NASA Biological and Physical Sciences Advisory Committee

April 25-26, 2024

Virtual/In-Person Hybrid Meeting

NASA Headquarters
Washington, D.C.

Jamie Foster, Chair

Mike Robinson

Michael Robinson, Executive Secretary

Table of Contents

1. Call to Order and Administrative Remarks 3
2. Welcome and Opening Remarks 3
3. Introductions 4
4. FACA Ethics 4
5. Artemis 4
6. Public Comment 7
7. BPS Update 7
8. Decadal Survey 9
9. Initial BPS Response 11
10. Decadal Q&A for NAS and BPS 12
11. NASA ISS Update
12. CASIS ISS Update
13. CLD Program
14. BPAC Discussion/Wrap Up for Day 1
15. Call to Order and Opening Remarks
16. Space Biology
17. Fluids, Combustion, and Materials
18. Fundamental Physics and Soft Matter
19. BPAC Discussion
20. BPAC Outbrief
21. Wrap Up for Day 2
22. Adjourn

Appendix A- Attendees
Appendix B- Membership
Appendix C- Presentations
Appendix D- Agenda

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Thursday, April 25

Call to Order and Administrative Remarks

Dr. Michael Robinson, Designated Federal Officer (DFO)/Executive Secretary of the Biological and Physical Sciences Advisory Committee (BPAC), called the hybrid meeting to order and gave a brief background on the Committee. BPAC was formed under Federal Advisory Committee Act (FACA) regulations, which require that BPAC meetings are open to the public and all statements are part of the public record. The meeting was recorded on WebEx and by attending, participants consented to their voices and likenesses being recorded and shared on the BPAC website and in any media in existence now or in the future. Meeting participants released NASA from any claims and demands that may arise from such use, including claims for compensation. All BPAC member conversations were on the record, and formal minutes were taken. While discussions during the meeting were for BPAC members only, the public had opportunities to ask questions via the WebEx chat feature and participate during two public comment sessions.

The NASA Science Mission Directorate (SMD) Associate Administrator appoints Committee members based on their subject matter expertise. Members must comply with Federal ethics laws applying to members' status as Special Government Employees (SGEs). Committee members are required to recuse themselves from discussion of any topics for which they have personal or institutional financial conflicts of interest (COIs). Two conflicts of interest were identified at the April 25 meeting and members were asked to recuse themselves during the relevant discussions—Dr. Nathan Lundblad and Dr. Maren Mossman on NASA's Cold Atom Laboratory (CAL). Dr. Robinson said that members with ethics concerns could contact him and be put in touch, if necessary, with a NASA ethics attorney.

Dr. Robinson then welcomed BPAC members, thanked them for their time, and turned the meeting over to Dr. Jamie Foster, BPAC Chair.

Introductions

Dr. Foster switched the order of the agenda while awaiting the arrival of the next speaker, and welcomed members to the first official BPAC meeting. She asked Committee members to introduce themselves, after which Dr. Lisa Carnell, Division Director for Biological and Physical Sciences (BPS), thanked BPAC members for helping to shape the next decade at BPS.

Welcome and Opening Remarks

Dr. Nicky Fox, Associate Administrator for SMD, emphasized the importance of advisory committees, particularly because BPS recently received its Decadal Survey. BPAC will help shape the response to that Decadal as well as provide ongoing program feedback, said Dr. Fox. She recognized new BPS staff and recent award winners, then took questions from BPAC members.

Dr. Dan Dumbacher asked about coordination with the Exploration Systems Development Mission Directorate (ESDMD). Dr. Fox said that coordination has been strong, mostly under the Moon to Mars (M2M) Program umbrella. She noted that she will soon be able to discuss upcoming BPS science on Artemis II, and said that plants are also part of Artemis III. While coordination is going well, Dr. Fox added that she always aims to do better and the recommendations and findings from advisory committees help her do so.

Dr. Fox noted that ESDMD is playing a large role in the Commercial low Earth orbit (LEO) Destination (CLD) Working Group. CLD is another area where the SMD can use BPAC's help, including the equipment footprint inside CLDs and BPS science priorities.

Dr. Dumbacher asked whether ESDMD challenges will affect SMD priorities. Dr. Fox replied that the challenges will not affect her priorities, but they may affect her ability to get those priorities done. To succeed with advocacy of science priorities, they need to be well-articulated, supported with one voice at the SMD

level, and be considered NASA science priorities, not just those of SMD. Dr. Fox said that BPS is clearly at the forefront of what SMD will accomplish in low Earth orbit and with Artemis. She said she is also interested in broadening beyond traditional partners like the International Space Station (ISS) and CLD to put BPS experiments on standing rockets, balloons, satellites, etc.

Other topics discussed by Dr. Fox and the Committee include:

- The benefits of sharing LEO information and collaborating with other federal agencies that fund space research, including the Defense Advanced Research Projects Agency (DARPA), the Air Force, the National Science Foundation (NSF), and the National Institutes of Health (NIH). Dr. Fox said that if a potential partnership looks particularly fruitful and BPS wants to pursue it, she will step in to support it. Collaborations are one way to fund more BPS research and will continue to grow both domestically and internationally. They make better use of government resources by avoiding duplication and elevating the science.

- The NASA Streamlining Partnerships for Research and Education for Engineering and Science (SPREES) Act. The legislation is currently moving through Congress and would significantly ease the process for NASA to jointly fund research with other federal agencies. SPREES has received bipartisan support.

- The Low Earth Orbit Science and Technology Interagency Working Group, initiated by the White House Office of Science and Technology Police (OSTP). The working group has led to government agencies partnering together and forming sub-working groups.

- Pending legislation on NASA's National Institute for Space Research (NISR). NIRC would comprise all of NASA and would bring in agency heads to serve on the Board of Directors and work on areas such as LEO. Legislative language was modeled after White House OSTP recommendations for government agencies to work together for space research and maintaining U.S. leadership, especially as ISS is decommissioned. The bill includes NASA-CLD coordination.

- Increasing the capacity of institutions to conduct science and more broadly engage society. Dr. Fox said those are literally SMD's goals, including getting more people excited about NASA science. Solar eclipse activities are one example of using any NASA science topic to promote all of NASA science. Another area of engagement is supplying infrastructure to support PIs who apply for and win NASA grants. The logistics of managing a grant can be intimidating and prompt institutions to avoid such awards. Dr. Fox welcomed BPS ideas on how provide support.

- A requirement for future Research Opportunities in Space and Earth Science (ROSES) that the inclusion plan brings in underrepresented institutions beginning in summer of 2024. Requirement language was crafted so that it does not conflict with state policies against funding diversity, equity, and inclusion (DEI) activities. Similar requirements have been in place within SMD for several years, with no DEI problems arising after thousands of proposals.

<u>FACA Ethics</u>
Mr. Griffin Farris, attorney for the NASA Office of the General Counsel (OGC), briefed BPAC members on Committee operations under FACA.

<u>Artemis</u>
Dr. Kevin Sato, Program Scientist for Exploration, briefed BPAC members on Moon to Mars: Mission Considerations for Future BPS Science Research. He briefly described the organization of the M2M Program Office within ESDMD. He highlighted the SMD's Exploration Science Strategy and Integration Office

(ESSIO) as responsible for executing M2M work across divisions, Directorates, and international space agencies. The ESSIO staff are the reason that BPS is front and center in M2M. They are consistent in making sure that BPS needs and requirements are heard.

Moon to Mars Architecture

Dr. Sato explained that M2M has three exploration pillars: science, inspiration, and national posture. Science is a principle reason to go to the Moon, from fundamental research to application work. He recommended that people interested in the program read NASA's Moon to Mars Strategy Objectives and Development and the 2023 Moon to Mars Architecture Definition Document.

Dr. Sato told BPAC members that M2M has 26 science objectives in six areas. BPS and Fundamental Physics are captured mainly within the Human Biological Science and the Physics and Physical Science areas, although there are BPS fingerprints in all six areas. He explained that the program is "architecting from the right," meaning the goals and objectives that are necessary to be successful scientifically and inspirationally are what drive the requirements and missions.

Each year in February, a working group meets for two days where NASA invites experts to ask questions and provide comments on M2M. Invitees include academics/scientists, commercial concerns, and international agencies. NASA releases in January the architecture documents on which it seeks community comment and white papers. Based on those comments, invitations are sent out for the workshop. Day 1 is international space agencies; Day 2 is academia and industry. Next comes a Strategic Analysis Cycle to expand on workshop results. An internal NASA Architecture Concept Review (ACR) takes place each November that includes Center Directors to determine how they want to update the architecture and identify new actions. This process is important because the community has major input into M2M activities and architecture documents.

Dr. Sato told BPAC members that he is the NASA lead for Strategic Analysis Cycle Task 24, to identify the science drivers for surface habitat that will serve as a laboratory on the Moon. He is currently helping to organize the Lunar Surface Science Workshop, a one-to-two day gathering the week of August 20-21, 2024. At the workshop, NASA will ask for input from scientific communities on sustained lunar exploration. Included will be Fundamental Physics, Space Biology, Physical Sciences, the Human Research Program (HRP), Astrobiology, and Astrophysics.

Artemis Missions and BPS Science Opportunities

Dr. Sato outlined the architectural segments of NASA's return to the Moon and beyond:

Human Lunar Return, which involves Orion, the Space Launch System (SLS), Exploration Ground Systems (EGS), the Gateway space station orbiting the Moon, Human Landing System, Deep Space Logistics to supply the Gateway, and Exploration Extravehicular Activity Services (xEVAS).

Foundational Exploration, which includes delivery of the Lunar Terrain Vehicle (LTV), a pressurized Rover, multipurpose habitat, and a large cargo delivery system.

Sustained Lunar Evolution, which includes power, *in situ* resource utilization, expansion of mobility, and longer-duration habitats for living and conducting science on the Moon.

Humans to Mars, which includes transportation; entry, descent, and landing (EDL); ascent; science opportunities; and return needs.

Dr. Sato explained that these phases will overlap. Activities for Mars are ongoing and there will be more

workshops in the future.

Dr. Sato presented planned experiments for upcoming Artemis missions and beyond:

- September 2025 – A BPS pathfinder tissue investigation on Artemis represents an effort among multiple government agencies, including NASA's Directorates, as well as academia and a commercial company.
- 2026 – A SpaceX Starship uncrewed demonstration will be a one-way flight, with only data returned. Physical Sciences and Space Biology investigations are under evaluation. NASA is also requesting tank-to-tank cryogenic fluid transfer data sharing from SpaceX. NASA does not own and is not directing this demonstration. The data can be considered proprietary by SpaceX, so the company determines what data it will provide.
- September 2026 – Marks the beginning of the Human Lunar Return (HLR) segment. Science payloads will be delivered on SpaceX Starship and Orion, with specimens returned on Orion. The Artemis III investigation of Lunar Effects on Agriculture Flora (LEAF) has been awarded, cosponsored by BPS and ESSIO, and a tissue physiology investigation is under assessment by Artemis.
- September 2028 – Gateway will become active. Four payloads have been selected. BPS is involved in the European Radiation Sensor Array (ERSA) and European Internal Dosimeter Array (IDA). Other payloads include SMD Heliophysics Environment and Radiation Measurement Experiment Suite (HERMES) and Human Research Instruments. Gateway intentionally seeks international investigations for research participation. All data will be open for analysis.
- Artemis V will test Blue Origin's Blue Moon lander in an uncrewed demonstration. BPS will work with NASA Human Landing System (HLS) for opportunities to fly science payloads.
- 2030 – Marks the beginning of the Foundation Exploration segment, with a lunar Rover. BPS has been working with ESSIO on potential research investigations using LTV and Gateway.
- 2031 and beyond – Artemis VI will have the first pressurized Rover. BPS is working with ESSIO and the Japanese Aerospace Exploration Agency (JAXA) to determine the capabilities for supporting science both inside and outside a pressurized habitat. BPS is also investigating opportunities on Gateway.

Dr. Sato said that the upcoming lunar habitat workshop will cover how to set the structure and define the capabilities and size required to have a laboratory on the Moon. A future workshop on Mars is also in the works.

Thirteen sites have been identified as possible landing areas for Artemis III on the Moon's south pole. They were identified by the scientific community as the highest-value sites for the mission. This area of the Moon is side-lit.

Upcoming Science Opportunities and Community Involvement

Dr. Sato presented a list of upcoming ESSIO Artemis-related calls. He highlighted the Payloads and Research Investigations on the Surface of the Moon (PRISM)-Stand Alone Landing Site Agnostic (SALSA) Commercial Lunar Payload Services (CLPS) Solicitation (2024). This call is important for BPS because up until now, the PRISM calls have required a location on the Moon. This call is site-agnostic in recognition of the fact that BPS can conduct science anywhere on the Moon.

In his listing of opportunities to provide input—including workshops and studies—Dr. Sato pointed out that the Lunar Exploration Analysis Group (LEAG) is soliciting for a single community representative for the biological and physical sciences.

Discussion
Dr. Dumbacher asked what the effect would be on research if mission schedule dates slip. Dr. Sato replied that the question will be what can be put on the shelf and on held until launch. The science team with the expertise required may move on to other things unless trickle funding is in place. The Artemis ESSIO call has a margin within the budget to address that. There has also been some scenario planning in case of delays.

BPAC members also discussed how much missions rely on the Deep Space Network (DSN) for monitoring and tracking, and whether oversubscription to DSN presents a threat. Dr. Sato replied that the missions do rely on DSN and avoiding over-subscription is part of active planning discussions right now. If it is problematic, other options are needed to get data home. BPS pays for use of DSN, but launch, equipment, maintenance, etc. does not come out of the BPS budget. Artemis will take priority for DSN usage, so the risk is to all the other missions that use DSN.

Public Comment
Dr. Foster gave members of the public the opportunity to comment, but no one came forward.

BPS Update
BPAC 101

Dr. Carnell introduced Dr. Diana Ly, the new BPS Deputy Division Director. Dr. Carnell then gave a brief description of BPAC's status as an advisory committee chartered under FACA to provide information and advice on issues affecting BPS policies and programs. BPAC provides its recommendations and findings to Dr. Carnell. BPAC enables a broad discussion of BPS science and its role within and outside NASA.

The Committee also evaluates BPS annually for progress against NASA performance objectives and the Government Performance and Results Act/Modernization Act (GPRAMA) science goal: "NASA shall demonstrate progress in understanding the properties of physical and biological systems in spaceflight environments to advance scientific knowledge, enable space exploration, and benefit life on Earth."

BPAC provides real-time feedback as well as a letter to the Division Director within approximately 30 days after the meeting. The letter includes a summary of events, findings (no response required), recommendations (response required) and requests for follow-up. Dr. Carnell noted that meeting minutes are taken by a professional notetaker and distributed to BPAC members for an accuracy check.

BPS Status Update October 2023 – Present

Dr. Carnell described the BPS mission as pioneering scientific discovery through research at the fundamental level, enabling exploration through translating fundamental research to applied science, and contributing to life on Earth. BPS Program areas include Space Biology, Physical Sciences, Fundamental Physics, the Commercially-Enabled Rapid Space Science (CERISS) Initiative, and the Open Science Initiative. BPS Programs impact biomedical research (the Tissue Chip Initiative), agricultural innovations (partnering with the U.S. Department of Agriculture on growing crops in austere environments), consumer products, and technology advancements (CAL on ISS).

BPS has 167 active investigations as of fiscal year (FY) 2024. Sixty percent of the portfolio goes to Space Biology and 40 percent to Physical Sciences. Dr. Carnell outlined the federal budget process. BPS is currently planning its FY2026 budget.

Most of the activities of the Biological and Physical Sciences Fleet is centered on ISS, although BPS is working to build its presence beyond LEO through Artemis II, LEAF, and the Lunar Explorer Instrument for Space Biology Applications (LEIA) while still maintaining the agency's presence in LEO, whether on ISS or in a commercial environment.

FY2025 budget highlights include:

- Dramatically increasing the pace of research through CERISS, including adaptation to a commercial environment.
- Optimizing the budget through partnerships, which increases the amount of science done and brought back to Earth. Partnerships encompass organizations both inside and outside of NASA, including SMD and international partners.
- Aligning with high-priority, high-visibility initiatives such as Cancer Moonshot.
- Transformative science to implement Decadal Survey recommendations.
- Sustaining core capabilities, such as open science platforms and training programs.

Dr. Carnell gave a snapshot of BPS's budget status, noting that the FY24 budget stands at $87.5M. The budget request for FY2025 is $90.8M, with a focus on the CERISS initiative. She noted that the increase in the program management section of the budget will help fund increased partnerships. This may or may not continue in out years.

Science Highlights

- *Nature* featured CAL and dual-species atom interferometry and evaluating and measuring Bose Einstein condensates for the first time in space.
- Zero Boil-off Tank (ZBOT) experiments are improving a model system that can be used for cryogenic fluids transfer.
- Launches: SpaceX-29 (November 2023) carrying four experiments – bacterial adhesion and corrosion, rodent reproductive capabilities in space, plant water management, and plant habitat. NG-20 (January 2024) carrying three experiments – plant microbe interactions in space, the role of stem cells in microgravity-induced bone loss, use of canisters to study bacteria behavior in a space flight environment. SpaceX-30 (March 2024) carrying replacement equipment and two experiments studying thermophysical properties and how bacteria adapt to space.

Award Spotlights

- Multi-agency $18M investment to study extending the longevity of tissue chips.
- Joined with the Space Technology Mission Directorate (STMD) to award an opportunity for CERISS-enabled development of hardware that will fly on one of the parabolic missions. The experiment will examine automated fluid sample preparation in space.
- Joined with the Astromaterials Research and Explorations Sciences (ARES) Division to study the effects of lunar regolith simulants as well as actual regolith.
- Partnered with ESSIO on the LEAF experiment to put plants on the Moon.

Education, Outreach, IDEA Updates

Science, Technology, Engineering, and Mathematics (STEM) Opportunities – Dr. Carnell highlighted how BPS staff often speak to the science community and students from K-12 to graduate students. She highlighted an award from the National Eagle Scout Association and student award-winners from the Drop Tower Challenge.
Inclusion, Diversity, Equity, Accessibility (IDEA) – Dr. Carnell highlighted Growing Beyond Earth for Spanish speakers, where students grow plants in the classroom using a similar setup to ISS and submit input to a NASA database; bringing space science to historically Black colleges and universities (HBCU) and minority-serving institutions (MSIs); and the Open-Source Science analysis working group, which welcomes all participants, including high school students. She said that dual anonymous peer review of solicitations will help advance IDEA in grant awards. In response to a question about whether SMD tracks students who

participate in various programs, Dr. Carnell responded that NASA tracks interns. She added that expansion of tracking to other programs would be a good BPAC recommendation and would assist with advocating for programs.

Conferences, Events & Briefings

Dr. Carnell said that one of her goals is to put BPS on the map through letting people know the value of the Division's work. She listed the 14+ conferences and events and six Capitol Hill staff briefings where BPS was present and people asked many questions about the Division science. She said these outings are important for BPS recognition and advocating for budget increases.

Discussion

Dr. Carnell said that while she is not making formal measurements of BPS outings, inquiries from many other attendees increase after events, as do social media hits.

Addressing the transition to CLD, Dr. Carnell said that SMD is working to highlight BPS programs and the capabilities and hardware that the Division would need to do end-to-end experiments in space. BPS has a limited budget, and rather than doing major custom hardware builds, the aim is to identify hardware gaps and calculate what it would cost to adapt current equipment to address those gaps. She said BPS is working to be more agile looking forward, since multi-million dollar builds that take 10 years no longer make sense.

Decadal Survey

Drs. Krystyn Van Vliet and Robert J. Ferl, Decadal Survey Co-Chairs, briefed BPAC remotely on Thriving in Space – Ensuring the Future of Biological and Physical Sciences Research: A Decadal Survey for 2023-2032. Dr. Van Vliet said the latest Decadal is focused on thriving in space at an inspirational moment and a challenging time in BPS research. In the next decade, NASA will be transitioning from ISS to working with commercial entities. The space ecosystem will expand with more people, destinations, activities, commercialization, and longer mission lengths. The previous Decadal focused on rebuilding after budget cuts and other downturns. The next decade is critical for the United States to play a leadership role, including through partnerships with other countries, on a sustainable path from the Moon to Mars.

Dr. Van Vliet told BPAC members that the current Decadal focuses on scientific questions rather than topics to be studied. The report also focuses on interdisciplinary research to enable exploration and discovery. In composing the report, experts in biological sciences, physical sciences, and the engineering and science interface were intentionally mixed together to develop chapters and recommendations. This diversity helped the various communities understand each other's input and improved communication among Steering Committee and panel members. The Decadal team consisted of a Steering Committee with 18 experts from across the United States and BPS disciplines, 50+ experts organized into working groups, and community input from 250+ topical concept papers, 60+ research campaign concept papers, and 2+ years of public meetings with government and industry experts.

The process included technical risk and cost evaluation (TRACE) of research campaigns, which was new to both BPS and the Decadal staff. The process allowed assessment of the actual cost of ambitious team science. NASA directed the content of the Decadal, which includes an assessment of the current state of knowledge at BPS and key scientific questions. The report does not rank questions in order of importance because all are critical for the coming decade.

Dr. Van Vliet provided a high-level summary of the Decadal's 25 recommendations, highlighting those most needed for the United States to thrive in space. These include:

1. Increasing BPS research resources tenfold.

The Decadal did not set out to create a BPS budget. The recommendation resulted from gaining an understanding from TRACE of the resources needed to fund priorities. Dr. Van Vliet said that BPS must grapple with the difference between the recommendation and the current budget outlook. Without a budget increase, BPS will not be able to meet the bare minimum to complete its missions, particularly considering the sunsetting of ISS. The recommendation translates to $1B annually to be reached well before the end of the decade.

2. Focusing on 11 key scientific questions.

These questions will have an impact on science and society. The Decadal intentionally did not specify in what venue the 11 questions should be answered—commercial LEO, lunar surface, etc. That was left to the scientific community. Decadal writers first formulated the key questions, then recognized that they fell into three themes:

Adapting to space. How do physical and biological systems adapt to the space environment (microgravity, radiation, temperature)?
Living and traveling in space. From bacteria to humans, what does it take to occupy a space environment over longer missions?
Probing phenomena that are hidden by the Earth.

Dr. Van Vliet presented the rubric used by the Decadal Steering Committee to determine what activities would be key over the coming decade. The six criteria covered areas such as grand science challenges, transformational change, access to space, reduction of uncertainty about the benefits and risks of space exploration, societal benefit, reduction of space exploration costs, and new options for space exploration.

3. Adopting at least two research campaigns with societal impact and audacious goals that answer key questions and make the best use of the M2M missions. Characteristics include longer time periods of study, larger budget envelopes, and more integrated questions. The Decadal presents two research campaigns that would produce scientific understanding and accomplishment within the decade:

Bioregenerative Support Systems (BLISS) – Would enable long-duration exploration of deep space by providing a fully or partially closed-loop biological life support system for plants and other systems.
Manufacturing Materials and Processes for Sustainability in Space (MATRICES) – The goal is a sustainable circular space economy. Building materials and waste materials all need to be incorporated over time. This campaign is an opportunity to learn from the lessons on Earth about how to manufacture without damaging the environment.

Dr. Van Vliet noted that the research community may not recognize many costs that need to be built into science budgets. She said that it is paramount to answer the key scientific questions first. The research campaigns are an add-ons.

The Decadal also included elements in addition to the research campaigns. One was a multiagency opportunity to probe the fabric of space-time (PFaST). The report recommends that NASA not delve into this area without collaborators. If NASA moves forward with PFaST, the next decade would have to be devoted to development. Outcomes of this undertaking would be of interest to other organizations, so multiagency collaboration makes sense. The second additional element included in the Decadal was Polar Radiation of Model Organisms (PROMO), involving creation of a polar orbit around the Earth that would provide access to higher radiation gradients and other extremes important to understanding organisms as NASA prepares for the Mars mission.

3. Broadening the workforce. This is essential for BPS science to thrive over the next decade. The BPS research community is already working on broadening representation. To keep this community engaged,

there has to be a healthy and regular cadence of BPS grant dollars. Research institutions funded by NASA should also be expected to broaden the participation. Interactions with other U.S. government and non-U.S. space agencies are necessary, as is collaboration with the emerging commercial space science platforms and activities.

4. Planning for the unexpected. Although researchers are used to this planning, it is more difficult over such a complex and broad area. Dr. Van Vliet gave two examples:

- If BPS researchers are granted more access to ISS, the focus should be on experiments that involve development or validation of the commercial LEO transition. If researchers are granted less access, technical/biological replicate experiments should be prioritized.
- It cannot be taken for granted that BPS experiments will be prioritized on CLDs. LEO destinations are commercial and must at least cover their costs. BPS research is for the public, good even if it is not profitable. If BPS researchers have more access to CLDs, then the focus should be on answering key scientific questions representing all three themes. If researchers have less access to the CLDs, they would focus on only the first and third theme.

Dr. Van Vliet concluded with a quote from the Decadal: "The U.S. BPS community has an amazing decade of discovery, transformation, and translation ahead—if we seize it."

Initial BPS Response

Dr. Carnell emphasized that SMD takes the Decadal seriously and she cites it at every meeting with congressional appropriations staff and when speaking in public. She commented that the Decadal unites the entire Division. Three Decadal retreats have identified BPS research already done on the key questions and formulated big, audacious goals to continue to support that work. BPS is working on an internal roadmap that Dr. Carnell can use when reaching out to partners such as ISS and STMD.

Dr. Carnell the gave her response to Decadal recommendations:

- Key Science Questions – Dr. Carnell noted that BPS already has numerous funded activities underway that align with each of the questions.
- Collaboration – BPS is already collaborating with many organizations, including other NASA partners, government agencies, academic institutions, and international partners.
- Commercial Engagement - The current budget supports the CERISS program, a frequent topic of discussion with congressional staffers. BPS is working with the commercial space industry, and Dr. Carnell said she frequently meets with commercial companies, NASA's Flight Opportunities Program, and the CLD Program to take advantage of commercially available platforms.
- Inclusion, Diversity, Training – BPS participates in all SMD programs, which are proactive in IDEA.
- Open Science – The budget supports open science and BPS operation of its databases. She noted that SMD has a regulatory mandate to make its science available.
- Ground Infrastructure – BPS plans to maintain its ground-based facilities, although the budget does not currently support expansion. She highlighted key BPS ground-based facilities, including the Zero Gravity Drop Tower, the Microgravity Simulation Support Facility, the Plant Processing Facility, Electrostatic Levitation Facility, Rodent Gravity Unloading, Centrifuge/Gravity Loading, and the NASA Space Radiation Lab.
- New Office – The Decadal recommends that BPS, in collaboration with other government agencies, establish an office/mechanism for commercial sponsorship and teaming with non-profit organizations. Dr. Carnell responded that BPS already has mechanisms in place through its Office of Interagency and International Relations. The Division also fosters relationships with both commercial entities and non-profits and will continue to do so. The process will become easier if SPREES passes.

- Research Campaigns – BPS is considering stepping stones toward these campaigns. Many NASA activities in other Directorates are underway in both campaign areas. BPS will open discussions about collaborations.
- Big Audacious Goals – Dr. Carnell reiterated that BPS is already developing big, audacious goals that consider both the Key Scientific Questions and the larger campaigns. These goals will help the Division talk to people inside and outside of NASA with a multidisciplinary approach. BPS is creating roadmaps that can serve as stepping stones toward achieving research campaign objectives. The Division is also leveraging the M2M missions.
- Funding – The Decadal recommends increasing BPS funding by a factor of 10. Dr. Carnell said that BPS will continue to maximize science returns with the budget available. She said an annual 30 percent budget increase would get BPS where it needs to go. She added that her priority is to ensure that research dollars are set aside for a regular award cadence so the science community can expect a solicitation every year for biology and physical sciences research. She said she is aiming for a release within the next few months.

Decadal Q&A for NAS and BPS

In response to a suggestion that grant solicitations could alternate every other year between biology and physical sciences, Dr. Carnell said that an annual cadence for both helps to bring in new researchers. She has even considered releasing solicitations twice a year. Researchers have complained that when they have only one shot a year, the timing of their data point collection can mean another year's wait. After a solicitation, the review process takes almost another year. Two years is a long time to wait to do research.

BPAC members discussed building resilience for the unexpected, including the possibility that BPS experiences a gap or has insufficient access to CLD after ISS is retired. Dr. Carnell said that discussions are already ongoing with CLDs to avoid such circumstances and BPS is keeping an eye on multiple alternatives.

Dr. Foster asked who within BPS is conducting the road mapping. Dr. Carnell replied that drafting will be done by the whole BPS team. She then wants to release the draft to the science community for suggested additions and improvements. Solicitations will not be held up until road mapping is complete, since that process can take more than a year. BPS is looking at content highlights from the Decadal along with Division priorities for a broad range of solicitations. As far as the budget process, Dr. Carnell commented that BPS is living in the current reality. NASA has been hit with a $2.5B reduction over the next two years. Once the agency moves past that, BPS can request a budget increase. Dr. Fox told Dr. Carnell that if she is sold on such a request, Dr. Fox will be a strong advocate to support it. In the meantime, Dr. Carnell said she is working on stretching budget dollars by leveraging partnerships, such as the tissue chips and LEAF projects.

Dr. Dumbacher asked how the Office and Management and Budget (OMB) staff reacted to the Decadal's $1B BPS budget recommendation. Dr. Van Vliet said OMB understands that the figure represents the whole government's investment in BPS science and the total does not have to come from one agency. OMB staff did not find the number shocking or unjustified, but said the scientific community would have a tough fight competing with other priorities. In context, however, $1B is not a big piece of the NASA budget or even the SMD, said Dr. Van Vliet. It is a matter of order and priorities, not whether that much money will be spent on research in space. She said she also briefed Senate and House appropriations staff. They were enthusiastic about the research, while recognizing there are many national priorities. She advised BPS to demonstrate its connection to national missions and for lay audiences, emphasize the M2M aspects rather than complex science. BPAC members also discussed emphasizing what science brings to life on Earth rather than answering scientific questions. Dr. Van Vliet said that the first criteria for the Key Scientific Questions was identifying a clear benefit that is recognizable to the public, not just scientists in the field. She said that funded PIs should be able to identify the benefits as well. Success must be articulated terms of societal impact in addition to traditional academic metrics of success.

Dr. Dan Tagle noted the value of addressing medical countermeasures in space, such as surgeries,

telemetries, pharmacy on demand, that can translate to better medical care access for under-resourced communities on Earth. Dr Carnell said research has been and is being done to develop capabilities such as onboard automated clinical assistance and providing pharmacy in space. BPS and HRP can work synergistically on these capabilities. For example, fundamental research could be done by BPS using the tissue chips, then HRP could take the results to the translational level. Dr. Val Vliet mentioned DARPA's Biomanufacturing: Survival, Utility, and Reliability beyond Earth (B-SURE) program as an area of synergy with BPS.

Dr. Rubins raised the topic of partnering with commercial companies to rapidly develop a technology for space where BPS instigates the teaming. Dr. Carnell said that she is already looking at available technology. She suggested creating a team to assess available technology and what it will take to get it operational, then identify gaps. Dr. Rubins commented that contracting innovations are needed to for rapid acquisitions from commercial providers within federal regulations. Dr. Van Vliet commented said that the Decadal's new office recommendation was meant to make BPS more contractually agile. BPAC members discussed existing mechanisms to streamline contracting. Dr. Carnell said that having partnerships within NASA is helpful in gaining approval for safety standards and other agency criteria.

BPAC members also discussed possible synergies with CERISS and NASA's Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems. Because timing is important, Dr. Carnell said experienced vendors are often more agile, and agility is important because it reduces costs. Dr. Dumbacher recommended that procurement decision making be delegated to the lowest organizational level possible. Dr. Ken Davidian suggested the possibility of Other Transaction Authority (OTA), a vehicle that federal agencies can use to simplify access to important technology.

Dr. Nathan Lundblad noted that funding is available across many federal agencies for quantum mechanics, quantum information, quantum sensing, quantum computing, and other quantum areas. Every other agency that deals with physical science is trying to figure out how to spend its quantum money. BPS can partner with these agencies, noting they may not be aware to what extent BPS researches quantum mechanics in orbit. NASA needs to take an equal place at the quantum table. Dr. Carnell said that on the way to implementing PFaST, she would like to see a bold middle level quantum goal accomplished within the next decade. BPS wants to lead in many areas and needs to leverage the technology development across SMD. Dr. Van Vliet said the community is ready for a collaborative effort. Much of the current quantum funding is going to commercial efforts, not fundamental science. The government can help the United States play the long game in this area.

Dr. Lundblad commented that the United States is now behind in drop tower technology. DoD is interested in drop towers and may be receptive to a collaboration. Dr. Carnell mentioned the study she has initiated to assess the important technologies for the future. A drop tower would not be built at the expense of funding for the research community, but if it is a critical infrastructure, a budget overguide request may be appropriate. One factor will be how long it would take to build a drop tower and whether the structure will still be relevant when completed. If not, it may make sense to spend the money on other pursuits. She said that the upcoming technology assessment will look at such tradeoffs.

Dr. Foster noted that NASA's ground facilities are at the agency's Centers, where access is restricted. She suggested there may be a way to make those behind-the-gate resources more widely available to the research community, such as locate some facilities at universities. Dr. Dumbacher pointed to the Texas A&M Space Institute just outside Johnson Space Center (JSC) as a model. Dr. Rubins said the Space Institute received state funding.

<u>NASA ISS Update</u>

<u>Discussion</u>

CASIS ISS Update

Dr. Michael Roberts, Chief Scientific Officer, ISS National Laboratory (ISSNL), gave a brief background of the Center for the Advancement of Science in Space (CASIS), created by Congress in 2011. Through a cooperative agreement with NASA, CASIS manages the ISSNL, engaging with the commercial and academic sectors and other U.S. government agencies. The lab offers a unique vantage point for scientific observation and technology development that expands beyond NASA's exploration goals. When CASIS approaches another organization about a new partnership or access to LEO, the conversation starts with understanding that organization's mission and whether access to ISS can accelerate the fundamental knowledge about that organization's programs.

Microgravity research and technology development has the potential to accelerate not only scientific discovery, but the translation of observations and applications for humans on Earth. The lab's portfolio includes:

- The fundamental and foundational science at the heart of BPS, as well as use-inspired, translational, transformative science. The lab is starting to focus on a better understanding of how access to LEO can inform researchers about topics such as improvements in manufacturing processes, the long-term risks of microgravity exposure, and treatment of diseases on Earth. CASIS conducts annual joint solicitations with NSF, primarily through the Directorate for Engineering. The science yields both fundamental and applied physics results, including tissue engineering and mechanobiology.
- Technology development demonstration payloads.
- In-space production applications.
- Commercial LEO development, such as maturing manufacturing technologies. Dr. Roberts commented that the lessons learned from studying the manufacturing process are as valuable as what gets manufactured. In building its portfolio, CASIS conducts market analysis to understand important research areas that require government funding because they are not ready to be turned over to the private sector. He noted there are 30+ commercial facilities in operation on ISS that provide either new or substantially improved capabilities. Those commercial providers also have the opportunity to bring their own fully funded investigations.
- STEM engagement and workforce development.

Dr. Roberts presented examples of science from the CASIS portfolio:

- Improved drawing of optical fibers in a microgravity environment.
- Analysis of crystallization experiments in space, which in turn enables advances in drug discovery, drug development, pre-clinical testing, and manufacturing.
- A partnership with Boeing that has improved the manufacture of artificial retinas to treat macular degeneration and retinitis pigmentosa.

The goal in supporting manufacturing innovations on ISS is for companies to move from phase one, where the primary sponsor is government funding, to phase two, which is early manufacturing and production with some government support, to phase three, with 80 percent or more of costs covered by the private company.

The NIH-CASIS Tissue Chips in Space Program began in 2016 and sponsored nine projects. Those investigations have led to others sponsored by government agencies and the private sector to exploit the advantage of microgravity for expanding cultivation of masses of cells, such as cardiomyocytes, that can be used for tissue culture. Researchers are now looking to exploit the space environment to grow large masses of cells that can be used as test subjects in tissue chip-like systems or for the expansion of stem cells with potential therapeutic use on Earth. The limitations of manufacturing platforms for gene therapy and other biological products on Earth make it difficult to attract investment to scale out these technologies until

investors see a clear path to sustainable expansion models. Access to space facilitates can lead to better ways of producing these products.

The ISS has proven to be a reliable, capable platform offering research and development capabilities that exist nowhere on Earth. Feeding into the building out of ISS have been a tremendous amount of ground-based research, public-private research, non-profit organizations, and the continued investment of NASA, BPS, and other government programs. ISS offers a test kitchen for CLDs to de-risk their approach for technologies. Dr. Roberts said that one of the most exciting aspects of the move to CLD platforms is a far more democratized access to space, from small entrepreneurs to large companies. This expansion will increase the return on investment that the U.S. government has made in space.

Dr. Roberts highlighted the CASIS-Boeing Technology in Space Prize, after which many small business awardees have translated the success of their microgravity experiments into new discoveries and attracted infusions of private capital. Post-flight private capital funding of companies that had ISS access totaled $231M in FY23, and $2.1B since 2011.

Dr. Roberts highlighted the NASA/BPS partnership to address national priorities such as Cancer Moonshot, and told Committee members that the collaboration will expand to study organoid-based models for other diseases, including neurodegenerative disease.

NASA and other agencies are planning the transition from ISSNL to a National Lab operating on multiple CLD platforms by the time ISS is deorbited in 2030. He termed 2020-2030 the Decade of Results in which NASA will have achieved much higher efficiency in space research. Sometime around 2026, CLDs will begin to operate in orbit. Varda has already begun studying manufacturing in space. Dr. Roberts said CLDs will offer facilities with more variability and diversity, including both crew-tended and unmanned ships. NASA is working with CLDs to avoid an operations gap by ensuring that the agency can support a transition while ISS is still operating.

Dr. Roberts encouraged BPAC members to attend the ISS Research and Development Conference, July 29-August 1, 2024, in Boston. He highlighted pre-conference workshops on space manufacturing and advanced materials. Dr. Roberts added that announcements will be made about NIH partnerships (Tissue Chips 2.0) and other programs that CASIS seeks to grow while ISS is still operating.

Discussion

BPAC members asked whether CASIS has plans to address the challenge to scale up projects on ISS. Dr. Roberts replied that ISS accommodates multiple users conducting a variety of research and does not have the capacity for scaling up onboard manufacturing. ISSNL programs are built to help derisk technologies that can then be deployed on future CLD facilities.

Dr. Weislogel asked whether private companies use the same integrators as CASIS. Dr. Roberts replied that CLD operators often use commercial service companies that have NASA for years. Experienced service providers eliminate the frustrating learning curve of a company that has not worked in space.

CLD Program

Dr. Kirt Costello

Discussion

BPAC Discussion/Wrap Up for Day 1

Because all BPAC findings/recommendations must be discussed in public, Dr. Foster opened the floor to any issues of concern that were not covered in the day's proceedings.

Dr. Simon Gilroy noted that while the Decadal sets large goals, the BPS roadmap will reveal where the agency is going. Since some programs may take two years to develop a Request for Proposals (RFP), Dr. Gilroy said it would be helpful if BPS gave PIs an idea of future areas of emphasis. Dr. Carnell said the next solicitation will include such high-level goals, although it will not be as detailed as a roadmap.

Dr. Dumbacher said that the data being gathered by SpaceX is critical to LEO development. He said he is concerned that NASA is negotiating away the data that it will need in the future. BPAC should consider feedback to BPS about the issue. Dr. Carnell said that BPS does not have control over the HLS contract with SpaceX. Dr. Sato said he will be working with SpaceX regarding data return and maximum need. He encouraged BPAC to include a finding/recommendation about the issue and said he will work with HLS to negotiate as much data as possible.

BPAC members noted that BPS may not know right now what data it needs. Trying to reconstruct that data 10 or 20 years later would not be cheap or easy. If BPS cannot procure every piece of data on the front end, it can at least pay for companies to retain the data in case it is needed. Dr. Dumbacher said that whenever taxpayers pay for an investment, historically under most NASA contracts, all of the data becomes public. In cost share arrangements with private companies, where they share part of the risk and funding, some of those data rights could be negotiated away. As an example, SpaceX will determine what data NASA receives on fluid transfer. The taxpayers have paid for part of that project. Dr. Foster made note of the issue in the findings section and said BPAC can make a recommendation. Dr. Carnell commented that Dr. Sato can take BPAC's recommendation to HLS to gain additional leverage.

Dr. Dumbacher said that NASA is actively seeking the fluid transfer data. The effort to develop a cryogenic numerical model based on real-life gravity data has been a decade-long journey. One experiment in a three-part series has been completed on ISS and another will be launched next year. This data will greatly accelerate the knowledge base. The point is, NASA is developing a sophisticated model that ironically is sought after by SpaceX to help the company develop its tank transfer design. The government is making a service available to a company and needs the data to strengthen the model for the benefit of all. BPAC members discussed the balance between pushing for data needed and being a good collaborator.

Dr. Foster emphasized the importance of having multiple CLDs, not just one. She urged the Committee to make a recommendation so that a gap is avoided in LEO operations after ISS ends its mission. She expressed concern that one company may not be able to meet NASA requirements, even if it has multiple modules. BPAC members debated whether the recommendation should be for multiple vendors or sufficient capacity. Dr. Foster suggested that multiple vendors is the safer way to go. Dr. Costello said that six viable companies are in competition for Phase 3, so the CLD field may be larger than BPAC members envision. Having multiple companies is an advantage for difficult design challenges, because when one company runs into an issue, NASA will not be dependent on that one design. Most companies are proposing some type of modularity. Dr. Carnell said that the future configuration may be one permanent CLD platform, with modules flying sortie missions.

In response to a budget question from Dr. Ali Rangwala, Dr. Carnell said that any out-year budget numbers are being reshaped during the current planning, programming, budgeting, and execution (PPBE) process. The budget totals will be the same, but funding distribution will be different and guided by the Decadal. Dr. Rangwala also asked whether SpaceX will have an advantage in obtaining scientific data from projects paid for with tax dollars because the company is carrying a payload for Artemis III. Dr. Carnell said that data belongs to NASA, not SpaceX. Dr. Rangwala asked who will regulate safety assurance and maintenance of numerous private spacecraft flying in LEO. Dr. Carnell said that the regulatory framework is still under discussion at NASA and in Congress. Dr. Rubins said that NASA has requirements for any ship that flies agency astronauts. Dr. Guenther suggested that BPAC focus on recommending an assurance model that platforms be viable and safe to conduct BPS experimentation. Dr. Carnell said that BPAC needs to emphasize that NASA must track not only when hardware launches, but whether the vehicle has the capabilities to do

experiments. NASA must also track any gap between the time ISS turns off the lights and the time when a new commercial destination is viable.

Dr. Rubins said a BPAC finding/recommendation should speak to the budget risk. The ISS program is being asked to take a 20 percent cut at its prime when the platform is producing the most amount of research. The budget must accommodate development of multiple CLDs while still funding ISS. Artemis currently takes a large chunk of that budget. Flat and decreasing funding is not going to support BPS goals. If funding falls off in the next five years, it will take BPS a long time to get experiments started on a new platform. There will be a cost to learning how to do experiments on new stations. Dr. Carnell thanked BPS for is efforts to help the agency advocate. She welcomed advice for how to frame the issue with congressional staffers. She added that the Space Flight Federation may be able to help BPS understand more about where commercial sector interests lie.

Dr. Foster encouraged BPAC members to add any additional thoughts to the ongoing findings/recommendations Google Doc for committee discussion on Day 2.

Adjourn
Dr. Foster adjourned the meeting at 5:55 p.m.

Friday, April 26

Call to Order and Opening Remarks
Dr. Robinson welcomed attendees and called the BPAC meeting to order for the second day. He explained meeting recording, audience muting, public comment, and FACA rules, and thanked the support people behind the scenes and turned the meeting over to Drs. Foster and Carnell. Dr. Foster encouraged BPAC members to continue to place their findings and recommendations in Google Docs. Dr. Carnell echoed Dr. Robinson's appreciation of behind-the-scenes staff.

Space Biology
Dr. Sharmila Bhattacharya, Space Biology Program Scientist, updated BPAC members on key activities:

Recent Space Flight Missions

- Biological Experiment 1 on Artemis 1 was a complex package consisting of two fungal experiments, one algae experiment, and one plant seed experiment to uncover genetic and biochemical pathways that confer survival advantage under spaceflight stressors. The experiment won the NASA 2023 Agency Honor Award for Group Achievement.

- Rodent Research-20 is a study of the effects of space flight on the fertility of adult female mice. The tissue of half the mice was preserved on ISS for further study. Half the mice returned to Earth alive to be bred. Their pups currently are under study and may exhibit potentially interesting epigenetic phenotypes.

- Multi-use Variable-g Platform (MVP)-Cell-02A is a fitness test during which different strains of *Bacillus subtilis* were 'raced' along solid surfaces on ISS. When returned from space, the bacteria were examined for mutation, population dynamics, and other effects of space flight.

- Microgravity Associated Bone Loss-A (MABL-A) assessed the effects of microgravity on bone marrow mesenchymal stem cells (MSCs); specifically, their capacity to secrete bone-forming and bone-dissolving cytokines. The samples were derived from 12 human bone marrow donors, including males, females, and young and old adults to compare age- and sex-related differences.

- Mouse Habitat Unit-8 (MHU-8) was a collaboration among BPS, the Human Research Program (HRP), and JAXA. It was the first Space Biology rodent mission on ISS to test partial gravity using centrifugation. The PIs will investigate multiple biological systems, including bone, muscle, cardiovascular, neuro-performance, circadian rhythms, and microbiome.

Dr. Bhattacharya listed other Space Biology experiments, highlighting plant studies, particularly plant-microbial interactions. She commented that the more science that investigators can accomplish while ISS is still operational, the better for everybody.

Recent Activities and Achievements

- Dr. Raymond Wheeler, NASA Senior Scientist at Kennedy Space Center, was named the 2023 American Society for Gravitational and Space Research Fellow. Dr. Anna-Lisa Paul, a BPS-funded PI, was honored as a Lifetime Fellow by the American Association for the Advancement of Science.
- *A Researcher's Guide to Plant Science* (2023) was published. The document describes how to conduct plant experiments in space.
- NASA Space Life Sciences Library was released for public use.
- NASA Kennedy Space Center established a partnership with the Australian Research Council, an international government/private/academic consortium that has allotted $37 million to study innovative methods for plant and food redesign to enable human deep space exploration.
- Plant Space Biology conducted a well-attended plenary session on plant biology in deep space at the 2023 meeting of the American Society of Plant Biologists.
- Space Biology is organizing a September workshop in Liverpool, U.K., along with international life sciences and European low gravity research organizations on "Plant Science for Space Exploration and Earth Applications."

Dr. Bhattacharya listed more key collaborations between U.S. government and international organizations, noting their importance in stretching BPS research dollars.

Accomplishments in Open Science

Dr. Bhattacharya explained that the Open Science Data Repository (OSDR) has three categories: The Ames Life Sciences Data Archive (ALSDA) houses physiological/phenotypic/imaging/environmental telemetry data; GeneLab houses molecular/omics data; and the NASA Biological Institutional Scientific Collection (NBISC) houses unused biological samples from missions, including microbial culture collections. PIs who submit successful applications receive samples for free.

The NASA Offices of Planetary Science and Planetary Protection, which lack their own repositories, have agreed to cost-share with Space Biology on OSDR. The repository is experiencing near-daily data growth, including contributions from international space agencies.

Dr. Bhattacharya described examples of how access to OSDR enables new discoveries:

- A new Analysis Working Group (AWG) of PIs from around the world have monthly meetings to sort through the GeneLab omics database for publication material. She said that many PIs who access the data subsequently apply for grants, including PIs who have never worked in space flight before.
- A new AWG is forming on artificial intelligence markup language (AIML).
- GeneLab will be receiving human data from Inspiration4, the first all-civilian crewed mission.
- Multi-Study VIZ, a visualization app, is available for free to anyone using NASA databases to compare data across RNA-sequencing studies.

As OSDR brings in more and different kinds of data, Space Biology must expand the repository's capabilities

for controlling access, said Dr. Bhattacharya. OSDR should be able to accommodate usage ranging from open data on animals to closed and permission-only data on humans.

Other Open Science highlights include:

- Peripheral (meta) data that support primary experiments are sometimes critical to interpreting research results. To that end, the portal RadLab provides a single point of access to radiation telemetry data from databases maintained by multiple space agencies. The Environmental Data App (EDA) is another portal where users can visualize and compare ISS cabin environmental telemetry and radiation data. Space Biology is growing storage capability for these as demand increases.

- NASA and the European Space Agency (ESA) are discussing a formal collaboration agreement to connect the GeneLab database with ESA's Human and Robotic Exploration Data Archive (HREDA). To enhance discoverability, HREDA and OSDR will cross link experiment pages and data from similar missions for one-to-one comparisons. NASA also collaborated last year to link with JAXA's Integrated Biobank for Space Life Science. PIs can see where to go for information, but cannot directly access the data.

Recent and Anticipated Funding Opportunities

- Space Biology Solicitation for Lunar Regolith (Simulant) Studies. Selectees will be given lunar simulant that resembles regolith from the lunar south pole. Researchers who show good results will be given actual regolith samples from Apollo missions to conduct a final set of validation studies.
- Space Biology Solicitation to Study How Organisms Can Thrive in Space. One experiment will take place on ISS and the second will be a ground-based radiation study.
- HRP's Recent Call in Collaboration with Space Biology. One part of this two-part call solicits information on humans, the other on rodents. The study will compare how space affects human and rodent physiological systems for a given set of parameters or phenotypes.
- Consortium in Biological Sciences. The call is in response to congressional appropriations legislation directing NASA to establish a consortium, including academic institutions, with demonstrated expertise in the human health, animal, and plant sciences. The call is scheduled for release in May 2024.
- Space Biology's Upcoming Annual Research Opportunities in Space and Earth (ROSES) Solicitation will focus on Decadal recommendations.

Science Highlights

Dr. Bhattacharya gave highlights of published research on:

- The adverse effects of spaceflight on mouse eyes.
- How genetic diversity modulates the response of skeletal muscle to simulated microgravity in male mice. A large divergence was noted among eight different mouse strains after hind limb unloading.
- Sex differences in the muscle health of rats in simulated micro- and partial-gravity environments in rats. Females showed a larger detriment. Removal of the ovary did not affect the outcome.
- Using Open Science databases to increase the impact of research. This study of glycogen synthase kinase 2 as a potential target to mitigate spaceflight impacts on muscle and bone loss drew on tissue from NBISC and the Biology Biospecimen Sharing Program.
- Research into telomere function related to plant survival in harsh environments. Results indicate a novel protective function of the telomerase enzyme.
- A study of plant response to flooding, which is mediated by calcium acting through a protein called Cation Exchanger 2 (CAX2). Research is aimed at engineering plants to thrive in space.

- Research into the effect of modeled microgravity's effect on innate immunity by studying the interaction between the Hawaiian bobtail squid and the beneficial bacterium *Vibrio fischeri*. Results reinforce previous findings that spaceflight could negatively impact innate immunity.

Dr. Bhattacharya summarized Space Biology's primary areas of interest as mitochondrial dysregulation and metabolism; epigenetics; understanding the effects of genetic diversity, sex-specific changes, and multigenerational systems; and crops for the future as a sustainable way to exist beyond LEO. Research into using tissue chips and organoids, model organisms, and plants will help NASA look beyond ISS and LEO. A challenge, however, is to make things work with a flat or declining budget.

Discussion

Prompted by a question on validating ground-based mouse experiments in space, Dr. Bhattacharya commented that funding is one of the biggest challenges for research on the ISS. Although rodent studies can be impactful, they take a lot of resources. Space Biology has had to cut back the number of solicitations involving rodents, especially as activity increases on ISS. Dr. Bhattacharya pointed out that as space research moves into the CLD world, NASA is not assured that it will be able to place rodent research hardware on CLD platforms. This raises concerns over how much fundamental research will take place. More ground studies can be done, but eventually, NASA will want to validate results in LEO.

Human samples are also costly to obtain and study inflight. BPAC members discussed funding solutions for human and human-rodent comparison studies, such as collaborating with HRP through Open Science databases and road mapping mutual goals. Dr. Bhattacharya commented that if she could do one thing differently about space biology, it would be adding the ability for a PI to replicate experiments to ensure that data is repeated through different missions. BPAC members again brought up experiments "in the pantry," where material is placed in cold storage awaiting use. Committee members also discussed a new approach called "science on demand," where materials are sent to space when storage room is available to await later use.

BPAC members also discussed international collaboration as way to stretch funding. Dr. Bhattacharya mentioned the International Space Life Sciences Working Group, which meets twice a year. The working group was originally comprised of ISS partners, and has an expanding membership. Space Biology attends working group meetings. Each partner describes its capabilities. Open Science was strengthened as group members connected their databases. She described two ways to form a partnership—an agreement similar to that between NASA-JAXA for the MHU-8 rodent mission, and joint research solicitations that cross international borders that allow PIs from different countries to work together. Dr. Bhattacharya said that Canada and the DLR (German Aerospace Center) are talking with NASA about how they can build lunar habitats for plants. Once the infrastructure is in place, organizations can solicit for research to be done there.

Dr. Bhattacharya explained that NASA solicitations allow for responses by PIs from international organizations, although NASA fund pay for those PIs' work. Funding for these projects work best when the PIs from other countries have buy-in from their own space agencies. Dr. Aleksandra Radlinska pointed to two projects from her lab that illustrate the benefits international collaboration. One project was a spinoff of BPS-funded research and resulted in international collaboration with ESA. These second project, scheduled to fly in autumn 2024, is a continuation of research funded by NASA and will involve use of material already stored on ISS.

Dr. Dumbacher asked whether NASA has given the CLDs the microgravity design and program requirements so the companies can support agency research. Dr. Bhattacharya said NASA has provided requirements for rodent habitat, plants, and tissue culture. The agency has no way of being sure that a CLD provider is going to pick up the requirements to do these studies onboard. How requirements get prioritized is not up to NASA. The agency has not, however, issued an RFP that includes requirements. The BPS representative to the CLD

program began rigorous requirement development in autumn 2023 and is working on a detailed requirements document that the CLDs were scheduled to receive in May 2024. Dr. Rubins suggested that the CLD program create an insight team to pass on best practices knowledge for operating equipment.

Physical Sciences Status (Fluids, Combustion, and Materials)
Dr. Brad Carpenter, Program Scientist for Fundamental Physics, updated BPAC on his program's activities.

Science Highlights

Fire Safety – Dr. Carpenter informed BPAC members about an experiment to explore fire safety in space using the drop facility at NASA's Glenn Research Center. The study looked at differences in the effects of 1G and microgravity on solid fuel combustion to understand flame spread on solid fuels. In a hot flame, there is expanding gas that is less dense than the surrounding gas. It rises in a gravitational field, but does not rise in microgravity. This results in large differences between flame spread in microgravity and flame spread on Earth. In gravitational environments like those found on the Moon, there is a unique balance between the loss of heat in reaction to gas that is pulled in as a weak but present microgravitational effect, and the heat that is needed to keep the flame going.

Understanding these processes is important for lunar habitation environments, which will have oxygen concentration percentages in the high 30s. In those environments, many things that are not flammable on Earth, such as Kevlar, become extremely flammable. Hair also burns amazingly well. Fire safety is critical, including understanding how fires start, spread, and can be extinguished, as well as sourcing materials that are safe to use in that environment.

Dr. Carpenter described the experiment logistics for using the drop rig. The testing allows researchers to pull out the important parameters for sustaining a flame in microgravity. Researchers have been able to conclude that external flow and heat transfer to the solid are both important factors in flame quenching and that current numerical models cannot predict flame extinction limits. That will require more detailed reaction kinetics and inclusion of radiation effects.

Thermal Fluids – The Fundamental Physics team is planning an inflight experiment on ISS in 2027 called the Flow Boiling and Convection Experiment – Transfer Line. The experiment will study the transfer of cryogenic fuels between vehicles. The Government Accounting Office called out this transfer ability as a critical capability for exploration missions, including a return to the Moon. One unsolved problem is handling the vapor that results from fuel boiling during transfer from a fuel depot tank to a spacecraft. Researchers will build a model of heat transfer to study regime changes along the chill path of the fuel transfer line. Physical Science's contribution is conducting basic science to help engineers improve processes and meanwhile, train Ph.D. engineers who can take on the practical aspects of designing systems for cryogenic fluids transfer in orbit.

Microgravity Effects in Glass Formation – Effects studied include thermophysical properties, atomic structure, glass formation, and crystallization. The study, which is primarily remotely operated, uses the JAXA electrostatic levitation furnace (ELF) on ISS. JAXA provided ELF access to PIs for free. The experiment used neodymium titanate glass, which has good transparency in the infrared. By contrast, fluoride glasses have many complications, including water solubility and lack of strength. Neodymium titanate glass has been difficult to form on Earth. The glass spheres were processed in space, then brought back to Earth for analysis. X-ray results show that the atomic structures of glasses were nearly identical for Earth and microgravity processing conditions. This provides validation, at least for rare-earth titanates, that the same glass can be manufactured in space as on Earth.

Key Decadal Takeaways for Physical Sciences

Some Key Scientific Questions identified in the Decadal are compelling, important, and a good foundation for the next generation of research:

- What are the relevant chemical and physical properties and phenomena that govern the behavior of fluids in space environments? This includes cryogenic fuels transfer.
- What are the mechanisms by which organisms sense and respond to the physical properties of surroundings and to applied mechanical forces, including gravitational force? This question provides opportunities to interact more closely with the Space Biology community across the boundary between the traditional physical sciences and life sciences.
- What are the fundamental principles that organize the structure and functionality of materials, including, but not limited to, soft and active matter? This is a foundation for material sciences that will not be disappearing for the foreseeable future.

Actions that Physical Sciences needs to take include:

- After a decade, return to regular solicitations to reignite the relationship with the research community. The hope is that five years of regular solicitations will form a cohesive community.
- Plan research for alignment with the space exploration program, including bringing sustainable exploration into Physical Sciences' research focus. Sustainability must fit mass, performance, and safety requirements.
- Look for deeper collaborations with biological sciences. The Decadal Committee was brave to put development of recommendations in the hands of mixed communities.

Next Steps

ISS research is drawing down. Physical Sciences is looking to the future with:

- FM2 – Flammability of Materials on the Moon, an experiment payload aboard a lunar lander to conduct flammability tests of material in lunar gravity and 37% O_2. This work is important due to the enhanced oxygen environment that will be part of human habitation on the Moon.
- Returning to regular research solicitations, beginning with a small budget in 2025 that will grow substantially in 2026.
- Working internally on big, hairy, audacious goals as part of the program's response to the Decadal. These goals should be at the boundaries of what the program can accomplish. Dr. Carpenter said that Dr Carnell has been pushing the program to come up with ideas and refocus for the next generation of human space flight.

Discussion

In response to a question on student engagement, Dr. Carpenter replied that Physical Sciences' research awards will be largely ground-based, but the Program will also develop ideas for flight experiments and international facilities in Europe. One thing that has been traditional in the physical sciences is a strong theory program, which helps build competencies for the next generation of experiments. Dr. Carpenter said that in the past, Physical Sciences had a large presence in graduate student research programs. He commented that Physical Sciences should not spend all of its research funding in ROSES, and put some resources into the Future Investigators in NASA Earth and Space Science and Technology (FINESST) research awards.

Dr. Rubins underscored the importance of flammability studies in determining the balance of oxygen and pressure in space suits to avoid decompression sickness. She said that there is a campaign at JSC to test what amount of pressure in space suits still allows for mobility and dexterity. An underlying challenge is the

uncertainty about the flammability at higher oxygen contents. Physical Sciences' fundamental research in fire safety and cryogenic fuel transfer addresses two of the largest headaches in the Artemis program. The flammability research will support the entire Artemis architecture, in every single vehicle. She thanked Dr. Carpenter for his Program's work.

Dr. Rubins also suggested that synthetic biology is a prime area for the physical and biological sciences to interact. She noted that NASA's Translational Research Institute for Space Health (TRISH) is commissioning a roadmap for synthetic science at NASA. She also highlighted the Synthetic Biology: Engineering, Evolution & Design (SEED) conference in Georgia in June 2024 as the main engineering/synthetic biology conference.

BPAC members discussed cryogenic fuel transfer issues and challenges, including the fact that the size of tanks and transfer lines in NASA spacecraft are meters across, while experiments that can be done in space are at a much smaller scale. Excellent theory is needed for researchers to feel confident that experiments observed about soup can-sized tanks will be informative. Research on fuel transfer issues are fundamental to getting Artemis III off the ground, commented Dr. Weislogel, and people have a hard time recognizing that fact. He said that bubbles and droplets in microgravity are also important factors. Even lunar and Martian G levels may produce some fuel-related surprises. Dr. Carpenter said that lunar and Martian gravity can be modeled on the ground, but it requires a partial G drop tower, which NASA does not have. Dr. Rubins said this is a fundamental facility issue for NASA and Artemis. BPS should not bear the entire cost of such a drop tower since multiple Directorates need the facility. Dr. Weislogel said that the volume of future drops needed would likely justify the cost. A partial drop tower would be of national interest, including to other federal organizations such as the Department of Defense (DoD). Dr. Rubins called fire an astronaut-killer and program-ender, and said the edges of the envelope for partial gravity have not been explored across lunar and Mars and at higher oxygen concentrations. These underly the entire basis of the exploration program. She said that NASA needs to provide the resources for BPS to do the experiments. BPAC members discussed how the flammability and cryogenic fuel issues touch many aspects of NASA operations. There is a lack of cultural awareness across the agency of the importance of these issues and the need for fundamental research to address them.

Public Comments

Dr. Foster provided an opportunity for public comments. A member of the public inquired through the chat function whether there are any experiments comparing drop towers with other microgravity simulators such as a random positioning machine (RPM). BPAC members were not aware of research making extensive comparisons among drop towers, RPMs, and High Aspect Rotating-Wall Vessels (HARVs).

Fundamental Physics

Dr. Michael Robinson, Fundamental Physics Program Scientist and BPAC Executive Secretary, began by relating the science timeline from Albert Einstein's theory of general relativity, through advanced telescopes and spectroscopy, which revealed that the galaxies outside the Milky Way are moving away, up to today's understanding that dark matter and dark energy comprise 95 percent of the mass-energy content of the universe. Experiments on the ground to study dark energy and matter are have produced little information about their nature.

Fundamental Physics aims to conduct transformational experiments that require the unique environment of space, including work on microgravity, long baselines, and gravitational potentials. The portfolio seeks to understand the nature of dark matter and dark energy and why the two titans of modern physics—quantum mechanics and general relativity—do not synchronize. Physical Sciences has been developing tools, such as cold atoms, atomic clocks, atom interferometry, and quantum entanglement, that are all exquisitely sensitive on the ground. If they are sent into space, some of them become much more sensitive and can operate in a regime free of Earthly the influences.

Dr. Robinson provided a brief explanation of cold atoms. He noted that the difference between the temperature of the Sun's surface and outer space is only about four orders of magnitude. The difference between outer space and the temperatures reached in a cold atom lab is about 11 orders of magnitude. Dr. Robinson said that cold atom experiments are the workhorse of most of the techniques for atom interferometry and optical clocks.

Cold Atom Lab (CAL) Update. CAL researchers have observed dual species atom interferometry for the first time. This is important because it is a pathfinder to doing fundamental physics, such as measuring dark matter and dark energy and testing the equivalence principle. Other potential applications include geodesy, gravitational wave detection, precision navigation (DoD has expressed interest in this), and other fundamental physics areas of interest to a variety of federal agencies.

Current Projects

Bose Einstein Condensates & Cold Atoms Lab (BECCAL) is a collaboration with DLR and a follow-on to CAL, with upgrades that will allow fundamental physics experiments in microgravity as well as equivalence principle tests, dark energy searches, and many-body physics. Hardware is scheduled to be available in 2027. DLR is building the hardware and NASA is conducting the launch. The intent is for the organizations to split PI time on it. There is potential for hardware to be placed on ISS or CLD. NASA will also collaborate with DLR on direct detection of dark energy in the Einstein Elevator (D3E3). The first drop is scheduled for 2025.

Atomic Clock Ensemble in Space (ACES) is a collaboration with ESA that has not launched due to delays, but is scheduled to be delivered by SpaceX-32 in February 2025. ESA is building and launching the ensemble. The National Institute of Standards and Technology (NIST) and JPL will operate BPS-funded ground stations to transfer time. Moving clocks tick differently than stationary clocks, explained Dr. Robinson, so general relativity must be taken into account and clocks synchronized. The clock is a 10^{-16} Cesium atomic clock and will support experiments that include testing the equivalence principle and understanding the constancy of nature.

Space Entanglement and Annealing Quantum Experiment (SEAQUE) is a technology demonstrator for a larger program called the Deep Space Quantum Link, which is studying how quantum mechanics and general relativity relate to each other. SEAQUE will demonstrate the source of entangled photons and validate laser annealing to repair single-photon-detectors. The expected launch is September 2024 aboard SpaceX-31. This will be the first U.S. quantum entanglement experiment in space.

Selections From ROSES 2022 – These will include three new CAL flight investigations and four new ground investigations, which are the beginning of a healthy, robust research program in clocks, interferometry, and entanglement. Dr. Robinson said that he hopes to restore the annual cadence of fundamental physics awards.

Decadal Survey – Fundamental Physics

Scientific Question 11 asks: What new physics, including particle physics, general relativity, and quantum mechanics, can be discovered with experiments that can only be carried out in space? These areas include a search for new physics with clocks and gravitational effects on quantum optical systems and detectors. The work that Physical Sciences wants to do in fundamental physics is well justified in the Decadal.

Future Portfolio – Dr. Robinson emphasized that quantum science is a popular area, pointing to the National Quantum Initiative and the hundreds of millions of dollars being attracted to the area. Although much of the activity is in quantum computing and industry, there is also a lot of activity in Fundamental Physics' areas of interest, which comprise mostly quantum sensing:

- The Program staff have met with multiple groups and heard interest expressed by the National Science Foundation (NSF), DoD, DLR, and ESA.
- The Program established a Fundamental Physics Analysis Group with an Executive Committee made up of a who's who in atomic clocks, atom interferometry, and general relativity.
- The Program has also reached out to the Astrophysics Division's Physics Program Analysis Group, which will meet with the Fundamental Physics Analysis Group.

Soft Matter

Dr. Robinson described soft matter as a substance that is soft and flexible, but with a great deal of complexity, such as non-Newtonian fluids. The viscosity depends on the stress or force applied. Foams, polymers, granular materials, colloids, gels, and liquid crystals are all soft matter. It is a hugely broad field that ranges from the interstitial fluid in blood and cells to the granular material found on the Moon.

From the Fundamental Physics perspective, soft matter is categorized as:

Granular media, such as lunar regolith. Studies can include developing a fundamental model describing rheology under different gravity conditions or understanding the impact of size, shape, and electrostatic charge on flow behavior.

Active media, which may involve development of functional soft materials (e.g., a DNA functionalized colloidal particle) or understanding the interplay of competing microscopic forces in active matter. When experiments are done on Earth, researchers must deal with convection and buoyancy. Gravity dominates the short-range forces of interest. In microgravity, these short-range molecular forces dominate behavior, leading to 3D structures different from 2D assemblies seen in a terrestrial environment.

Dr. Robinson described the Soft Matter Program as currently treading water. Most, if not all, awards have ended, although papers are still coming out based on experiments done in the last decade. New studies are being done at NASA's Glenn Research Center, where research is underway on new techniques for inexpensive and compact microscopy. For example, an advanced colloid experiment ran on ISS and involved colloid spheres in microgravity that self-assembled into a perfect face-centered cubic lattice, which cannot be accomplished on the ground. An example of an application for the process is making tailored photonic crystals.

Fundamental Physics is also collaborating with NSF and DLR on the dusty plasma experiment. DLR is building the hardware for a planned NASA launch in 2028 to ISS or CLD. PI time will be divided into 50 percent DLR, 25 percent NASA, and 25 percent NSF. Such collaboration has significantly added to the Fundamental Physics portfolio. Dr. Robinson commented that granular studies are hard enough on Earth, where conditions are well controlled. Experiments with lunar dust being bombarded by solar wind and cosmic rays in one-sixth of Earth's gravity can create difficult dynamics.

Decadal Survey – Dr. Robinson said that work in soft matter can affect many topics in the Decadal's Key Science Questions, including those covering life sciences, particularly where the physics of microgravity may affect biological issues.

Dr. Robinson concluded by presenting a list of fundamental physics and soft matter publications over the last year.

Discussion

Dr. Robinson clarified that BPS is providing the funding for NASA's 25 percent of the dusty experiment PI

team.

He also clarified that Fundamental Science's 30-year vision is to have a network of optical clocks in space, including in lunar orbit, to function as a GPS for the solar system and test gravitational theories. The vision also includes a network of atom interferometers for geodesy, position navigation, and timing, as well as fundamental physics, including the search for dark matter.

Dr. Rubins asked whether Fundamental Physics plans to use Artemis to deliver experiments to the lunar surface. Dr. Robinson said that some experiments could be done on the Moon, but the more interesting approach is to put them into orbit. He added that he has been considering for the last year where experiments should be done, what theory to test, who could be potentials collaborators, and in what orbit experiments should take place. The program is in the nascent stages of working out these logistics. Dr. Rubins said that one BPS finding/recommendation should be that Gateway design be compatible with these kinds of experiments. The Committee discussed that the success of CAL is due to its capacity for a unique environment.

BPAC members also discussed the fact that experiments like the upcoming ROSES investigations are the seed corn for future flight experiments—a connection that is not always made when considering ground-based experiments.

Dr. Robinson refined his description of CAL to add that not only is it a pathfinder for future discoveries, but a workhorse for understanding quantum science in microgravity. Before the Decadal came out, quantum science was already a focus area of BPS. While the annual cadence of Fundamental Physics NASA Research Awards (NRAs) is in the planned budget, soft matter is not specifically included. Dr. Robinson said his hope is that there will be NRAs for soft matter.

BPAC matters acknowledged that right now, the BPS budget does not pay for launch costs, hardware builds, and telemetry. BPS can take advantage of ISS partners through 2030, but after that, who will pay for all of those costs? BPS must pay attention to planned programs such as the LEO National Lab to watch how resources are allocated and who gets priority. Such decisions may limit how much research BPS can do on a CLD. BPS has a mission as an agency. CLD operators have a mission to generate revenue. They will have to account for all expenses. Someone must pay the bills.

BPAC Discussion

At Dr. Carnell's request, Dr. Foster said she will turn BPAC findings and recommendations into a slide presentation. Committee members spent the next 15 minutes polishing the draft material in Google Docs for the meeting outbrief.

Before presenting committee findings/recommendations, Dr. Foster noted that BPAC members would have a May 3 deadline for editing the Google Doc. After creating the draft presentation slides, she will distribute the document to members for editing. She cautioned that FACA rules forbid the addition of concepts not discussed during the public meeting.

BPAC Outbrief

Dr. Foster presented BPAC's 12 major findings:

1. Concern about the lack of control or oversight of what kind of data BPS is obtaining from SpaceX. There seems to be a lack of transparency that may cause a problem for post-flight analyses and critical data sharing for the whole LEO space economy as well as be inconsistent with Open Science policies. Renegotiations or greater effort to obtain data may be needed.

2. BPAC appreciates the budget constraints that BPS is under, but is concerned with a limited agency budget that could impact capacity and momentum of BPS experiments. This may, in turn, cause serious technical or schedule threats to Artemis, since so much of the mission depends on fundamental BPS knowledge being gathered.

3. There is a risk that the Commercial Low Earth Orbit (LEO) Destinations (CLDs) will not meet the current capacity and capabilities of the ISS for some time. That may generate not only significant time lags, but could create a back log and reduce the overall amount of science being done on the ISS. This represents an important risk that needs to be evaluated.

4. There are two facets to road mapping activities. One is a concern that the road mapping might not happen in time for the science community to truly understand BPS priorities. Perhaps there can be some sort of road map fast-tracking before the new initiatives are released. This couples with a concern about a possible time crunch created between the end of ISS and the ramp-up of the CLDs to maturity. The degree of challenge depends on how long road mapping will take.

5. The Decadal Survey recommends a significantly increased research budget. This can come in the form of additional funding, partnerships, or other creative methodologies.

6. The planned cuts to the annual ISS operating budget are estimated to be approximately 20 percent, which may significantly constrain the amount of science that can be accomplished in the final years of ISS despite the fact that this is now a mature and productive platform. That might represent an additional risk to getting BPS science done.

7. BPS experiments are subject to program schedules and priorities outside the control of BPS and this represents a risk to the agency's priorities.

8. Space biology requirements must be conveyed from the BPS arena into the CLD arena, including best practices learned from space station research.

9. There is a critical need for construction and access to partial gravity drop towers to test key physical processes, such as combustion under these partial gravity conditions to support upcoming missions like Artemis. This includes getting more access to the European platforms or collaborating with other entities to create a resource that NASA can have to address these issues.

10. To uphold the advancement of fundamental physics in space-based environments beyond the ISS, future platforms like Gateway must have the infrastructure necessary to support fundamental physics research.

11. Student training and engagement is critical to the long-term success of mission, as is more leveraging of funding.

12. Leverage international collaboration wherever possible to expand research capabilities.

Dr. Foster said that BPAC created about 30 recommendations in rough form that will be polished and associated with the appropriate findings when put into slide form. Dr. Carnell said BPAC's work is incredibly valuable. She expressed appreciation for the candid discussion and advice.

Wrap Up for Day 2

Dr. Carnell informed BPAC members that although a date and time has not been set for the next BPAC public meeting, she expressed a preference for and in-person gathering in the fall.

Dr. Foster explained that she will present the BPAC findings and recommendations to the SMD Science Advisory Committee at their fall meeting and suggested that BPAC hold its next meeting before then. Dr. Radlinska suggested that BPAC create a brief video highlighting BPS accomplishments over the last year as a way to reach a broader audience. Dr. Foster directed that Dr. Radlinska's suggestion be added to the recommendation list.

Dr. Carnell thanked meeting attendees and BPAC members for contributing their time and being so engaged.

Adjourn

Dr. Foster adjourned the meeting at 2:47 p.m.

Appendix A
Participants

Biological and Physical Sciences Advisory Committee

Lisa Carnell, *Biological and Physical Sciences Division Director*
Mike Robinson, Biological and Physical Sciences Division, *Executive Secretary*
Jamie Foster, University of Florida, *Chair*
Ken Davidian, Impossible Research LLC
Will Davis, Office of Equal Opportunity and Diversity, NASA Headquarters
Dan Dumbacher, American Institute of Aeronautics and Astronautics
Simon Gilroy, University of Wisconsin, Madison
Mary Guenther, Commercial Spaceflight Federation
Nathan Lundblad. Bates College
Maren Mossman, University of San Diego (attended remotely)
Aleksandra Radlinska, State University (attended remotely)
Ali Rangwala, Worcester Polytechnic Institute
Kate Rubins, NASA Astronaut
Dan Tagle, National Center for Advancing Translational Sciences
Petia Vlahovska, Northwestern University
Mark Weislogel, IRPI LLC

Attendees at Headquarters
Sharmila Bhattacharya, NASA
Jennifer Buchli, NASA
Brad Carpenter, NASA
Francis Chiaramonte, NASA
Michelle Hanssen, NASA
Lynn Harrison, NASA
Paul Herr, NASA
Ursula Koniges, NASA
Julie Lele, NASA
Diana Ly, NAS

Webex Attendees –

NASA/JPL

Kelly Bailey
Ralph Beaty
Elison Blancaflor
John Callas
Lisa Scott Carnell
Melanie Dalby
Griffin Farris
Haley Fauntleroy
Ursula Koniges
Gamble Gilbertson
Amy Gresser
DeVon Griffin
Inseob Hahn
Kevin Hames
Hans Hansen
John Howard
Emily Johnson
Danielle Lopez
Melanie White Lyons
Keara Mangan
John Mcquillen
Michael Roberts
Mike SanSoucie
Kevin Sato
David Urban
Mary Walsh
Alan Wood

Webex Attendees – Non-NASA/Unknown

Alice Chien
Deborah Eby
Alec
Debjyoti Banerjee
Richard Barker
Alice Chien
Robert Corbin
Dennis Discher
Jemie Lee
James Lochner
Jason
Yoseline Angel Lopez
Lovorka
Megan
Monsi
Arul Mozhi
Kenneth Neiss
Ryan

Sarah
Victor Schneider
Jana Stoudemire
Suman
Katy Summerlin
Ivan Vidal

Appendix B
Biological and Physical Sciences Advisory Committee Members

Lisa Carnell
Biological and Physical Sciences Division Director
Science Mission Directorate
NASA Headquarters

Mike Robinson, Executive Secretary
Biological and Physical Sciences Division
Science Mission Directorate
NASA Headquarters

Jamie Foster, Chair
University of Florida

Ken Davidian
Impossible Research LLC

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Simon Gilroy
University of Wisconsin, Madison

Mary Guenther
Commercial Spaceflight Federation

Nathan Lundblad
Bates College

Maren Mossman
University of San Diego

Alexsandra Radlinska
Pennsylvania State University

Ali Rangwala
Worcester Polytechnic Institute

Kate Rubins
NASA Astronaut

Dan Tagle
National Center for Advancing Translational Sciences

Petia Vlahovska
Northwestern University

Mark Weislogel
IRPI LLC

Appendix C
Presentations

1. Moon to Mars: Mission Considerations for Future BPS Science Research, *Kevin Sato*
2. BPS Status Update, *Lisa Carnell*
3. 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*
4. NASA Initial Decadal Survey Response, *Lisa Carnell*
5. ISS Program Update, *Jennifer Buchli*
6. ISS National Lab Update, *Michael Roberts*
7. CLD Program, *Kirt Costello and Angela Hart*
8. Space Biology Program Update, *Sharmila Bhattacharya*
9. Physical Sciences Status, *Brad Carpenter*
10. BPAC: Fundamental Physics and Soft Matter, *Mike Robinson*

Appendix D
Agenda

Biological and Physical Sciences Advisory Committee
Mary W. Jackson NASA Headquarters Building
300 Hidden Figures Way
Washington D.C. 20546
Virtual WebEx
Conference Room 1Q39

Thursday, April 25th		
(Eastern time)		
9:30 AM	Call to Order and Administrative Remarks	Mike Robinson
9:35 AM	Welcome and Opening Remarks	Nicky Fox; Lisa Carnell
10:00 AM	Introductions	Jamie Foster and BPAC members Clevette Lee
10:10 AM	FACA	Kevin Sato
11:10 AM	Ethics	
11:40 AM	Artemis	
12:10 PM	Lunch	
12:15 PM	Public Comment	Lisa Carnell
12:45 PM	BPS Update	Robert Ferl and Krystyn Van Vliet Lisa Carnell
1:15 PM	Decadal Survey	BPAC Members
1:45 PM	Initial BPS	
2:45 PM	Response	
3:00 PM	Decadal Q&A for NAS and BPS	Jennifer Buchli
3:30 PM	Break	Michael Roberts
4:00 PM	NASA ISS	Kirt Costello/Angela Hart
4:30 PM	Update CASIS	
4:45 PM	ISS Update CLD	BPAC Members
5:15 PM	Program Break	
5:20 PM	BPAC Discussion	

Friday, April 26th		
10:00 AM	Call to Order and Opening Remarks	Mike Robinson; Jamie Foster/Lisa
10:10 AM	Space Biology	Carnell Sharmila Bhattacharya
11:10 AM	Fluids, Combustion, and Materials	Brad Carpenter
12:10 PM	Lunch	
12:40 PM	Public Comment	
12:45 PM	Fundamental Physics and Soft Matter	Mike Robinson
1:15 PM	BPAC Discussion	BPAC
2:15 PM	BPAC Outbrief	Members Jamie
2:25 PM	Wrap up for Day 2	Foster
2:30 PM	Adjourn	