BioSentinel
A 6U Nanosatellite for Deep Space Biological Science

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13th Annual Summer CubeSat Developers’ Workshop
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BioSentinel Project Objectives

• Advanced Exploration Systems (AES) Program Office selected BioSentinel to fly on the Space Launch System (SLS) Exploration Mission (EM-1) as a secondary payload
  • Payload selected to help fill **Strategic Knowledge Gaps in Radiation effects on Biology**
  • Current EM-1 Launch Readiness Date (LRD): July 31, 2018

• Key BioSentinel Project Objectives
  • Develop a *deep space nanosat* capability
  • Develop a *radiation biosensor* useful for other missions
  • Define & validate **SLS secondary payload interfaces and accommodations** for a biological payload

• Collaborate with two other AES selected missions (non-biological) for EM-1
  • Near Earth Asteroid (NEA) Scout (MSFC)
  • Lunar Flashlight (JPL)
A BioSensor in Space

• **What**: BioSentinel is a yeast radiation biosensor that will measure the response to DNA damage caused by space radiation, primarily double strand breaks (DSBs).

• **Why**: The space radiation environment’s unique spectrum cannot be duplicated on Earth. It includes high-energy particles, is omnidirectional, continuous, and of low flux. During solar particle events (SPEs), radiation flux can spike to a thousand nominal levels.

• **How**: Laboratory-engineered *S. cerevisiae* cells will receive ionizing radiation in desiccated state and in suspension; cell growth and metabolic activity in microwells will indicate DSB-and-repair events. Multiple microwells will be in active mode during the mission & extra wells will be activated in the event of an SPE.

**Why budding yeast?**

Eukaryotic organism; easy genetic / physical manipulation; availability of assays; flight heritage; ability to be stored in stasis for long durations; and common DNA repair mechanism with humans

While it is a simple model system, yeast is the best model organism for the job given the limitations and constraints of deep-space missions
## BioSentinel Mission Phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Entry</th>
<th>Exit</th>
<th>Duration</th>
<th>Summary &amp; Objectives</th>
</tr>
</thead>
</table>
| Pre-Launch                | Loading of biology            | L/V Lift-off              | ~180 days| • Load Flight Biology
• Charge, checkout, and configure FreeFlyer
• Integrate FreeFlyer with Dispenser and SLS                                           |
| Launch                    | L/V Lift-off                  | Deployment of FreeFlyer   | <1 day   | • FreeFlyer is powered off
• Survive launch environments and deployment                                             |
| Initialization            | Deployment of FreeFlyer       | Completion of FreeFlyer checkout | ~14 days | • Power-on, reduce tip-off rates, deploy solar arrays, transition to safe mode
• Ground station initial acquisition and tracking
• Checkout of FreeFlyer systems                                                         |
| Science                   | Nominal FreeFlyer SOH         | Final science data received at Science Data Center | 365 days | • Collect data from all payloads
• Execute biology experiments per science plan
• Respond to SPE events
• Maintain FreeFlyer bus health                                                         |
| Science (Extension)       | ATP Science Extension         | Final science data received at Science Data Center | 180 days | • Collect data from all payloads
• Execute biology experiments per science plan
• Respond to SPE events
• Maintain FreeFlyer bus health                                                         |
| Operational Decommission  | End of Nominal Science Ops    | FreeFlyer decommissioned (power-off) | ~7 days  | • Ensure all data downlinked
• Solar array switches open to ensure battery never recharges
• Transmitter power-down                                                               |
BioSentinel Spacecraft Modes

Pre-launch:
- Biology Load & Integration: 1 month
- Shipping & Dispenser Integration: 1 month
- Launch Vehicle Integration: 4 months

Launch:
- Checkout: 2 weeks

Spaceflight:
- Science Operations: 12 months

Extended Science:
- 6 months

Diagram:
- PRE-LAUNCH PHASE:
  - Power-off sequence
  - Launch (all off)

- INITIALIZATION PHASE:
  - Ejection from Dispenser
  - Startup
  - Checkout

- SCIENCE PHASE:
  - Science Mode
  - Comm Mode

- DECOMMISSIONING PHASE:
  - Shutdown Mode

Legend:
- Ground Cmd
- Onboard Cmd
- Onboard Logic
- Transition
- Operating Mode

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• 13 - dispenser locations that each support a 6U (14 kg) secondary payload
• 1 - bracket location allocated to a sequencer
• EM-1 only accommodates 6U payloads; EM-2 may accommodate 12U payloads
Launch Phase

Total Payload Deployment Mission Duration: 10 days

2) Perigee Raise Maneuver (PRM) ICPS - 100x975 nmi (185x1806 km)

3) TRANS-LUNAR INJECTION (TLI) ICPS

4) MPCV/ICPS Separation 10 min. after TLI

5a) Trajectory Correction Maneuvers (TCMs)
Orion Outbound: 3 - 8 days

5b) Trajectory Disposal Maneuvers (TDMs)
ICPS w/2nd Payloads 45 – 60 min.

6a) Mission & Return to Earth
Orion Outbound: 3 - 8 days

6b) 2nd Payload Deployment - Start Deployment window 10 days

7) ICPS to Helio Orbit 2nd Payload Option(s)
• Orbit Moon
• Impact into Moon
• Fly out past moon

2nd Payload Deployment Conditions
• Ground launch window up to 2 hours long (depends on launch day in weekly window).
• DRO Mission Scenario—Weekly Launch Window with Lunar Arrival ~3.5 to 8.5 days, early in window is longest trip time.
• End of the disposal maneuver, the ICPS is at 26,700 km from Earth, inertial velocity of 5.279 km/s.
Deployment “Bus Stops”

<table>
<thead>
<tr>
<th>Bus Stops</th>
<th>Distance</th>
<th>Flight Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26,700 km</td>
<td>4 Hrs. &amp; 32 Min.</td>
</tr>
<tr>
<td>2</td>
<td>64,000 km</td>
<td>13 Hrs. &amp; 17 Min.</td>
</tr>
<tr>
<td>3</td>
<td>192,500 km</td>
<td>3 Days, 10 Hrs. &amp; 18 Min.</td>
</tr>
<tr>
<td>4</td>
<td>238,900 km</td>
<td>6 Days, 20 Hrs. &amp; 51 Min.</td>
</tr>
<tr>
<td>5</td>
<td>313,400 km</td>
<td>7 Days, 9 Hrs. &amp; 38 Min.</td>
</tr>
</tbody>
</table>

Bus Stops

1. First opportunity for deployment, 2nd radiation belt
2. Clear radiation belt plus an hour
3. Half way to the moon
4. At the moon (~250 km from surface)
5. Past the moon plus 12 hours (lunar gravitational assist)
Science Operations are periodic with 8 time points throughout the 12 months:
- Activation Time points: T0, T0+45 days, T0+90 days, T0+135 days, T0+180 days, T0+225 days, T0+270 days, T0+315 days
- Schedule is adjustable as part of Science Planning process during operations
- Two 4x4 cards are activated at a time
- Two media are used for each biology 4x4 cards
  - Media A for 4 weeks rehydrates the desiccated samples
  - Media B for 2 weeks includes raising the temperature and adding growth media with Alamar Blue
Heliocentric Orbit

Range from Earth

Sun-BioS-Earth Angle

Range in AU

Mission Day

Sun-BioS-Earth Angle (deg)

Mission Day

Nominal Mission (380d, 0.56AU)

Nominal Mission (379d, 71.9deg)

Extended Mission (540d, 0.71AU)

Extended Mission (540d, 64.1deg)

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Based on current trajectory and transponder design assumptions, the system supports:

- 8 kbps through the minimum mission duration (3 months)
- 500 bps through the nominal mission duration (12 months)
- 250 bps through the extended mission duration (18 months)
More work in progress…
Thank you!

Questions?
BACK-UP
BioSentinel FreeFlyer Spacecraft Bus Summary

- LEON3 RT based C&DH
  - Embedded VxWorks OS with cFS/cFE
  - Port of LADEE FSW for Bus
  - Port of EcAMSat / SporeSat FSW for P/L
- 3-axis controlled GNC system
  - Blue Canyon XACT Integrated GN&C Unit
    - 3 Reaction Wheels
    - Star Tracker
    - CSS, IMU for safe mode
    - 5° pointing requirement
- Propulsion
  - 3D printed system from GT / LSR
  - Null tipoff rates and momentum management
  - Seven cold gas R236cf thrusters
  - ~60 sec Isp
  - ~200 grams propellant
- Communications
  - X-Band to DSN @ 62.5 - 8000 bps
  - LGA and MGA patch antennae
  - IRIS v2 coherent transponder
- Power
  - ~32 W generated power EOL
  - Deployable HaWK arrays from MMA
  - Panasonic 18650 batteries
  - ARC design EPS and switch controllers
- Structure
  - 6U nominal volume
  - ARC Nanosat heritage
  - EcAMSat provided baseline for BioSentinel development
- Thermal
  - Cold biased system
  - Heaters, thermistors, paint, reflective tape for control
- Supports Payloads
  - Yeast based BioSensor Payload
  - JSC LET Spectrometer
  - Teledyne based TID Dosimeter
  - 4U volume
BioSentinel Month-in-the-Life ConOps

### Monitor Bus Functions

1. **Media A: 4 weeks**
   - Wet new cards with Media A (2 fluidic cards every 6 weeks, ATS)
   - Collect science data (Continuous, RTS)

2. **Media B: 2 weeks**
   - Wet cards with Media B (4 weeks after Media A, RTS)

#### Major Functions

<table>
<thead>
<tr>
<th>Major Functions</th>
<th>Sub-functions</th>
</tr>
</thead>
</table>
| Select card              | • Determine fluidic card  
                           | • Select μ-controller  
                           | • Select pump and valve set |
| Apply Fluids             | • Open inlet valve  
                           | • Open plate valve  
                           | • Open nutrient valves  
                           | • Activate Pump         |
| Configure Thermal Control| • Apply cold set points to other cards  
                           | • Warm set points for Media B         |
| Close System             | • Close inlet valve  
                           | • Close plate valve  
                           | • Close nutrient valves  
                           | • De-activate pump       |

#### Major Functions

<table>
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<th>Sub-functions</th>
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</table>
| Readout BioSensor        | • Determine fluidic card  
                           | • Select μ-controller  
                           | • Select pump and valve set |
| Readout TID sensor       | • Determine fluidic card  
                           | • Select u-controller  
                           | • Select and power well LEDs  
                           | • Select and readout sensor |
| Readout LET Spectrometer | • Apply power to sensor  
                           | • Wait for stabilization  
                           | • Sample analog readouts |
| Monitor for SPE          | • Acquire binned data  
                           | • Store data in file system |
|                          | • Sample TID readout  
                           | • Sample LET shutter info  
                           | • Wet new card if SPE detected |

### Transmit to DSN

(Daily, 30 minute contact, ATS)

- Align spacecraft
  - Determine vector to Earth
  - Slew to Earth vector
- Power Tx
  - Power transmitter
- Broadcast data
  - Broadcast SOH
  - On CFDP command, transmit BioSensor, LET, TID data
- Deactivate Tx
  - Power off transmitter
- Realign spacecraft
  - Slew back to sun vector

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LET Spectrometer & TID Dosimeter Radiation Monitoring

- Linear Energy Transfer (LET) Spectrometer Designed by JSC RadWorks specifically for the BioSentinel Project.

- Total Ionizing Dose (TID) Dosimeter using a Teledyne uDOS001 sensor, board design by ARC. Prototype board with dummy sensor.
Ground System Architecture

Space Communication and Navigation (SCaN) Networks
- NASA Deep Space Network (DSN)
  - Goldstone 34-m BWG (x3)
  - Goldstone 34-m HEF (x3)
  - Canberra 34-m BWG (x3)
  - Canberra 34-m HEF (x2)
  - Madrid 34-m BWG (x2)
  - Madrid 34-m HEF (x1)
  - Morehead St 21-m (x1) (in dev.)
- NASA Near Earth Network (NEN)
  - Hawaii 13-m (x2)
  - Wallops 11-m (D/L only)
  - Dongara 13-m / 7-m
  - Hartebeestok 10-m (D/L only)

Mission Operations Center - ARC
- Telemetry & Command System
- Activity Planning System
- Command Sequencing System
- Flight Dynamics System
- Engineering Analysis System
- Plotting & Trending System
- Simulation System
- Monitor & Alerting System
- Short-Term Data Archival System

File & Data Management
- Productivity Tools
- Networking

Science Data Center - ARC
- Science Data Calibration
- Plotting & Trending System
- Short-Term Data Archival System

File & Data Management
- Space Weather Prediction & Monitoring

NASA Life Sciences Data Archive (ARC)

Legend
- Real Time
- Delayed
- RF Link
- Open for Trade (any color)

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<table>
<thead>
<tr>
<th>Mission Phase</th>
<th>Length</th>
<th>Mission Operations Staffing Profile</th>
<th>Assumptions/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Launch</td>
<td>~ 30 day</td>
<td>- 4x5 support for monitoring of BioSentinel</td>
<td>- DSGC must start while BioSentinel is at KSC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DSGC pre-launch profile</td>
<td></td>
</tr>
<tr>
<td>Launch &amp; Ascent</td>
<td>~ 1 day</td>
<td>- Full team will staff the MOC</td>
<td>- BioSentinel is powered off. No real-time stream of data from S/C into the MOC during L&amp;A</td>
</tr>
<tr>
<td>Initialization</td>
<td>~ 14 days</td>
<td>- 24x7 console support for L + 5 days to check out S/C bus systems, ensure payloads are functional, perform orbit determination and update activity plan</td>
<td>- Launch dispersions and deployment uncertainty will require BioSentinel re-plan cycle.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Launch dispersions and deployment uncertainty will require BioSentinel re-plan cycle.</td>
<td>- No propulsive maneuver to achieve heliocentric orbit.</td>
</tr>
<tr>
<td>Science (early)</td>
<td>~ 60 days</td>
<td>- 8x5 console support to monitor first two biosensor experiments and to assist in planning and executing calibration activities as needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Surge support if needed</td>
<td>- Autonomous momentum dumping</td>
</tr>
<tr>
<td>Science (routine)</td>
<td>~ 305 days</td>
<td>- One planning cycle every week with goal of two weeks</td>
<td>- Review of DSN schedule every month, for three months in the future</td>
</tr>
<tr>
<td></td>
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<td>- Uplink console supports once per week, available for other with notice</td>
<td>- Limited real-time changes to schedule and plan except for SPE response</td>
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<tr>
<td></td>
<td></td>
<td>- Continuous trending of S/C bus data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Console staff on-call to respond to SPE</td>
<td></td>
</tr>
<tr>
<td>Extended Science</td>
<td>~ 180 days</td>
<td>- Continuation of Science</td>
<td></td>
</tr>
</tbody>
</table>
Spacecraft to Sun Range

Sun Range in AU

- Nominal Mission (380d)
- Extended Mission (540d)

Sun-BioSentinel Range (AU)

Mission Day

- 20% Power Loss
- 10% Power Loss
Power Budget

Actual Power Margin (No SE Contingency)

Power (Watts) vs. Mission Days

- Avg Draw
- Supply, Gimbal
- Supply, No Gimbal
- Margin, Gimbal
- Margin, No Gimbal

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Battery Discharge

DOD After 30 Minute Comm Pass (Iris in Tx/Rx) with SE Contingency

Mission Days

Depth of Discharge

- Maximum
- No gimbal
- Gimbal

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BioSentinel Teaming

The Project Team

- **Mission Management** - Bob Hanel, Dawn McIntosh, James Chartres, Mario Perez, Elwood Agasid, Vas Manolescu, Matt D’Ortenzio
- **Science** - Sharmila Bhattacharya, Sergio Santa Maria, Diana Marina, Macarena Parra, Tore Straume, C. Mark Ott, Sarah Castro, Greg Nelson, Troy Harkness, Roger Brent
- **Payload** - Charlie Friedericks, Rich Bielawski, Tony Ricco, Travis Boone, Ming Tan, Aaron Schooley, Mike Padgen, Diana Gentry, Terry Lusby, Scott Wheeler, Susan Gavalas, Edward Semones
- **Spacecraft and Bus** - Hugo Sanchez, Matthew Sorgenfrei, Matthew Nehrenz, Vanessa Kuroda, Craig Pires, Shang Wu, Abe Rademacher, Josh Benton, Doug Forman, Ben Klamm

Affiliations

NASA Ames, NASA JSC - RadWorks, LLUMC, Univ. Saskatchewan

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