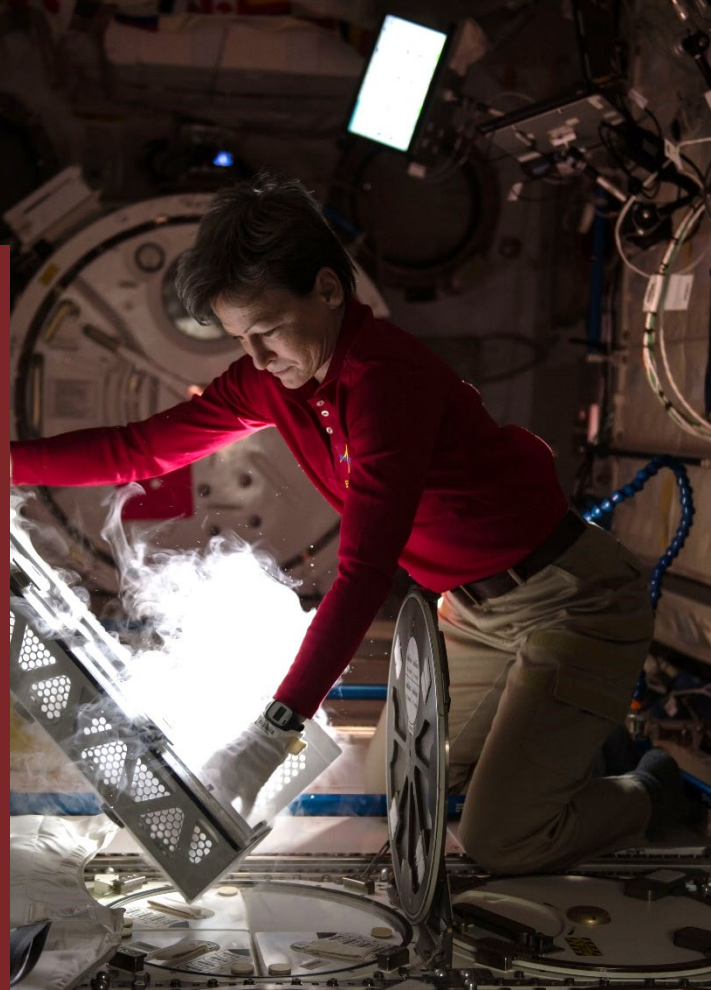


# Thriving in Space - Ensuring the Future of Biological and Physical Sciences Research

A Decadal Survey for 2023-2032

*Robert J. Ferl and Krystyn J. Van Vliet, Co-Chairs*

[nationalacademies.org/bps-decadal](https://nationalacademies.org/bps-decadal)





The next decade heralds exciting  
new advances as we move to  
explore the Moon and Mars.



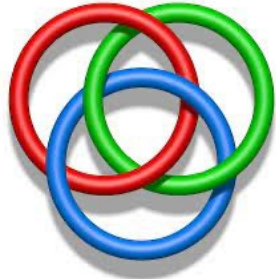


# The space ecosystem is expanding rapidly

The next decade will involve:

- More people
- More destinations, including the Moon and Mars
- Longer duration missions
- More activity types
- More commercialization

# Steering Committee, Expert Panels, & Community Input



Biological Sciences  
Physical Sciences  
Engineering and Science  
Interface

**Steering Committee:** 18 experts from across the US and the **BPS** disciplines

**Panels:** 50+ experts, organized in working groups that mixed **BPS** disciplinary expertise on the current state of the field, future science priorities, and feasibility

**Community Input:** 250+ topical concept papers; 60+ research campaign concept papers; 2+ years of public meetings with government + industry experts

# Report Snapshot



[nationalacademies.org/bps-decadal](https://nationalacademies.org/bps-decadal)

- Summary
- 1: Introduction
- 2: Current State of Knowledge in BPS
- **3: Key Science Themes and Questions**
- 4: Science to Enable Space Exploration
- 5: Science Enabled by the Space Environment
- **6: Research Campaigns**
- 7: Infrastructure, Access, and Community

**3**

Science  
Themes

**11**

Science  
Questions

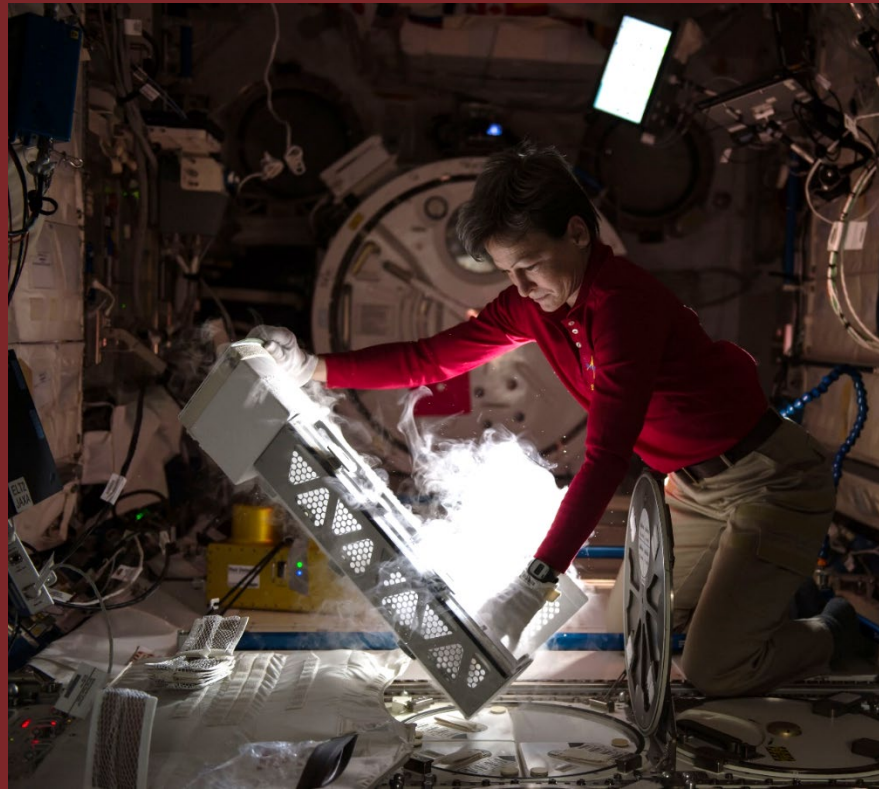
**2**

Research  
Campaigns

**25**

Recs

# Focus on Key Scientific Questions





# Key Science Themes

## ADAPTING TO SPACE



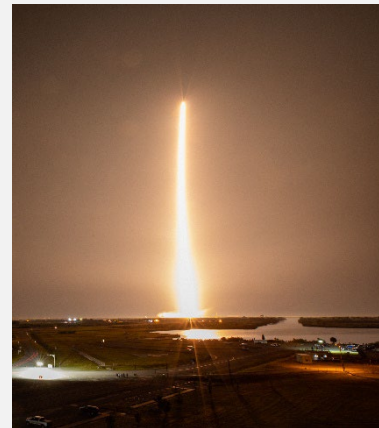
What fundamental processes change when away from Earth?

## LIVING AND TRAVELING IN SPACE



What does it take to occupy space environment over the long haul?

## PROBING PHENOMENA HIDDEN BY EARTH



What principles are hidden by gravity or revealed only by being in space?



# Adapting to Space

## Key Scientific Questions

- How does the space environment influence biological mechanisms required for organisms to survive the transitions to and from space, and thrive while off Earth?
- How do genetic diversity and life history influence adaptation to the space environment?
- How does the space environment alter interactions between organisms?





# Living and Traveling in Space

## Key Scientific Questions

- What are the important multi-generational effects of the space environment on growth, development, and reproduction?
- What principles guide the integration of biological and abiotic systems to create sustainable and functional extraterrestrial habitats?
- What principles enable identification, extraction, processing, and use of materials found in extraterrestrial environments to enable long-term, sustained human and robotic space exploration?
- What are the relevant chemical and physical properties and phenomena that govern the behavior of fluids in space environments?



# Probing Phenomena Hidden by Gravity or Terrestrial Limitations

## Key Scientific Questions

- What are the mechanisms by which organisms sense and respond to physical properties of surroundings, and to applied mechanical forces including gravitational force?
- What are the fundamental principles that organize the structure and functionality of materials, including but not limited to soft and active matter?
- What are the fundamental laws that govern the behavior of systems that are far from equilibrium?
- What new physics, including particle physics, general relativity, and quantum mechanics, can be discovered with experiments that can only be carried out in space?

# Connect to societal impact with Research Campaigns





The background of the slide is a photograph of Earth as seen from space, showing the curvature of the planet and the blue atmosphere. The image is partially obscured by a white rectangular box containing text.

New **Research Campaigns** with audacious goals will help drive solutions to the key science questions within the decade and make best use of missions to the Moon and Mars.

# Research Campaigns

## BLISS



**Bioregenerative Life Support Systems**

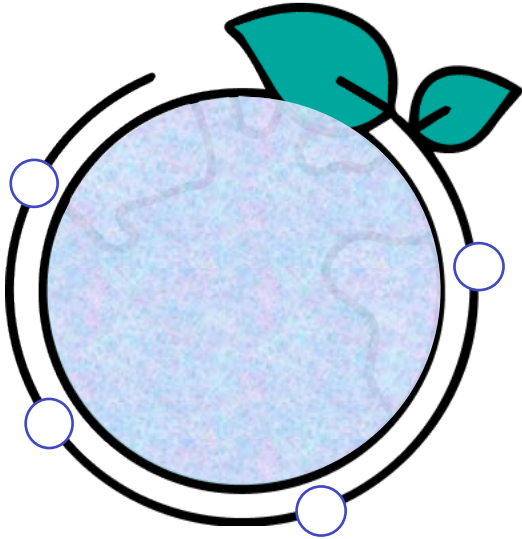
## MATRICES



**Manufacturing mATeRials and ProcessEs for Sustainability in Space**

# Research Campaigns

## BLiSS Goals



In the context of global competition for LEO research with Earth benefits

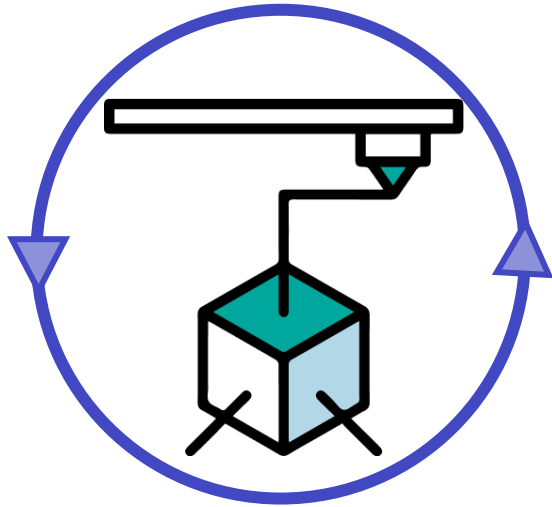
1. Self-sustainable system to produce food, clean water, renew air, process waste, and create critical materials to meet the challenges of long-duration space missions.





# Research Campaigns

## MATRICES Goals



In the context of global competition for resource use & manufacturing expertise off-Earth

1. Learn how materials and energy interact in non-terrestrial environments, and use that knowledge to design infrastructure for responsible space exploration.



# Beyond NASA-anchored Campaigns

PFaST: Probing the Fabric of Space-Time  
*Multiagency Opportunity*

PROMO: Polar Radiation of Model Organisms  
*Notional Concept*

# Plan for the Unexpected





## Plan for the Unexpected.

1. NASA is appropriated *more* or *less* federal funding for the BPS Division.
2. NASA-sponsored researchers are granted *more* or *less* access to the International Space Station (ISS)
3. BPS researchers have *more* or *less* access to commercial LEO destinations (CLDs) or payload service providers
4. NASA gains *more* or *less* U.S. interagency cooperation and co-funding of BPS research
5. The United States enjoys *more* or *less* international cooperation with launch, crew time for research, or infrastructure and mission co-development

# Plan for the Unexpected.

## 2. NASA-sponsored researchers are granted *more* or *less* access to the ISS:

If researchers are granted *more* crew time or upmass on the ISS, experiments that serve as development or validation of commercial low Earth orbit (LEO) destination-planned experiments are prioritized.

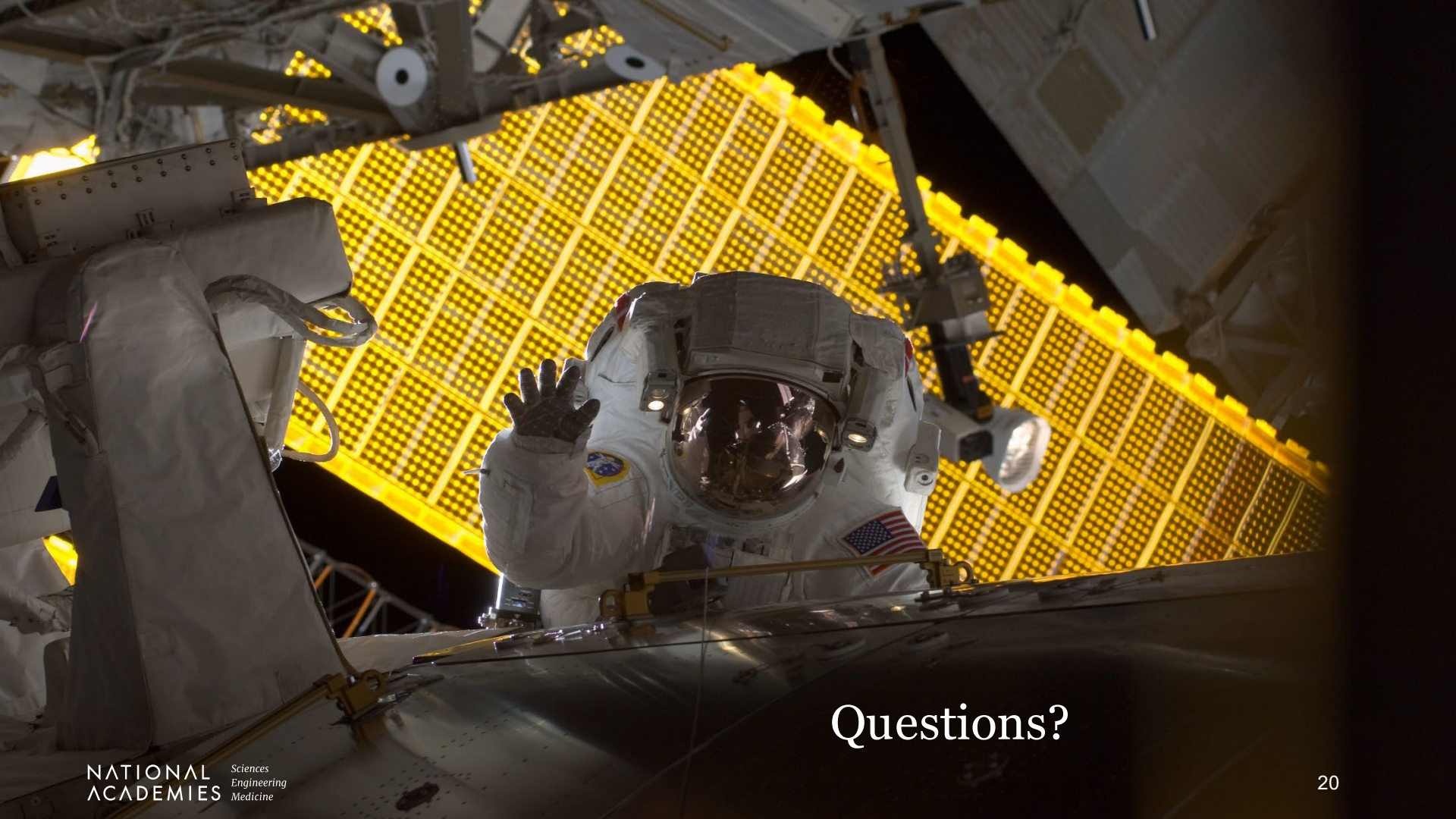
If researchers are granted *less* crew time or upmass on ISS, technical/biological replicate experiments are prioritized.

## 3. BPS researchers have *more* or *less* access to commercial LEO destinations (CLDs) or payload service providers:

If researchers have *more* access to CLDs, projects focused on KSQs representing all three themes and research campaign elements are prioritized.

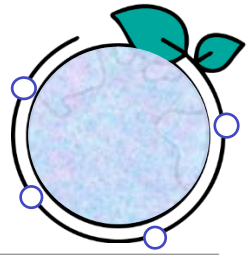
If researchers have *less* access to CLDs, projects focused on KSQs representing at least the adapting to space theme and probing hidden phenomena theme are prioritized until answered.



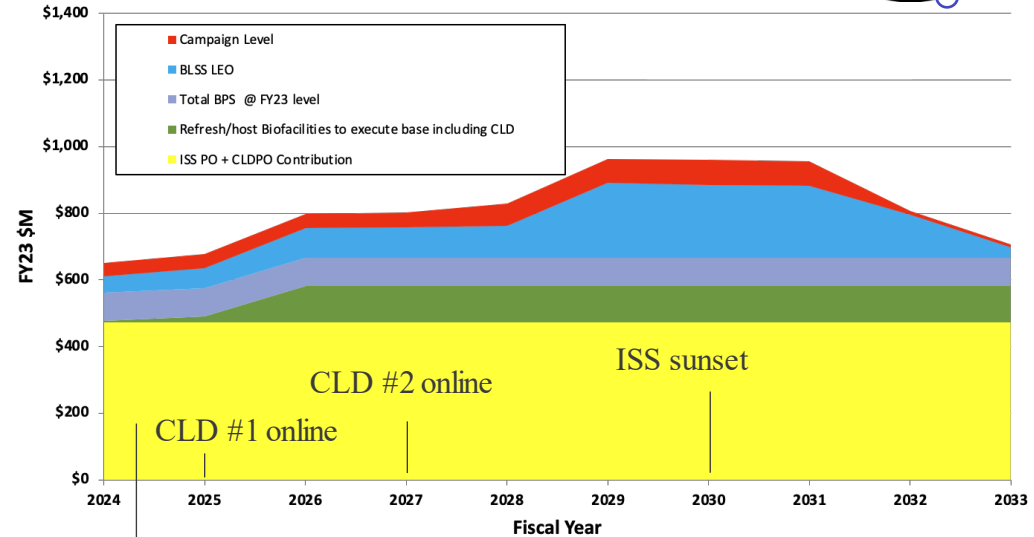


Questions?

# Research Campaign Assumptions



- At least 2 commercial lunar destinations (CLDs) *for scientific research* use this decade. Otherwise, US severely disadvantaged on prep for Moon to Mars.
- Launch costs excluded from *BPS research program* cost estimates, consistent with current practice
- Coordination services provided by US Program Office, for LEO and other research destinations



ISS+CLD PO CLD Contribution: ROM estimate of the allocation of launch and return vehicle services, crew time and integration and operations services provided for the total BPS program



# Bolstering U.S. space science research excellence

**FINDING:** A robust and resilient BPS program requires:

- a **healthy and regular cadence of proposal calls and grant dollar awards** that are consistent with sustaining a diverse and productive BPS community over the course of the next decade, including the necessity of training a diverse scientific workforce of sufficient size and caliber to maintain the BPS community over a generational timescale;
- **broadened and more inclusive participation in the U.S. BPS community**, including diversity of both scientific expertise and by lived socioeconomic experience, recognizing the slow progress in attracting and retaining women and persons of color into graduate and post-graduate research roles;
- a **total science budget sufficient to meet current national needs** and international competitor/collaborator challenges;
- **interactions with other U.S. government and non-U.S. space agencies** necessary for optimal BPS community productivity in science and technology development; and
- significant awareness and **collaboration with the emerging commercial space science, platforms and activities**, as appropriate for BPS program goals.

# Space Science Researchers propel us forward

In a highly competitive global science and engineering environment, the **U.S. must stay on the leading edge** of the practice of science & engineering, improving the research environment and setting the standard for ethics and values.

—Dr. Ellen Ochoa

