Campaign: Telemetry-based biology
for the Artemis era and beyond

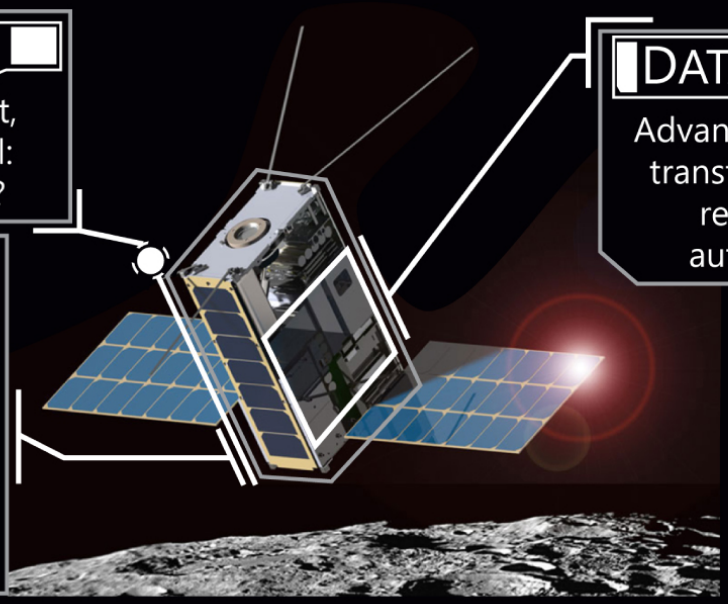
A White Paper Submitted on 23 December 2021
to the
Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032

Principal Author:
Name: Egle Cekanaviciute
Phone: 415.623.0033
Institution: NASA Ames Research Center
Email: egle.cekanaviciute@nasa.gov

Co-authors:
- *Jared Broddrick, NASA ARC (Co-lead)*
- *Alain Berinstain, Space Tango*
- *Christopher Hinojosa, eMulate*
- *Jessica A. Lee, NASA ARC*
- *Sergio Santa Maria, Univ. of NM/NASA ARC*
- *Tobias Niederwieser, BioServe Space Tech.*
- *Nathaniel Szewczyk, Ohio University*
- *Abhijit Biswas, NASA JPL*
- *Therese Moretto Jorgensen, NASA ARC*
- *Matthew Lera, NASA ARC*
- *Anand Narayanan, Florida State Univ.*
- *Antonio Ricco, NASA ARC*
- *Camilla Urbaniak, NASA JPL*

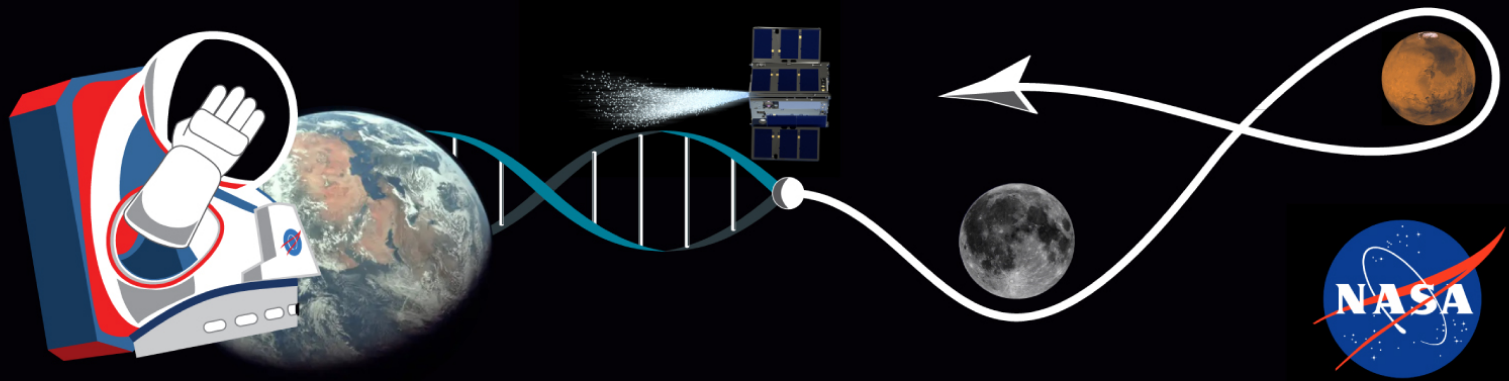
HARDWARE
Small, high-throughput, robust and meaningful: how do we get there?

EXPERIMENTAL DESIGN
Scaled-down cellular, tissue and organism models to achieve NASA Space Biology science objectives



DATA CONSTRAINTS
Advances in deep-space data transfer and dimensionality reduction to support autonomous payloads.

BUS
Build and expand on perspectives from CubeSats and other autonomous payloads



All images courtesy of NASA

I. Background: The need for biology research beyond low-Earth orbit.

A stated goal of the NASA Space Biology program is "Thriving In DEep Space (TIDES)." This initiative sets the stage for fundamental biology research in support of the Agency's human exploration objectives. It recognizes **the unique stressors** (galactic cosmic ray radiation in combination with reduced gravity, increased distance from Earth, exposure to lunar dust as well as other aspects of hostile environment) **present beyond low earth orbit (BLEO) and the need to characterize and mitigate the effect of these stressors on crew and spacecraft**. However, to date, the only BLEO space biology experiments have been performed in the Apollo era and were severely limited by payload capacity. While the soon-to-be-launched BioSentinel CubeSat mission will take space biology back to the BLEO environment, significant challenges remain in the effort to truly enable TIDES.

Space biology research on the International Space Station (ISS) has been privileged by dedicated crew support for the initiation, sample preparation, maintenance, data collection, and stowage of biological experiments. Additionally, the proximity to Earth and the data storage capabilities afforded by that proximity have placed few, if any, constraints on the transfer of experimental data back to the investigators. In contrast, crew time dedicated to space biology experiments during lunar missions will likely be limited, and there are no current plans for continuous human occupation of the lunar orbiting station, Gateway. Thus, **NASA Space Biology must leverage autonomous experimental systems that can either be manifested as secondary payloads on Artemis missions or commercial crew vehicles, or function in a highly autonomous fashion in lunar orbit and on lunar surface**. Furthermore, sample return will be rare, and all *in situ* experimental results will be transmitted via telemetry, placing unique constraints on mission design.

These constraints are beginning to be reflected in lunar experimental proposal solicitations at NASA. A current solicitation "Payloads and Research Investigations on the Surface of the Moon" (PRISM) includes language such as "investigations must be lander agnostic and utilize common interfaces," as well as strict mass limits and constraints on communications, power, temperature, etc. These constraints are shared by the BLEO BioSentinel mission and will likely be typical for BLEO space biology payloads. However, at present there is a **lack of hardware, biological models and computational approaches available to address these considerations, creating a lag in investigating fundamental biological effects of the BLEO environment and adequately preparing to address the associated risks of human deep space exploration.**

In an effort to characterize the current state of the field with regard to the challenges imposed by these new limitations, NASA Space Biology and NASA Ames Research Center held a **workshop, "Telemetry-Based Biology for the Artemis Era and Beyond**" in August 2021. The main purpose of the workshop was to identify the focus areas and gaps in the development of automated biological payloads for BLEO experiments. The results of the workshop highlighted a series of challenges and recommendations.

II. Challenges and recommendations for automated biological payload development.

Hardware.

Challenge: Currently, lack of standardized experimental platforms forces continual development of hardware, often with overlapping and partially redundant functions. Little

emphasis is placed on compatibility between hardware models, resulting in lengthy timelines, cost overruns, and failed experiments.

Recommendations:

- Development of modular hardware system (s) and their utilization across multiple applications with limited modifications for each biological model (including model organisms as well as cell/tissue/organ models), using a similar approach to the extension of the BioSentinel's BioSensor system to lunar payloads (as described in the LEIA solicitation).
- Defining a suite of essential technologies for biological support and biological measurements, followed by a) assessment of their availability, b) identification of the developments needed to convert them to autonomous, space-ready format, and c) dedicated funding to fill the technological gaps.
- Development of a single integrated suite of automated instruments that could be utilized by multiple research groups to address a variety of experimental questions, while avoiding solicitations that would encourage each awarded investigator to create their own instrumentation *de novo*.
- Iterative testing of hardware performance in increasingly complex environments: ground → scientific balloons → parabolic flights → low-Earth orbit → BLEO, e.g. lunar orbit/surface.

Data.

Challenge: Data bandwidth will become a dominant constraint on the volume and types of data that can be collected during BLEO space biology experiments.

Recommendations:

- Utilize academic and commercial communications facilities for space-to-ground data transfer in addition to the NASA Deep Space Network.
- Focus on data dimensionality reduction together with automated in-flight processing, filtering and prioritization to minimize the quantity of data to be telemetered.
- Develop robust command sequences of complex autonomous actions to initiate and control on-board instruments and experiments that would not require connection to Earth.

Experimental design.

Challenge: The current suite of automated sample preparation systems, scaled-down biological models, and data acquisition methods are insufficient for TIDES.

Recommendations:

- Fund a comprehensive campaign to increase the technology readiness level (TRL) of automated sample preparation and miniaturized biological support systems that can obtain mechanistic insights of the effects of the BLEO environment on humans, vertebrates, invertebrates, plants and microorganisms.
- Fund a comprehensive campaign to develop flight-ready instruments, working together with efforts in the Planetary Sciences Division. (See Topical White Paper *Co-leveraging Scientific Advances in Space Biology and Astrobiology towards Achieving NASA's Life Science Objectives*, Principal Author: Jared Broddrick.)
- Define a minimal set of environmental data parameters (e.g., radiation dose, temperature) that will be collected for every experiment to facilitate comparative analysis of results.

Programmatic considerations.

Recommendations:

- **Fund large-scale projects and coherent campaigns encompassing all aspects of an autonomous biological mission (hardware, biological models, data transfer) instead of multiple individual grants focused on separate payload aspects.**
- Allocate funding to maximize science gains should biological payloads operate beyond their designed lifetime.
- Extend the CubeSat Launch Initiative to incorporate small biological payloads in and beyond low Earth orbit, to Gateway and to lunar surface via Commercial Lunar Payload Services (CLPS).
- Accommodate late handover and integration (days instead of weeks or months) of biological experiments on deep space missions.
- Ensure that NASA trains and supports sufficient science and engineering workforce for leading long-duration missions. (See related Topical White Papers: *Biological and Physical Sciences Outreach*, Principal Author: Egle Cekanaviciute; and *Enhancement and Retention of Space Bioscientists and Students*, Principal Author: Amber M. Paul.)

III. Campaign for automated biology research beyond low-Earth orbit.

Initial efforts.

BLEO access for biological payloads. The Agency's exploration timeline envisions NASA and its international partners back on the Moon by 2025. Lunar orbit and surface missions will provide opportunities to begin the characterization of the lunar environment and its effects on biological systems. Solicitations for new research proposals, such as PRISM, should include biological payloads based on current capabilities. Additionally, the Biological and Physical Sciences Division should coordinate with the Planetary Sciences Division to include secondary biological payloads on future deep space missions (e.g., Mars Sample Return).

Standards. To facilitate future hardware and experimental design, we propose that NASA, in collaboration with researchers and payload developers, establish broad requirements to which all BLEO space biology payloads must conform. This could be achieved in a Technical Interchange Meeting with the goal of balancing the need for rapid integration of experiments and hardware without overly constraining the types of science questions that can be addressed.

Milestones. Programmatic support for biological research integration in Artemis mission and a set of standards that will be included in funding solicitations in the following stages.

Intermediate stages of the campaign.

Technology development. By the intermediate stage, we propose a series of solicitations to directly advance the TRL of instruments and approaches that can a) sustain automated biological systems, b) analyze their responses to environmental stressors, and c) miniaturize spaceflight-relevant biological models. The solicited hardware will ideally include testing of flight stability and reduced gravity compatibility, for example, on parabolic or suborbital flights. The solicited models should allow investigation of a wide variety of biological phenotypes using spaceflight-compatible instruments. These solicitations should also include a dedicated campaign to develop proof-of-concept models for data dimensionality reduction of space biology datasets (images, video, 'omics data) and their performance evaluation on the existing space biology datasets, such

as those currently located in NASA GeneLab.

Milestones. A set of high-TRL instruments and biological models ready for integration with lunar orbit and surface missions. Identification of areas that require additional ground development.

Late-stage campaign.

Payload integration and deployment. Towards the end of the campaign, we propose that the most successful high-TRL instruments and models from the prior phase be integrated into deep space missions, e.g. Artemis on the lunar surface, Gateway, collaborations with Planetary Science Division missions, or free flyers like CubeSats.

Iterative advancement of technology. To build on initial deep space missions, we advocate a second iteration of funded efforts that would continue the technological advancement of automated biological payloads. This stage should also include the optimization of operational procedures that mimic communications delays in preparation for deep space biological payloads to Mars.

General suggestions.

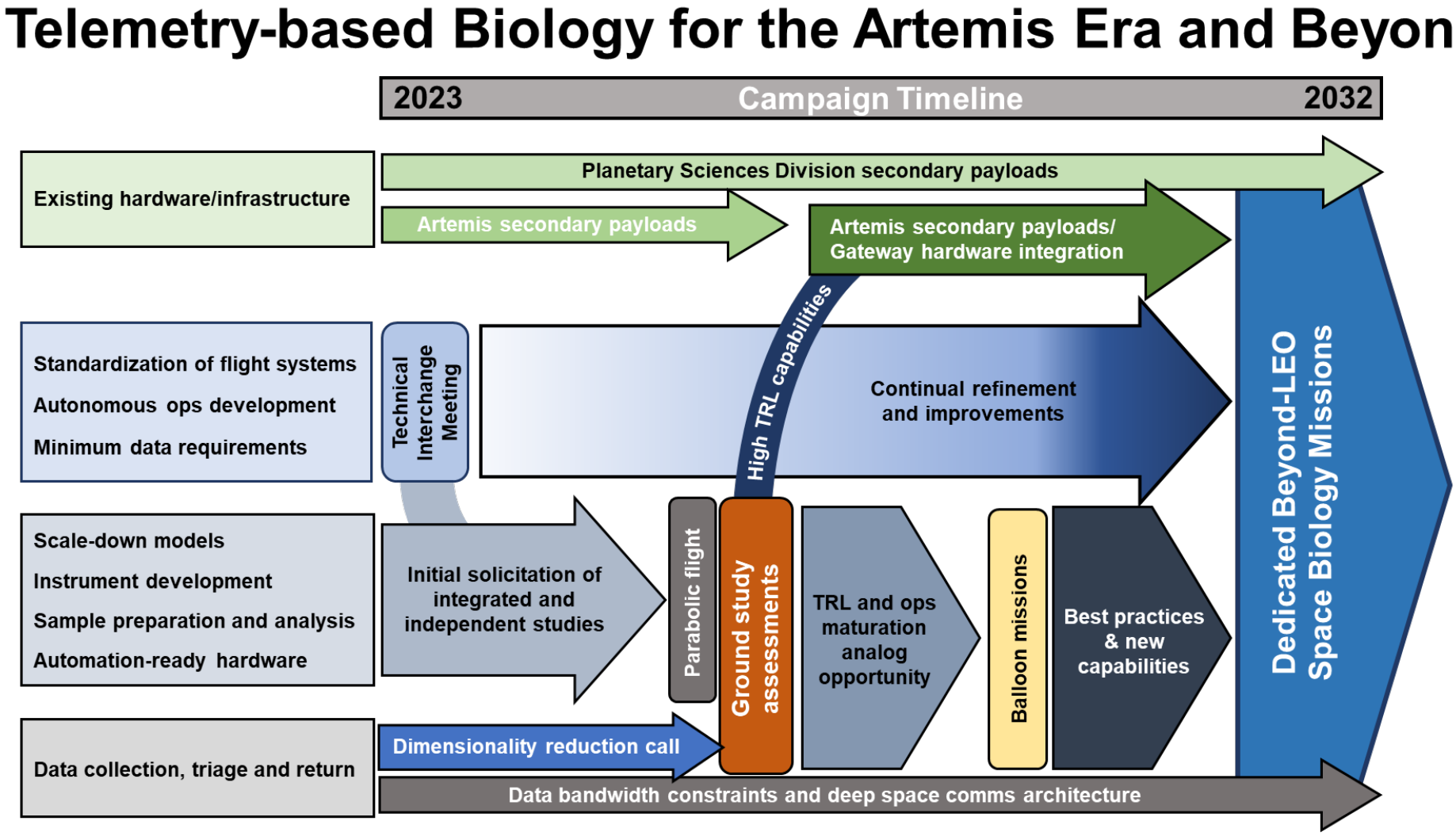
Data. During all phases of the campaign, Space Biology must continuously monitor, support, and provide requirements to the Deep Space Network to ensure that their architecture adequately addresses Space Biology needs.

Approach: scientific balloons for payload testing. Long duration balloon missions are an ideal testbed to develop and validate more complex payloads and operational procedures. They also provide science opportunities by exposing biological systems to spaceflight-relevant doses of ionizing radiation. (See Topical White Paper *A Dedicated, Long Duration Balloon Mission from Antarctica to Study the Effects of Low Dose Galactic Cosmic Radiation on Biology*, Principal Author: David J. Smith.) We suggest that Space Biology expand the use of balloon missions to speed the maturation of new autonomous technologies at a fraction of the costs of spaceflight missions.

Milestones. All milestones should be considered as setting the stage for comprehensive BLEO Space Biology experimental capabilities that will facilitate TIDES. The ultimate goal of this campaign is to develop scalable architecture that can provide fundamental biology support to human space exploration for the Artemis era and beyond.

IV. Conclusions.

In summary, we call for a **major campaign to develop and fly autonomous biological payloads in lunar orbit and on the lunar surface during the next decade**, followed by subsequent expansion to Martian orbit. This ambitious goal will require dedicated effort to develop hardware, biological models and data acquisition and processing techniques. We believe that it would be best achieved as a single comprehensive, NASA-led and funded mission project, analogous to planetary science missions. Furthermore, technological developments should be accompanied by collaborations within and between agencies and a robust program for acquisition and retention of talented scientists and engineers.



Graphical summary. Campaign design to establish robust Space Biology presence beyond low-Earth orbit.