National Aeronautics and Space Administration

International Space Station Facilities

Research in Space 2017 and Beyond

CSA ASC

esa

JAXA

ROSCOSMOS

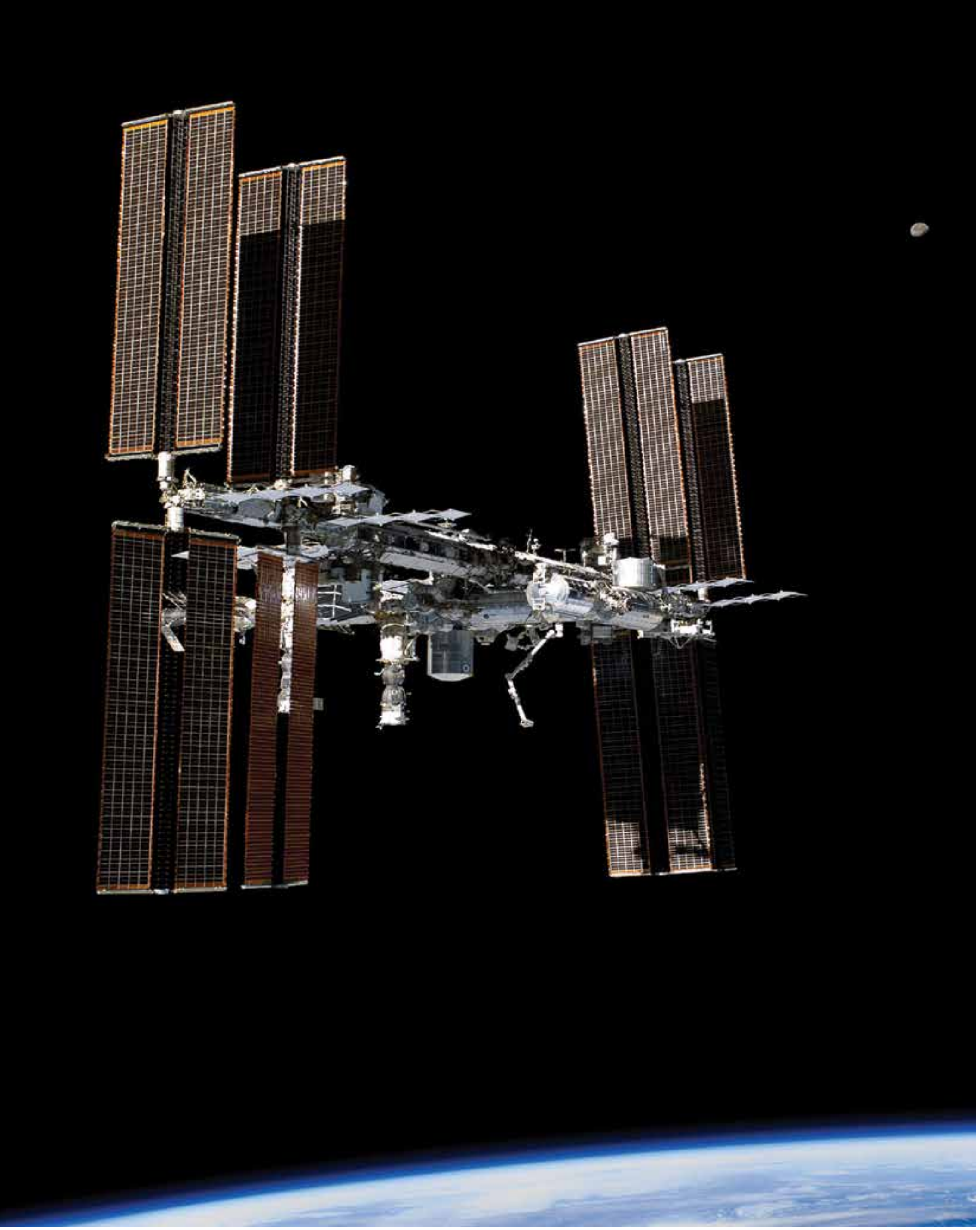

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Table of Contents

Welcome to the International Space Station

The International Space Station (ISS) is an unprecedented human achievement from conception to construction, to operation and long-term utilization of a research platform on the frontier of space.

Fully assembled and continuously inhabited by all space agency partners, this orbiting laboratory provides a unique environment in which to conduct multidisciplinary research and technology development that drives space exploration, basic discovery and Earth benefits.

The ISS is uniquely capable of unraveling the mysteries of our universe—from the evolution of our planet and life on Earth to technology advancements and understanding the effects of spaceflight on the human body. This outpost also serves to facilitate human exploration beyond low-Earth orbit to other destinations in our solar system through continued habitation and experience.

This orbiting laboratory is humanity's largest foothold in space. Exploration, research and discovery, bound with international cooperation and commercial development, serve to highlight the best that we can be.

We look forward to sharing this brochure, which outlines and highlights our ISS research capabilities and potential as we continue to push the bounds of on-orbit research.

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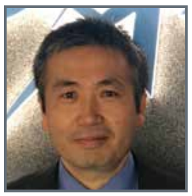

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Research Goals of Many Nations

It is the unique blend of unified and diversified goals among the world's space agencies that will lead to improvements in life on Earth for all people of all nations. While the various space agency partners may emphasize different aspects of research to achieve their goals in the use of the ISS, they are unified in several important overarching goals.

All of the agencies recognize the importance of leveraging the ISS as an education platform to encourage, inspire and ultimately motivate today's youth to pursue careers in math, science and engineering: **educating the children of today to be the leaders and space explorers of tomorrow.**

Advancing our knowledge in the areas of human physiology, biology, material and physical sciences and translating that knowledge to health, socio-economic and environmental benefits on Earth is another common goal of the agencies: **returning the knowledge gained in space research for the benefit of society.**

Finally, all the agencies are unified in their goals to apply knowledge gained through ISS research in human physiology, radiation, materials science and engineering to enable future space exploration missions: **preparing for the human exploration of destinations beyond low-Earth orbit.**

An Orbiting Laboratory Complex

The laboratories and operational components of the ISS have been assembled and are up and running. As all ISS partner nations expand their research programs, international collaboration and interaction among scientists worldwide is growing rapidly.

The ISS has become a unique laboratory in space since its initial habitation in 2000 by the Expedition 1 crewmembers. At that time, the Zvezda Service Module of the Russian Segment was the primary module for conducting research. The US Destiny laboratory arrived on orbit in 2001 and provided researchers additional capabilities and facilities. The ISS capabilities for conducting research expanded significantly in 2008 with the addition of the European Space Agency (ESA) Columbus module and Japan Aerospace Exploration Agency (JAXA) Kibo laboratory, as well as several external platforms. The ISS Russian Segment expanded with the inclusion of the Mini Research Modules (MRMs)—Poisk (MRM2) and Rassvet (MRM1)—in 2009-2010. Over these final years of assembly, many initial experiments were completed in the newest racks and the crew complement onboard the ISS doubled to accommodate 6 rotating crewmembers; thus, our transition from "early utilization" to "full utilization" of the ISS became reality.

At this time, construction and enhancement of the ISS Russian Segment continues. The Multipurpose Laboratory Module (MLM), which is scheduled for launch in 2017, will be the largest Russian laboratory in the ISS complex. Following the MLM, Node Module and Scientific-Power Module will be launched in 2019. All of these modules, as well as the existing ones, will provide new capabilities for accommodation of existing and next-generation research facilities.

Early science on the ISS has taught us much about what to expect as additional research facilities become operational. Many hypotheses about what will happen without gravity are being challenged across the scientific spectrum. Data from ISS experiments are causing scientists to rethink existing models and propose different lines of research as they seek to understand new data from orbit. Rather than waiting years for the next flight opportunity, ISS discoveries generate new hypotheses that can often be tested in a short period of time—in the same way that scientists would follow a compelling result in a laboratory on Earth. We are able to push the bounds of previous research and extend the duration of investigations over many months and even years. We do not yet know what will be the most important knowledge or benefit gained from the ISS; however, through dedication to research, we do know that some amazing discoveries are on their way!

Knowledge and Benefits for all Humankind

The ISS is a unique scientific platform that enables researchers from all over the world to put their talents to work on innovative experiments that could not be done anywhere else. Although each space station partner has distinct agency goals for station research, each partner shares a unified goal to extend the resulting knowledge for the betterment of humanity. We may not know yet what will be the most important discovery gained from the space station, but we already have some amazing breakthroughs.

In the areas of human health, innovative technology, education and observations of Earth from space, benefits have already been demonstrated to people back on Earth. Lives have been saved, station-generated images assist with disaster relief, new materials improve products and education programs inspire future scientists, engineers and space explorers.

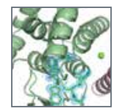
The *International Space Station Benefits for Humanity, 2nd Edition,* summarizes the scientific, technological and educational accomplishments of research on the space station that have and will continue to impact life on Earth. All of these accomplishments serve as examples of the space station's potential as a groundbreaking research facility. Through advancing the state of scientific knowledge of our planet, looking after our health, developing advanced technologies and providing a space platform that inspires and educates the science and technology leaders of tomorrow, these benefits will drive the legacy of the space station as its research strengthens economies and enhances the quality of life here on Earth for all people.

Highlights from the *International Space Station Benefits for Humanity, 2nd Edition*

Robotic arms lend a healing touch
The world's first robotic technology capable of performing surgery inside magnetic resonance machines makes difficult surgeries easier or impossible surgeries possible.

Improved eye surgery with space hardware
An eye-tracking device allows the tracking of eye position without interfering with a surgeon's work during corrective laser eye surgery.

Bringing space station ultrasound to the ends of the Earth
Small ultrasound units, tele-medicine and remote guidance techniques make medical care more accessible in remote regions.



High-quality protein crystal growth experiment aboard Kibo
Protein crystal growth experiments contribute to the development of medical treatments. JAXA is making positive advancements in research on obstinate diseases through experiments in space.

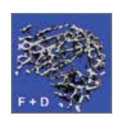
Earth remote sensing from the space station
ISS contributes to humanity by collecting data on global climate, environmental change, and natural hazards using its unique complement of crew-operated and automated Earth observation payloads.

Advanced ISS technology supports water purification efforts worldwide
At-risk areas can gain access to advanced water filtration and purification systems affording them clean drinking water.

Tomatosphere™: Sowing the seeds of discovery through student science
This award-winning educational project with an estimated 3 million students participating is helping researchers answer questions about growing food in space while teaching students about science, agriculture and nutrition.

Calling cosmonauts from home
Currently aboard the Russian segment of the station are four space investigations that have educational components to inspire future generations of scientists, technologists, engineers and mathematicians.

Commercialization of low-Earth orbit (LEO)
Forward-thinking, agile companies like NanoRacks and UrtheCast believe routine utilization of the unique environment of outer space has come of age, and that at long last ISS is open for business.



Space mice teach us about muscle and bone loss
Biotech and pharmaceutical companies like Amgen use spaceflight to study their drugs and do preclinical work important for FDA approval.

The book is available electronically at http://www.nasa.gov/mission_pages/station/research/benefits/index.html.

Astronaut Sandra Magnus works with the Smoke Point In Co-flow Experiment (SPICE) using the Microgravity Science Glovebox (MSG) during Expedition 18 (ISS018E026974).

What is an ISS Facility?

The purpose of this reference document is to detail the research facilities located on the ISS and to provide a short description of each facility. The research facilities listed here meet the following definition:

ISS research facilities enable scientific investigations and are defined as 1) available onboard or as a sortie to the ISS for long periods of time (i.e., more than a single increment) **and** 2) can be scheduled for use by investigators **or** provide an interface for connecting investigations to the ISS/environment by someone other than the hardware's original developer/owner.

Keeping this definition in mind, the remainder of this document outlines and highlights the capabilities of the facilities already or soon to be in use onboard the ISS as of the date of this publication.

Since the list of all facilities onboard the ISS (and the availability of those facilities) periodically changes, please be sure to contact the Program Science Office in case of questions at jsc-iss-research-helpline@mail.nasa.gov, or check the latest facility information, availability and research results at http://www.nasa.gov/stationfacilities. Additional information on ISS facilities can also be found in the ISS Researcher's Guide (https://www.nasa.gov/mission_pages/station/research/researcher_guide) series.

Why do we highlight facilities onboard the ISS? These facilities enable research by providing the infrastructure and equipment to conduct many different experiments. By leveraging these existing facilities, researchers can develop scientific protocols and conduct research more efficiently and with less expense. The facilities described in this book can be available for utilization and should be considered a starting point for developing ISS research proposals.

ISS Research History and Status

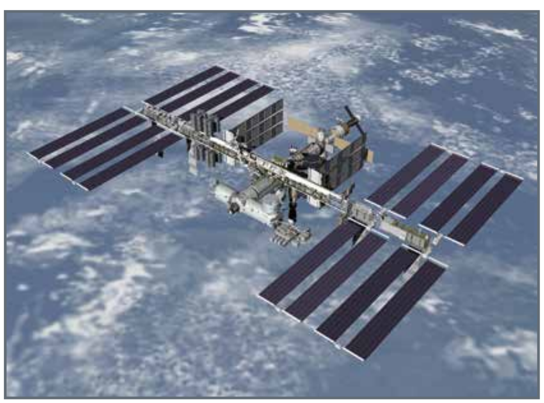
The ISS was first inhabited just before the turn of the millennium. This laboratory in space has continuously grown and supports ongoing research into how the microgravity environment impacts fields of research from the physical sciences to biology to human physiology. Much of the knowledge gained crosses over and directly impacts many aspects of our daily lives.

In 2009, a significant space exploration goal was established. The number of astronauts capable of living onboard the ISS increased from 3 to 6, providing researchers with more astronaut time to perform ISS research. In addition, ISS laboratories now accommodate an unprecedented amount of space-based research with new and exciting capabilities being continuously proposed and developed.

This Earth-orbiting laboratory and living facility houses astronauts who continuously conduct science across a wide variety of fields including human life sciences, biological science, human physiology, physical and materials science, and Earth and space science. More than 1900 unique experiments have been conducted on the ISS during the past 16 years of continuous research.

Current ISS utilization statistics, including a cumulative history of research completed, is continuously being tracked and updated, and can be found here: https://www.nasa.gov/sites/default/files/atoms/files/expeditions_0-46_utilization_statistics_brochure_final_pdf.pdf.

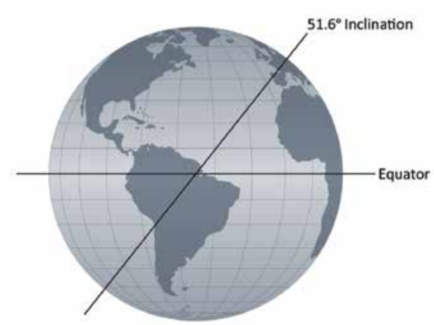
For up-to-date information regarding ISS activities, research and accomplishments, please visit the following link: http://www.nasa.gov/iss-science.



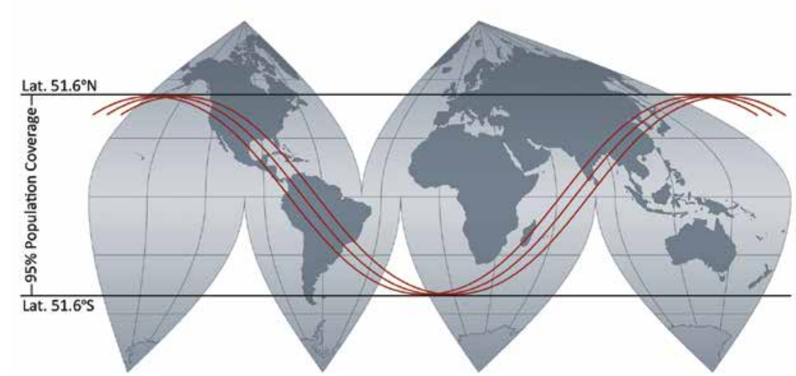
Computer-generated scene showing the International Space Station (JSC2006E25646).

ISS Topology "Where things are!"

This section provides an overview of the ISS, its structures, and the locations that house and supply all of the individual ISS research facilities. All labels and locations depict the onboard layout at the time of this publication, though upgrades are planned and in work.

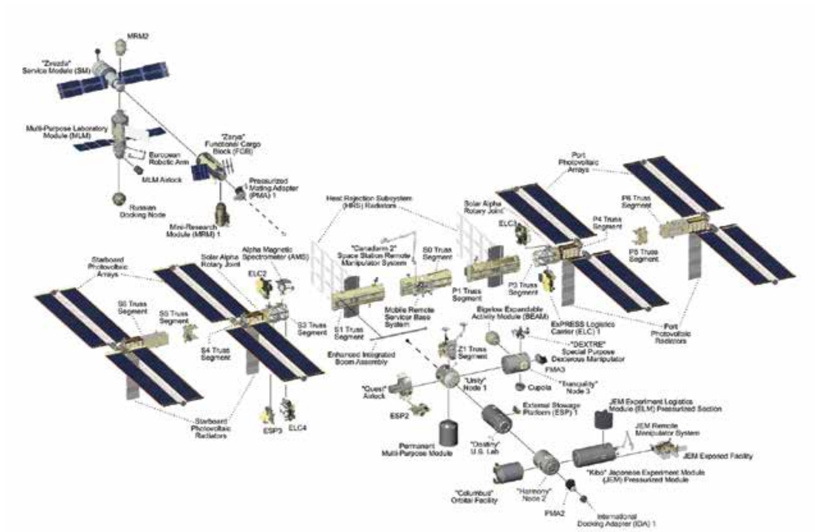


Orbiting once every 90 minutes, the ISS passes over 90 percent of the Earth's habitable land mass.

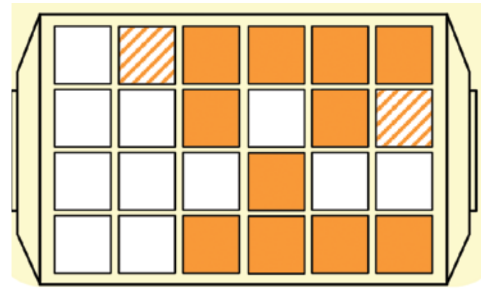


Before we begin discussing the layout, we should review a little about the unique location this laboratory inhabits high above our heads. The ISS resides in a 51.6-degree inclined low-Earth orbit that repeatedly provides a view of the majority of the populated surface of the Earth. Perpetually free-falling, the microgravity environment on the ISS provides a unique location for conducting unparalleled biological, physical, Earth and space science research. From an average altitude of 400 km, surface details in such features as glaciers, agricultural fields, cities and coral reefs can be clearly observed. Coordinated with ground observations, the ISS provides a flexible, repeatable and efficient sources of space-based data.

This graphical breakout shows the major ISS elements and components with regard to their current locations.

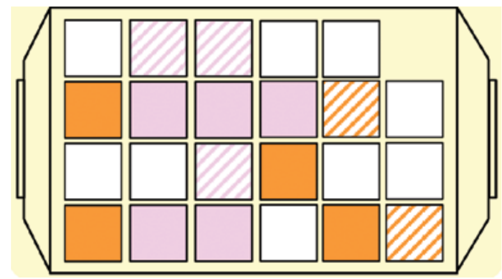


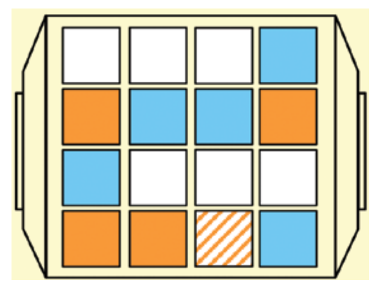
US On-orbit Segment (USOS) Laboratory Research Rack Locations at Increment 47/48



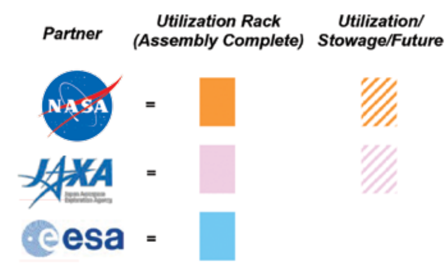
Destiny

Kibo



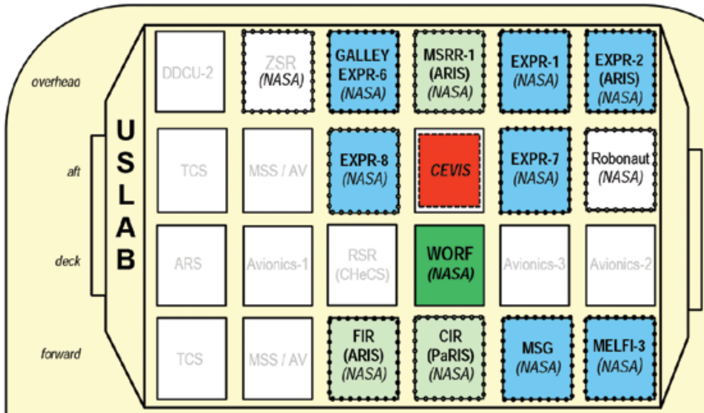


Columbus



ISS Destiny Laboratory Internal Facility Locations

Configuration for Increment 47/48



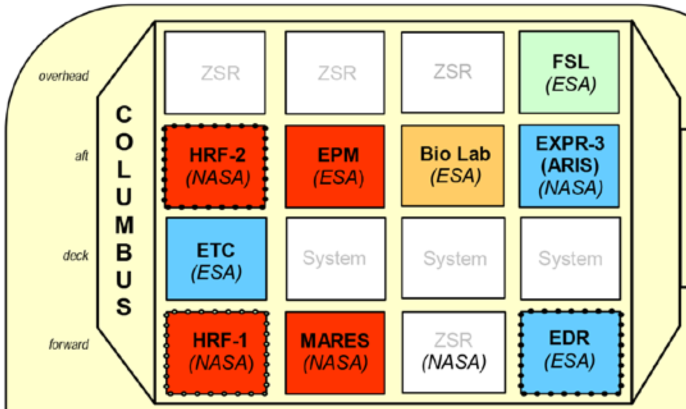
CEVIS = Cycle Ergometer with Vibration Isolation System
CIR (PaRIS) = Combustion Integration Rack (Passive Rack Isolation System)
EXPR-# = EXPRESS Rack Number
FIR (ARIS) = Fluids Integrated Rack (Active Rack Isolation System)
MELFI-# = Minus Eighty Degrees Laboratory Freezer for ISS
MSG = Microgravity Science Glovebox
MSRR-# (ARIS) = Materials Science Research Rack (Active Rack Isolation System)
WORF = Window Observational Research Facility
ZSR = Zero-Gravity Stowage Rack

11 NASA Utilization Racks

- Physical Sciences and Materials Research
- Earth Science
- Human Research
- Multipurpose
- Systems and Stowage
- ARIS/PaRIS Capable

ISS Columbus Laboratory Internal Facility Locations

Configuration for Increment 47/48



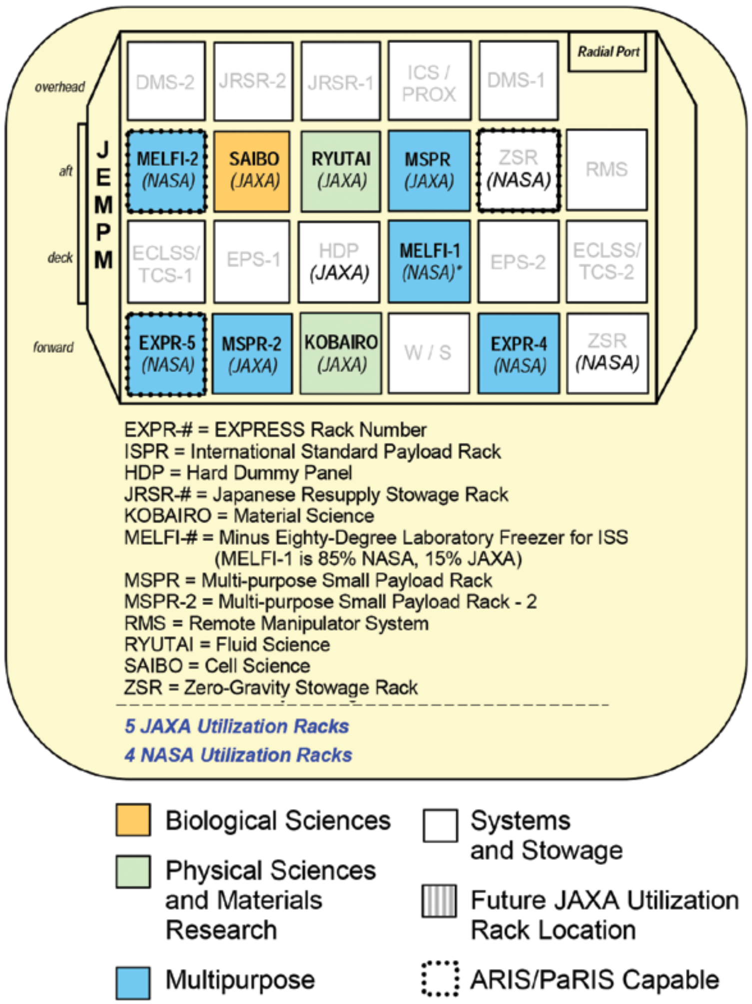
Bio Lab = ESA Biolab Facility
EDR = European Drawer Rack
EPM = European Physiology Module
ETC = European Transport Carrier
EXPR-# (ARIS) = EXPRESS Rack Number (Active Rack Isolation System)
FSL = Fluid Science Laboratory
HRF-# = Human Research Facility-Number
MARES = Muscle Atrophy Resistive Exercise System
ZSR = Zero-Gravity Stowage Rack

4 NASA Utilization Racks
5 ESA Utilization Racks

- Biological Sciences
- Human Research
- Physical Sciences and Materials Research
- Multipurpose
- Systems and Stowage
- ARIS/PaRIS Capable

ISS Kibo Laboratory Internal Facility Locations

Configuration for Increment 47/48



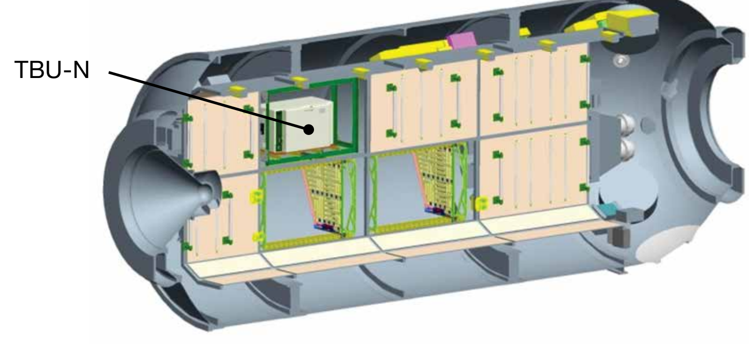
ISS Russian Segment Laboratory Internal Research Locations

The Russian Segment has 5 modules used to support on-orbit research: the Zvezda Service Module, the MRMs (MRM1 and MRM2), the Docking Compartment-1 Pirs, and one US-sponsored module—the Functional Cargo Block Zarya. Additional modules are planned for the future.

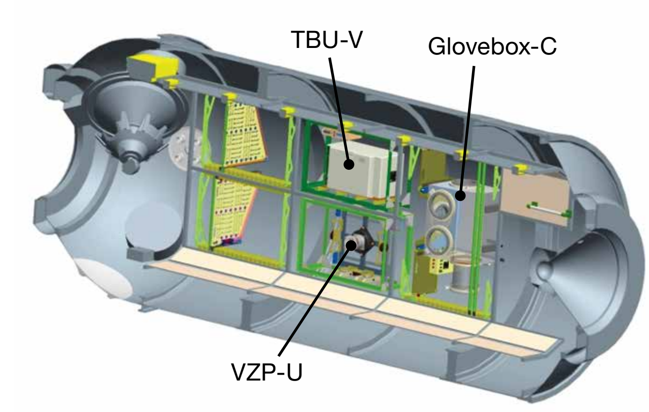
The MRM1 module contains 8 internal workstations equipped with facilities including a glovebox, 2 incubators (TBU-V and TBU-N) to accommodate high- and low-temperature experiments, and a Multipurpose Vibration Protective Platform (VZP-U).

The MLM, which is scheduled for launch in 2017, will be the largest Russian laboratory in the ISS complex.

MRM1 - Port side



MRM1 - Starboard side



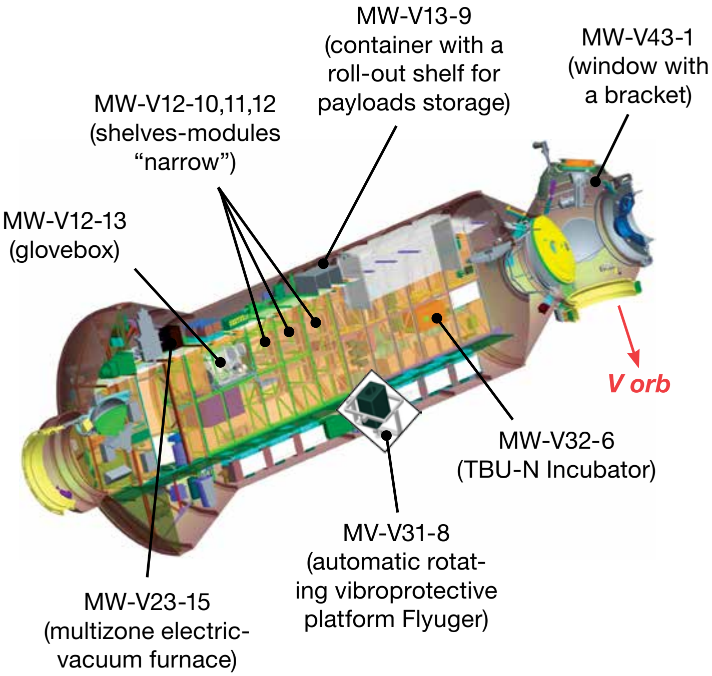
Graphics courtesy of
Roscosmos State Corporation, 2011

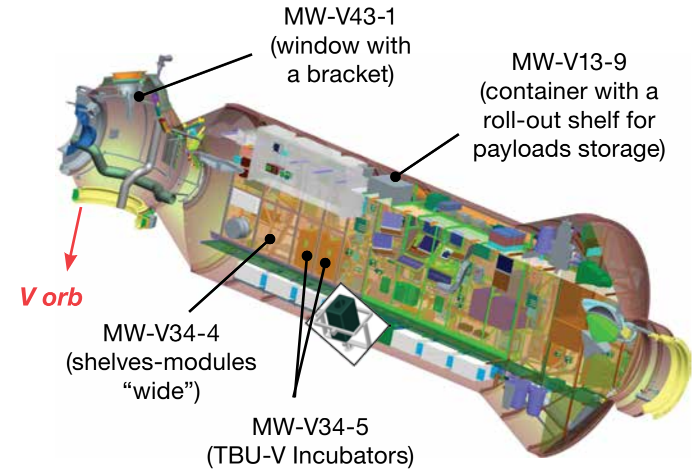
MLM Onboard Support Facilities and Mechanical Adapters Accommodations

In the pressurized compartment of the module, 14 multipurpose workstations (MWs) equipped with mechanical adapters and support facilities are established, seven MWs for equipment storage and four MWs will be equipped with roll-out shelves-modules.

- One roll-out shelf with a glovebox (Glovebox-C facility)
- Two roll-out shelves-modules with Universal Biotechnological Incubators for higher temperature (TBU-V)
- One roll-out shelf-module with Universal Biotechnological Incubator for lower temperature (TBU-N)
- One roll-out shelf-module with automatic rotating vibroprotective platform Flyuger
- Two MW with multizone electric-vacuum furnace
- One MW near the 426 mm Ø window equipped with a bracket to implement Crew Earth Observing experiments
- Three working areas on panels of interior equipped with mechanical adapters to install payloads

MLM – Starboard Side

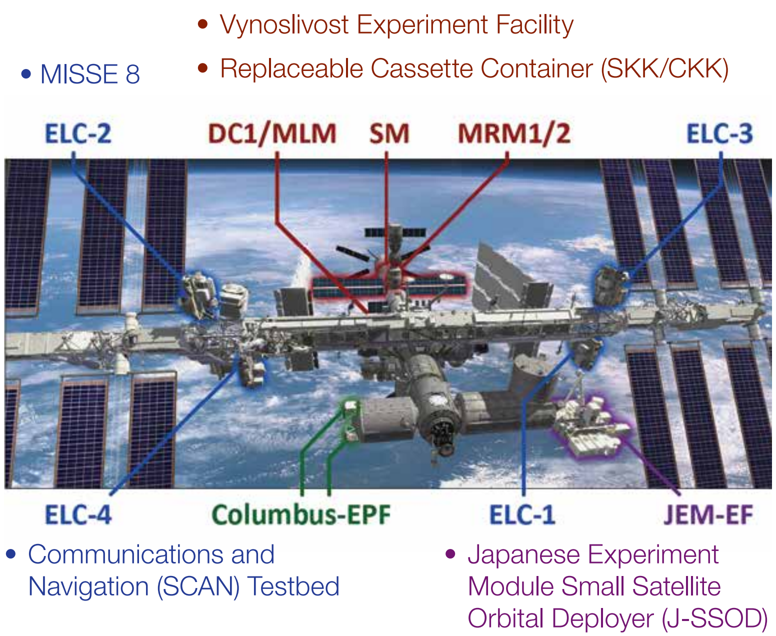




MLM – Port Side

ISS External Facility Locations

This graphical representation of the ISS flying toward the viewer highlights the primary locations where external facility interface infrastructure and hardware is located, including a subset of current ISS facilities housed at those locations.



Multipurpose Laboratory Facilities

Multipurpose ISS facilities represent a wide array of internal and external structures and devices designed to support a variety of investigations. These facilities often provide attachment locations for individual investigations or provide an assortment of research equipment that can be used by different research teams in furthering their own experiments.

This section is divided into two areas to highlight those facilities that are available inside the habitable volume of the ISS, as well as those that are external and open to the space environment. Additions and changes to the makeup of these facilities occurs over time. The remainder of this section provides an overview of current capabilities and locations:

Internal Facilities:

- European Drawer Rack (EDR) [ESA]
- European Physiology Module (EPM) [ESA]
- Expedite the Processing of Experiments to Space Station (EXPRESS) Racks [NASA]
- Freezer Refrigerator of Stirling Cycle (FROST) [JAXA]
- General Laboratory Active Cryogenic ISS Equipment Refrigerator (GLACIER) [NASA]
- Life Sciences Glovebox (LSG) [NASA]
- Light Microscopy Module (LMM) [NASA] - described in Physical Science Research
- Microgravity Acceleration Measurement System/Space Acceleration Measurement System-II (MAMS/SAMS-II) [NASA]
- Microgravity Experiment Research Locker/Incubator (MERLIN) [NASA]
- Microgravity Science Glovebox (MSG) [ESA, NASA]
- Minus Eighty-Degree Laboratory Freezer for ISS (MELFI) [ESA, JAXA, NASA]
- Multi-purpose Small Payload Rack (MSPR) [JAXA]
- Multi-purpose Small Payload Rack-2 (MSPR-2) [JAXA]
- NanoRacks Platforms [NASA, Commercial]
- Polar [NASA]
- Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Facility [NASA]

External Facilities:

- Columbus-External Payload Facility (Columbus-EPF) [ESA]
- Expedite the Processing of Experiments to the Space Station (EXPRESS) Logistics Carrier (ELC) [NASA]
- Exposed Experiment Handrail Attachment Mechanism (ExHAM) [JAXA]
- Intravehicular Activity (IVA)-replaceable Small Exposed Experiment Platform (i-SEEP) [JAXA]
- Japanese Experiment Module (JEM) External Facility (JEM-EF) [JAXA]
- JEM Small Satellite Orbital Deployer (J-SSOD) [JAXA]
- NanoRacks CubeSat Deployer (NRCSD) [NASA, Commercial]
- NanoRacks MicroSat Deployer (Kaber) [NASA, Commercial]
- NanoRacks External Platforms (NREP) [NASA, Commercial]
- Russian Segment External Facilities [Roscosmos]
- Space Station Integrated Kinetic Launcher for Orbital Payload Systems (SSIKLOPS) or Cyclops [NASA]

Internal Multipurpose Facilities

The following section provides an overview of existing internal facilities that are multidisciplinary in nature, providing access to the microgravity environment as well as ISS resources and crewmembers.

International Standard Payload Rack Utilities and Capabilities

Power

- 3, 6 or 12 KW, 114.5-126 VDC

Gases

- Nitrogen
  - Flow = 0.1 kg/minute minimum, 517-827 kPa nominal, 1379 kPa maximum
  - 517-827 kPa nominal, 1379 kPa maximum
- Argon, Carbon Dioxide, Helium
  - 517-768 kPa nominal, 1379 kPa maximum

Data

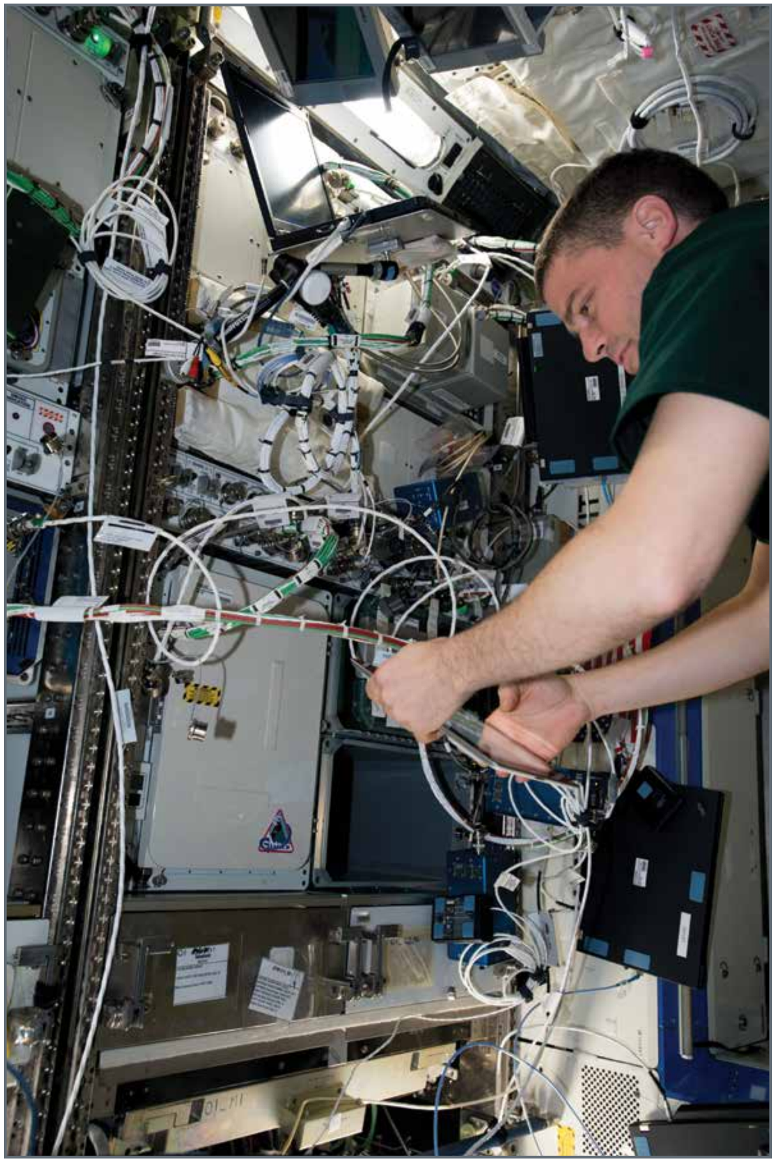
- Lo Rate: MIL-STD- 1553 bus 1Mbps
- High Rate: 100 Mbps
- Ethernet: 10 Mbps
- Video: NTSC

Vacuum

- Venting: 10^{-3} torr in less than 2 hours
- Vacuum Resource: 10^{-3} torr

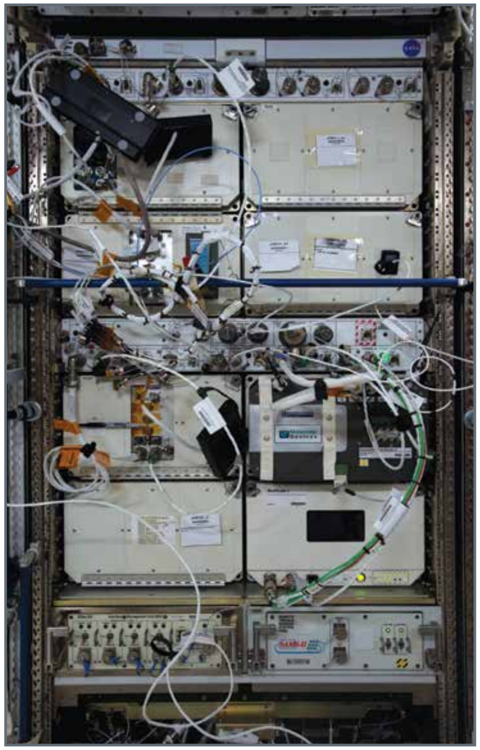
Cooling Loops

- Moderate Temperature: 16.1°C - 18.3°C
- Flow rate: 0-45.36 kg/hr
- Low Temperature: 3.3°C - 5.6°C
- Flow rate: 233 kg/hr



ISS crewmember Reid Wiseman during GLACIER install from the EXPRESS Rack 2 (ISS041E078070).

Expedite the Processing of Experiments to Space Station (EXPRESS) Racks [NASA] are modular multipurpose payload racks designed to store and support experiments aboard the ISS. Each rack provides structural interfaces, power, data, cooling, water and other items needed to operate science experiments on the ISS. Experiments are exchanged in and out of **EXPRESS Racks** as needed; some smaller multi-user facilities will remain in **EXPRESS** for the life of the ISS, whereas others are used for only a short period of time.

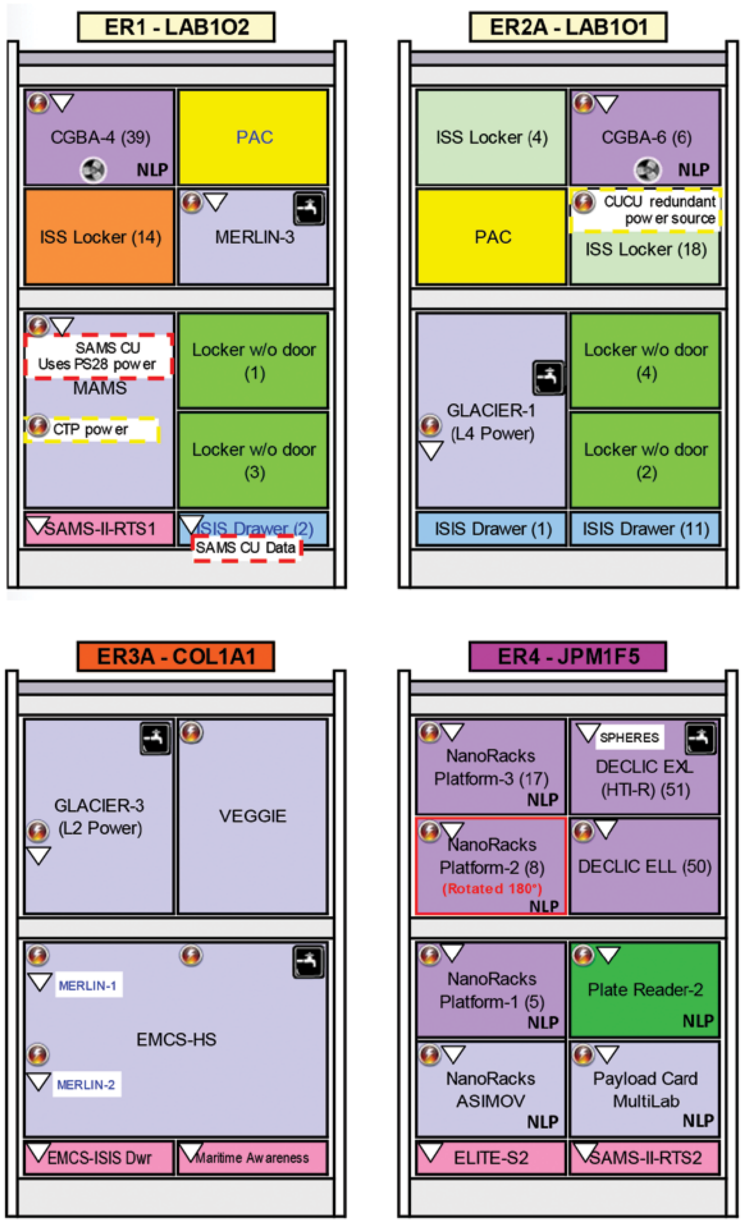


EXPRESS Rack 4 located in the JEM during ISS Expedition 49 (ISS049E040805).

EXPRESS Racks are one of the primary means of accommodating scientific hardware in the habitable volume of the ISS. **EXPRESS Racks** are the most flexible modular research facility available on the ISS, and are used by NASA, JAXA and ESA

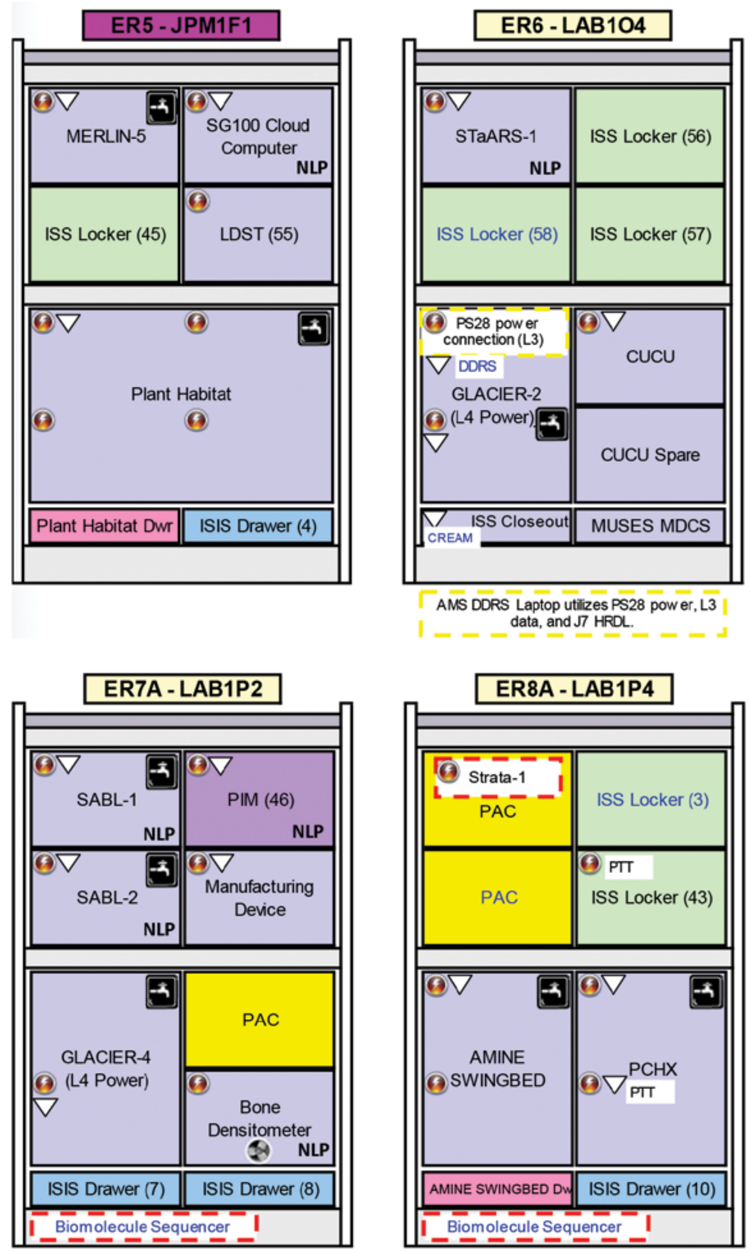
EXPRESS Rack Configuration

Layout of all ISS EXPRESS Racks as planned through the SpaceX-11 mission docked operations timeframe. See legend (page 28) for more details.



EXPRESS Rack Configuration

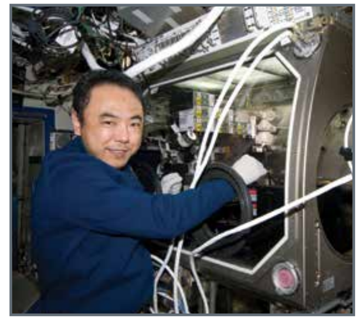
See legend (page 28) for more details.



EXPRESS Rack Configuration Key

- ISS Locker - Stowage Locker
- ISS Locker - Reserved for Lean Payloads
- Payload - Payload Insert
- Payload - Locker Replacement Payload
- PAC - Payload Air Closeout
- ISIS Dwr - ISIS Drawer
- Payload - Drawer Replacement Payload
- requires water (TCS)
- requires EXPRESS Rack provided power
- requires EXPRESS Rack provided data connection
- Front Breather payload
- deployed payload
- power resource utilized
- NLP - National Lab Payload

Gloveboxes provide containment for experiments, ensuring that small particles or hazardous materials are confined and do not float about the cabin. The **Microgravity Science Glovebox (MSG)** is continuously used for experiments ranging from combustion science, to the study of complex fluids, to the preparation of biological specimens.



JAXA astronaut Satoshi Furukawa, Expedition 29 flight engineer, works at the MSG in the Destiny laboratory of the ISS (ISS029E040016).

The **Microgravity Science Glovebox (MSG) [ESA, NASA]** is an International Standard Payload Rack size facility where experiments in the field of material science, biology and biotechnology, fluid science, combustion science and crystal growth research can be conducted in a closed and protected environment. Experiments are housed within the glovebox, thereby protecting the crewmembers who are conducting the research. Access to the experiment hardware inside the glovebox is through specially designed ports equipped with rugged, sealed gloves. The work volume is equipped with lighting, mechanical, electrical, data, gas and vacuum connections, as well as thermal control. An attached airlock allows specimens and tools to be inserted or removed during **MSG** operations with limited environmental exchange between the working volume and the ISS cabin. Built by ESA and operated by NASA, **MSG** is the largest glovebox ever flown in space.

The **Life Sciences Glovebox (LSG) [NASA]** provides a sealed work area in the ISS specifically for life science and biological experiments. The **LSG** allows crewmembers to safely perform experimental procedures requiring confinement and supports experiments by providing power, lighting, vacuum, active filtration as well as thermal control. Animal habitats can be designed to attach to the **LSG** in a manner that prevents contamination of the crew cabin. The **LSG** is currently in development and is scheduled to be available for use in 2018.

The LSG. Image courtesy of Bradford Engineering.

European Drawer Rack (EDR) [ESA] is a highly flexible, multidisciplinary facility that supports up to seven modular experiment modules. Each payload has its own cooling, power, data communications, vacuum, venting and nitrogen supply. **EDR** facilitates autonomous operations of sub-rack types of experiments in a wide variety of scientific disciplines. The **EDR** also provides a data downlink capability for an ESA high-definition three-dimensional video camera.

ISS crewmember Alex Gerst during installation completion of the EML inside the EDR in the Columbus module. (ISS041E107734).

Since 2014, the **EDR** has accommodated the **ElectroMagnetic Levitator (EML)** a facility for basic materials science and applied research that provides containerless melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and high purity gas conditions. Heating and positioning of the sample is achieved by electromagnetic fields generated by a coil system. The Facility for Adsorption and Surface Tension (FASTER) investigation studied the links between emulsion stability and physicochemical characteristics of droplet interfaces, as well as various protein crystal growth studies that attempt to understand how crystals grow in purely diffusive condition.

Instruments originally hosted within **EPM** included Cardiolab (French Space Agency (CNES) and German Aerospace Center (DLR), which supported many different human research investigations including PEMS.

Eropean Physiology Module (EPM) [ESA] is a multi-user facility originally designed for investigating the effects of microgravity on short-term and long-duration spaceflight on the human body and included equipment for studies in neuroscience, cardiovascular, bone and muscle physiology as well as investigations of metabolic processes. The **EPM** now hosts multiple investigations, including physical science and radiation monitoring investigations such as Dose Distribution Inside the International Space Station (DOSIS).

ISS crewmember Chris Hadfield is photographed in front if the EPM during BP Reg (a simple in-flight method to test the risk of fainting on return to Earth after long-duration space flights) experiment operations. He is wearing the Leg/Arm Cuff System (LACS) on his thighs, and the Continuous Blood Pressure Device on his left hand (ISS035E022357).

Multi-purpose Small Payload Rack (MSPR) [JAXA] is a multi-user facility that has a work volume that can hold research hardware and a workbench, and a small experiment area. The rack also provides general interfaces, such as power, nitrogen gas supply and exhaust, heat rejection, smoke detection, sound suppression, communications and video. The **MSPR** can support a wide range of research hardware as well as educational objectives.

NASA astronaut Karen Nyberg works to setup the MSPR fluorescence microscope in the Kibo laboratory of the ISS during ISS Expedition 36 (ISS036E020949).

Multi-purpose Small Payload Rack - 2 (MSPR-2) [JAXA] is a multi-user facility developed as a series payload rack of **MSPR**. **MSPR-2** electrical components and user interface have compatibility with **MSPR**. Some user resources are updated, such as power supply, gas supply and video interface. The primary purpose of the **MSPR-2** is to support **Electrostatic Levitation Furnace (ELF)** experiments.

MSPR-2 ELF set up by astronaut Scott Kelly in the JEM Pressurized Module (ISS046E018682).

The FROST Installed on JEM1A7-10 panel in the JEM during ISS Expedition 36 (ISS036E037475).

The **Freezer Refrigerator of Stirling Cycle (FROST) [JAXA]** is able to keep temperatures below -70°C even during power outages.

General Laboratory Active Cryogenic ISS Equipment Refrigerator (GLACIER) [NASA] serves as an ascent/descent and on-orbit ultra-cold refrigerator/freezer. **GLACIER** temperature is limited to -95°C to +4°C for ascent/descent due to power and resource constraints, but can provide -160°C to +4°C on the ISS. The **GLACIER** has a generic tray design that allows multiple sizes of science samples requiring cryogenic thermal storage to utilize the **GLACIER**.

ISS crewmember Koichi Wakata, Expedition 20 flight engineer, works with the GLACIER in the U.S. Laboratory of the ISS (ISS020E010017).

Microgravity Experiment Research Locker/Incubator (MERLIN) [NASA] can be used as either a freezer, refrigerator or an incubator (between -20.0°C to + 48.5°C). **MERLIN** can be used during transportation to and from the ISS; however, its primary use is on the ISS.

ISS crewmember Tracy Caldwell Dyson works with the MERLIN in the Destiny laboratory of the ISS (ISS024E008590).

Polar [NASA] provides cold stowage in support of research objectives during transport to and from the ISS as well as onboard the ISS. Polar can meet researchers' requirements from -80°C to +4°C, operates on 75 W supplied power and uses air cooling as its heat rejection method.

Installation of Polar during ISS Expedition 47 (ISS047E070826).

Just as in any Earth-based laboratory, refrigerators and freezers are critical for conducting research. The ISS has multiple types of specialized refrigerators and freezers that can be configured to specific research requirements. Several of these not only are resident on the ISS, they will be used in launch and return vehicles to meet delivery and return research requirements.

Minus Eighty-Degree Laboratory Freezer for ISS (MELFI) [ESA, NASA, JAXA] freezers allow for fast freezing and storage of samples at temperatures below -80°C. **MELFI** is designed to maintain temperature below -68°C for 8 hours in the event of a power failure. **MELFI** has multiple set points to accommodate a range of research requirements.

ISS crewmembers Ron Garan (left) and Mike Fossum remove samples from GLACIER and insert in the MELFI-1 in the Kibo laboratory of the ISS (ISS028E014916).

The ability to rapidly freeze biologic samples is a requirement of many researchers and is critical for meeting their research objectives. In Earth-based labs, liquid nitrogen is commonly used to flash freeze samples; however, due to microgravity on ISS, liquid nitrogen freezing is not feasible. Several of the existing freezers on the ISS can offer cooling rates for small samples that approach that of liquid nitrogen. New facilities are currently in development to address the need of the research community in regard to flash freezing of both small and large samples.

NanoRacks Platforms [NASA, Commercial] support CubeLab Modules by providing power and data transfer capability to operate investigations on the space station. Each platform provides room for up to 16 customer payloads to plug into a USB connector, which provides both power and data connectivity. This standardized interface reduces integration cost and schedule for research on the orbiting laboratory. The CubeLab Module is designed to be flexible enough that most mission concepts can be accommodated.

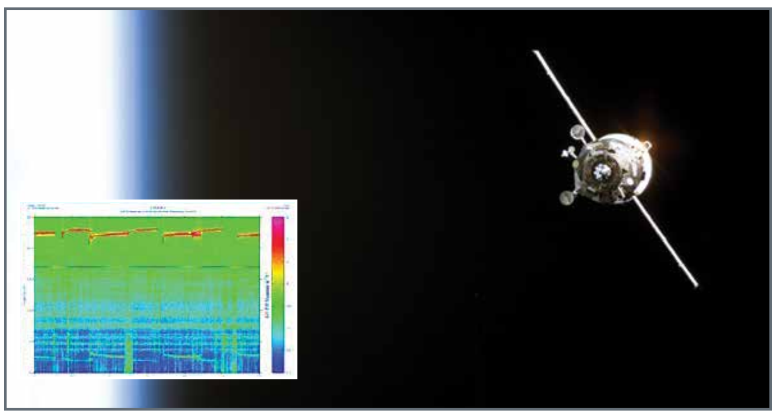
Luca Parmitano observing the Student Spaceflight Experiments Program CubeLab module during ISS Expedition 36/37 (ISS037E004825).

Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Facility [NASA] is a suite of free-flying satellites used to perform preprogrammed coordinated flight demonstrations and is capable of supporting multiple attachments to perform investigations from fluid physics to technology demonstrations. The **SPHERES Facility** has been used for numerous investigations to date, as well as educational outreach and student competitions.

Astronaut Greg Chamitoff programming a SPHERES test run during Expedition 17 and 18 (ISS018E005212).

The **Microgravity Acceleration Measurement System (MAMS)** and the **Space Acceleration Measurement System-II (SAMS-II) [NASA]** measure the forces, or vibrations and accelerations, on the ISS that result from the operation of hardware, crew activities, dockings and maneuvering. Results are used to generalize the types of vibrations affecting vibration-sensitive experiments and quantify the accelerations in the space station environment during experiment operations. The SAMS-II and the MAMS are complementary, the SAMS-II measures acceleration disturbances between 0.01 Hz and 400 Hz, and MAMS measures accelerations below 0.01 Hz.

ISS crewmember Frank Culbertson poses with MAMS hardware in the U.S. Laboratory during Expedition 3 (ISS003E6010).

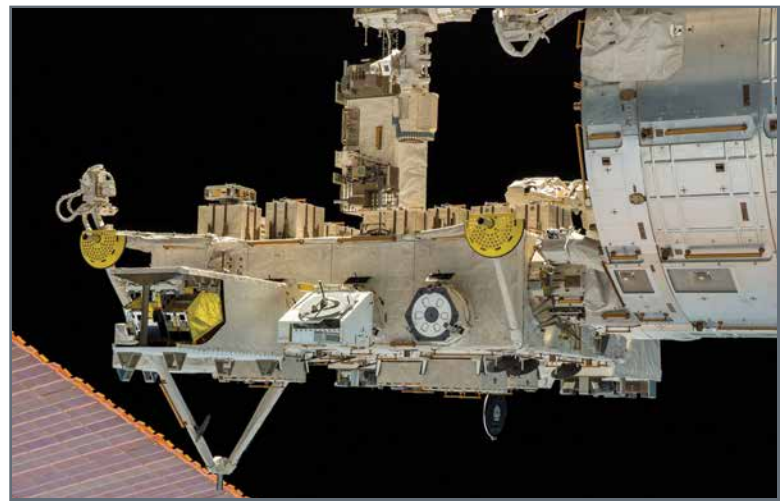


An unmanned Progress supply vehicle approaches the ISS during Expedition 7 against a backdrop of the blackness of space and Earth's horizon. Inset image shows microgravity acceleration data provided by the SAMS-II hardware during a Progress docking with ISS (ISS007E06980).

External Multipurpose Facilities

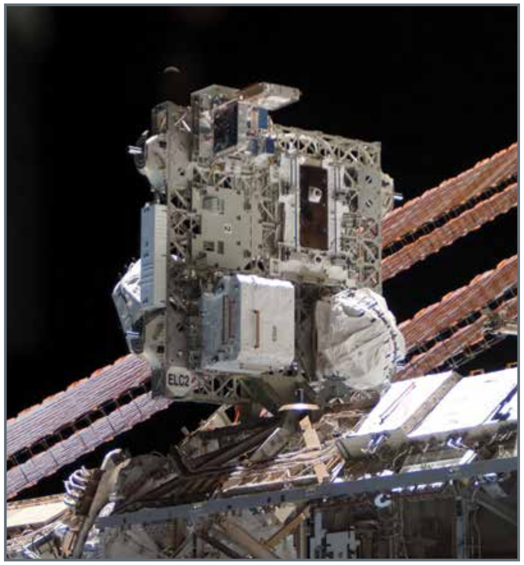
This section gives an overview of existing External Facilities that are multidisciplinary in nature, providing access to multiple sites that are exposed to the space environment and which include structural attachment points and utility interface.

Exposed Experiment Handrail Attachment Mechanism (ExHAM) [JAXA] enables space investigations in an exposed environment by providing attachment onto the JEM Kibo's Exposed Facility, taking advantage of Kibo's unique function having both airlock and robotic arm among modules on the ISS. **ExHAM** is a cuboid mechanism equipped with a grapple fixture for the Kibo's robotic arm, JEM Remote Manipulator System (JEMRMS) Small Fine Arm (SFA). The number of loadable investigation samples is 7 on the upper surface and 13 on the side surfaces.



View of the JEM Exposed Facility. The Hyperspectral Imager for the Coastal Ocean (HICO)/Remote Atmospheric and Ionospheric Detection System (RAIDS) Experiment Payload (HREP), NanoRacks External Platform (NREP), ExHAM, and Space Environment Data Acquisition equipment - Attached Payload (SEDA-AP) are in view. (ISS048E057068).

Expedite the Processing of Experiments to the Space Station (EXPRESS) Logistics Carrier (ELC) [NASA] is a pallet designed to support external research hardware and store external spares (called Orbital Replacement Units) needed over the life of the ISS. Currently, 4 **ELCs** are mounted to ISS trusses, providing unique vantage points for space, technology and Earth observation investigations. Two **ELCs** are attached to the starboard truss 3 (ITS-S3) and 2 **ELCs** to the port truss 3 (ITS-P3). By attaching at the S3/P3 sites, a variety of views such as zenith (deep space) or nadir (earthward) direction with a combination of ram (forward) or wake (aft) pointing allows for many possible viewing opportunities. The Lightning Image Sensor is planned for deployment on a nadir-facing **ELC** location in 2017. The sensor will provide real-time lightning data useful for weather, climate and geophysical studies.

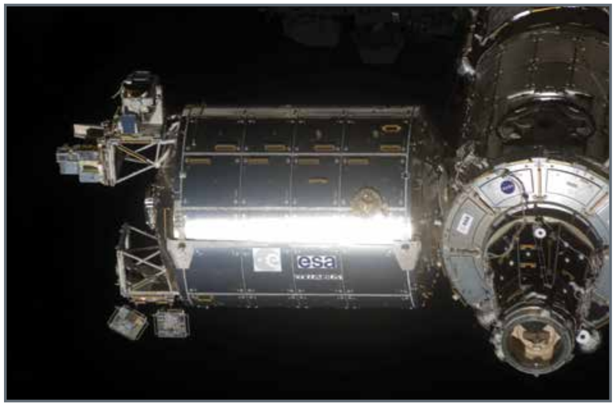


Expedition 22/STS-130 joint operations photograph of ELC 2 taken during a survey of the ITS-S3 (S130E010286).

EXPRESS Logistics Carrier ELC

- Mass: 227 kg (8 sites across 4 ELCs; not including adaptor plate)
- Volume: 1.2 m^3
- Size: 0.8m x 1.2m x 1.2m
- Power: 750 W, 113-126 VDC; 500 W, 28 VDC
- Data: Low Rate: 1 Mbps; MIL-STD-1553; Medium Rate: 6 Mbps (shared)

Columbus-External Payload Facility (Columbus-EPF) [ESA] provides 4 powered external attachment site locations for scientific payloads or facilities, and has to date been used by ESA and NASA. Each of the 4 attachment sites may hold a mass of up to 290 kg, and are provided utility connections for power and data.



A fly-around view of the forward and zenith sides of the Pressurized Mating Adapter 2 (PMA-2), Node 2 and Columbus module with the Columbus External Payload Facility. The Sun Monitoring on the External Payload Facility of Columbus (Solar), European Technology Exposure Facility (EuTEF) and Materials International Space Station Experiment (MISSE) Payloads in view as documented by the STS-124 crew during fly-around of the ISS after undocking (S124E010226).

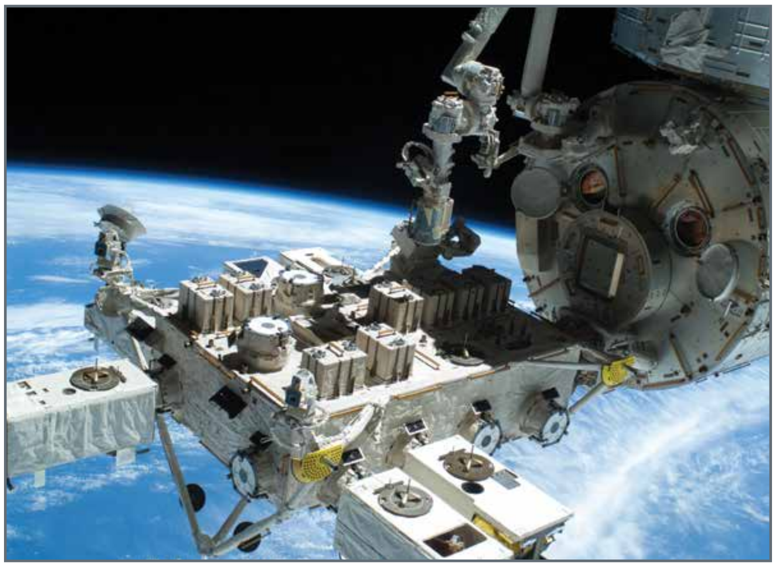
In the future, the Atomic Clocks Ensemble in Space (ACES) investigation which includes two high precision atomic clocks and the Atmosphere Space Interaction Monitor (ASIM) will be installed on the Earth-facing external attachment sites on the Columbus-EPF.

Columbus-EPF

- Mass: 230 kg per site (4 sites; uses Columbus External Payload Adapter (CEPA)
- Volume: 1.2 m^3
- Size: 0.8m x 1.2m x 1.2m
- Power: 1250 W, 120 VDC (shared)
- Data: Low Rate: 1 Mbps; MIL-STD-1553; Medium Rate: 2 Mbps (shared); Ethernet: 10 Mbps

The IVA-replaceable Small Exposed Experiment Platform (i-SEEP) [JAXA] is an exposed platform to support exchangeable experiment systems by supplying electrical power, Ethernet communication and removal of heat. The experiment equipment is exchanged in JEM – Pressurized Module (JEM-PM) by IVA, therefore **i-SEEP** is moved from JEM-PM to JEM-EF and vice versa through JEM Airlock. **i-SEEP** users include GPS Demo Unit and HDTV-EF2.

JEM External Facility (JEM-EF) [JAXA] is an unpressurized multi-purpose pallet structure attached to the JEM, or Kibo (meaning Hope). This external platform is used for research in areas such as communications, space science, engineering, technology demonstration, materials processing and Earth observation. Accessible from the internal pressurized volume of the ISS via the JEM Airlock, articles interfacing with this structure are grappled and moved using the JEMRMS. This entire platform is roughly 5.6 m x 5 m x 4 m, and includes utilities at each of the nine attachment sites.



View taken of JEM Exposed Facility seen by the Expedition 35 crew during EVA 21 (ISS035E037567).

Current users of the **JEM-EF** include Space Environment Data Acquisition equipment-Attached Payload (SEDA-AP) that measures the space environment around the ISS, Monitor of All-sky X-ray Image (MAXI) which is a space X-ray observatory, CALorimetric Electron Telescope (CALET) is an high energy electron and gamma ray observatory, Hyperspectral Imager for the Coastal Ocean (HICO)/Remote Atmospheric and Ionospheric Detection System (RAIDS) Experiment Payload (HREP), consists of two Earth observation devices, Cloud-Aerosol Transport System (CATS) measures atmospheric constituents, and **Exposed Experiment Handrail Attachment Mechanism (ExHAM)**, which is a small facility for material exposure experiments.

JEM-EF

- Mass: 500 kg (10 Standard Sites, mass includes PIU adaptor); 2500 kg (3 Heavy Sites, mass includes PIU adaptor)
- Volume: 1.5 m^3
- Size: 1.85m x 1m x 0.8m
- Power: 3 kW/6 kW, 113-126 VDC
- Thermal: 3 kW/6 kW cooling
- Data: Low Rate: 1 Mbps; MIL-STD-1553; High Rate: 43 Mbps (shared); Ethernet: 100Base-TX

The **NanoRacks External Platform (NREP) [NASA, Commercial]** is the first external commercial research capability and allows users to test a variety of equipment and materials, as well as conduct scientific investigations, in a cost effective manner. The **NREP** is located on the JEM-EF and payloads are deployed by the JEMRMS.

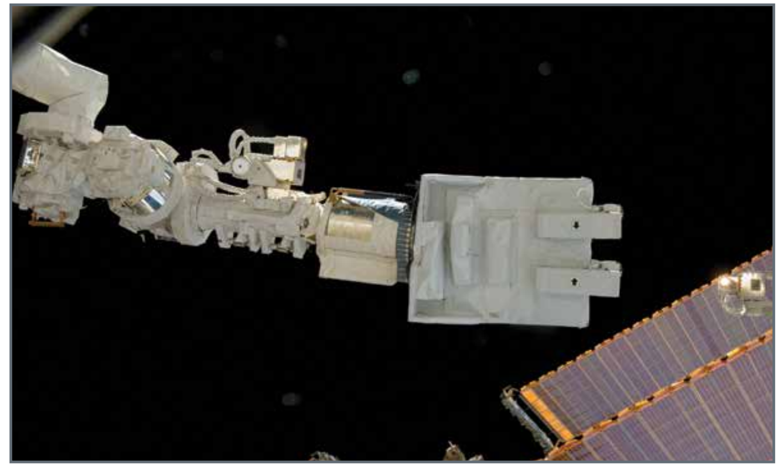
View of the NREP installed on August 9, 2016, to the exterior of the ISS (ISS048E049716).

The **Space Station Integrated Kinetic Launcher for Orbital Payload Systems (SSIKLOPS)** or **Cyclops [NASA]** is a mechanism used to robotically deploy satellites from the ISS and is designed to provide the ISS Program with a method to transfer internally stowed satellites to the external environment. The **Cyclops** is designed to provide a common payload interface and to accommodate payloads up to the internal volume of the JEM Airlock Slide Table. **Cyclops** fills the payload deployment gap between small CubeSat launchers and major payloads, thus enabling a whole new range of payload possibilities.

View of the Special Purpose Inexpensive Satellite (SpinSat) following its release from the SSIKLOPS, or Cyclops, launch platform. Cyclops is grappled by the JEMRMS SFA (ISS042E016845).

Traditional methods of launching satellites from Earth using rockets is expensive, but small satellites can be delivered to the ISS in a cost-effective manner and then deployed into low-Earth orbit. The **Cyclops**, also known as the **SSIKLOPS**, ejects nanosatellites from outside the ISS. Nanosatellites are inserted into the **Cyclops** platform inside the JEM airlock then once outside the ISS they are deployed into low-Earth orbit by the by the JEMRMS SFA.

The **JEM Small Satellite Orbital Deployer (J-SSOD) [JAXA]** provides small satellite deployment opportunities from Kibo/ISS. The **J-SSOD** is a new method of transporting satellites into orbit, taking advantage of Kibo's unique function having both JEM Airlock (JEMAL) and JEMRMS.



View of the JEMRMS in front of the JEM Airlock (JEMAL) during J-SSOD operations (ISS033E009897).

The first **J-SSOD** mission was performed in 2012. This has opened up new capabilities for Kibo utilization and new possibilities for small satellites. In 2015, two 3U-sized CubeSats, SERPENS developed by the University of Brasilia, Brazil, and S-CUBE of the Chiba Institute of Technology, Narashino, Japan, successfully deployed from Kibo. There are now more opportunities for CubeSat deployment from Kibo, and various projects are ongoing, such as AOBA-VELOX-III (of Singapore and Kyushu Institute of Technology) and a 50-kg Microsat DIWATA-1 (jointly developed by the Philippines, Tohoku University and Hokkaido University).

The **NanoRacks CubeSat Deployer (NRCSD) [NASA, Commercial]** is a stackable, modular, ground-loaded launch case. Each **NRCSD** accommodates up to 6.5U, and 8 launch cases are stacked for each JEM Airlock opening. For a deployment, the platform is moved outside via the Kibo Module Airlock and slide table that allows the JEMRMS to move the deployers to the correct orientation for the satellite release and also provides command and control to the deployers. Each **NRCSD** is capable of holding 6 CubeSat Units, allowing it to launch 1U, 2U, 3U, 4U, 5U and 6U CubeSats. The **NRCSD** meets the growing demand to deploy CubeSat format satellites from the ISS for a variety of customers.

The **NanoRacks Microsat Deployer (Kaber) [NASA, Commercial]** is a system that deploys commercial satellites in the 50-100 kg mass range from the ISS. The **Kaber** system utilizes the NanoRacks Separation System (NRSS) for satellite deployment once the satellites are moved to the exterior of the ISS through the JEM Airlock. Satellites are deployed at approximately 0.25-0.5m/sec velocity by the NRSS system.

NanoRacks CubeSat Deploy during Expedition 38 (ISS038E057006).

Russian Segment External Facilities [Roscosmos] consists of many multi-user external facility interface locations and associated support structures. The following list outlines, by element, the primary locations, types and nomenclature for these sites.

Service Module or Zvezda:

- URM-D multipurpose workstations
- Biaxial pointing platforms
- Handrail clamp locations

Docking Compartment-1 or Pirs:

- Magnetomechanical anchors/locks
- Handrail clamp locations

MRM2 or Poisk:

- URM-D multipurpose workstations
- Magnetomechanical anchors/locks

MLM:

- Magnetomechanical anchors/locks
- Handrail clamp locations
- URM-D multipurpose workstations

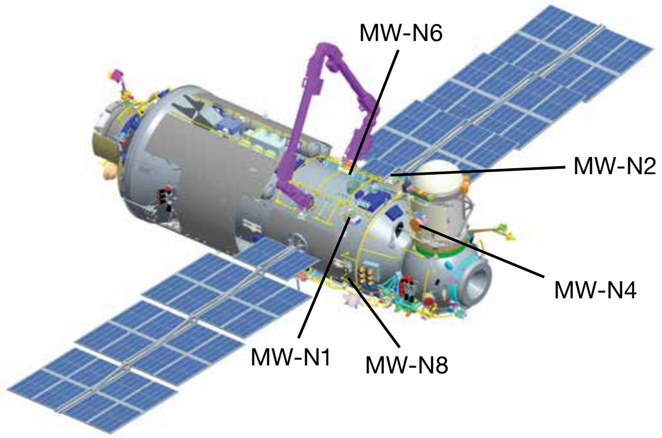
URM-D multipurpose workstation with integrated Photon-Gamma experiment taken during Increment 26 EVA-28 (ISS026E027349).

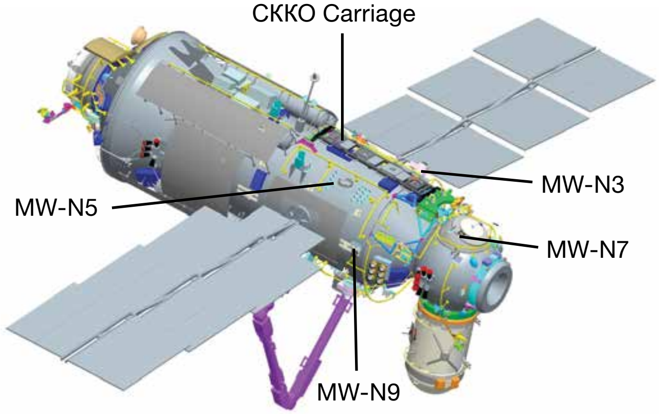
URM-D is Russian multipurpose workstation with capabilities for resupply.

Sixteen multipurpose workstations equipped with mechanical adapters are established on the MLM external surface, including:

- 13 with use of 2 "base points passive", 4 "payload's adapters passive", 3 "bearings";
- 3 with use of 2 "payload's adapters active", and 1 "base point passive" installed on a special carriage to support large-size equipment accommodation (CKKO carriage).

MPM – Port Side





MPM – Starboard Side

Biological Research

The microgravity environment of the ISS has opened a whole new frontier for long-duration study and experimentation in our ongoing quest to understand biological processes, protect biological systems and engineer ever more efficient and effective means of cultivating biological products. Provisioned with a multitude of advanced facilities and coupled with an interdisciplinary focus, the ISS supports an array of scientific investigations in the field of biological research. Akin to any biological research laboratory here on Earth, the ISS is outfitted with all the instrumentation and tools needed to conduct modern biological investigations including: incubators, centrifuges, animal and plant habitat systems, glove boxes, freezers and coolers, spectrometers and microscopes.

This section provides an overview of the current and growing capabilities afforded by the ISS in the fields of animal, plant, cellular and microbial research:

- Advanced Biological Research System (ABRS) [NASA]
- Aquatic Habitat (AQH) [JAXA, Roscosmos]
- Bioculture System Facility [NASA, Commercial]
- BioLab Experiment Facility [ESA]
- Biorisk [Roscosmos]
- Bone Densitometer [NASA, Commercial]
- Commercial Generic Bioprocessing Apparatus (CGBA) [NASA, Commercial]
- European Modular Cultivation System (EMCS) [ESA, NASA]
- Expose Experiment (Expose) [ESA]
- JAXA Microscope Observation System (Fluorescence Microscope) [JAXA]
- Kriogem-3M [Roscosmos]
- KUBIK [ESA]
- Mouse Habitat Unit (MHU) [JAXA]
- Multipurpose Variable-g Platform (MVP) [NASA, Commercial]
- NanoRacks Astrium Centrifuge [NASA, Commercial]
- NanoRacks Plate Reader [NASA, Commercial]
- Osteoporosis Experiments on Orbit (Osteo-4) [CSA]
- Plant Habitat [NASA]
- Rodent Research Hardware System [NASA]
- Space Automated Bioproduct Laboratory (SABL) [NASA, Commercial]
- Space Technology and Advanced Research Systems – 1 Experiment Facility (STaARS-1 EF) [NASA, Commercial]
- Saibo Rack (Saibo) [JAXA]
- TangoLab-1 [NASA, Commercial]
- TBU-N Low-temperature incubator [Roscosmos]
- TBU-V High-temperature incubator [Roscosmos]
- Vegetable Production System (Veggie) [NASA]
- WetLab-2 [NASA]

The first experiments in **ABRS** included the first trees flown in space. This study, Cambium, utilized willows for a Canadian study of cambium formation. Another investigation, Transgenic Arabidopsis Gene Expression System (TAGES), was an American study that used green fluorescent proteins as indicators of environmental stress.

Advanced Biological Research System (ABRS) [NASA] is a single locker system providing two growth chambers. Each growth chamber is a closed system capable of independently controlling temperature, illumination and atmospheric composition to grow a variety of biological organisms including plants, microorganisms and small arthropods (insects and spiders).

ISS crewmember Jeffrey Williams conducts a daily status check of the Advanced Plant Experiments on Orbit (APEX) experiment in ABRS. During each check, Williams looks for health and color of the plants (ISS022E011304).

BioLab Experiment Laboratory (BioLab) [ESA] can be used to perform space biology experiments on microorganisms, cells, tissue cultures, small plants and small invertebrates. Such studies provide a better understanding of the effects of microgravity and space radiation on biological organisms. **BioLab** includes an incubator, a glovebox, two freezer units and two centrifuges to simulate the effects of gravity.

ESA astronaut Frank De Winne installs experiment containers in the BioLab incubator in the Columbus laboratory of the ISS (ISS020E044457).

Several experiments have been performed on **BioLab**, studying the effect of microgravity on seeds and cells, such as Waving and Coiling of Arabidopsis Roots at Different g-levels (WAICO), Yeast and Triplelux (Gene, Immune and Cellular Responses to Single and Combined Space Flight Conditions). The **BioLab** cooling units and glovebox have been used as well in support of other experiments; e.g., Gravi (Threshold Acceleration for Gravisensing) for **EMCS**.

Biological Research

Kriogem-3M [Roscosmos] is a refrigerator-incubator used for the stowage of biological samples or medical kits and for the culture and incubation of bioreactors such as Recomb-K, Lutch-2.

ISS crewmember Oleg Kononenko places experiment hardware in the Kriogem-03 (Cryogem-03) Refrigerator (ISS017E018403).

The ISS is equipped with high quality laboratory equipment that is found in Earth-based labs, providing researchers with the ability for direct comparison of space-based and Earth-based samples.

ISS Expedition 49 crewmember Sergey Ryzhikov prepares TBU-N facility in MRM1 module for biotechnology investigations (image courtesy of Roscosmos).

TBU-N Low temperature incubator [Roscosmos] provides a refrigerated environment for carrying out a variety of experiments in human life sciences, biology and biotechnology.

TBU-V High-temperature incubator [Roscosmos] enables a variety of experiments in human life sciences, biology and biotechnology at elevated temperatures.

ISS Expedition 49 commander Anatoly Ivanishin works with the TBU-V in MRM1 (image courtesy of Roscosmos).

Incubators and bioreactors are specialized, environmentally controlled hardware used for growing cells, tissues and microorganisms.

The **Commercial Generic Bioprocessing Apparatus (CGBA) [NASA, Commercial]** provides programmable, accurate temperature control—from cold stowage to a customizable incubator designed for biotechnology experiments in microgravity. **CGBA** can be used in a wide variety of biological studies, such as protein crystal growth, small insect habitats and plant development, as well as antibiotic producing bacteria and cell culture studies.

Mike Hopkins working with NLP-Vaccine investigation, checking the group activation packs (GAPs) within the CGBA during ISS Expedition 38. (ISS038E031401).

The **Space Automated Bioproduct Laboratory (SABL) [NASA, Commercial]** provides the researcher with advanced incubator technology and complements the existing **CGBA** incubator. **SABL** supports a wide variety of experiments to support the development of applications for use on Earth by pharmaceutical, biotechnology and agribusiness companies. **SABL** provides a temperature range of -5°C to +43°C, and is designed to be user friendly for the crewmember.

View of the SABL power, data and thermal connections in the rack located in the U.S Laboratory (ISS046E046608).

CGBA and **SABL**, operated by Bioserve Space Technologies, are key facilities being used by investigators as part of the ISS National Laboratory initiative.

The **Space Technology and Advanced Research Systems – 1 Experiment Facility (STaARS-1 EF) [NASA, Commercial]** is a multipurpose facility that will enable a broad range of experiments on the ISS. It is anticipated that once on the ISS and operational, **STaARS-1 EF** will facilitate novel drug discovery, drug compound production and virulence modeling. **STaARS-1 EF** will support biomedical therapeutic markets through drug delivery system development, regenerative tissue engineering (stem cell technologies) and biofilm formation prevention. Within the energy markets, **STaARS-1 EF** will support studies targeting novel biofuel production through enhanced quality and quantity of multiple compounds.

Internal view of the STaARS-1 EF. Image provided by STaARS Inc.

The **Bioculture System Facility [NASA, Commercial]** is a cell biology research platform that supports short- and long-duration studies involving the culture of living cells, microbes and tissues. A principal advantage of this facility is the automation of standard laboratory processes such as media feeds, removal of waste, sample collection, protocol additions, and other additions such as antibiotics or growth factors to the culture. These are 10 independently controlled experiment cartridges, each with independently controlled temperature set points. The **Bioculture System Facility** is a platform that can be reconfigured and customized to meet specific scientific objectives.

Bioculture System Facility with 10 independent cassettes. Image provided by Tissue Genesis, Inc.

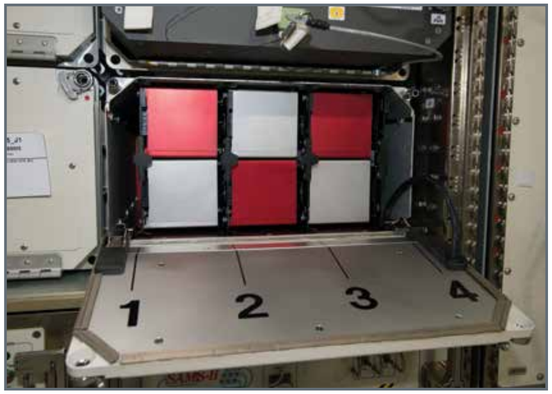
The **Bioculture System Facility** addresses a critical need for ISS National Lab academic and commercial space bioscience research – a containment system that allows for initiation, intervention and analysis of experiments on orbit.

KUBIK [ESA] is a cubic box container measuring 37 cm^3 and composed of a thermal chamber with a volume of 9.36 L, which can function both as an incubator or a cooler. It operates from 6°C to 38°C with a stability of 0.1°C. The thermal chamber can be equipped with removable inserts designed for maximal sample flexibility. The KUBIK has a centrifuge insert, which has a selectable acceleration from 0.2g to 2g in 0.1g increments.

Cosmonaut Fyodor Yurchikhin, Expedition 15 commander, is photographed working with a KUBIK incubator in the Zvezda Service Module (ISS014E19187).

KUBIK is primarily utilized for self-contained automatic biological experiments, either contained in standard small containers (called KICs) or ad-hoc containers for specific use. Examples include: the Role of Apoptosis in Lymphocyte Depression (ROALD) and Role of Apoptosis in Lymphocyte Depression - 2 (ROALD – 2) investigation, which study the immune processes in human cells; the Antibody V(D)J Recombination Machinery in Normal and Altered Gravity (Amphibody) investigation, which researched amphibians; the Influence of Gravity on the Cytoskeleton and the Determination of the Division Plane in Plants (TUBUL) investigation, which studies the effect of microgravity cytoskeleton of plants; Spheroids investigation, which examined weightlessness on tube formation, differentiation and mechanisms of apoptosis in human endothelial cells; SPHINX Investigation, which examines human umbilical vein endothelial cells in microgravity; the Endothelial Cells and the Stem Cell Differentiation investigations as well as various protein crystal growth studies that attempt to understand how crystals grow in purely diffusive condition.

TangoLab-1 [NASA, Commercial] provides a standardized platform and open architecture for experimental modules, which help reduce the development cycle and cost for research and development leading to whole new products and markets. **TangoLab-1** presents opportunities to numerous investigators to explore new and potentially game-changing discoveries in areas such as human tissue regeneration, drug development and treatments for diseases such as cancer and other life-threatening and chronic conditions, as well as energy research and novel materials.

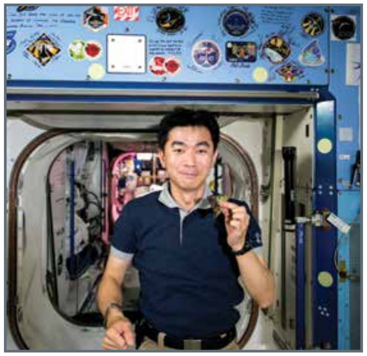


TangoLab-1, installed in Locker 8 of EXPRESS Rack 4, in Kibo (ISS048E046388).

The **Plant Habitat [NASA]** is a fully automated facility that will be used to conduct plant bioscience research on the ISS. Plant Habitat provides a large, enclosed, environmentally controlled chamber designed to support commercial and fundamental plant research or other bioscience research onboard the International Space Station (ISS) for at least one year of continuous operation without maintenance and integrates proven microgravity plant growth technologies with newly developed fault tolerance and recovery technology to increase overall efficiency, reliability, and robustness.


ISS crewmember Rick Mastracchio installs the Veggie hardware into EXPRESS Rack 3 (ISS039E019105).

The **Vegetable Production System (Veggie) [NASA]** is an advanced plant growth chamber that supports a variety of experiment objectives. The growth chamber is the largest on the ISS at this time and allows for larger-sized plants to be grown than in previous ISS experiments. Additionally, the large adjustable LED light bank makes **Veggie** an ideal facility for experiments requiring a controlled light source. The total plant growing area is 0.13 m^2, and water is provided passively to the rooting media using capillary connections to a reservoir.

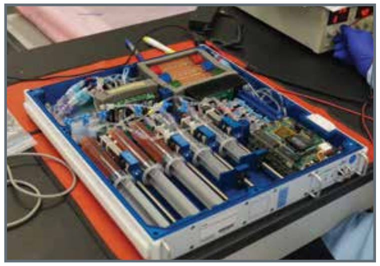

ISS crewmember Kimiya Yui in the JEM holding a piece of lettuce grown in Veggie (ISS044E045602).

European Modular Cultivation System (EMCS) [ESA, NASA] is an ESA experiment facility that is dedicated to studying plant biology in a reduced-gravity environment. It supports the cultivation, stimulation and crew-assisted operation of biological experiments under controlled conditions (e.g., temperature, atmospheric composition, water supply and illumination). The facility has performed multi-generation (seed-to-seed) experiments and studies the effects of gravity and light on early development and growth, signal perception and transduction in plant tropisms. Experiments with cell and tissue cultures are also being planned for the **EMCS**.


ESA astronaut Thomas Reiter installing the EMCS into EXPRESS Rack 3A (ISS013E66810).

The **EMCS** has two centrifuges that can be precisely set to meet specific science requirements for g-levels up to twice Earth's gravity (2.0g). Different experiment containers can hold a variety of organisms, as well as seeds and plants. The **EMCS** has already supported a number of plant growth experiments operated by ESA, NASA and JAXA.

OSTeoporosis Experiments on Orbit (Osteo-4) [CSA] cell culture facility, adapted for the ISS, provides the controlled environmental conditions needed to grow bone cells in microgravity. This culture system has been used successfully on the Space Shuttle, ISS and an ESA-Russian recoverable satellite mission. It is available for use to study bone cell function on ISS. Modification of the bioreactors could accommodate other attached cell types.



Inner view of the Osteo-4 hardware. Image courtesy of Calm Technologies, Inc.

Understanding the changes in bone cells in microgravity could be key for understanding the bone loss that occurs in astronauts while they are in space or during the aging process at home on Earth.

The **Mouse Habitat Unit (MHU) [JAXA]** is designed specifically for rodent research investigations and can accommodate 12 mice with an integrated life support and environment control system as well as a video recording system. The **MHU** consists of three units: the onboard Habitation Cage Unit (HCU), Transportation Cage Unit (TCU) for launch and return of mice by transportation vehicles, and the MHU Glovebox, which provides containment for the animal maintenance and mice transfer tasks. The HCUs are attached to the **Cell Biology Experiment Facility (CBEF)** and will be able to utilize the **CBEF** centrifugation system for studies requiring an artificial gravity environment up to 1g for 6 mice, which enables a comparison with 6 other mice in microgravity conditions. In addition, the HCU provides Light Emitting Diode (LED) lights for prescribed light/dark cycles as well as necessary lighting for observation and video recording. Data are transmitted to the ground for monitoring and analysis.

Video Screen Shot of Yui Kimiya working with the MHU within the CBEF onboard the ISS during Expedition 45.

Rodent Research Hardware System [NASA] provides a containment system for rodents in support of biological studies. This hardware contains a complex assortment of ancillary equipment and hardware support kits, all designed to safely and comfortably transport and house animal subjects and provide basic analytical capabilities onboard. The **Rodent Research Hardware System** has three fundamental components: the Transporter that safely transports rodents from Earth to the space station; the Animal Access Unit that is used during initial animal transfers to the ISS, as well as all animal transfers required for science operations; and the Rodent Habitat that provides long-term housing for rodents aboard the station.

The Rodent Research Hardware System includes three modules: (left) Habitat, (center) Transporter, and (right) Animal Access Unit (NASA).

The **Bone Densitometer [NASA, Commercial]** complements the onboard rodent research and provides researchers near real-time measures during rodent research studies. Quantitative measures of bone and muscle loss in rodents during spaceflight are needed for the development of countermeasures for crewmembers by NASA and for bone-loss syndromes on Earth. Planned studies, academic and commercial, require on-orbit analytical methods including bone and muscle densitometry.

Bone Densitometer onboard the ISS during Expedition 43 (ISS043E286992).

The **Bone Densitometer** provides bone mineral and body composition results from total body imaging. The results can provide soft tissue density, lean/fat ratio and total animal mass, which gives researchers on the ground insight into the actual weight of the rodent during the mission.

The **Saibo Rack (Saibo) [JAXA]** is a multi-purpose rack consisting of two main parts, the **Clean Bench (CB)** and **Cell Biology Experiment Facility (CBEF)**. The primary purpose of the **Saibo Rack** is to support cell culture, plant culture and mouse projects across a range of life and biological sciences.

The **CB** is a sterilized glovebox equipped with a phase contrast microscope. The microscope has different modes: Bright-Field, Phase-Contrast and Fluorescence Microscope, and the objective lens can be switched among four magnification levels.

The **CBEF** is an incubator that is designed for life science research. The **CBEF** provides controlled temperature, humidity and carbon dioxide concentration (from 0% to 10%), and it has a two compartments—one for the nominal microgravity environment, and one equipped with a small centrifuge to provide a gravity exposure environment from 0.1 G to 2.0 G to compare the two different gravity environments.

ISS crewmember Koichi Wakata works with the CBEF (left) and CB (right) in the JEM Kibo (ISS020E005881 and ISS018E044269).

Saibo (細胞) means "Cell" in Japanese. This rack consists of the CBEF and CB, which supports not only various cell culture experiments, but also plant culture experiments and mouse projects. Its first use included studies on the effects of space radiation.

Aquatic Habitat (AQH) [JAXA, Roscosmos], located in the MSPR facility, is designed for breeding small fresh-water Medaka or Zebrafish for up to 90 days in the microgravity environment in the ISS. Such fish provide many advantages as model animals for microgravity research of biological processes and systems. The **AQH** is composed of two aquariums that contain automatic feeding systems, day/night cycle LED lighting, charge-coupled device (CCD) cameras and a water quality control system comprised of a biological filter with nitrifying bacteria and a physical filter with activated charcoal for particulate and organic waste removal.

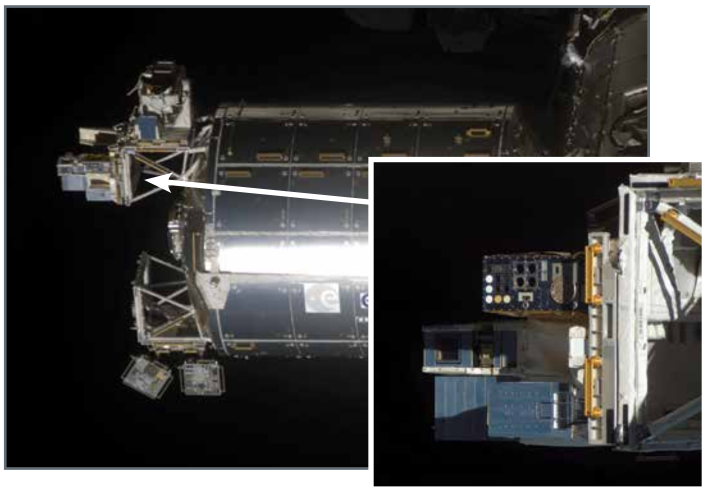
ISS crewmember Kevin Ford working at the AQH in the JEM during ISS Expedition 34 (ISS034E009608).

Video screenshot of Medaka fish in the AQH onboard the ISS during Expedition 35/36.

The **AQH** consists of some accessory components, the fish carrier that supports fish from launch to transfer into the **AQH**, the fish catcher that attaches to the **AQH** and allows the crew to remove fish for study, and the fish fixation kit that is used for chemical fixation (paraformaldehyde) or RNA preservation of fish removed from the **AQH**. Living fish can also be returned to Earth for study. Multiple lines of biological research are planned for **AQH** including bone degradation, muscle atrophy and radiation impacts.

Biological Research

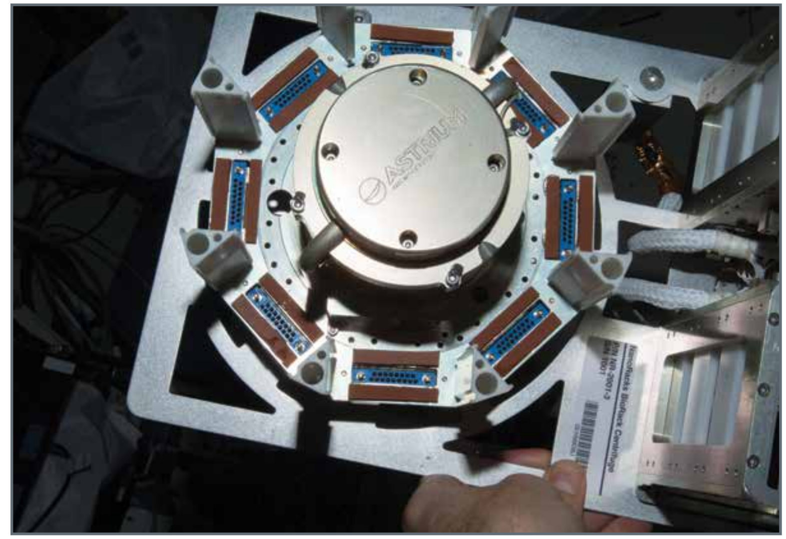
Expose Experiment (Expose) [ESA] is a multi-user facility that allows short- and long-term exposure of experiments to space conditions and solar ultraviolet radiation reaching the ISS. The **Expose** facility is located external to the ISS and has been installed on the external surfaces of the Zvezda Service Module (Expose-R) and the European Columbus laboratory (Expose-E). The **Expose** facility offers researchers a platform for exobiology research as well as organic chemicals. Research in this area is focused on whether organisms and organic matter can survive on comets, meteorites, Mars and other places that do not have a protective atmosphere. **EXPOSE** utilization was completed in 2016. A follow-on Exobiology exposure facility is under development, which will include in-situ measurements.



This image shows the location along with a close-up view of the ESA European Technology Exposure Facility (EuTEF) platform located externally on the Columbus module. EuTEF houses 9 experiments including Exposure Experiment (Expose) (S124E010226 (background) and S123E009654 (foreground)).

As part of the ESA Expose-R2 project, 46 species of bacteria, fungi and arthropods were delivered by a Progress supply ship to the space station in July 2014. Spacewalking cosmonauts Alexander Skvortsov and Oleg Artemyev attached the package to the outside of the Zvezda module on August 18, 2014, and this was returned as planned.

The **NanoRacks Astrium Centrifuge [NASA, Commercial]** provides researchers and commercial users with the ability to simulate an artificial gravity environment (up to 1g) on 6 individual experimental containers located within the centrifuge. Research in this particular facility focuses on biology and microbiology experiments and offers on-orbit capability to conduct molecular and cellular investigations on plant and animal tissue.

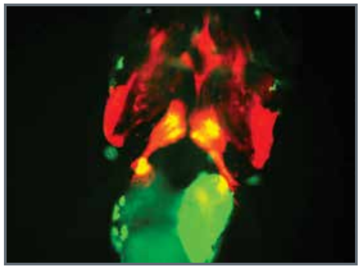


View of Nanoracks Astrium Centrifuge during installation and performance check during Expedition 38 (ISS038E008547).

The **Multipurpose Variable-g Platform (MVP) [NASA, Commercial]** is a multi-use platform available for space station researchers. The **MVP** has twin independent, self-balancing centrifuges that provide up to 2g loading and each centrifuge accommodates 6 experiment modules. The experiment modules provide controlled lighting, gas exchange, fluid exchange (for cell culture), thermal and humidity control capabilities as well as video recording. The **MVP** is well suited for model organism and cell cultures research.

The **JAXA Microscope Observation System (Fluorescence Microscope) [JAXA]** is located in the **MSPR** or in the cabin area. It is an inverted fluorescence microscope, a Leica DMI 6000B. It has 6 different objective lenses, with a monochrome CCD camera. The microscope is equipped with an LED illumination unit and can perform time-lapse videomicroscopy. It also is equipped with a stage heater (up to 40°C) to enable cell culture observation. The **Fluorescence Microscope** is controlled and remotely commanded from the ground once samples are placed into it by the onboard crew. It has been used for biology (cultured cell and fish larva) and plant experiments onboard the ISS/Kibo.

ISS crewmember Karen Nyberg works to set up the JAXA Microscope Observation System (Fluorescence Microscope) in the Kibo laboratory of the ISS during ISS Expedition 36 (ISS036E020972).



Observations of Medaka larva onboard the ISS during the Medaka Osteoclast investigation (JAXA).

WetLab-2 [NASA] is a research platform for conducting real-time quantitative gene expression analysis aboard the ISS. The system enables spaceflight genomic studies involving a wide variety of biospecimen types in the unique environment of space. The **WetLab-2** system includes a commercial polymerase chain reaction (PCR) instrument that can perform up to 16 PCR reactions in parallel using up to 4 optical channels to measure fluorescence. The average time to deliver results is less than 4 hours.

ISS crewmember Jeffrey Williams works with the Wet Lab-2 onboard the ISS (ISS047E066248).

WetLab-2 enables traditional uses of quantitative PCR, such as measuring gene transcription or rapid detection of gene targets that indicate infectious disease, cell stress, changes in cell cycle, growth and development, and/or genetic abnormality. Applications range from fundamental biology investigations to commercial drug discovery efforts. **WetLab-2** also may be used for real-time analysis of air, surface, water or clinical samples to monitor environmental conditions and crew health. It can also be used to validate terrestrial analyses of samples returned from the space station by providing quantitative gene expression benchmarking prior to sample return to Earth.

View of NanoRacks Plate Reader onboard the ISS during Expedition 34 (ISS034E005601).

The **NanoRacks Plate Reader [NASA, Commercial]**, a modified commercially available plate reader (Molecular Devices' SpectraMax® M5e Multi-Mode Microplate Reader) allows researchers access to real-time analysis from their microtiter samples on the ISS. This device provides analysis of experiments in areas such as biochemistry, molecular biology, stem cell and cancer research, immunology, enzymatic type studies, microbial growth and endotoxin testing. In addition, on-orbit reactions can be imaged using the fluorescence polarization within the plate reader.

Biorisk [Roscosmos] is a suite of hardware used to measure the impacts of the space environment on biological activity. Two internal components, the Biorisk-MSV container and Biorisk-KM case, and one external Biorisk-MSN container, allow researchers to obtain new information about limits of an organism's (phenotypical) adaptation and its associated response or genotypical changes. The focus with this hardware is on bacteria and fungi that form conventional colonies of microorganisms living on structural materials used in space technology. Biorisk-MSN, on the other hand, is designed to support long-term exposure for monitoring the resting stages of organisms on the external surface of the ISS Russian modules.

ISS crewmember Roman Romanenko is photographed outside the Pirs Docking Compartment), where he will retrieve Biorisk-MSN experiment Container 2 (ISS035E023963).

Biorisk experiments conducted to date provide evidence that bacterial and fungal spores as well as dormant forms of organisms that have reached higher levels of evolutionary development (for instance, dehydrated embryos of lower crustaceans in the state of deep diapauses) have the capability to survive a long-term exposure to the harsh outer space environment. This observation suggests that such organisms can be transferred on external surfaces of spacecraft during interplanetary missions and therefore may drive future requirements with regard to planetary protection.

Human Physiology and Adaptation Research

ISS Facilities support an array of scientific investigations concerning human physiology, adaptation and the health of crewmembers. All facilities in this section support investigations that directly employ human subjects as the focus of the experiment. Much of the hardware serves the dual purpose of maintaining or assessing crewmembers' health as well as equipment capable of supporting scientific research.

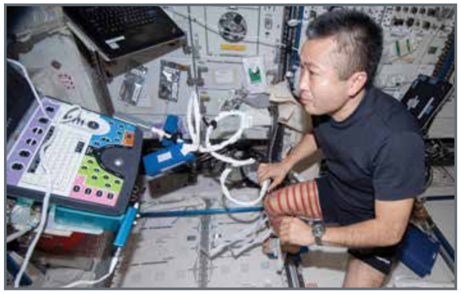
This section provides overviews and highlights with regard to facilities that can support research into human physiology and space adaptation presently available onboard the ISS:

- Advanced Resistive Exercise Device (ARED) [NASA]
- Cycle Ergometer with Vibration Isolation System (CEVIS) [NASA]
- Combined Operational Load Bearing External Resistive Exercise Treadmill (COLBERT) [NASA]
- ELITE S2 [NASA, ASI]
- Human Life Research Complex [Roscosmos]
- Human Research Facility (HRF-1 and HRF-2) [NASA]
- Intra-Vehicular Tissue Equivalent Proportional Counter (IV-TEPC) [NASA]
- Measuring Radiation Hazards in Space (Matryoshka) [Roscosmos, ESA, JAXA]
- Muscle Atrophy Research Exercise System (MARES) [ESA]
- Onboard Diagnostic Kit (ODK) [JAXA]
- PAssive Dosimeter for Lifescience Experiments in Space (PADLES) [JAXA]
- Percutaneous Electrical Muscle Stimulator (PEMS) [ESA]

Muscle Atrophy Research Exercise System (MARES) [ESA] is used for research on musculoskeletal, biomechanical and neuromuscular human physiology to better understand the effects of microgravity on these related systems. This instrument is capable of assessing the strength of isolated muscle groups around joints by controlling and measuring relationships between position/velocity and torque/force as a function of time.

CSA astronaut Chris Hadfield and NASA astronaut Tom Marshburn work with MARES hardware (ISS034E014618).

Human Research Facility (HRF-1 and HRF-2) [NASA] enables human life science researchers to study and evaluate the physiological, behavioral and chemical changes induced by long-duration spaceflight. **HRF-1** and **HRF-2** are ISS racks that contain a range of hardware as well as infrastructure to allow for remote commanding, data storage and uplink/downlink capability to support human research. Included in the suite of hardware is the **Refrigerated Centrifuge [NASA], Ultrasound 2 [NASA], Space Linear Acceleration Mass Measurement Device (SLAMMD) [NASA], Cerebral Cochlear Fluid Pressure Analyzer (CCFP) [NASA], Distortion Product Otoacoustic Emissions (DPOAE) [NASA], Holter Monitor 2 (HM2) [NASA], Actiwatch Spectrum System [NASA]** and the **Pulmonary Function System (PFS) [ESA, NASA]**.



ISS crewmember Koichi Wakata performing an Ultrasound Scan for the Sprint investigation using the HRF Ultrasound2 (ISS038E007119).

Techniques developed for using ultrasound technology on the ISS are now being used in trauma facilities to more rapidly assess serious patient injuries.

Advanced Resistive Exercise Device (ARED) [NASA] provides resistive exercise capabilities to crewmembers on the ISS. The **ARED** also collects data regarding the parameters (loads, repetitions, stroke, etc.) associated with crew exercise, and transmits it to the ground.

ISS crewmember Dan Burbank exercises using the ARED) in the Tranquility node of the ISS (ISS030E012688).

Combined Operational Load Bearing External Resistive Exercise Treadmill (COLBERT) [NASA] is an exercise treadmill that can be used to collect data such as body loading, duration of session, and speed for each crewmember.

ISS crewmember Mikhail Kornienko uses the COLBERT on the ISS for the Roscosmos Great Start investigation (ISS045E028084).

ISS crewmember Barry Wilmore exercising on the CEVIS in the Destiny U.S. Laboratory (ISS042E016676).

The **Cycle Ergometer with Vibration Isolation System (CEVIS) [NASA]** is a structurally isolated aerobic exercise cycle that serves as a countermeasure to cardiovascular deconditioning on orbit.

Crew health care hardware used for daily exercise onboard the ISS collects information on protocols and forces that are used as supplemental data for physiological studies including muscle and bone loss and cardiovascular health during long-duration spaceflight.

Measuring Radiation Hazards in Space (Matryoshka) [Roscosmos, ESA, JAXA] consists of a spherical phantom (Matryoshka-R) that is used to measure radiation doses experienced by astronauts at various locations both outside and inside the ISS. Matryoshka-R represents a human body radiation equivalent and is filled with water and a series of passive radiation detectors that measure radiation entering the spherical phantom. Research institutes from around the world have collaborated and shared data from the project, and the results will allow researchers to better correlate between skin and organ dose and therefore provide better risk assessments for future long-duration spaceflight.

Cosmonaut Elena Serova is photographed during Phantom setup for the Matryoshka-R experiment (ISS042E207594).

Participants from 10 countries provided dosimeters and other components of **Matryoshka**, making it one of the most interesting collaborative investigations on the ISS. This program started in 2004 and continues under Russian leadership today.

Human Life Research Complex [Roscosmos] includes a variety of devices and systems designed to study human life in space. Components include the Cardiovascular System Research Rack, Weightlessness Adaptation Study Kit, Immune System Study Kit, and Locomotor System Study Facility.

Cardiovascular Research System

Weightless Adaptation

Locomotor System

The **PAssive Dosimeter for Lifescience Experiments in Space (PADLES) [JAXA]** contains the following set of hardware for assessing the space radiation environment: Area **PADLES** are used to monitor radiation at prescribed locations inside the Kibo module, Bio **PADLES** assesses the biological effects of radiation exposure, Crew **PADLES** measures the personal dose acquired by an individual astronaut, and Free-Space **PADLES** investigate the space radiation dose outside the JEM Kibo. These small, portable devices measure absorbed doses (Gy) and dose equivalent (Sv). Dose records are used to assess astronaut radiation exposure limits in low-Earth orbit and help researchers better understand human exploration beyond low-Earth orbit. By comparing the dose measured by the Area **PADLES** set in the interior of Kibo and the Free-Space **PADLES** exterior to the module, an evaluation of the radiation shielding capability of Kibo's hull wall becomes possible. This is the first time that a direct measurement of the radiation shielding of the Kibo module is measured in orbit. The data obtained from the **PADLES** experiments will assist with risk assessment of Extravehicular Activities (EVAs) and the assessment and optimization of hull wall thickness for manned spacecraft.

ISS Expedition 28 crewmember Furukawa poses with PADLES Dosimeters (ISS028E007155).

Human physiology research is coordinated by an internal working group to efficiently schedule experiments and share data. An astronaut or cosmonaut can participate in as many as, or sometimes more than, 20 physiology experiments on orbit during an increment.

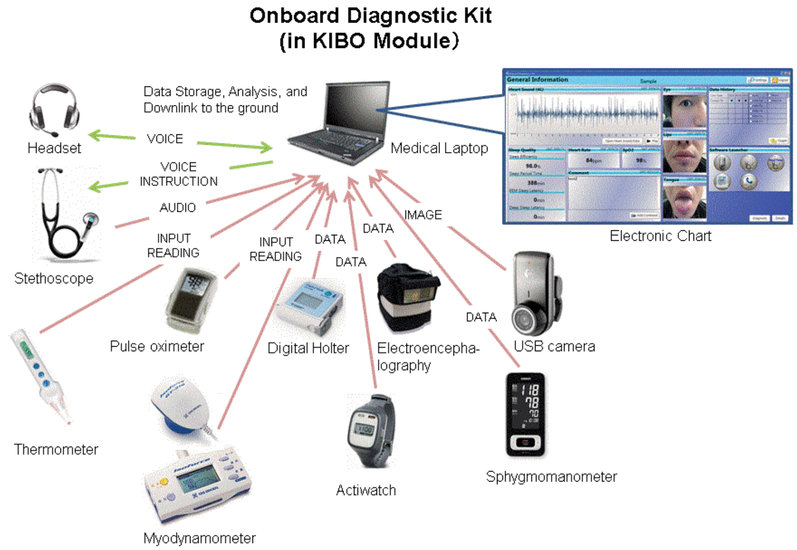
Intra-Vehicular Tissue Equivalent Proportional Counter (IV-TEPC) [NASA] is a portable, active ionizing radiation monitor that measures the internal radiation environment in near real time using a simulated tissue site device. Some of the information generated by this instrument is used to make operational radiation protection decisions and risk assessments by estimating the physiological consequences to crewmembers from radiation exposure during spaceflight. As a portable unit, it may be used to characterize the radiation environment in different locations within the ISS and assess varying impacts related to humans during long-duration spaceflight.

The bronze box is the IV-TEPC radiation monitor after it was located to JEM1 F3 (ISS043E241659).

ELITE S2 [NASA, ASI] is a passive optoelectronic analyzer. Retroreflective markers are applied on the subject body on specific landmarks; digital cameras collect the markers' position, reflecting the light provided by infrared illuminators; the tridimensional coordinates of the markers are acquired by specific software running on the payload computer. Part of the instrument is mounted into a NASA rack for the scientific data acquisition and collection, the power management and the connection to the ground control center for command and data transmission. The rack-mounted equipment is connected to the cameras deployed in the ISS by means of cables. The instrument makes use of a laptop computer to provide the crewmember with directions and feedback.

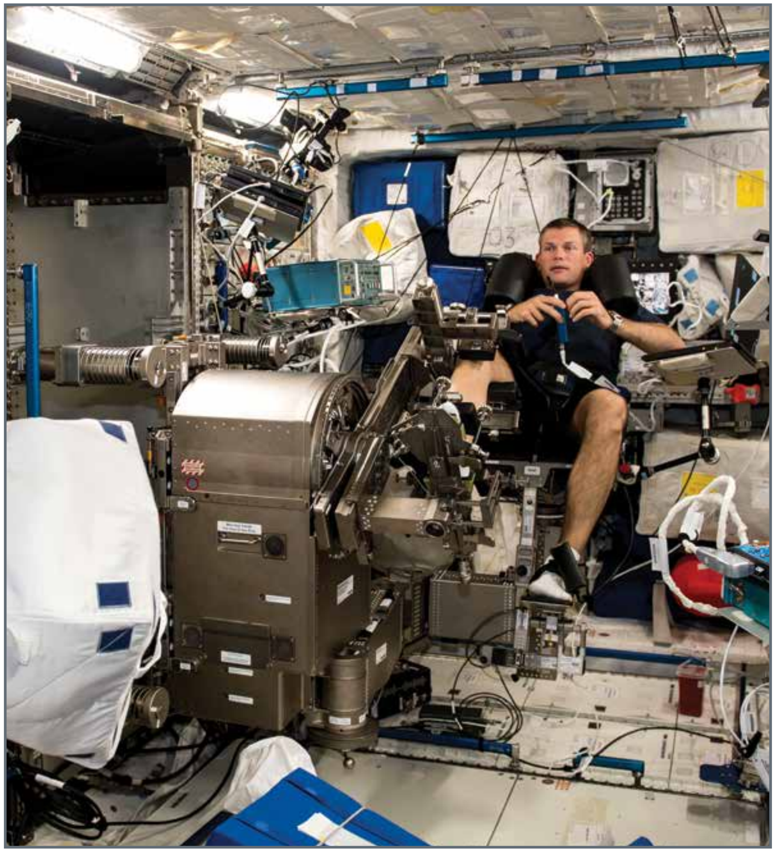
Elite S2 Interface Management Unit (ISIS Drawer) integrated in EXPRESS Rack (ISS033011716).

The **Onboard Diagnostic Kit (ODK) [JAXA]** is a non-invasive, health-monitoring system capable of measuring, storing and analyzing crewmember medical data while onboard the ISS. The medical data collected onboard can be sent to the ground immediately, whereby doctors can quickly diagnose crewmember health.



One component of the ODK is the digital Holter ECG recorder, a portable 24-hour electrocardiogram recording device used to monitor ISS crewmembers' cardiovascular and autonomic functions (JAXA).

Percutaneous Electrical Muscle Stimulator (PEMS) [ESA] is a portable, self-contained neuromuscular research device that may be used stand-alone or in conjunction with other physiological instruments. The purpose of this device is to deliver electrical pulse stimulation to non-thoracic muscle groups of a human test subject, thereby creating contractile responses from the muscles. It is capable of providing single, variable amplitude pulses or pulse trains according to a pre-adjusted program.



ISS crewmember Andreas Mogensen setting up the ESA MARES rack and its ankle mechanism assembly in the Columbus module. PEMS is located to the right (ISS044E101255).

Physical Science Research

Scientific investigations concerning the physical sciences and materials research are supported by an array of onboard ISS facilities. Today, researchers are examining fundamental scientific questions from how fluids behave and crystals develop to how things burn and how smoke moves through the environment—and these represent a small sample of the contributions being made in the physical sciences onboard the ISS. Additionally, by exposing and understanding how various materials perform and change in the microgravity and space environments allows future designers the ability to more wisely build spacecraft, systems and long-lived components.

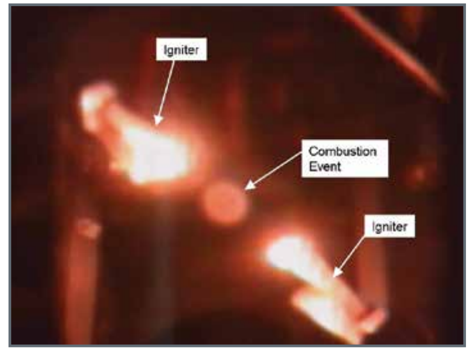
This section provides highlights of the current physical and material science platforms available onboard the ISS. An overview of each of the following is provided within this section:

- Advanced Combustion via Microgravity Experiments (ACME) [NASA]
- Additive Manufacturing Facility (AMF) [NASA, Commercial]
- Chamber for Combustion Experiment (CCE) [JAXA]
- Cold Atom Laboratory (CAL) [NASA]
- Combustion Integrated Rack (CIR) [NASA]
- Device for the study of Critical Liquids and Crystallization (DECLIC) [CNES, NASA]
- ElectroMagnetic Levitator (EML) [ESA, DLR]
- Electrostatic Levitation Furnace (ELF) [JAXA]
- Fluid Science Laboratory (FSL) [ESA]
- Fluids Integrated Rack (FIR) [NASA]
- Gradient Heating Furnace (GHF) [JAXA]
- Kobairo Rack (Kobairo) [JAXA]
- Light Microscopy Module (LMM) [NASA]
- Materials International Space Station Experiment – Flight Facility (MISSE-FF) [NASA]
- Materials Science Laboratory (MSL) [ESA]
- Materials Science Research Rack (MSRR-1) [ESA, NASA]
- Observation and Analysis of Smectic Islands in Space (OASIS) Liquid Crystal Facility [NASA]
- Plasma Kristall – 4 (PK-4) [ESA, Roscosmos]
- Replaceable Cassette-Container (SKK/CKK) [Roscosmos]
- Ryutai Rack (Ryutai) [JAXA]
- Vynoslivost Experiment Facility (Endurance) [Roscosmos]

Combustion Integrated Rack (CIR) [NASA] is used to perform sustained, systematic combustion experiments in microgravity. It consists of an optics bench, a combustion chamber, a fuel and oxidizer management system, environmental management systems, interfaces for science diagnostics and experiment specific equipment, as well as 5 different cameras to observe the patterns of combustion in microgravity for a wide variety of gasses and materials. The **CIR** provides up to 90% of the required hardware to perform a majority of future microgravity combustion experiments onboard the ISS and the remaining 10% of the hardware (fuel, igniters, etc.) is provided by the specific investigation teams. The **CIR** accommodates experiments that address critical needs in the areas of spacecraft fire safety (i.e., fire prevention, detection and suppression), fundamental understanding of the combustion process, flame spread, soot production, material selection, power generation and incineration of solid wastes.

ISS crewmember Frank De Winne works with the CIR in the Destiny laboratory of the ISS (ISS020E029879).

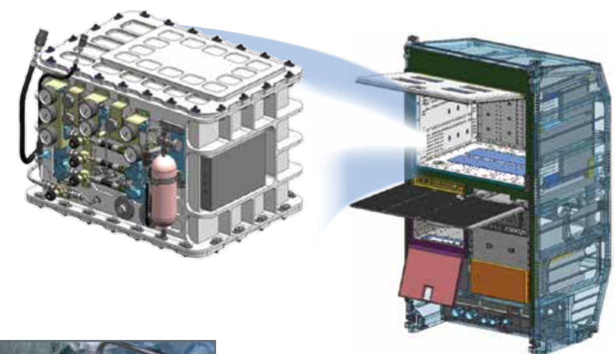
The Flame Extinguishment Experiment (FLEX) and the Flame Extinguishment Experiment - 2 (FLEX-2) investigations study the special characteristics of burning fuel in microgravity. They examine the speed at which the fuel burns and the conditions required for soot to form. These two investigations were conducted in the **CIR**.



Video Screen Shot of FLEX Ignition 1, beginning of combustion event (NASA).

The **Advanced Combustion via Microgravity Experiments (ACME) [NASA]** enables a suite of investigations and is focused on advanced combustion technology via fundamental microgravity research to improve efficiency and reduce pollutant emission in practical terrestrial combustion. The **ACME** investigations will operate in the **CIR**.

Chamber for Combustion Experiment (CCE) [JAXA] is located in the **Multi-purpose Small Payload Rack (MSPR)** facility and enables researchers to conduct controlled combustion experiments aboard the ISS.



The CCE is shown during ground processing prior to launch (JAXA).

Materials Science Research Rack (MSRR-1) [ESA, NASA] is a powerful multi-user facility that enables researchers by providing hardware to control the thermal, environmental and vacuum conditions of experiments, as well as monitor experiments using video, and supply power and data handling for experiment instrumentation.

Expedition 21 Commander Frank De Winne reinstalls the MSL Intermediate Support Plate in the MSL Core Facility during MSRR commissioning activities in the U.S. Laboratory/Destiny (ISS021E006227).

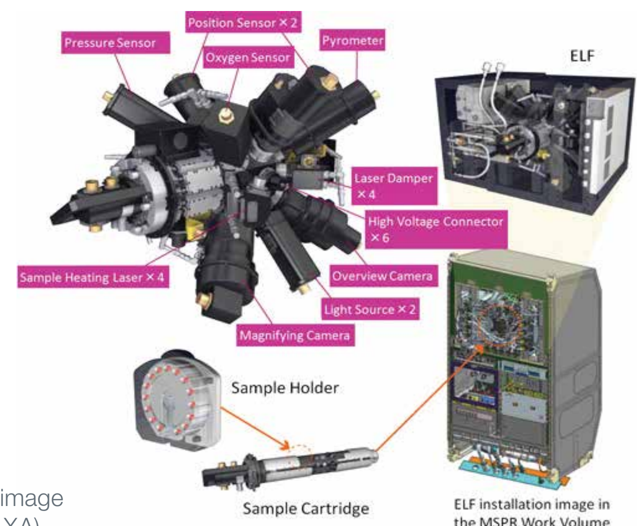
The Materials Science Laboratory (MSL) [ESA] is hosted in the **MSRR-1**, and is a multi-user facility that supports microgravity research in the areas of metallurgical solidification, semiconductor crystal growth (Bridgman and zone melting), and measurement of thermophysical properties of materials. The **MSL** is based on the concept of on-orbit exchangeable, resistance-heater Furnace Inserts (FIs). At present, two such FIs are being operated in the **MSL**. The **Low Gradient Furnace (LGF)**, which is a Bridgman furnace that supports directional solidification of metals and growth of semiconductors at temperature gradients up to 40 K cm^{-1}, and the **Solidification and Quenching Furnace (SQF)**, which is a Bridgman furnace that supports directional solidification of metal alloys with temperature gradients in the 50 - 150 K cm^{-1} range and sample quenching at end of processing. The main mode of operation of the **LGF** and **SQF** is directional solidification of metal alloys and semiconductors. The experiment samples are contained in Sample-Cartridge Assemblies (SCAs) that are inserted one at a time into the intended FI for processing. The **MSL** provides an accurate control of the experiment parameters (e.g., temperature profiles and growth speed) as well as various experiment diagnostics and stimuli.

Expedition 21 Commander Frank De Winne installs a LGF in the MSL Core Facility during MSRR commissioning activities in the U.S. Laboratory/Destiny (ISS021E006213).

Experiments in the **MSL** are coordinated by international teams, sharing the responsibility of sample selection and data analysis. Columnar-to-Equiaxed Transition in Solidification Processing (CETSOL) and Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions (MICAST) were the first two investigations in the **MSL** that supported research into metallurgical solidification, semiconductor crystal growth, and measurement of thermophysical properties of materials.

The **EML (ElectroMagnetic Levitator) [ESA, DLR]** jointly developed by ESA and DLR, is accommodated in ESA's **EDR** in the European Columbus Laboratory on the ISS. The **EML** provides containerless melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and/or high purity gas conditions. The **EML** is capable of heating metals up to 2100°C and then rapidly cooling the metals by forced gas convection, since the **EML** does not offer quenching. The **EML** supports research in the field of meta-stable states and phases and in the field of measurement of high-accuracy thermophysical properties of liquid metallic alloys at high temperatures (surface tension, viscosity, melting range, solid fraction, specific heat, heat of fusion, mass density and thermal expansion) together with thermal transport properties. In addition, electrical conductivity and to some extent magnetic susceptibility can be measured. Research on thermophysical properties is highly oriented to applications where reliable data for high temperature melts are required for accurate modelling of industrial processes and where these are difficult or impossible to be obtained on ground, in particular for reactive melts.

The **Electrostatic Levitation Furnace (ELF) [JAXA] i**s located in the **MSPR 2** and is designed to levitate/melt/solidify materials by containerless processing techniques using electrostatic levitation electrodes and creating Coulomb forces between the charged sample and electrodes. With this facility, thermophysical properties of high temperature melts will be measured and solidification from deeply undercooled melts will be achieved.



Close-up image of ELF (JAXA).

The **Kobairo Rack (Kobairo) [JAXA]** contains the **Gradient Heating Furnace (GHF) [JAXA]**, which provides all utility interfaces for this material science furnace.
The **GHF** is a vacuum furnace that contains 3 heating blocks, and is used mainly to conduct high-quality crystal growth experiments using unidirectional solidification. The 3 heater units can generate the high temperature gradients needed to produce large-scale pure crystals. **GHF** has an automatic sample exchange system that can be accommodate up to 15 samples to reduce crew operation.

Expedition 27 Flight Engineer Cady Coleman takes electrical resistance measurements of the GHF heating units Insulation Measurement Adapter with the Multimeter volt/amp instrument during maintenance on the GHF in the Kobairo Rack (ISS027E019792).

Kobairo, which is short for ondo-kobairo (温度勾配炉), means "temperature gradient furnace." The JAXA experiment, Growth of Homogeneous SiGe Crystals in Microgravity by the TLZ Method (Hicari), examined crystal-growth by using the Travelling Liquidous Zone method in microgravity.

The **Materials International Space Station Experiment – Flight Facility (MISSE-FF) [NASA]** is a test bed for materials and coatings attached to the outside of the ISS being evaluated for the effects of atomic oxygen, direct sunlight and extremes of heat and cold. This facility allows the development and testing of new materials to better withstand the rigors of space environments. Results will provide a better understanding of the durability of various materials when they are exposed to the space environment. Many of the materials may have applications in the design of future spacecraft.

Computer generated image of the MISSE-FF (NASA).

Physical Science Research

Replaceable Cassette-Container (SKK/CKK) [Roscosmos] is a materials test facility mounted on the outside of the ISS to provide direct exposure to the harsh environment of space. **SKK/CKK** are detachable cassette containers that measure the level and composition of contamination as well as monitor the change in operating characteristics for samples of materials from the outside surfaces of the ISS Russian Segment.

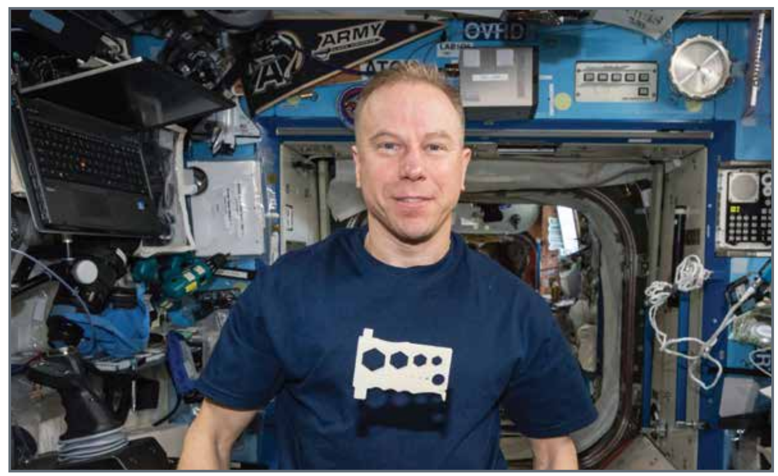
Both the **Replaceable Cassette-Container (SKK/CKK)** and Vynoslivost Experiment Facility consist of two-flap structures and consist of a casings and spool holders that contain sample cassettes of materials of the outside surfaces of the ISS Russian Segment modules.

Vynoslivost Experiment Facility (Endurance) [Roscosmos] is a materials science facility designed to investigate the impact of the space environment with regard to material deformation, strength and fatigue of present space technologies and structural materials. Long-term exposure of loaded and unloaded samples of structural materials is carried out on the external surface of MRM2 module. The data obtained will be used to more accurately assess the durability of the ISS Russian Segment modules structural elements, and for providing recommendations for the selection of more efficient and reliable structural materials for use in future designs and structural elements.

Photographic documentation taken of sample removal from Panel number 2a of the Vynoslivost experiment in preparation for return (ISS040E109662).

The **Additive Manufacturing Facility (AMF) [NASA, Commercial]** enables the production of components on the ISS for both NASA and commercial objectives. Parts, entire experiments, and tools can be created on demand utilizing the **AMF** that is installed into an EXPRESS Rack locker location. The **AMF** is capable of producing parts out of a wide variety of thermopolymers, including engineered plastics.

View of the Additive Manufacturing Facility during ISS Expedition 47 print removal (ISS047E152500).



ISS Commander Tim Kopra with a Print from the Additive Manufacturing Facility floating in the foreground during Expedition 47 (ISS047E152525).

Fluids Integrated Rack (FIR) [NASA] is a multi-user fluid physics research facility designed to accommodate and image a wide variety of microgravity fluid experiments. **FIR** features a large user-configurable volume for experiments. The **FIR** provides data acquisition and control, sensor interfaces, laser and white light sources, advanced imaging capabilities, power, cooling and other resources. The **FIR** will host fluid physics investigations into areas such as complex fluids (colloids, gels), instabilities (bubbles), interfacial phenomena (wetting and capillary action) and phase changes (boiling and cooling). An additional component of the **FIR** that is itself considered a multipurpose facility is the **Light Microscopy Module (LMM) [NASA]**, a ground-controlled, automated microscope that allows flexible imaging (bright field, dark field, phase contrast, etc.) for physical as well as biological experiments.

Expedition 47 ISS crewmember Jeff Williams configuring the Light Microscopy Module (LMM) for Microchannel Diffusion investigation (ISS047E066551).

NASA astronaut Nicole Stott, Expedition 21 flight engineer, installs hardware in the FIR in the Destiny laboratory of the ISS (ISS021E011438).

Reference mUltiscale Boiling Investigation (RUBI) [ESA] is among the upcoming investigations to be operated in the **FSL**, addressing the fundamentals of single bubble pool boiling and the bubble interaction with an electrostatic field and shear flow. The Soft Matter Dynamic instrument has multiple objectives covering the studies of foam coarsening, emulsions stabilization and dynamics in agitated granular matter and has been designed in such a way to be able to detect and analyze multiple scattering light in order to monitor the dynamics and the temporal evolution of these systems.

Fluids under microgravity conditions perform differently than those on Earth. Understanding how fluids react in these conditions will lead to improved designs of fuel tanks, water systems and other fluid-based systems.

Fluid Science Laboratory (FSL) [ESA] is a multi-user facility for conducting fluid physics research in microgravity conditions. The **FSL** provides a central location to perform fluid physics experiments onboard the ISS that gives insight into the physics of fluids covering areas such as foam and emulsion stability, geophysical fluid flow and thermodiffusion. An enhanced understanding of how fluids behave in space and on Earth will help researchers improve mathematical models of fluids and geophysical processes and may lead to improvements in many industrial processes involving fluid system.

View of the FSL Rack located in the European Laboratory/ Columbus (ISS021E016880).

The first experiment processed in the **FSL**, GEOFLOW, examined an experimental model of a planet in order to improve knowledge of geophysical fluid flow. The more complex follow-up experiment, GEOFLOW-2 is in progress and both have provided a wealth of fundamental data. Another series of investigations, known as FASES, studied emulsion properties using advanced optical diagnostics which could enhance processes in the oil extraction, chemical and food industries.

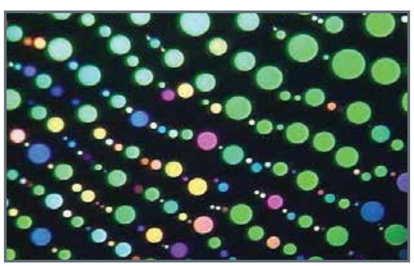
Microgravity Vibration Isolation Subsystem (MVIS) [CSA] was designed to allow experiments to be conducted in low gravity without interference from vibrations produced by the ISS. Through collaboration with the ESA in their **FSL**, **MVIS** will aim to improve the opportunities for the exploitation of microgravity vibration isolation technology.

Device for the study of Critical Liquids and Crystallization (DECLIC) [CNES, NASA] is a multi-user facility developed by the ESA-member agency Centre National d'Etudes Spatiales (French Space Agency, CNES) and flown in collaboration with NASA. It is designed to support experiments in the fields of fluid physics and materials science. Special inserts allow researchers to study both ambient temperature critical point fluids and high-temperature super-critical fluids. Another class of insert will study the dynamics and morphology of the fronts that form as a liquid material solidifies.

View of DECLIC Experiment Locker (ISS030E234823).

DECLIC provides the environment (set temperature in the range 30°C to 65°C) and stimuli for the cells containing samples under study. One cell is used for direct observation, the other for interferometric (pertaining to the science of combining two or more waves) observation.

The **Observation and Analysis of Smectic Islands In Space (OASIS) [NASA]** facility examines the unique characteristics of freely suspended liquid crystals in a microgravity environment to advance the understanding of complex fluids physics. **OASIS** is used within the **Microgravity Science Glovebox (MSG)** and has a removable sample container that can be filled with a variety of viscous fluids for creation of 15mm diameter thin film bubbles. **OASIS** is designed for autonomous operation through remote operations from the ground. Intermittent support from the onboard crew is required for experiment installation, sample loading and experiment initiation.



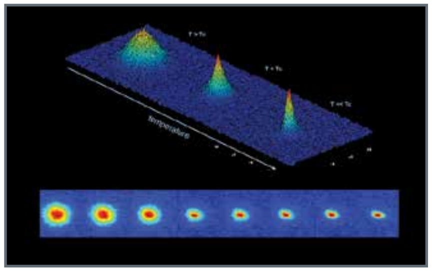
Microscopic detail of Liquid Crystal Domains/islands tethered like necklaces when an external electric field is applied near the very thin film surface. Properties such as this are part of the OASIS investigation operating aboard the ISS (NASA).

Ryutai Rack (Ryutai) [JAXA] is a multipurpose, multi-user rack system that supports various fluid physics experiments. **Ryutai** consists of 4 sub-racks. **Fluid Physics Experiment Facility (FPEF) [JAXA]** is a multi-user experiment facility to investigate fluid physics phenomena in a microgravity environment. **Solution Crystallization Observation Facility (SCOF) [JAXA]** investigates morphology and growth of crystals. **Protein Crystallization Research Facility (PCRF) [JAXA]** investigates protein crystal growth in microgravity. The **Image Processing Unit (IPU)** supports the entire rack with regard to image data handling. **Ryutai** enables teleoperations of experiments while providing the electrical power, ground command and telemetry monitoring, water cooling and gas supply needed by those sub-rack facilities.

JAXA astronaut Koichi Wakata works on an experiment at the Ryutai fluid science experiment rack in the Kibo laboratory of the ISS (ISS018E044235).

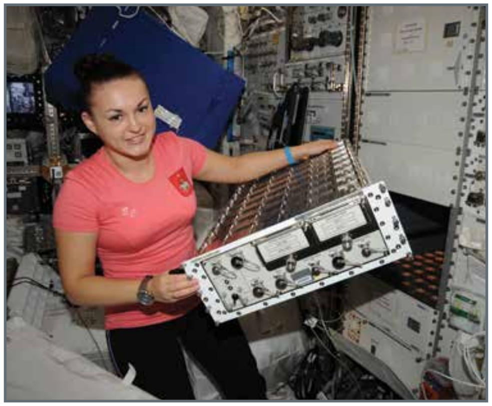
Ryutai (流体) means "Fluid Dynamics" in Japanese. This Rack consists of **FPEF, SCOF, PCRF** and **IPU**, which supports various fluid physics experiments including protein crystal growth experiment.

The **Cold Atom Laboratory (CAL) [NASA]** makes use the space station's unique microgravity environment to observe quantum phenomena that would otherwise be undetectable from Earth. CAL studies ultra-cold quantum gases; scientists use the facility to explore how atoms interact when they have almost no motion due to such cold temperatures. Due to the microgravity environment of the ISS, matter can stay in the form of a Bose Einstein condensate longer than on Earth, giving researchers the unique opportunity to observe this phenomena.



False-color images show the formation of a Bose-Einstein condensate in the Cold Atom Laboratory prototype at NASA's Jet Propulsion Laboratory as the temperature gets progressively closer to absolute zero. The red in each figure indicates higher density. Bottom image is a sequence of false-color images (Jet Propulsion Laboratory).

The **Plasma Kristall – 4 (PK-4) [ESA, Roscosmos]** investigates the liquid phase and flow phenomena of complex plasmas and enables observation of the movement of individual particles in microgravity. Using **PK-4**, physical processes occurring at the atomic or molecular level become visible and can be investigated in a targeted manner. The main feature of the **PK-4** facility (in comparison with its predecessors onboard the ISS, such as PK-3 and PK-3+) is a new concept of its discharge chamber. Application of a combined discharge that consists of a direct current discharge, inductive HF discharge and capacitive HF discharge allows varying the topology of studied plasma-dust formations in a wide range.



Cosmonaut Elena Serova works with elements of PK-4 facility aboard Columbus module of the ISS (Rososmos).

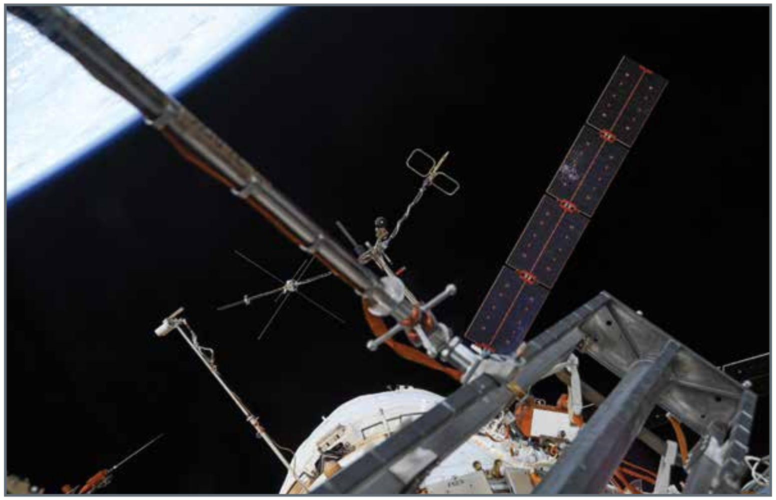
Earth and Space Science Research

Circling the Earth every 90 minutes in an inclined low-Earth orbit, covering more than 90 percent of the planet's habitable land mass, the ISS provides a unique vantage point for collecting Earth and space science data. From an average altitude of about 400 km, detailed data regarding the space environment, atmosphere, land features, environmental changes and land use taken from the ISS can be layered with other sources of data, such as orbiting robotic satellites and aerial photogrammetry, to compile the most comprehensive information available.

Facilities in this section show some of the current and growing capabilities afforded by the ISS in the following fields of research: glaciers, agriculture, urban development, natural disaster monitoring, atmospheric observations and space radiation:

- Columbus-External Payload Facility (Columbus-EPF) [ESA]—previously described in External Multipurpose Facilities
- Cosmic Ray Detectors and Ionosphere Probes [Roscosmos]
- Crew Earth Observations (CEO) Facility [NASA]
- Earth Resources Sensing and Geophysics Instruments [Roscosmos]
- Expedite the Processing of Experiments to the Space Station (EXPRESS) Logistics Carrier (ELC) [NASA]—previously described in External Multipurpose Facilities
- JEM External Facility (JEM-EF) [JAXA]—previously described in External Multipurpose Facilities
- Multiple User System for Earth Sensing (MUSES) [NASA, Commercial]
- Napor-MiniRSA [Roscosmos]
- Seismoprognosis [Roscosmos]
- Sun Monitoring on the External Payload Facility of Columbus (Solar) [ESA]
- Window Observational Research Facility (WORF) [NASA]

Cosmic Ray Detectors and Ionosphere Probes [Roscosmos] are important for ongoing studies of cosmic rays and the low-Earth orbit environment. Several external investigations and instrument packages are available including BTN-Neutron (neutron flux detector) and Vsplesk (gamma ray and high-energy charged particle detector). Obstanovka is another suite of detectors used to measure several ionosphere parameters and plasma-wave characteristics.



View of antenna on the Obstanovka (Environment) experiment (installed during Russian EVA 32) on the Service Module (ISS037E005130).

View of the BTN-Neutron experiment, attached to the Zvezda Service module. The BTN-Neutron experiment builds a physical model for generation of charged and neutral particles during solar flares. It also develops a physical model of neutron albedo of the Earth's atmosphere with regard to helio- and geophysical environment, measurement point longitude and altitude effects, time of the day and lighting conditions, atmosphere conditions. Also it develops a physical model of neutron background in the vicinity of the ISS in different flight conditions, as well as recording space gamma bursts (ISS014E14541).

Earth Resources Sensing and Geophysics Instruments [Roscosmos] are a suite of instruments used in the study of geophysics, natural resources, ecology and natural disaster monitoring. Fialka is an ultraviolet imager and spectrometer used to study radiation emitted by reactions between atomic oxygen in space and the propulsion system exhaust products from the ISS, Progress and Soyuz thrusters. It is also used to study the spatial distribution and emission spectra of atmospheric phenomena such as airglow. **Photospectrometric System (FSS)** is used for monitoring natural disasters (Uragan) and ecological monitoring (Econ). **FSS** uses a spectral range of 350-1050 nm and resolution of better than 3 nm. In all, this suit of instruments practically and efficiently increases the ability to perform scientific and Earth observation experiments from the ISS. **Video-spectrometric System (VSS)** measures radiation characteristics reflected from underlying surface wavelength range from 400-950 nm and digital imaging in a visible range for Uragan.

Russian experiment Fialka multispectral ultraviolet system hardware installed on the Service Module/Zvezda window (ISS015E28944).

Fyodor Yurchikhin working during a session of the GFI-8 Uragan Earth-imaging program at Service Module/Zvezda window 9 with use of the FSS (ISS024E007525).

The **Window Observational Research Facility (WORF) [NASA]** provides a unique ISS facility for conducting crew-tended or automatic Earth observation and scientific research using the Destiny module's large optical-quality window. **WORF** is a multipurpose facility that provides structural support hardware, avionics, thermal conditioning and optical quality protection in support of a wide variety of remote sensing instruments and scientific investigation.

NASA astronaut Ron Garan, Expedition 27 flight engineer, works with ISSAC hardware in the Destiny laboratory of the ISS (ISS027E023657).

Destiny features an Earth observation window with the highest-quality optics ever flown on a human occupied spacecraft. The first remote sensing instrument to be used in **WORF** was ISS Agricultural Camera (ISSAC), a multi-spectral, visible and infrared camera that imaged crops to aid in land use management practices for farmers, as well as collecting imagery in support of natural disaster response and recovery. The ISS SERVIR Environmental Research and Visualization System (ISERV) Pathfinder system (currently in stowage on the ISS) was a very-high spatial resolution, pointable and ground-commanded camera that supported the USAID-NASA SERVIR Program and collection of imagery to support disaster response. Currently, the Meteor video camera and diffraction spectrometer system collects compositional information on meteors that enter Earth's atmosphere.

The **Crew Earth Observations (CEO) Facility [NASA]** utilizes the ISS crew and handheld, visible-wavelength digital cameras (currently Nikon D4 series) to photograph the Earth surface and atmosphere from low-Earth orbit. A variety of available camera lenses allows for both wide-field, low spatial resolution panoramic and Earth-limb imagery (useful for atmospheric science studies), and very high spatial resolution (~ 3 meters/pixel), targeted ground imagery that supports urban, environmental, coastal, agricultural and geologic research and applications. A major emphasis of the **CEO Facility** is to collect image data in support of disaster response and recovery efforts. All data collected using the **CEO Facility** are publicly available through the Gateway to Astronaut Photography of Earth website at https://eol.jsc.nasa.gov. From this website, researchers and educators can also propose specific sites for the crew to collect imagery.

ESA astronaut Luca Parmitano preparing to collect data for the Crew Earth Observations Facility in the ISS Cupola (ISS036E005769).

CEO Facility astronaut photograph of flooding in North Carolina following Hurricane Matthew, taken from the ISS on October 13, 2016. The image was fully georeferenced by the CEO Facility ground team and delivered to the United States Geological Survey to contribute to disaster response efforts. The Geocam Space system, planned for deployment on the ISS in mid-2017, will greatly enhance the ability to automate the production of fully georeferenced astronaut imagery by capturing camera pose information simultaneously with image capture.

Seismoprognosis [Roscosmos] tests methods for monitoring of electromagnetic and plasmic signals of earthquakes, emergency situations and other disasters.

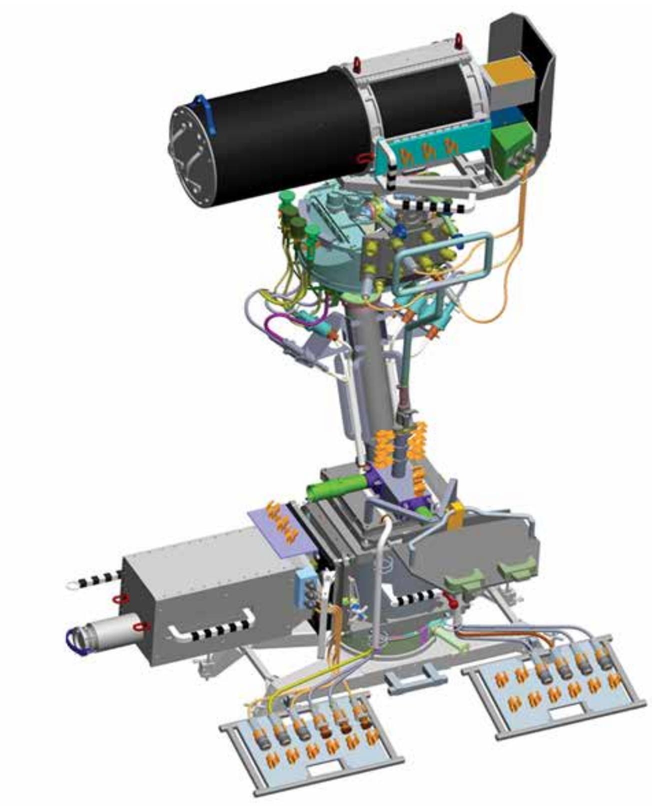
The Seismoprognosis monoblock has been installed on the external handrails of SM during Russian EVA-37 (Expedition 38). Beginning February 25, 2014, the instrument provides scientific information continuously (ISS038E021720).

The **Multiple User System for Earth Sensing (MUSES) [NASA, Commercial]** hosts Earth-viewing instruments, such as high-resolution digital cameras and hyperspectral imagers, and provides precision pointing and other accommodations. It hosts up to 4 instruments at the same time, and offers the ability to change, upgrade and robotically service those instruments. The **MUSES** is planned to be installed on ELC-4 in 2017.

Photo of MUSES taken in Huntsville, AL (JSC2014E089091).

The DLR Earth Sensing Image Spectrometer (DESIS) will be mounted to MUSES and begin collecting imagery to monitor natural disasters such as fires, floods and drought for emergency response and farming purposes. DESIS will have cameras scan multiple bands of light that are invisible to the human eye and spot environmental changes quickly for commercial, scientific and humanitarian benefits.

The **Napor-MiniRSA [Roscosmos]** performs inflight testing and fine-tuning of portable microwave synthetic aperture radar that is designed on the basis of active phased microstrip arrays, and operates jointly with the system of optical sensors (telescopes) for natural resources management, ecological monitoring, and monitoring of emergency situations.



Napor-MiniRSA hardware (Roscosmos).

Sun Monitoring on the External Payload Facility of Columbus (Solar) [ESA] was a monitoring observatory that measured the solar spectral irradiance. Apart from scientific contributions for solar and stellar physics, the knowledge of the solar energy irradiance into the Earth's atmosphere and its variations is of great importance for atmospheric modeling, atmospheric chemistry and climatology. Solar operated on ISS from 2008 - 2017.

View of Sun Monitoring on the External Payload Facility of Columbus (Solar) (S122E009344)

Technology Demonstration Research

Future exploration—the return to the moon and human exploration of Mars—presents many technological challenges. Studies on the ISS can test a variety of technologies, systems and materials that will be needed for future exploration missions. Some of the technology development facilities have been proven successful such that the hardware has been transitioned to operational status on the ISS. A small but growing portion of ISS facilities directly relates to investigations that demonstrate and test new or evolving technologies for use in the space environment. Having hardware that multiple users can use to perform experiments saves researchers time and money since they do not need to develop the shared equipment.

- Additive Manufacturing Facility (AMF) [NASA, Commercial] - previously described in Physical Science Research
- Bar [Roscosmos]
- Global Transmission Services (GTS) [ESA, Roscosmos]
- Proboy (Puncture) [Roscosmos]
- Space Communications and Navigation Testbed (SCAN Testbed) [NASA]
- Vessel Identification System (VIS) [ESA]
- Vibrolab [Roscosmos]

Global Transmission Services (GTS) [ESA, Roscosmos] is a continuously operating facility, located within the Russian Segment of the ISS, which tests the receiving conditions of time and data signals from dedicated receivers on the ground. Special coding of the time signal allows the receiver to determine the local time anywhere on the Earth. The main objective of this hardware is to verify the performance and accuracy of a time signal transmitted to the Earth's surface. This assessment includes signal quality and data rates achieved on the ground, measurement of disturbing effects such as Doppler shifts, multipath reflections, shadowing and elevation impacts. The **GTS** technology is being developed for future applications by the International Cooperation for Animal Research Using Space (ICARUS) Initiative, which includes the goal of developing a technological solution for the global tracking of small objects (e.g., animals). The purpose of the ICARUS Initiative is to obtain data on the migration patterns of birds, bats, insects, etc. for scientific study.

The **Vessel Identification System (VIS) [ESA]** is a multi-user radio receiver that operates in the VHF maritime band. The orbit of the ISS provides an ideal location for space-based signal reception, and the incorporation of this system will verify the capability of tracking global maritime traffic from space. VIS is capable of receiving a multitude of ship information including identity, position, course, speed, cargo and voyage, and then communicating the data between other vessels and shore sites.

VIS Antenna shown installed on the external surface of the Columbus module (S129E007770).

Bar [Roscosmos] uses a unique set of instruments for conducting ultrasonic probing, measuring and mapping spacecraft temperatures and pyroendoscopic analysis of potentially dangerous locations and conditions onboard the ISS as a result of material degradation or corrosion during operations in orbit. Zones of possible formation of condensation have been revealed, and potential corrosion damage has been evaluated.

Roman Romanenko in the Service Module, taken during session of the Bar/Expert investigation to measure environmental parameters (i.e., temperature, humidity, air flow rate) and module shell surface temperatures behind Service Module panels and other areas susceptible to possible microdestruction (corrosion), before and after insolation (day vs. night) (ISS020E035022).

In a related investigation, colonies of micromycets were found on the internal walls of a pressurized ISS compartment during the Investigation of the Early Symptoms of Microdestruction of Structures and Instrument Modules in Russian Segment of ISS (Expert) experiment. Understanding and maintaining environmental integrity from structures to microbiology will ultimately allow humans to explore beyond low-Earth orbit and become permanent inhabitants of space.

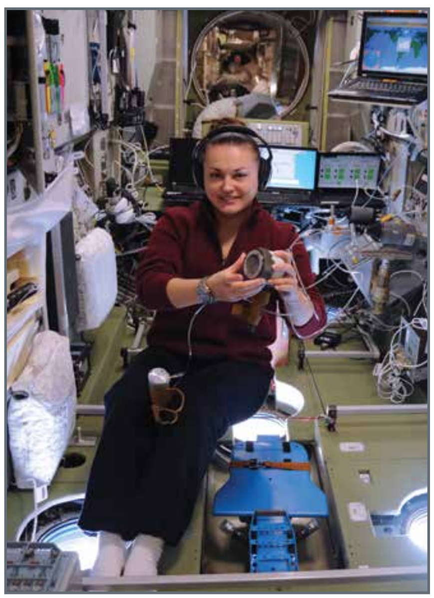
Ulocladium: a genus of water-needing fungi or mold.

Cladosporium: a common indoor/outdoor fungus.

The **Space Communications and Navigation Testbed (SCAN Testbed) [NASA]** consists of a set of reconfigurable software defined radios (SDRs), which have software that can be modified on orbit to allow users to test multiple radio frequency bands using the same hardware. By providing reconfigurable software to an existing radio platform, **SCAN Testbed** allows different radio vendors the ability to demonstrate unique radio configurations based on the common Space Telecommunications Radio System architecture standard. The goal of providing this facility is to encourage the development and advancement of SDR technologies for common, space-based architectures in hopes of reducing future developmental risks and costs. This hardware is located on **ELC-4** and points earthward (ISS nadir).

External image of the ISS showing SCAN Testbed installed on ELC 4 nadir side (NASA).

Proboy (Puncture) [Roscosmos] tests a method associated with fast detection of point of puncture coordinates in the ISS module hull (made by a high-speed micrometeoroid or technogenic particles) with detection of acoustic waves in the module's cabin air.



ISS crewmember Elena Serova works with Proboy equipment aboard the ISS Service Module (Roscosmos).

Vibrolab [Roscosmos] tests and fine-tunes methods and instruments for monitoring of microaccelerations aboard the ISS Russian Segment associated with implementation of research programs in a microgravity environment.

The facility consists of Sinus-Accord electronic unit, micro(vibro)accelerations sensors and cables. It is handheld equipment and can be installed in different locations inside the ISS (Roscosmos).

Acronyms

ABRS	Advanced Biological Research System
ACES	Atomic Clocks Ensemble in Space
ACME	Advanced Combustion via Microgravity Experiments
AMF	Additive Manufacturing Facility
APEX	Advanced Plant Experiments on Orbit
AQH	Aquatic Habitat
ARED	Advanced Resistive Exercise Device
ARIS	Active Rack Isolation System
ASIM	Atmosphere Space Interaction Monitor
CAL	Cold Atom Laboratory
CALET	CALorimetric Electron Telescope
CATS	Cloud-Aerosol Transport System
CB	Clean Bench
CBEF	Cell Biology Experiment Facility
CCD	Charge-Coupled Device
CCE	Chamber for Combustion Experiment
CCFP	Cerebral Cochlear Fluid Pressure Analyzer
CEO	Crew Earth Observations
CEPA	Columbus External Payload Adapter
CETSOL	Columnar-to-Equiaxed Transition in Solidification Processing
CEVIS	Cycle Ergometer with Vibration Isolation System
CFR	Combustion Integrated Rack
CGBA	Commercial Generic Bioprocessing Apparatus
CIR	Combustion Integration Rack
CNES	French Space Agency
COLBERT	Combined Operational Load Bearing External Resistance Treadmill
DECLIC	DEvice for the study of Critical LIquids and Crystallization
DESIS	DLR Earth Sensing Image Spectrometer
DLR	German Aerospace Center
DOSIS	Dose Distribution Inside the International Space Station
DPOAE	Distortion Product Otoacoustic Emissions
EDR	European Drawer Rack
ELC	EXPRESS Logistics Carrier
ELF	Electrostatic Levitation Furnace
EMCS	European Modular Cultivation System
EML	ElectroMagnetic Levitator
EPF	External Payload Facility
EPM	European Physiology Module
ESA	European Space Agency
ETC	European Transport Carrier
EuTEF	European Technology Exposure Facility
EVA	Extravehicular Activity
ExHAM	Exposed Experiment Handrail Attachment Mechanism
EXPRESS	Expedite the Processing of Experiments to Space Station
FI	Furnace Insert
FIR	Fluids Integrated Rack
FLEX	Flame Extinguishment Experiment
FPEF	Fluid Physics Experiment Facility
FROST	Freezer Refrigerator of Stirling Cycle
FSL	Fluid Science Laboratory
FSS	Photospectrometric System
GAP	Group Activation Pack
GHF	Gradient Heating Furnace
GLACIER	General Laboratory Active Cryogenic ISS Equipment Refrigerator
GTS	Global Transmission Services
HCU	Habitation Cage Unit
HDP	Hard Dummy Panel
HICO	Hyperspectral Imager for the Coastal Ocean
HMZ	Holter Monitor Z
HREP	HICO/RAIDS Experiment Payload
HRF	Human Research Facility
ICARUS	International Cooperation for Animal Research Using Space
IPU	Image Processing Unit
i-SEEP	Intravehicular Activity-replaceable Small Exposed Experiment Platform
ISERV	ISS SERVIR Environmental Research and Visualization System
ISIS	International Sub-rack Interface Standard
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSAC	ISS Agricultural Camera
IVA	Intravehicular Activity
IV-TEPC	Intra-Vehicular Tissue Equivalent Proportional Counter
JAXA	Japan Aerospace Exploration Agency
JEM	Japanese Experiment Module
JEMAL	JEM Air Lock
JEM-EF	JEM External Facility
JEM-PM	JEM Pressured Module
JEMRMS	JEM Remote Manipulator System
J-SSOD	JEM Small Satellite Orbital Deployer

LACS	Leg/Arm Cuff System
LED	Light Emitting Diode
LGF	Low Gradient Furnace
LSG	Life Sciences Glovebox
MAMS	Microgravity Acceleration Measurement System
MARES	Muscle Atrophy Research and Exercise System
MAXI	Monitor of All-sky X-ray Image
MELFI	Minus Eighty-Degree Laboratory Freezer for ISS
MERLIN	Microgravity Experiment Research Locker/Incubator
MHU	Mouse Habitat Unit
MICAST	Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions
MISSE-FF	Materials International Space Station Experiment – Flight Facility
MLM	Multipurpose Laboratory Module
MRM	Mini Research Module
MSG	Microgravity Science Glovebox
MSL	Materials Science Laboratory
MSPR	Multi-purpose Small Payload Rack
MSRR	Materials Science Research Rack
MUSES	Multiple User System for Earth Sensing
MVIS	Microgravity Vibration Isolation Subsystem
MVP	Multipurpose Variable-g Platform
MW	Multipurpose Workstation
NLP	National Lab Payload
NRCSD	NanoRacks CubeSat Deployer
NREP	NanoRacks External Platforms
NRSS	NanoRacks Separation System
OASIS	Observation and Analysis of Smectic Islands In Space
ODK	Onboard Diagnostic Kit
PADLES	PAssive Dosimeter for Lifescience Experiments in Space
PCR	Polymerase Chain Reaction
PCRF	Protein Crystallization Research Facility
PEMS	Percutaneous Electrical Muscle Stimulator
PFS	Pulmonary Function System
PK-4	Plasma Kristall – 4
PMS	Pressurized Mating Adapter
RAIDS	Remote Atmospheric and Ionospheric Detection System
RMS	Remote Manipulator System
ROALD	Role of Apoptosis in Lymphocyte Depression

RUBI	Reference mUltiscale Boiling Investigation
SABL	Space Automated Bioproduct Laboratory
SAMS	Space Acceleration Measurement System-II
SCA	Sample Cartridge Assembly
SCAN	Space Communications and Navigation
SCOF	Solution Crystallization Observation Facility
SDR	Software Defined Radio
SEDA-AP	Space Environment Data Acquisition equipment-Attached Payload
SFA	Small Fine Arm
SKK/CKK	Replaceable Cassette-Container
SLAMMD	Space Linear Acceleration Mass Measurement Device
SPHERES	Synchronized Position Hold, Engage, Reorient, Experimental Satellites
SPICE	Smoke Point In Co-flow Experiment
SpinSat	Special Purpose Inexpensive Satellite
SQF	Solidification and Quenching Furnace
SSIKLOPS	Space Station Integrated Kinetic Launcher for Orbital Payload Systems
STaARS-1 EF	Space Technology and Advanced Research Systems – 1 Experiment Facility
TAGES	Transgenic Arabidopsis Gene Expression System
TBU-V	Universal Bioengineering Thermostat V
TCS	Thermal Control System
TCU	Transportation Cage Unit
USOS	United States On-orbit Segment
VHF	Very High Frequency
VIS	Vessel Identification System
VSS	Video-spectrometric System
VZP-U	Vibration Protective Platform
WAICO	Waving and Coiling of Arabidopsis Roots at Different g-levels
WORF	Window Observational Research Facility
ZSR	Zero Gravity Stowage Rack

Index

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https://www.nasa.gov/sites/default/files/atoms/files/np-2015-05-022-jsc-iss-guide-2015-update-111015-508c.pdf

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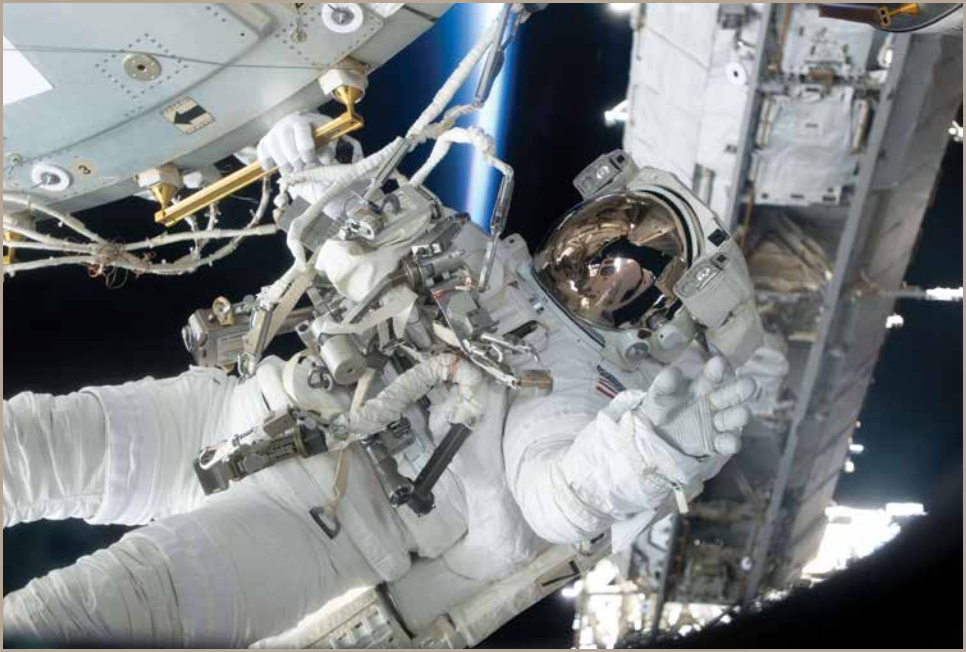

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