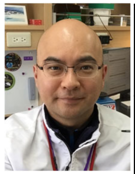
【Grant-in-Aid for Transformative Research Areas（A）】

Life in Space: the Exploration of Environmental Responses and Robustness of Biological Systems to Predict the Future of Life on and beyond Earth



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Purpose and Background of the Research

●Outline of the Research

For humans to live long-term in space, challenges such as health maintenance and food production must be addressed. Understanding how living organisms respond to space environments is key. Studying how life, shaped over four billion years on Earth, behaves in space offers new insights into adaptation to future on and beyond Earth.

In the International Space Station (ISS), experiments with animals and plants in microgravity have shown that many physiological functions change in space. However, not all are affected, and investigating these specific changes deepens our understanding of gravity's biological role.

Notably, some space-induced changes involve the decline of traits characteristic of vertebrates that were acquired during the transition from water to land. For example, muscles and hard bones for posture control and locomotion, ion regulation, and organ function regress toward ancestral states (Figure 1).

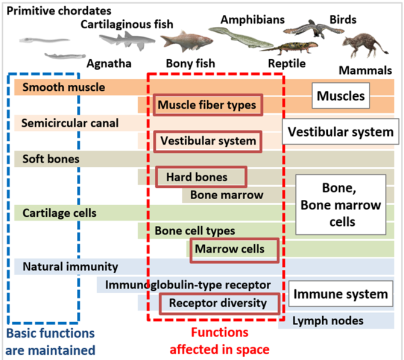

Figure 1. Functions affected in space

Such "reversions" or "space-induced atavistic phenotypes" suggest that traits fixed by evolution still respond to Earth's environment (Figure 2). Mouse studies have also shown that spaceflight effects can persist into the next generation, raising the possibility of new evolutionary paths in low-gravity environments like the Moon or Mars.

As physiological evolution leaves little fossil record, it has been hard to study. But focusing on environmental responses allows for experimental modeling of intergenerational effects, enabling predictions of past and future biological changes.

This research area explores the balance between "homeostatic maintenance," which stabilizes bodily functions on Earth, and "environmental responsiveness," which becomes evident in space. By activating functions hidden under Earth conditions, we seek to reveal latent genomic capabilities. These discoveries may support future applications in health, agriculture, environmental solutions, and biomimetic technologies, both in space and on Earth.

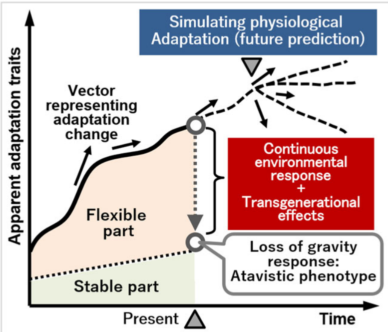

Figure 2. Continuous environmental responses in "established traits".

Expected Research Achievements

● Group A01: Environmental effects on development and physiological functions

A01 identifies genes and genomic regions involved in changes to various organs and tissues under space conditions (Figure 1). It also clarifies shared patterns of epigenomic regulation and the neural control systems, both central and peripheral, that sense and relay gravity, along with their evolutionary context.

● Group A02: Stress responses affected in space

Functions like oxidative stress response, UV and radiation defense, and mitochondrial metabolism, linked to adaptation on land, also shift under space conditions (Figure 3). A02 examines their molecular mechanisms and intergenerational effects through samples from space and ground-based simulations.

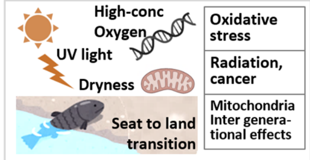

Figure 3. Environmental stress during transition from set to land

● Group A03: Extended linage integration

A03 conducts comparative analyses across a wide range of species while considering evolutionary lineages (Figure 4). By focusing on gravity sensors, we develop "comparative mechanobiology" to understand their evolutionary origins (Figure 5).

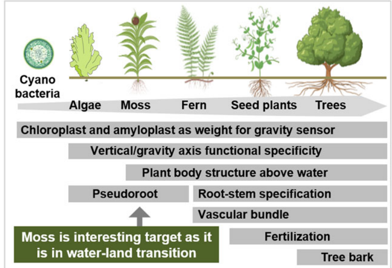

Figure 4. Environmental response in photo synthetic organisms

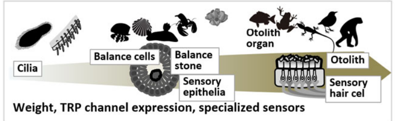

Figure 5. Comparative mechanobiology

● Expected outcomes and broader impacts

This research area explores the latent genomic functions and physiological adaptability revealed by space environments, focusing on homeostatic maintenance functions and environmental stress responses, and aims to elucidate their robustness and flexibility at the system level. Furthermore, by applying the insights derived from these findings across diverse species, we aim to develop both theoretical frameworks and experimental models, thereby advancing the prediction of the future of Earth's life (Figure 6).

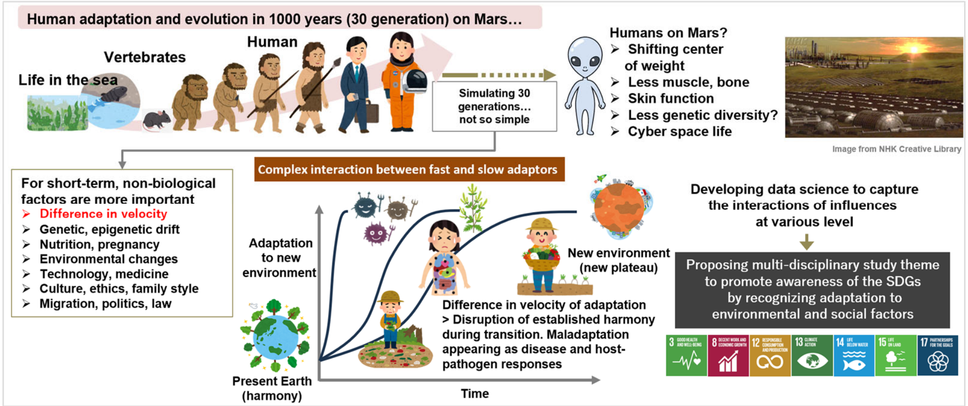

Figure 6. Extended data integration to support sustainable development on and beyond Earth

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Homepage Address, etc.	"Life in Space" Homepage https://www.life-in-space.org/introduction-en