The “Kibo” laboratory 400 km above Earth in the palm of your hand

National Research and Development Agency
Japan Aerospace Exploration Agency,
Human Spaceflight Technology Directorate

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JAXA

Summary of the “Kibo” utilization

“Kibo”: Opening Up Future Exploration

The Value and Future That "Kibo" Brings to Us

The Japanese Experiment Module (JEM), known as "Kibo", is Japan's first human-rated space facility on the International Space Station (ISS) The ISS orbits about 400 km above Earth in 90 minutes.
In "Kibo", the special environment of space, mainly characterized by microgravity, is used to perform various activities. The results from these activities are applied to medicine, manufacturing, and other areas, and some are already used in our daily lives.

The ISS is humankind's only laboratory in which a microgravity environment can be obtained over a long period of time. Experiments utilizing this environment that cannot be recreated on Earth are expected to solve problems of interest to companies, universities, and research institutions, leading to the growth of business and research.

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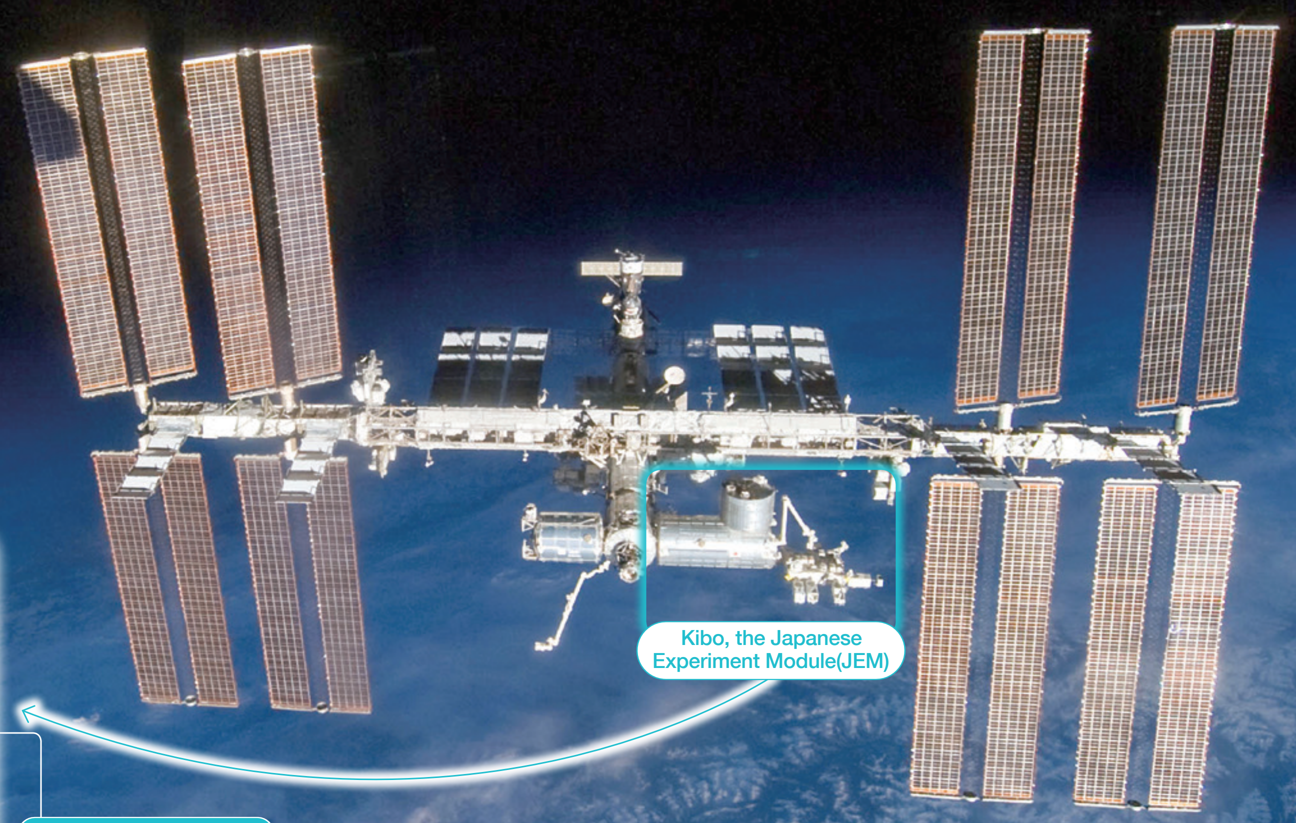
This is “Kibo”.

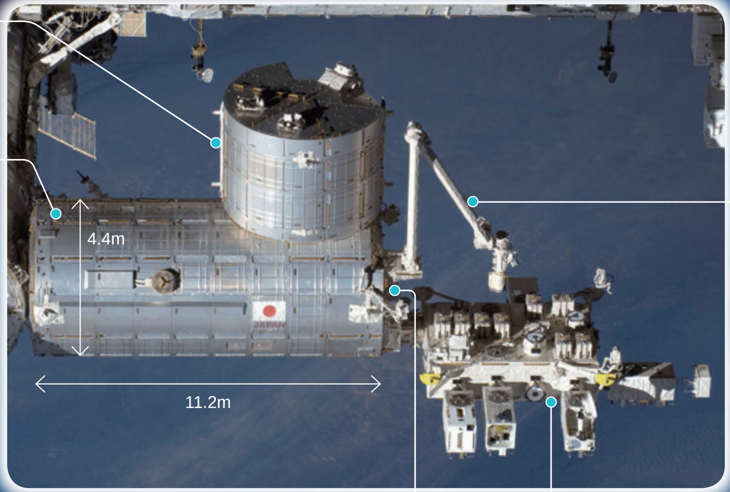
About the International Space Station

The International Space Station (ISS) is a manned laboratory built in space approximately 400 km above the Earth through the cooperation of 15 countries including Japan, the U.S., Russia, Canada, and several European countries. Construction began in 1998 and was completed in 2011. It is approximately the size of a soccer field, and orbits the Earth in about 90 minutes. The ISS has six onboard astronauts who perform various experiments. Japan has committed to participating in the operation of the ISS until 2024.

About “Kibo”

“Kibo” is Japan's first manned laboratory on the ISS. Experiments commenced in “Kibo” in 2008. The area for experiments consists of the Pressurized Module, which is filled with air at a pressure of 1 atmosphere and can accommodate activities performed in the same clothes as on Earth, and the Exposed Facility for performing experiments in space.





Experiment Logistics Module, Pressurized Section

An area for storing experimental equipment, materials, consumables, etc.

Pressurized Module

The area for experiments that is the heart of Kibo. This module can be used to perform experiments like the following.

- Experiments in life science (cell cultures, growing plants, rearing mice, etc.)
- Experiments in materials science and physical sciences (crystal growth, combustion, fluids, melting materials, etc.)
- Medical experiments with astronauts as subjects

JEM-Remote Manipulator System

Performs work such as exchanging experimental equipment for extravehicular experiments.

JEM Airlock

Used when moving experimental equipment through the pressure differential between the pressurized module and space.

Exposed Facility

Used to perform experiments with the experimental equipment exposed to space. For example, the following experiments are possible:

- Verification tests of space equipment, sensors, etc.
- Evaluation of space materials
- Earth observation
- Celestial observation

Kounotori

The space station supply vehicle for transporting cargo to the ISS.

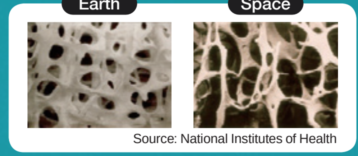
Characteristics of the space environment

Microgravity	The apparent gravity that acts on the ISS is very small, from one millionth to one ten thousandth of that on Earth.
Hard vacuum	The pressure at the altitude of the ISS orbit is 10-5 Pa, which is one ten billionth of that on Earth.
Complex space radiation	There are various types of space radiation, including galactic cosmic rays, solar particle radiation, Van Allen belt particle radiation, and secondary particle radiation.
Wide field of view	The ISS orbits the Earth in about 90 minutes and has a wide field of view. This is useful for Earth and space observations.
Living in a closed environment	Measures are required to prevent harm to human health, for example, due to psychological stress or microbial infections.

Characteristics of microgravity

1 Changes to the body

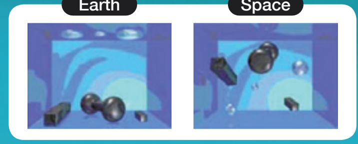
Since there is no gravity in space, a variety of changes are observed at a genetic level and a functional level in the body. Investigating the causes of these problems and their solutions may lead to new treatments and countermeasures for problems such as osteoporosis and deterioration of immune function.



Source: National Institutes of Health

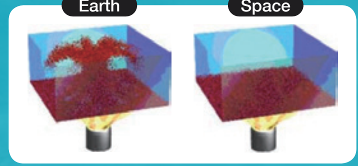
2 No sedimentation

On Earth, materials sink or float depending on their density. In microgravity environments, even materials with different specific gravities such as water and oil disperse evenly. This can be useful in creating highly functional materials.



3 No thermal convection

On Earth, when liquids and gases are heated, convection occurs due to differences in specific gravities In microgravity environments, the differences in specific gravities do not cause convection. It is thus possible to create high-quality protein crystals and material structures that cannot be created on Earth, where convection causes problems.



4 Floating without a container

IIn the microgravity, material can be levitated easily, and melted material stays in a stable (spherical) state without a container. This method of handling materials without a container is called “containerless processing”. This processing allows us to closely investigate the behavior of materials in their molten states, which is difficult to do on Earth.

What you can do on “Kibo.”

Various experiments have already been performed on “Kibo” and we have obtained revolutionary scientific results in the life sciences, space science, material science, and physics. We have also developed technologies for supporting space experiments. “Kibo” has a tremendous capability to contribute to even more discoveries and provide good solutions to problems. Below, we introduce some of the results obtained in “Kibo” and our new challenges for the future.

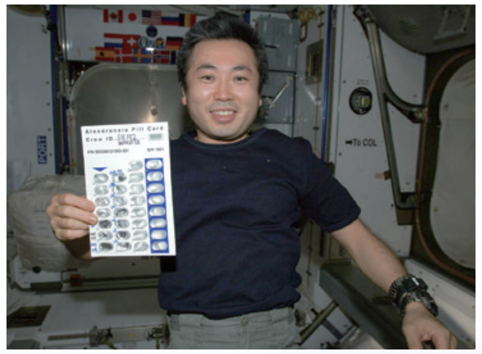
01 Supporting a healthy society with longevity.

See P.8 and 9

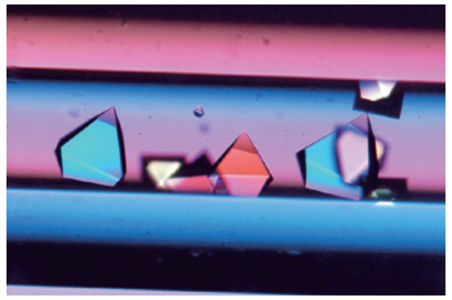
In Japan, where one in four people is 65 years of age or older, people hope to stay healthy as long as possible. In microgravity, bones weaken extremely quickly, at approximately 10 times the rate seen in people with osteoporosis, and muscles weaken extremely quickly, at approximately twice the rate of people confined to bed. Research focusing on these phenomena, which could be called an accelerated model of aging-like physiological changes, is expected to contribute to the prevention and treatment of locomotive syndrome, in which motor organs such as bones and muscles become atrophied.

Along another line, because convection and sedimentation do not occur in microgravity, protein crystals can be grown with higher quality than on Earth. Using these high-quality protein crystals makes it possible to determine the structure of proteins in more detail, and this is useful for drug research and development.

In the future, we will conduct new experiments, such as crystalizing membrane proteins for drug targets and producing 3D tissues/organs from stem cells for regenerative medicine. We also plan to conduct epigenome research to clarify genetic changes caused by microgravity.



Astronaut Koichi Wakata participated as a subject in experiments on preventing reduction of bone density. We investigated the change in his bone density after taking a drug intended to treat osteoporosis.



High-quality protein crystals grown on “Kibo”

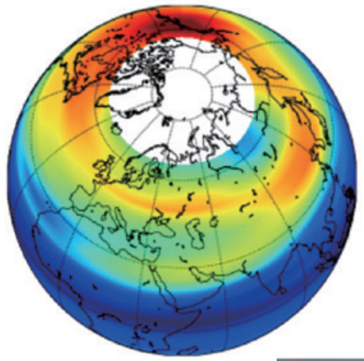
02 Contributing to a prosperous, safe, and secure life.

See P.10 and 11

Global warming, an increased frequency of extreme weather events, and the food shortages that accompany them … Humanity is currently facing a variety of problems. On “Kibo”, we are working to help solve these kinds of problems and to ensure a prosperous, safe, and secure life. For example, observation of Earth from space is useful for predicting environmental variations and monitoring disasters that cover wide areas. Furthermore, experiments on cultivating plants in microgravity environments are expected to deliver results such as the creation of rice that will not easily be damaged, even by typhoons.

Surgical robots that are now actively used in medicine were created from the technology of Canadarm2, the Canadian robotic arm mounted on the ISS. The Japanese robotic arm (Remote Manipulator System) on “Kibo” is also a practical robot that is capable of fine operations by remote control. This technology is also applicable to medical treatment and nursing care on Earth.

We are beginning a trial to provide the opportunity to perform space experiments more easily, so that “Kibo” can be used to explore a wider range of applications and new ideas with the aim of contributing to the realization of a prosperous, safe, and secure life.



Distribution of the ozone layer as observed by “Kibo”. These data have contributed to understanding the mechanisms of ozone layer depletion.

Rice germinated on “Kibo”. Cell walls, which provide plants with structural support, were investigated.

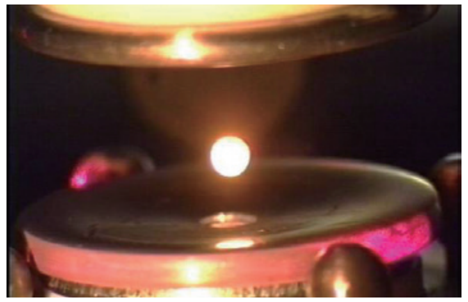
03 Improving technologies in manufacturing

See P.12 and 13

On “Kibo”, it is possible to manufacture materials with physical properties that would be difficult to obtain under the influence of gravity on Earth. For example, we successfully created large single crystals of next-generation high-performance semiconductor materials by using the environment in which no convection or sedimentation occurs. We are also currently performing an experiment to clarify the mechanism that changes the structure of macromolecules thought to contribute to the maturation of alcoholic beverages and making them mellow.

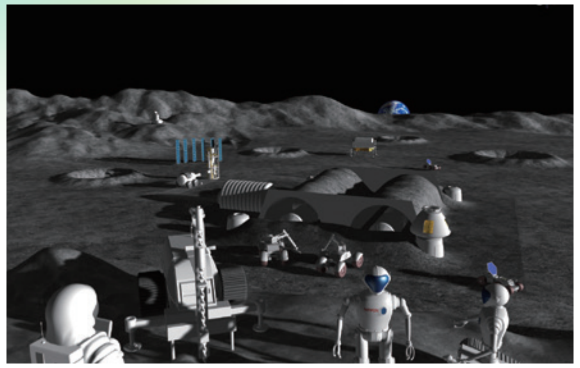
In the microgravity, liquid can be levitated easily and does not need containers. Also, melted materials can keep them in a stable (spherical) state. This method of handling materials without containers is called “containerless processing”. This processing allows us to closely investigate the behavior of materials in their molten states, which is difficult to do on Earth.

The data obtained from experiments on “Kibo” are useful for creating new innovations and technologies, and for increasing the competitiveness of Japanese manufacturing.



A high-temperature sample floating in the Electrostatic Levitation Furnace on Earth. In space, results are expected for materials that are more difficult to electrically charge.

Artist’s rendering of full-fledged use of the Moon



04 To unexplored space.

See P.14 and 15

We are currently discussing international space exploration to the Moon, Mars, and beyond. For preparing long-duration human spaceflight, we are developing new systems and equipment on “Kibo”, incorporating technology from Earth.

For example, we are developing water recycling systems that are compact, require little power, and do not need filter replacement; remote medical treatment systems for astronauts; and next-generation spacesuits that are lightweight and easy to move in, even on celestial bodies that have gravity.

Japan has many excellent technologies outside of the space development field. By actively incorporating more of these technologies, we will contribute internationally and also establish the technology needed for manned space missions.

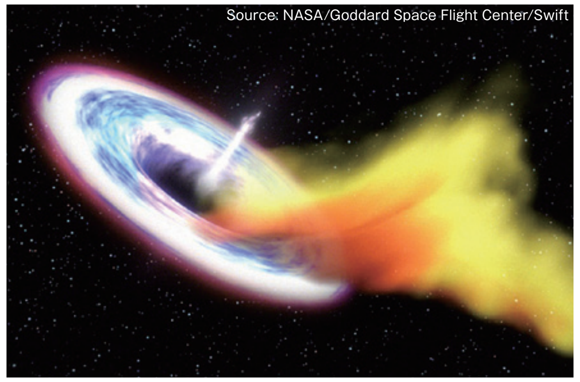
05 Pioneering new fields.

See P.16 and 17

Humankind was born in the gravity of Earth, and science and technology have been developed though research "with our feet on the ground." Eventually, we leapt from the Earth and put our effort into “Kibo”, a facility that allows us continuously perform experiments in space, where we are free from the effects of gravity. On “Kibo”, we are also conducting scientific research rooted in the intellectual curiosity of humankind.

X-ray observation of the entire sky and elucidation of the mechanisms of ice crystal growth are examples of research that can only be performed in space. In addition, observation of the atmosphere over a wide range from the Earth’s surface up to the upper atmosphere will lead to the creation of new academic fields. We are also making advances in observations aimed at clarifying the acceleration mechanisms of high-energy cosmic rays and the true nature of dark matter.

On “Kibo”, we are looking deeply into scientific truths and pioneering new fields that are possible only in space.



Artist’s rendering of a giant black hole accreting gas from a neighboring star, drawn based on the results of X-ray measurements

01 Supporting a Healthy Society with Longevity.

Why do bones and muscles become weak in space? Research to answer this question can provide insight into ways to extend people's healthy lifespan.

In microgravity environments, the bones and muscles that support the body become weak, even in healthy astronauts. The reduction in bone density is approximately 10 times larger in astronauts than in osteoporosis patients on Earth. The daily reduction in calf muscle size is equivalent to the reduction seen in a person who is bedridden for 2 days or in an elderly person during a roughly 6-month period.

On "Kibo", we are conducting research on this phenomenon, which has been called an accelerated model of aging-like physiological changes. As a result, we have clarified that the reduction in bone density in space is triggered by activation of osteoclasts, a type of cell that breaks down bone, and identified an enzyme that causes muscle atrophy. Based on these results, new medical treatments for osteoporosis and functional foods that prevent muscle atrophy are being developed. The astronauts themselves have become the subjects of experiments investigating mechanisms for maintaining muscle and validating training equipment for effectively suppressing muscle atrophy.

Locomotice syndrome, in which motor organs such as bones and muscles become atrophied, has recently become a growing problem. We are also planning to conduct pre-clinical trials on "Kibo" for identifying the factors that enable early diagnosis of aging-like phenomenon and for investigating the efficacy and safety of preventive drugs and treatment candidates by introducing a new research platform using a good mammal model, such as mice. The results from these studies are expected to extend healthy life through prevention and treatment of locomotive syndrome.

User institutions Tokushima University, Tokyo Institute of Technology, Kanazawa University, Tohoku University, Kurume University, Kyoto University
Available equipment Cell Biology Experiment Facility (CBEF), Aquatic Habitat (AQH), Mouse Habitat Unit (MHU)

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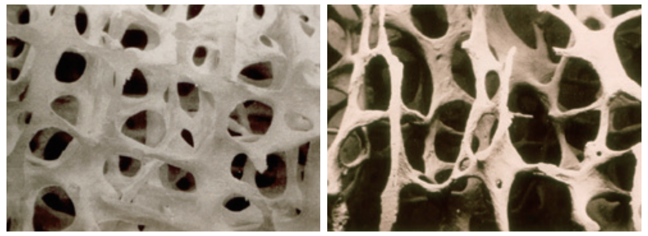
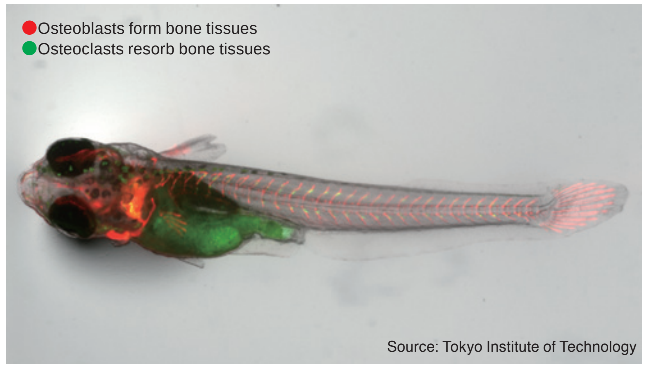
All human activities, ranging from those involving food, clothing, and shelter to medical treatment, relating to aging in some way. On "Kibo", we are conducting research on aging-like phenomena that will advance business and research on Earth.

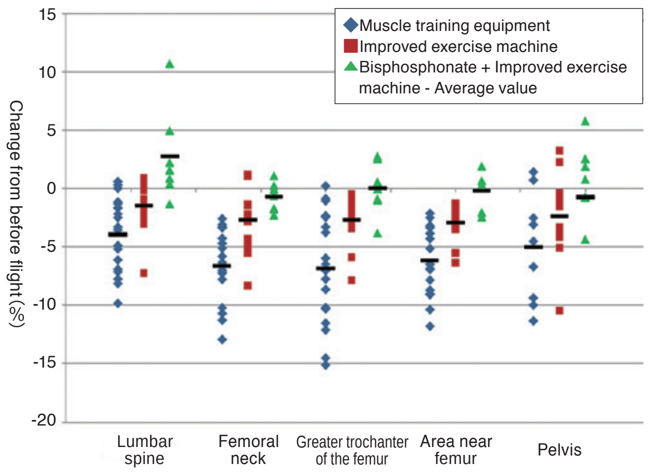


Normal bone (left) and bone with reduced bone density (right)

Source: National Institutes of Health



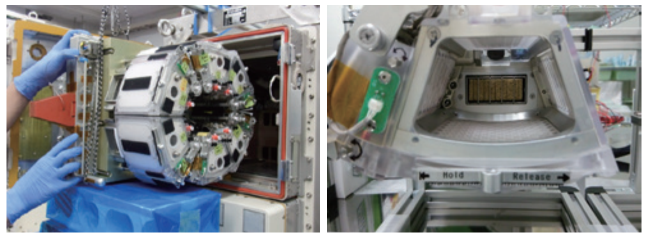
Two kinds of bone cells in Medaka fish were labeled with fluorescent protein of different colors. This fish is the same strain that was raised in space.



Change in bone density in astronauts before and after space flights. The astronauts who exercised and took bisphosphonate, which is a drug for treating osteoporosis, exhibited a smaller decrease in bone density (green) than did astronauts who performed exercise only (blue and red).

Excerpt from Smith S, et al., J Bone Miner Res 2012; LeBlanc A, et al., Osteoporis Int 2013, 24:2105-14.

Astronaut Akihiko Hoshide exercising on an improved exercise machine



The Mouse Habitat Unit (MHU) on "Kibo". Six cages for housing mice are installed in the upper deck (microgravity compartment) and six more are installed in the lower deck (artificial gravity compartment) of the environment control device of the biological experiment facility with a centrifuge, so that we can make comparisons to investigate gravitational effects on mice.

High-quality protein crystal growth experiments on the ISS will contribute to the design of drugs with high efficacy and fewer side effects.

Over 100,000 kinds of proteins are at work in a human body. Forming the right 3D structure is required for them to function. Knowing the structure of a disease-associated protein allows us to design new drug candidates, which modulate the activity of the protein by binding to its active site. This approach is called structure based drug design (SBDD). Compared with the high-throughput screening widely used in the pharmaceutical industry, SBDD is permits designing a new compound with fewer side effects and at less expense.

High-quality protein crystals are necessary to determine a precise protein structure. It is not easy to grow highly ordered crystals, partly because of convection driven by gravity. Thus, better crystals can be grown in the microgravity of "Kibo".

Over one hundred different proteins provided by universities and companies have been crystallized on "Kibo". Prior to the experiment on the ISS, crystallization conditions are optimized to make the most of the space experiment. In approximately 60% of the proteins, crystals grown in space contributed more detailed structural information than those grown on Earth.

We have conducted crystallization experiments of proteins related to drugs for treating diseases such as influenza, cancer, and muscular dystrophy. The obtained structural information has contributed to drug research and development.

User institutions Universities, pharmaceutical companies, etc.
Available equipment Protein crystallization device, Freezer-Refrigerator of Stirling Cycle (FROST)

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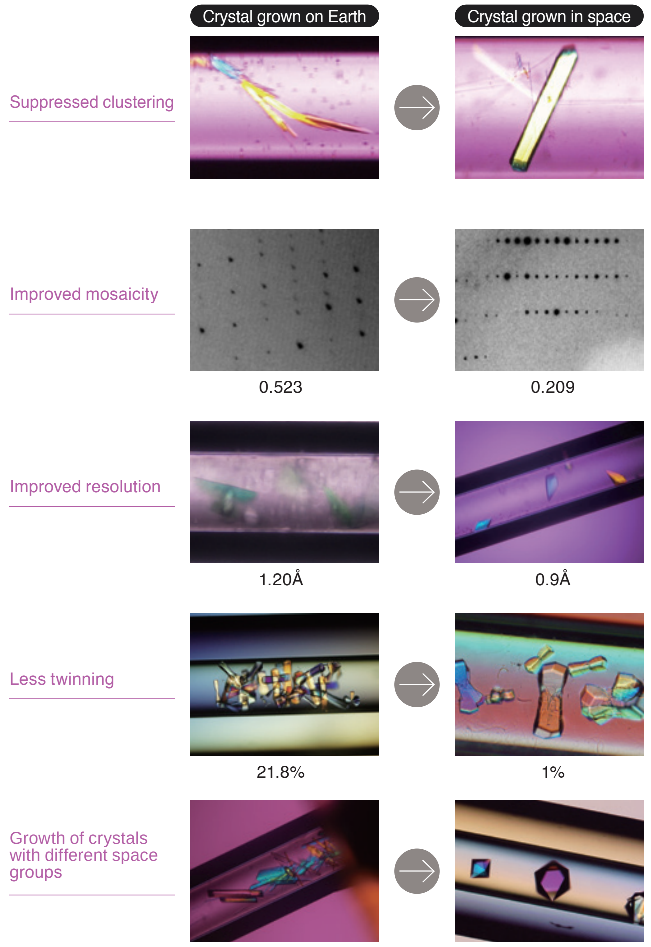
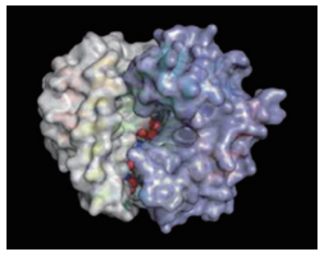
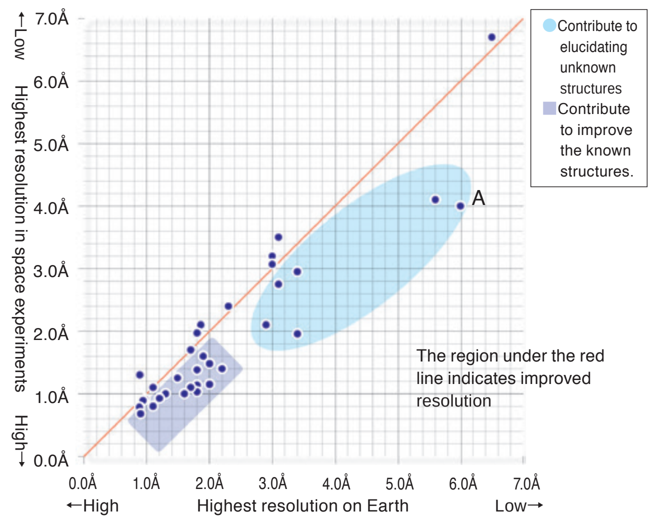
Space environment allows us to create high-quality protein crystals. This leads to useful data by analyzing 3-dimendional structure of target proteins, such as for the design of drugs or industrial enzymes.



On "Kibo", higher quality crystals can be grown.

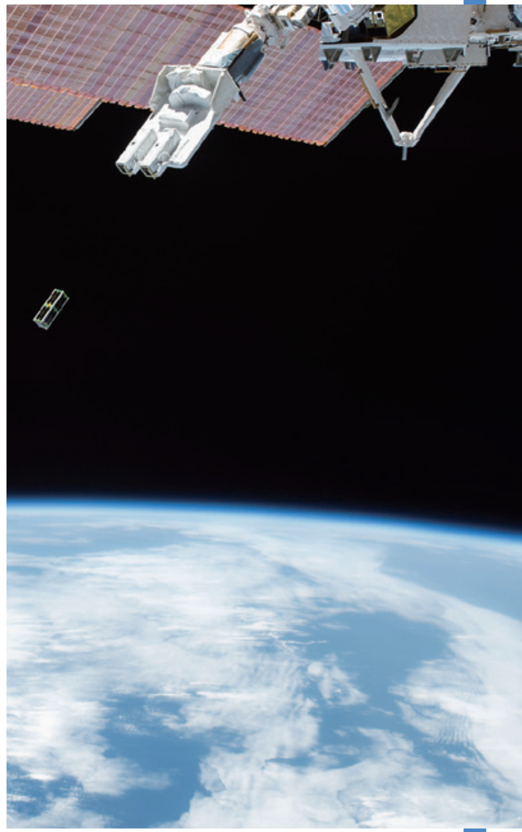


3D structure of the protein HPGDS (hematopoietic prostaglandin D synthase) as determined by using crystals grown on "Kibo". With this structure, the locations of water molecules could be observed, which was not seen in previous results. HPGDS is a protein related to the onset of Duchenne muscular dystrophy.



Improved resolution of structural analysis using high-quality protein crystals produced in space. For example, the resolution of the crystals of protein A grown on Earth was approximately 6 Å, while this was improved to approximately 4 Å using crystals grown in "Kibo".

02 Contributing to a Prosperous, Safe, and Secure Life.



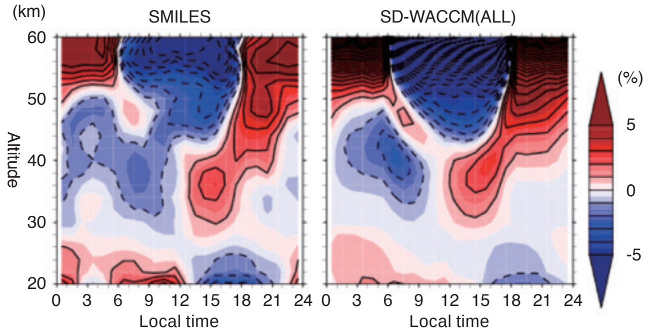
"Kibo" gives a bird's eye view of Earth. Enabling prediction of environmental changes and monitoring of wide-area disasters.

Getting a fast and accurate understanding of global-scale changes such as global warming and ozone layer depletion is essential for predicting environmental changes and implementing measures to address them. It is therefore effective to observe the entire Earth from space.

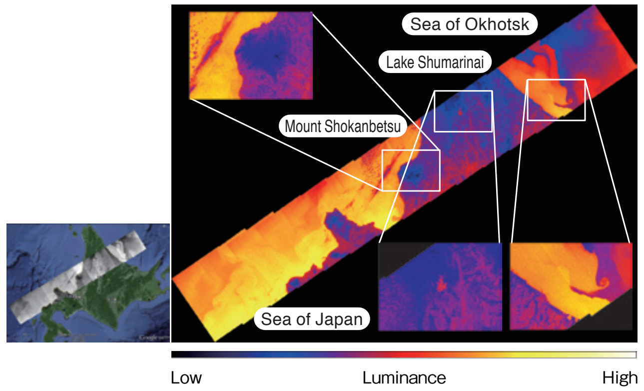
The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES), which was mounted on the Exposed Facility, made the first ever high-precision observation of the increases and decreases in the amount of ozone over the course of one day. This result has attracted much attention, and was cited in the "Ozone Assessment Report 2014" report issued by the United Nations Environment Programme and the World Meteorological Organization.

Furthermore, images and videos of Earth captured from the ISS are provided to analysis teams on the ground through the international framework of cooperation between Sentinel Asia and the International Disasters Charter, and are useful for analyzing the state of wide-area disasters such as floods and forest fires.

User institutions Kyoto University, JAXA
Available equipment Superconducting Submillimeter-Wave Limb-Emission Sounder, high-definition video, external commercial high-definition video system, small infrared camera for Earth observation



The left shows the results of SMILES observing the amount of ozone in the tropics, and shows that the changes in the amount of ozone over time. The right shows the results of numerical simulations, which reproduce a similar daily variation.



Infrared image of Hokkaido at night as captured by the Compact Infrared Camera (CIRC) for Earth observation that is mounted on the Exposed Facility of "Kibo". The temperature of a body can be determined from the differences in the emissivity of infrared rays, and is used for detecting forest fires and observing volcanoes.

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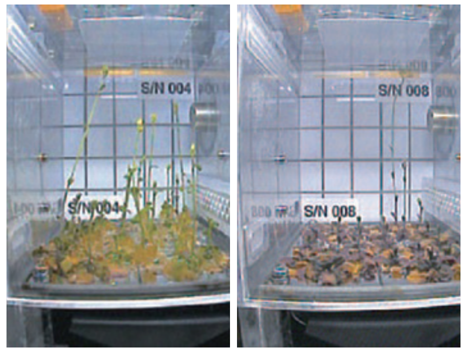
"Kibo" can put within your grasp the wide field of view that only a satellite had provided so far. Furthermore, you can see a different face of the Earth by observing at different frequencies of electromagnetic waves. You can see Earth as humankind has never seen it before.

What happens if you grow plants in space? This research may lead to rice that is resistant to wind damage.

On "Kibo", we are conducting experiments in which plants are grown in the microgravity environment. For example, we have investigated the strength of cells walls by growing rice in a microgravity environment and have clarified one of the mechanisms of rice for resisting gravity and supporting itself. We expect that this result will lead to the development of rice that is resistant to wind damage.

Humankind is currently facing serious environmental problems and food problems. The results of experiments on the plants obtained in the microgravity environment will also contribute to the development of agriculture in dry climates and efficient plant production technology for plant factories.

User institutions University of Toyama, Tohoku University
Available equipment Plant Experiment Unit



Arabidopsis thaliana (thale cress) grown in microgravity on "Kibo" (left) and *Arabidopsis thaliana* grown in a device that produces artificial gravity (right). Under microgravity, stems grow more quickly and leaves age more slowly.

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We have collected a variety of "seeds" from this research on topics such as the mechanisms of life, improved breeds, and new cultivation methods of plants from plant experiments in space. Plants hold the keys to the advancement of life onto land and also of the advancement of humankind into space.

Is the barrier to space experiments high? With "Kibo", you can easily perform space experiments.

It is commonly thought that the barrier to space experiments is high. However, "Kibo" provides the opportunity for more people to use a wider range of methods to perform simple space experiments by utilizing the features of both the airlock and the robotic arm.

In the development of materials for space and other applications, there was the problem that experimental samples could not be returned to Earth and evaluated directly. By using the Exposed Experiment Handrail Attachment Mechanism (ExHAM), it is possible to return experimental samples to Earth after attaching them for a long time outside of "Kibo". Since there is a dedicated adapter, experiments can be performed simply by providing the samples.

"Kibo" also has an external general-purpose platform that provides services such as power and communication. Since it is sufficient to fabricate only part of the mission equipment, it makes it possible to perform Earth observation, space observation, technical proving, and the like relatively easily.

Furthermore, small satellites can be launched from "Kibo". By 2015, 139 small satellites, both from Japan and other countries, have been launched for various aims including communications, Earth observation, and technical proving.

This is driving generation of the space business, and provides the opportunity to perform space experiments more easily and more frequently.

↑Example of ExHAM experimental samples. The samples are arranged inside the 10-cm square adapter.
→Small satellite launched from the JEM Small Satellite Orbital Deployer (J-SSOD)

User institutions Japan Manned Space Systems Corporation, Obayashi Corporation, Junkosha, JAXA, etc.
Available equipment JEM Small Satellite Orbital Deployer, Exposed Experiment Handrail Attachment Mechanism, intravehicular activity (IVA)-replaceable Small Exposed Experiment Platform

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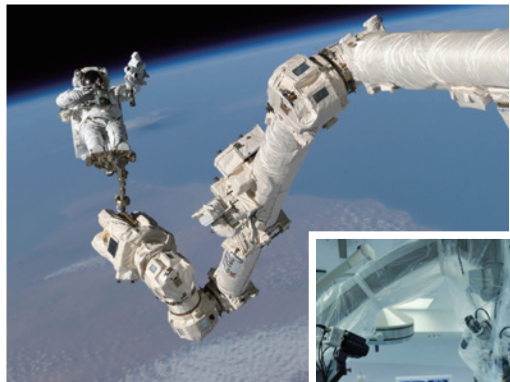
"Kibo" is a test bed that allows you to easily try out the space environment. Saying that space quality is proven could bring great changes to your business and research.

The robotic arm performs heavy lifting and fine manipulations instead of astronauts. Surgical robots were born from this technology.

SSRMS (Space Station Remote Manipulator System) mounted on the ISS has been used for various applications including assembling the ISS, moving supplies and experimental equipment around, and helping astronauts with extravehicular activities. The world's first robot able to perform surgical procedures inside magnetic resonance imaging (MRI) equipment was developed from the SSMRS technology for performing fine movements.

The Japanese robotic arm on "Kibo" also has high performance, and is used for external installation of experimental equipment and for launching small satellites. This technology is expected to be applicable not only to future manned probes, but also to medical treatment, nursing, and work in dangerous places on Earth.



↑SSRMS on the ISS
→View while preparing the NeuroArm surgical robot

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The fine motion connected the greatly different scales of space work and surgery. Technology that was developed for space may be able to be used in unexpected locations on Earth.

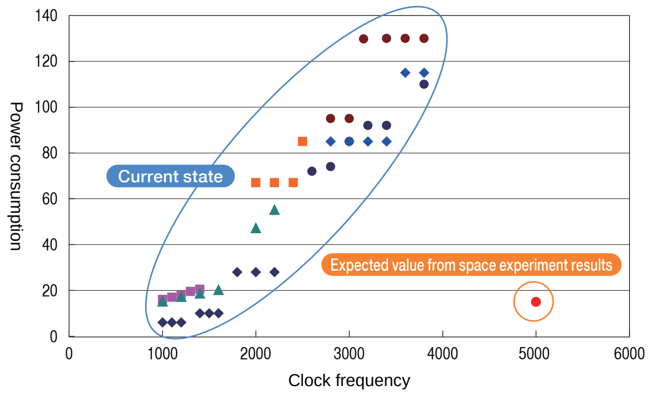
03 Improving Technologies in manufacturing.

A still environment without convection or sedimentation. This allows the creation of uniform, high-performance materials.

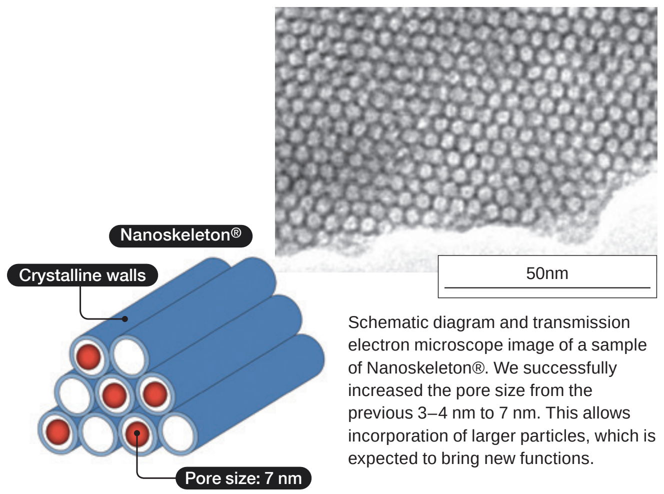
When a material is created, the regularity of its structure is disturbed due to the effects of convection and sedimentation, which occur due to gravity on Earth. In microgravity environments where there is no convection or sedimentation, distortions in the material structure less readily occur and highly regular materials can be obtained.

For example, we succeeded in creating the first large single crystals of silicon germanium ($Si_{0.5}Ge_{0.5}$), which is expected to serve as the semiconductor material for next-generation high-speed low-power devices. Although it is extremely difficult to fabricate large single crystals of $Si_{0.5}Ge_{0.5}$, the experimental results from “Kibo” demonstrated that it is possible, even on Earth, and this was a big step toward practical application.

In experiments on fabricating nanoscale porous materials (Nanoskeleton®) by using self-organization, we succeeded in enlarging the pore size and aligning the pore directions. This made it possible to give the pores various physical properties, and we are currently investigating application to high-efficiency photocatalysts, solar cells, and devices for removing harmful materials such as environmental pollutants.



Prediction of SiGe device performance. Processing power improved several fold and power consumption reduced to one-seventh compared with existing computers are expected when the large single crystal of $Si_{0.5}Ge_{0.5}$ with uniform composition grown on “Kibo” is used as a substrate.



Schematic diagram and transmission electron microscope image of a sample of Nanoskeleton®. We successfully increased the pore size from the previous 3–4 nm to 7 nm. This allows incorporation of larger particles, which is expected to bring new functions.

User institutions Universities, companies (Shiseido, etc.), etc.
Available equipment Gradient Heating Furnace, mixing bag

CHECK

If the structure of a material can be made uniform, new functions can be expected If crystals can be made bigger, another level of performance can be expected “Kibo” may be able to overcome barriers to the development of materials.

Alcoholic beverages that mature in space become mellow!?

It is known that for many varieties of alcoholic beverages, a mellow taste is created by a long period of aging. However, the full details of the mechanisms have not been clarified.

One hypothesis is that the water, ethanol, and other components contained in the alcoholic beverages contribute to mellowness by forming polymer structures. Because the formation of polymers is thought to be promoted by the absence of convection, we have focused on the microgravity environment where convection does not occur and we are conducting an experiment in which alcoholic beverages are stored for a long time on “Kibo” in order to clarify the relationship between convection and the effect of the alcohol becoming more mellow.

User institutions Suntory Global Innovation Center

Six samples were transported to “Kibo” by “Kounotori” for storage.

CHECK

Space can also be used for developing foods. The secret to the delicious taste is the microgravity.
——This kind of innovative food could be a great business opportunity.

Levitating and melting materials using Coulomb force without a container.

On Earth, a liquid needs a container to stay put. Because no containers are suitable for temperatures higher than 2,000 °C, it is difficult to melt materials with a high melting point on Earth. Containers react to high temperature and contaminate the materials.

In microgravity, liquid can be levitated easily and does not need containers. This method of handling materials without a container is called “containerless processing”. This processing allows us to closely investigate the behavior of materials in their molten state, which is difficult to do on Earth.

The electrostatic levitation method, which is one containerless processing technique, uses the Coulomb force between charged samples and electrodes and controls the sample position by using high-speed feedback from the camera image.

In 2015, JAXA completed the development of the Electrostatic Levitation Furnace (ELF) for the ISS. The ELF is a facility for materials science that melts levitating materials having a very high melting point, measures their properties, and then solidifies them from a supercooled phase by taking advantage of the microgravity environment. The target sample of the ISS mission is oxides. The melt oxides cannot be levitated by electromagnetic force, and it is difficult by Electrostatic Levitator on ground because the electric charge of nonconductors is much less than that of conductors.

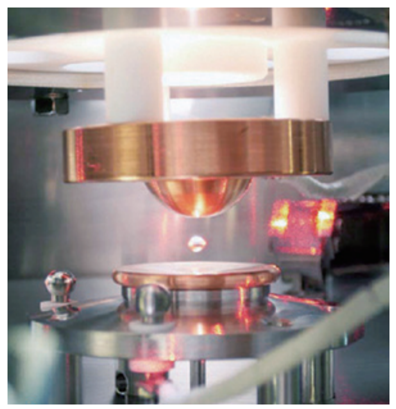
During the preparatory research for the ELF on "Kibo", the techniques of measuring the thermophysical properties of high-temperature melts have been improved with a ground-based facility. Many thermophysical properties of refractory metals have been revealed for the first time.

Moreover, containerless processing can provide a large supercooled state that allows formation of different crystalline structures and phases, from which new materials can be created.

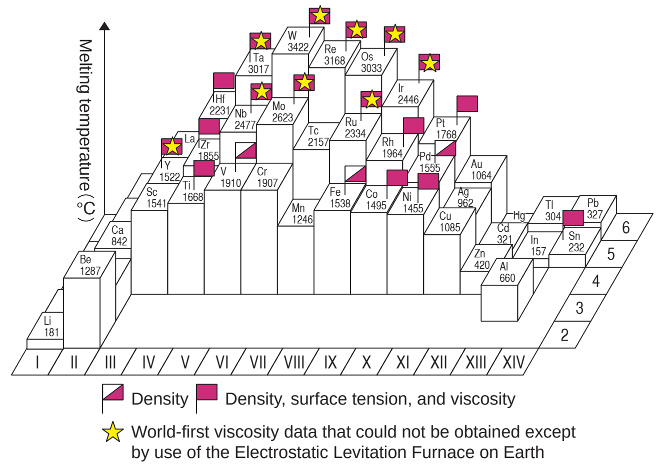
We levitated and melted barium titanate ($BaTiO_3$) without a crucible during a ground-based experiment and crystallized it through supercooling. As a result, we succeeded in developing a high performance material that has a huge dielectric constant and is unaffected by temperature changes.

The thermophysical data acquired from "Kibo" will dramatically improve the fundamental data of material science. These thermophysical properties will then be used as the basic data for computer-based casting simulation programs in order to develop high-performance heat resistant coating technology to be applied to efficient turbines for electric generation systems, aircraft, and the next generation of jet engines.

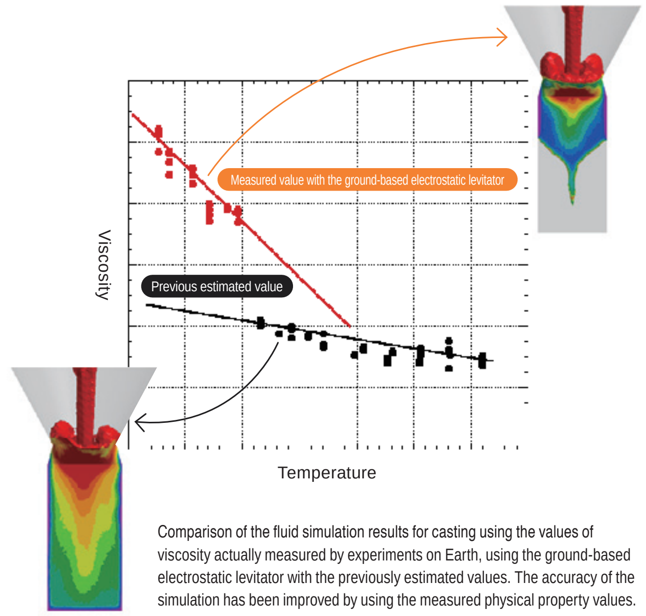
We also expect to find new characteristics of materials through crystallization using containerless processing.



The ground-based electrostatic levitator. Controlling the sample position using Coulomb force between charged samples and electrodes.



Thermophysical properties of refractory metallic elements acquired with the ground-based electrostatic levitator. Stars in the figure denote the world's first viscosity data, acquired only by using the electrostatic levitator on ground.



Comparison of the fluid simulation results for casting using the values of viscosity actually measured by experiments on Earth, using the ground-based electrostatic levitator with the previously estimated values. The accuracy of the simulation has been improved by using the measured physical property values.

User institutions JAXA, etc.
Available facilities Electrostatic Levitation Furnace (on ground, space)

CHECK

The physical properties of materials with a high melting point were substituted with those of similar materials and old reference values, and refinement of parameters in material development was by trial and error. Data provided by the newly developed Electrostatic Levitation Furnace could lead to new research.

04 To Unexplored Space.

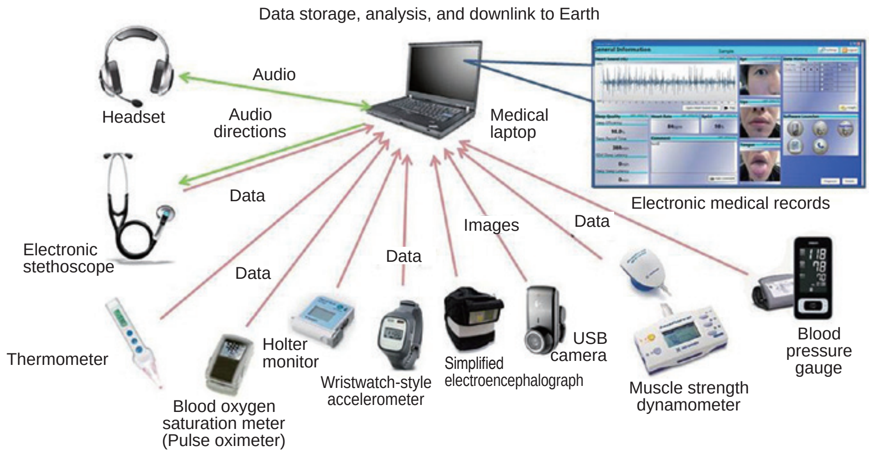
Go further for longer. Searching for measures to live in space.

To sustain and develop human space activities, it is essential to have technology for maintaining health over a long period of time in an enclosed microgravity environment.

To accomplish this, it is important to first correctly understand the effect of the space environment on the human body. In the past, we have confirmed that changes appear in the vestibular system, which governs sense of balance, intraocular pressure, and we have been accumulating knowledge. Suppression of immune function is another risk of long-term residence in space. Microorganisms called probiotics are known to improve intestinal microbiota and to regulate immune function. We are investigating in cooperation with companies whether probiotics are also effective in space.

Human activity in space is expected to spread to the Moon and Mars. Since it is difficult to get assistance from Earth, we are investigating remote medical treatment systems and autonomous health management methods. Furthermore, although the amount of radiation exposure while staying on the ISS is approximately 150 times that on Earth, it becomes even higher outside of the magnetosphere of Earth. We are further developing the technology for predicting accumulated exposure on ISS in order to utilize the results in radiation shielding designs for future spacecraft.

Life has the mechanism of plasticity that allows adaptation to changes in the external environment. However, life cannot continue if irreversible damage builds up. In the extreme environment of space, what is the extent of the plasticity of life? We have started to gain an overall understanding of the plasticity and failure of living organisms that transcends existing research fields.



Remote medical treatment system. Accumulates and manages medical device data.

User institutions Gifu University, Yakult Honsha, JAXA
Available equipment Space medicine experiment assistance system, passive space radiation dosimeter

CHECK

Although the health problems of astronauts are specific to space, some are also common to Earth. It may be possible to extend previously developed health management devices and functional foods to space.

Simply transporting cargo is a waste. “Kounotori” can also be used for experiments.

After the Japanese H-II Transfer Vehicle “Kounotori” has transported cargo to the ISS, it is loaded with waste materials, such as experimental equipment that has finished being used, and reenters the atmosphere, where it burns up. We have performed experiments that make use of this property.

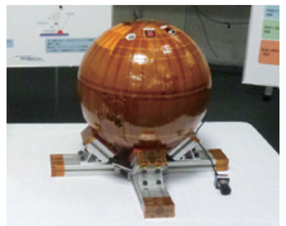
One is the reentry data collection unit (i-Ball). i-Ball was mounted on “Kounotori” and collected data and images such as acceleration, position, and temperature during atmospheric reentry. These data was used to increase the prediction accuracy of the range over which the fragments fall to the Earth, and was useful for increasing safety. It will also be used for developing spacecraft that can reenter the atmosphere from space.

In the future, we plan to perform proving experiments of conductive tethers (KITE) as one of the main technologies for removing large pieces of space debris.

User institutions JAXA/IHI Aerospace
Available equipment “Kounotori”

CHECK

Experiments using “Kounotori” have only just started. Since this is a new endeavor, there are bound to be discoveries. How we use it will depend totally on your ideas.



↑i-Ball. Diameter 40 cm.
→Schematic diagram of KITE

Vest-style cooling undergarment created through research on liquid cooling undergarments for spacesuit. Cooling water circulates through a tube that extends throughout the vest.

Source: Teikoku Seni Co., Ltd.

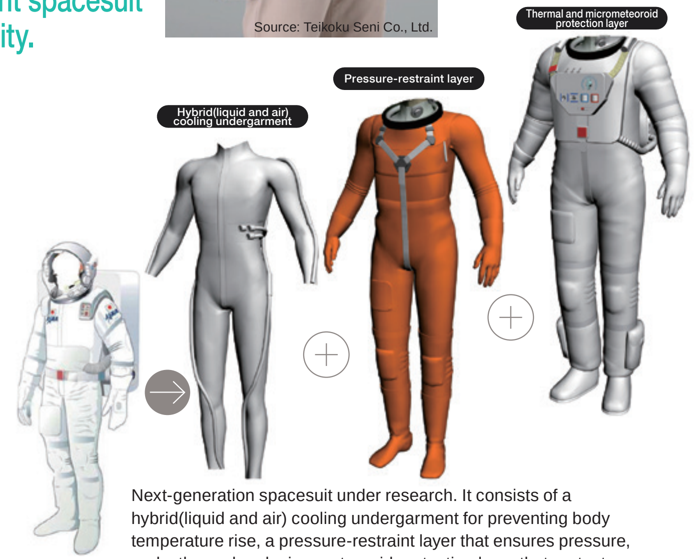
An effective cooling spacesuit that is easy to wear, easy to move. JAXA has been conducting research on a lightweight spacesuit that can be used for human space exploration activity.

The American and Russian spacesuits that are currently used on the ISS require several hours to prepare for conducting extravehicular activities(EVA). Aiming for future human space exploration to the Moon and Mars, JAXA has been continuing research on developing a lightweight spacesuit that can be prepared in a much shorter time and is easy to move.

Inside the spacesuit, because of its high thermal insulation, the temperature gradually rises from the heat produced by the astronaut’s body during EVA, possibly resulting in astronauts experiencing a heatstroke. To solve this problem, a liquid cooling undergarment is worn inside the spacesuit to efficiently cool the body. As one of the outcomes from the spacesuit research, a vest-style cooling undergarment has been developed and commercialized. It is expected to be effective for lowering the risk of heatstroke for people working under hot sun and for people wearing special garments, such as fireproof clothing or chemical protective clothing.

We are researching with the aim of developing a sophisticated spacesuit by bringing together various technologies at which Japan excels, such as advanced materials, clothing design, and precision machining.

User institutions Nippon Uniform Center



Next-generation spacesuit under research. It consists of a hybrid(liquid and air) cooling undergarment for preventing body temperature rise, a pressure-restraint layer that ensures pressure, and a thermal and micrometeoroid protection layer that protects from the extreme environment of space.

CHECK

Japanese excellent technology is used to develop spacesuits, and the technology obtained through spacesuit development is utilized in everyday life and clothing. This cycle has been started.

Water recycling is a key technology for human space activities [JAXA1]. JAXA realizes maintenance-free operation by using cutting-edge technology.

In human space activities, astronauts cannot survive without drinking water. However, since the amount of transportation into space is limited, water is extremely valuable. To reduce the transportation mass, the moisture contained in the breath, sweat, and urine of astronauts needs to be recycled.

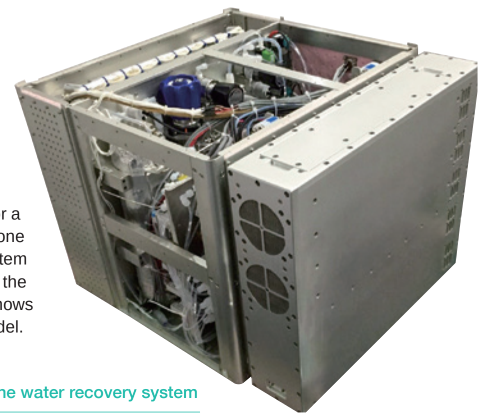
JAXA is developing a water recovery system with a high recovery rate, low mass, and low power consumption, in cooperation with leading-edge Japanese companies. The system allows consumables to regenerate and does not have any parts or consumables that need to be replaced periodically.

This water recovery system will be of benefit not only for the ISS, but also for future manned missions to the Moon and Mars.

User institutions JAXA
Available equipment Water recovery system

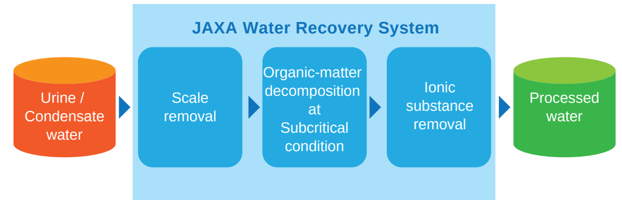
CHECK

Taking the excellent technologies of Japanese companies to the “space” level. In addition to water recycling systems, there are also other fields where Japanese technology would contribute worldwide.



JAXA is aiming for a size reduction to one quarter of the system currently used on the ISS. The photo shows the prototype model.

Mechanisms of the water recovery system



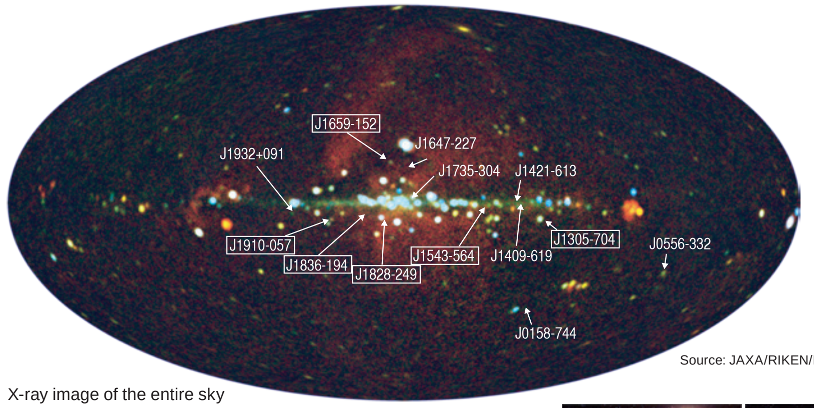
05 Pioneering New Fields.

Watching as a giant black hole sucks in a star. Observing the violent changes of space with X-rays.

The Monitor of All-sky X-ray Image (MAXI) that is mounted on the Exposed Facility observes the entire sky for X-rays as its name states. There are dizzying changes, with celestial bodies suddenly appearing and the brightness of celestial bodies changing. When MAXI observes unexpected celestial phenomena such as new celestial bodies or gamma ray bursts, it is reported to astronomers and other scientists around the world. When this happens, many telescopes and celestial observation satellites turn toward that object to observe it in more detail, and its true form is clarified.

MAXI has observed for the first time a giant block hole consuming a star, discovered half of the candidate black holes found to date, and made a major contribution to the development of X-ray astronomy.

User institutions Riken, etc.
Available equipment Monitor of All-sky X-ray Image



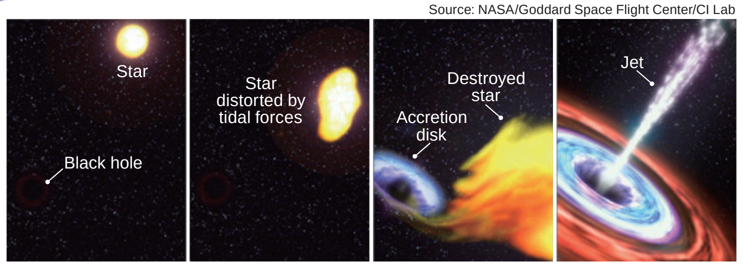
Source: JAXA/RIKEN/MAXI team

X-ray image of the entire sky created from the 4.6 years' worth of data collected by MAXI. The 13 new celestial bodies discovered by MAXI are indicated. Square frames indicate celestial bodies that are black hole candidates.

CHECK

By using the feature of the ISS in Earth orbit, we have implemented all-sky observation without any moving parts. Although some wondered whether the ISS would be suitable for observation of celestial bodies, we continue to produce results that dispel any doubts.

Source: NASA/Goddard Space Flight Center/CI Lab

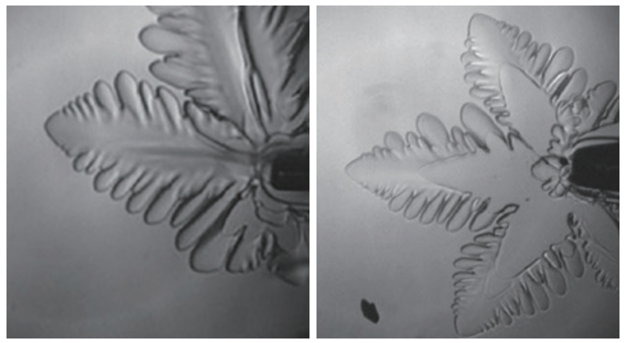


Schematic diagram of the state of a giant black hole consuming a star

Discovering more about the most familiar of substances. Why ice crystals form.

You have likely seen, at least once, snow on your sweater, or frost on your windows. Yet, the formation process of ice crystals (the crystal growth process) is complex, and the detailed formation mechanism remains unknown. We were able to obtain precise data related to the crystal growth process for the first time by repeatedly performing experiments to check the reproducibility of the measurements under different temperature conditions in the microgravity environment without heat convection. As a result, we confirmed that ice crystals grow more slowly in space compared with on Earth and constructed a new theory of the crystal growth process. The obtained knowledge could lead to understanding of the reaction of the living body, help in developing a long-term organ preservation method, and improve the quality of frozen food. Furthermore, fundamental understanding of the crystallization process of ice crystals will clarify the relations among planetary science, geoscience, and environmental science.

User institutions Hokkaido University, Tohoku University
Available facility Solution Crystallization Observation Facility


Left: An ice crystal obtained on Earth. Right: An ice crystal obtained on "Kibo" that has a more symmetrical shape than the one from Earth.

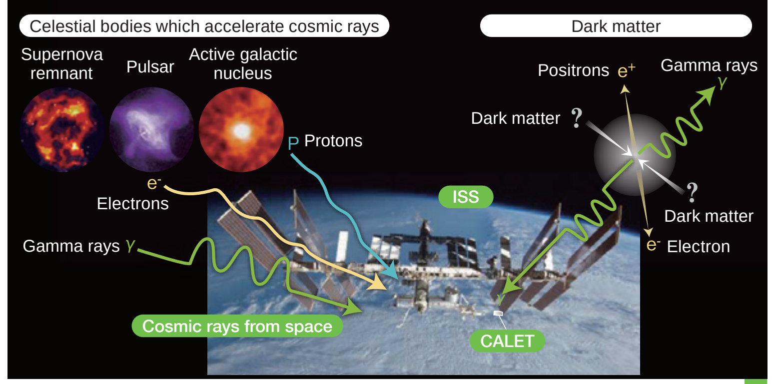
CHECK

Research into the crystal growth of ice is useful for understanding a variety of items including crystal growth of other materials, weather phenomena, living organisms that live below water's freezing point without freezing, frozen food quality, and methane hydrate formation.

High-energy cosmic rays, dark matter, gamma ray bursts Searching dynamic deep space that is invisible to the human eye.

Although deep space appears calm to our eyes, it is actually very dynamic and violently crossed by high-energy cosmic rays such as X-rays and gamma rays which are not visible to the human eye.

The Calorimetric Electron Telescope (CALET) mounted on the Exposed Facility of "Kibo" uses that latest detection and electronics technology to measure the energy, species, and direction of particles traveling through space. The observations by CALET are expected to clarify the mechanisms of acceleration and propagation of high-energy cosmic rays, which remain unexplained even now, 100 years after they were first discovered. Other major aims of CALET are searching for dark matter and explaining the nature of gamma ray bursts.



Results aimed for by CALET

User institutions Waseda University
Available equipment High-energy electron, gamma ray observation device

CHECK

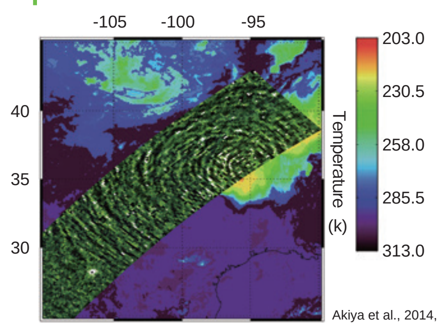
Approximately 95% of space is thought to be occupied by dark matter and dark energy, whose nature is unknown. Cosmic rays are expected to be the key for understanding the true nature of these phenomena.

Where Earth's atmosphere and space plasma mix. Various phenomenon in this mixing can be observed through meteorology and astronomy in the atmosphere.

Where the Earth's atmosphere gives way to space, a variety of phenomena occur due to mixing between the atmosphere and space plasma. However, understanding this from Earth is challenging due to obstruction by clouds and other difficulties.

The Ionosphere, Mesosphere, Upper Atmosphere, and Plasmasphere Mapping Mission (IMAP) and Global Lightning and Sprite Measurement Mission (GLIMS) were mounted on the Exposed Facility. IMAP observes disturbances in the atmosphere by capturing images of airglow. We have successfully captured the state of the upper atmosphere violently shaken by tornados over a wide area. This has shown the relation between the upper and lower atmosphere. GLIMS is continuing to clarify the overall phenomenon of lightning, which was previously not completely understood, by observing sprites—a luminous phenomenon directed toward space that occurs in the upper parts of thunderclouds accompanying lightning discharges.

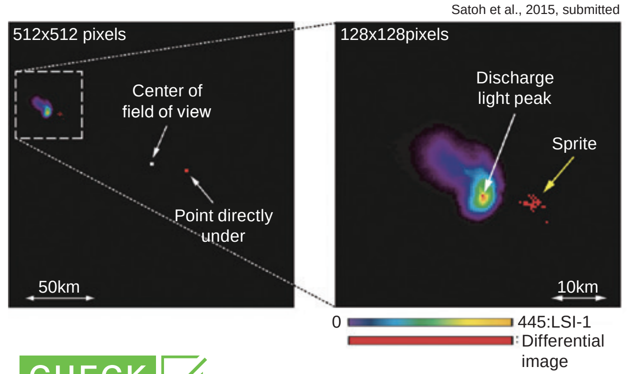
The observation results of IMAP and GLIMS both show the importance of the new concept of the "whole atmosphere," where a wide range of the atmosphere—from near the Earth's surface to the upper layers—is treated as a single system.



← Concentric circular structure of airglow from oxygen molecules as captured by the Visible and Near-Infrared Spectral Imager (VISI) on IMAP.
↓ Left: Image of a sprite and discharge airglow from the lightning that caused it as captured by GLIMS. Right: An enlarged image.

Akiya et al., 2014, GRL

Satoh et al., 2015, submitted



User institutions Kyoto University, Osaka University
Available equipment Ionosphere, Mesosphere, Upper Atmosphere, and Plasmasphere Mapping Mission, Global Lightning and Sprite Measurement Mission

CHECK

When a large disturbance occurs in the upper atmosphere, our daily lives are affected by things such as the radio waves sent from satellites to Earth being disturbed, hampering use of GPS. This is an important area that is far away yet familiar.

Our New Challenges.

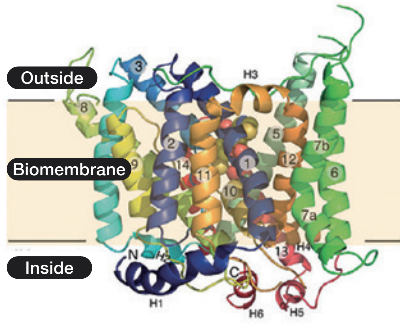
Since “Kibo” went into operation in 2008, a variety of experiments have been performed on it ,and we have accumulated the advanced technology and knowledge required for space experiments. In response to further requests from users, we will tackle experimental challenges that have previously been difficult.

Crystallization of high-quality crystals of membrane proteins, which are targets for drug development.

In recent years, membrane proteins, which are present in the biomembranes of cells, have been focused on as main targets for drug research and development. However, it is very difficult to crystallize membrane proteins. We are therefore aiming to develop techniques for growing high-quality membrane protein crystals on “Kibo”, using the knowledge obtained by previously developed techniques for water soluble protein crystallization.

Furthermore, we are also working to enlarge the crystal size of the existing water soluble proteins. If the high-quality crystals can be made larger, it will allow us to perform neutron beam analysis, which can determine the exact coordinates of the hydrogen atoms; this plays a critical role in the function of proteins. These results will enable the more precise design of better drug candidates.

For the remaining proteins that have an important function but are difficult to crystallize, particularly the membrane proteins that are targets for drug development, we are working on obtaining more accurate structural information.



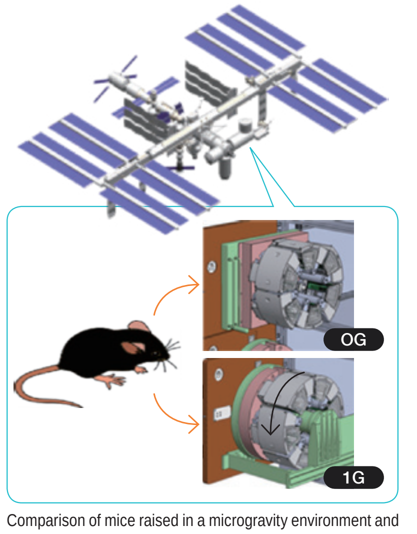
Source: Nagasaki International University/Kyoto University

Structure of a complex consisting of the band 3 protein, which is a membrane protein, and a compound that inhibits its function.

Discovering methods for treating and preventing various aging-related phenomena.

Elderly people are subject to various aging-related diseases, including decreasing bone density, muscle atrophy, and decreased immune function. Establishing methods for the treatment and prevention of disease is a pressing problem, particularly for Japan with its aging society. Similar phenomena are also observed in healthy astronauts staying in microgravity environments, where they advance even more rapidly. We are therefore proceeding with experiments that use “Kibo” as a platform for research on aging-like phenomenon.

We will first clarify what changes occur in the bodies of astronauts staying in a microgravity environment by performing omics analysis that connects information obtained through genes, transcription products, proteins, metabolites, and phenotypes. We will also investigate the epigenome, a part of the genome that undergo changes due to various environmental factors. Furthermore, we will contribute to the prevention and treatment of aging-related diseases through genomic medicine, for example, by identifying factors that will allow aging-related diseases to be diagnosed earlier.



Comparison of mice raised in a microgravity environment and in an artificial gravity (1G) environment on “Kibo” (illustration)

Producing 3D tissues/organs from stem cells under microgravity for regenerative medicine.

Stem cells have the ability to differentiate into a wide variety of cells. Regenerative medicine is spotlighted because stem cells have high potential for recovery of tissues/organs lost to injury or disease. It is very difficult, however, to produce 3D organs with the proper function and with a complex structure on the Earth because gravity disturbs the growth of 3D organs.

Microgravity is a suitable environment for producing tissue/organs three-dimensionally, and we are hopeful that it will provide high-quality tissues/organs. We believe that the knowledge of 3D culture technology gained on ”Kibo” will widely contribute to the medical front.

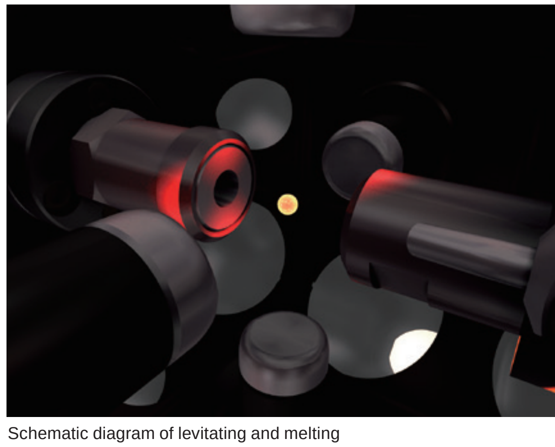
Clinostat: an apparatus that simulates microgravity on Earth by randomly changing the orientation of the experiment platform

Measuring unknown properties of high-temperature molten materials.

When high melting point materials are used, knowing their physical properties, such as density, surface tension, and viscosity, is extremely important. However, in the past, at high temperatures of up to 3000 °C, the container holding the sample begins to melt first, and its components mix with the sample, making it impossible to perform accurate measurements.

We would like to measure the physical properties of high-temperature molten materials. The Electrostatic Levitation Furnace on “Kibo” answers this demand. By keeping samples floating while heating and melting them with a laser, it is possible to measure the physical property values of molten materials with high accuracy free from contamination from the container. The Electrostatic Levitation Furnace on “Kibo” is the world’s only equipment capable for measuring the physical property values of a wide range of high-temperature molten materials from metals to insulators.

The obtained physical property values of these materials will contribute to advances in simulations of processes such as casting and welding, and improvements in manufacturing processes. Furthermore, since use of this furnace makes it easy to perform supercooled solidification, it is also expected to lead to the development of new materials that have never-before-seen functions.



Schematic diagram of levitating and melting materials on the Electrostatic Levitation Furnace in “Kibo”

Recovering experimental samples from space.

The samples obtained through experiments on “Kibo” are very precious. So, there have long been requests to recover the samples to Earth. In biology experiments, in particular, there has been a strong desire to analyze the samples on Earth. However, the means of transporting experimental samples to Earth has been limited to American and Russian spacecrafts, and it is not possible to carry all experimental samples.

To meet this demand, it is essential for Japan to have an independent means of carrying samples back to Earth. We are therefore taking on the challenge of return technology, and we are proceeding with research and development of a compact return capsule that can bring experimental samples back to Earth.

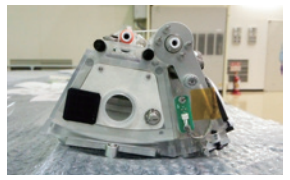
↑High-altitude drop experiment performed using a model compact recovery capsule. Capsule recovery after splashdown.
←Artist’s rendering of the recovery capsule launched from “Kounotori”

Introduction to the Experimental Facility on "Kibo."

Pressurized Module

Five Japanese experiment racks are installed into the pressurized module. Two of them are Japanese multipurpose experiment racks, which can accommodate various exchangeable-type experimental facilities. In addition, "Kibo" is equipped with an American experiment rack, a freezer, storage racks, and other equipment.

Biological experiment rack

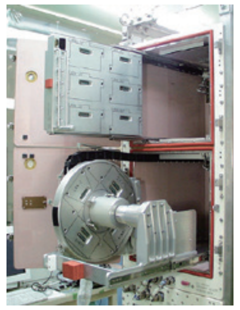


Mouse Habitat Unit (MHU)

For raising 12 mice

Clean Bench (CB)

For microscope observation



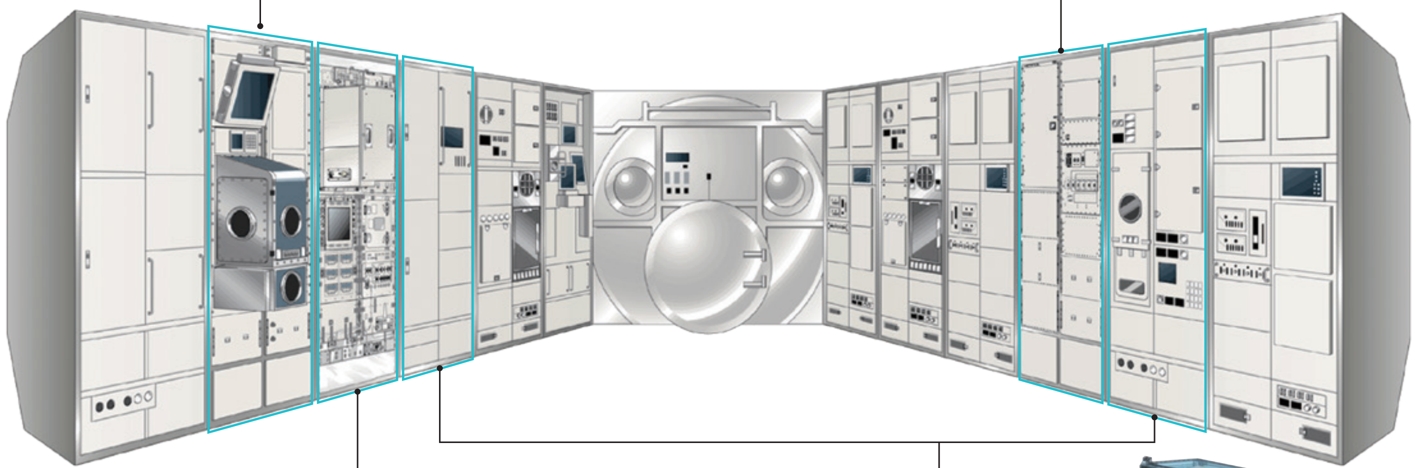
Cell Biology Experiment Facility (CBEF)

For cultivation of cells, microorganisms, small plants, etc., in an incubator with a centrifuge.

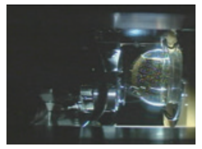
Gradient Heating Furnace rack

Gradient Heating Furnace (GHF)

A vacuum furnace for performing crystal growth of semiconductors and other materials using a variety of temperature profiles up to a maximum of 1600 °C



Fluid experiment rack

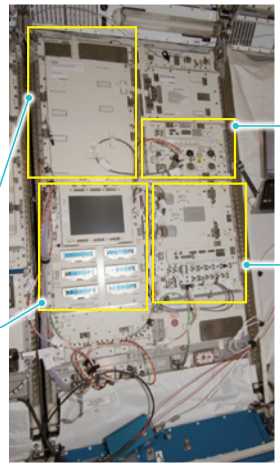


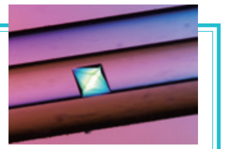
Fluid Physics Experiment Facility (FPEF)

Observation of fluid phenomena using infrared light and ultrasound

Image Processing Unit (IPU)

Records experimental images and transmits them to Earth





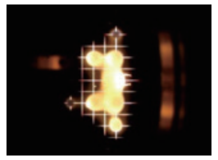
Protein Crystallization Research Facility (PCRF)

For controlling protein crystallization environment.

Solution Crystallization Observation Facility (SCOF)

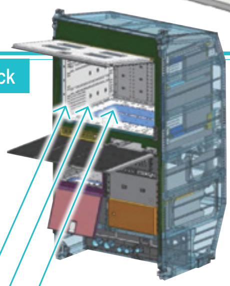
For investigating the process of crystal growth

Multipurpose experiment rack



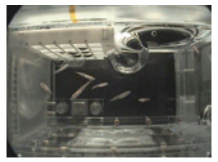
Chamber for Combustion Experiment (CCE)

For performing combustion experiments



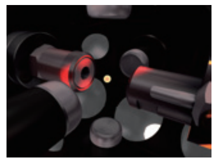
Aquatic Habitat (AQH)

For raising small fish



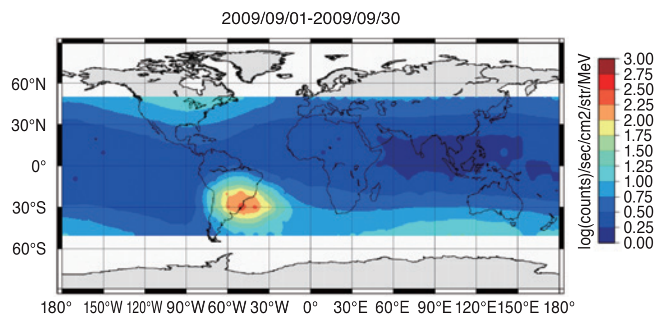
Electrostatic Levitation Furnace (ELF)

For levitating and melting materials such as ceramics by heating up to 3000 °C



Exposed Facility

The Exposed Facility is a multipurpose experiment area for performing observations of celestial bodies, observation of Earth, communications, robotics experiments, materials experiments, and other types of experiments that use aspects of the space environment such as microgravity and high vacuum. The Exposed Facility has 10 attachment points (ports), allowing various experiments to be performed by swapping out the experimental equipment.



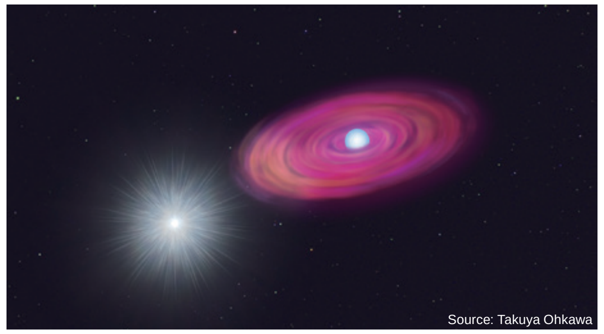
Radiation band measurement data

Space Environment Data Acquisition Equipment - Attached Payload (SEDA-AP)

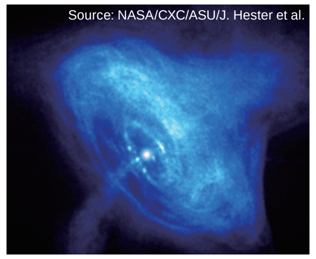
Measures the space environment (neutrons, plasma, atomic oxygen, dust, etc.) in the orbit of the ISS.

Monitor of All-sky X-ray Image (MAXI)

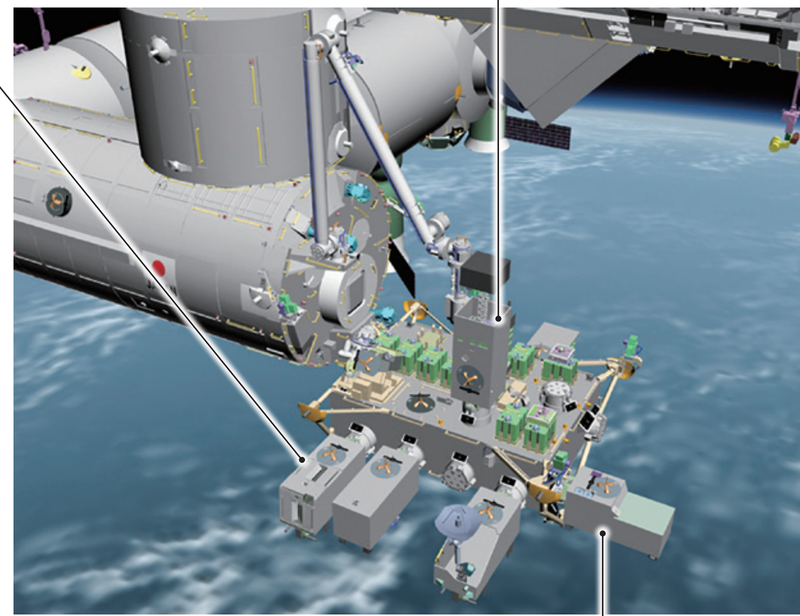
For observation of active celestial bodies such as black holes inside and outside the Milky Way by using an X-ray camera with the world's largest field of view.



Artist's rendering of MAXI J0158-744, for which MAXI successfully observed the moment the star went supernova. A massive blue-white fixed star with a gas disk (right) and a white dwarf star (left) are a binary system.



Pulsars are thought to be one of the celestial bodies that accelerates cosmic rays



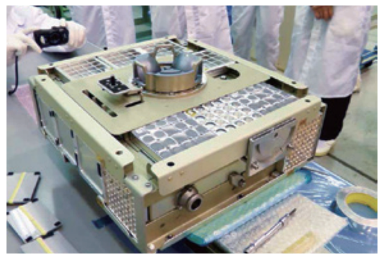
Calorimetric Electron Telescope (CALET)

Performs observations of high-energy electrons and gamma rays to understand the acceleration and propagation mechanisms of high-energy cosmic rays, to search for dark matter, etc.

Simple exposure experiments

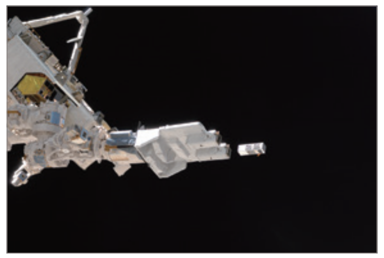
Exposed Experiment Handrail Attachment Mechanism (ExHAM)

Up to a maximum of 20 experimental samples of size 10 cm square can be attached and exposed to space for a year or more and then returned to Earth.



JEM-Small Satellite Orbital Deployer (J-SSOD)

Up to 6 small satellites of size 10 cm cubed can be launched into orbit at once by using the "Kibo" robotic arm.



IVA-replaceable Small Exposed Experiment Platform (i-SEEP)

Expands possibilities for exposed testing and verification of equipment outside of "Kibo".