UNOOSA Webinar Series on Hypergravity/Microgravity

# Artificial Gravity Environment In Kibo


June 16, 2021

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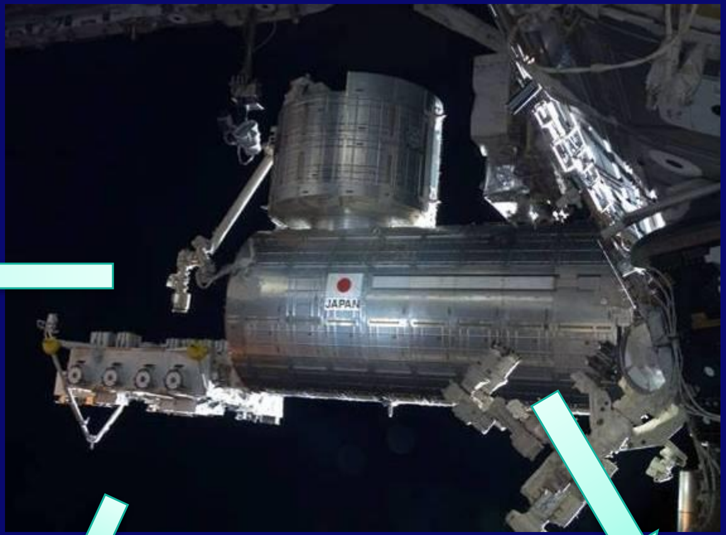
JEM "Kibo" Utilization Center, Human Spaceflight Technology Directorate,
Japan Aerospace Exploration Agency (JAXA)

# Japanese Experiment Module "Kibo"



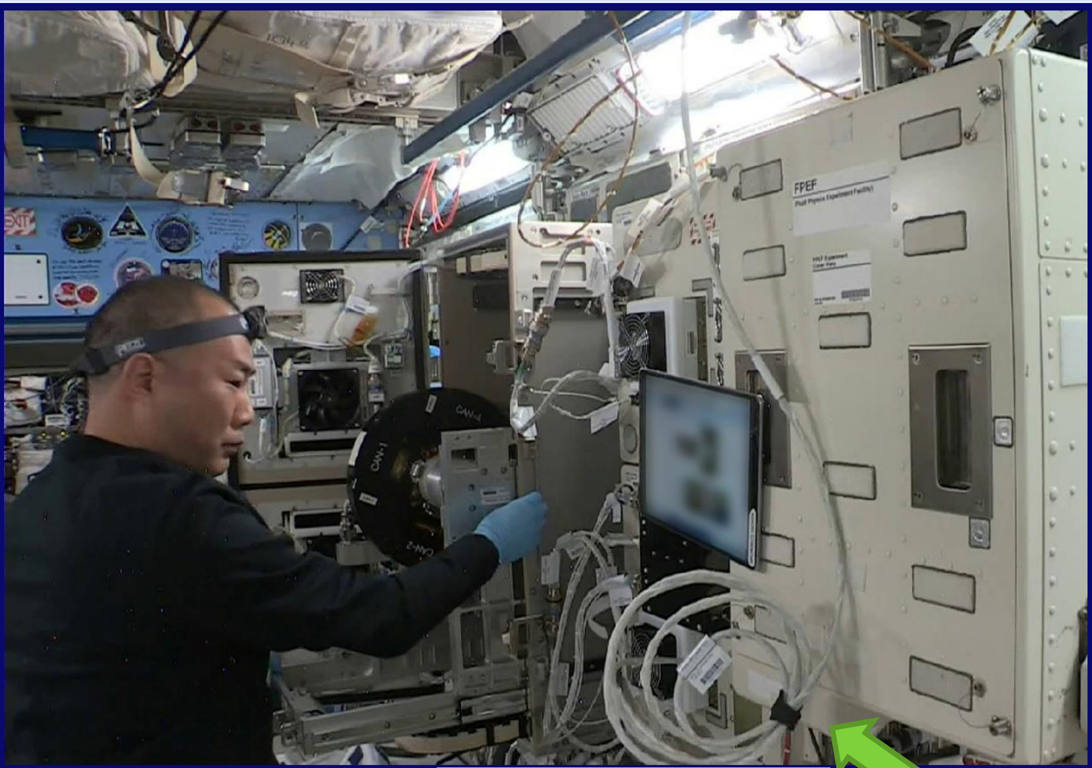


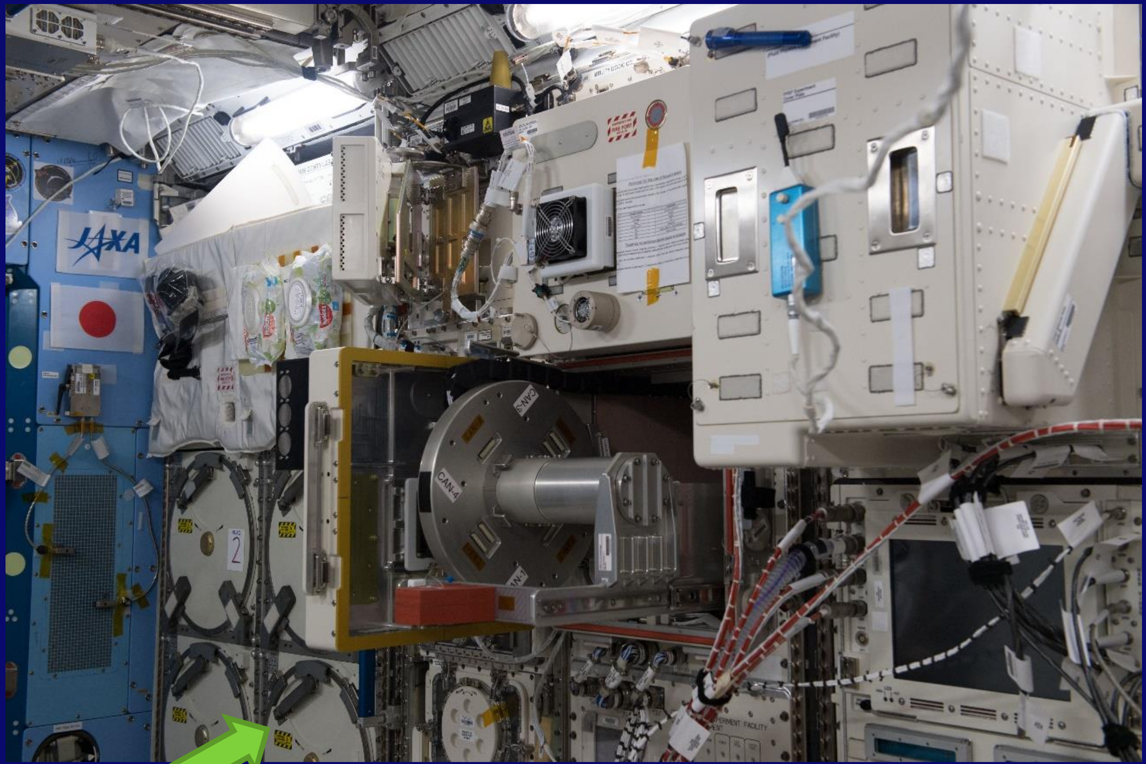
The largest platform on ISS for external payloads

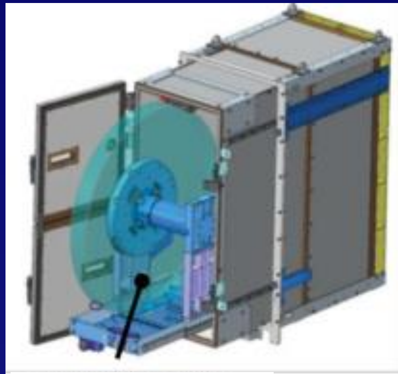
The largest pressurized module in ISS

# Centrifuges in Kibo : CBEF

## (Cell Biology Experiment Facility or Centrifuge-equipped biological experiment facility)

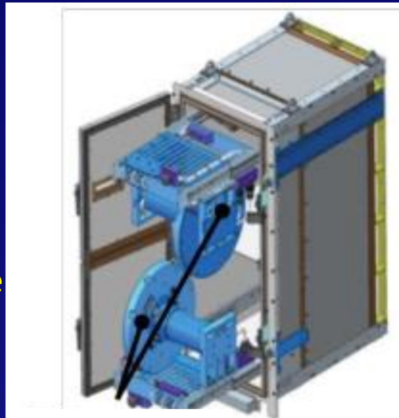




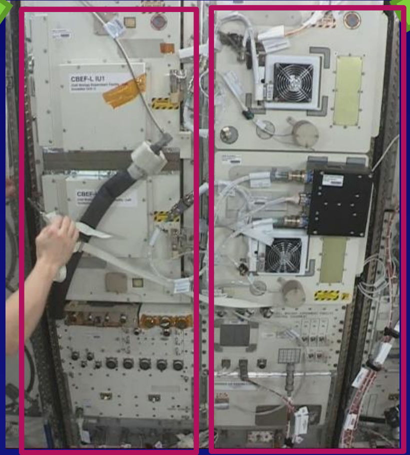


Large centrifuge

Exchangeable



2 centrifuges



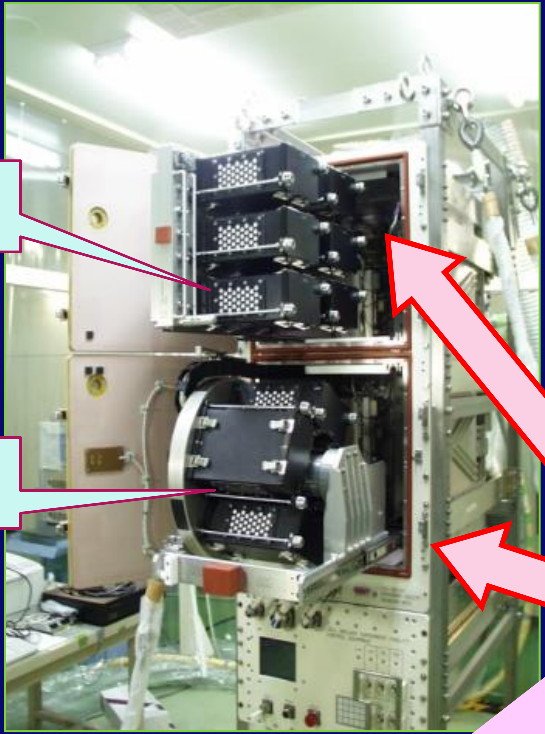


Micro-g section

Artificial-g section

# Gravitational biological research

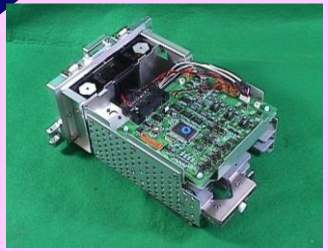
CBEF



Microgravity

Artificial-g

Various experiment units can be placed


Cell Experiment Unit (CEU)

Plant Experiment Unit (PEU)


Measurement Experiment Unit (MEU)

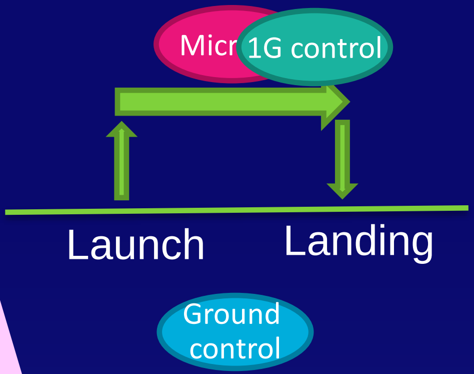

Mouse Habitat Unit (MHU)


Measurement Experiment Unit with camera (VMEU)


Sample Holder


Cell Culture Chamber and Pre-Fixation Kit

Comparison of micro-g / artificial-g is effective for science.



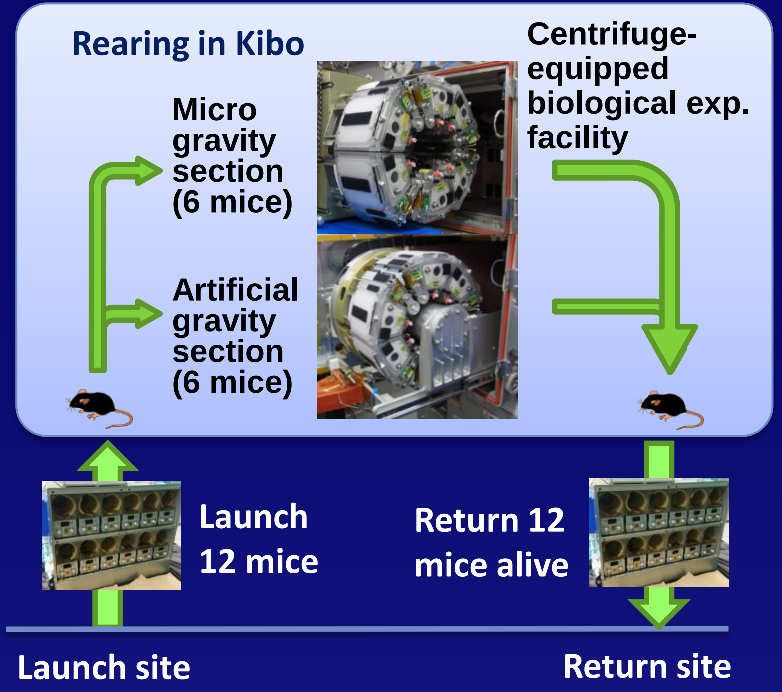
# An example of gravitational research in Kibo
# — JAXA Rodent Missions —

Mouse
Habitat Unit
(MHU)

# JAXA rodent research capability

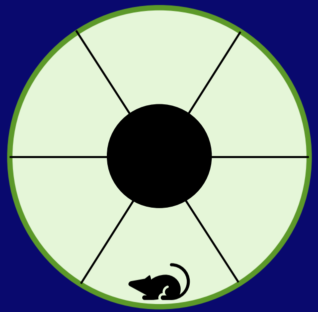
- Living in space causes various physiological changes
  - ✓ Weakened bones and muscles, which are similar to those associated with aging.
- Progress of these symptom in space is ~10 times faster than that on Earth.
- Much severer changes in model organisms (animal).
- ISS/Kibo is an accelerated platform for aging research
  - ✓ Help us understand the mechanisms of aging-related symptoms
  - ✓ Develop methods of prevention


- Aim to develop new JAXA rodent facility
  - ➢ Support research on human health on Earth
  - ➢ Investigate gravitational effects on mammal in detail
- Unique features of the JAXA facility
  - ➢ Comparison between microgravity and artificial gravity conditions
    - ✓ Provides the world's first long-term artificial gravity environment for mammals in space

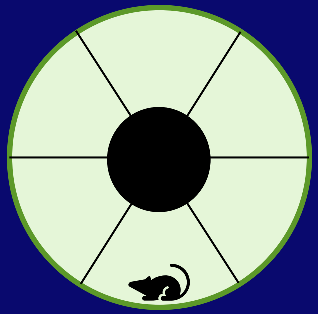


# Onboard video images of mice

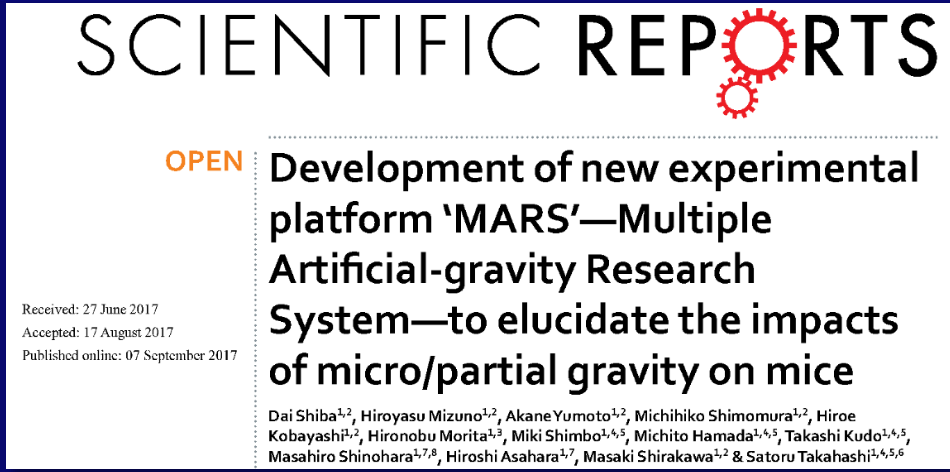
Micro-g




Artificial-g



# Bone loss and muscle atrophy in space



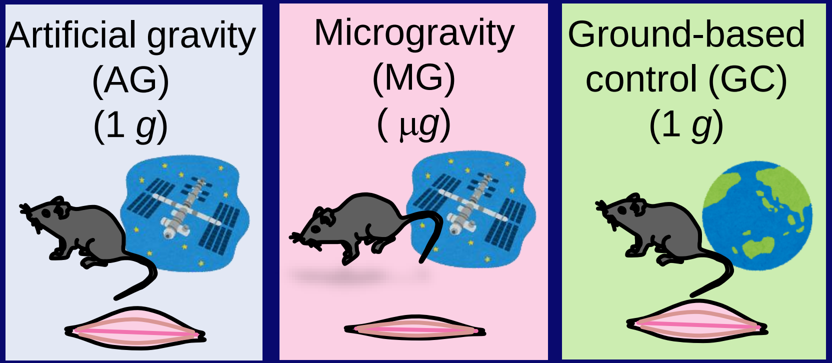
SCIENTIFIC REPORTS

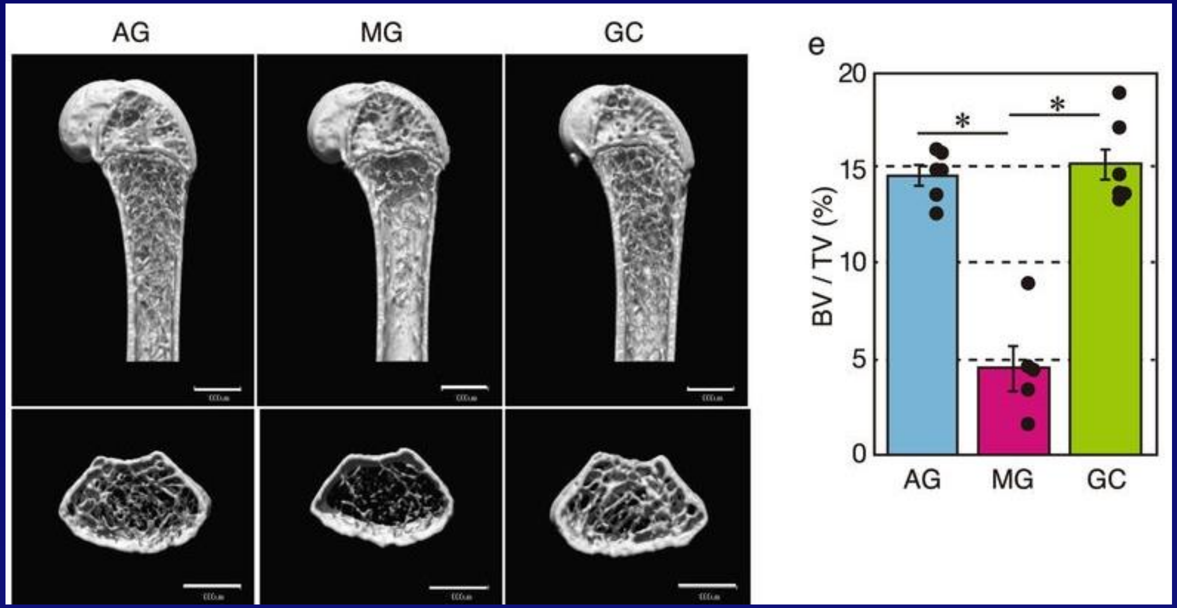
OPEN

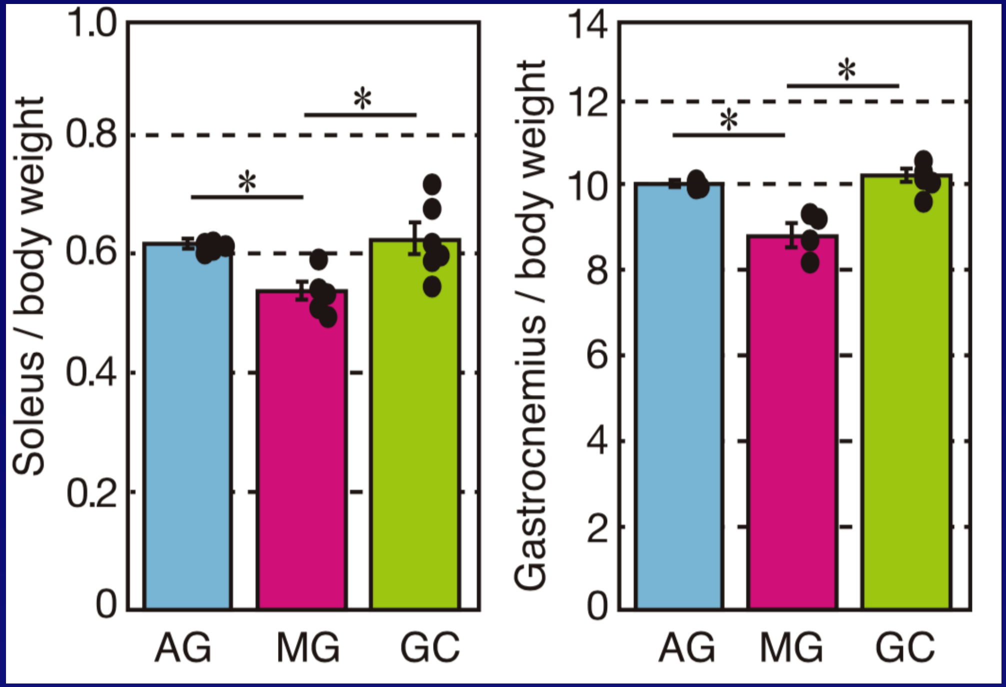
**Development of new experimental platform 'MARS'—Multiple Artificial-gravity Research System—to elucidate the impacts of micro/partial gravity on mice**

Received: 27 June 2017
Accepted: 17 August 2017
Published online: 07 September 2017

Dai Shiba[1,2], Hiroyasu Mizuno[1,2], Akane Yumoto[1,2], Michihiko Shimomura[1,2], Hiroe Kobayashi[1,2], Hironobu Morita[1,3], Miki Shimbo[1,4,5], Michito Hamada[1,4,5], Takashi Kudo[1,4,5], Masahiro Shinohara[1,7,8], Hiroshi Asahara[1,7], Masaki Shirakawa[1,2] & Satoru Takahashi[1,4,5,6]




(Shiba et al., Sci Rep, 2017)

# Publications on gravitational effect using artificial gravity environment

International Journal of *Molecular Sciences* MDPI

Article

## Impact of Spaceflight and Artificial Gravity on the Mouse Retina: Biochemical and Proteomic Analysis

Xiao W. Mao [1,*], Stephanie Byrum [2,3], Nina C. Nishiyama [1], Michael J. Pecaut [1], Vijayalakshmi Sridharan [4], Marjan Boerma [4], Alan J. Tackett [2,3], Dai Shiba [5], Masaki Shirakawa [5], Satoru Takahashi [6] and Michael D. Delp [7]

scientific reports

OPEN

## Transcriptome analysis of gravitational effects on mouse skeletal muscles under microgravity and artificial 1 *g* onboard environment

Risa Okada[1,2], Shin-ichiro Fujita[3,4], Riku Suzuki[5,6], Takuto Hayashi[3,5], Hirona Tsubouchi[5], Chihiro Kato[5,7], Shunya Sadaki[5], Maho Kanai[5,6], Sayaka Fuseya[3,5], Yuri Inoue[3,5], Hyojung Jeon[5], Michito Hamada[5], Akihiro Kuno[5,6], Akiko Ishii[8], Akira Tamaoka[8], Jun Tanihata[9], Naoki Ito[10], Dai Shiba[1,2], Masaki Shirakawa[1,2], Masafumi Muratani[1,4], Takashi Kudo[1,5] & Satoru Takahashi[1,5]

scientific reports

OPEN

## Study of mouse behavior in different gravity environments

Michihiko Shimomura[1,2], Akane Yumoto[1,2], Naoko Ota-Murakami[3], Takashi Kudo[1,4], Masaki Shirakawa[1,2,5], Satoru Takahashi[1,4], Hironobu Morita[1,6,7] & Dai Shiba[1,2,5]

SCIENTIFIC REPORTS

natureresearch

OPEN

## Impact of spaceflight on the murine thymus and mitigation by exposure to artificial gravity during spaceflight

Kenta Horie[1,10], Tamotsu Kato[2,10], Takashi Kudo[3,4,10], Hiroki Sasanuma[5], Maki Miyauchi[1], Nobuko Akiyama[6], Takahisa Miyao[1], Takao Seki[1], Tatsuya Ishikawa[1], Yuki Takakura[1], Masaki Shirakawa[7], Dai Shiba[7], Michito Hamada[3,4], Hyojung Jeon[3,4], Nobuaki Yoshida[4,5], Jun-ichiro Inoue[8], Masafumi Muratani[4,9], Satoru Takahashi[3,4], Hiroshi Ohno[2*] & Taishin Akiyama[1,4*]

SCIENTIFIC REPORTS

OPEN

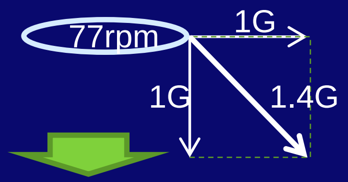
## Down-regulation of GATA1-dependent erythrocyte-related genes in the spleens of mice exposed to a space travel

Received: 31 January 2019
Accepted: 30 April 2019
Published online: 21 May 2019

Kenta Horie[1], Hiroki Sasanuma[2,3], Takashi Kudo[3,4], Shin-ichiro Fujita[3,5], Maki Miyauchi[1], Takahisa Miyao[1], Takao Seki[1], Nobuko Akiyama[1], Yuki Takakura[1], Miki Shimbo[3,4], Hyojung Jeon[3,4], Masaki Shirakawa[3,6], Dai Shiba[3,6], Nobuaki Yoshida[2,3], Masafumi Muratani[3,5], Satoru Takahashi[3,4] & Taishin Akiyama[1,3]

# Ground-based study using centrifuges

- Feasibility of use of the short-arm (15cm in radius) centrifuge of CBEF was confirmed by comparing with a 1.5m-radius centrifuge.





(Source: JAXA/Gifu Univ.)

PLOS | ONE

RESEARCH ARTICLE

**Feasibility of a Short-Arm Centrifuge for Mouse Hypergravity Experiments**

Hironobu Morita[1,2*], Koji Obata[1], Chikara Abe[1], Dai Shiba[3], Masaki Shirakawa[3], Takashi Kudo[2,4,5], Satoru Takahashi[2,4,5]

- Effect of hypergravity load (10G x 2min as the worst-case) in re-entry and splashdown phase was investigated with 1.5m-radius centrifuge.

(Source: NASA)

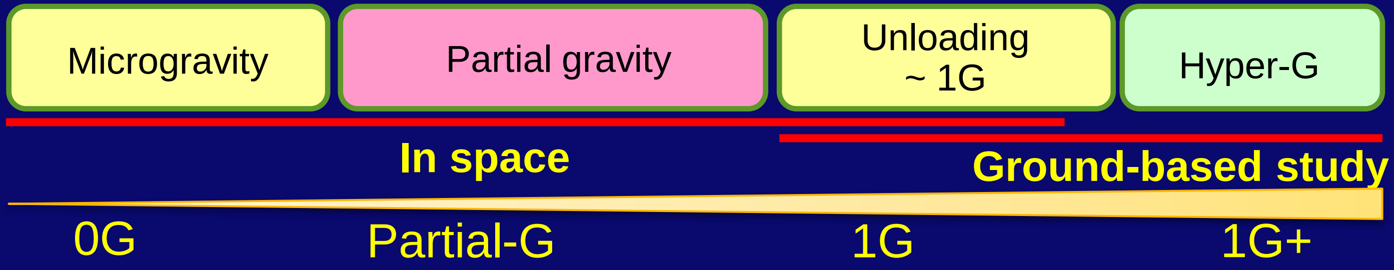
**Impact of a simulated gravity load for atmospheric reentry, 10 *g* for 2 min, on conscious mice**

Hironobu Morita[1,4] · Aoi Yamaguchi[1] · Dai Shiba[2] · Masaki Shirakawa[2] · Satoru Takahashi[3,4]

J Physiol Sci
DOI 10.1007/s12576-017-0526-z

SHORT COMMUNICATION

# Ground-based studies using centrifuges




- Ground-based hyper-G experiments are effective to investigate:
  1. Sensitivity to a gravitational change (+ G on the ground; - G in space)
  2. Persistency of effects to confirm the effects last from the time of splashdown to the hand-over of mice (about 3 days for ISS mission).
  3. Effect of reduced gravity change when prolonged hyper-gravity was stopped, e.g. change of 2G (hyper-G) to 1G yields -1G.

1.5m-radius centrifuge at Gifu University

(Source: JAXA/Gifu Univ.)

# Ground-base gravitational research

SCIENTIFIC REPORTS

OPEN

## Hypergravity and microgravity exhibited reversal effects on the bone and muscle mass in mice

Received: 2 November 2018
Accepted: 8 April 2019
Published online: 29 April 2019

Tsukasa Tominari[1], Ryota Ichimaru[1], Keita Taniguchi[1], Akane Yumoto[2], Masaki Shirakawa[2], Chiho Matsumoto[1], Kenta Watanabe[3], Michiko Hirata[1], Yoshifumi Itoh[3,4], Dai Shiba[2], Chisato Miyaura[1,3] & Masaki Inada[1,3]

PLOS | ONE

RESEARCH ARTICLE

## Effects of gravity changes on gene expression of BDNF and serotonin receptors in the mouse brain

Chihiro Ishikawa[1☯], Haiyan Li[1☯], Rin Ogura[1☯], Yuko Yoshimura[1], Takashi Kudo[2,3,4], Masaki Shirakawa[4,5], Dai Shiba[4,5], Satoru Takahashi[2,3,4], Hironobu Morita[4,6], Takashi Shiga[1,4,7]*

PLOS | ONE

RESEARCH ARTICLE

## Hypergravity Provokes a Temporary Reduction in CD4+CD8+ Thymocyte Number and a Persistent Decrease in Medullary Thymic Epithelial Cell Frequency in Mice

Ryosuke Tateishi[1,2☯], Nobuko Akiyama[1,2☯], Maki Miyauchi[1,2], Riko Yoshinaga[1,2], Hiroki Sasanuma[2,3], Takashi Kudo[2,4,5], Miki Shimbo[2,4,5], Masahiro Shinohara[2,6,7], Koji Obata[2,8], Jun-ichiro Inoue[1], Masaki Shirakawa[2,9], Dai Shiba[2,9], Hiroshi Asahara[2,6], Nobuaki Yoshida[2,3], Satoru Takahashi[2,4,5], Hironobu Morita[2,8]*, Taishin Akiyama[1,2]*

Contents lists available at ScienceDirect

ELSEVIER

Biochemical and Biophysical Research Communications

journal homepage: www.elsevier.com/locate/ybbrc

BBRC

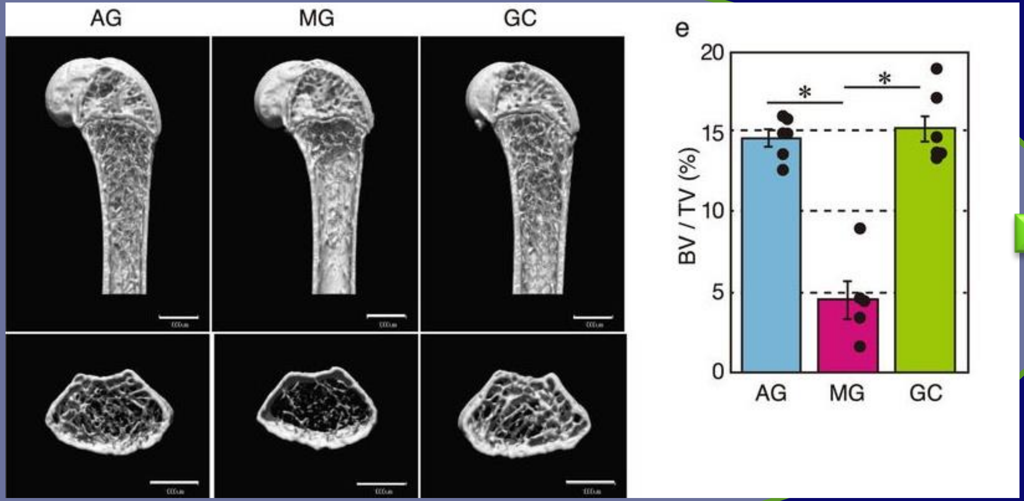
## Long-term hindlimb unloading causes a preferential reduction of medullary thymic epithelial cells expressing autoimmune regulator (Aire)

Check for updates

Kenta Horie [a,b,1], Takashi Kudo [b,c,1], Riko Yoshinaga [a,b,1], Nobuko Akiyama [a,b], Hiroki Sasanuma [b,d], Tetsuya J. Kobayashi [e], Miki Shimbo [b,c], Hyojung Jeon [b,c], Takahisa Miyao [a], Maki Miyauchi [a], Masaki Shirakawa [b,f], Dai Shiba [b,f], Nobuaki Yoshida [b,d], Masafumi Muratani [b,g], Satoru Takahashi [b,c], Taishin Akiyama [a,b,*]

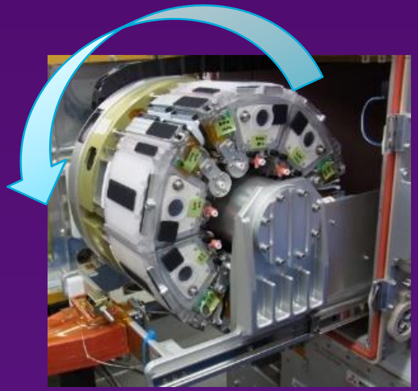
# Two directions of JAXA rodent missions

- Bones in MG mice dramatically decreased in comparison with those of AG & GC groups. Symptom similar to severe osteoporosis was observed by rearing in space for only 35 days.
- **Revealed for the first time that gravitational loading significantly suppressed the bone loss.**

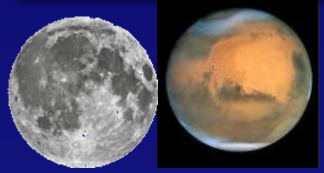


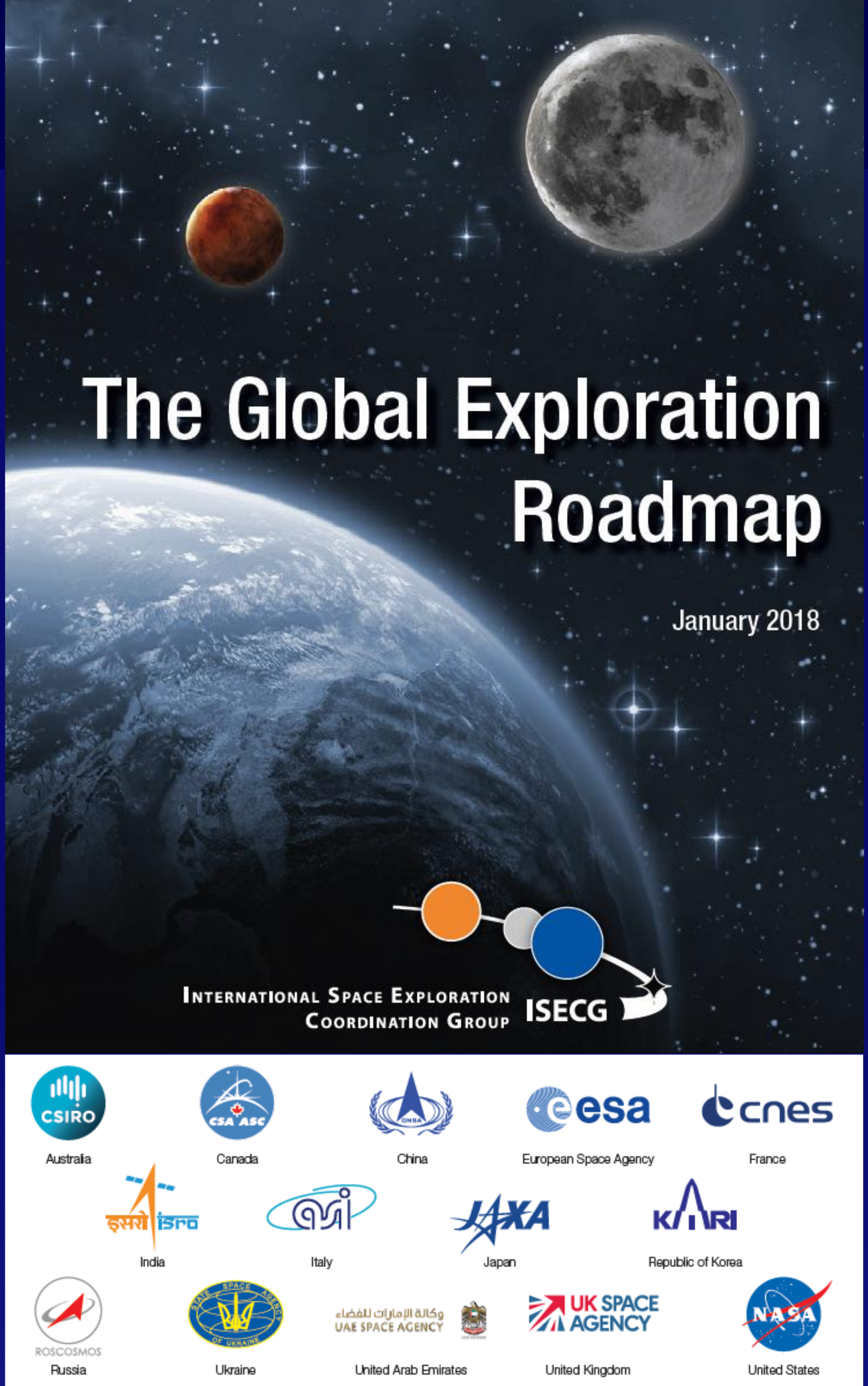

**Human Health on Earth**

- The system provides both microgravity (μ*g)* and artificial gravity environments.
  - 77rpm → Earth's gravity (1 *g*),
    48rpm → Mars' gravity (0.38 *g*),
    31rpm → Moon's gravity (0.16 *g*)
  - The System can contribute to risk assessment and scientific validation of long-term habitation in partial gravity environment.



**Human Exploration**
**Only "MARS" can provide Partial-G environment for mammal**






## Managing Human Health and Performance Risks for Space Exploration

Long-duration missions and planetary operations entail numerous risks that must be understood and mitigated in order to maintain the health and productivity of crew members. The five human spaceflight hazards that need to be considered for any deep space exploration mission are:

1. Radiation – in deep space, radiation exposure is a top concern.
2. Isolation – psychological stress associated with limited space and group dynamics.
3. Distance from Earth – some operations in deep space, such as medical activities and procedures, are a challenge.
4. Gravity – The different levels of gravity will affect many of the human physiological systems.
5. Environment – hostile and closed environments will affect the overall living environment (e.g., toxicology, microbiology, etc.).

To address these challenges, agencies are actively performing studies in laboratories, ground analogues and on board the ISS and other flight platforms, including the deep space Gateway.

### On the Ground

Isolation facilities are used for studies on behavioural performance. The facilities being used include the Human Exploration Research Analogue in Houston, Texas, and the Institute of Biomedical Problems Ground-based Experimental Complex in Moscow, Russia.

Other important ground facilities are located in Europe. These facilities host studies of musculoskeletal and cardiovascular deconditioning and psychological effects of long-term confinement. One example is the MEDES, an institute for space medicine and physiology in Toulouse, France.

### In Flight

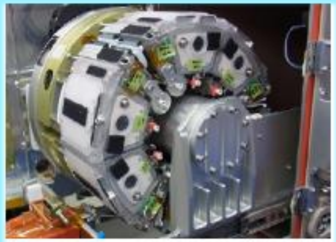
Numerous studies are ongoing onboard the ISS. Information on past and present studies can be found at **https://www.nasa.gov/mission_pages/station/research/** and **http://www.esa.int/Our_Activities/Human_Spaceflight/Research**.

The first one-year mission has completed and preliminary results are interesting. Most notably, gene expression in space is altered, thereby opening new research possibilities aimed at mitigating health effects of long-duration spaceflight and with potential applicability to terrestrial health.

Today, bioanalytical and biomonitoring capabilities in space are limited. Canada is focusing on in-space analysis capabilities to remove these limitations. One example is a bioanalyser for space that can measure different populations of blood cells and measure diverse proteins in a single sample. This eliminates the need for storing samples and speeds the analysis. Another is a garment that can continuously collect an array of physiological data which is being developed for testing on ISS. An early version of this garment, Astroskin, has been used in isolation experiments on Earth. Canada is also developing a simple, robust technology to isolate biomolecules or cells of interest in order to enhance research capabilities on ISS and support science and medicine for future space exploration. Italy developed and positively tested on the ISS (VITA mission) a payload consisting in a garment containing water as shielding material against radiation, and a portable bioanalyzer enabling direct analysis of samples, rather than collecting and storing samples that will be analyzed upon their return to Earth.

**NASA's Human Exploration Research Analogue is used several times per year to understand and test mitigation strategies for human performance risks.**

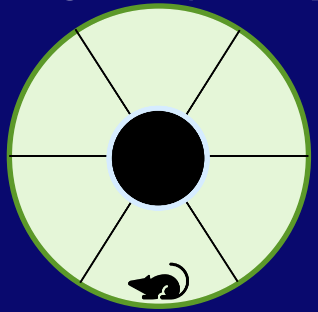
**Aquapad: During the ISS Proxima mission, CNES, in partnership with the bioMérieux company, tested a technology to detect microbial contamination of water. The technology, which is simple and can be stored in ambient conditions, has been used on Earth for the detection of cholera in high-risk locations.**



**JAXA's Multiple Artificial-gravity Research System is a rodent habitat for ISS. The system includes a centrifuge that allows studies from 0 g up to and including 1 g. This capability enables investigations comparing gravity effects on animals in the same space environment with gravity as the only variable.**

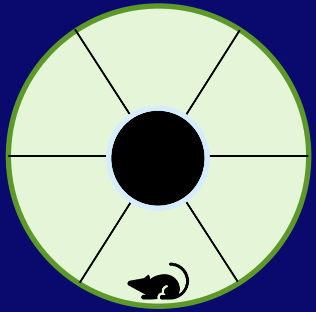
# World's First Rodent Partial-G Mission

## Microgravity in space



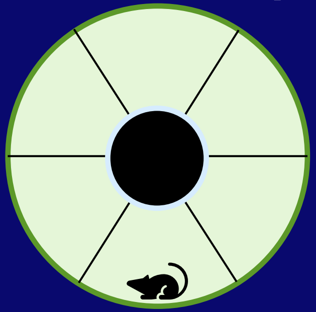

**floating**

## Artificial 1/6G in space




**floating ←→ "landing"**

## Artificial 1G in space




**"standing"**

# Another example of use of centrifuge: Exploration

An investigation named “Hourglass”

- Examine the relationship between gravity and the behavior of granular materials such as regolith that covers the surface of planets and planetary-like bodies.
- Observe various granular materials inside an hourglass and a measuring cylinder under different gravity conditions.
- Better understanding of the behavior of these materials supports the design of spacecraft for future missions landing on the surfaces of planets and other celestial bodies.

Source: NASA

# Summary

1. **Centrifuges on ISS / Kibo provides artificial gravity environment**
   - Centrifugation capability in Kibo:
     - ✓ Centrifuge-equipped incubator : Φ0.35m centrifuge + microgravity compartment, and
     - ✓ New centrifuge system: 1 large (Φ0.76m) centrifuge or two Φ0.35m centrifuges
   - Unique environment for producing long-term partial-g

2. **Rodent missions using the artificial gravity environment.**
   - Useful for gravitational research on mammal
   - Revealed gravitational effects which will be beneficial for aging study on Earth

3. **Artificial gravity / partial gravity environment for exploration**
   - World's first demonstration of long-term artificial Moon's gravity (1/6 G) for mammal
   - Useful for technological study for exploration