National Aeronautics and Space Administration

Space Life and Physical Sciences Research and Applications Program Status

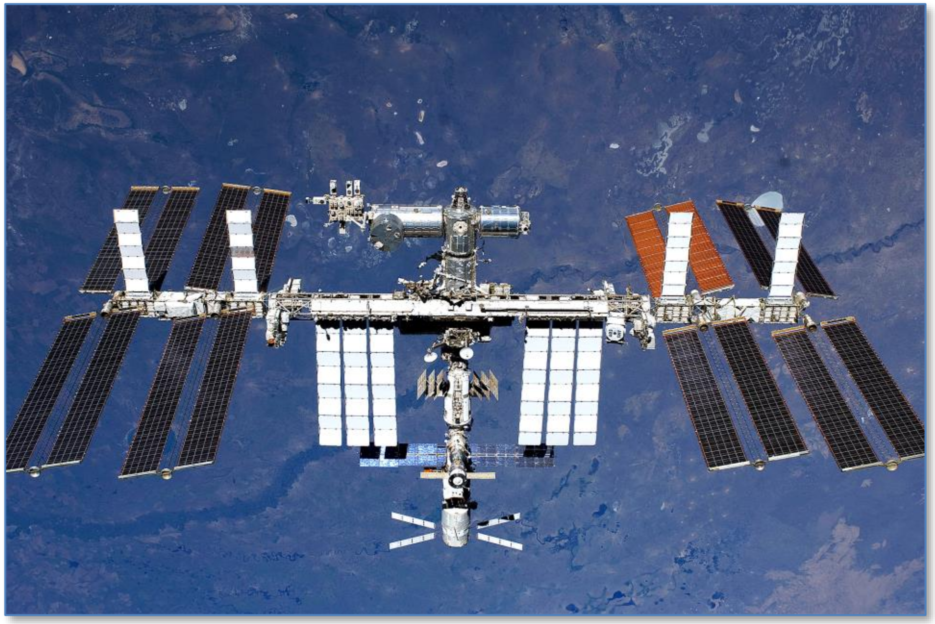
Committee on Biological And Physical Sciences in Space (CBPSS)

March 27, 2018

Craig Kundrot, Ph.D.
Director, Space Life and Physical Sciences Research & Applications
Human Exploration & Operations Mission Directorate

Outline

- Recent SLPSRA activities
- Midterm assessment of implementation of Decadal Survey
- President's Budget Request
- NASA Strategic Plan
- Lunar Orbital Platform - Gateway
- SLPSRA Strategic Plan
- Conclusion



Space Life and Physical Sciences Research and Applications Division

Human Research Program

- Human Health Countermeasures
- Human Factors and Behavioral Performance
- Space Radiation
- Exploration Medical Capability
- ISS Medical Project

Space Biology

- Cell & Molecular
- Microbiology
- Animal
- Plant
- Developmental, Reproductive & Evolutionary

Physical Sciences

- Fluid Physics
- Complex Fluids
- Combustion
- Materials Science
- Biophysics
- Fundamental Physics

Tasks and Workforce

Program	Tasks	PIs	Co-Is	Post Docs	PhD students	Masters students	Bachelor students
Human Research Program	188	156	565	74	120	35	64
Space Biology	77	66	142	44	50	27	132
Physical Sciences	99	92	143	48	113	27	56
Total	364	314	850	166	283	89	252

1,954

https://taskbook.nasaprs.com/Publication/index.cfm

HRP: Exploration Exercise (ATLAS)

current ISS exercise hardware – CEVIS, TVIS, ARED

ATLAS will replace ISS exercise hardware for exploration

- **Fall 2017 – Functional breadboard unit delivered to HRP**
- **16 Jan 2018 – Authority To Proceed (ATP) to PDR**
- **27 Feb 2018 – PDR initiated at GRC**
- **Mar 2020 – Flight Hardware to CH&S SMT**

HRP: Crew Performance after Landing

- n=36 returning crewmembers (19 USOS, 17 Rus) from 17 Soyuz landings
- Every returning crewmember exhibits vestibular/cerebellar and sensorimotor decrements
- Every crewmember experiences landing-related motion sickness
- There is considerable variations between crewmembers performance
- Strength is likely not the limiting factor because of current in-flight exercise countermeasures
- Emergency egress during/after a water landing will present a significant risk to astronaut safety







SB: Rodent Research-9 and Biospecimen Sharing

- **Flew 20 mice for ~30 days**
- **Evaluate physiological changes in the brain, eye, and lymphatic system, and knee/hip degradation.**
- **Returned live for dissection in Primary Investigator's lab**

RR-9 PI TISSUE LIST

DELP

1. Brain
2. Basilar arteries
3. Cerebral arteries
4. Choroid plexus
5. Parietal cortex
6. Coronary arteries
7. Basal veins
8. Jugular Veins
9. Cervical lymphatics
10. Carotid artery

WILLEY

1. Hind limbs

MAO

1. Blood serum
2. Eyes

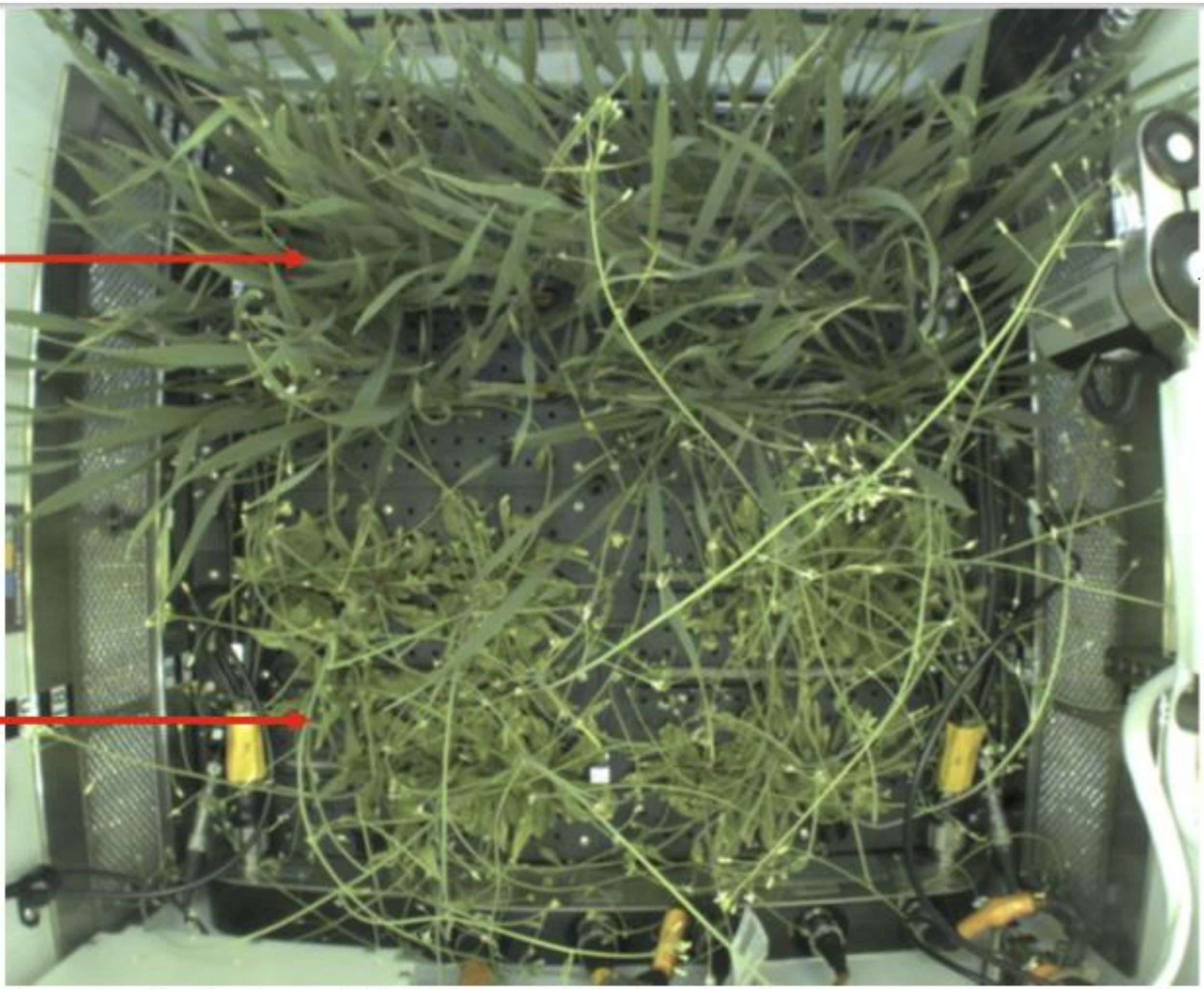
RR-9 BSP TISSUE LIST

1. Abdominal lymphatic nodes
2. Adrenal glands
3. Aorta (abdominal and thoracic)
4. Axillary lymph nodes/ lymphatics
5. Blood serum
6. Calvaria
7. Cecum
8. Cephalic lymphatics
9. Colon
10. Cribriform plate of head
11. Diaphragm
12. Duodenum
13. Esophagus
14. Fat (abdominal/brown adipose)
15. Feces
16. Femur
17. Heart
18. Humerus
19. Ileum
20. Inguinal lymph nodes/lymphatics
16. Jejunum
17. Kidneys
18. Liver
19. Lungs
20. Mandible
21. Mesentery
22. M. gastrocnemius
23. M. Extensor digitorum (EDL)
26. M. longissimus dorsi
27. M. quadriceps vastus lateralis
28. M. soleus
29. M. splenius
30. M. tibialis anterior
31. Pancreas
32. Paw
33. Rectum
34. Skin dorsal
35. Skin femoral lateral
36. Spine/pelvis
37. Spleen
38. Stomach
39. Tail
40. Testis
41. Tibia
42. Thymus
43. Whiskers with skin

SB: Advanced Plant Habitat

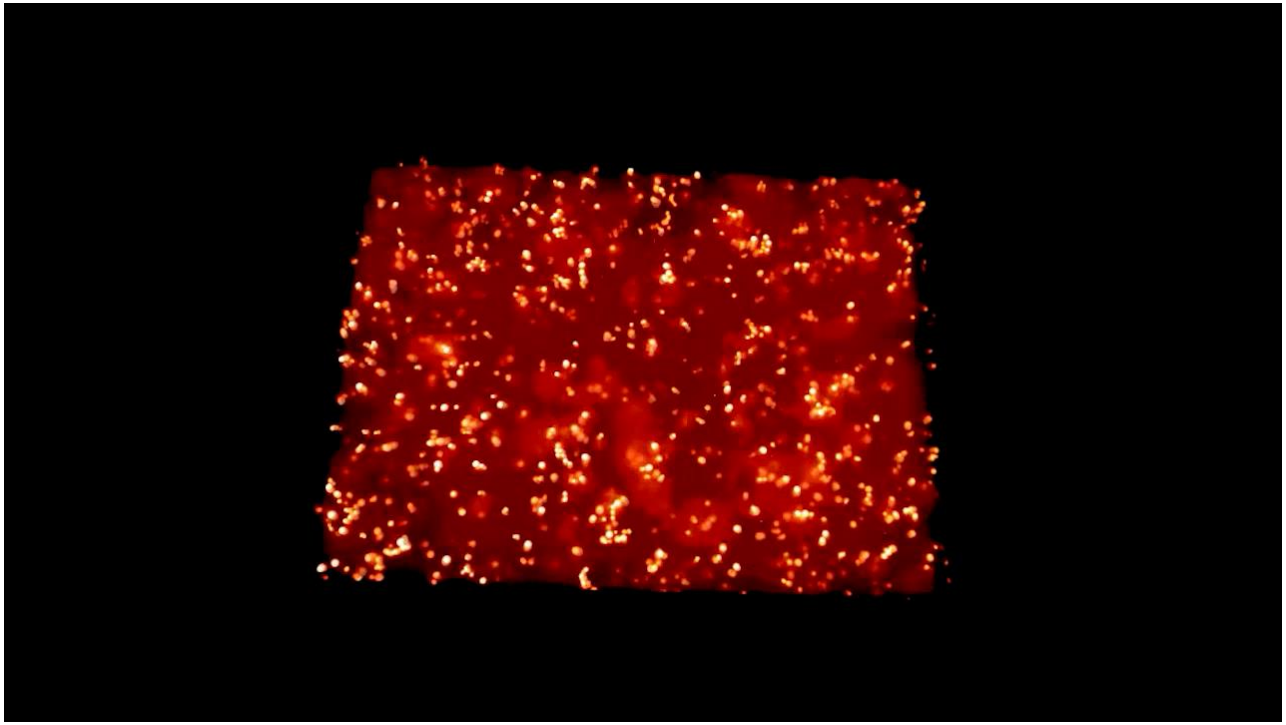
Dwarf Wheat

Arabidopsis



- The Arabidopsis started on 1/22/18 and this is about 5 weeks of growth. The Dwarf wheat was started on 2/7-8/18 and this is about 3 weeks of growth.

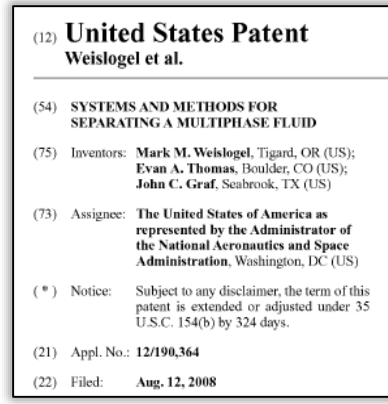
PS: Advanced Colloids Experiment (ACE-T6)



- **First experiment using 3D confocal upgrade to the Light Microscopy Module**
- **Principal Investigator: Mathew Lynch, Principal Scientist of Procter and Gamble**
- **Four patent applications pertaining to product development and shelf life in work**
- **Partnership with P&G and CASIS**

PS: Capillary Flow Experiments

- **CFE and CFE-2 (PI: Prof. Mark Weislogel, Portland State University):**
  - Investigated large length scale capillary flows and phenomena in low gravity.
  - Obtained data as it pertains to fluids management systems such as fuels and cryogen storage systems, water collection and recycling, thermal control systems, and materials processing in the liquid state.
  - Operated from 2005 to 2017 in Maintenance Work Area by over 35 astronauts in over 100 ~3hr operations on ISS.
- **Resulting Spinoffs from research:**
  - Microgravity urine collection device patent, ISS coffee and espresso cups and machines, plant watering system, ISS water “ping pong” outreach
  - IRPI, LLC, a small company has completed 40 capillary fluidics space projects
    - Developed SE-FIT (Surface Evolver-Fluid Interface Tool).
      - Graphical Interface for using a Surface Area Minimization Code
      - Prebuilt Geometries including tanks, CFE experiments, fundamental science, etc.
  - More than 40 peer reviewed publications and conference papers


(12) **United States Patent**
Weislogel et al.

(54) **SYSTEMS AND METHODS FOR SEPARATING A MULTIPHASE FLUID**

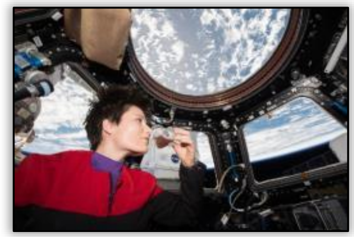
(75) Inventors: **Mark M. Weislogel**, Tigard, OR (US); **Evan A. Thomas**, Boulder, CO (US); **John C. Graf**, Seabrook, TX (US)

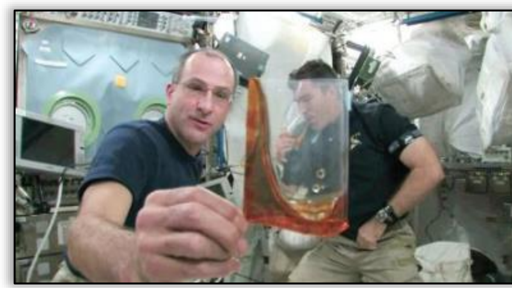
(73) Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, DC (US)

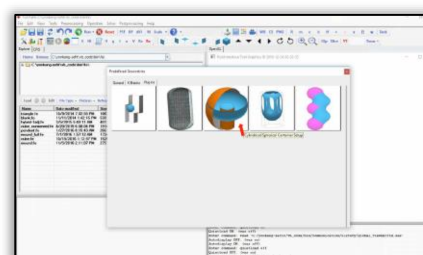
(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 324 days.

(21) Appl. No.: **12/190,364**

(22) Filed: **Aug. 12, 2008**







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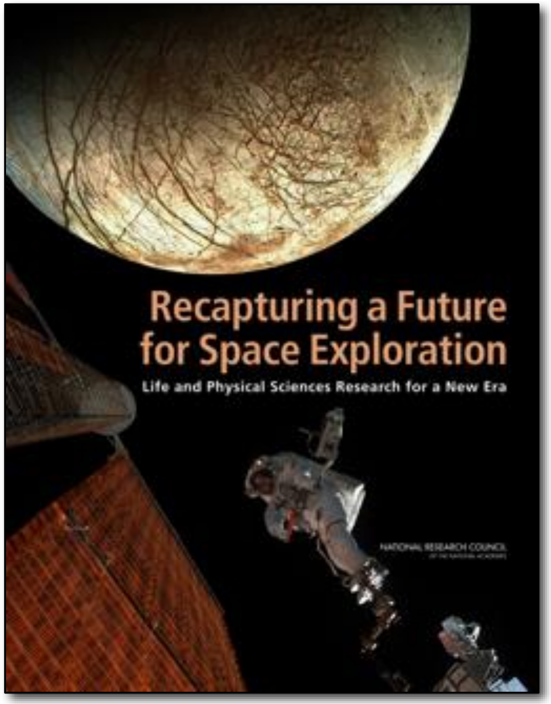
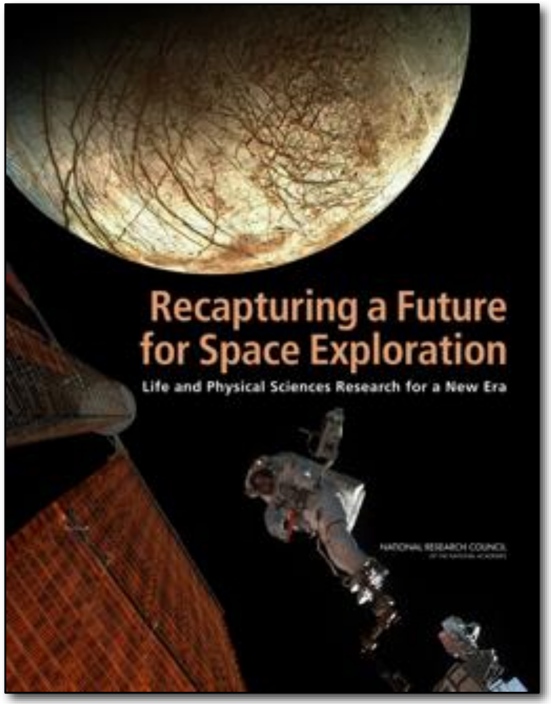
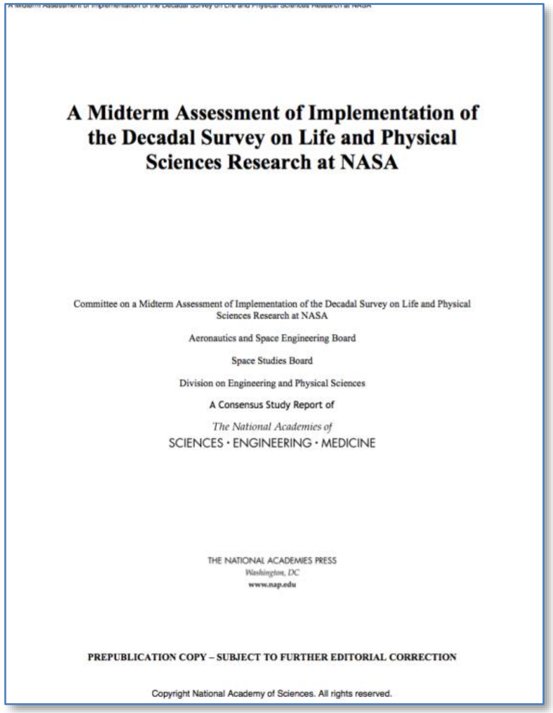


Decadal Survey: Midterm Assessment




A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA

Committee on a Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA

Aeronautics and Space Engineering Board

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, DC
www.nap.edu

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- **Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Science Research at NASA**
  - Released December, 2017
  - 12 Findings
  - 13 Recommendations

https://www.nap.edu/catalog/24966/a-midterm-assessment-of-implementation-of-the-decadal-survey-on-life-and-physical-sciences-research-at-nasa

Midterm Assessment

- **Recommendation 5-11: NASA should aggressively lead in the 46 research priorities for deep space exploration identified in Table 4.1 of this midterm report to provide as much "pull" as possible for exploration enhancement using space life and physical sciences. NASA should, for example, lead in the development of microgravity-adapted biological and physical systems, making maximum use of all available platforms, including the International Space Station, specifically for the science behind the design and implementation of microgravity-optimized operation.**

- **Agree**
  - This is a helpful prioritization to guide the allocation of SLPSRA resources
  - The (Earth analog | LEO | BLEO) breakout works well with the SLPSRA "stepping stone" approach
  - SLPSRA is working in many of these areas
    - Many with well established "pull' from other NASA programs
    - Some are well-positioned to obtain "pull"
    - A few need to be "pushed" to NASA programs with results and analysis before other programs will "pull" for such work

Midterm Assessment

- **Recommendation 5-12: The committee recommends that a cautious approach be used when shifting the NASA research portfolio more toward those types of experiments necessary for deep space exploration, so as to maintain the benefits of important basic experiments, especially those uniquely enabled by International Space Station microgravity and already in progress, which may in the long term have the potential for major impacts in fundamental physical science.**

- **Agree**
  - Part of SLPSRA's mission is to pioneer scientific discovery for other government agencies, commercial companies, and international partners.
  - Therefore, areas like fundamental physics are an important part of the SLPSRA portfolio.
  - Moreover, such research helps develop the future commercial workforce and be the foundation of future generations of space technologies.

Midterm Assessment

- **Recommendation 5-8: In order to maximize the implementation of decadal survey priorities within its constrained resources, NASA should continue to be mindful of the full range of platforms (including drop towers, aircraft, balloons, suborbital vehicles, and free-flyers) and terrestrial analogs and ground-based laboratories available for decadal survey research.**

- **Agree**
  - SLPSRA is actively pursuing utilization of the full range of research platforms.
  - We currently utilize many terrestrial facilities, drop towers, aircraft, sub-orbital vehicles and free-flyers, and are increasing our utilization.
  - We have recently solicited for new Space Biology research in aircraft, on balloons, and in terrestrial microgravity simulators.
  - We are actively considering research on platforms such as
    - the U.S. Air Force X37-B
    - commercial platforms (e.g., New Shepard , Cygnus, DragonLab, Dream Chaser)
    - international partner platforms (e.g., Eu:CROPIS, BION M-2).

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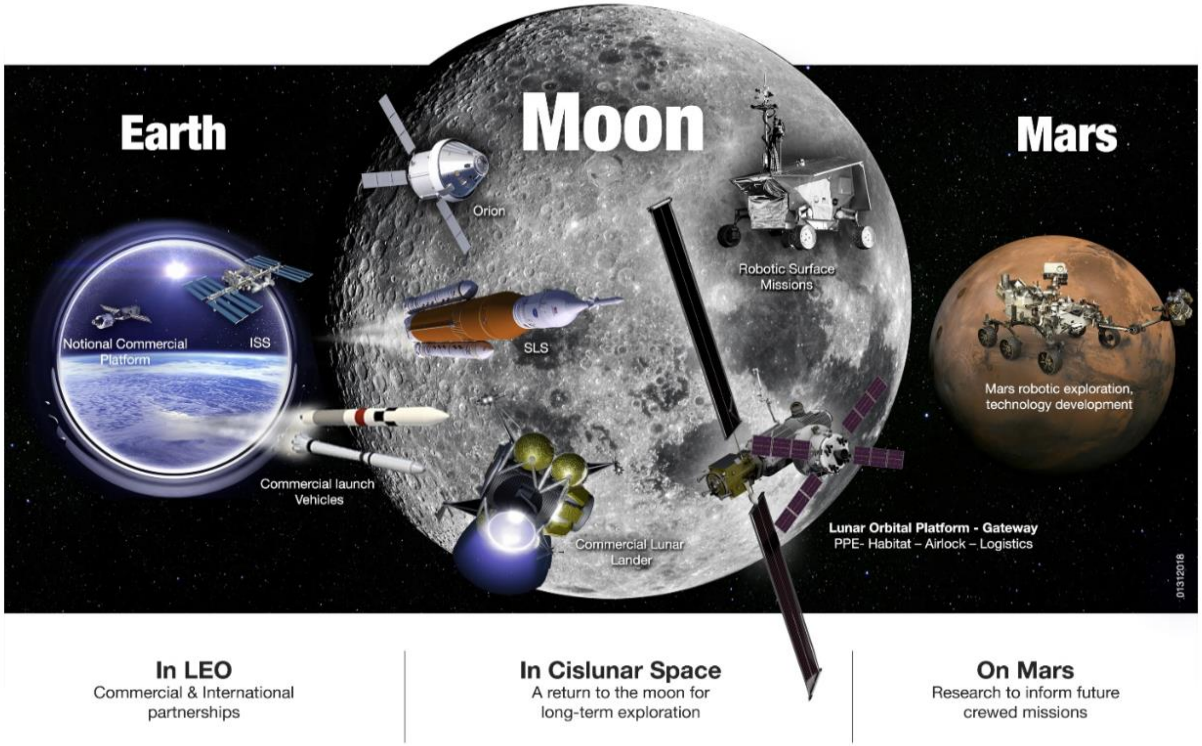
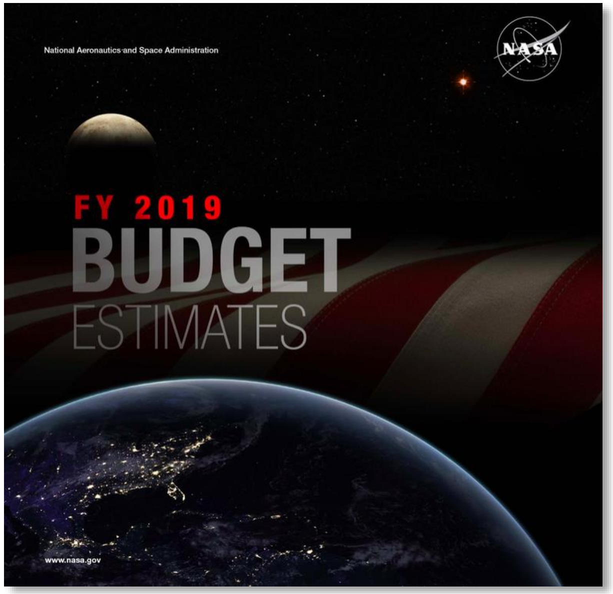


President's Budget Request for FY19

- **Budget**
  - Human Research Program (HRP)
    - Unchanged at $140M / year
  - Biological and Physical Sciences (BPS)
    - Within ISS Research budget line
    - Presumed unchanged at ~$80M / year
- **Restructuring options for HEOMD + STMD**
  - 1) Two Directorates
    - Exploration Operations Mission Directorate
      - ISS, LEO operations, and cross cutting support areas
      - Presumably includes BPS
    - Exploration Systems and Technology Mission Directorate
      - Deep space mission elements and technology developments needed for sustainable human exploration
      - Includes HRP in Exploration Research & Technology (right)
  - 2) One Directorate
    - HRP in ERT and separate BPS with ISS/LEO
- **Examining moving BPS with HRP to ERT**



FY 2019 Structure
Exploration Research & Technology
Early Stage Innovation and Partnerships
Agency Technology and Innovation
Early Stage Innovation (includes AES)
Partnerships and Technology Transfer (includes AES)
Technology Maturation (includes AES)
Technology Demonstration
Restore/In-Space Robotic Servicing (ISRS)
Laser Comm Relay Demonstration (LCRD)
Solar Electric Propulsion (SEP)
Small Spacecraft, Flight Opportunities & Other Tech Demonstration (includes AES)
Human Research Program
SBIR and STTR

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NASA Strategic Plan

- **Strategic Objective 1.2: Understand Responses of Physical and Biological Systems to Spaceflight**
  - Conduct a robust program of space-based research to
    - advance technologies that enable space exploration
    - pioneer uses of the space environment to benefit life on Earth
  - The space flight environment stresses physical and biological systems in many ways, including microgravity and space radiation
    - Understanding the responses of physical and biological systems to these stressors is necessary for designing and executing longer, more distant human space flight missions..
    - These stressors can also be used as experimental tools to enable scientific discovery with applications here on Earth
  - The first stages of progress toward achieving this strategic objective will be clearly measured by the formulation of agreements between
    - the research programs
    - the internal NASA customer (for enabling exploration) or external organizations (for scientific discovery)
  - Final accomplishment of the research objectives will be measured by showing how the research products address the original agreement's needs.

Strategic Objective 1.2

NASA 2018 Strategic Plan Framework

Theme	Strategic Goal	Strategic Objective
DISCOVER	EXPAND HUMAN KNOWLEDGE THROUGH NEW SCIENTIFIC DISCOVERIES.	1.1: Understand the Sun, Earth, Solar System, and Universe.
		1.2: Understand Responses of Physical and Biological Systems to Spaceflight.
EXPLORE	EXTEND HUMAN PRESENCE DEEPER INTO SPACE AND TO THE MOON FOR SUSTAINABLE LONG-TERM EXPLORATION AND UTILIZATION.	2.1: Lay the Foundation for America to Maintain a Constant Human Presence in Low Earth Orbit Enabled by a Commercial Market.
		2.2: Conduct Exploration in Deep Space, Including to the Surface of the Moon.
DEVELOP	ADDRESS NATIONAL CHALLENGES AND CATALYZE ECONOMIC GROWTH.	3.1: Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation.
		3.2: Transform Aviation Through Revolutionary Technology Research, Development, and Transfer.
		3.3: Inspire and Engage the Public in Aeronautics, Space, and Science.
ENABLE	OPTIMIZE CAPABILITIES AND OPERATIONS.	4.1: Engage in Partnership Strategies.
		4.2: Enable Space Access and Services.
		4.3: Assure Safety and Mission Success.
		4.4: Manage Human Capital.
		4.5: Ensure Enterprise Protection.
		4.6: Sustain Infrastructure Capabilities and Operations.

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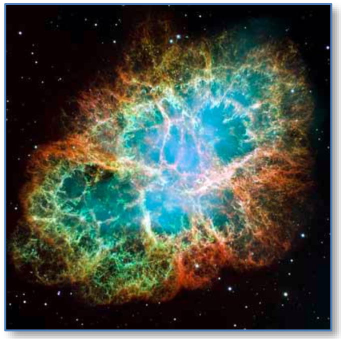
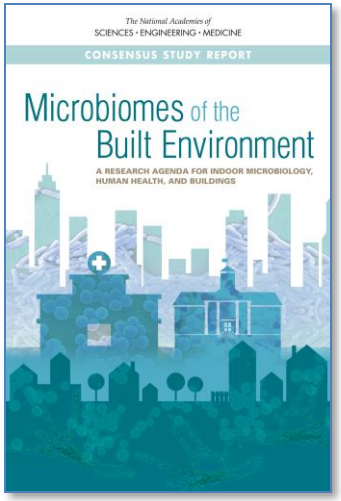
Lunar Orbital Platform – Gateway Workshop

- **SLPSRA HRP and Space Biology**
  - – 46 of 110 papers presented
  - – Coordinating with Astrobiology and Planetary Protection through Life Science Research Capability Team
- **Scientific Opportunity**
  - – Strong ties to Decadal Survey
  - – Deep space radiation: spectrum and dose rate
  - – Biological response to radiation and countermeasures
  - – Microbiome of built environment (MoBE)
  - – External exposure facility
- **Gateway Considerations**
  - – Internal and external payloads
  - – Limited volume, power, crew time, dormant periods, cold stowage, sample return
  - – Desire for glovebox, microscopes, freezers, wetlab, remote operations, high capacity data transmission, robotic tasking, automation, etc.
- **Collaboration between basic science, human health, technology development, mission planners**





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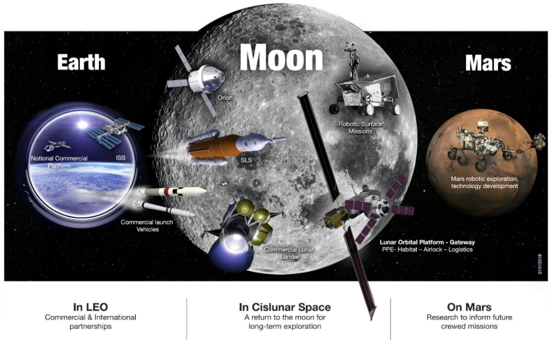
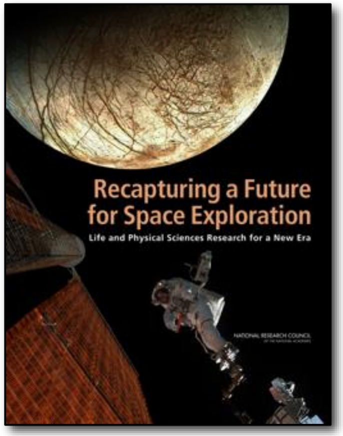
Purpose - Unchanged

- **Vision**
  - We lead the space life and physical sciences research community to enable space exploration and benefit life on Earth



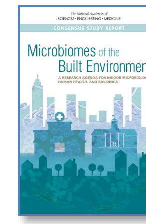
- **Mission**
  - Enable exploration to expand the frontiers of knowledge, capability, and opportunity in space
  - Pioneer scientific discovery in and beyond Low Earth Orbit to drive advances in science, technology, and space exploration to enhance knowledge, education, innovation, and economic vitality



Goals – In Work

1. **Enable exploration by providing research and technology development products to meet the known needs for future exploration mission needs**

2. **Enable exploration by demonstrating to stakeholders how emerging knowledge and technology could improve the execution and reduce the risks of exploration missions**

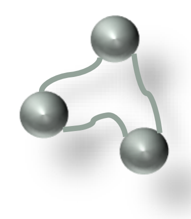


3. **Pioneer scientific discovery by refining the use of space for research and technology development across the full range of established and new spaceflight platforms**

4. **Pioneer scientific discovery by helping other organizations utilize the spaceflight environment effectively**

CASIS

5. **Maintain key scientific and engineering capabilities for NASA and the Nation**



Implementation Emphases - Original

- **Open Science**
  - Maximize community participation in the **formulation** of investigations where feasible
    - Co-Principal Investigator Teams
    - Topical Teams
    - Science Definition Teams
  - **Disseminate and reuse** data, tools, and samples post-project
    - GeneLab
    - Physical Science Informatics
    - Life Sciences Data Archive
- **Partnerships**
  - Generate pull for enabling exploration; identify adopters for pioneering scientific discovery
  - Leverage resources
  - Access new experimental platforms
  - Strengthen technical foundation

Implementation Principles - Expanded

1. **Ensure Scientific Integrity**

2. **Maximize Open Science**

GeneLab
Open Science for Exploration

P.S.I
Physical Sciences Informatics System

3. **Cultivate Partnerships**

NIH BARDA ИМБП DLR CASIS P&G

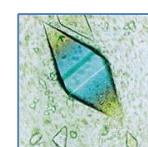
4. **Use Stepping Stones**





5. **Be an Early Adopter of New Spaceflight Platforms**


6. **Facilitate Commercialization of Space by Making Research Available to Commercial Companies**



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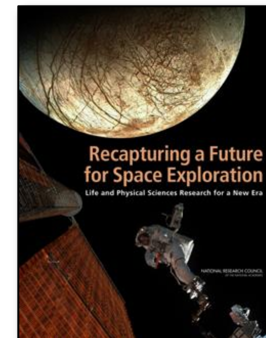
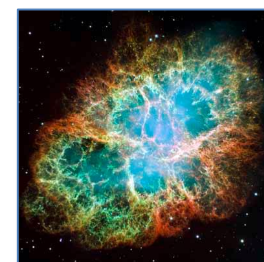
Conclusion

- **SLPSRA is executing valuable research**
  - To enable exploration
  - To pioneer scientific discovery
  - Guided by the Decadal Survey
  - Guided by NASA-identified needs
- **The Midterm Assessment of the Decadal Survey**
  - Prioritization & implementation advice
- **President's Budget Request for FY19**
  - Budget appears stable
  - Re-organization could separate HRP and BPS
- **Lunar Orbital Platform – Gateway**
  - Deep space radiation provides new opportunities for biological research
- **SLPSRA Strategic Plan**
  - Supporting the post-ISS and beyond LEO era






Thank You

- **Recommendation 3-1: As NASA continues to develop deep space mission scenarios involving long durations in microgravity, understanding the direct and interactive effects of radiation, microgravity, and small habitats on human biology and on the performance of biological and physical systems in space over long durations will need to have high priority in NASA science plans. NASA should also improve the coordination among the science research and engineering teams to better address the integrated effects in the design of the exploration elements and systems.**

  – Response: Agree.
    - The combined effects of radiation and weightlessness on human physiology are not understood.
    - Mechanisms for the interaction of radiation and weightlessness in living systems are currently a matter of speculation.
    - We are hoping to be able to resolve uncertainties in this area to some extent through research conducted at the Deep Space Gateway.

- **Recommendation 5-1: NASA should recognize the need for regular requests for research proposals, in order to keep an active external research community available to do exploration-related space life and physical sciences research.**

  - Response: Agree.
    - We’ve been relatively successful at maintaining a regular cadence of broad-based research announcements in the Human Research Program and in Space Biology.
    - This hasn’t been possible in the Physical Sciences because of cost growth in several flight projects.
    - We are working on resolving that situation in the next few years.

- **Recommendation 5-2: NASA should continue and increase its efforts to maximize International Space Station (ISS) resource synergy across the ISS National Laboratory, international partners, and the Division of Space Life and Physical Sciences Research and Applications, particularly with regards to crew time availability and research priority on the ISS. Continued efforts to increase cargo and crew transport to and from the ISS should be expedited as much as possible.**

  – Response: Agree.
    - Given the scope of potential research, efficient use of resources aboard the ISS will always be important for NASA, the ISS National Laboratory, and our international partners.
    - Thankfully, the presence of four US operating segment crew members has relieved the limitation of crewtime for at least a while.
    - But we acknowledge that we will always need to be aware that there will always be a limiting resource (be it crew time, up mass, down mass, volume, power, etc.), and we do need to coordinate to maximize our efficiency.

- **Recommendation 5-3: NASA should consider decadal survey priority tracking integration within Agency elements and utilize existing, commercially available, well-known research reporting and open-science database tools that are in use across the academic research spectrum for accurate, timely, and sustainable information. NASA should also make a determined effort to build on the significant improvements in the International Space Station program for communicating the value of the investigations.**

  – Response: Agree.
    - We are working with the ISS program to better coordinate our research databases, and are discussing with the Science Mission Directorate the use of their RAPTOR tool to track project funding.

- **Recommendation 5-4: Relationships with the National Institutes of Health, the National Institute of Standards and Technology, the National Science Foundation, the Department of Defense, the Department of Energy, and other agencies should be strengthened to better address the decadal survey and midterm review identified research priorities, especially exploration priorities. NASA should consider negotiation with the Center for the Advancement of Science in Space regarding International Space Station research allocations to better address NASA's exploration priorities.**

  - Response:
    - While other Federal agencies have a great deal of expertise in various fields of research, in general they lack a rationale for investment in research focused on space exploration.
    - When we can find research questions of mutual interest, we will pursue collaborations with other Federal agencies.
    - The issue of resource allocation between exploration-focused research and ISS National Laboratory utilization has yet to arise in ISS research planning. If it does, the 2010 NASA Authorization Act provides a mechanism for resolution.

- **Recommendation 5-5: NASA should establish and document traceability of the research priorities to the technology roadmaps, the design reference missions, and the exploration strategy.**

  - Response: Agree.
    - We recognize the importance of establishing this traceability, and are working to develop a research plan that includes this element.

- **Recommendation 5-6: NASA should further balance communication and reporting efforts across the organization.**

  – Response: See response to Recommendation 5-3.

- **Recommendation 5-7: NASA should direct an increasingly higher priority toward the conduct of science within existing International Space Station (ISS) hardware and research capabilities. Utilization of existing, including privately developed, ISS facilities should be maximized in recognition of the current funding limits, the ISS transition timeline, and the need for high-priority microgravity research.**

  – Response: Agree.

    - In practice, our research announcements are largely focused on the use of existing facilities, with minimal development of experiment unique equipment.
    - We only anticipate the development of new capabilities when they are essential to the achievement of a high-priority strategic objective.
    - Addressing this recommendation will also help address recommendation 5-1.

- **Recommendation 5-8: In order to maximize the implementation of decadal survey priorities within its constrained resources, NASA should continue to be mindful of the full range of platforms (including drop towers, aircraft, balloons, suborbital vehicles, and free-flyers) and terrestrial analogs and ground-based laboratories available for decadal survey research.**

  - Response: Agree.
    - We are very interested in utilizing the full range of research platforms.
    - We currently utilize many terrestrial facilities, drop towers, aircraft, sub-orbital vehicles and free-flyers and are increasing our utilization.
    - We have recently solicited for new Space Biology research in aircraft, on balloons, and in terrestrial microgravity simulators.
    - We are actively considering research on platforms such as the US Air Force X37-B, commercial platforms (e.g., New Shepard , Cygnus, DragonLab, Dream Chaser), and other international partner platforms (e.g., Eu:CROPIS, BION M-2).

- **Recommendation 5-9: In light of the resource constraints, NASA should raise the priority of Space Life and Physical Sciences Research and Applications Division research within the International Space Station (ISS) to address the risks and unknowns of human space exploration, particularly given the value of microgravity research for exploration and the urgency resulting from the potential transition of the ISS. These priorities should be directly traceable to the space exploration strategy, linked research priorities, and related technologies. Table 4.1 can be used to initiate this traceability.**

  – Response: Agree.
    - We have been successful in having several of our flight investigations recognized as "Exploration Critical" in NASA's research prioritization process.
    - We understand that demonstrated traceability to exploration requirements and technologies is a key, and recognize that categorizations that the one in Table 4.1 can improve the alignment of our research portfolio with exploration needs.

- **Recommendation 5-10: It is essential that NASA as quickly as possible develop a International Space Station-post-2024 strategy. This development factors strongly in the overall exploration strategy, space life and physical sciences research priorities, and resource allocation in terms of crew time, cargo delivery, and funding. This post-2024 strategy should address clear cost allocation among the various research activities and partners.**

  – Response: Agree.

    - Plans for ISS post-2024 are a subject of active discussion among the ISS partners.
    - We are also actively considering research on platforms such as the US Air Force X37-B, commercial platforms (e.g., New Shepard , Cygnus, DragonLab, Dream Chaser), and other international partner platforms (e.g., Eu:CROPIS, BION M-2).

- **Recommendation 5-11: NASA should aggressively lead in the 46 research priorities for deep space exploration identified in Table 4.1 of this midterm report to provide as much "pull" as possible for exploration enhancement using space life and physical sciences. NASA should, for example, lead in the development of microgravity-adapted biological and physical systems, making maximum use of all available platforms, including the International Space Station, specifically for the science behind the design and implementation of microgravity-optimized operation.**

  – Response: Agree.

    - All 46 of the priorities are important for space exploration, though some, like TSES13, Ascent and descent system technologies, may have limited relevance to research on microgravity platforms.
    - In general, we understand this recommendation as encouragement to involve the life and physical sciences research community in the advancement of science and the development of technologies needed for space exploration, and we agree with that recommendation.

- **Recommendation 5-12: The committee recommends that a cautious approach be used when shifting the NASA research portfolio more toward those types of experiments necessary for deep space exploration, so as to maintain the benefits of important basic experiments, especially those uniquely enabled by International Space Station microgravity and already in progress, which may in the long term have the potential for major impacts in fundamental physical science.**

  – Response: Agree.
    - Areas like fundamental physics, in which internationally recognized scientists are conducting leading edge research in areas like atom interferometry, with potentially revolutionary applications like precision detection of gravitational anomalies and gravity waves, are an important part of our portfolio.
    - International interest in this area is very high. We are currently working with the German aerospace agency, DLR, on a project for fundamental cold atom physics on the ISS that they call one of their "lighthouse projects." We're very excited about this collaboration.
    - Research on the ISS has never been solely focused on exploration. A big part will always be looking for new knowledge, and new ways to use the space environment for scientific and economic return.