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.

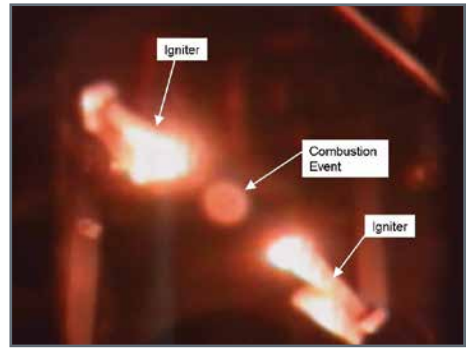
This section provides highlights of the current physical and material science platforms available onboard the ISS. An overview of each of the following is provided within this section:

- 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).

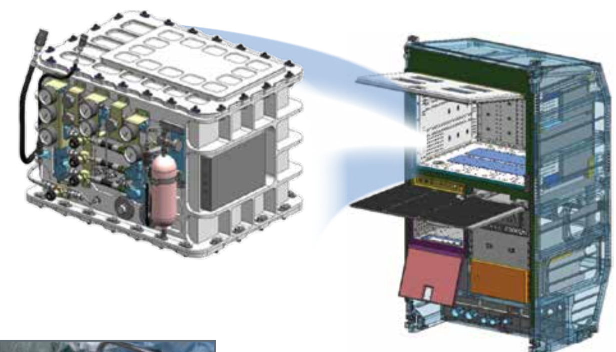
The Flame Extinguishment Experiment (FLEX) and the Flame Extinguishment Experiment - 2 (FLEX-2) investigations study the special characteristics of burning fuel in microgravity. They examine the speed at which the fuel burns and the conditions required for soot to form. These two investigations were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

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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).

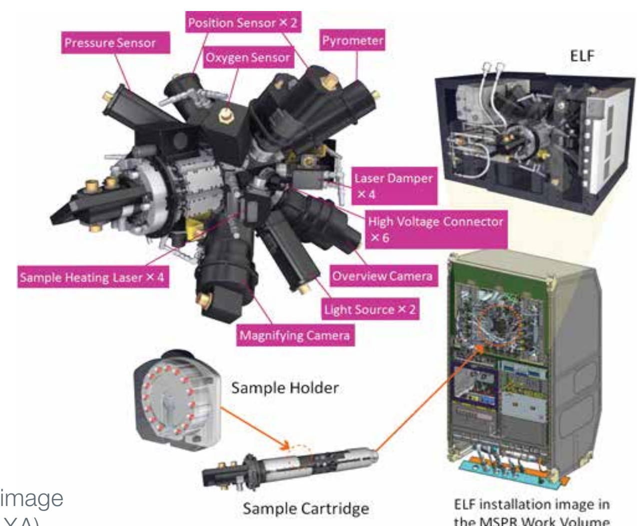
The Materials Science Laboratory (MSL) [ESA] is hosted in the **MSRR-1**, and is a multi-user facility that supports microgravity research in the areas of metallurgical solidification, semiconductor crystal growth (Bridgman and zone melting), and measurement of thermophysical properties of materials. 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).

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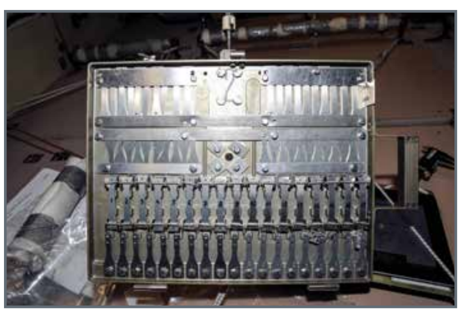
Replaceable Cassette-Container (SKK/CKK) [Roscosmos] is a materials test facility mounted on the outside of the ISS to provide direct exposure to the harsh environment of space. **SKK/CKK** are detachable cassette containers that measure the level and composition of contamination as well as monitor the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

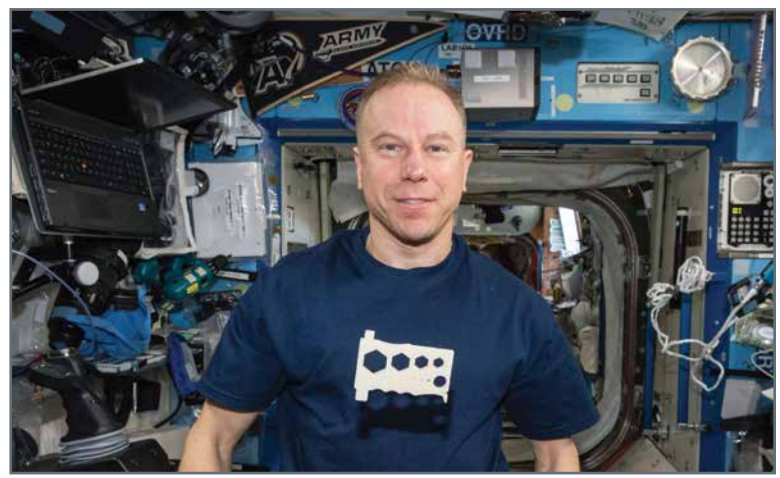
Vynoslivost Experiment Facility (Endurance) [Roscosmos] is a materials science facility designed to investigate the impact of the space environment with regard to material deformation, strength and fatigue of present space technologies and structural materials. Long-term exposure of loaded and unloaded 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).

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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.

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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.

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

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.

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.

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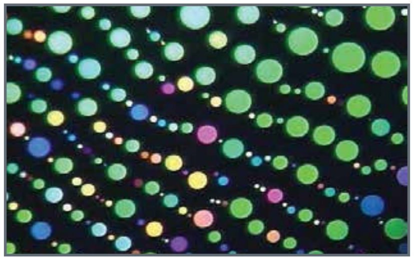
Device for the study of Critical Liquids and Crystallization (DECLIC) [CNES, NASA] is a multi-user facility developed by the ESA-member agency Centre National d'Etudes Spatiales (French Space Agency, CNES) and flown in collaboration with NASA. It is designed to support experiments in the fields of fluid 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.



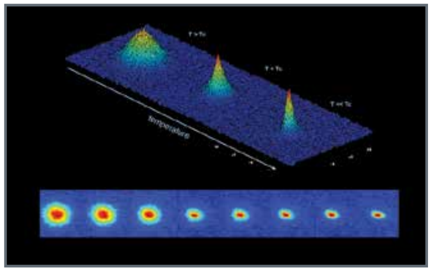
Microscopic detail of Liquid Crystal Domains/islands tethered like necklaces when an external electric field is applied near the very thin film surface. Properties such as this are part of the OASIS investigation operating aboard the ISS (NASA).

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).

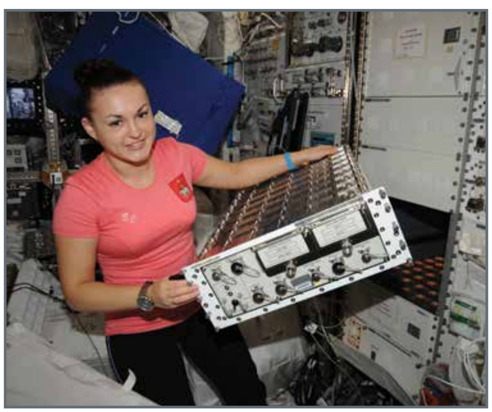
Ryutai (流体) means "Fluid Dynamics" in Japanese. This Rack consists of **FPEF, SCOF, PCRF** and **IPU**, which supports various fluid physics experiments including protein crystal growth experiment.

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).