National Aeronautics and
Space Administration

2024 CoPP Fall Meeting

Update on NASA's Planetary Protection Research Portfolio

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December 4, 2024
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Agenda

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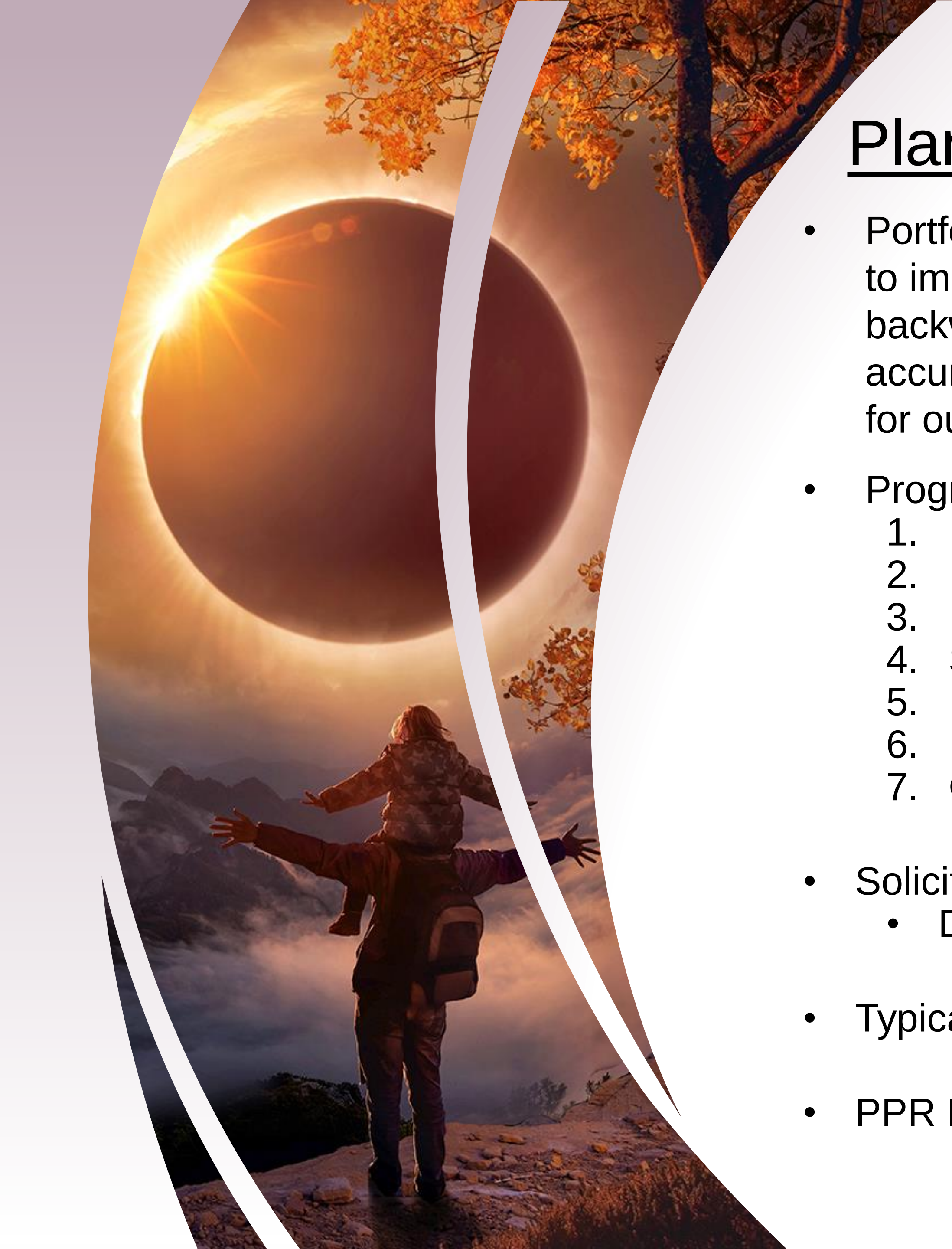
PPR Program Overview



Planetary Protection Research (PPR)

- Portfolio supports mission-enabling and capability-driven research required to improve NASA's understanding of the potential for both forward and backward contamination; and improve methods and technologies for accurate, efficient, and effective minimization of biological contamination for outbound spacecraft and return samples

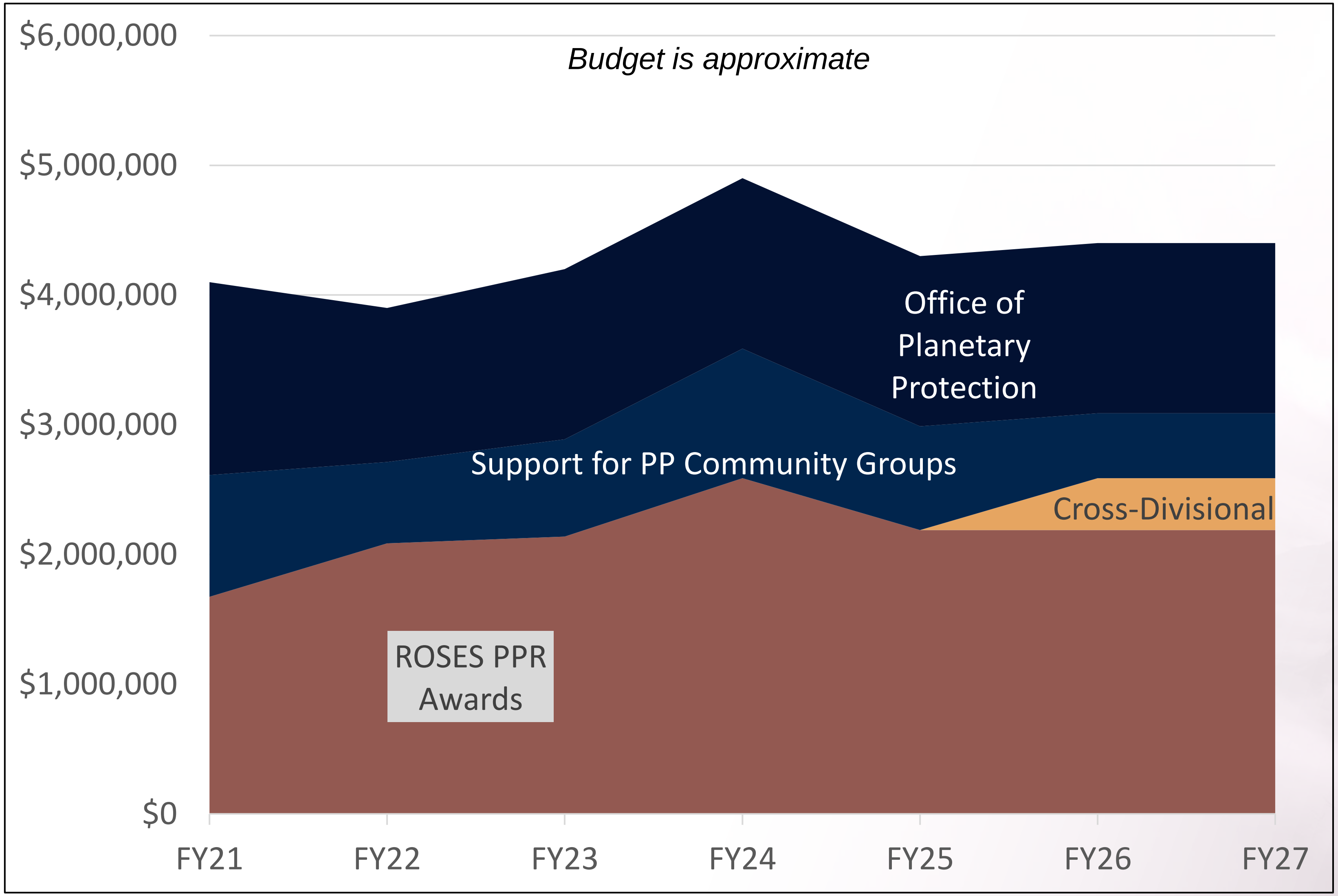
- Programmatic priorities:
  1. Planetary conditions controlling transport
  2. Detection and classification of terrestrial microbes
  3. Predict biodburden level
  4. Space environment impact on contamination
  5. Improving ways to meet planetary protection requirements
  6. Measure reduction of bioburden viability
  7. Characterize limits of life in relevant environments

- Solicited Annually in ROSES: **C.15/Planetary Protection Research**
  - Dual Anonymous Peer Review (DAPR)

- Typically select ~4-8 proposals per year (~$1.5M per year)

- PPR Program Scientist: David J. Smith (hq-ppr@mail.nasa.gov)

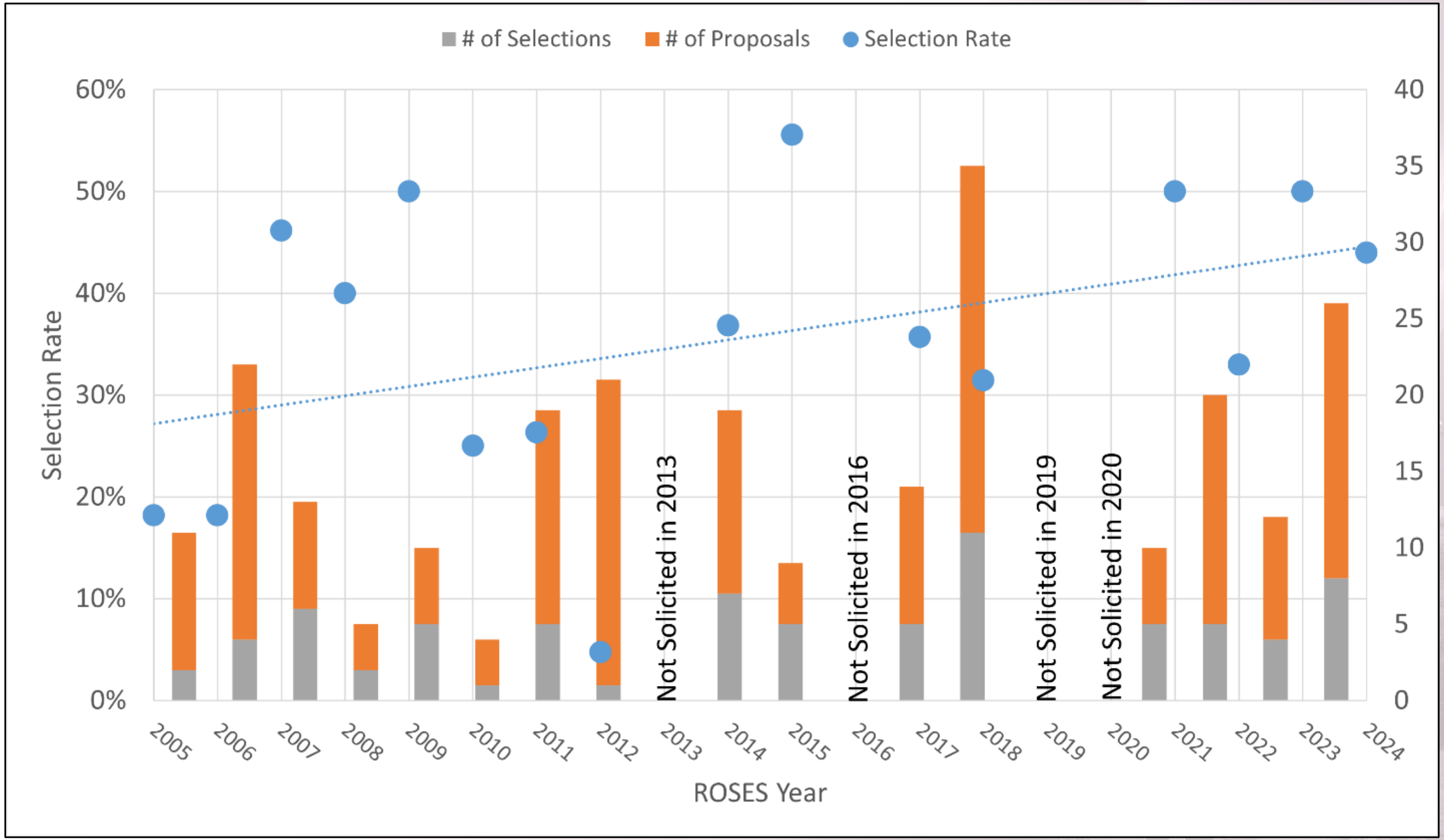
PPR Program Budget



- PSD budget remains healthy for ROSES PPR awards
- Cross-Divisional support planned
  - Space Microbial Culture Collection at NASA Ames, leveraging an established BPSD/Space Biology resource
- SMD is continuing robust support for OSMA's Office of Planetary Protection
- SMD is continuing support for community groups and inputs, e.g., NASEM CoPP

PPR Proposal Submission and Selection Rates

- Previous decade (2012-2021) PPR solicitation cadence was irregular. Variability created challenges for researchers.
- Since ROSES 2021, PPR has been solicited annually. Stability should assist with growing community & pace of research progress.
- Selection rates for past two cycles: 44-50%.
- Total number of proposal submissions was substantially higher for ROSES 2024.



Recent Planetary Protection Research Awards

ROSES 2021

1. Investigating Far-UVC Radiation to Reduce Microbial Burden During Spacecraft Assembly
2. Effects of Frost-Cycling on Microbial Survival and Growth under Simulated Martian Conditions
3. Rapid Sterilization of Spacecraft Hardware Using High Photon Fluxes from Femtosecond Pulsed Lasers
4. Survivability of spacecraft-associated microbes under simulated radiation environments of Europa and other icy moons
5. Development of In-Flight and In-Situ Microbial Sterilization System using UV LEDs and Heaters to Prevent Re-contamination and Cross-contamination

ROSES 2022

1. Metagenomic Methods for Meeting NASA's Planetary Protection Policy Requirements on Future Missions
2. Modeling the Transport of Microbe-Laden Particles in Plume Flows on Mars and Icy Moons
3. A Pilot Study on Forward Contamination in Planetary Analog Environments
4. Windblown Mineral Grains as a Source of Natural Transport of Biological Contamination
5. Responses of Microbial Isolates from Spacecraft Assembly Facilities to the Chemical and Physical Conditions of Mars and the Ocean Worlds

ROSES 2023

1. Impact of Rapid High Heat and Space Conditions on Proliferation and Inactivation of Self-Perpetuating Biomolecular Assemblies
2. Portable Active Plasma Sterilization system as a toolkit to reduce microbial contamination for space applications
3. Rapid Sterilization of Spacecraft Hardware Using High Photon Fluxes from the Newest Generation of High Power, High Repetition Rate Femtosecond Lasers
4. Devising Defenses: Curtailing Microbial Risks (CMR) in a Closed Human Habitat and Spacesuit Fabrics

Total PPR Portfolio includes 23 active awards that received funding in FY 2024-2025

ROSES-24 Selections

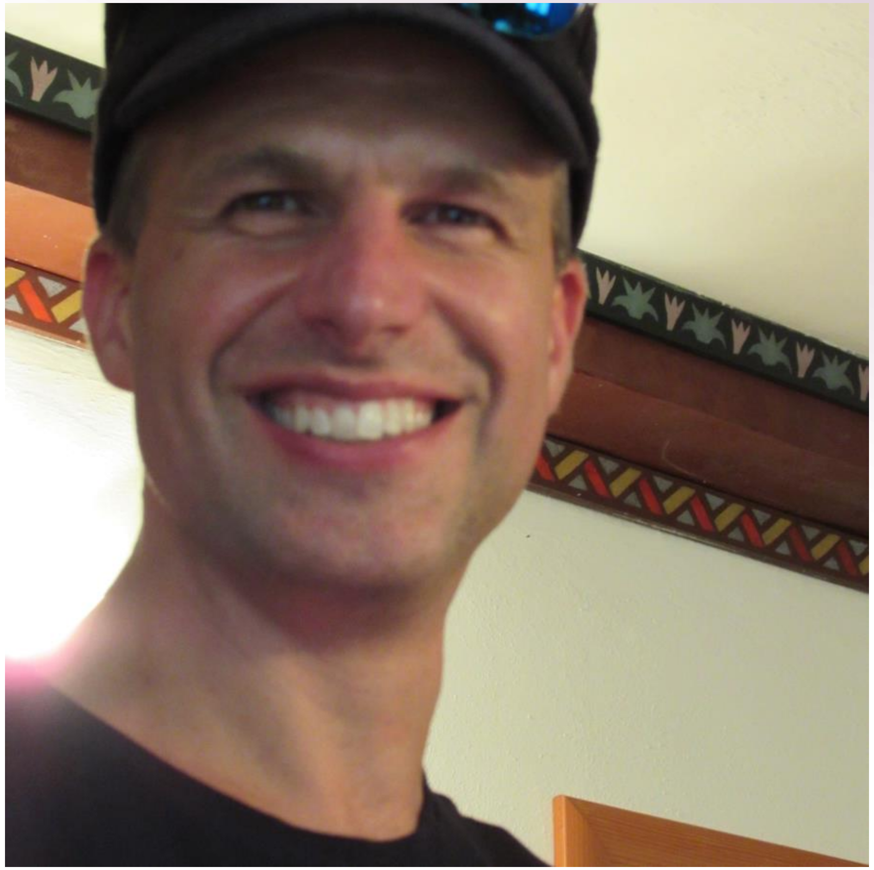
PPR-24 New Selections

Quantification of Bioburden Reduction Under Combined Stressors Applicable for Space Missions to Icy Bodies

Scientific and life detection missions to icy moons in the outer solar system must be sensitive to forward contamination by Earth-evolved microorganisms. Still, the harsh radiation, cold temperatures, and salts present in the water ice surfaces of these planetary bodies present a barrier to survival, persistence, and reproduction of Earth-evolved forward contamination. The project will use laboratory analogs of these factors to quantify the "bioburden credits" of these combined stressors. Electron radiation sources will be used to mimic the radiation environment around planetary bodies in the outer solar system. Hypothesizing a spacecraft heat source on the surface of an icy body, the project will quantify the ability of water ice and liquid brine solutions to attenuate electron radiation and protect Earth-evolved microorganisms. Additionally, the team will quantify the bactericidal effect of liquid saltwater pockets that might form around a spacecraft's heat source, as well as the possible reproduction of forward contamination in these solutions spiked with relevant concentrations of reduced carbon compounds. Overall, the project aims to create a series of quantitative values that enable risk-based planetary protection decisions for missions to the outer solar system.

Jared Broddrick/NASA Ames Research Center

PPR-24 New Selections



Paolo Gabrielli/Honeybee Robotics LLC

Experimental Assessment of the Mobilization of Drill-Associated Microbial Contaminants to the Subsurface of Planetary Icy Bodies (ExAM-Drill)

The main goal of the project is to assess forward contamination by terrestrial bacteria possibly introduced in the Icy Moons while sampling their surface and the shallowest ice down to 30 cm depth during the first mission by a lander. The team plans lab experiments to compare the microbial contamination introduced/mobilized on the surface and subsurface ice by two sterilized mocked and un-mocked sampling devices. As scoopers and drills are being developed to be employed to access and recover surface and subsurface samples from the Icy Moons (planetary protection category IV), it is imperative to assess their potential to deploy terrestrial organisms on the surface and/or to mobilize them in the subsurface down to a depth where they cannot be inactivated by intense natural radiations. The team's tests will assess whether contamination can be transferred on the surface and mobilized in the shallow depth (30 cm) during ice sampling. This will provide invaluable empirical information to optimize the strategy and the procedures to effectively sterilize the sampling devices and drills before they will be flown to space, to keep them contamination free during the flight and when they will be employed on the Icy Moons.

PPR-24 New Selections

Jessica Lee/NASA Ames Research Center

MIcrobial Airborne Simulation and Measurements for MArs (MIASMMA): Constraining Planetary Protection Risk for Crewed Exploration

The MIASMMA team aims to help address a pressing need for crewed exploration of Mars: how to predict and mitigate microbial contamination from astronaut activities. Microbial contamination poses a risk to scientific activities including the search for life on Mars. The project will contribute both empirical measurements and model-based predictions, addressing EVAs (ExtraVehicular Activities) and habitats as potential sources from which human-associated microbiota might leak into the Mars environment. The team will conduct research that directly supports quantitative advancement by measuring the rates associated with a key contamination process (space suit leakage), and simulating the atmospheric dispersion of biological contaminants sourced from human activities on Mars using the NASA Ames Mars Global Climate Model.

PPR-24 New Selections

Yuan Lian/Aeolis Research, Inc.

Modeling Contaminant Transport to Mars Special Regions

The team will simulate contaminant transport on Mars using a state of the art, high-resolution numerical global atmospheric model. Transport of contaminant between landing sites and Special Regions on Mars (defined as locations where Earth life might thrive) is likely mostly an atmospheric transport problem. The project will consider both gas and aerosol transport, using a range of approaches for gas and particulate emission. The numerical model will allow higher resolution to be used over source regions. The team will study the course of annual cycled and for a range of different dust forcing scenarios ranging from clear skies to global dust storm conditions.

PPR-24 New Selections

Numerical Impact Models as an Insight into the Survivability of Microbes Ejected from the Martian Surface and Implications on Sample Return from the Martian Moons

In order to better assess the likelihood that biological material is transferred from Mars to Phobos without significant shock alteration, the team will use novel 3D simulations of impacts onto Mars to determine the effect of impact parameters on material ejection, coupled with 2D simulations to examine the effects of porosity. Subsequently, the project will use 2D impact simulations to examine the effect of target porosity on the shock alteration of material ejected from Mars as it impacts Phobos and determine if the high degree of porosity expected for Phobos decreases the likelihood of microbe survival. The final, anticipated product of the team will be an estimate of the mass of potentially life-bearing, and bio-molecule-bearing, material accumulated on Phobos from impacts on Mars.

Simone Marchi/Southwest Research Institute

PPR-24 New Selections

Identifying Potentially Survivable Niches and Areas of High Biological Interest on the Lunar South Pole

The lunar surface will be highly explored in the coming decade, with a special focus on the lunar south pole. Regions within the lunar south pole, including ones near those that have been identified as potential Artemis exploration sites, may present survivable niches. The team will cross compare thresholds of key environmental parameters for several bacteria/fungi relevant to survival in space to maps of the South Pole of spatially resolved temperature variations, proxies of water and surface roughness using mapping software in a manner informed by both microbiologists/astrobiologists and lunar scientists/geologists. The project will focus on UV radiation, high temperature and energetic particle radiation. The study will then use ArcGIS to overlay thresholded regions from relevant datasets including those from Diviner (temperature), LEND and LAMP (water), and LOLA (topography) to assess potentially interesting niches. The team will produce new maps that show potential survivable niches for both survival and potentially to identify regions especially sensitive to forward contamination.

Prabal Saxena/NASA Goddard Space Flight Center

PPR-24 New Selections

Deep Space Environment: Friend or Foe for Planetary Protection?

Understanding the survivability of relevant microbes (e.g., from NASA cleanrooms) in space-like conditions is a crucial first step in answering the question of how the space environment may reduce bioburden and if it can be relied upon for adherence to planetary protection requirements. Therefore, this study will determine the individual and combined effects of vacuum, ionizing radiation, and cryogenic temperatures on microbial survival. Microbes will be applied to relevant polymeric materials, exposed to space environment stressors, and assayed to determine percent survival compared with controls. Furthermore, the work will determine the impacts of common sterilization procedures on cleanroom isolates, including alcohol, heat, and cold plasma. Finally, the project will compare genomes from surviving microbial strains to sensitive ones to identify genetic features that enable highly resistant strains to survive.

Tatyana Sysoeva/University Of Alabama, Huntsville

PPR-24 New Selections

David Welch/Columbia University

Far-UVC Inactivation of Hardy Microbes Using Realistic Surface and Airborne Exposure Scenarios

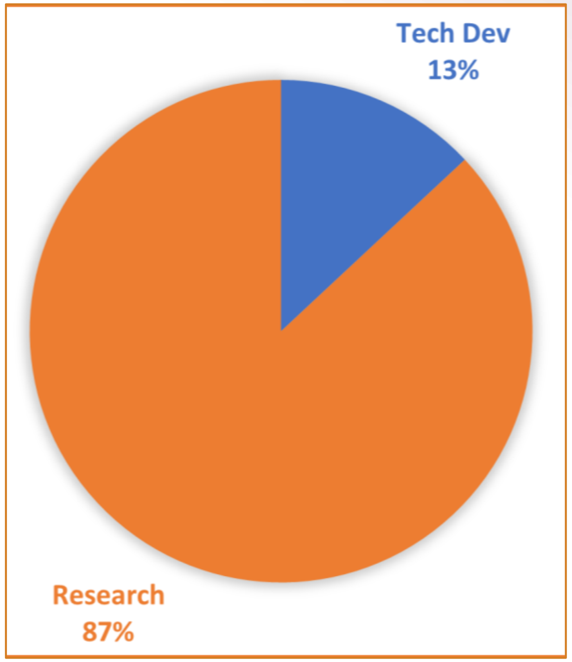
Previous work with far-UVC in the realm of planetary protection has demonstrated efficacy against hardy microbes, including vegetative bacteria cells and spores previously recovered from spacecraft assembly facilities. A key component that has not been considered previously is that microbes on spacecraft surfaces likely arrive upon these surfaces through airborne routes as an aerosol containing only a few cells or spores. Therefore, this project will investigate the efficacy of far-UVC to inactivate microbes in two scenarios that more closely model real-life situations: 1) inactivation of microbes which have deposited onto a surface as an aerosol, and 2) inactivation of microbes while suspended in air before depositing on a surface.

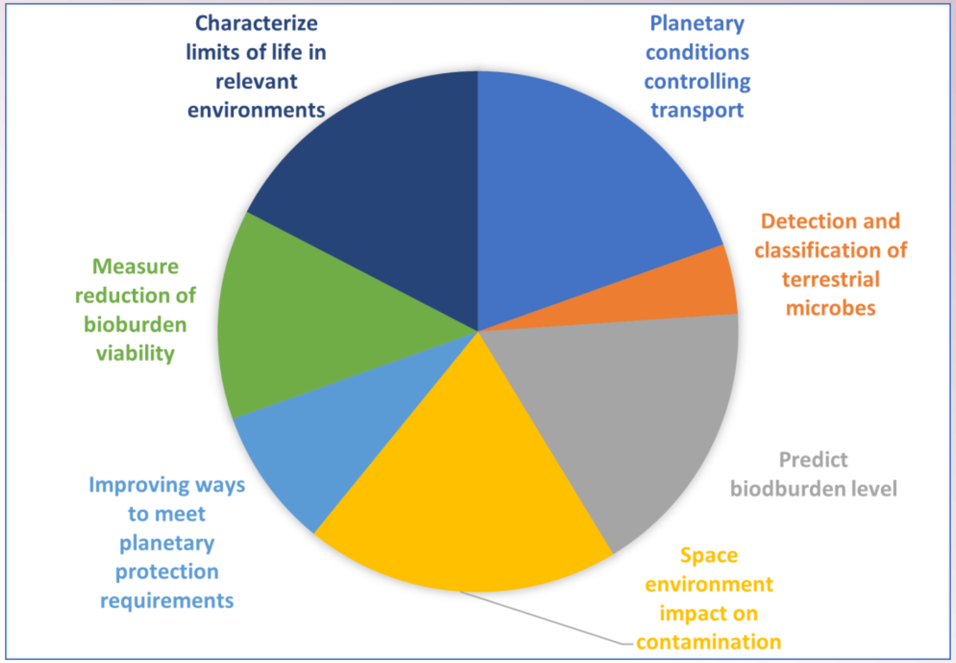
PPR Portfolio Balance

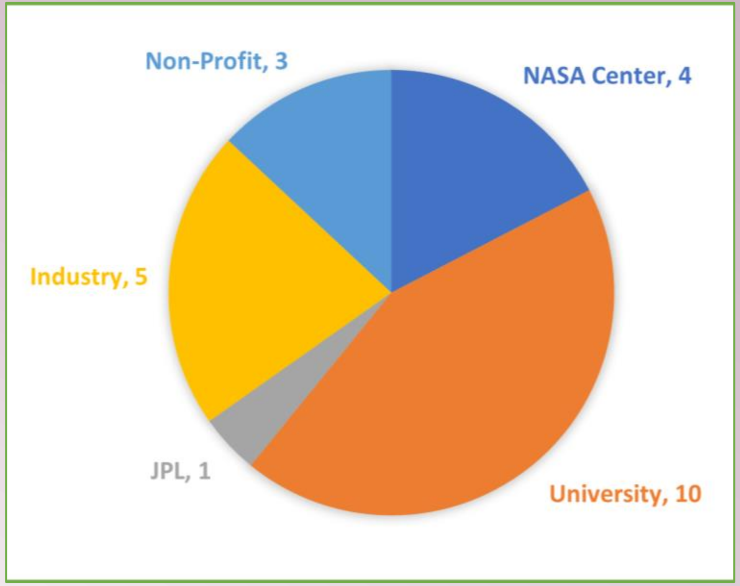
PPR mostly supporting fundamental research (with some tech development)

PPR awards are distributed across prioritized research areas

PPR work is occurring at a variety of institutions







# of Current Awards Binned by Type of Work

# of Current Awards Binned by Research Target Area

# of Current Awards Binned by Institution Type (PI)

Other Happenings Across SMD

PSD MARS EXPLORATION PROGRAM

DEC 2024

Mars Sample Return (MSR) Program
Program Director: Jeff Gramling
Deputy Program Director: Donya Douglas-Bradshaw
Deputy Program Director (Business): Rich Ryan

Executive Officer: Leo Gomez*

Lead Scientist: Lindsay Hays
Chief Engineer: Steve Thibault
HQ Systems Engineer: Megan Gorham*

MSR Program PE: George Thau
SRL/MAV PE: Chris Carson
CCRS/OS/STA PE: Michaela Munoz Fernandez

Senior Communications Manager: Dewayne Washington

Mars Exploration Program
Program Director: Eric Ianson
Deputy Program Director: Tiffany Morgan
Lead Scientist: Lindsay Hays

Mars Exploration Program Office (JPL)
Program Manager: Joe Parrish

Planetary Research Program
Director: Kathleen Vander Kaaden (Acting)
R&A PE: Meagan Thompson

Mission Generalist
Laura Ratliff

Mars R&A Lead
PS: Mitch Schulte

Mars Sample Receiving Project
PE: Karen Gelmis
PS: Lindsay Hays

ROSA (Rosalind Franklin)
PE: Dave Lavery
PS: Mitch Schulte

Mars2020 (Perseverance)
PE: George Tahu
PS: Mitch Schulte
DPS: Adrian Brown

ExoMars TGO
PE: Ramon DePaula
PS: Mitch Schulte (Acting)

MAVEN
PE: Ramon DePaula
PS: Bobby Fogel

MSL (Curiosity)
PE: Dave Lavery
PS: Becky McCauley Rench

MRO
PE: Ramon DePaula
PS: Mike Kelley

Mars Express
PE: Dave Lavery

Odyssey
PE: Ramon DePaula
PS: Mike Kelley

Science/Exploration Integration
Assistant Director for Science and Exploration: Rick Davis

Mars Technology Lead
J. Michael Newman

Humans To Mars
Becky McCauley Rench

Pre-formulation Missions

Formulation Missions

Implementation Missions

Primary Operations Missions

Extended Operations Missions

*Detail assignment

MEP FY25 Technology Proposals Round 3

"Advanced Biotechnology Metagenomics Technology for Mars Exploration" awarded to Moogega Cooper/JPL

PSD POC = j.m.newman@nasa.gov

PSD RESEARCH PROGRAMS

DEC 2024

Research Program Director: Kathleen Vander Kaaden (Acting)
Program Executive: Meagan Thompson

Research Program Support
LaJuan Moore*
Kanisha Armintia

PESTO
Lead: Erica Montbach (GRC)

Core Research Programs

- **ECA** – PO: Nick Lang
- **Emerging Worlds** – PO: Curtis Williams*; CS: Julie Ziffer
- **FINESST** – PO: Amanda Nahm*; CS: Julie Ziffer
- **PDART** – PO: KC Hansen*; CS: Nick Lang
- **PPR** – PO: David J. Smith
- **SSO** – PO: Julie Ziffer; APO: Rebekah Dawson-Rigas
- **SSW** – PO: Curtis Williams*; CS: Katie Robinson
- **XRP** – PO: Hannah Jang-Condell (Detail); APO: Rebekah Dawson-Rigas
- **YORPD** – PO: Julie Ziffer; APO: Josh Handal*

Data / Sample / Precursor Analysis Programs

- **ANGSA** – PO: Kathleen Vander Kaaden; APO: Sarah Noble
- **CDAP** – PO: Henry Throop*; CS: Nick Lang
- **DDAP** – PO: Aaron Burton
- **LARS** – PO: Katie Robinson
- **LDAP** – PO: Amanda Nahm*; CS: Katie Robinson
- **LMAP** – PO: Sarah Noble
- **MDAP** – PO: Majd Mayyasi; APO: Adrian Brown*
- **NFDAP** – PO: Henry Throop*; CS: Nick Lang
- **PSI-E** – PO: Henry Throop*; CS: Curt Niebur

Astrobiology Research Program

- **Exobiology** – PO: Alison Olcott; APO: Geoff Wheat
- **Habitable Worlds** – PO: Becky McCauley Rench
- **ICAR** – PO: Becky McCauley Rench
- **PSTAR** – PO: Becky McCauley Rench

Participating Scientist Programs

- **Akatsuki** – PO: Mitch Schulte
- **BepiColombo** – PO: Shoshana Weider*; CS: Delia Santiago-Materese
- **DART** – PO: Tom Statler
- **Hera** – PO: Tom Statler
- **InSight** – PO: Bobby Fogel
- **Juno** – PO: Delia Santiago-Materese
- **KPLO** – PO: Shoshana Weider*; CS: Delia Santiago-Materese
- **Lucy** – PO: Tom Statler
- **MMX** – PO: Tom Statler
- **MSL** – PO: Becky McCauley Rench
- **OSIRIS-REx** – PO: David J. Smith
- **VenSAR** – PO: Mitch Schulte

Other Research Activities

- **AASLO** – PO: Sarah Noble
- **Citizen Science** – PO: Nick Lang
- **Here to Observe (H2O)** – PO: David J. Smith; APO: Nick Lang
- **High-End Computing** – PO: KC Hansen*
- **ISFM** – PO: David J. Smith; APO: Aaron Burton
- **OSSI/CSDO** – Robin Fergason
- **PME/PSEF** – PO: Aaron Burton
- **SSERVI** – PO: Sarah Noble (Acting); APO: Amanda Nahm*
- **TWSC** – PO: Bradley Burcar*; CS: Kathleen Vander Kaaden

Technology (funded through ROSES)

- **COLDTech** – PO: Erica Montbach
- **DALI** – PO: Anna Maria Pal
- **HOTTech** – PO: Michael Lienhard
- **MatISSE** – PO: Michael Lienhard
- **PICASSO** – PO: Nalin Ratnayake

MatISSE-24

"Sterilizing Heat Infrared Emitting LED Device (SHIELD)"

Emily Seto/Honeybee Robotics LLC

PSD POC = michael.a.lienhard@nasa.gov

*Contractor
CS: Cognizant Civil Servant / IPA
PO: Program Officer
APO: Associate PO

Planetary Science Technology Development Strategic Plan

Anchored in “Origins, Worlds, and Life A Decadal Strategy for Planetary Science and Astrobiology”

Tech Dev Strategic plan final version in review and draft version available on **PESTO** website

Prioritized Technology Focus Areas*

Instrumentation, with an emphasis on:
- In Situ Search for Life/Astrobiology

Sample Containment and Return
- Planetary Protection and Contamination Control
- Sample Thermal Management
- Sample Acquisition and Handling

Autonomy
- Global Positioning System (GPS) deprived navigation
- Surface (planetary) operations
- On-board science data processing
- Ground Operations

Development typically occurs with:
- ROSES programs:
  - PICASSO
  - MatISSE
  - DALI
  - PSTAR
  - PPR
- SBIR
- Potential future focused programs

Robotics, with an emphasis on Advanced Mobility for:
- Aerial Rovers
- Subsurface Access**

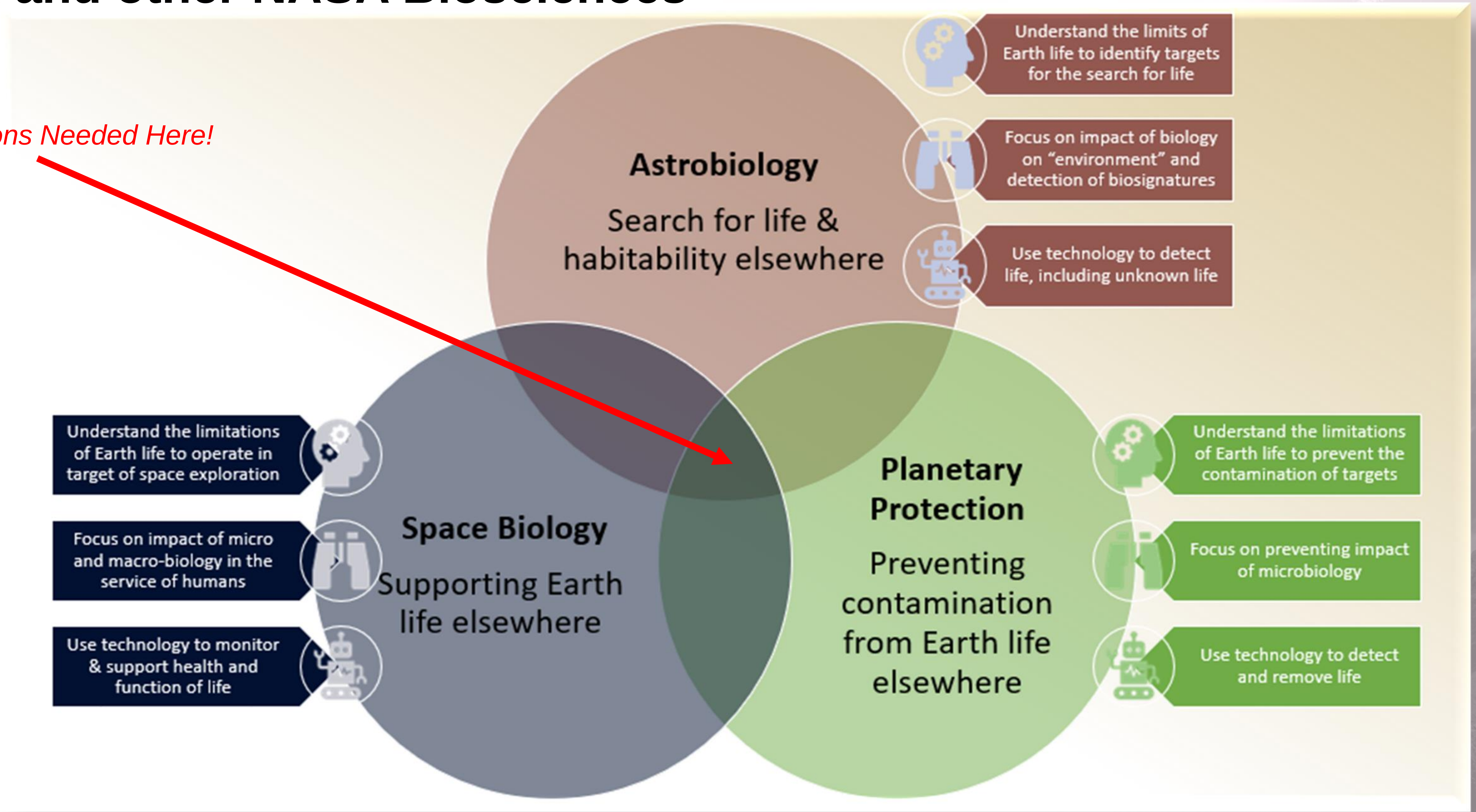
Higher-efficiency power conversion technology for radioisotope system

Development typically occurs with:
- STMD
- SBIR
- TP
- ACO
- ROSES programs - ESSIO
- RPS program (for last item)
- Potential future focused programs

*These are priority developments, however, future investments are not limited to these technologies
**Includes drilling

PPR and other NASA Biosciences

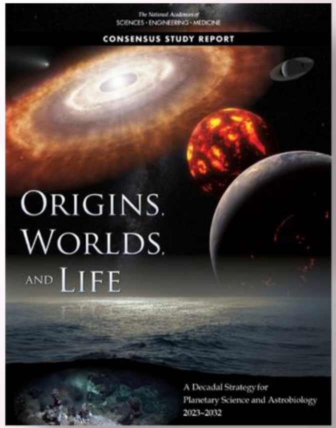
Definitions Needed Here!



New Opportunity for Community Inputs

NASA-DARES 2025:

The NASA Decadal Astrobiology Research and Exploration Strategy



- Seeking inputs in RFI!

  Topic 3: Foster Cross-Divisional and Cross-Directorate Collaboration

  Topic 4: Incorporate and Synthesize Recent Recommendations

  Topic 6: Evaluate Astrobiology's Role in Missions

  Topic 7: Astrobiology and Human Space Exploration

- RFI available on NSPIRES (Solicitation NNH25ZDA002L) – deadline is February 4, 2025

  Questions and comments about RFI can be emailed to HQ-RFIastrobio@mail.nasa.gov.

- Now launching in SMD: "Astrobiology Federation" with representation from all SMD Divisions (and potentially other Directorates) to facilitate cross-org collaboration and planning in topics relevant to astrobiology and other biosciences (including planetary protection).

  PSD POC = david.grinspoon@nasa.gov

Probable PPR Changes in ROSES-25

PPR Solicitation (C.15) Priorities in ROSES-25

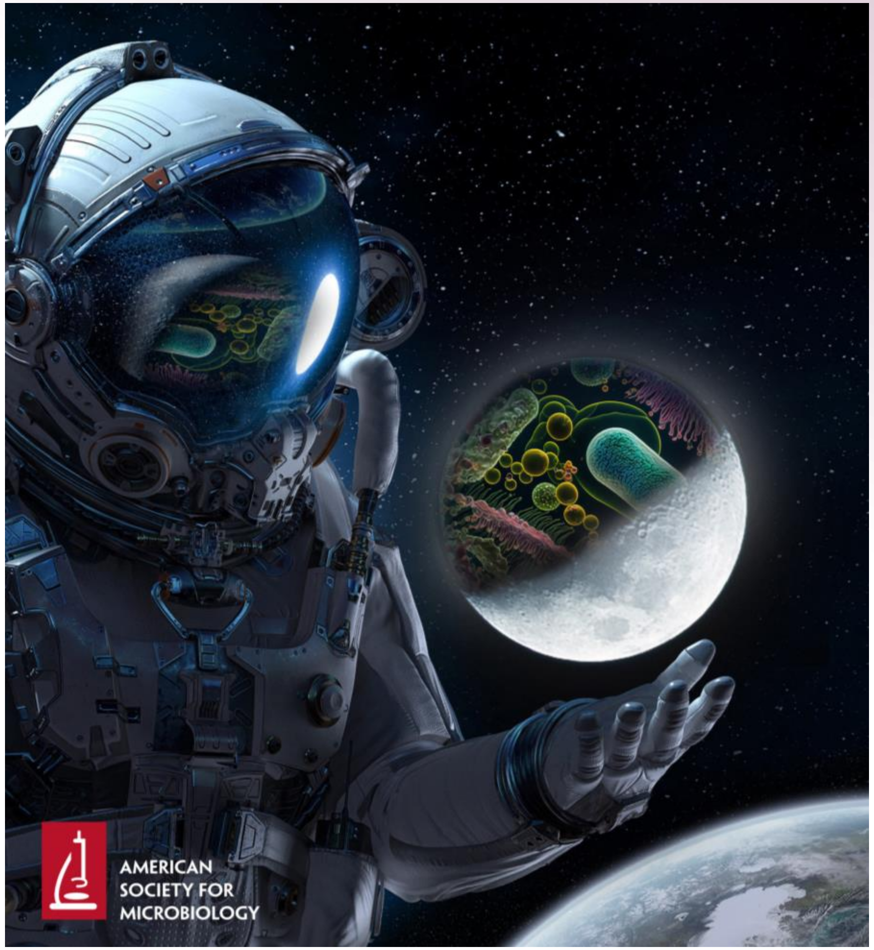


Image credit: American Society for Microbiology

Main Changes (under consideration):

- Priorities no longer rank-ordered
- Now six total program priorities
- Explicitly allowing for research related to organic contamination

- ❑ Planetary conditions controlling transport
- ❑ Detection and classification of terrestrial microbes
- ❑ Predictions of bioburden levels
- ❑ Deep space environment impact on contaminants
- ❑ Improving ways to meet planetary protection requirements
- ❑ Measuring bioburden survival or inactivation

PPR-25 Not Intended for Technology or Hardware Development

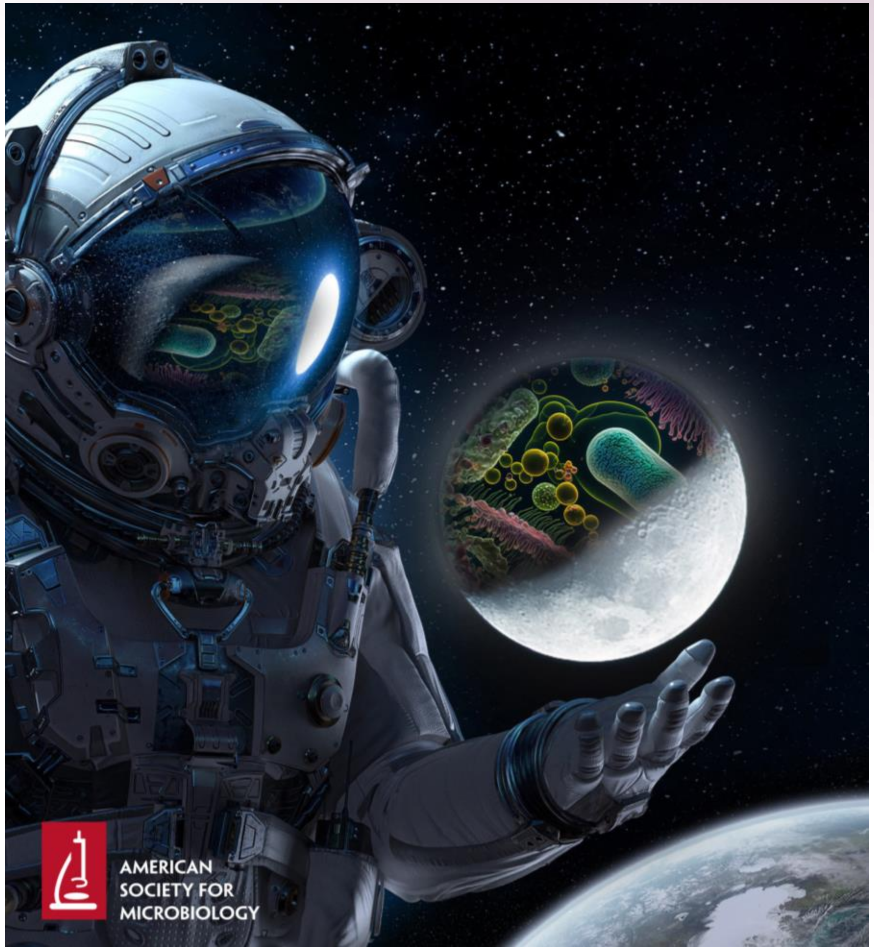


Image credit: American Society for Microbiology

Main Changes (under consideration):

- Proposals using commercial-off-the-shelf (COTS) hardware will be allowed; however, proposals for technology development and maturation should be submitted to other NASA programs in PESTO such as Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO/C.12) or Maturation of Instruments for Solar System Exploration (MatISSE/C.13) for proposals pertaining to planetary protection instruments, sampling and measurements.
- Technology proposals not related to instrumentation can consider STMD’s Space Technology Research Grants Program (STRGP) and the NASA Small Business Innovation Research / Small Business Technology Transfer (SBIR/STTR) Program.

PPR-25 Encouraging Use of NASA Open Science Assets

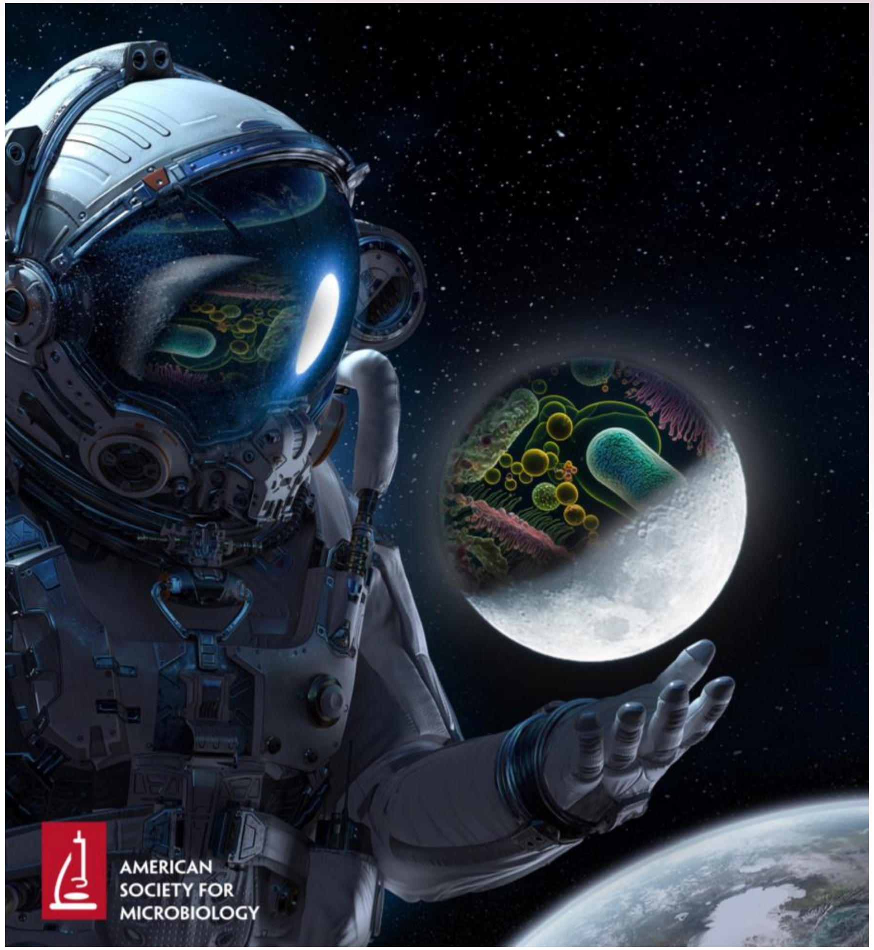


Image credit: American Society for Microbiology

Main Changes (under consideration):

- Proposals generating biological data are expected to utilize NASA's Open Science Data Repository (see SPD41A).
- Proposals requesting or producing biological specimens (from collections or experiments) are expected to utilize NASA's Biological Institutional Scientific Collection (NBISC), specifically the Space Microbial Culture Collection (SMCC).
  - Aiming to have ~8,000 spaceflight isolates from JPL ingested into SMCC starting in FY25, made available for community use (along with pertinent metadata)
    - M2020
    - Viking
    - Odyssey
    - MER
    - MSL
    - Insight
    - Europa Clipper

PPR-25 Might Become a No Due Date (NoDD) Program

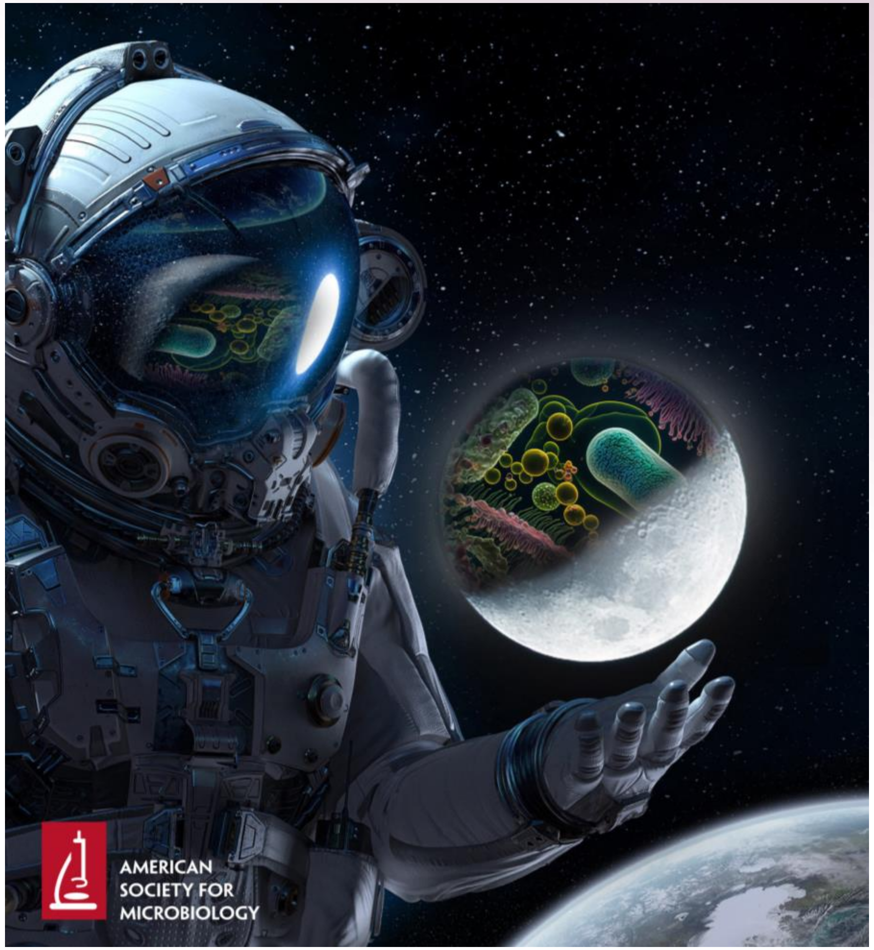
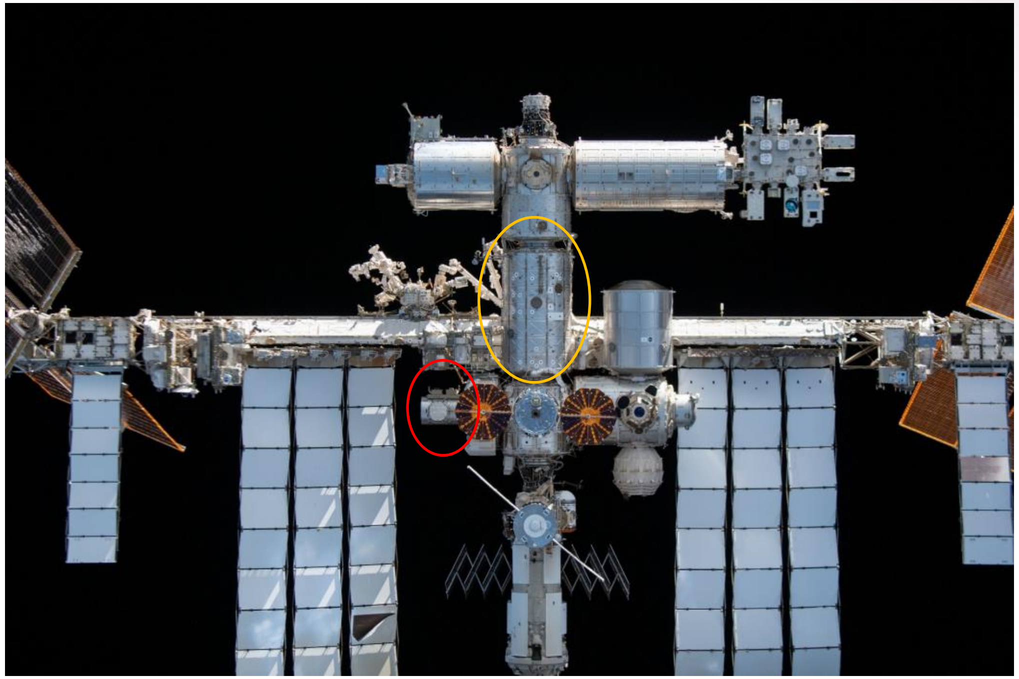


Image credit: American Society for Microbiology

- Several program elements in ROSES do not have a fixed due date. Proposals to these programs may be submitted at any time during the open period of ROSES.
- A goal of No Due Date (NoDD) is to provide flexibility in proposal submission (for individuals and AORs) and to expand potential reviewer pool.
- Appendix C (Planetary Science) has long had restrictions on submission of "duplicate" proposals and "resubmissions“; those rules still apply to NoDD programs.
- After 4 years of implementation in Appendix C (Planetary Science) for a subset of ROSES programs, NoDD outcomes are currently being evaluated by NASA PSD.
    - C.15/PPR is under consideration for next wave of NoDD expansion
    - We welcome community feedback on this topic

PPR Portfolio Highlights



ISS External Microorganisms: A tool to Collect microbes from External Surfaces on the International Space Station (ISS)

Aaron Regberg/NASA Johnson Space Center

Some microbes can survive prolonged exposure to space and it is known the ISS releases microbes through vents & airlocks.

Project Goals:

- Collect 6 samples + 2 controls from ISS external surfaces.
- Return samples to Earth for DNA sequencing.

Expected Results

- Address planetary protection knowledge gaps and allow NASA to design life support systems that can be used on Mars without introducing unwanted contamination.
- Tool could be used on future robotic and crewed missions to collect biological, chemical, and geological samples that address space biology, astrobiology, and planetary protection research questions.

Top: Astronaut Tracy Dyson with PPR supported hardware in June 2024 on ISS; Bottom: Planned ISS external sampling locations for PPR project, airlock (red circle) and lab module (yellow circle)

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Windblown Mineral Grains as a Source of Natural Transport of Biological Contamination

Lori Fenton/SETI Institute

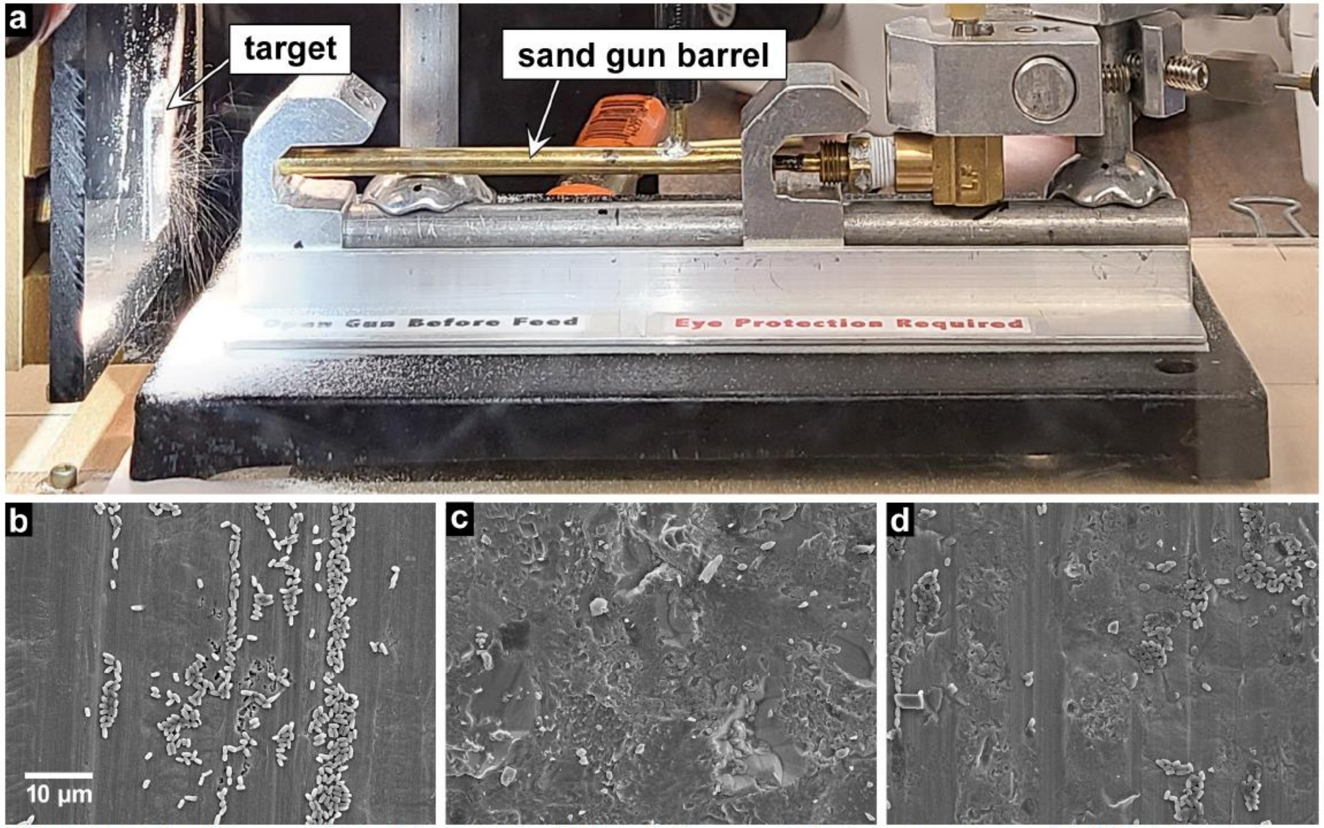

Figure 1. (a) Sand was accelerated down a tube (right to left) onto an aluminum target coated in killed *B. subtilis* HA101 spores. Beneath are portions of SEM images from three coupons: **(b)** Spores on an Al-6061 coupon that was not bombarded by sand (control case). **(c)** Near 100% spore removal by ~99% coverage by sand impacts at ~12.4±1.3 m/s. **(d)** Approximately 30% spore removal by ~99% coverage by sand impacts at ~2.4±0.2 m/s.

Experiment measured removal rate of *Bacillus subtilis* HA101 spores from aluminum surfaces under the bombardment of naturally rounded sand grains. To simulate grain impacts, team constructed a pneumatic sand-feed system and gun to accelerate grains to a desired speed, with independent control of impacting grain mass, flux, and angle. Results indicate that although spores directly impacted by sand grains would likely be killed, those immediately adjacent to grain impacts might be released into the environment intact. The experiments demonstrate a linear relationship between the fractional dislodgement rate of spores and grain impact speed, which can be used to estimate input to microbial transport models. Even the slowest grain impacts (~2.7 m/s) dislodged spores, which suggests that microbial dislodgement by slow saltation near the Mars surface is largely unavoidable.

Thank You!

David.J.Smith-3@nasa.gov
&
HQ-PPR@mail.nasa.gov

PPR Programmatic Priorities (from C.15)

It should be noted that the evolving planetary protection requirements of NASA's programs may affect the priorities for funding among these areas.

1. *Model or experimentally measure planetary environmental conditions and transport processes that could permit mobilization of spacecraft-associated contaminants to locations in which Earth organisms might thrive.*
2. *Develop or adapt modern molecular analytical methods to rapidly detect, classify, and/or enumerate Earth microbes carried by spacecraft (on surfaces and/or in bulk materials, especially at low densities) before, during, and after assembly and launch processing.*
3. *Model to understand and predict biological and organic contamination sourcing, transport, survival, and burden level of spacecraft, for both forward and backward contamination.*
4. *Model or experimentally measure space environmental conditions and spacecraft designs that could permit a decrease in biological contamination of spacecraft during the journey (e.g. bioburden credits) to the target destination with emphasis on reduction of organisms currently surviving under cleanroom conditions.*
5. *Identify and provide proof-of-concept on new or improved methods, designs, technologies, techniques, and procedures to support planetary protection requirements for outbound and return sample missions.*
6. *Experimentally measure reduction in viability of hardy terrestrial organisms, including viruses, exposed to high temperatures (e.g. 200 to 500 degrees centigrade) for short periods of time (e.g. seconds to minutes).*
7. *Characterize the limits of life in laboratory simulations of relevant planetary environments or in appropriate Earth analogs.*