



Biological and Physical Sciences

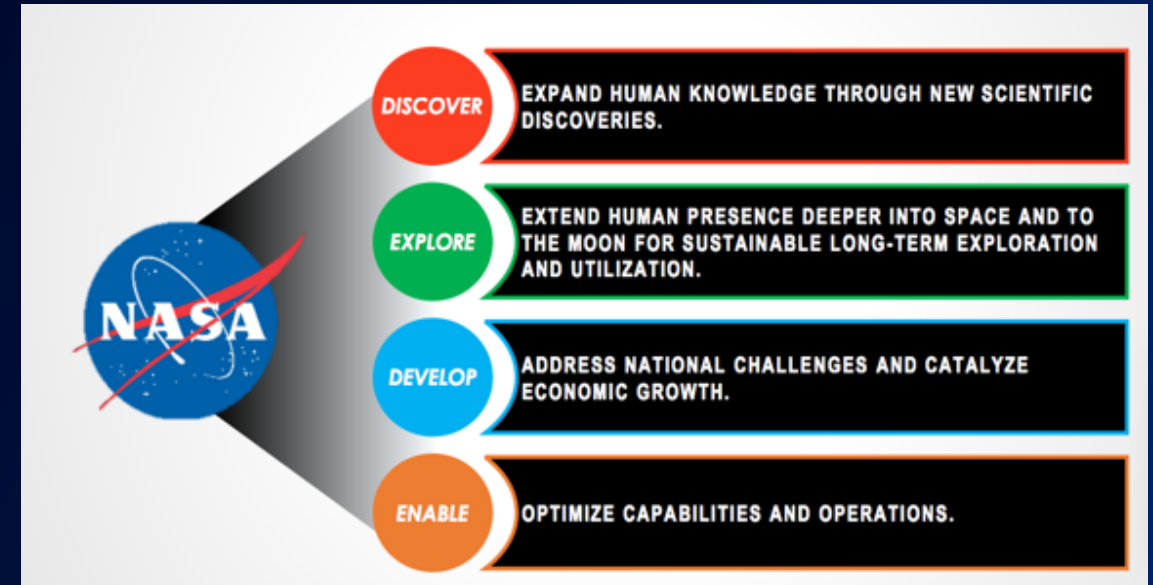
The Future of Space Biology Research as We Move Past LEO

Sharmila Bhattacharya
3/25/2021



NASA's Goals Prompt Space Biology Research on the Moon

- Humans to return to the Moon
- Sustained presence on the Moon
- Use the Moon to prepare for long-duration Mars missions



	Theme	Strategic Goal	Strategic Objective
	DISCOVER	EXPAND HUMAN KNOWLEDGE THROUGH NEW SCIENTIFIC DISCOVERIES.	1.1: Understand the Sun, Earth, Solar System, and Universe. 1.2: Understand Responses of Physical and Biological Systems to Spaceflight.
	EXPLORE	EXTEND HUMAN PRESENCE DEEPER INTO SPACE AND TO THE MOON FOR SUSTAINABLE LONG-TERM EXPLORATION AND UTILIZATION.	2.1: Lay the Foundation for America to Maintain a Constant Human Presence in Low Earth Orbit Enabled by a Commercial Market. 2.2: Conduct Exploration in Deep Space, Including to the Surface of the Moon.

In NASA's Strategic Plan 2018: Discover and Explore themes prompt Space Biology BLEO research

Challenges to.....

- **Biological Systems:**

- Radiation
- Reduced gravity
- Thermal & overall environment
- Altered day/night circadian cycles
- Social Isolation
- The combination of multiple stressors

- **Logistics, engineering, & operations:**

- Enclosed habitats that support life
- Autonomous systems
- Radiation shielding
- Controlling the thermal environment
- Early load of science payload into spacecraft
- Communications/Data transmission



Considerations for “Thriving in Deep Space” (TIDES):

- Utilize lunar/cis-lunar, free flyers, ISS, ground-based experiments, etc. to study the effects of combined spaceflight stressors in preparation for deep space exploration.
- Utilize lunar and cis-lunar experiments to study radiation and altered gravity
 - both are hard to replicate accurately on the ground.
- Start with simpler, smaller, robust organisms and progress to larger, more complex organisms as the technological resources mature on the lunar surface.
- We may have to start with experiment durations that work with current technology but eventually we need to study long duration experiments that mimic a 2- to 3-year mission to Mars.
- Along with the science, consider the technological advancements that are needed to sustain long-duration science experiments in deep space.
- Focus on the important underlying mechanisms of change and the genetic and physiological susceptibilities of biological organisms to the deep space environment.



Space Biology Lunar Surface Science Workshop (LSSW)

January 20-21, 2021 (Over 600 registrants)

Rationale:

- Educate and inform our science, engineering, and commercial space communities about NASA's life science and exploration goals on the Moon as a stepping-stone for Mars
(Plenary Sessions, Abstract talks, Pre-Recorded Poster Presentations)
- Engage the community via breakout sessions to obtain input for space biology research for lunar and deep space missions

Specific Aims:

- Obtain community input on key questions pertinent to deep space exploration.
 - Life science research
 - Technology and engineering applications for space biology

Scope:

- Lunar surface science
- Cis-Lunar orbit science
- Integrated ground, low-Earth orbit, and lunar investigations
- Prepare for future Mars science and deep space exploration missions

Space Biology LSSW Plenary Talks

Space Biology Research Beyond LEO (<https://www.youtube.com/watch?v=YoFqsjL894U>)

Sharmila Bhattacharya, Program Scientist, Space Biology Program

- We need more information about the biological effects of combinations of spaceflight stressors such as altered gravity and radiation. The Moon is a good platform for such work.
- Work needs to start with simpler, smaller robust organisms, and then progress to more complex ones as the technology matures.
- Begin with short studies but need to eventually expand to long duration studies that mimic a Mars mission.

Human Lunar Science Research (<https://www.youtube.com/watch?v=eEfNczcfA30>)

Steven H. Platts, Acting Chief Scientist, Human Research Program

- NASA's Human Research Program is dedicated to discovering the methods and technologies to support safe, productive human spaceflight. By conducting human research on the early lunar surface crews, results will help inform the missions of tomorrow.

Planetary Protection Knowledge Gaps at Intersection of Human and Science Missions to the Moon and Mars

(<https://www.youtube.com/watch?v=cZ9XrkAr0jk>)

Lisa M. Pratt, NASA Planetary Protection Officer, Office of Safety and Mission Assurance

- The lunar surface is an appropriate proving ground for human life-support systems in preparation for human exploration of Mars given the low likelihood of harmful biological contamination on the lunar surface.
- Lunar organics could provide calibration of abiotic background (for future Mars missions) which is difficult to do on Earth.

Astrobiology (<https://www.youtube.com/watch?v=1qrvyTzZbtU>)

Lindsay Hays, Deputy Program Scientist, Astrobiology Program, Planetary Science Division

- Main questions asked by Astrobiology include:
 - How does life begin and evolve?
 - Does life exist elsewhere in the Universe?
 - What is the future for life on Earth and beyond?
- The Moon may provide crucial context about the early history of our corner of the Solar System.

Space Biology LSSW Plenary Talks (Cont)

Artemis: HEO Capabilities for Science & Technology Utilization (<https://www.youtube.com/watch?v=dIv6nQYwPcU>)

Julie A. Robinson, Chief Scientist and Manager (Acting) Science & Technology Utilization, HEOMD

- Landing humans on the moon beyond 2024; extending Lunar missions to prepare for Mars.
- Relevant science objectives: Conducting experiments in lunar environment and investigating and mitigating exploration risks.

CLPS Lander Utilization (<https://www.youtube.com/watch?v=udh2WbfAy4I>)

Debra Needham, Program Scientist, Exploration Science Strategy and Integration Office, SMD

- Goal: Utilize commercial end-to-end delivery services to enable access to the lunar surface.
- Payloads and Research Investigations for the Surface of the Moon (PRISM) Announcement Opportunities.
 - PRISM stage-2 solicitations will state location for each delivery, allowing PIs to propose science optimized for locations.

Artemis III Science Definition Team Report Briefing (<https://www.youtube.com/watch?v=tZj-ceyPjKl>)

Noah Petro, Goddard Space Flight Center, SDT member

- The Science Definition Team (SDT) prioritized investigations under the 7 science objectives laid out in the Artemis Plan.
- Objective # 7a: Study the fundamental biological and physiological effects of the integrated lunar environment on human health and the fundamental biological processes and subsystems upon which health depends.

Space Radiation Environment at the Moon and Implications for Space Biology: Insights from the CRaTER Experiment on NASA's Lunar Reconnaissance Orbiter (<https://www.youtube.com/watch?v=FwsSXNi4eFc>)

Harlen E. Spence, Director, Institute for the Study of Earths, Oceans, and Space; Professor, University of New Hampshire

- Cosmic Ray Telescope for the Effects of Radiation: Designed to estimate Linear Energy Transfer of GCRs and SPs near the Moon and to characterize the ionizing radiation environment and its effects.
- Work has characterized the spatial and temporal variability of primary and secondary radiation in Lunar orbit from GCR and SP, which has obvious implications for Space Biology.

Space Biology LSSW Breakout sessions (01/21/21):

Times (CST)	Session Chair	Breakout Session Topics	Note Takers	Live Views
12:10 PM	Robin Elgart Gioia Massa Jamie Foster	Group A – Vertebrate	Rebecca Klotz, Egle Cekanaviciute	28
		Group B – Plant	Christina Johnson, Ben Greaves	39
		Group E – Invertebrate	Natasha Sng, Dennis Leveson-Gower	31
1:10 PM	Marianne Sowa Howard Levine Lucie Poulet	Group C – Vertebrate (II)	Stephanie Perreau	40
		Group D – Plant (II)	Elizabeth Keller, Molly Heit	19
		Group F – Invertebrate II	Sigrid Reinsch	16
2:20 PM	Tara Ruttle Jennifer Buchli	Group G – Microbiology	Ursula Koniges, Sara Humphrey	44
		Group I – Cell Biology Systems	Afshin Behesti, Ava Karanjia	47
3:20 PM	Louis Stodieck Lisa Carnell	Group H – Microbiology (II)	Dennis Leveson-Gower, Cesil Alex	22
		Group J – Cell Biology Systems (II)	Elizabeth Keller, Josh Tate	22



Questions Asked to Community at Breakout Sessions

- 1) What are the top priority space biology research topics that must be conducted on the Moon or in cis-lunar orbit (in order of priority) to facilitate sustained lunar habitation and future Mars missions? Which need to be initiated in the near term (5 to 10 years in order of priority)?
- 2) How can we begin to separate the biological effects of multiple spaceflight stressors (e.g., ionizing radiation, partial gravity, social isolation, altered gas compositions, etc.) that will enable countermeasure development?
- 3) What are key technologies, technical capabilities, and resources needed to conduct biological research on the Gateway and Moon (e.g., CLPS landers, Artemis vehicles, lunar base camp)?

Cross-Cutting (General) Points of Discussion From Breakout Sessions

Our work with ground-based and LEO research is a complement to deep space research.

- These platforms are important when answering Question # 2 (separating the biological effects of multiple spaceflight stressors), as both Earth and the ISS have different conditions and capacities than Gateway or even the lunar surface.
 - Centrifugation studies on the ISS can recapitulate the fractional gravity of the lunar environment, but with less radiation.
 - The radiation levels between the ISS and cis-lunar orbit are different, the biological effects of which can be studied.
 - Ground based-radiation studies are still needed.
- The ISS can still serve as a proving ground for testing new technology and hardware to be used in cis-lunar orbit, or even on the lunar surface.

Sample preservation and return on/from the moon is a concern and a priority.

- How can we extract and store nucleic acids? Can samples be properly frozen? Can we lyophilize proteins in the lunar environment?

Lunar dust is a major concern across disciplines for regarding lunar surface work.

- Lunar dust is abrasive, potentially toxic, and easily tracks everywhere. There is little work that has been done looking at the consequences of breathing in lunar dust with effects on lungs or other systems in animals. Also how does exposure to lunar dust effect plants, microbial growth, or even microbial communities?

Bioregenerative Life Support is on everyone's mind, but priorities and time-lines are still points of discussion.

- There were discussions, from many outside the plant community, in converting lunar regolith into useful soil, which led to discussion among members within the plant community regarding the practicality of the approach and consideration of the short-term vs long-term needs for sustainability.

Discussion Points From Vertebrate Breakout Sessions (Groups A and C)

Question 1: Priorities

- Discussions were mostly focused on rodent work.
- Space Biology can augment human research by conducting and expanding radiation research on vertebrates, since radiation research not feasible with humans.
- Focus should be on outcomes such as SANS, thrombosis, immune dysfunction, vascular changes, brain function/cognitive deficits, sex-specific differences.
- Additional focus on sleep deprivation, circadian rhythm studies.

Question 2: Separating the Biological Effects of Multiple Spaceflight Stressors

- Studies involving radiation shielding (inactive vs active) on the moon or in cis-lunar orbit.
- Ground studies that separate deep space radiation into its different components.
- Parallel studies of lunar and ISS missions, to tease out effects of differing radiation levels; can use centrifugation on ISS to simulate partial gravity vs microgravity.
- Studies of lunar dust exposure on animals, either on the surface, or bringing lunar dust back to Earth for study (chronic vs acute effects).

Question 3: Technologies, Capabilities and Resources

- Mouse habitat/breeding facility on the Moon.
- Live animal return from lunar environment (since humans similarly go through the re-adaptation/return phase).
- Advanced imaging capabilities (CT, DTT), video capabilities, ultrasound.

Discussion Points From Invertebrate Breakout Sessions (Groups E and F)

Question 1: Priorities

- Organisms suggested: Tardigrades (resistance to extreme environments), *Drosophila*, *C.elegans* (model organisms), vermiculture/regolith conversion with simple organisms, host-microbe interactions, etc.
- Studies should begin with simple experiments using well-vetted spaceflight models.
- Initially short-term experiments leading to future multigenerational studies in the lunar environment, measuring the environmental effects on mechanotransduction.
- Compost/soil studies assessing conversion of regolith to soil, pollination studies.

Question 2: Separating the Biological Effects of Multiple Spaceflight Stressors

- Parallel experiments should be run on ISS/Gateway/Lunar surface, using centrifugation to similar microgravity to parse out the effects of radiation.
- Suggested use of genetic tools/specific strains of organisms that are more sensitive to one stressor vs another to parse out different stressor effects, use these lines to test countermeasures.
- Additional radiation studies on ground should be conducted in parallel with ISS/lunar studies.

Question 3: Technologies, Capabilities and Resources

- Build on known habitats for invertebrates used on ISS, test effectiveness of radiation shielding.
- Video capabilities, simple radiation dosimetry, and data loggers for temp/humidity/pressure etc.
- Centrifuge for 1g control in each environment.
- Sample return - with simple preservation – either frozen or fixed.

Discussion Points From Cell Biology Systems Breakout Sessions (Groups I and J)

Question 1: Priorities

- Establishment of **Tissue on a Chip** and **3D printed/culture systems**, while understanding limitations and caveats of these systems.
- Cell systems should be **used to conduct drug therapy studies**, **assess DNA damage** and repair from radiation, assess the effects of radiation on proteins and other cellular components.
- Cell differentiation studies in the lunar environment.
- Cell model/tissue type studies: **nervous, cardiovascular systems, and others**.

Question 2: Separating the Biological Effects of Multiple Spaceflight Stressors

- Conduct cross-platform experiments (Gateway, Moon, ISS) to isolate/characterize the effects of radiation and microgravity across them.
- Examine probiotics (microbes)/nutraceuticals (plants) as countermeasures for cellular health.
- Conduct radiation/countermeasure studies on the ground, look at production and effects of reactive oxygen species/free radicals.
- Conduct high throughput studies (omics) and compare with spaceflight models.
- Examine the effects of lunar dust on cell models.

Question 3: Technologies, Capabilities and Resources

- **Imagery**, telemetry, dosimetry; temperature control (refrigeration/heating); real time sampling (material extraction for omics analysis); real time measurement collection.
- Sample recovery; automated preservation methods; remote data recovery.
- Partial gravity on flight platforms(centrifugation).

Discussion Points From Microbiology Breakout Sessions (Groups G and H)

Question 1: Priorities

- Increase our **microbial monitoring capabilities** of both the habitat and of its inhabitants (MoBE). Develop better sterilization techniques. Characterize antimicrobial resistance.
- Gain better **understandings of plant/microbe and animal (human)/microbe interactions in space and lunar environments** (look at bioregenerative life support potentials).
- Look at **biofilm formation** in lunar/space environment.
- Examine interactions of **microbes with regolith**, characterize their ability to convert regolith to soil.
- Expand studies to extremophiles and radiotrophic fungi (potential use as organic shielding?).

Question 2: Separating the Biological Effects of Multiple Spaceflight Stressors

- Develop a system of standard measures for microbial assays and monitoring systems that can be used across platforms and species, to biomap environmental/biological conditions.
- Use centrifugation to conduct fractional gravity studies, in parallel with radiation studies, or with other stressors (nutrient availability/deficiency, absence/presence of lunar dust). Examine effects on microbes when exposed to individual stressors, or in combination.

Question 3: Technologies, Capabilities and Resources

- **Autonomous microbiology monitoring systems**; real time monitoring; remote data collection; **microscopy and mass spectrometry** for solids and solutions; sample to sequencing techniques.
- Micromanipulation techniques (to deal with micro amounts of regolith).

Discussion Points From Plant Biology Breakout Sessions (Groups B and D)

Question 1: Priorities

- Work should begin by expanding LEO studies with current model plants (e.g., *Arabidopsis*) to lunar environment but should also be extended to crops. Seed to seed, lifecycle experiments must be conducted. The objectives of crop research should focus more on increasing nutrient density rather than caloric density.
- Little work has been done examining the effects of radiation on plants (esp. crops). The mutation rate of plants/crops under radiation should be examined, as well as effects of radiation & 1/6 g's on germination, development, and gene expression.
- Understand how lunar gravity effects plants differently from microgravity. Past work suggests they have similarities. Gain a better understanding of the relationship between gravitropism and phototropism.
- Examine ability of plants to grow on regolith/converted regolith (some feel that this is a lower immediate priority, but important for future sustained plant growth on moon). Particle size of regolith matters, because reduced gravity impacts water flow through it.

Question 2: Separating the Biological Effects of Multiple Spaceflight Stressors

- There was strong support for integrated studies (rather than reductionist studies) to understand the synergistic effects of a multi-stressor environment. It may not be easy to tease all variables apart and get meaningful data.
- Conduct studies on multiple platforms (ISS, Earth, Gateway, lunar surface) to tease apart effects of microgravity and radiation (centrifuge studies, BNL radiation).

Question 3: Technologies, Capabilities and Resources

- Modular systems for different roots or plant types; incubator system/atmospheric control; automated systems for sample collection, preservation and analysis (omics); imaging capabilities, telemetry; sample return.
- Genetic strains resistant to radiation, drought stress, hypoxia, etc.

Summary of the breakout sessions of the LSSW Workshop

- The LSSW was a two-day event. This presentation summarizes the highlights.
- LEO (Low-Earth Orbit) platforms like the ISS provide valuable information on the effects of the spaceflight environment on living systems and can serve as an important frame of reference for future BLEO (Beyond LEO) work.
 - Many support the idea of beginning lunar and cis-lunar work using model organisms and systems we are already familiar with, while also expanding that work to using systems that have translational value for future exploration work
 - Continue to use LEO platforms as “controls” in conjunction with lunar/deep space experiments to separate out the effects of partial gravity (e.g., ISS studies with centrifuges) and differing exposures to high LET radiation
- Future work needs to be a balance of basic science to gain knowledge of how BLEO environments impact biological systems, and applied science with a focus on crew health, safety, countermeasures, and the creation of a sustainable exploration environment.
 - Many recommendations by the radiation and gravity of the lunar environment to focus future animal work on understanding how human health is impacted and developing countermeasures.
 - Working with plant model organisms is a good place to start but work also needs to be done to produce edible plants with high nutritional value for astronauts.
 - Microbial work should be a balance of developing techniques to monitor and control the built environment microbiomes in these new locations, while also working to understand how microbes evolve in these environments, and if they can be manipulated for translational applications including bioregenerative life support.

Topics of interest to space biology for lunar science

- **“Omics” & systems biology** approaches to understand common spaceflight-induced changes in organisms
- **Quantitative genetics** experiments to elucidate the determinants of susceptibility to the deep space environment
- **Applying artificial intelligence (AI) and machine learning (ML)** approaches to space biology research, science data management, and to aid the development of risk models
- **Development of autonomous systems** to support long-duration biological research beyond low-Earth orbit

Acknowledgments

Lunar Surface Science Workshop (LSSW)

- Kevin Sato
- SMD LSSW Working Group
- Lunar and Planetary Institute, USRA
- NASA Solar System Exploration Research Virtual Institute
- Anthony Hickey

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1:10 PM	Marianne Sowa Howard Levine Lucie Poulet	Group C – Vertebrate (II) Group D – Plant (II) Group F – Invertebrate II	https://youtu.be/UoMi0RoiEsY https://youtu.be/48Yzea8iYtU https://youtu.be/aqXrKXueXQE
2:20 PM	Tara Ruttley Jennifer Buchli	Group G – Microbiology Group I – Cell Biology Systems	https://youtu.be/NvQEt71pIBQ https://youtu.be/kO5AIBKEKLk
3:20 PM	Louis Stodieck Lisa Carnell	Group H – Microbiology (II) Group J – Cell Biology Systems (II)	https://youtu.be/0ERHGko9-BQ https://youtu.be/0LkM5297O_4

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