BioSentinel: Mission Development of a Radiation Biosensor to Gauge DNA Damage and Repair Beyond Low Earth Orbit on a 6U Nanosatellite

Brian Lewis[1], Robert Hanel[1], Sharmila Bhattacharya[1], Antonio J. Ricco[1], Elwood Agasid[1], Debra Reiss-Bubenheim[1], Tore Straume[1], Macarena Parra[1], Travis Boone[1], Sergio Santa Maria[1], Ming Tan[1], Diana Marina[1], Charlie Friedericks[1], Aaron Schooley[1], Shang Wu[1], Matthew Sorgenfrei[1], Matthew Nehrenz[1], Abe Rademacher[1], Terry Lusby[1], Vanessa Kuroda[1], Craig Pires[1], Josh Benton[1], Doug Forman[1], Ben Klamm[1], Andres Martinez[1], Brittany Wickizer[1,], Hugo Sanchez[1,], Bobbie Gale Swan[2], Edward Semones[2], Scott Wheeler[2], C. Mark Ott[2], and Sarah Castro[2]

[1]NASA Ames Research Center, Moffett Field, CA, USA and [2]NASA Johnson Space Center, Houston, TX, USA

We are designing and developing a "6U" (10 x 22 x 34 cm; 14 kg) nanosatellite as a secondary payload to fly aboard NASA's Space Launch System (SLS) Exploration Mission (EM) 1, scheduled for launch in late 2017. For the first time in over forty years, direct experimental data from biological studies beyond low Earth orbit (LEO) will be obtained during BioSentinel's 12- to 18-month mission. BioSentinel will measure the damage and repair of DNA in a biological organism and allow us to compare that to information from onboard physical radiation sensors. In order to understand the relative contributions of the space environment's two dominant biological perturbations, reduced gravity and ionizing radiation, results from deep space will be directly compared to data obtained in LEO (on ISS) and on Earth. These data points will be available for validation of existing biological radiation damage and repair models, and for extrapolation to humans, to assist in mitigating risks during future long-term exploration missions beyond LEO.

The BioSentinel Payload occupies 4U of the spacecraft and will utilize the monocellular eukaryotic organism *Saccharomyces cerevisiae* (yeast) to report DNA double-strand-break (DSB) events that result from ambient space radiation. DSB repair exhibits striking conservation of repair proteins from yeast to humans. Yeast was selected because of 1) its similarity to cells in higher organisms, 2) the well-established history of strains engineered to measure DSB repair, 3) its spaceflight heritage, and 4) the wealth of available ground and flight reference data. The *S. cerevisiae* flight strain will include engineered genetic defects to prevent growth and division until a radiation-induced DSB activates the yeast's DNA repair mechanisms. The triggered culture growth and metabolic activity directly indicate a DSB and its successful repair. The yeast will be carried in the dry state within the 1-atm P/L container in 18 separate fluidics cards with each card having 16 independent culture microwells, with integral microchannels and filters to supply nutrients and reagents, confine the yeast to the wells, and enable optical measurement. The measurement subsystem will monitor each subgroup of culture wells continuously for several weeks, optically tracking DSB-triggered cell growth and metabolism. BioSentinel will also include physical radiation sensors based on the TimePix sensor, as implemented by JSC's RadWorks group, which record individual radiation events including estimates of their linear-energy-transfer (LET) values. Radiation-dose and LET data will be compared directly to the rate of DSB-and-repair events measured by the *S. cerevisiae* biosentinels.

The spacecraft bus will operate in a deep space environment with functions that include command and data handling, communications, power generation (via deployable solar panels) and storage, and attitude determination-and-control system with micropropulsion. Development of the BioSentinel spacecraft will mature and prove multiple nanosatellite advances in order to function well beyond LEO:

- Communications from distances of ≥ 500,000 km
- Autonomous attitude control, momentum management, and safe mode of nanosatellites in deep space
- Shielding-, hardening-, design-, and software-derived radiation tolerance for electronics
- Reliable functionality for 12 – 18 months of key subsystems for biofluidics, memory, communications, power, etc.
- Close integration of living biological radiation event monitors with miniature physical radiation spectrometers
- Biological measurement of solar particle events beyond Earth orbit

In addition to providing the first biological results from beyond LEO in over 4 decades, BioSentinel will provide an adaptable small-satellite instrument platform to perform a range of human-exploration-relevant measurements that characterize the biological consequences of multiple outer space environments. BioSentinel is being developed under NASA's Advanced Exploration Systems program.