National Aeronautics and Space Administration

Biological and Physical Sciences Program Overview

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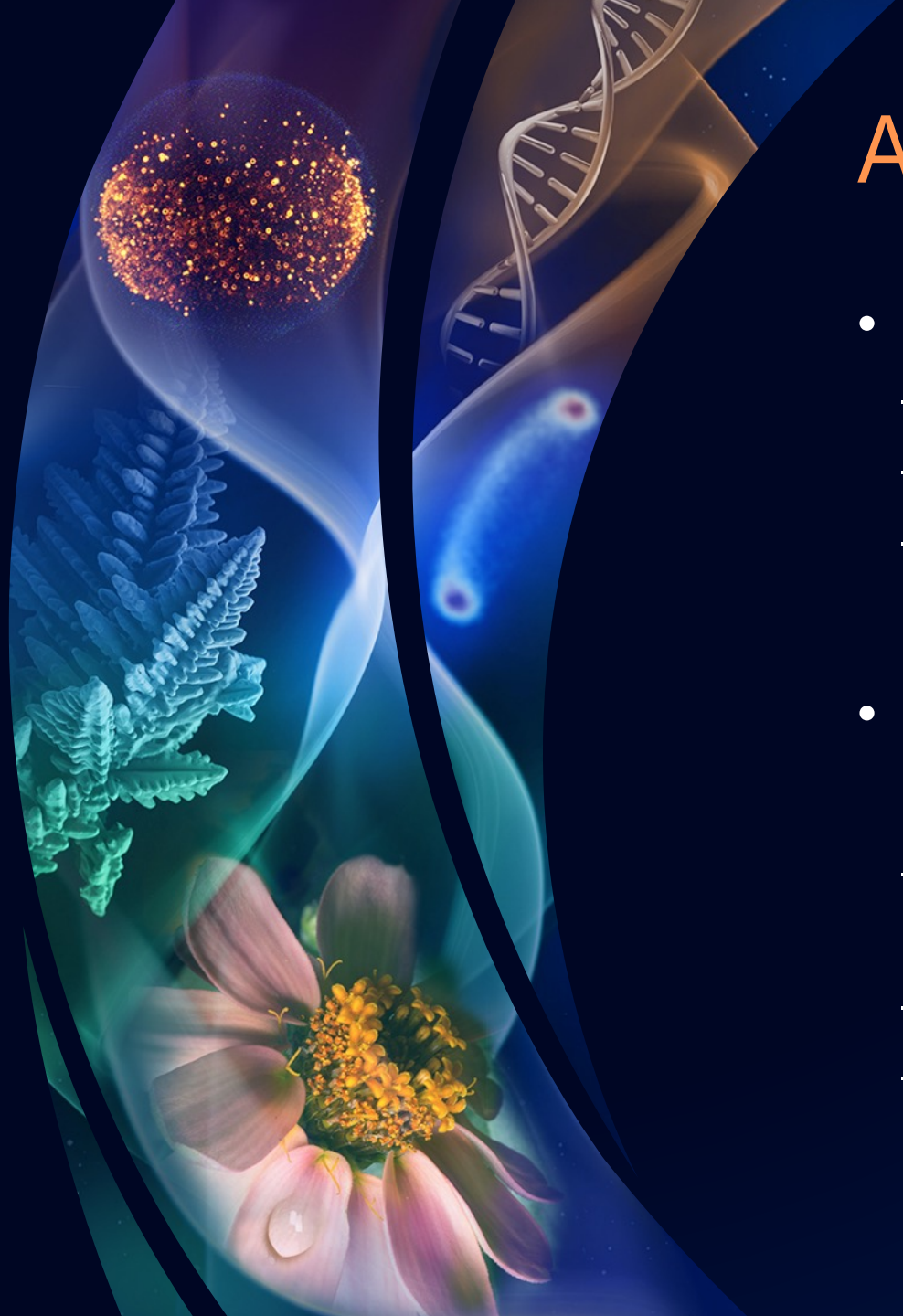
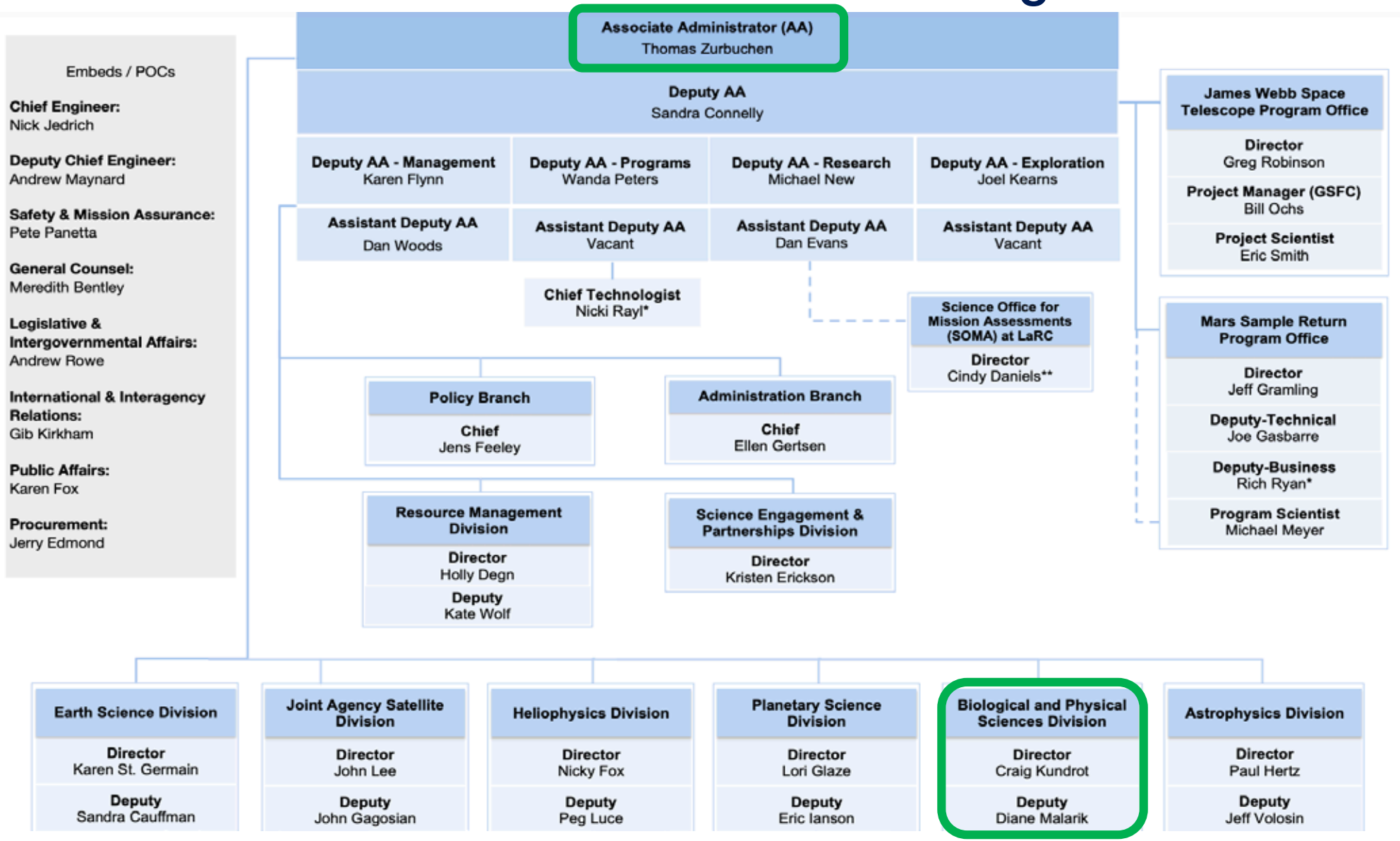


Agenda

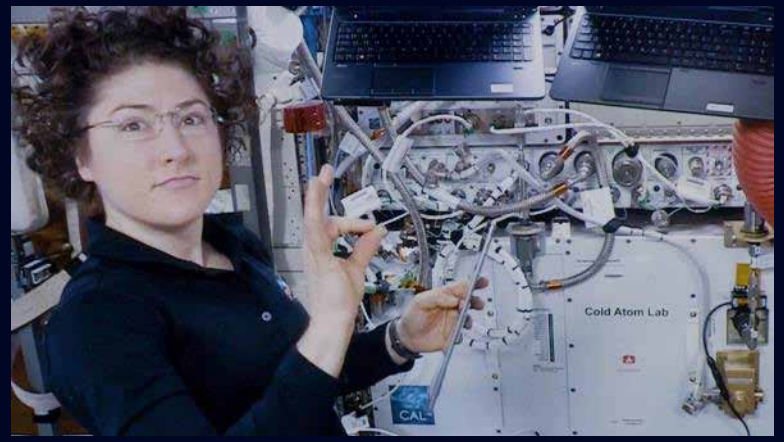
- Overview of Biological and Physical Sciences
  - Vision and mission
  - Program scope and objectives
  - Strategy going forward
- Information requested by Steering Committee
  - Roles of experimental platforms and environments
  - Relationships to other organizations
  - Diversity

Overview of Biological and Physical Sciences

Science Mission Directorate Org Chart



BPS Vision



Example of Physical Sciences research: Studying quantum gasses

Example of Space Biology research: Growing plants in space

We use spaceflight environments to study biological and physical systems.

Examining phenomena under extreme conditions can help us better understand how they function.

This can contribute to significant scientific and technological advancements that

- make fundamental advances in science,
- enable space exploration, and
- benefit life on Earth.

Experimental Variables in Spaceflight Environments

Property	Types / Values	Biological Impact Examples	Physical Sciences Impact Examples
Acceleration: (Altered sedimentation, buoyancy-driven convection, hydrostatic pressure)	Microgravity Lunar surface (1/6-g) Mars surface (3/8-g) Earth (1-g) Launch & landing (3 to 9-g)	Fluid shifts, body forces, neuro-vestibular, plant growth	Flammability, two-phase flow, solidification, additive manufacturing, soft matter structure and dynamics
Ionizing Radiation	Solar Particle Events (SPE), Galactic Cosmic Rays (GCR), lunar albedo, Van Allen belts	Damage to animals, plants, microbes	Damage to materials
Atmosphere (vehicle)	pCO_2, pH_2O, pHe; volatile organics, temperature Infrequent influx of crew and materials Unoccupied periods	Microbiome of humans, plants, vehicle Biofilm production, biocorrosion	-
Atmosphere (external)	LEO (vacuum, atomic oxygen), deep space (hard vacuum)	Dessication, radiation exposure	Damage to materials
Lunar surface composition	Regolith, dust	Dust toxicity, plant growth	Granular materials processing, in-situ surface construction, cement/concrete production Metal and/or O2 extraction from regolith Dust mitigation
Extreme thermal changes	LEO, deep space, lunar surface (-170 C to +120 C)	Challenge for life support systems	Thermal expansion/contraction
Lighting	Unattenuated solar spectrum, attenuated solar spectrum, artificial lighting	Plant growth Circadian rhythm entrainment	-
Distances	Up to Earth-Moon distance (340, 000 km)	Social isolation	Long-range fundamental physics (e.g., quantum entanglement)

BIOLOGICAL & PHYSICAL SCIENCES FLEET

- FORMULATION
- IMPLEMENTATION
- OPERATIONAL
- AVAILABLE

PARTNER-LED*

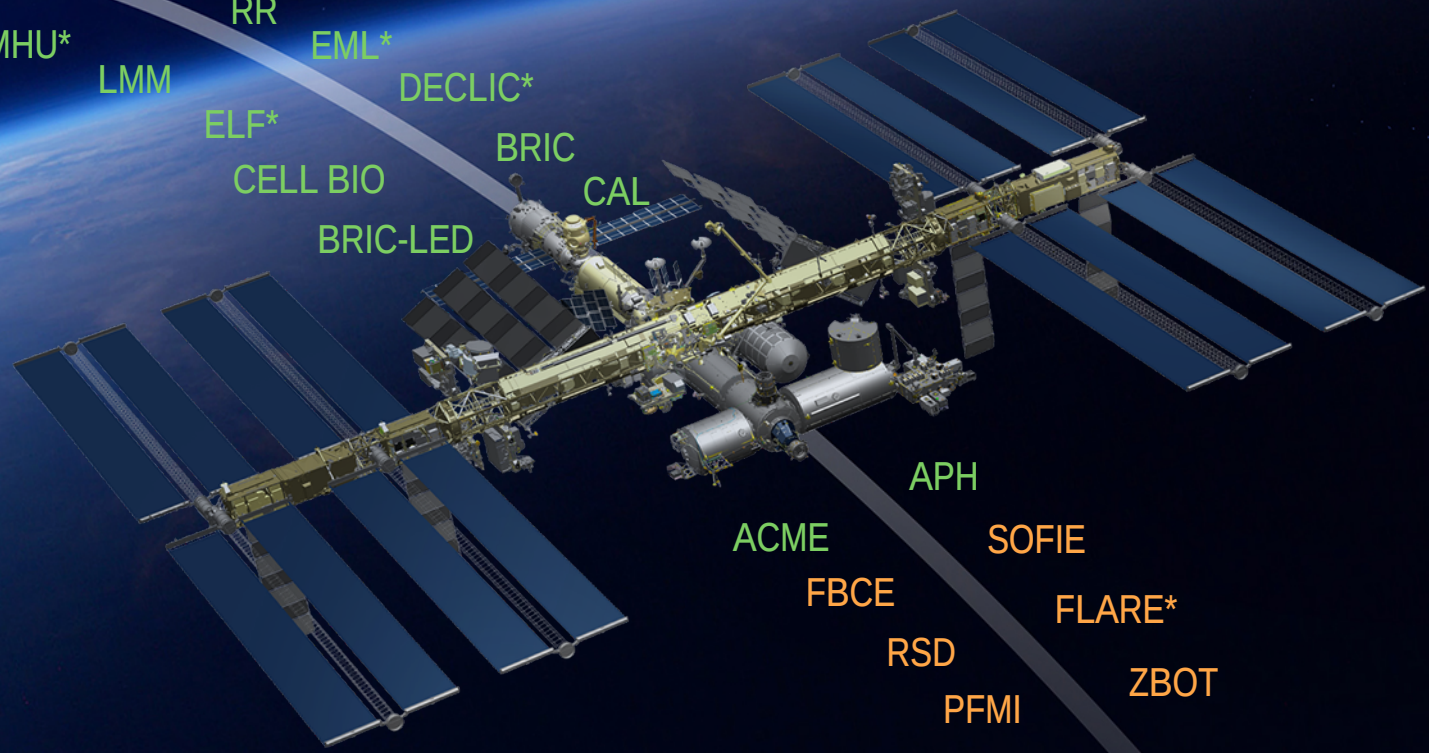
LEIA

BIOEXPT-1

BION*

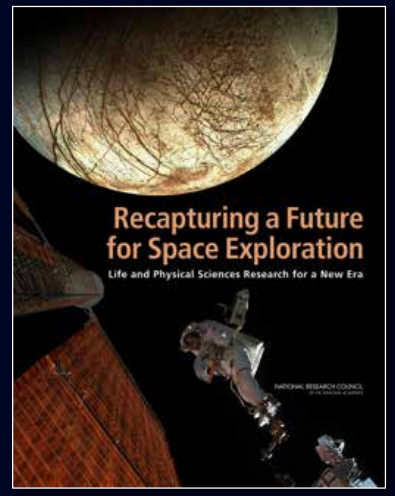
RAD-SEED

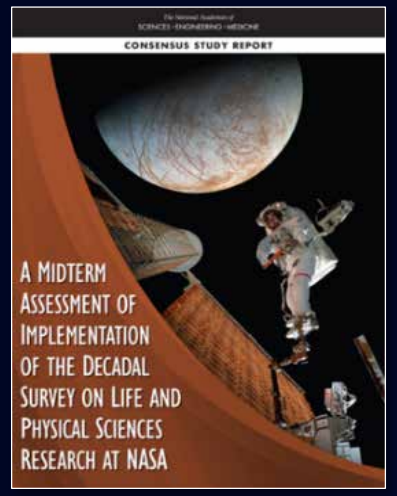
PBRE
MT
MOSL
SMD*
MICRO
RR
PK-4*
MSRR
MHU*
EML*
LMM
SUBSA
DECLIC*
VEGGIE
ELF*
BRIC
WETLAB-2
CELL BIO
CAL
FFL
BRIC-LED



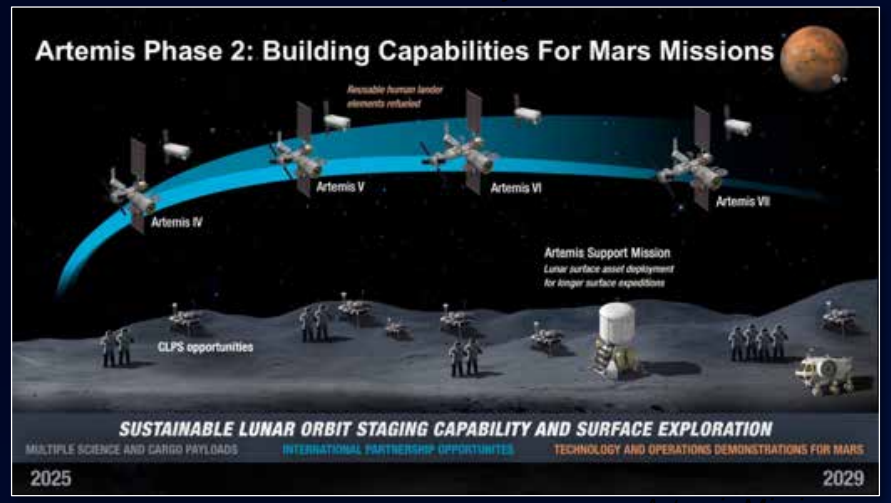
APH
ACME
SOFIE
FBCE
FLARE*
RSD
ZBOT
PFMI
BECCAL*

BPS Mission & Goals





Decadal Survey



Artemis Missions

Pioneer Scientific Discovery

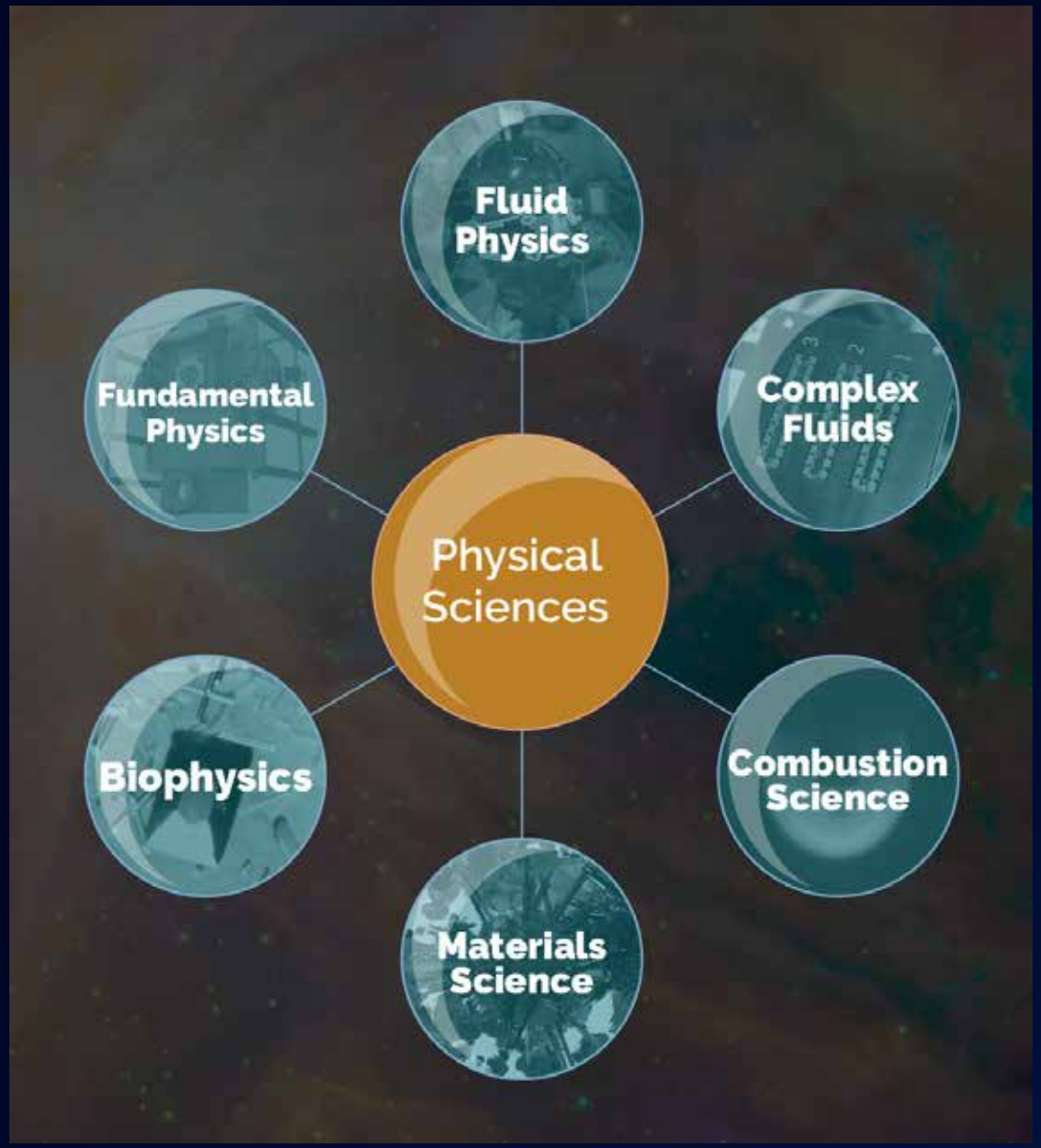
- Proactively seek out new ways to expand fundamental scientific knowledge
- Provide expertise and support to others seeking to utilize space

Enable Exploration

- Anticipate and investigate critical areas for scientific knowledge and technology development
- Deliver results to other NASA organizations

Objectives

- Discover how biological systems **respond** to the space environment
- Identify the underlying **mechanisms** and develop models for biological systems in space
- Develop **technologies** to enable spaceflight research
- Promote **open science** through the GeneLab Data System and Life Science Data Archive
- Provide mechanistic understanding to support human **health in space**
- Transfer the knowledge and technology of space-based research to **benefit life on Earth**



Objectives

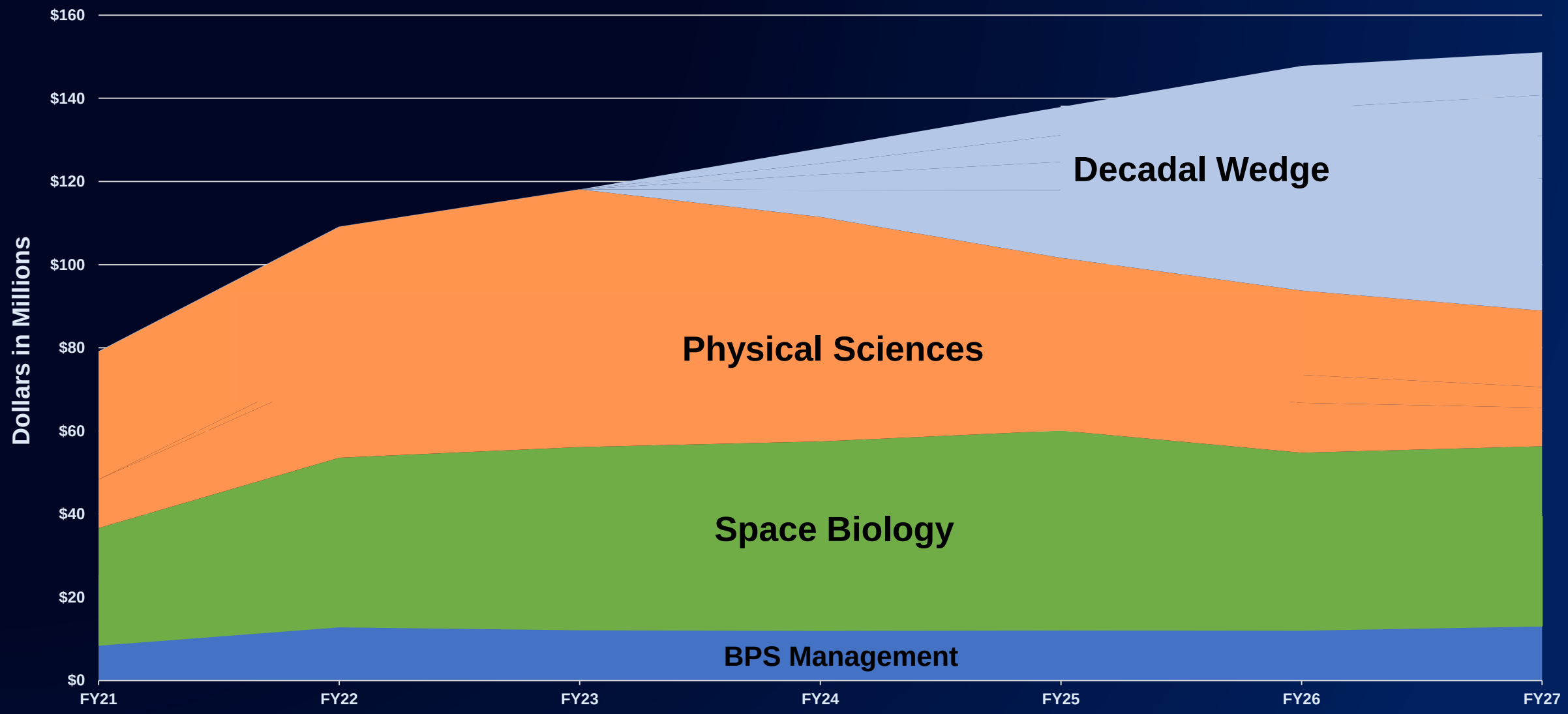
- Investigate **fundamental laws** of physics and **physical processes** using the space environment
- Identify the underlying **processes** and develop models for physical systems in space
- Develop **technologies** to enable spaceflight research
- Promote **open science** through Physical Science Informatics
- Transfer the knowledge and technology of space-based research to **benefit life on Earth**

BPS Strategy

- Focus on transformative research
  - Recommended by the 2011 Decadal Survey
  - Likely to be recommended by the 2023 Decadal Survey
- Include large research activities
  - Keystone Capabilities/Missions
  - Research Campaigns
- Use NASA and non-NASA capabilities, especially commercial
- Balance flight-based research program with strong ground-based research program

- Near-term: Focus on transformative areas
  - Bolster three areas likely to be recommended by the 2023 Decadal Survey
    1. Quantum Science (Cold matter)
    2. Thriving in Deep Space (TIDES) (Animal/Human, Plant)
    3. Soft Matter (Far-from-equilibrium processes; unique assemblies)
  - Pause other areas until 2023 Decadal Survey received
    - Complete funding existing grants; Defer or descope future solicitations; Pause early-stage flight projects
- Long-term: Implement 2023 Decadal Survey priorities

BPS Budget Plan Based on President's Budget Request FY22



BPS over the Next 10 Years

- Pioneer transformative science at the frontiers of biology and physical sciences in space
  - Frontiers: Conceptual and Physical
    - Areas where BPS can uniquely
      - Advance scientific knowledge
      - Meet the needs of exploration missions
      - Provide terrestrial benefits
    - Locations include
      - Commercial and governmental ground-based; commercial sub-orbital
      - Commercial Low Earth Orbit
      - Lunar orbit (Gateway)
      - Lunar surface (Commercial Lunar Payload Services, Human Landing System)
      - Mars transit vehicle
  - Pioneer
    - BPS first or among first at a frontier
    - Expect other organizations (government, commercial, academic, international) may follow
    - BPS collaborates in all phases
      - First tests of feasibility and value assessment
      - Refining methods and re-assessing value
      - Sustained research and returning value

Summary of Overview

- BPS research has made advances in a broad range of disciplines over several decades

- BPS now seeks to tackle the most transformative research questions
  - Driven by
    - Advancing science
    - Enabling exploration
    - Benefiting life on Earth
  - Using capabilities in and beyond current and planned NASA programs
    - Commercial and governmental platforms
    - Ground-based, low Earth orbit, Gateway, lunar surface

- The 2023 Decadal Survey will
  - Identify, recommend, and rank the highest priority, most transformative research activities for BPS to tackle in the next decade
  - Recommend an ambitious program to provide transformative outcomes
  - Provide the building blocks for the next decade of BPS research

Information Requested by Steering Committee

BPS Will Use Multiple Spaceflight Platforms

- The Decadal Survey priorities will dictate the choice of platform and environment
- Experiments or applications may be conducted in several spaceflight environments
  - Ground-based, sub-orbital, low Earth orbit (LEO), deep space, lunar orbit, lunar surface, Martian orbit, Martian surface
  - Commercial and governmental

- A series of environments or platforms may be employed as stepping stones
  - Stepping stones have some, but not all, of the attributes of the spaceflight environment of ultimate interest
  - E.g., the progression 1/6-g in drop tower -> parabolic flight -> sub-orbital flight -> ISS -> lunar surface vary in
    - Duration
    - Coriolis effect
    - Acceleration before and after the nominal experiment

BPS Platforms for Research

*Future Platforms

CubeSat

International Space Station

Free Flyers (BION)

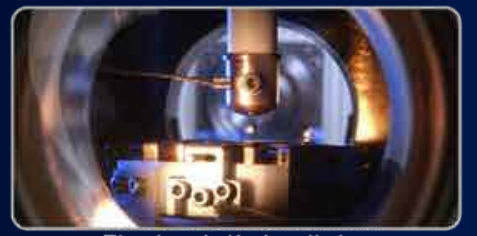
*Lunar Gateway

*Commercial Lunar Lander Services

Drop Tower

Parabolic Flight

Sounding Rocket
Sub-orbital Vehicle


Electrostatic Levitator

*Human Landing System

Rodent Unloading

Centrifuge

Balloon Flight

NASA Space Radiation Lab

NASA Isolation Chamber

NSF Polar Station

Russian Isolation Chamber

Gravity Vector Averaging

Physical Sciences
Informatics

GeneLab

Role of Ground-based (Sub-orbital) Platforms

- Ground-based platforms are used for
  - Rapid, low-cost tests of experiment concepts and new technology to reduce risk prior to flight
  - The experiment environment for an investigation

- To the extent required to achieve Decadal Survey priorities,
  - BPS will continue use of
    - Microgravity simulators (e.g., clinostats)
    - Drop towers
    - Parabolic flight
    - Balloons
    - Radiation facilities (e.g., NASA Space Radiation Laboratory)
  - BPS will develop use of
    - Multi-factor ground based simulators
      - E.g., low dose rate radiation + altered atmosphere + simulated microgravity
    - Sub-orbital flight
      - Autonomous payloads
      - Crew-tended payloads

Role of Low Earth Orbit (LEO) Platforms

- Platforms in LEO have provided the spaceflight environment for the majority of BPS investigations
- BPS will use these platforms to the extent required to achieve Decadal Survey priorities

- ISS
  - Premier destination for long-duration, crew-tended microgravity research
  - Stepping stone for research beyond LEO
  - BPS assumes ISS will operate through 2030
  - BPS interested in reviving concept of Payload Specialist
    - Private Astronaut Missions (PAMs) or other mechanisms
- Commercial LEO Destinations (CLDs)
  - Available in the mid- to late 2020s
  - Individually, less capability than ISS
  - In aggregate, capability closer to ISS
- Un-crewed free-flyers
  - BPS interested in CubeSats, SmallSats, modules, and spacecraft that return to Earth

Role of Platforms Beyond LEO

- Platforms Beyond LEO are destinations for human exploration and/or a stepping stone to Mars missions
- BPS will use these platforms to the extent required to achieve Decadal Survey priorities

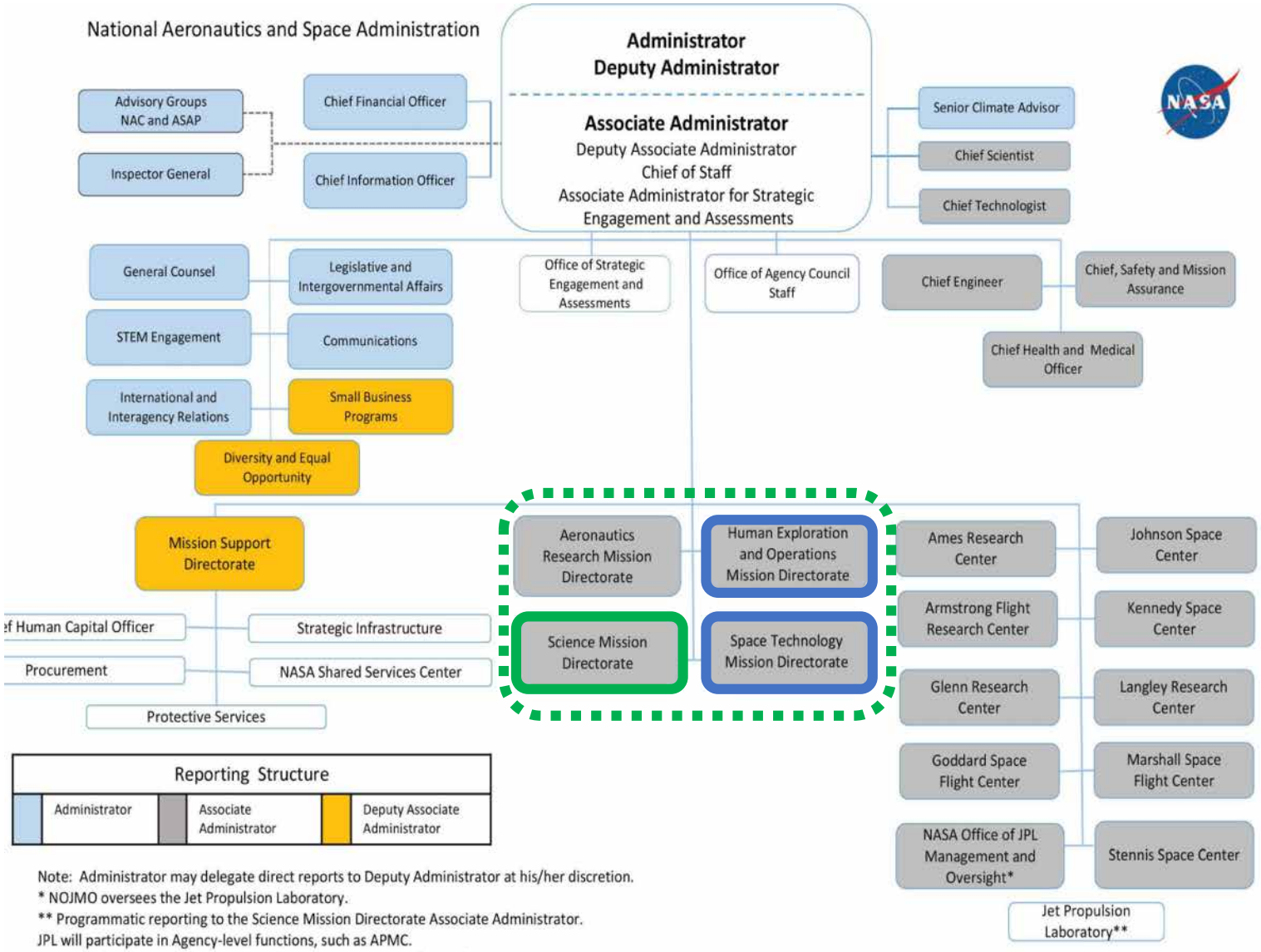
- Artemis
  - BPS pioneering use of and planning long-term use of
    - Gateway
    - Orion (e.g., Artemis I and II)
    - Commercial Lunar Payload Services (CLPS)
  - BPS plans use of integrated Artemis mission capabilities (including Human Landing System (HLS)) as they develop

- Un-crewed free-flyers
  - BPS interested in CubeSats, SmallSats, modules, and spacecraft that return to Earth

Connections to SMD Organizations

- Astrophysics Division
  - For the Astrophysics Decadal Survey, Astro2020
    - Fundamental physics, other than through naturally occurring observables, is outside the scope of astrophysics
    - "Microgravity research" is outside the scope of Astro2020 Decadal
      - Microgravity research: experimental research made possible by the near-absence of gravity
    - Use of gravitational wave detectors to study the fundamental nature of matter is not in scope
      - Gravitational wave observations for "the full breadth of astronomy and astrophysics" are in scope
- Planetary Sciences Division
  - Astrobiology is about the study of life in the universe—its origin, evolution, future, and distribution
    - Space Biology studies adaptation of Earth-based life (primarily microbial life) to space environments over much shorter timescales than most Astrobiology
    - Space Biology may bring a perspective to the remote detection of biosignatures that aids studies for the search for life (distribution)
  - Planetary Protection
    - Space Biology studies two areas of interest for forward contamination
      - Accommodation of individual Earth-based organisms to spaceflight environments
      - Adaptation of the Earth-based populations to spaceflight environments (primarily microbial)
  - Geomicrobiology
    - Facilitate plant growth with *in situ* regolith

NASA Organization



Note: Administrator may delegate direct reports to Deputy Administrator at his/her discretion.
* NOJMO oversees the Jet Propulsion Laboratory.
** Programmatic reporting to the Science Mission Directorate Associate Administrator.
JPL will participate in Agency-level functions, such as APMC.
JPL is a Federally Funded Research and Development Center (FFRDC).

Connections with Space Technology Mission Directorate (STMD)

- Zero Boil Off Tank Experiment (ZBOT) Series: ZBOT –1, Pressurization & Pressure Control (complete), ZBOT-NC: Effect of NonCondensable Gases, ZBOT-DP: Droplet Phase Change, & ZBOT-FT: Tank Filling & Transfer
  - ZBOT is integrated in the STMD roadmap for Cryogenic Fuel Management for crewed missions
  - ZBOT Model development & validation of ZBOT microgravity data & NASA 1g large tank cryogenic experiments
  - Funding for Highly Parallel Computational Infrastructure and model development
  - ZBOT aligned with NASA Technology Taxonomy 14.1

- Lunar *in situ* resource utilization (ISRU)
  - Moon to Mars Planetary Autonomous Construction Technologies (MMPACT) project for Lunar Surface Construction, high priority in STMD
    - STMD working on Advancing 3D Printing Construction Systems using regolith 'processing' materials methodologies (e.g. cementitious, micro-wave sintering,..etc) and will need make a down select on materials and processing in the near future ahead of a flight opportunity (tech demo). The tech demo is in FY26.
    - BPS may participate by investigating the effects of reduced gravity on porosity, microstructure and materials properties.

BPS provides fundamental, mechanistic understanding and solutions based thereon

Connections to Human Exploration and Operations Mission Directorate (HEOMD) Organizations

- The Human Research Program (HRP)
  - HRP identifies, characterizes, and mitigates risks to crew health and performance
  - HRP research generally does not extend down to molecular mechanisms
    - Space Biology animal research generally seeks molecular level understanding
      - Identifies potential biomarkers for monitoring crew health
      - Identifies candidate approaches for countermeasure development
  - Space Biology plant research seeks to develop crop plants that can provide crew with micronutrients and increased behavioral health in exploration missions
  - Space Biology microbiological research studies the microbiome of animals/crew, plants, the built environment and the interactions between the three
    - HRP focuses on the impact of the microbiome on crew health

BPS provides fundamental, mechanistic understanding and solutions based thereon

Connections to HEOMD Organizations

- Advanced Exploration Systems (AES)
  - The Environmental Control and Life Support Systems – Crew Health and Performance Systems Capability Leadership Team (ECLSS-CHP SCLT or 'SCLT) is developing the systems needed for future exploration missions
  - BPS contributes to the 'SCLT in areas of
    - Space crop production
    - Combustion/fire safety
    - Two-phase flows (for water recovery and thermal management systems)
  - BPS research is incorporated into 'SCLT roadmaps
  - Handoff between BPS and 'SCLT is generally between TRL 4 and TRL 6
  - BPS also leverages platforms/technology developed by Advanced Exploration Systems (AES)
    - The BioSensor hardware developed for BioSentinel CubeSat developed for the Artemis I mission will be used by Space Biology for a future lunar surface mission

BPS provides fundamental, mechanistic understanding and solutions based thereon

Connections to Human Exploration

BPS Program	BPS Discipline	Mission Directorate	Organization	Applications
Space Biology	Animal	HEOMD	HRP	Biomarkers, countermeasures, risk assessment
	Plant	HEOMD	HRP	Micronutrients, behavioral health; macronutrients, life support
	Plant	HEOMD	SCLT	Crop growth systems
	Microbial	HEOMD	HRP	Risk management
	Microbial	HEOMD	AES	Radiation biodosimetry
	Cell Biology	HEOMD	HRP	Biomarkers, countermeasures, risk assessment
Physical Sciences	Combustion	HEOMD	AES	Fire safety
	Fluid Physics	HEOMD	AES	Water recovery systems, cryogenic fluid management
	Fluid Physics	HEOMD	ISS	ISS Water recovery system
	Fluid Physics	STMD	Tech Demo	Cryogenic fluid management, thermal management
	Materials Science	STMD	Game Changing	In-space manufacturing
	Materials Science	STMD	Game Changing	Lunar ISRU - 3D Printing Construction Systems

Relation to Other Government Agencies (OGAs)

- OGAs have different research and technology development priorities than BPS
- Different organizational priorities and outcomes may be addressed by addressing the same underlying problems
- Many types of problems are of common interest to OGAs and BPS
  - Research questions
  - Technology development
  - Infrastructure capability
- Collaboration takes many forms
  - Situational awareness
  - Exchanges: data, biospecimens, technology, personnel
  - Joint activities: seminars, workshops, working groups ; research solicitations; co-funded investigations; technology development
  - Sharing: facility access, peer reviewers, grant supplements

BPS collaborates with OGAs on shared research questions and technology & infrastructure needs

ISS National Lab (ISSNL) Background

- 2005: NASA Authorization Act designated "the U.S. segment of the ISS as a national laboratory" and directed the Administrator "to seek to increase the utilization of the ISS by other federal entities and the private sector"

- 2010: NASA Authorization Act directed NASA to enter into a cooperative agreement with a not-for-profit entity to manage non-NASA access to the ISSNL
  - Provided ISSNL sponsored experiments access to a minimum 50% of U.S. research capacity and crew time

- 2011: 10-year cooperative agreement between NASA and the Center for the Advancement of Science in Space (CASIS)

- 2017: Cooperative agreement extended to September 2024

- 2020: The International Space Station (ISS) Cooperative Agreement Independent Review Team provides report and NASA proposes changes at NASA and CASIS based on the report
  - https://www.nasa.gov/sites/default/files/atoms/files/iss_cooperative_agreement_irt_final_report.pdf
  - NASA and CASIS begins changes in response to the report and changes in commercial space

- 2021: NASA and CASIS have completed majority of the changes outlined in response to the report

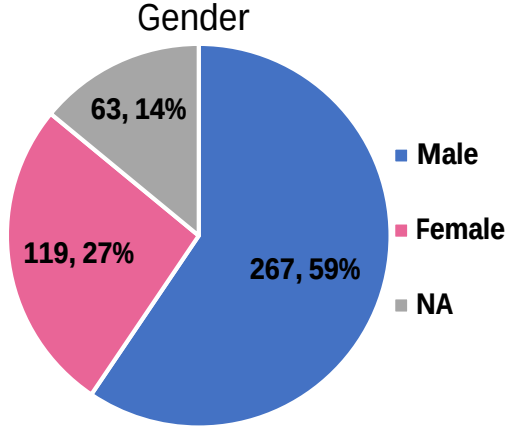
Role of ISS National Lab (ISSNL)

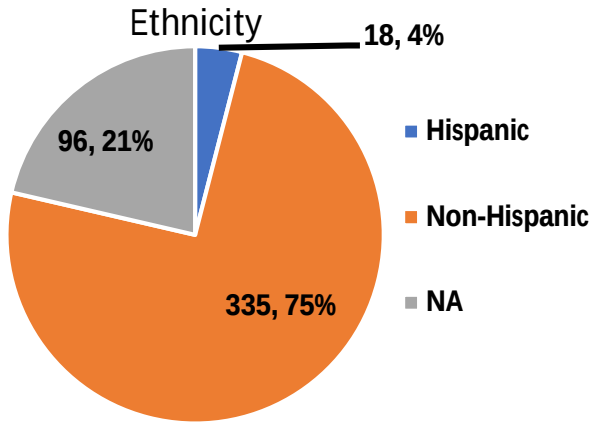
- ISSNL provides mechanisms for other government agencies, companies, non-profits and academics to use the ISS for science, research, and educational activities independent of other NASA programs.
- Many activities and capabilities on ISS meet the interests of both ISSNL users and BPS research programs.
- ISSNL and BPS collaborate when research interests overlap or require the use of the same capabilities.
  - Interests of ISSNL users
  - Interests of CASIS on behalf of potential ISSNL users
- ISSNL and BPS collaborate in several ways:
  - Co-sponsor workshops, seminars, etc.
  - Develop, with the involvement of other NASA programs, coordinated roadmaps for ISS utilization
  - Co-sponsor flight investigations
  - Share data, biospecimens, lessons learned
  - Project science support for ISSNL investigations using BPS hardware

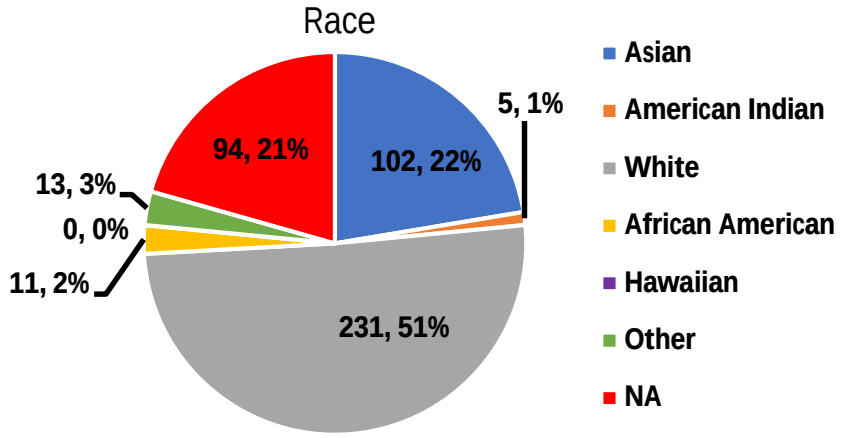
ISSNL and BPS collaborate when research interests overlap or use the same capabilities

Demographic Diversity of BPS Principal Investigators

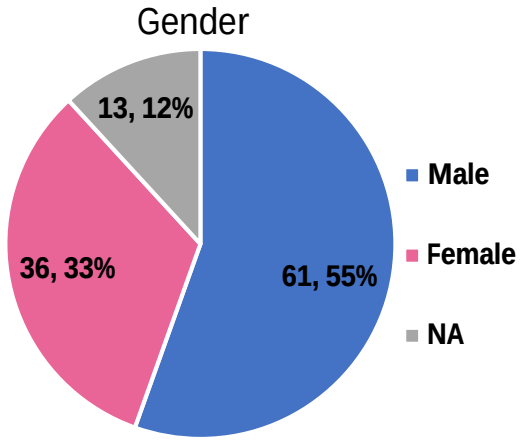
Total Proposals Submitted

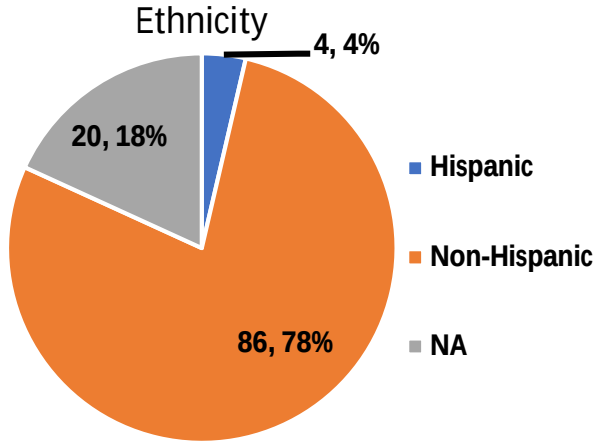


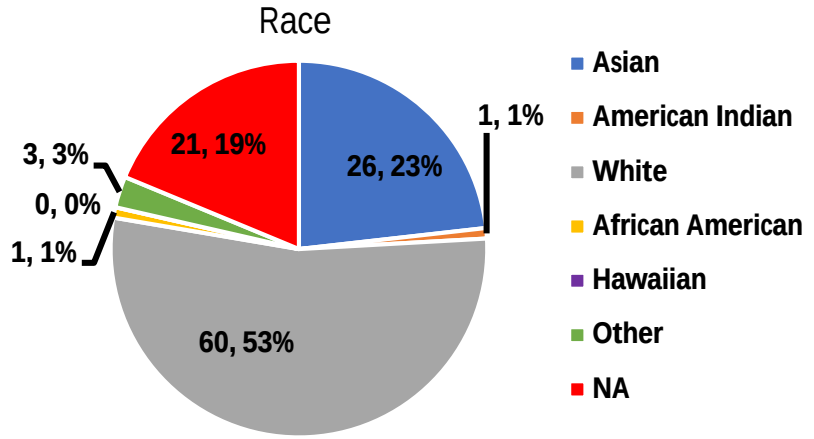




Proposals Selected







BPS participates in SMD's initiatives to address Diversity, Equity, Inclusion and Access (DEIA)

**Voluntary diversity data collection began in 2016*

Diversity in Expertise

Taxonomy: NSF fine fields of study (ncses.nsf.gov/pubs/nsf21308/data-tables)

Life sciences

- Agricultural sciences and natural resources
- Agricultural sciences
- Agricultural and horticultural plant breeding
- Agronomy and crop science
- Horticulture science
- Plant pathology and phytopathology, agricultural
- Plant sciences, other
- Soil chemistry, microbiology

Diversity in Expertise

Taxonomy: NSF fine fields of study (ncses.nsf.gov/pubs/nsf21308/data-tables)

Biological and biomedical sciences

- Bacteriology
- Biochemistry (biological sciences)
- Bioinformatics
- Biomedical sciences
- Biometrics and biostatistics
- Biophysics (biological sciences)
- Biotechnology
- Botany and plant biology
- Cancer biology
- Cell, cellular biology, and histology
- Computational biology
- Developmental biology and embryology
- Ecology
- Endocrinology
- Entomology
- Evolutionary biology
- Genetics, genomics, human and animal
- Immunology
- Microbiology
- Molecular biology
- Neurosciences, neurobiology
- Nutrition sciences
- Pathology, human and animal
- Physiology, human and animal
- Plant genetics
- Plant pathology and phytopathology (biological sciences)
- Plant physiology
- Structural biology
- Virology
- Biological and biomedical sciences, general
- Biological and biomedical sciences, other

Diversity in Expertise

Taxonomy: NSF fine fields of study (ncses.nsf.gov/pubs/nsf21308/data-tables)

Health sciences

- Health and behavior
- Medical physics, radiological science
- Physical sciences and earth sciences
- Chemistry
- Physical chemistry
- Polymer chemistry
- Theoretical chemistry
- Chemistry, other

Physics and astronomy

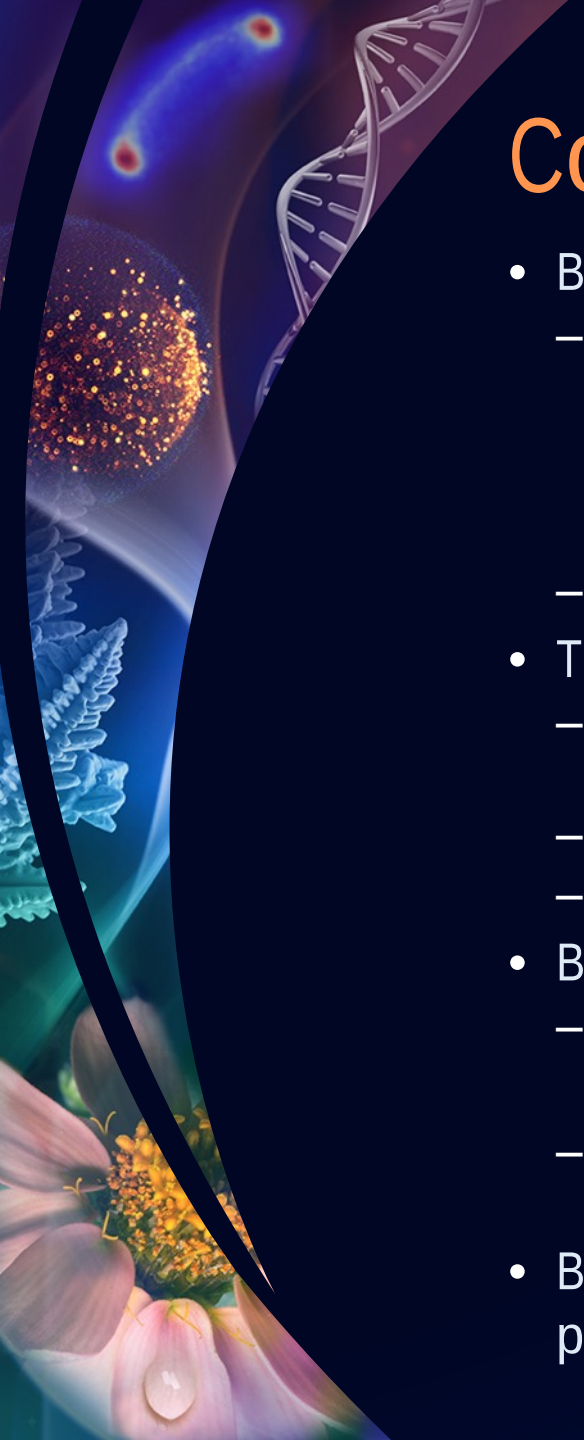
- Physics
- Atomic, molecular, chemical physics
- Biophysics (physics)
- Condensed matter, low-temperature physics
- Plasma, high-temperature physics
- Polymer physics

Diversity in Expertise

Taxonomy: NSF fine fields of study (ncses.nsf.gov/pubs/nsf21308/data-tables)

Engineering

- Bioengineering and biomedical engineering
- Chemical engineering
- Civil engineering
- Industrial and manufacturing engineering
- Materials science engineering
- Mechanical engineering
- Other engineering
  - Metallurgical engineering



Conclusion

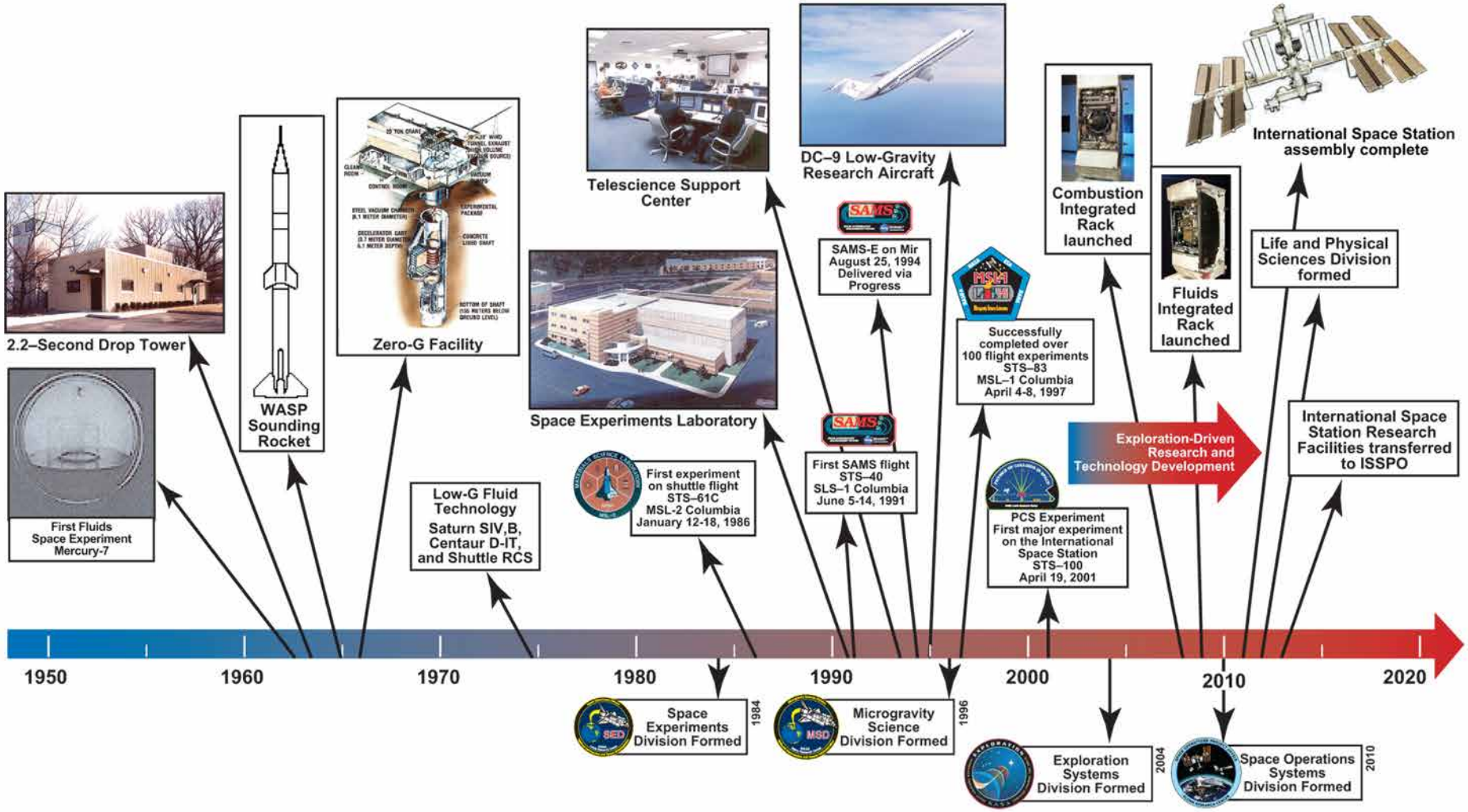
- BPS seeks to tackle the most transformative research questions
  - Driven by
    - Advancing science
    - Enabling exploration
    - Benefiting life on Earth
  - Using capabilities in and beyond current and planned NASA programs
- The 2023 Decadal Survey will
  - Identify the highest priority, most transformative research activities for BPS to tackle in the next decade
  - Recommend an ambitious program to provide the transformative results
  - Provide the building blocks for the next decade of BPS research
- BPS will use, to the extent recommended by the 2023 Decadal Survey,
  - A broad range of spaceflight platforms
    - Commercial and governmental; Sub-orbital, orbital, lunar
  - Partnerships with other NASA organizations, other government agencies, international partners, and industry
- BPS will continue focus on improving accessibility, diversity, inclusion and equity in its programs

Thank you!

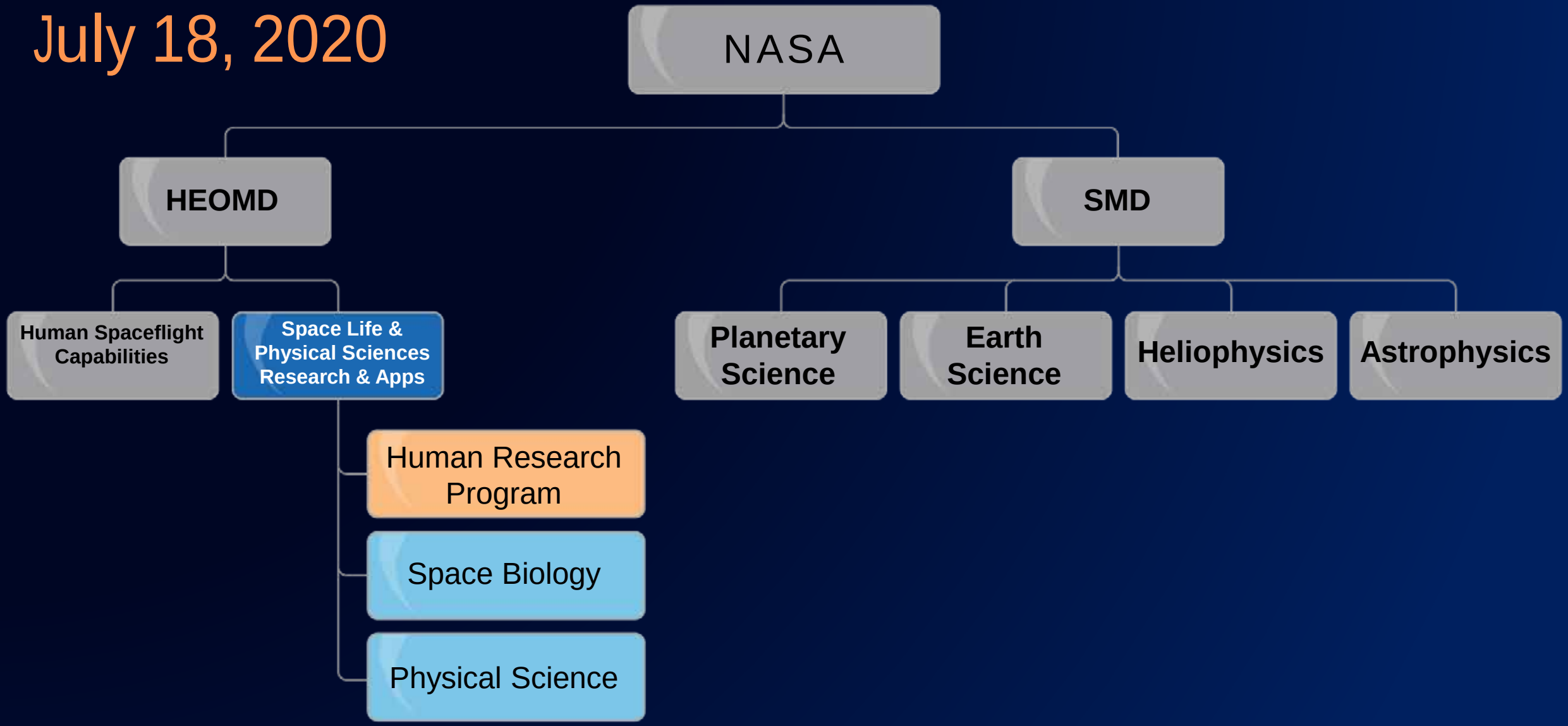
Supplemental Information

BPS Programs Started in the 1960's

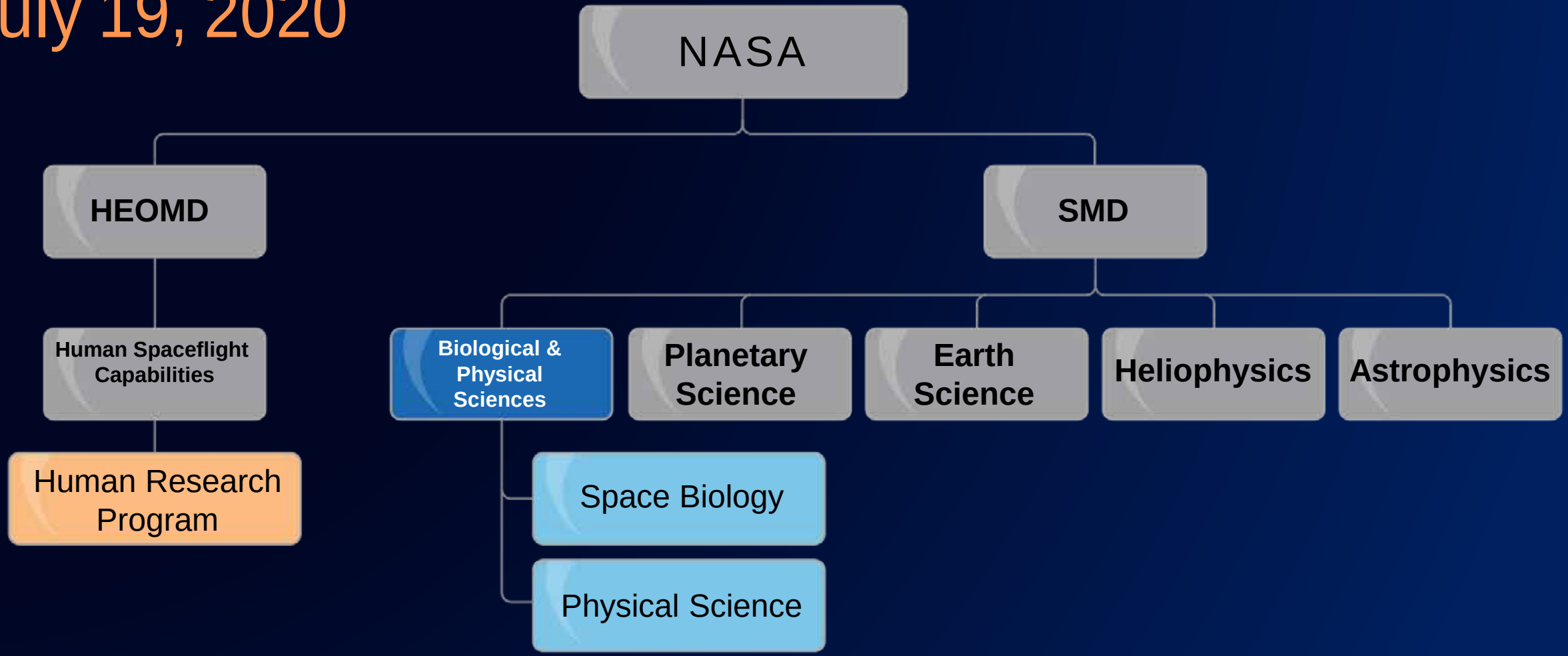
Fluid Physics History at Glenn Research Center



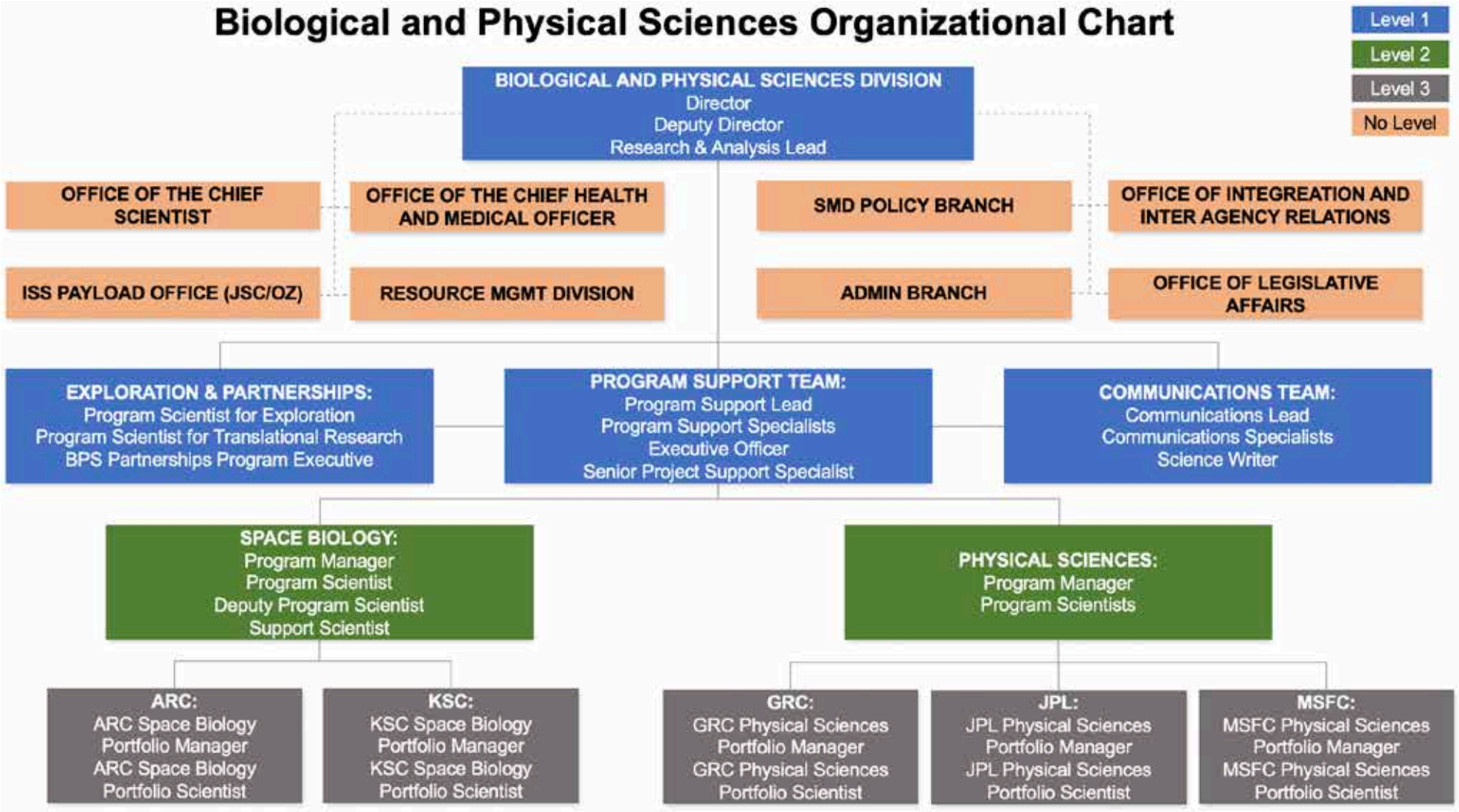
Pre-SMD Move: July 18, 2020



Post-SMD Move: July 19, 2020



Biological and Physical Sciences Org Chart



Biological and Physical Sciences Division Leadership

Dr. Craig Kundrot
Division Director

Diane Malarik
Deputy Director

BPS Program Leadership

Space Biology

Mary Walsh*
Program Manager

Sharmila Bhattacharya
Program Scientist

Mamta Nagaraja*
Deputy Program Scientist

Anthony Hickey
Support Scientist

Physical Sciences

DeVon Griffin
Program Manager

Bradley Carpenter
Fundamental Physics Program Scientist

Fran Chiaramonte
Fundamental Physical Sciences Program Scientist

Exploration & Partnerships

Kevin Sato*
Program Scientist for Exploration

Lisa Carnell
Program Scientist for Translational Research

Doug Gruendel
Partnership Coordinator

*On detail

BPS Partnerships Summary

Agreements Executed

USDA-NASA Agency-level MOU signed; two BPS-supported MOU's:

- *Microgreen Research MOU*
- *Research at USDA Biotechnology Laboratory at EPCOT MOU*

- NIH/NCATS Trans-agency Solicitation MOU

BPS, HRP, ISS NL and ISS Program MOU

Collaboration between BPS, ISSNL, NSF, and ISSPO to utilize FBCE

Activities in Work

Trans-agency Solicitation on 3D Tissues and Microphysiological Systems

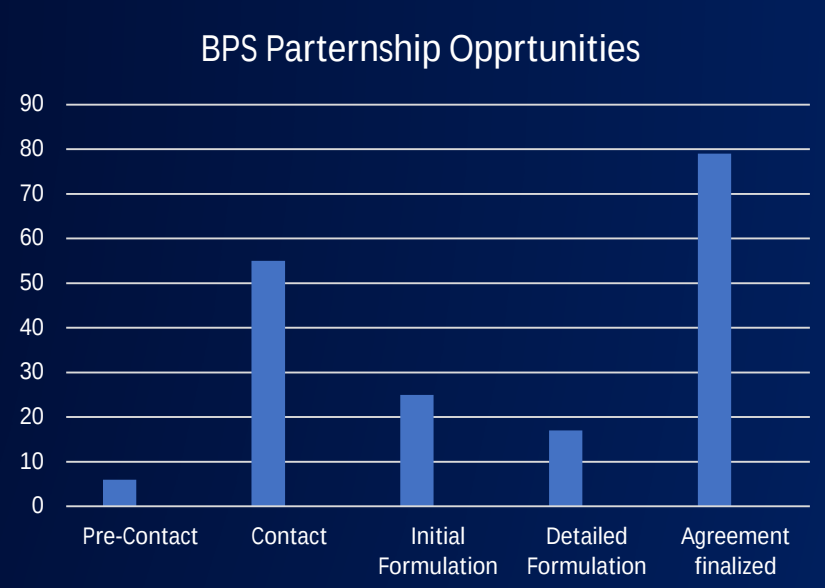
- *NIH/NCATS, NIH/NIAID, NIH/NCI, NIH/NICHD, BARDA, FDA, Space Biology, Human Research Program*
- *Solicitation released May 27, 2021; Step-2 proposals due September; awards mid FY22*

NSF-NASA-DOD Emerging Frontiers in Research and Innovation (EFRI) program solicitation (to be released 2021)

Developing "Human-on-Chip" Challenge in Partnership with NCATS and Methuselah Foundation

BPS and AES co-funded eXposed Roots On Orbit Technology System (XROOTS) Technology Demonstration scheduled to fly on SpaceX-24

BPS working with NASA EPSCoR to provide research content to be included in FY22 EPSCoR research solicitations



Workshops Co-Organized

- NYAS "Bioengineering in Space" Symposium, December 9-10, 2020
- Mitochondria Workshop, (virtual) Dec 2021
- RRS/NCI/NASA Workshop: "Particle Radiobiology for Spaceflight and Oncology" June 15-17, 2022 **https://na.eventscloud.com/website/8881/**
- Explore NCI-NIH -NASA Joint Symposium in Health and Space Science Research, May 2022

HHS-NASA Activities

- SPACE Group: quarterly meetings of representatives from other government agencies
- Webinar Series: Spring, Summer, Fall showcasing NASA and NIH research

BPS Partnerships

Acronyms

Acronym	Term
BPS	Biological and Physical Sciences Division (NASA)
CAL	Cold Atom Lab
CLPS	Commercial Lunar Payload Services
ECLSS-CHP SCLT ('SCLT)	Environmental Control and Life Support Systems – Crew Health and Performance Systems Capability Leadership Team
HEO /HEOMD	Human Exploration Operations / Mission Directorate (NASA)
HLS	Human Landing System
HRP	Human Research Program (NASA)
ISS	International Space Station
ISSNL	International Space Station National Lab
ISRU (Lunar ISRU)	In Situ Resource Utilization
LEO	Low Earth Orbit
MOU	Memorandum of Understanding
SMD	Science Mission Directorate (NASA)
STMD	Space Technology Mission Directorate (NASA)
ZBOT	Zero-Boil-Off Tank (experiment)