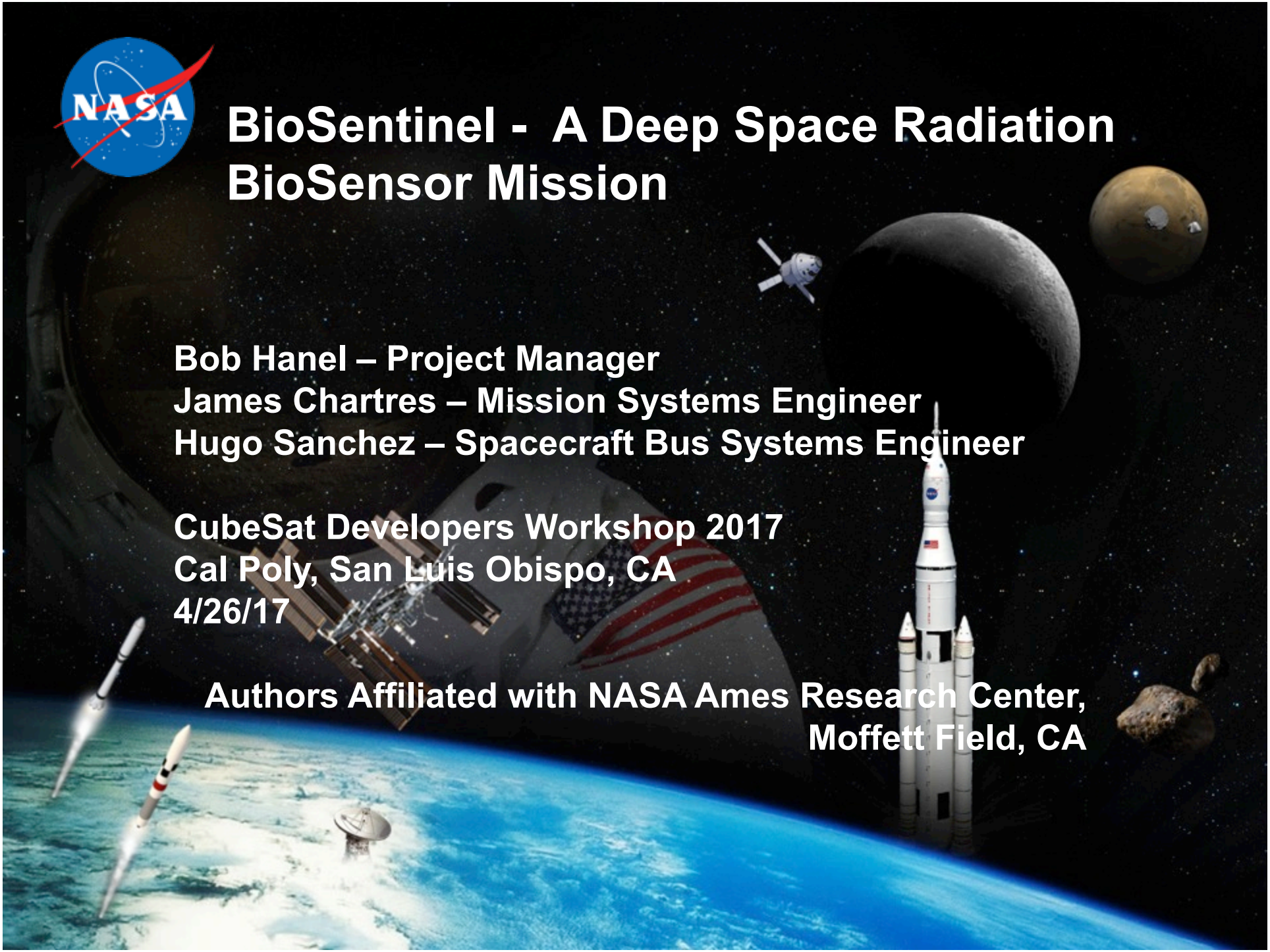


BioSentinel - A Deep Space Radiation BioSensor Mission

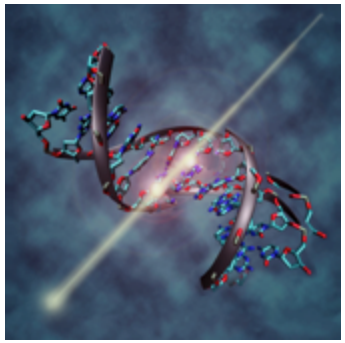
Bob Hanel – Project Manager
James Chartres – Mission Systems Engineer
Hugo Sanchez – Spacecraft Bus Systems Engineer

CubeSat Developers Workshop 2017
Cal Poly, San Luis Obispo, CA
4/26/17

Authors Affiliated with NASA Ames Research Center,
Moffett Field, CA

BioSentinel Project Objectives

- Advanced Exploration Systems (AES) selected BioSentinel to fly on the Space Launch System (SLS) Exploration Mission (EM-1) as a secondary payload
  - Payload selected to help fill **HEOMD Strategic Knowledge Gaps in Radiation effects on Biology**
  - Delivery to Dispenser Integrator, Tyvak, by 4/30/18
  - Current EM-1 Launch Readiness Date (LRD): 9/30/18
- 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



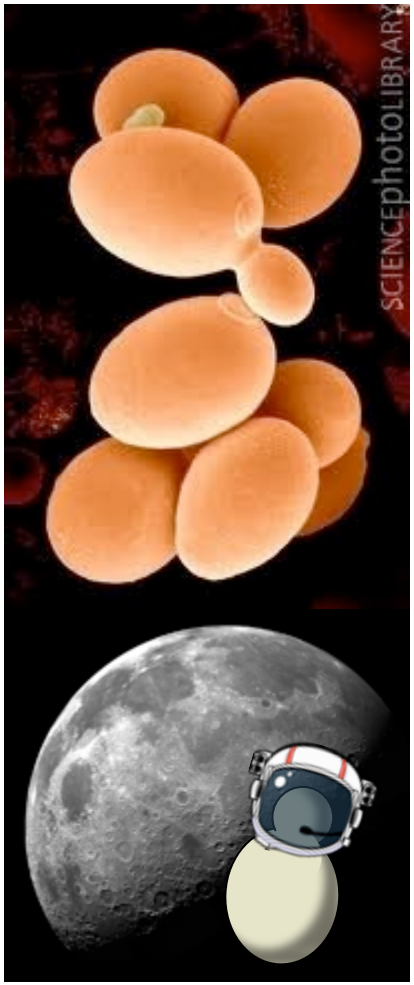
- Collaborate with two other AES selected missions(non-biological) for EM-1
  - Near Earth Asteroid (NEA) Scout (MSFC)
  - Lunar Flashlight (JPL)

BioSentinel Science Concept

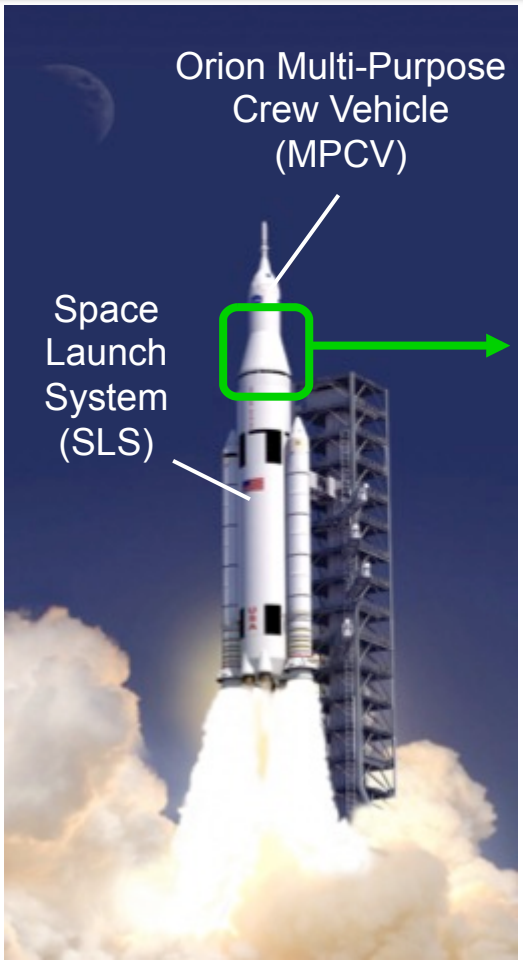
- Quantify DNA damage from space radiation environment
  - Space environment cannot be reproduced on earth
  - Omnidirectional, continuous, low flux with varying particle types
  - Health risk for humans spending long durations beyond LEO
  - Radiation flux can spike 1000x during a Solar Particle Event (SPE)

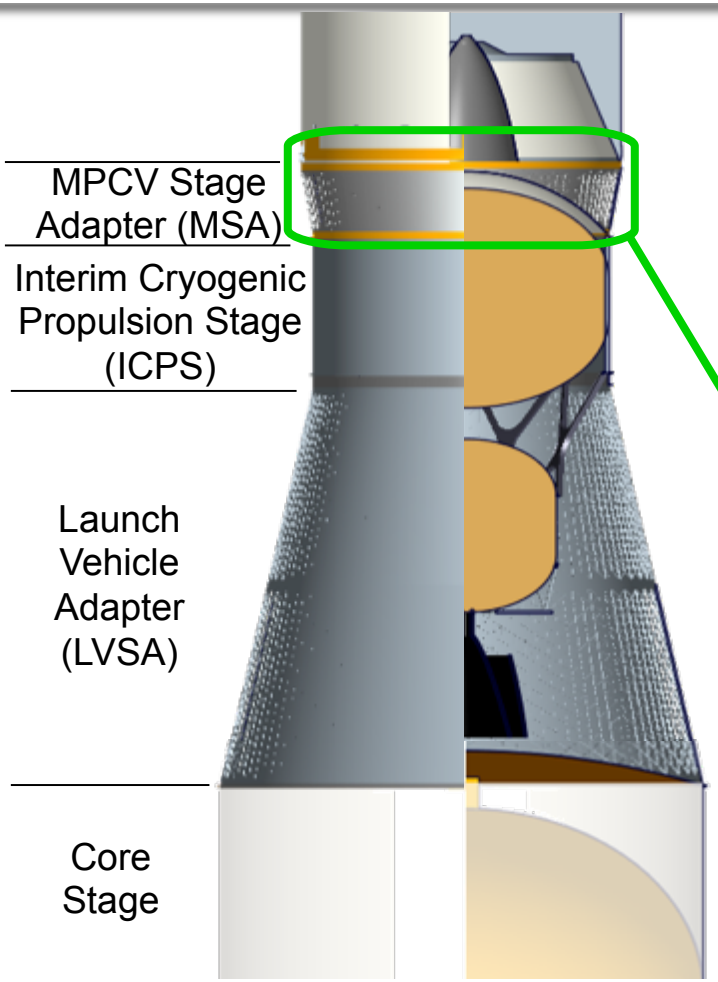
- Correlate biologic response with LET Spectometer data
  - **BioSensor** payload uses engineered *S. cerevisiae* yeast
  - Measures rate of Double Strand Breaks (DSB) in DNA
  - **Linear Energy Transfer (LET) Spectrometer** measures particle energy and count

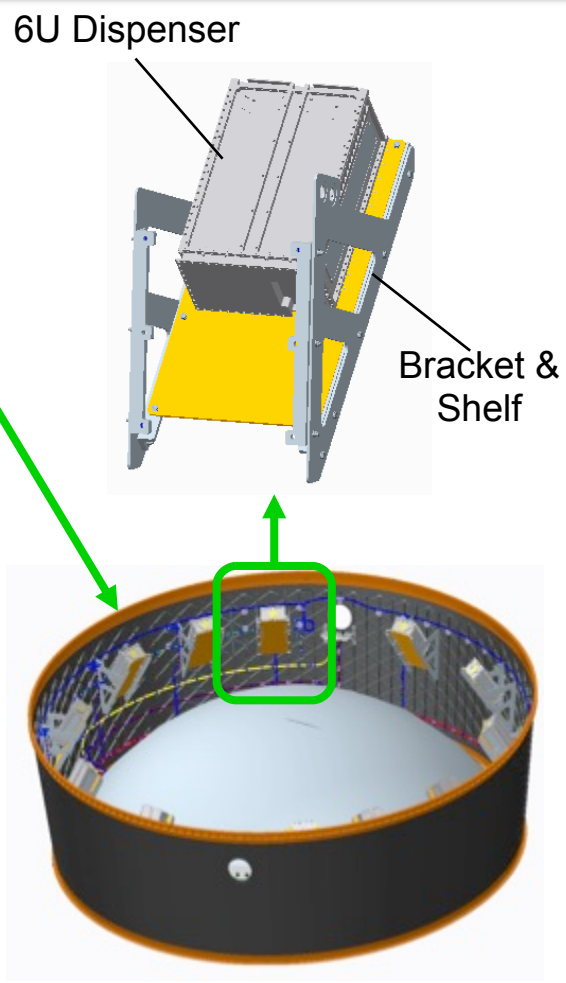
- Yeast assay uses microfluidic arrays to monitor for DSBs
  - Three strains of *S. cerevisae*, two controls and engineered strain
  - Wet and activate multiple banks of micro-wells over mission lifetime
  - DSB and associated repair enable cell growth and division
  - Activate reserve wells in event of a Solar Particle Event (SPE)



Secondary Payload Location on SLS EM-1







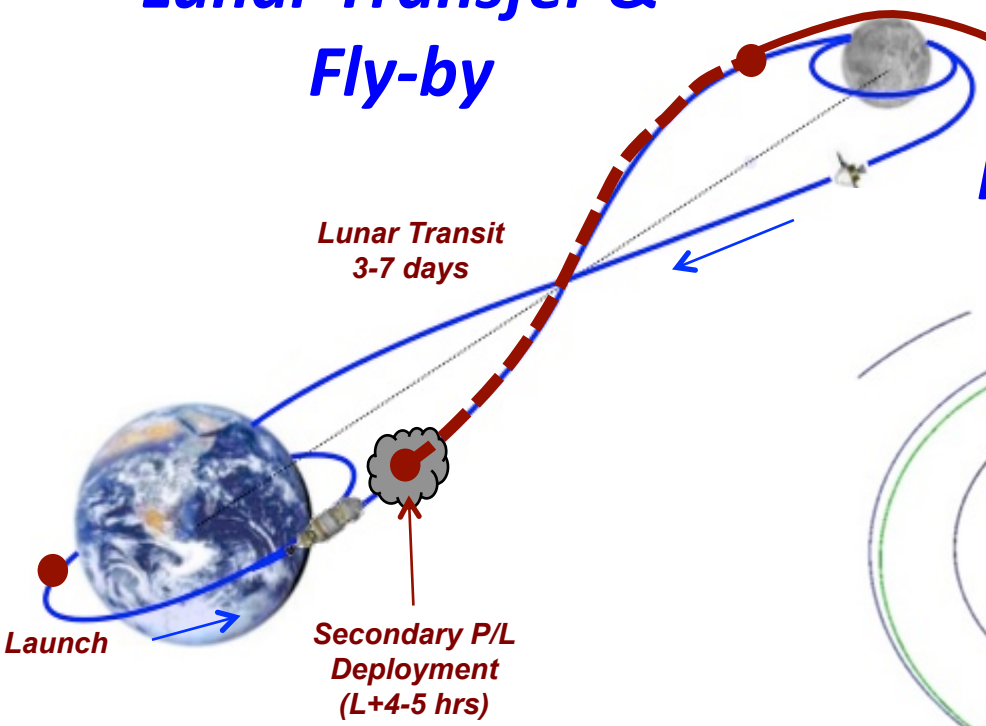
- 13 - dispenser locations that each support a 6U (14 kg) secondary payload
- 1 - bracket location allocated to a sequencer
- EM-1 only accommodates 6U payloads; EM-2 may accommodate 12U payloads

BioSentinel EM-1 Mission

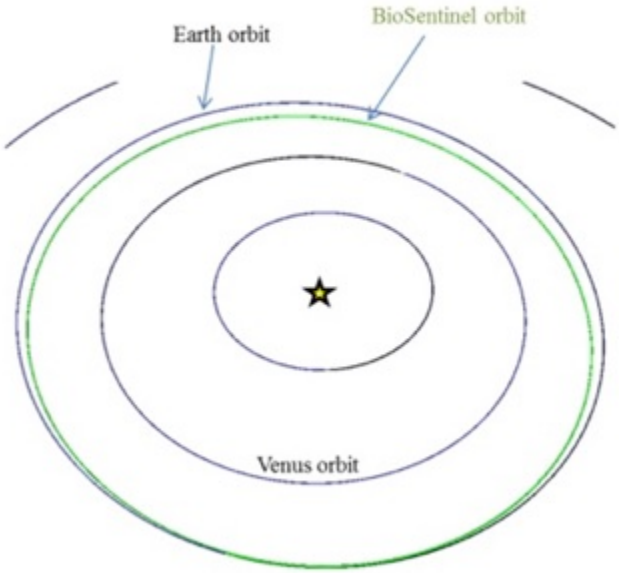
Launch

Artist's rendering of the Space Launch System

Lunar Transfer & Fly-by



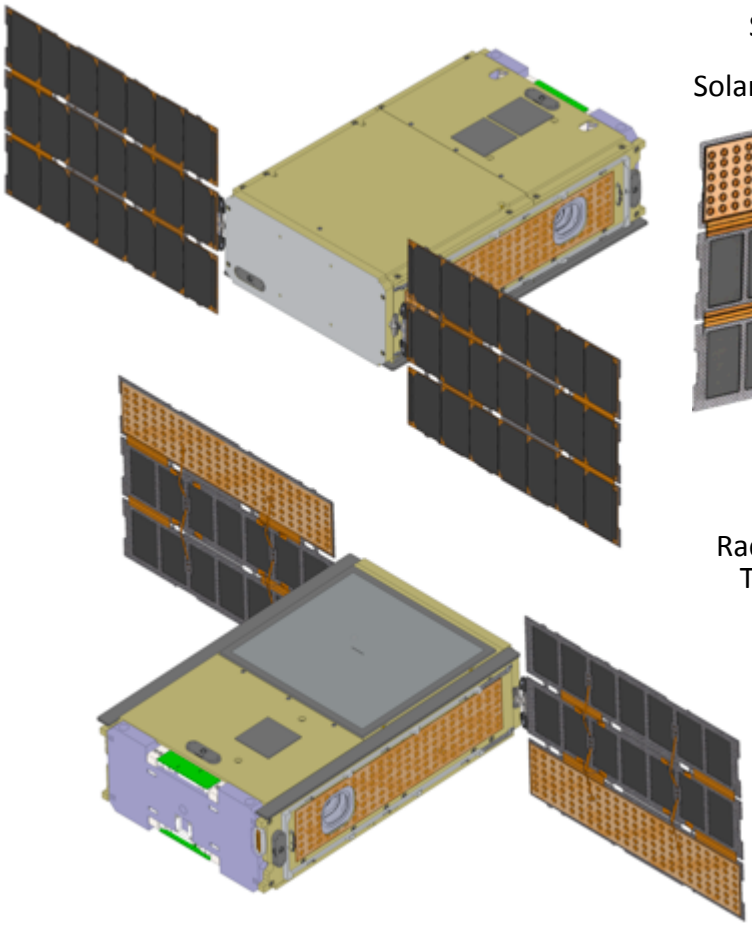
Mission Orbit



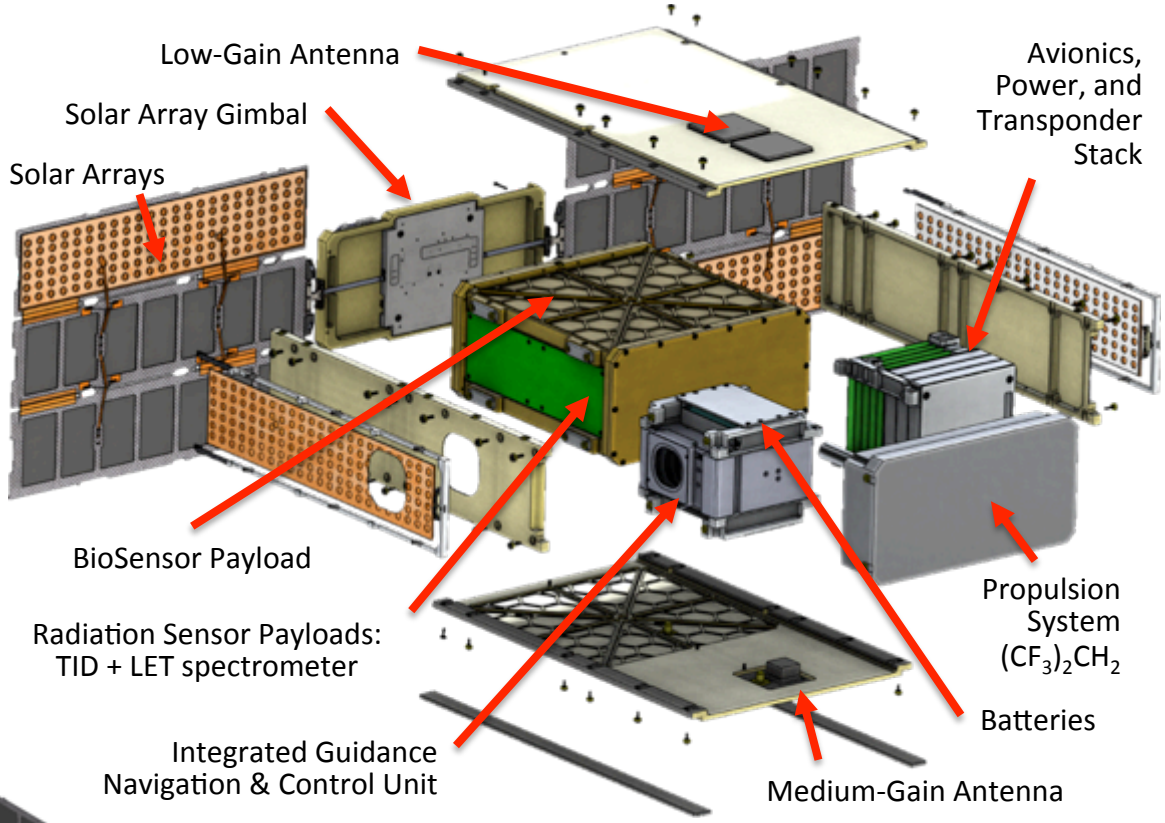
- Up to 13 secondary payloads deployed and powered within the same 2 hour window
- Low relative velocity between secondary payloads
- BioSentinel will not perform a delta-V maneuver, will follow ICPS into disposal orbit

- Final orbit of secondary's to be determined
- Will likely be Earth-interior, heliocentric orbit
- Far outside the LEOs typically occupied by CubeSats
  - Range to Earth of 0.73 AU at 18 months
  - Far outside the protective shield of Earth's magnetosphere

BioSentinel FreeFlyer Spacecraft: Physical Overview

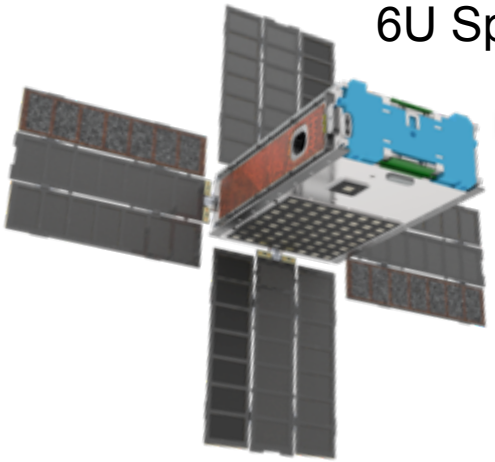


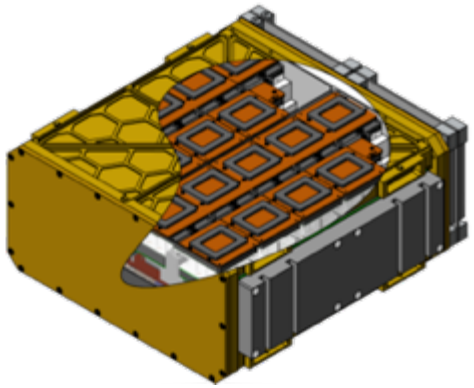
Only showing 2-Panel
Gimbaled Solar Array



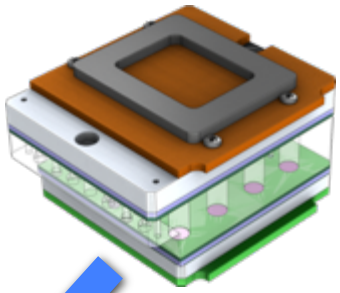
BioSensor – Optical Measurement of Yeast in Fluidic Card Well

6U Spacecraft



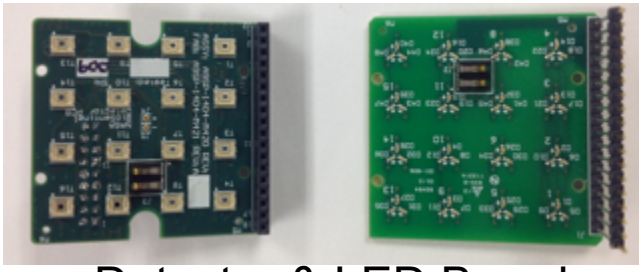


~4U BioSensor Payload

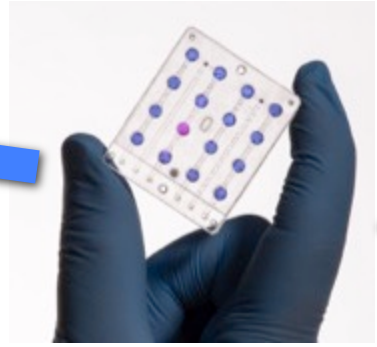


Microfluidic cards (x18)

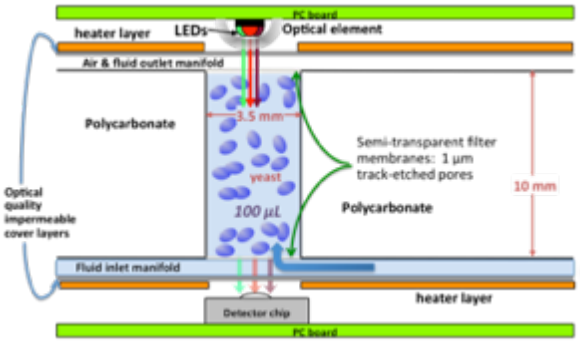
Fluidic Card with Optical Detection System



Detector & LED Boards



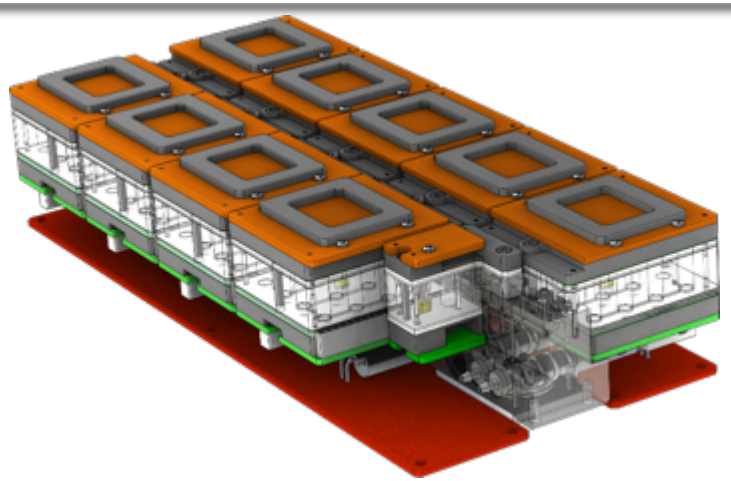
Fluidic Card

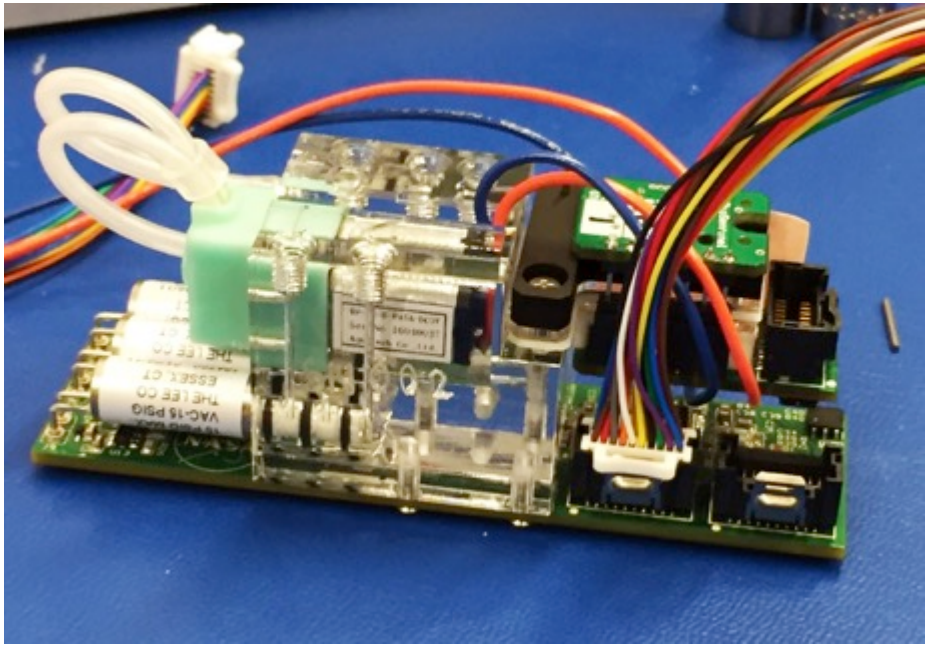


Fluidic Card cross section of a single well

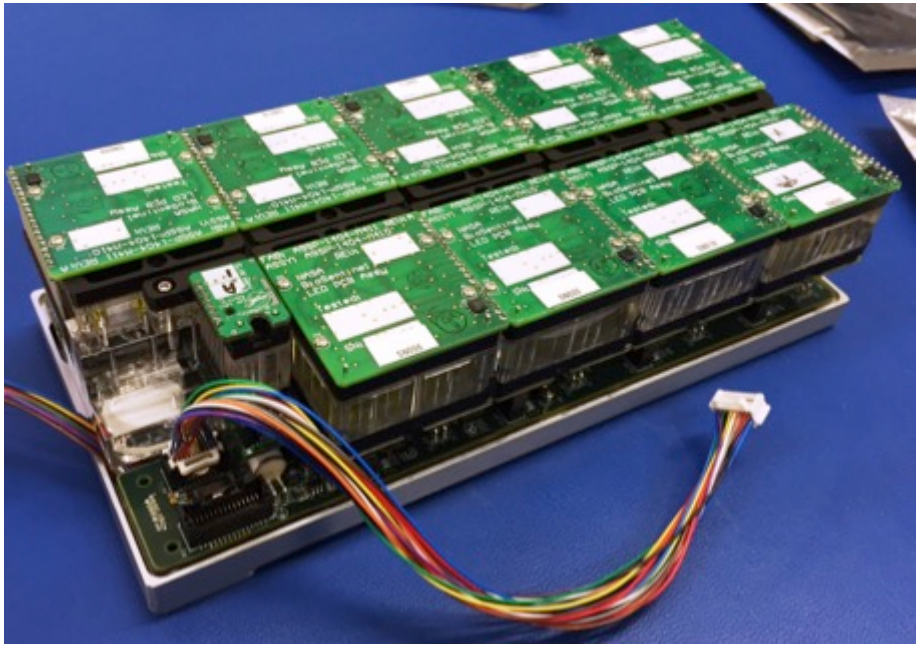
BioSensor Payload Hardware

9-Card Manifold with Bubble Traps & Desiccant





Nutrient Supply Manifold with Electronics

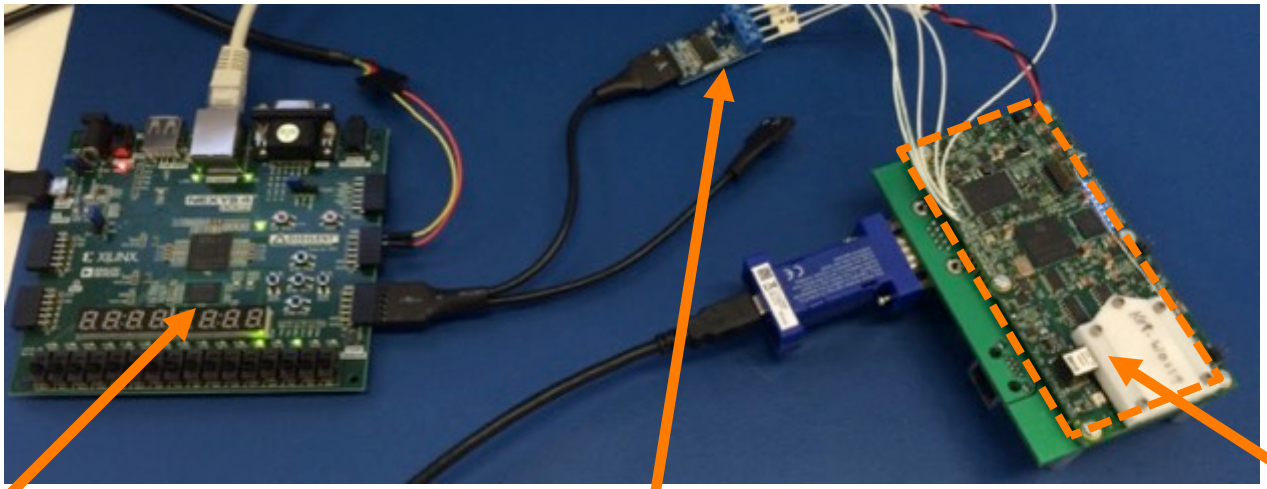


BioSensor 9-Card Manifold Assembly

BioSentinel – LET Spectrometer

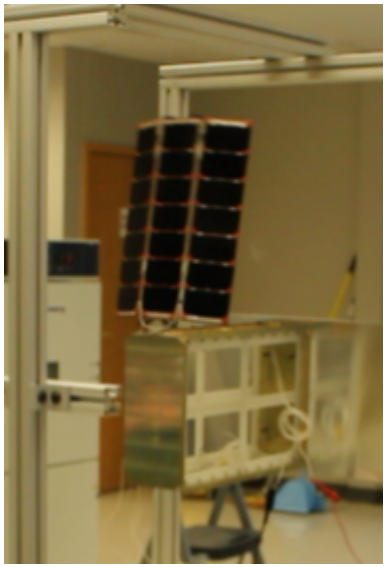
Radiation LET spectrometer supplied by JSC RadWorks

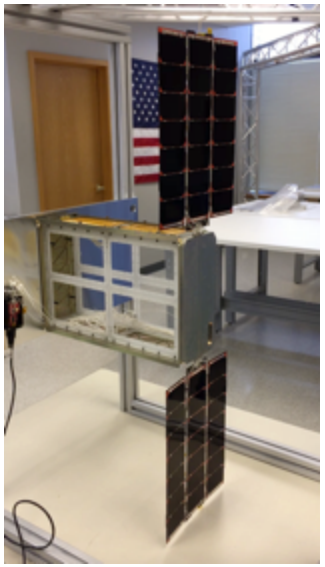
- Both LET EDUs have been delivered to ARC
- LET EDU#1 will be used to support a EDU spacecraft bus level vibe and thermal test.
- LET EDU#2 used in Flatsat testing
- First Flight Unit delivery to Ames scheduled for 5/31/17.

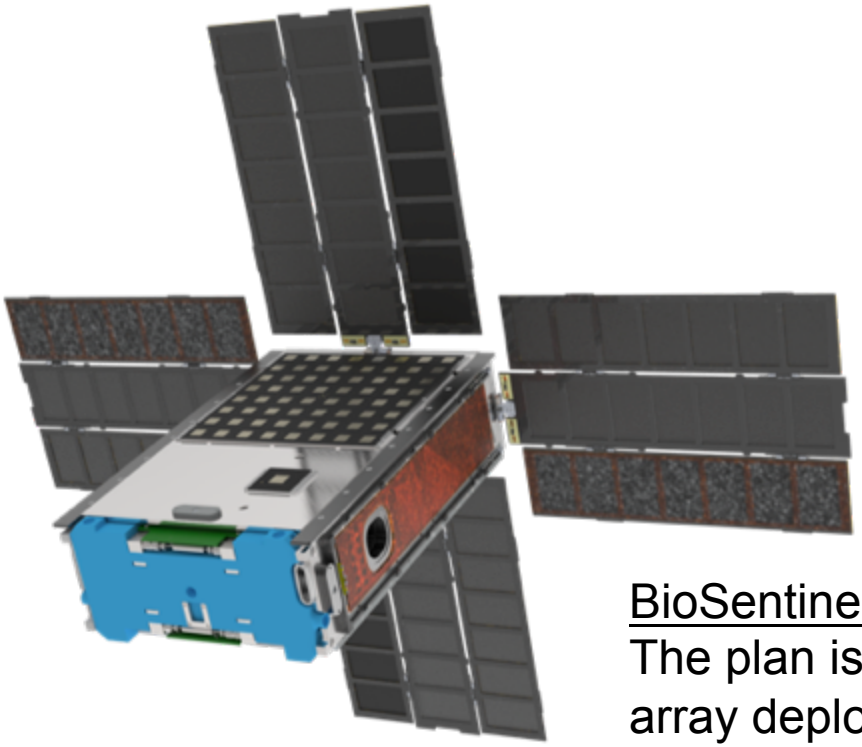


Solar Array: 2-Panel Gimbal, Adding 2-Panels

BioSentinel 2-Panel Gimballed Solar Array EDU
1-Panel deployment test
2-Panel gimbal test

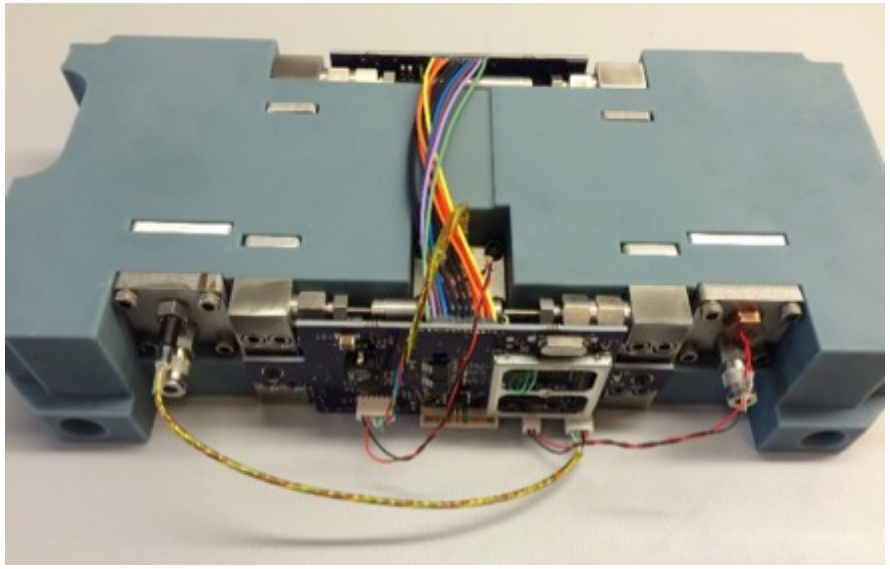






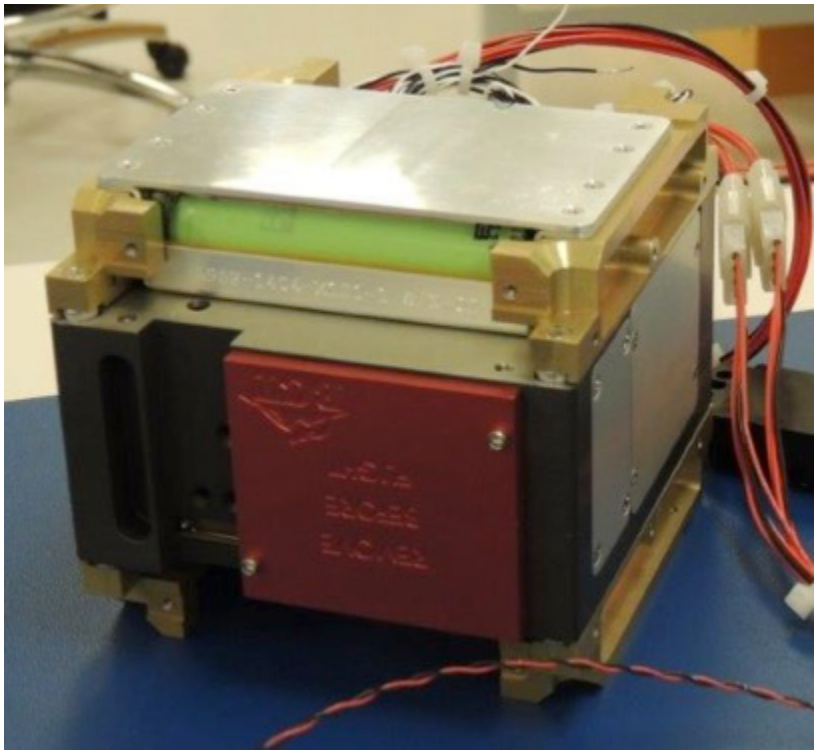
BioSentinel with 4-Panel Solar Array.
The plan is to keep the 2-panel Gimbaled Hawk array deployed from the 1x3 U sides (trifolds) and then add 2 – 2x3U panels that are also hinged to the gimbal housing

Propulsion System, XACT, & Battery Packs

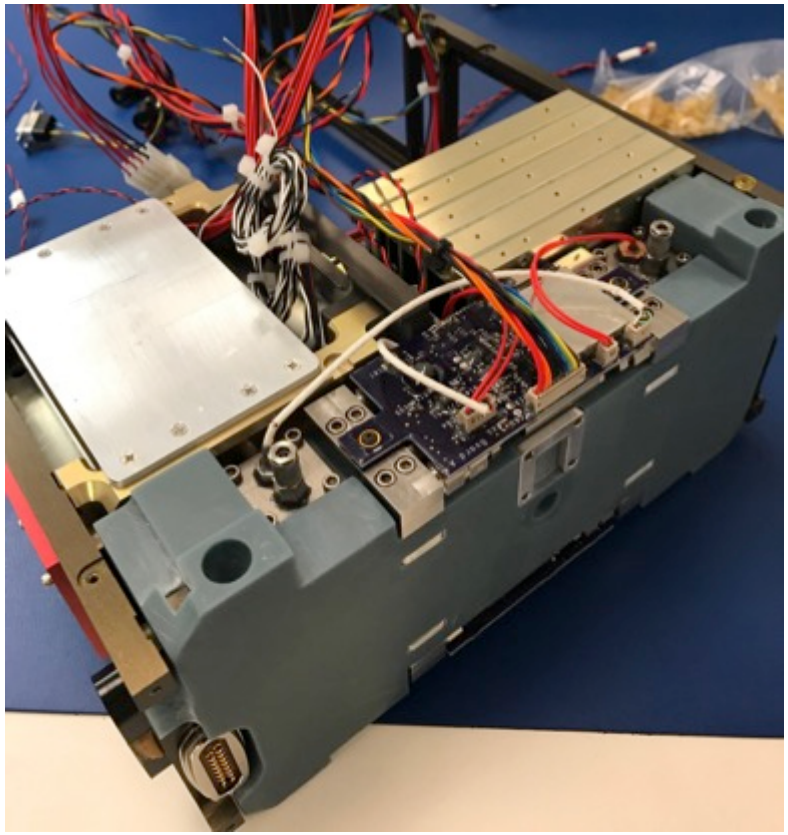


Propulsion System

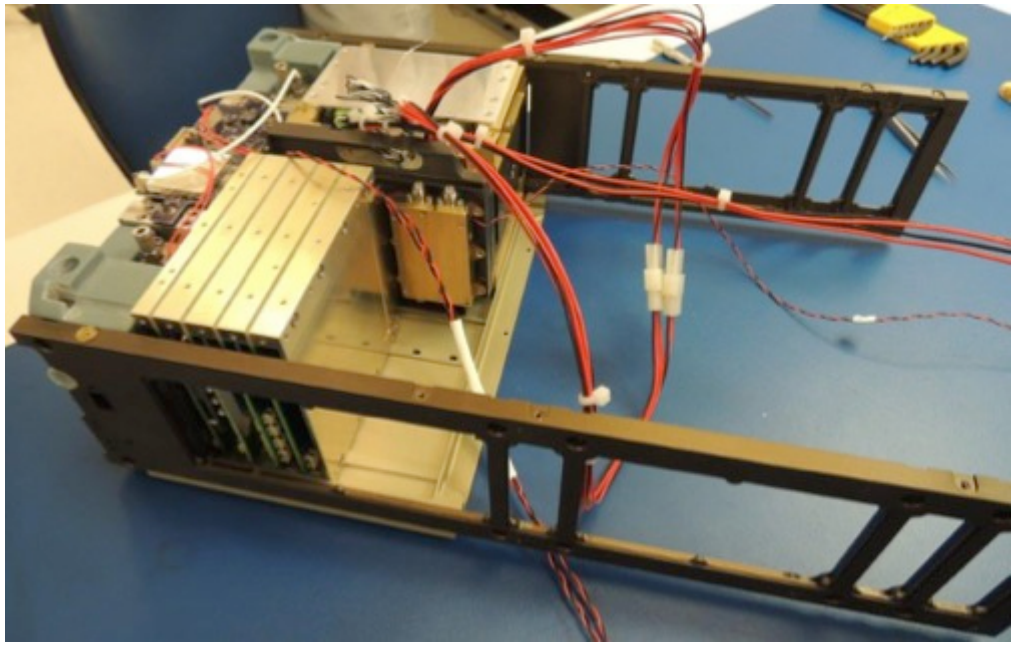
XACT ADCS unit sandwiched between 2 battery packs (top & bottom)



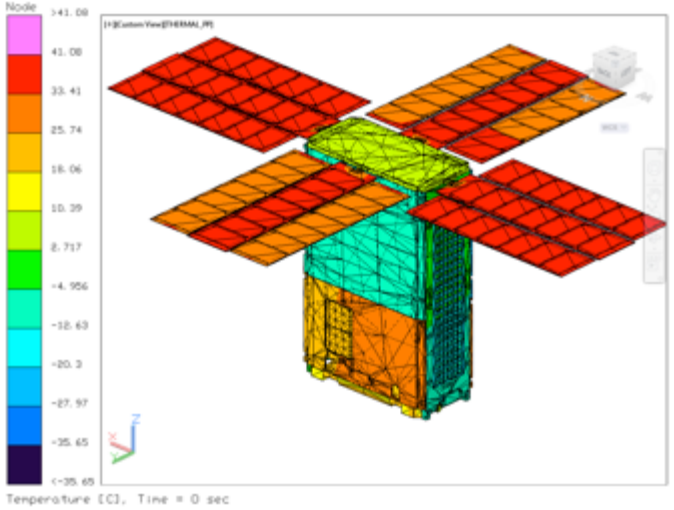
Spacecraft Subsystem Fit CheckFit

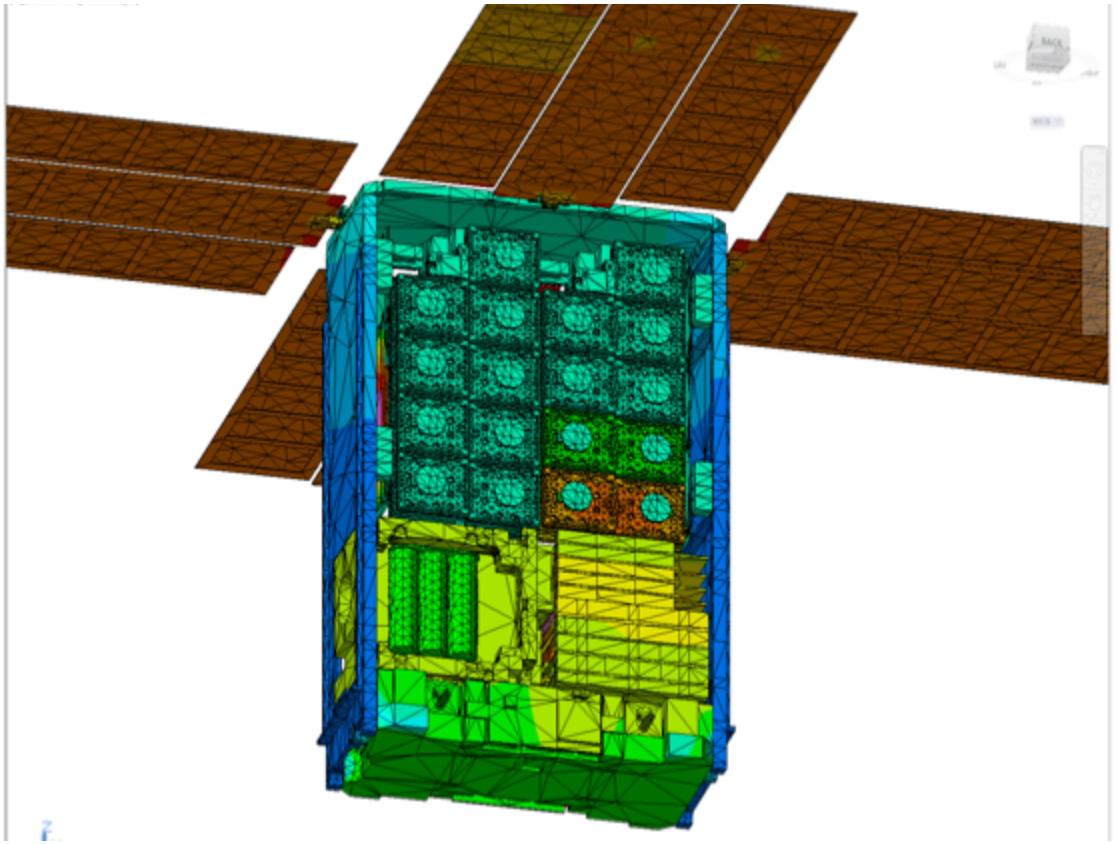


Initial fit check of Structural Panels, Propulsion System, XACT, 2 Battery Packs, Iris Transponder Thermal Simulator, Sun Sensor, Dispenser Separation Connector



Thermal System Analysis



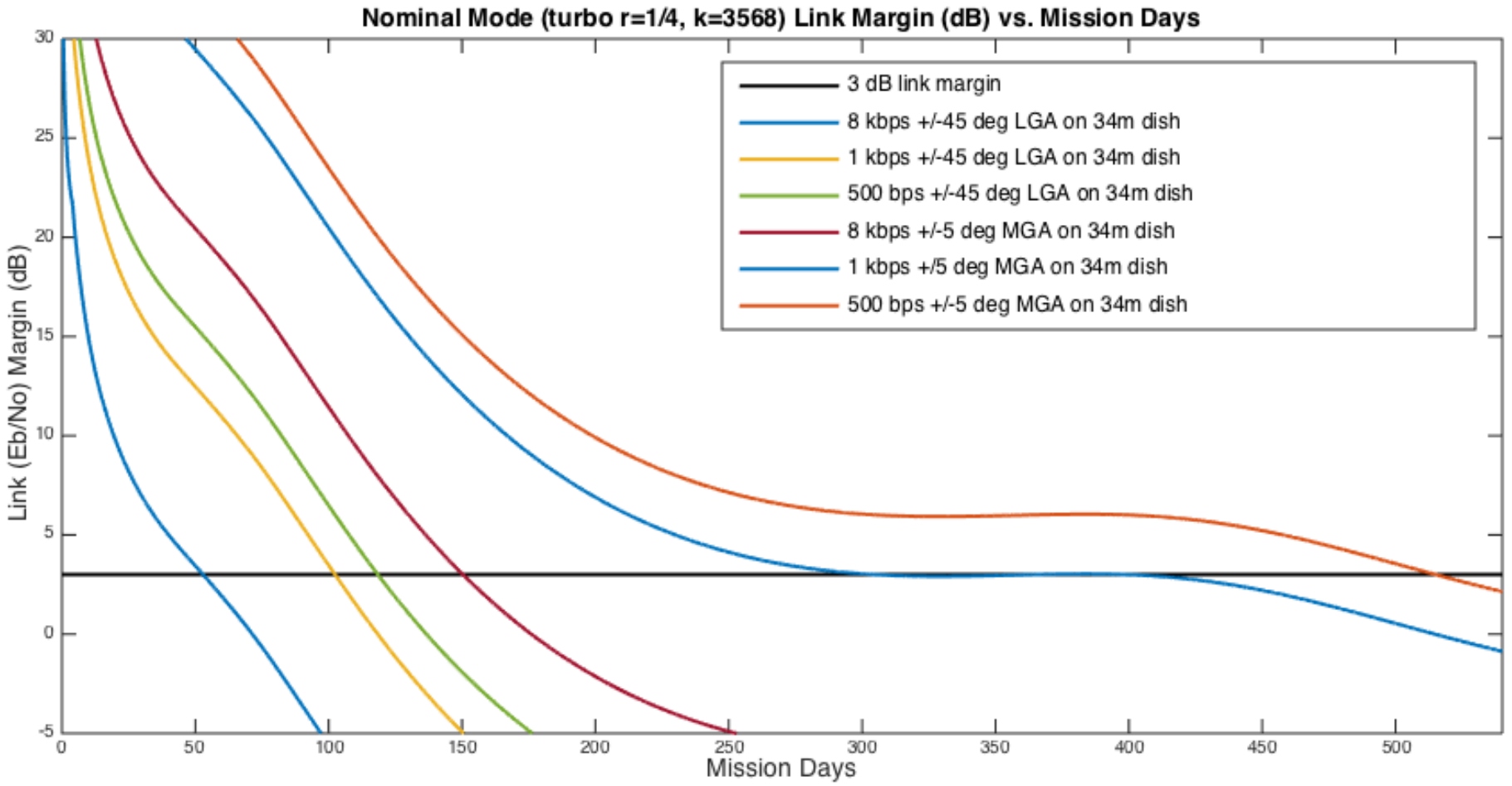


Thermal challenge is to keep warm spacecraft bus subsytems isolated from BioSensor (4-6°C). Cards raised to 23°C during cell growth phase

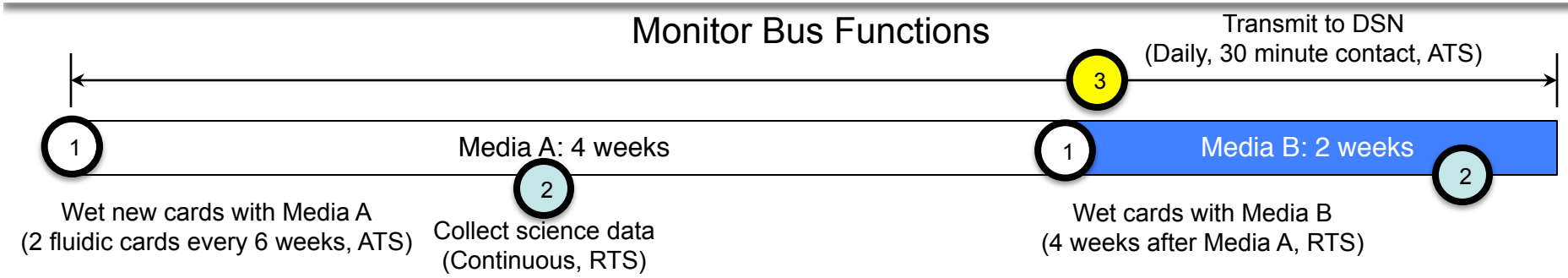
BioSentinel Mission Phases

Phase	Entry	Exit	Duration	Summary & Objectives
Pre-Launch	Loading of biology	L/V Lift-off	~6 months	• Configure BioSentinel for launch, then power-off
Launch	L/V Lift-off	Launcher Deploys BioSentinel	~5 hours	• Powered off • Survive launch environments and deployment
Initialization	BioSentinel separates from SLS	Complete S/C checkout	~14 days	• Power-on, reduce tip-off rates, deploy solar arrays, transition to safe mode • Ground station initial acquisition and tracking • Check-out of S/C systems • Lunar fly-by likely to occur
Science	Nominal Spacecraft SOH	Final BioSensor card is expired	365 days (goal of 540)	• Collect data from all payloads • Execute card experiments per science timeline • Respond to SPE events • Collect Spacecraft SOH
Decommissioning (note, not same as Project Phase F)	End of Nominal Science Operations	Final pass with decommissioning command	~7 days	• Ensure all data downlinked • Solar array switches open to ensure battery never recharges

BioSentinel Link Margin (dB) vs. Mission Days



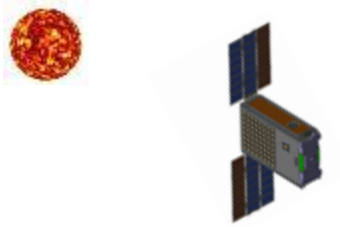
BioSentinel Month-in-the-Life ConOps

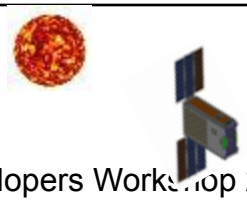


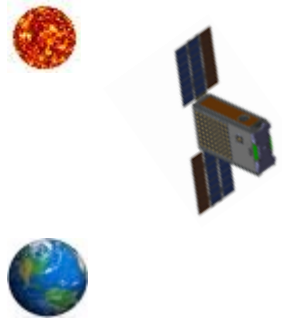
Major Functions	Sub-functions 1
Select card	• Determine fluidic card • Select µ-controller • Select pump and valve set
Apply Fluids	• Open inlet valve • Open plate valve • Open nutrient valves • Activate Pump
Configure Thermal Control	• Apply cold set points to other cards • Warm set points for Media B
Close System	• Close inlet valve • Close plate valve • Close nutrient valves • De-activate pump

Major Functions	Sub-functions 2
Readout BioSensor (15 min cadence)	• Determine fluidic card • Select u-controller • Select and power well LEDs • Select and readout sensor • Iterate all wells
Readout TID sensor (5 min cadence)	• Apply power to sensor • Wait for stabilization • Sample analog readouts
Readout LET Spectrometer sensor (1 hour cadence)	• Acquire binned data • Store data in file system
Monitor for SPE	• Sample TID readout • Sample LET shutter info • Wet new card if SPE detected

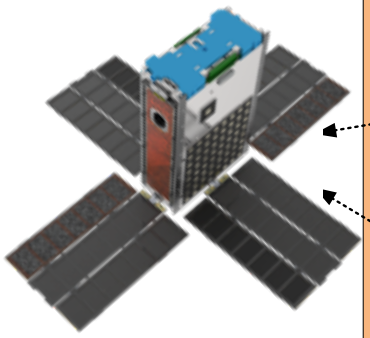
Major Functions	Sub-functions 3
Align spacecraft	• Determine vector to Earth • Slew to Earth vector
Power Tx	• Power transmitter
Broadcast data	• Broadcast SOH • On CFDP command, transmit BioSensor, LET, TID data
Deactivate Tx	• Power off transmitter
Realign spacecraft	• Slew back to sun vector







Ground System Architecture



Space Communication and Navigation (SCaN) Networks

X-band TLM, CMD and TRK

NASA Deep Space Network (DSN)
- Goldstone 34-m BWG (x3)
- Goldstone 34-m HEF (x1)
- Canberra 34-m BWG (x3*)
- Canberra 34-m HEF (x1)
- Madrid 34-m BWG (x2)
- Madrid 34-m HEF (x1)
- Morehead St 21-m (x1) (in dev.)

X-band TLM, CMD and TRK (early mission)

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)

TLM and CMDS
Station Status Packets
Stored TLM Files
Tracking Files
Ephemeris/Acq Files
Scheduling Files

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

TLM and CMDS
Stored TLM Files
Payload TLM and CMDS
Env. TLM and CMDS

International Space Station (ISS) Infrastructure
- BioServe
- ISS On-board Network
- Ground Dist.
- HOSC

HK TLM
Mission and Science Products
Planning Inputs
SPE Planning Input

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

Delayed Async. Ground Control Facility - ARC
- Free-Flyer GC
- Ground Support Equipment
- Environment Control (FF-GC)
- ISS GC
- Ground Support Equipment
- Environment Control (ISS-GC)

Results for Archive

Space Weather Reports
Space Weather Alerts

Space Weather Prediction & Monitoring

Calibrated Data Set

NASA Life Sciences Data Archive (ARC)

Radiation Ground Control Facility - BNL
- Ground Support Equipment

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

bs_ground_segment_overview_rev5
M. D'Ortenzio – 4/11/2016

Preliminary Operational Staffing Profile

Mission Phase	Length	Mission Operations Staffing Profile	Assumptions/Comments
Pre-Launch	~ 30 day	- 4x5 support for monitoring of BioSentinel DSGC pre-launch profile	- DSGC must start while BioSentinel is at KSC
Launch & Ascent	~ 1 day	- Full team will staff the MOC	- BioSentinel is powered off. No real-time stream of data from S/C into the MOC during L&A
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	

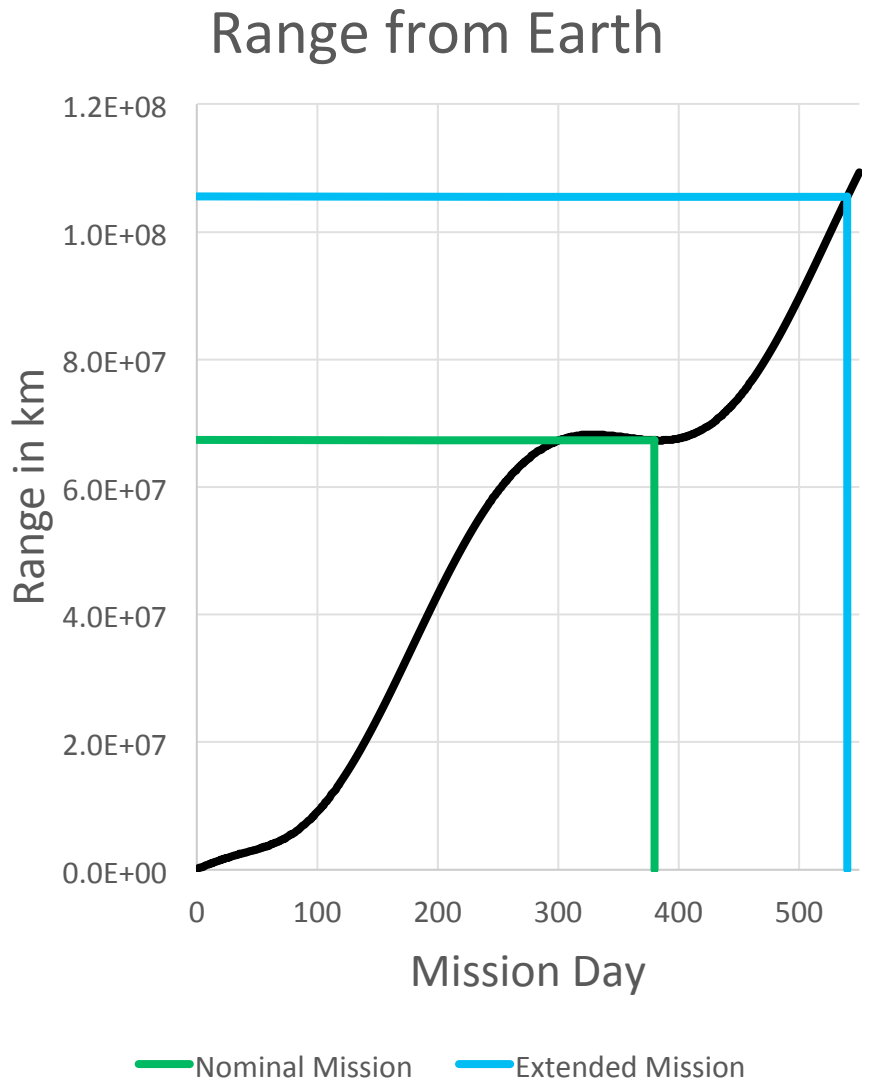
BioSentinel Back-Up Charts

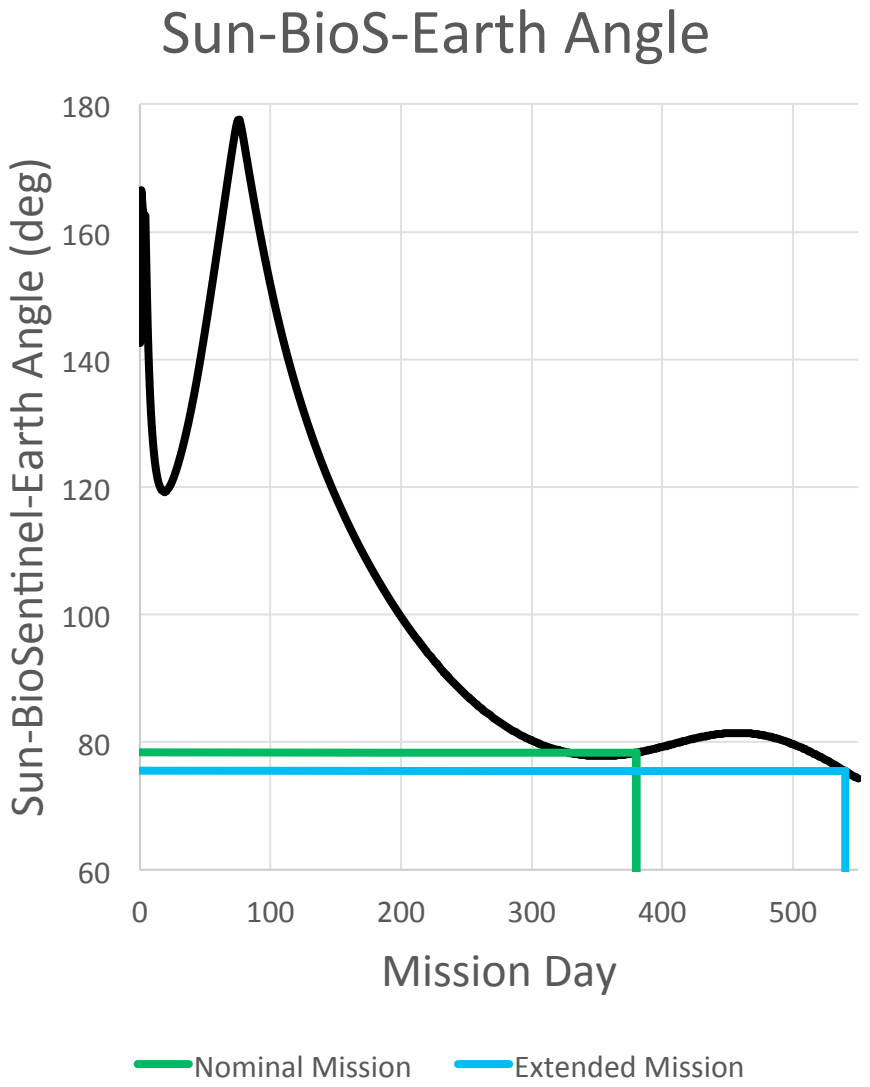
Questions & Back-Up Charts

BioSentinel FreeFlyer Spacecraft Bus Summary

- LEON3 RT based C&DH - Space Dynamics Lab
  - 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
  - XACT Integrated GN&C Unit - Blue Canyon
    - 3 Reaction Wheels
    - Star Tracker
    - CSS, IMU for safe mode
  - 5° pointing requirement
- Propulsion – Lightsey Space Research
  - 3D printed system
  - 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 - JPL
  - IRIS v2.1 coherent transponder - JPL
- Power
  - ~64 W generated power EOL
  - 2- Panel gimballed deployable HaWK arrays & 2 additional 2x3 U deployable panels - 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
  - LET Spectrometer – *JSC RadWorks*
  - 4U volume

Overview - Orbital Impact on Communications





BioSentinel Teaming

- **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, Eric Tapio, Tony Ricco, Travis Boone, Ming Tan, Aaron Schooley, Mike Padgen, Lance Ellingson, Griffin McCutchenson, Diana Gentry, Dayne Kemp, Scott Wheeler, Susan Gavalas, Edward Semones
- **Spacecraft and Bus** - Hugo Sanchez, Matthew Sorgenfrei, Jesse Fusco, 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.