

4. ISS research data mining: access to the data

Numerous international agencies contribute to research efforts onboardon ISS, with each agency managing its own set of data repositories [11]. These agencies also support open-data sharing, ensuring that the data collected can be accessed by the global community. Some open-source data repositories such as GeneLab are readily accessible and can be used through a web page. GeneLab is a comprehensive database for space-related omics research, providing molecular data on how biology responds to the spaceflight environment [12]. The NASA Life Sciences Portal (NLSP) provides access to a vast array of datasets related to human health and performance in space, with much of the data being publicly available. However, some datasets, particularly those involving sensitive or restricted information, require a formal application process for access. Researchers must first identify the dataset of interest through the portal's repositories and carefully review the specific access requirements for each dataset. If the data is restricted, the applicant may need to submit a research proposal, Institutional Review Board (IRB) approval (if human subjects are involved), and a data security plan to ensure privacy and compliance with ethical standards. Once the necessary documentation is prepared, researchers submit their application through the portal's submission guidelines, either via an online form or email. The application then undergoes through a review process that can take several weeks. Finally, the approved applicants are granted access to the dataset.

Additionally, access to the Utilisation ISS (UTISS) Database, managed by ASI, is governed by strict protocols. Researchers seeking access must submit a formal application that includes a detailed research proposal outlining the study's objectives and methodology. In addition, they must provide evidence of ethics approval from a recognized IRB, ensuring that the research meets necessary ethical standards. ASI is planning to port the UTISS database to the Space Science Data Center (SSDC) (https://www.ssdc.asi.it/), an ASI facility with data from several Astrophysics and Earth Observation missions currently not covering biological experiments. The goal is to develop a portal to include Space Life Sciences, that will follow the same access protocol used in UTISS.

The OSRD is based on the Findable, Accessible, Interoperable, Reusable (FAIR) access to spaceflight biological studies. For instance, the 2021 SpaceX Inspiration4 (I4) mission collected biological measurements from civilian astronauts, providing a wealth of data to characterize the effects of spaceflight on regular citizens, and enabling the publication of a recent article [13]. which illustrates pathways to access metadata and data from this repository. These data, like any other datasets deposited into the OSDR

repository, can be programmatically accessed through GLOpenAPI (https://visualization.genelab.nasa.gov/GLOpenAPI/) .

5. Utilization of archived data: the challenges

The information summarized in Table 2 shows that many data portals providing access to ISS data are available on the internet. Although these data may be available, several factors may limit their usability. The first obstacle is the visibility of some of these portals and the awareness of the general research community of their existence. Except for well-known resources such as GeneLab maintained by NASA or the Erasmus Experiment Archive providing access to data from ESA-funded or co-funded experiments, many of the repositories listed in Table 2 have limited visibility. In the context of the Program Science Forum (PSF), ISS partners are evaluating ways to raise the awareness of these resources in the international community. One option could be to engage with the research community during major space research conferences, either through a webinar or by including guidelines in the conference programs. These events provide a valuable opportunity to reach a diverse and global audience from various countries and space agencies. In addition to conferences, engagement could be broadened through collaborative research initiatives, open-access publications, and the development of interactive platforms where data and findings could be shared.

Sharing research data on crew health during space missions faces a specific challenge due to the confidentiality of the crew medical data and the requirement to obtain the informed consent of investigation subjects to collect and analyze human data. Human subjects provide their agreement to participate in specific studies approved by research ethics boards, following an Informed Consent Briefing (ICB). During this step, the science team provides details to crew members on the purpose of the investigation, the type of data collected, and potential risks for the subjects. Only after the crew members and the investigator sign the Inform Consent Form (ICF) can the data be collected and analyzed specifically for the purpose of that investigation. This means that even if the data are made available in a data repository, they cannot be used for any another investigation without the consent of the crew members involved in the study. Therefore, access to human data requires a much higher level of oversight by space agencies, to comply with research ethics guidelines. A solution to this obstacle may be to include in the ICF the authorization from the crew members to use the data for a future investigation approved by a research ethics board, if confidentiality is ensured and the purpose of the research is to reduce health risks of spaceflight.

Another challenge is the data format and the requirement to provide meta data for a meaningful analysis. Each data portal has specific requirements for meta data and information on data collection and format. As a good example, the Guidelines for Data Submission to OSDR (https://www.nasa.gov/osdr/) include detailed instructions for meta data input and provide specific templates for this purpose. Other data repositories may not have such extensive requirements which may complicate data analysis.

The ISS partners could also develop a new metric to confirm whether these data are used by the research community. Information on the number of requests for access to ISS data by portal may be useful to identify the portals that are underused. The space agency managing the portal could monitor portal usage and communicate the information to the PSF to include this information in a regular publication such as the ISS Statistics.

6. Optimizing data access and scientific output from previous (and future) investigations

To maximize the scientific output of the ISS research program, it is critical to increase the visibility of existing ISS data repositories. Links to these portals should be added to more prominent web pages or to national solicitations. The CSA is providing funds to Canadian investigators to support data mining based on data from previous investigations (whether they were Canadian or international investigations). Examples of major data portals are included in the solicitation, and the applicants must demonstrate they have access to the data to receive the grant.

In the context of the PSF, the idea of using Digital Object Identifiers (DOI) to tag datasets or databases was discussed. A DOI is a digital identifier of an object, any object — physical, digital, or abstract. These tags are currently used to identify specific publications, for instance, and provide a short link to the internet page that provides access to the publication. Some of the datasets are already tagged with a DOI, as demonstrated in the following example. A DOI (for example a cardiovascular study https://doi.org/10.57780/esa-72xqlcm) was assigned to the microgravity and ground-based studies accessible through the HREDA database maintained by ESA [14].

7. Conclusions

The vast amount of data generated over the years in the context of the ISS program already supported many publications in diverse research fields from Astrophysics to Material Sciences. Findings from these data supported Earth applications as well as critical knowledge for space exploration beyond Low Earth Orbit. However, this is the proverbial tip of the iceberg and so much more can be done to maximize the scientific output of this unique international program. Facilitating access to these data repositories would be a powerful step to increase the impact of the ISS program, which will also benefit the international expertise in space research.

References

[1] NASA. (2022). *International Space Station benefits for humanity*. https://www.nasa.gov/wp-content/uploads/2022/09/iss_benefits_for_humanity_2022_book.pdf?emrc=170cd1

[2] Dansberry, B. E., Costello, K., Cohen, L., Schoen, A., Ngo-Anh, T. J., Shirakawa, M., Sakamoto, K., Karabadzhak, G., Savinkov, V., Sorokin, I. V., Cotronei, V., Valentini, G., & Anthony, E. (2021). Reflections on 20 years of research on the International Space Station. *Proceedings of the International Astronautical Congress*, IAC, B3.

[3] NASA. (2024). *Annual highlights of results from the International Space Station, 2024*. https://www.nasa.gov/wp-content/uploads/2025/02/ahr-2024-final.pdf?emrc=519fad

[4] Gebre, S. G., Scott, R. T., Saravia-Butler, A. M., Lopez, D. K., Sanders, L. M., & Costes, S. V. (2025). NASA open science data repository: Open science for life in space. *Nucleic Acids Research*, 53(D1), D1697–D1710. https://doi.org/10.1093/nar/gkae1116

[5] Stefanov, W.L., Jones, L.A., Cameron, A.K., Vanderbloemen, L.A., and Evans, C.A. (2019) A Researcher's Guide to: International Space Station Earth Observations (2nd Edition*). Johnson Space Center Publication* NP-2019-07-003-JSC, 58 p.

[6] Requier, A., Varade, S., Galvani, N., Pasquet, M., Cohen Addad, S., Gehin-Delval, C., Höhler, R., Pitois, O., Rio, E., Salonen, A., & Langevin, D. (2025). Wet foam coarsening: More than film permeability. *Journal of Colloid and Interface Science*, 696, 137825. https://doi.org/10.1016/j.jcis.2025.137825

[7] Volpe, G., Bechinger, C., Cichos, F., et al. (2022). Active matter in space. *npj Microgravity*, 8, 54. https://doi.org/10.1038/s41526-022-00230-7

[8] Fecht, H.-J., & Mohr, M**.** (Eds.). (2022). *Metallurgy in space: Recent results from ISS*. Springer Cham. https://doi.org/10.1007/978-3-030-89784-0

[9] Thoma, M. H., Thomas, H. M., Knapek, C. A., et al. (2023). Complex plasma research under microgravity conditions. *npj Microgravity*, 9, 13. https://doi.org/10.1038/s41526-023-00261-8

[10] Bassi, A., Cacciapuoti, L., Capozziello, S., et al. (2022). A way forward for fundamental physics in space. *npj Microgravity*, 8, 49. https://doi.org/10.1038/s41526-022-00229-0

[11] Warren, L. E. (2020). International Space Station open-source data. *Patterns*, 1, 100172. https://doi.org/10.1016/j.patter.2020.100172

[12] Ray, S., Gebre, S., Fogle, H., Berrios, D. C., Tran, P. B., Galazka, J. M., & Costes, S. V. (2019). GeneLab: Omics database for spaceflight experiments. *Bioinformatics*, 35(10), 1753–1759. https://doi.org/10.1093/bioinformatics/bty884

[13] Sanders, L. M., Grigorev, K. A., Scott, R. T., et al. (2024). Inspiration4 data access through the NASA Open Science Data Repository. *npj Microgravity*, 10, 56. https://doi.org/10.1038/s41526-024-00393-5

[14] Masson, A., De Marchi, G., Merin, B., Sarmiento, M. H., Wenzel, D. L., & Martinez, B. (2021). Google dataset search and DOI for data in the ESA space science archives. *Advances in Space Research*, 67(8), 2504–2516. https://doi.org/10.1016/j.asr.2021.01.035

[15] NASA. (n.d.). *Open-source science opportunities on the International Space Station*. NASA. https://www.nasa.gov/missions/station/open-source-science-opportunities/

[16] NASA. (n.d.). *Space Station Research Explorer*. https://www.nasa.gov/mission/station/research-explorer/

[17] Berrios, D. C., Beheshti, A., & Costes, S. V. (2018). FAIRness and usability for open-access

omics data systems. *AMIA Annual Symposium Proceedings*, 2018, 232–241. PMCID: PMC6371294

[18] Berrios, D. C., Galazka, J., Grigorev, K., Gebre, S., & Costes, S. V. (2021). NASA GeneLab: Interfaces for the exploration of space omics data. *Nucleic Acids Research*, 49(D1), D1515–D1522. https://doi.org/10.1093/nar/gkaa887

[19] Evans, C. A., Robinson, J. A., & Tate-Brown, J. M. (2009). Research on the International Space Station – An overview. *AIAA Aerospace Sciences Meeting*, AIAA 2009-186. https://doi.org/10.2514/6.2009-186

[20] Scott, R. T., Grigorev, K., Mackintosh, G., Gebre, S. G., Mason, C. E., Del Alto, M. E., & Costes, S. V. (2020). Advancing the integration of biosciences data sharing to further enable space exploration. *Cell Reports*, 33(10), 108441. https://doi.org/10.1016/j.celrep.2020.108441

[21] Overbey, E. G., Kim, J., Tierney, B. T., et al. (2024). The Space Omics and Medical Atlas (SOMA) and international astronaut biobank. *Nature*, 632, 1145–1154. https://doi.org/10.1038/s41586-024-07639-y