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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

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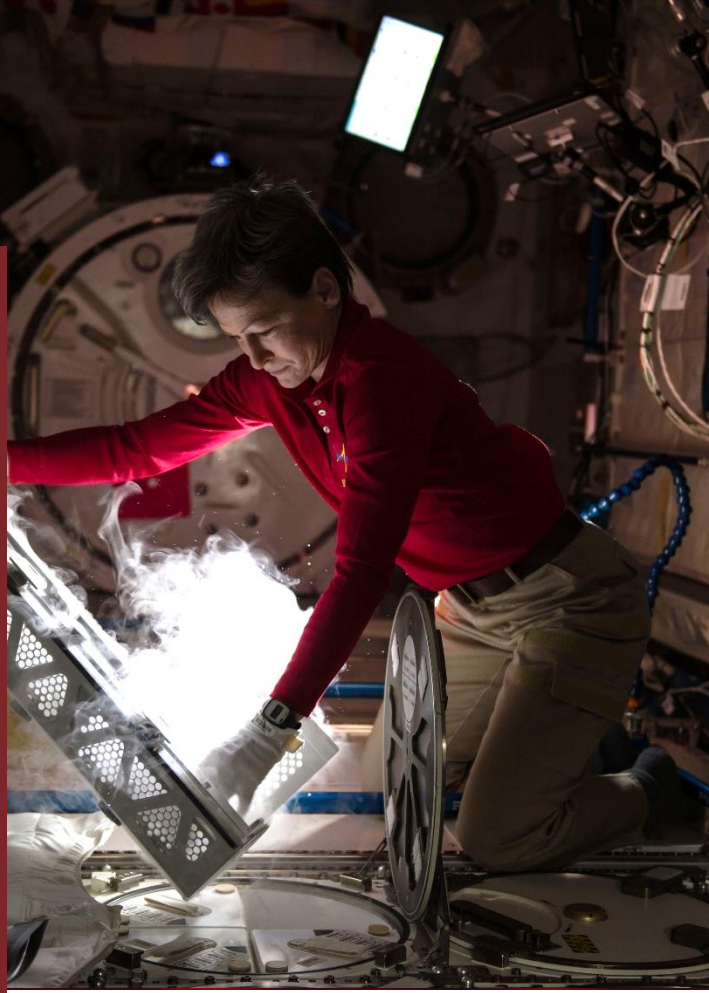
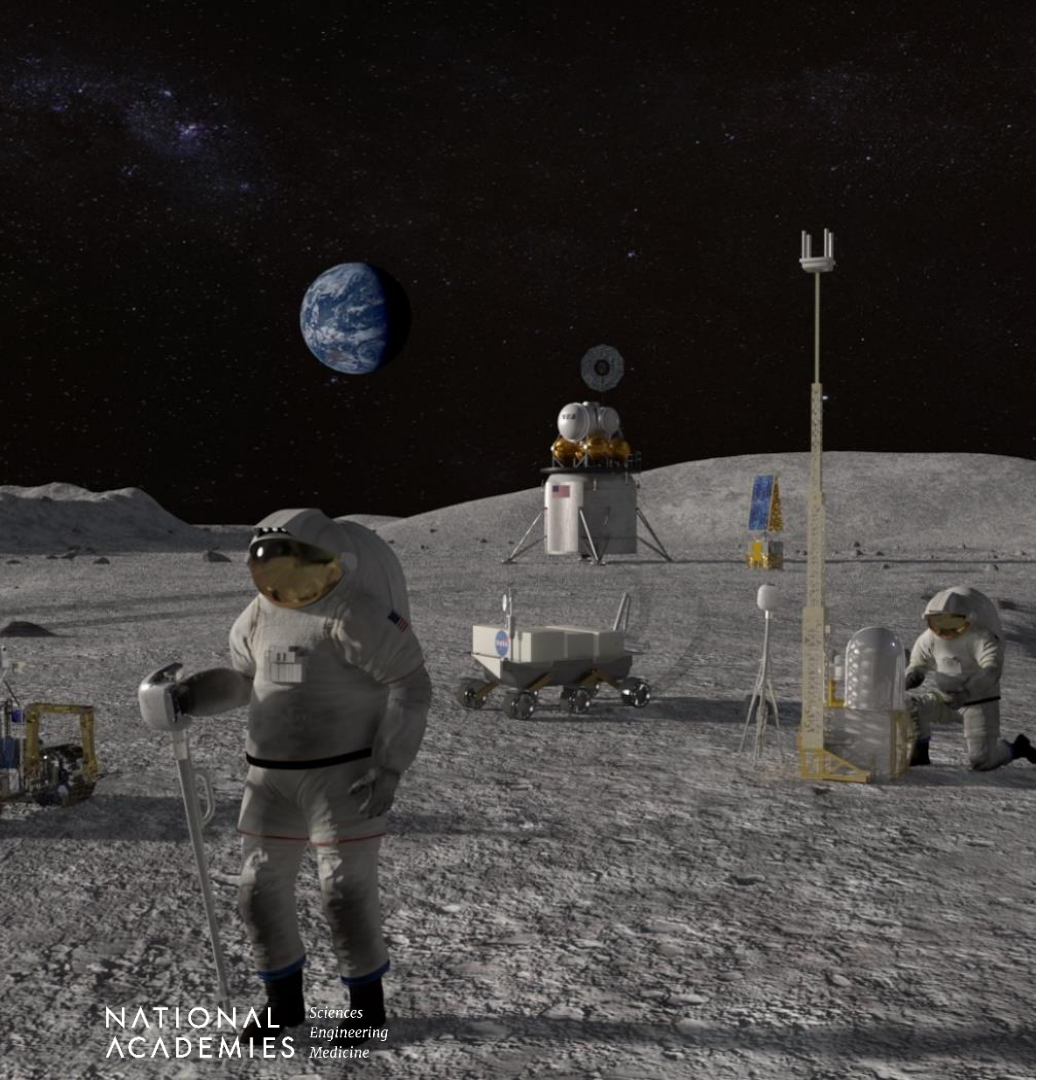


REPORT BRIEFING

Not since Apollo missions have so many looked toward space for inspiration and new solutions.

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

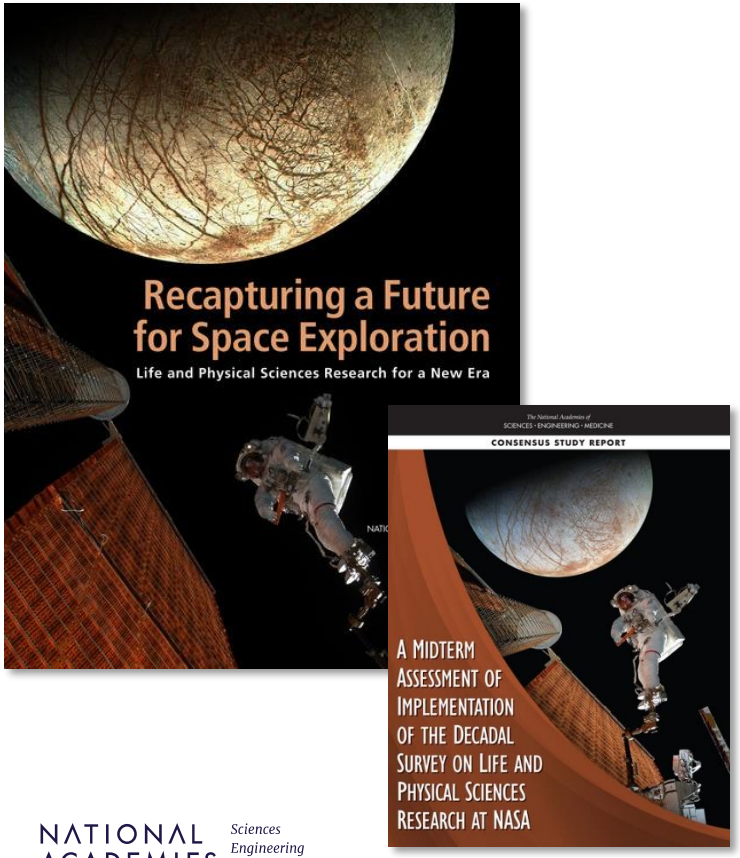


The space ecosystem is expanding rapidly

The next decade will involve:

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

Thriving in Space – we live in a different world



This last decade in space science research was one of:

- Rebuilding researcher engagement
- Adapting to change
- Struggling for priority
- And *still* making amazing new discoveries and grappling with new challenges for space exploration and space-enabled breakthroughs in science.

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Study Scope

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- Current state of knowledge
- Identify compelling science and frontiers
- Scientific research priorities
  - Enabled by space access and enabling exploration from Earth to moon to Mars
  - Campaigns with TRACE
- Comprehensive strategy
  - Unique NASA roles in the research enterprise
  - Synergies with OGAs and SMD Divisions
  - Research in LEO and ISS transitions
  - Decision rules to inform during rapid change
  - Drawing on full US talent base
  - US national needs and world leadership

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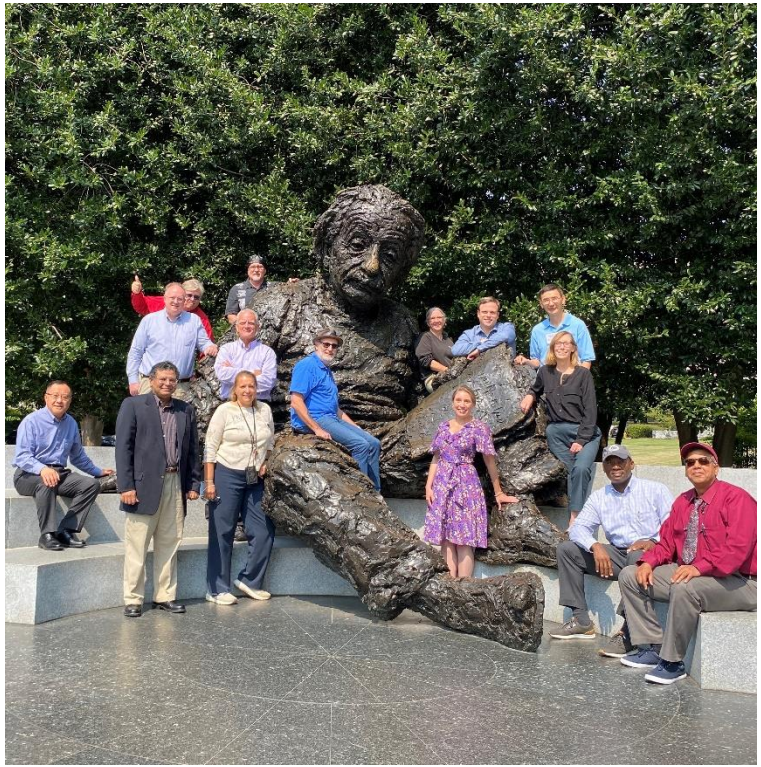
Steering Committee



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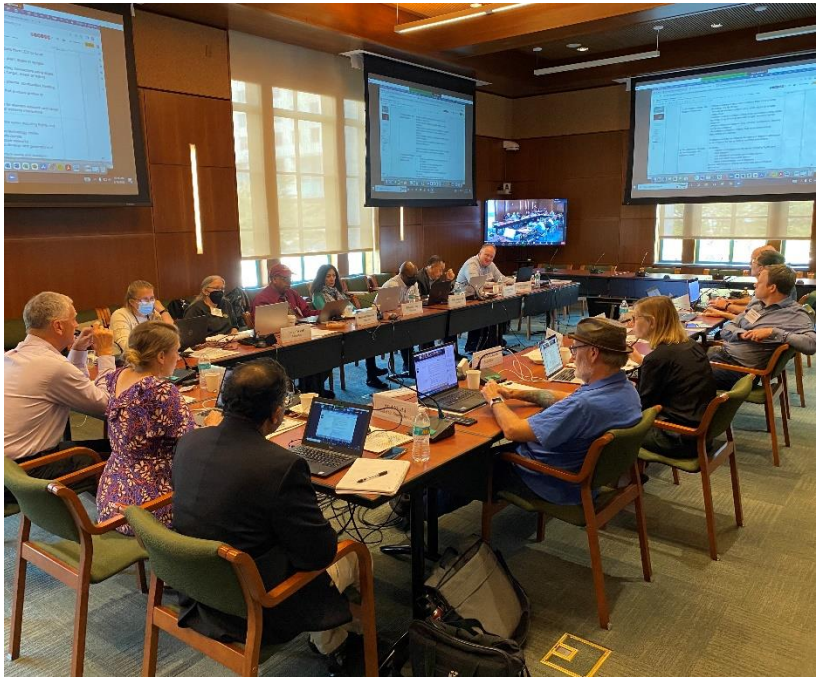
Panels



A special thank you to the Space Studies Board, staff, and especially the 50+ experts who served on three decadal survey panels.

These colleagues from across the country provided critical input on the current state of the field, future science priorities, and feasibility.

- Biological Sciences
- Physical Sciences
- Engineering and Science Interface

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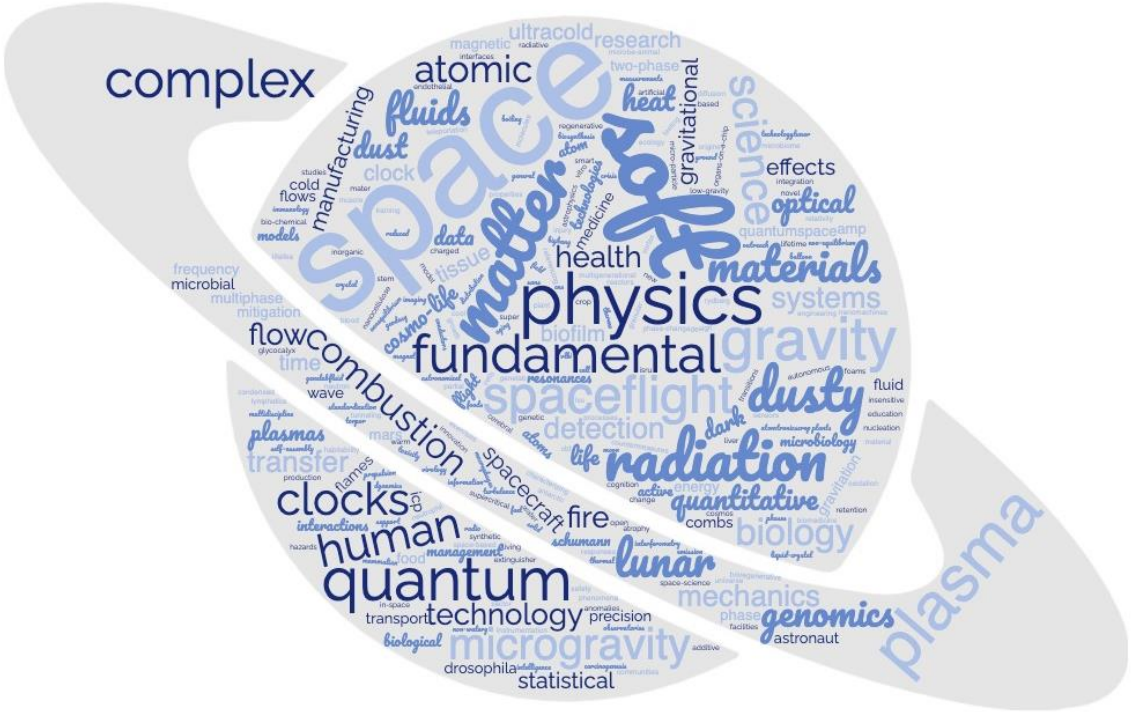
Community outreach and input



250+ Topical Input Papers

60+ Research Campaign Input Papers

Community consensus after **2+ years of public sessions**, including invited presentations from government and industry

All organized and managed by the National Academies

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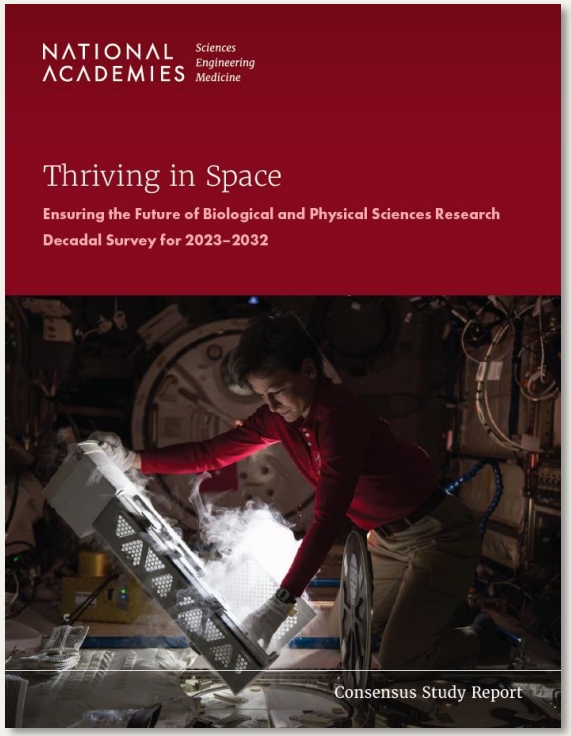
Report Snapshot



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- 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	11	2	25
Science Themes	Science Questions	Research Campaigns	Recs

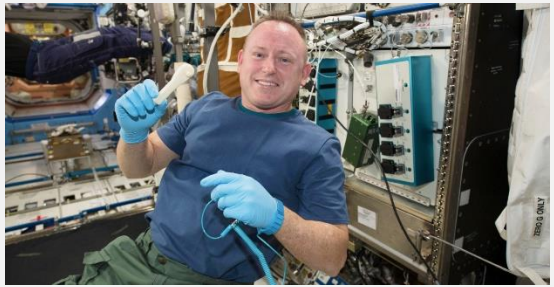
Thriving in Space

builds on last decade's momentum of trials, errors, and surprises in many space-environment laboratories

The first experiments on multigenerational growth of crops in space

The study of matter at the coldest temperatures ever achieved

DNA and RNA sequencing in space to allow rapid response to human health changes



3d printing and materials science to enable manufacturing and repair in space

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Increase national investment

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The decadal survey recommends that **funding for BPS research increase tenfold before the end of the decade** to meet the nation's space exploration science needs.

Increasing Investment in BPS Research

RECOMMENDATION: To retire many of the key scientific questions by the end of the decade, NASA should establish support for the Biological and Physical Sciences program to levels that reflect the current national need and to build the science community in size, diversity of technical expertise and lived experience, and capability to reach the science goals of the nation, toward levels that are an **order of magnitude above the current funding and well before the end of the decade**.

Maintaining U.S. Leadership in Space Exploration

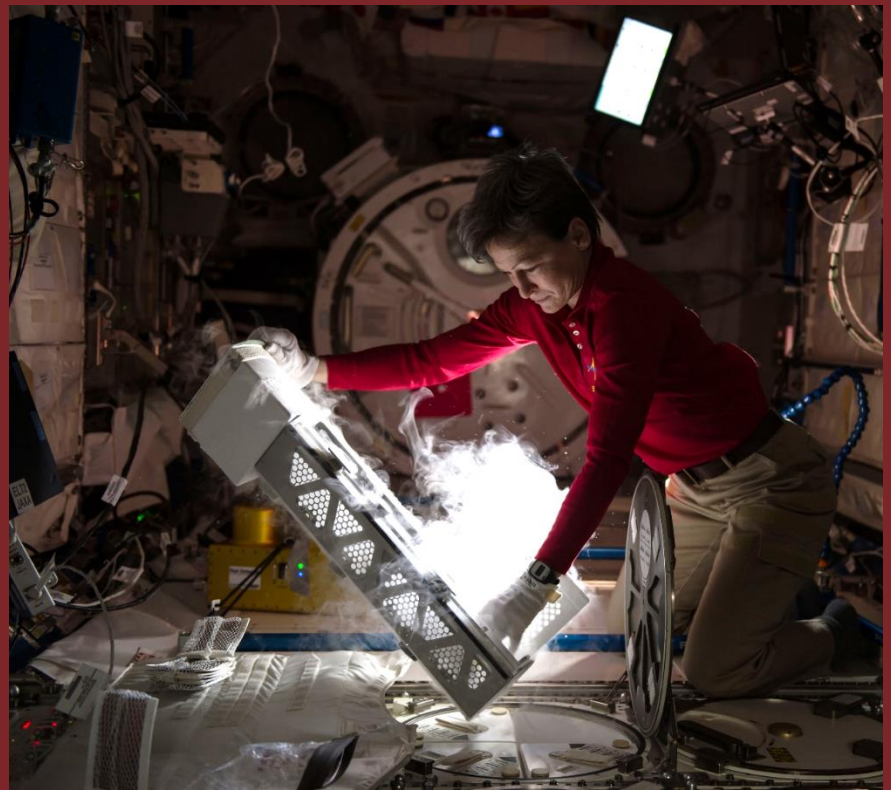
RECOMMENDATION: Because the nation benefits from global leadership in space science and technology, and given the emergence of commercial platforms that can be tasked to the nation's science, NASA should:

- **Seek significant funding increases for BPS** with new monies or through rebalancing the portfolio across SMD, and in coordination with other U.S. government agencies, as the community needs to grow significantly in size to reach the science goals of the nation;

- **Actively engage commercial spaceflight firms**, using science funding as a driver and with all due haste, to ensure that science needs are met with clear priority, guaranteeing that national science needs are enabled along with those of potential commercial customers using those platforms; and

- Ensure that the funded science community **fully engages diversity and inclusivity** in the pursuit of the nation's space exploration science priorities.

Focus on Key Scientific Questions



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In this era of rapid, expansive exploration and commercial interest in space, **the U.S. must lead the world in making space useful, safe, and open for responsible development**.

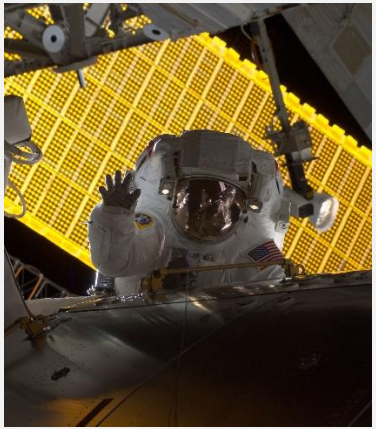
This challenge requires answering
Key Scientific Questions
through research on Earth and on the way to the Moon and to Mars.

Key Science Themes

ADAPTING TO SPACE

What fundamental processes change when away from Earth?

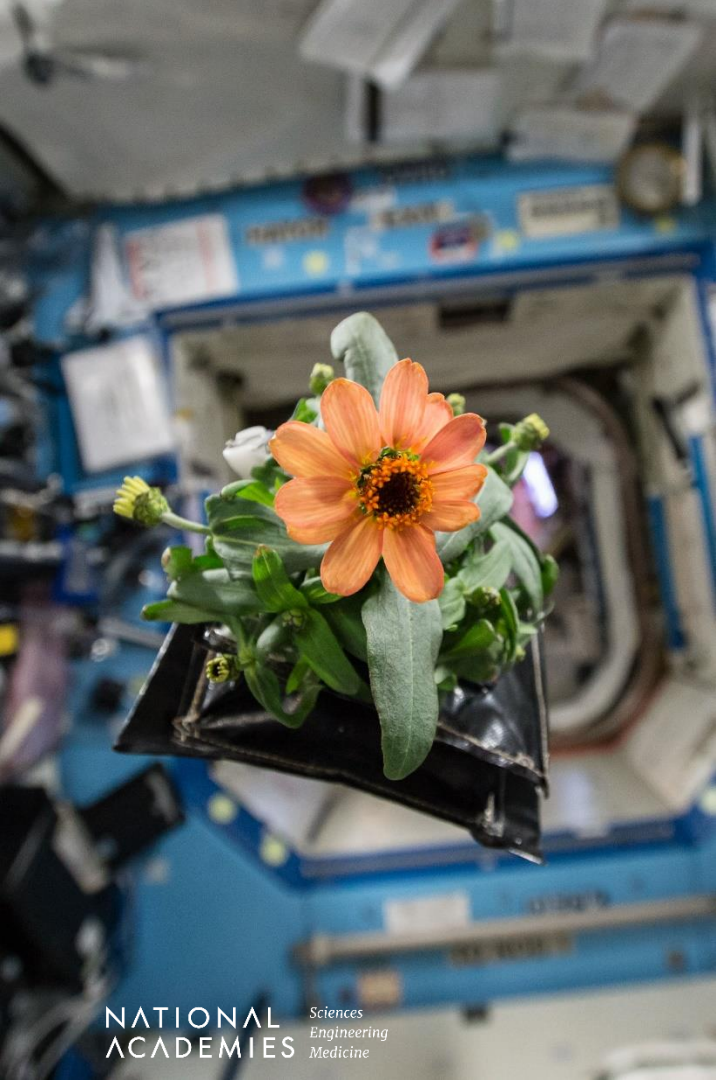
LIVING AND TRAVELING IN SPACE



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?

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Living and Traveling in Space
Key Scientific Questions

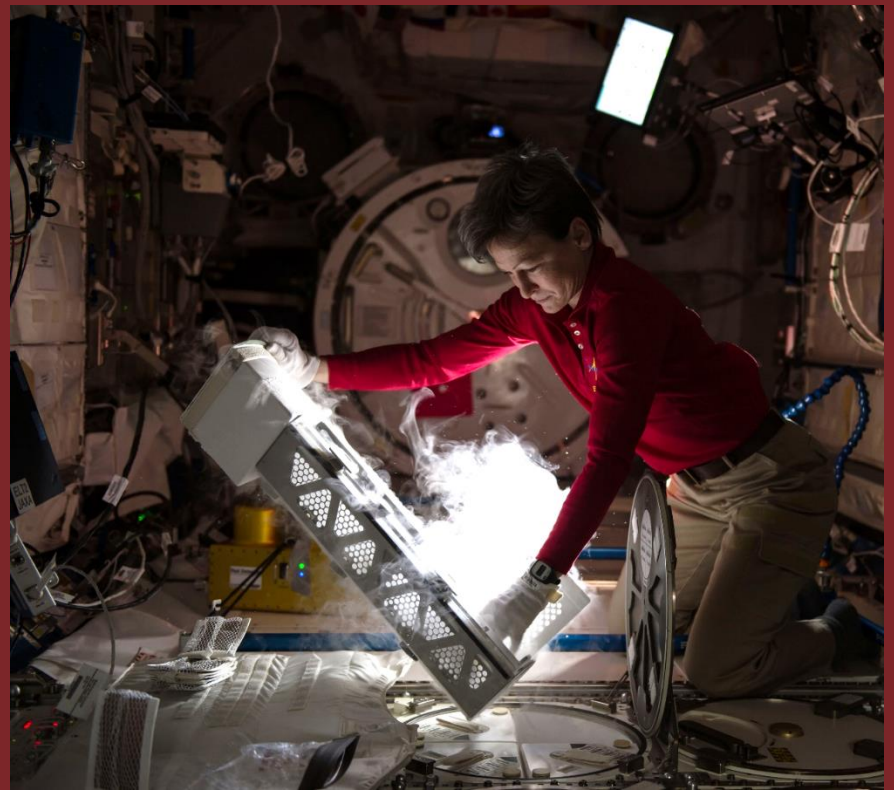
- What are the important multi-generational effects of the space environment on growth, development, and reproduction?
- What principles guide the integration of biological and abiotic systems to create sustainable and functional extraterrestrial habitats?
- What principles enable identification, extraction, 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



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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

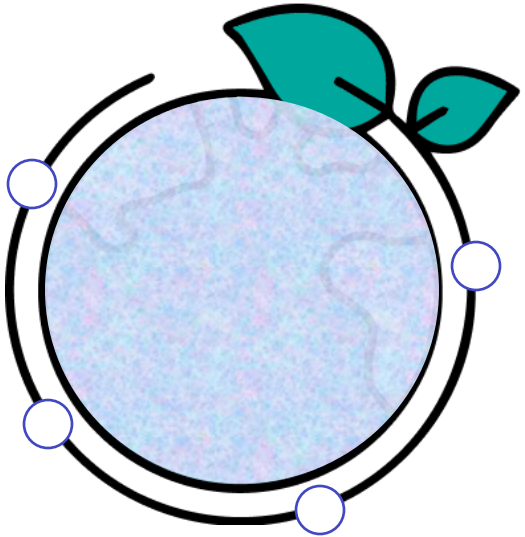
Bioregenerative **Li**fe **S**upport **S**ystems

MATRICES

Manufacturing m**AT**e**R**ials and Process**E**s for **S**ustainability in Space

Research Campaigns

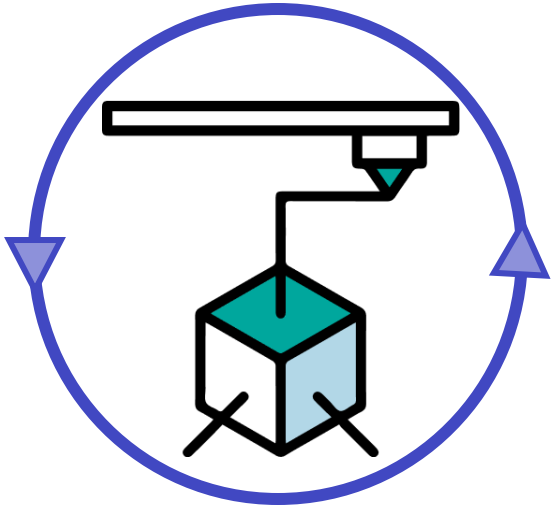
BLiSS Goals



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.
2. Harness beneficial properties of plants and microbes that will enable humans to live in space, independent of resupply from Earth.
3. Create a highly functioning, resilient ecosystem and space environment that is self-sustainable under extraterrestrial radiation and gravity conditions.
4. Enable long-duration (>3 years) exploration of deep space by providing a fully or partially closed–loop biological life-support system.

Research Campaigns

MATRICES Goals

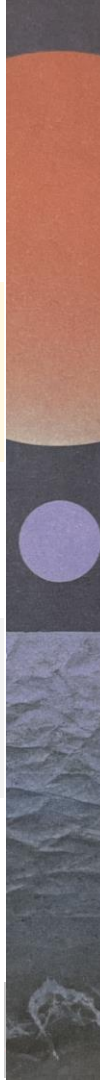


1. Learn how materials and energy interact in non-terrestrial environments, and use that knowledge to design infrastructure for responsible space exploration.
2. Enable sustainable in-space economy by learning to make and manufacture much of what is needed in space.
3. Develop non-living aspects of sustainable circular systems of materials/processes via fundamental understanding of phase characteristics & transitions in space.
4. Understand and exploit synergies of living and non-living systems for production of needed materials.

Beyond NASA-anchored Campaigns

PFaST: Probing the Fabric of Space-Time
Multiagency Opportunity

PROMO: Polar Radiation of Model Organisms
Notional Concept



Broaden the BPS Research Talent Spectrum

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

1980

public sector

2017

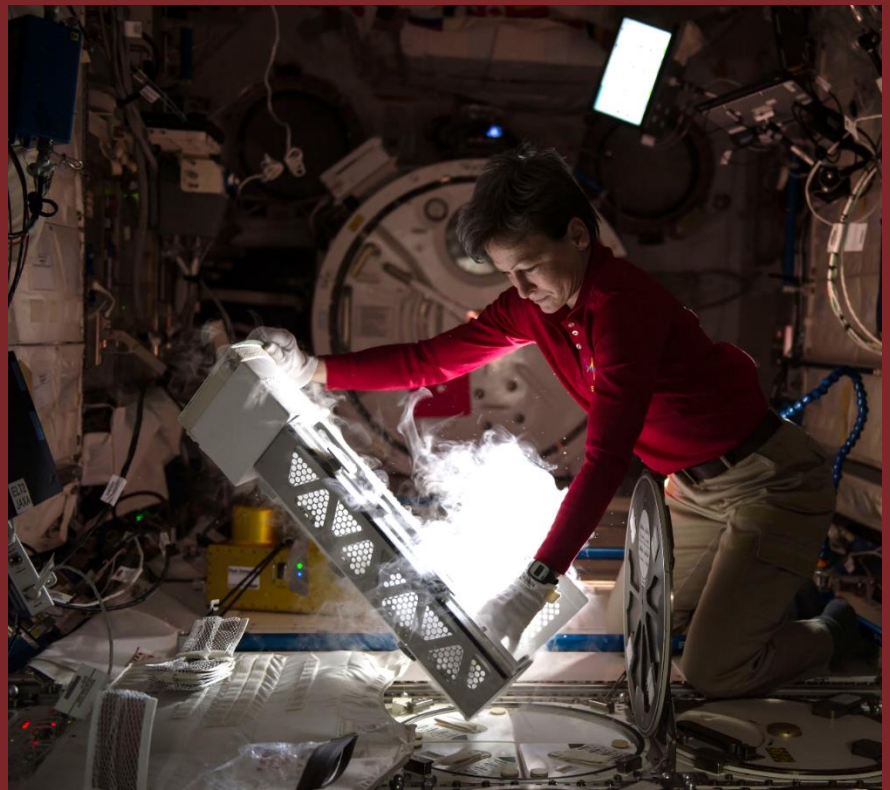
private sector

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.

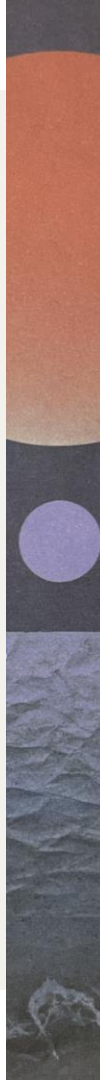
—Dr. Ellen Ochoa

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:

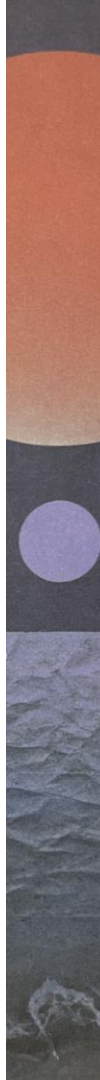
If researchers have *more* access to CLDs, projects focused on KSQs representing all three themes and research campaign elements are prioritized.

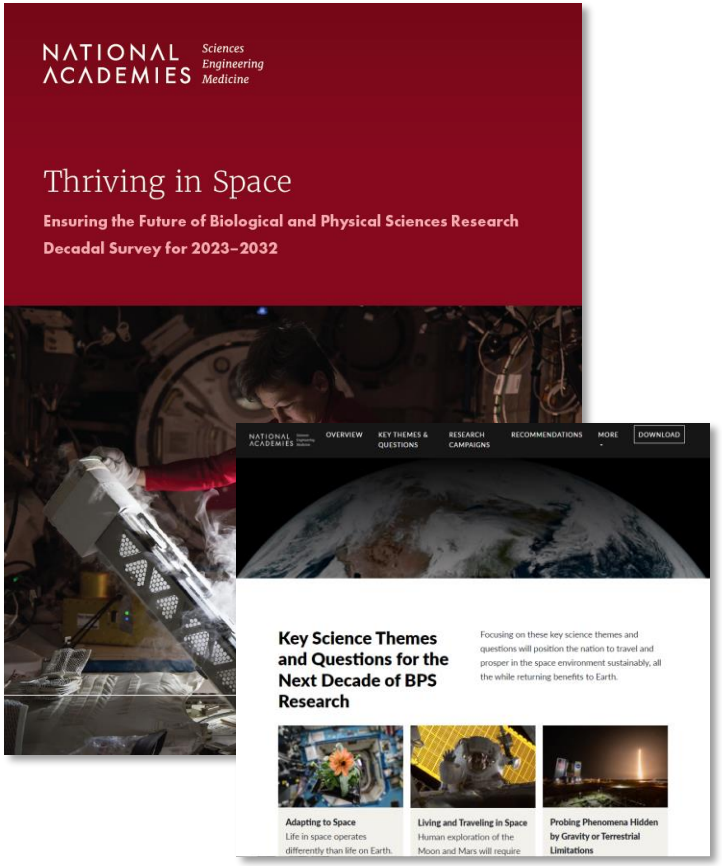
If researchers have *less* access to CLDs, projects focused on KSQs representing at least the adapting to space theme and probing hidden phenomena theme are prioritized until answered.

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

By the end of the decade, the ISS will be a relic of past partnerships, and several missions will take research questions well beyond the hostile environment of LEO.

The U.S. BPS community has an amazing decade of discovery, transformation, and translation ahead—**if we seize it**.





Learn More

Check out the digital report summary and download the full report at:

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The slides and video from this presentation will be posted within the next few days.


Questions?