BioSentinel
A 6U Nanosatellite for Deep Space Biological Science

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13th Annual Summer CubeSat Developers’ Workshop
Logan, UT

8/6/16
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 FreeFlyer Spacecraft: Physical Overview

- Propulsion System
- Batteries
- Integrated Guidance Navigation & Control Unit
- Solar Arrays
- Solar Array Gimbal
- Medium-Gain Antenna
- Low-Gain Antennas
- Transponder
- Avionics and Power
- BioSensor Payload
- Total Ionizing Dosimeter (TID) and Linear Energy Transfer (LET) spectrometer

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

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

Launch
- Checkout: 2 weeks
- Science Operations: 12 months

Spaceflight
- Extended Science: 6 months

Diagram:
- PRE-LAUNCH PHASE: Diagnostics Mode (Power-off sequence) → Launch (all off)
- INITIALIZATION PHASE: Ejection from Dispenser → Startup → Checkout
- SCIENCE PHASE: Safe Mode → Science Mode → Comm Mode
- DECOMMISSIONING PHASE: Shutdown Mode

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

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Secondary Payload Location on SLS EM-1

- 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
Total Payload Deployment Mission Duration: 10 days

1) LAUNCH

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, 2\textsuperscript{nd} radiation belt
- **Bus Stops** 2: Clear radiation belt plus an hour
- **Bus Stops** 3: Half way to the moon
- **Bus Stops** 4: At the moon (~250 km from surface)
- **Bus Stops** 5: Past the moon plus 12 hours (lunar gravitational assist)
Science Operations: 12 months

- Science Operations are periodic with 8 time points throughout the 12 months
- 2 cards are kept in reserve for Solar Particle Events (SPEs)
- 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

Nominal Mission (380d, 0.56AU)
Nominal Mission (379d, 71.9deg)
Extended Mission (540d, 0.71AU)
Extended Mission (540d, 64.1deg)
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)

BioSentinel Communication Links

**Link Margin (dB) vs. Mission Days**

- 90 days – Min. Mission
- 380 days - Nominal
- 540 days - Extended
More work in progress…
Thank you!

Questions?
BioSentinel Back-Up Charts

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

<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 |

#### Transmit to DSN

- (Daily, 30 minute contact, ATS)

<table>
<thead>
<tr>
<th>Major Functions</th>
<th>Sub-functions</th>
</tr>
</thead>
</table>
| Readout BioSensor | Determine fluidic card  
| (15 min cadence) | Select u-controller  
|                  | Select and power well LEDs  
|                  | Select and readout sensor  
|                  | Iterate all wells |
| Readout TID sensor | Apply power to sensor  
| (5 min cadence) | Wait for stabilization  
|                  | Sample analog readouts |
| Readout LET Spectrometer sensor | Acquire binned data  
| (1 hour cadence) | Store data in file system |
| Monitor for SPE | Sample TID readout  
|                 | Sample LET shutter info  
|                 | Wet new card if SPE detected |

#### Media A: 4 weeks

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

#### Media B: 2 weeks

- Wet cards with Media B (4 weeks after Media A, RTS)

#### Media B: 2 weeks

- Wet cards with Media B (4 weeks after Media A, RTS)
LET Spectrometer & TID Dosimeter Radiation Monitoring

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

  LET Spectrometer Engineering Development Unit (EDU)

• 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 BGW (x3)
- Goldstone 34-m HEF (x1)
- Canberra 34-m BGW (x3*)
- Canberra 34-m HEF (x1)
- Madrid 34-m BGW (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
- Hartebeethok 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
- Results for Archive
- Space Weather Reports
- Space Weather Alerts
- Calibrated Data Set

NASA Life Sciences Data Archive (ARC)

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

International Space Station (ISS) Infrastructure

BioServe

ISS On-Board Network

Ground Dist.

HOSC

Delayed Async. Ground Control Facility - ARC

Ground Support Equipment

Environment Control (FF-GC)

Ground Support Equipment

Environment Control (ISS-GC)

Radiation Ground Control Facility - BNL

Ground Support Equipment
### Preliminary Operational Staffing Profile

<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 DSGC pre-launch profile</td>
<td>- DSGC must start while BioSentinel is at KSC</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>
</tbody>
</table>
| Initialization      | ~ 14 days| - 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 | - Launch dispersions and deployment uncertainty will require BioSentinel re-plan cycle.  
- No propulsive maneuver to achieve heliocentric orbit. |
| Science (early)     | ~ 60 days| - 8x5 console support to monitor first two biosensor experiments and to assist in planning and executing calibration activities as needed  
- Surge support if needed                                         | - Autonomous momentum dumping                                                         |
| Science (routine)   | ~ 305 days| - One planning cycle every week with goal of two weeks  
- Uplink console supports once per week, available for other with notice  
- Continuous trending of S/C bus data  
- Console staff on-call to respond to SPE                          | - Review of DSN schedule every month, for three months in the future  
- Limited real-time changes to schedule and plan except for SPE response |
| Extended Science    | ~ 180 days| - Continuation of Science                                                                            |                                                                                       |
Spacecraft to Sun Range

Sun Range in AU

Mission Day

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

20% Power Loss
10% Power Loss
Power Budget

Actual Power Margin (No SE Contingency)

Mission Days

Power (Watts)

Margin

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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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

Support

NASA Human Exploration and Operations Mission Directorate (HEOMD); Advanced Exploration Systems Division – Jitendra Joshi, Jason Crusan Program Execs.