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BioSentinel: An Adaptable Platform for Studying the Biological Effects of Deep Space Radiation

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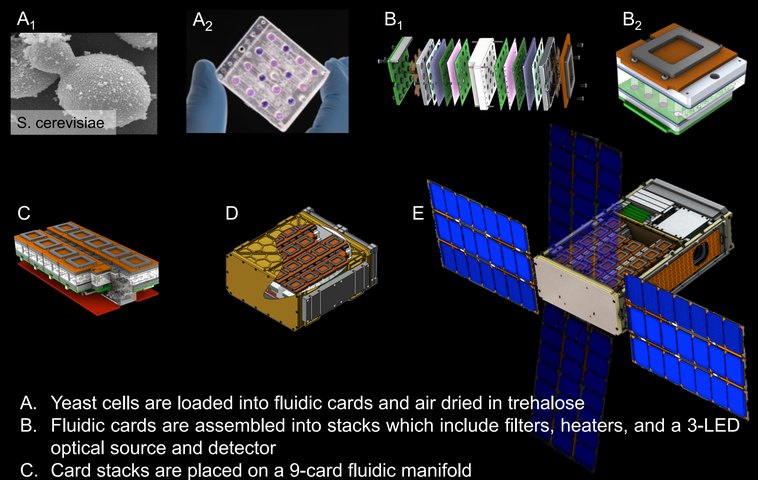
Abstract

NASA's BioSentinel mission is a 6U nanosatellite with autonomous life support that will utilize the budding yeast *Saccharomyces cerevisiae* to study the DNA damage response to the deep space radiation environment. BioSentinel is planned to launch in 2019 as a secondary payload on the Space Launch System's first Exploration Mission (EM-1), and will undergo a lunar fly-by and enter heliocentric orbit after deployment. As the first biological mission beyond Low Earth Orbit (LEO) in nearly half a century, this mission will help fill critical gaps in knowledge about the effects of uniquely composed, chronic, low-flux deep space radiation on biological systems. Yeast is well-suited for this mission due to its desiccation tolerance and space-flight heritage. As a eukaryotic model organism, it also serves as a robust analog for human cells. Data gathered on this mission will thus inform us of the hazards involved in long-duration human exploration in deep space, and the protections necessary to mitigate them. Due to its low-cost, flexible and advanced technology, the 4U BioSensor payload contained within the nanosatellite is adaptable to other model microorganisms, exploration platforms and environments relevant to human exploration, such as the ISS, the Lunar Orbital Platform – Gateway and future lunar landers.

In order to query the DNA damage response to deep space radiation, BioSentinel contains a wild type yeast strain as a positive control, and a radiation sensitive *rad51* mutant strain that is defective for DNA repair. Yeast cells are desiccated in microfluidic cards, and rehydrated with growth medium and metabolic indicator dye at the desired time points during the mission. A thermal control system supports these stasis and growth states, and an optical system continuously measures cell growth and metabolism. An onboard radiation spectrometer and dosimeter allows us to correlate the dose, energy and particle-type of deep space radiation to the biological response. Data received from the deep space biosensor will be compared to control payloads on Earth and the ISS. Ongoing science testing for the BioSentinel project includes optimization for cell viability, desiccation tolerance, and long-term biocompatibility, as well as radiation experiments to understand the sensitivity and responsiveness of cells to varying radiation doses and particle types.

The BioSentinel Payload



A. Yeast cells are loaded into fluidic cards and air dried in trehalose
B. Fluidic cards are assembled into stacks which include filters, heaters, and a 3-LED optical source and detector
C. Card stacks are placed on a 9-card fluidic manifold
D. Two 9-card manifolds and corresponding reagent bags are integrated into the 4U biosensor payload enclosure
E. The payload is integrated into the spacecraft together with the 2U bus, which contains power, propulsion and guidance systems, a transponder, and a LET radiation sensor

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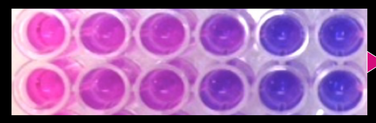
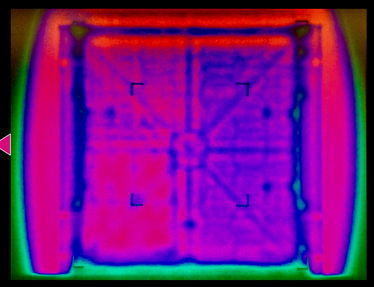
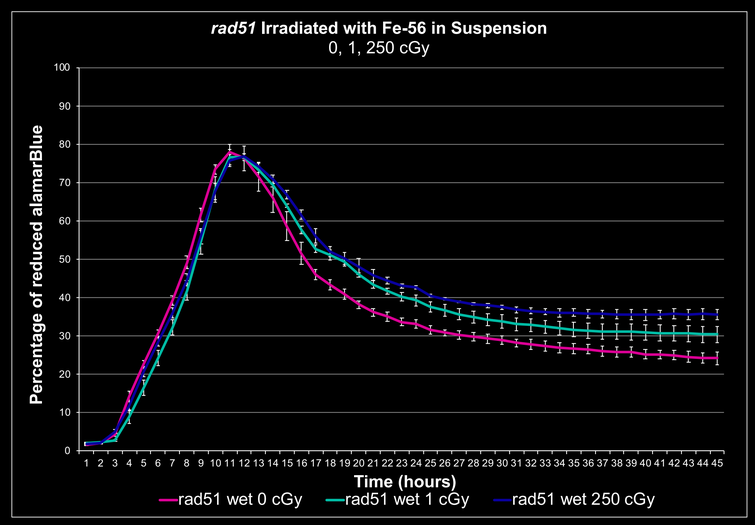
Radiation Testing



alamarBlue metabolic indicator dye allows for detection of changes in yeast growth kinetics and metabolism caused by radiation-induced DNA damage

Aged yeast is irradiated both dry and in suspension to understand the metabolic response to variable doses and types of radiation including protons, Ti, Si, Fe, and gamma irradiation. Solar Particle Event (SPE) simulations have also been performed, as SPEs will be a salient risk to astronaut health and safety during deep space travel. Shown to the right is a beam profile of the payload's aluminum enclosure which provides minimal shielding to the yeast.





After prolonged periods of desiccation, yeast cells remain sensitive to low doses of radiation down to 1 cGy, and demonstrate dose-dependent responsiveness, as shown above.

RNA-Seq experiments are in progress to analyze transcriptomic changes induced by radiation at various stages of cell growth, as well as flow cytometry experiments to assess radical oxygen species formation in response to radiation.

Long-Term Biocompatibility Testing

Retention of reagent integrity and yeast viability in space-flight-like conditions has been demonstrated in a variety of ongoing biocompatibility tests:

- Ethylene Oxide (EtO) Biocompatibility (15 months)
- Epoxy Biocompatibility (12 months)
- Stasis Temperature Biocompatibility (6 months)
- Fluidic Card Biocompatibility (25 months)
- Long-term Reagent Storage Compatibility (24 months)
- Full system biocompatibility unit upcoming

Viability and Desiccation Tolerance

The BioSentinel payload will undergo a 6-9 month integration period into SLS-EM1 on the ground at Kennedy Space Center. After the launch and deployment of the payload, science operations will take place for an additional 6-12 months. For optimal cell survival, yeast is air-dried in trehalose, a disaccharide sugar known to provide desiccation tolerance in biological organisms. Long-term desiccation studies indicate that WT and *rad51* cells will retain sufficient viability under variable launchpad and flight–like temperature conditions to produce usable data throughout the mission (shown below). Since viability declines over time, experiments are being conducted to optimize cell growth conditions and enhance protective molecular mechanisms for improved desiccation tolerance.

References

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