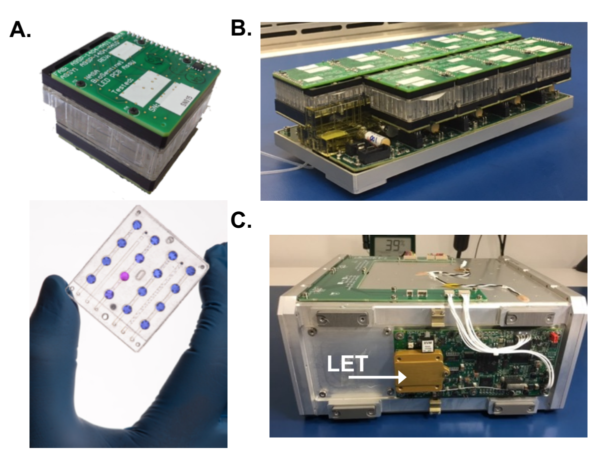
LUNAR BIOSENSOR: AN AUTONOMOUS INSTRUMENT TO STUDY THE EFFECTS OF THE LUNAR ENVIRONMENT ON BIOLOGICAL ORGANISMS. S.R. Santa Maria[1,2], A.J. Ricco[1], Z. Young[1], D. McIntosh[1], and S. Bhattacharya[1], [1]NASA Ames Research Center, Moffett Field, CA 94035, [2]University of New Mexico. Corresponding author: Sergio R. Santa Maria; sergio.santamaria@nasa.gov

Introduction: One of the major challenges to long-duration space travel and habitation in deep space is an in-depth understanding of the biological effects of space radiation, often convoluted by the impact of reduced gravity. Nonetheless, due to the near impossibility of simulating prolonged exposure to these combined effects in terrestrial facilities, actual missions are needed to characterize the radiobiological hazards of this environment.

NASA Ames Research Center has been the leader in developing autonomous bio nanosatellites to address strategic knowledge gaps about the effects of space travel on biological organisms, including GeneSat, PharmaSat, EcAMSat, and BioSentinel. BioSentinel will be the first interplanetary bio nanosatellite or CubeSat to study the biological response to space radiation outside Low Earth Orbit (LEO) in almost 50 years. BioSentinel is an autonomous platform able to support biology and to investigate the effects of space radiation on a model organism in interplanetary deep space. It will fly onboard NASA's Artemis-1, from which it will be deployed on a lunar fly-by trajectory and into a heliocentric orbit [1].



(A) Microfluidic card. (B) Fluidic manifold. (C) 4U BioSensor payload showing LET spectrometer.

The BioSentinel nanosatellite, a 6U deep space CubeSat (1U = 10-cm cube), will measure the DNA damage and response to ambient space radiation in a model biological organism, which will be compared to information provided by an onboard physical radiation sensor and to data obtained in LEO (on the International Space Station, ISS) and on Earth. Even though the primary objective of the mission is to develop an autonomous spacecraft capable of conducting biological experiments in deep space, the 4U BioSensor science payload contained within the 6U free-flyer is an adaptable instrument platform that can perform biological measurements with different microorganisms and in multiple space environments, including the ISS, lunar gateway, and on the surface of the Moon. Thus, nanosatellites like BioSentinel (and BioSensor) can be used to study the effects of both reduced gravity and space radiation and can house different bio organisms to answer specific science questions. In addition to their flexibility, nanosatellites also provide a low-cost alternative to more complex and larger missions, and require minimal crew support, if any.

Lunar BioSensor: The *Lunar BioSensor* follows a trail blazed by BioSentinel. The proposed 4U instrument will leverage the payload design of the 6U BioSentinel free-flyer, utilizing the lunar lander for power and data relay. This instrument measures the DNA damage and response to ambient radiation (and reduced gravity) using a model bio organism, the budding yeast *Saccharomyces cerevisiae*. Budding yeast was selected not only for its similarity to human cells, facile genetic manipulation, and flight heritage, but also because yeast can be desiccated and remain dormant for long periods of time [2]. In addition, the payload includes an LET (linear energy transfer) TimePix-based spectrometer that registers the number, arrival time, and LET values of impacting ionizing particles and provides accurate dosimetry that can be correlated with biological changes induced by radiation [1].

The 4U BioSensor payload was developed to fly in a heliocentric orbit and onboard the ISS. Flight data will be compared to those from an identical unit on the ground. The data from this *Lunar BioSensor* will be a critical complement to the Artemis-1 BioSentinel free-flyer and ISS missions in order to map the radiation/gravity continuum of biological effects using a common measurement device. It will demonstrate direct measurements of the biological effects of cis-lunar radiation at partial gravity on the surface of the Moon, and at microgravity in lunar orbit, as well as in transit from Earth to the Moon. Currently, both the 6U free-flyer and the 4U BioSensor payload exceed TRL 6 (some components, like the TimePix sensor, are at TRL 9) and will be flight-ready in mid-2020 (TRL 8).

Instrumentation: The *Lunar BioSensor* payload reuses the hermetic containment vessel of ~ 4U volume (10 x 20 x 20 cm) and about 7 kg of mass (5kg for science payload plus 2kg for associated lander interface hardware) and ~ 6 – 7 L volume. The science payload has dimensions of 4 x 9 x 9 inches. The components were selected to survive the Space Launch System (SLS) conditions, indicating that the *Lunar BioSensor* can be mounted without vibration isolation. The electrical and control systems incorporate key components of the BioSentinel free-flyer, while interfacing with the lander for power and communication. These interfaces will be configured for the selected lander, assuming a 28 VDC power supply (nominal 6 W) and an RS-422 data connection (1 Mbit / day). The thermal conditions on the lander may require additional insulation and/or shading of the BioSensor enclosure to maintain a desired 4 – 35 °C operating environment. The science payload does not incorporate active cooling but does include heaters to maintain optimal yeast growth temperatures in cold environments.

The flight hardware leverages and expands the proven LADEE Software Framework generalized with the CAST (Common Avionics Software Testbed) infrastructure. The CAST framework is built upon the cFE (Core Flight Executive) and cFS (Core Flight Services) packages developed by Goddard Space Flight Center. The existing data architecture calls for science data to be recorded on the C&DH board for 24 hours before transmission to the ground. Approximately 1 Mbit of data are created each day. The frequency and duration of data transmission is negotiable based on the concept of operations for the lander provider. The existing data system includes 8 GB of storage; sufficient to retain over a decade of BioSensor data acquisition. This enables significant adaptability for the relaying of data to the ground.

The experimental yeast strains have been selected for their ability to survive in a desiccated state for long-duration space missions [2]. The yeast cells are loaded into polycarbonate microfluidic cards. Once sealed, optical detection boards and heating elements are mounted onto each card. During flight, nutrients are injected into each fluidic card at different time points, and cell growth and metabolic activity are monitored using a metabolic indicator dye. Significant redundancy is provided by twin fluidic manifolds of 9 microfluidic cards [1]. Furthermore, each card contains 16 microfluidic wells, for a total of 288 wells in the entire payload.

Our *Lunar BioSensor* advances multiple nanosatellite systems in order to perform autonomous biological measurements: (A) biology support in 18 independent microfluidic cards with 16 microwells each; (B) fluid delivery system consisting of pumps, valves, tubing, and media external to cards; (C) dedicated thermal control for each fluidic card capable of maintaining biological payload during stasis and growth phases; (D) dedicated 3-color optical detection system at each microwell for optical density and metabolic dye absorbance measurements; (E) biofluidics managing long-term (12 – 18 months) biological stasis and modular integrated samples instrumentation; (F) close integration of living biosensors with miniature physical radiation spectrometer (LET spectrometer), pressure and humidity sensors; (G) shielding-, hardening-, design-, and software-derived radiation tolerance for electronics; (H) communications from distances of ≥ 500,000 km.

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References:

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