BioSentinel - A Deep Space Radiation BioSensor Mission

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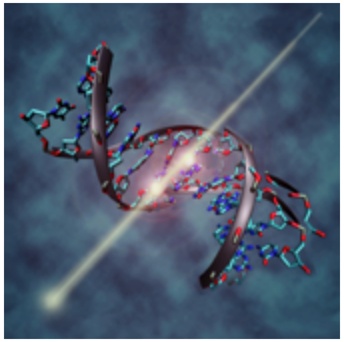
BioSentinel Project Objectives

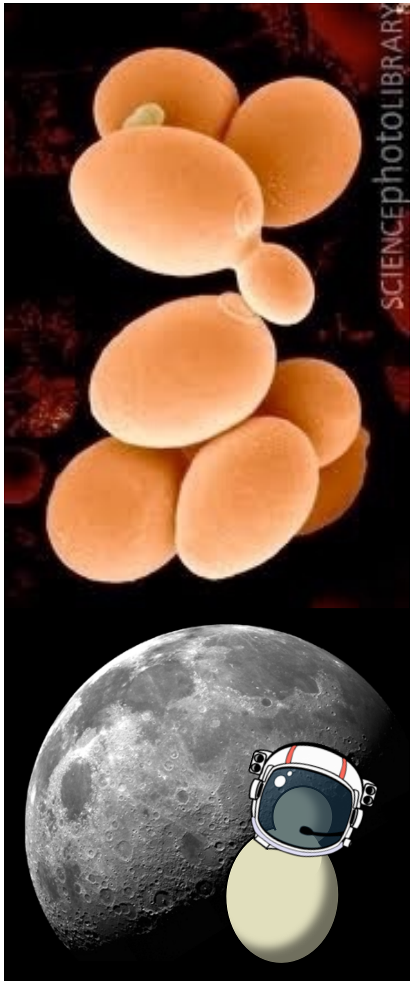
- Advanced Exploration Systems (AES) selected BioSentinel to fly on the Space Launch System (SLS) Exploration Mission (EM-1) as a secondary payload
  - Payload selected to help fill **HEOMD Strategic Knowledge Gaps in Radiation effects on Biology**
  - Delivery to Dispenser Integrator, Tyvak, by 4/30/18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



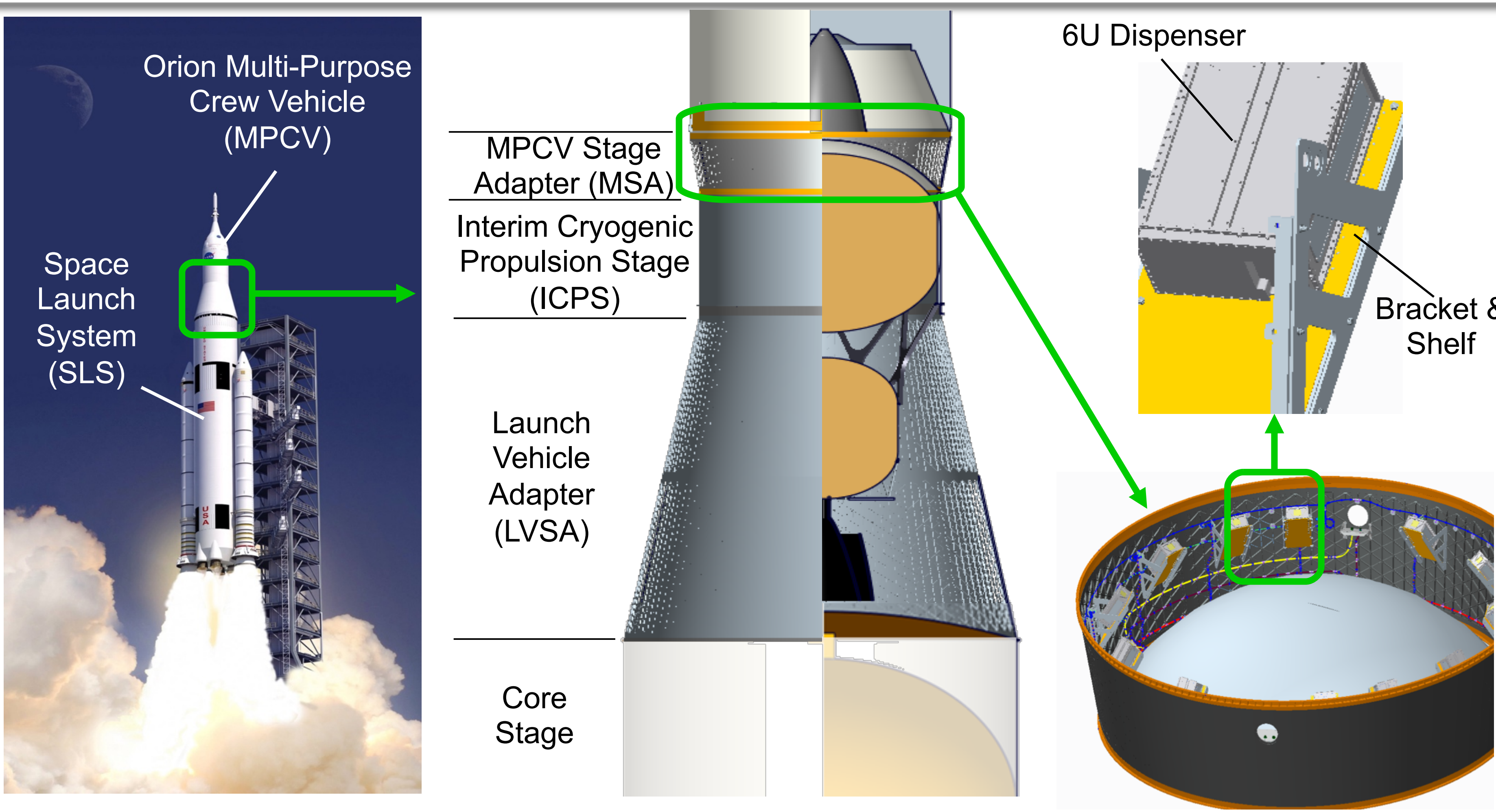
- Collaborate with two other AES selected missions (non-biological) for EM-1
  - Near Earth Asteroid (NEA) Scout (MSFC)
  - Lunar Flashlight (JPL)

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



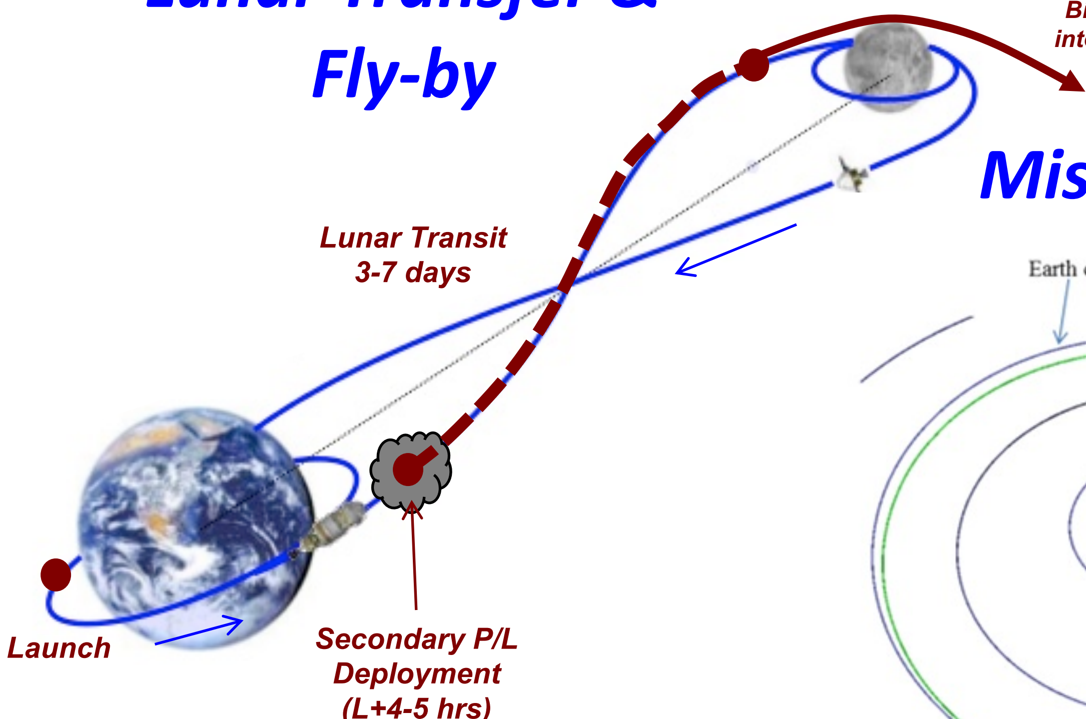
- 13 - dispenser locations that each support a 6U (14 kg) secondary payload
- 1 - bracket location allocated to a sequencer
- EM-1 only accommodates 6U payloads; EM-2 may accommodate 12U payloads

BioSentinel EM-1 Mission

Launch

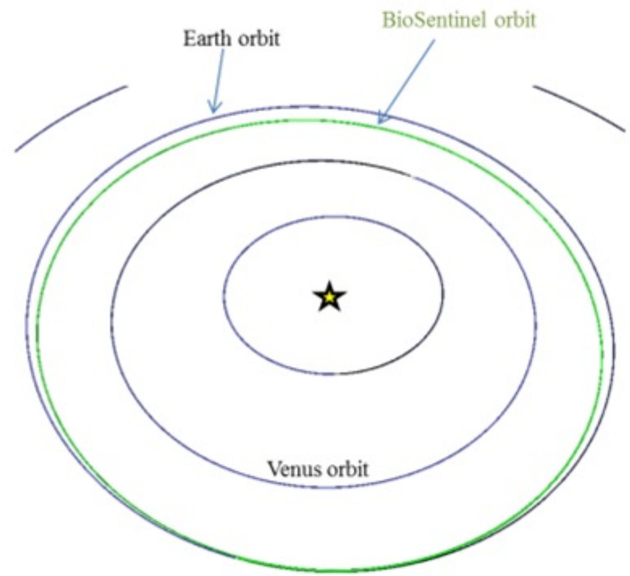
Artist's rendering of the Space Launch System

Lunar Transfer & Fly-by



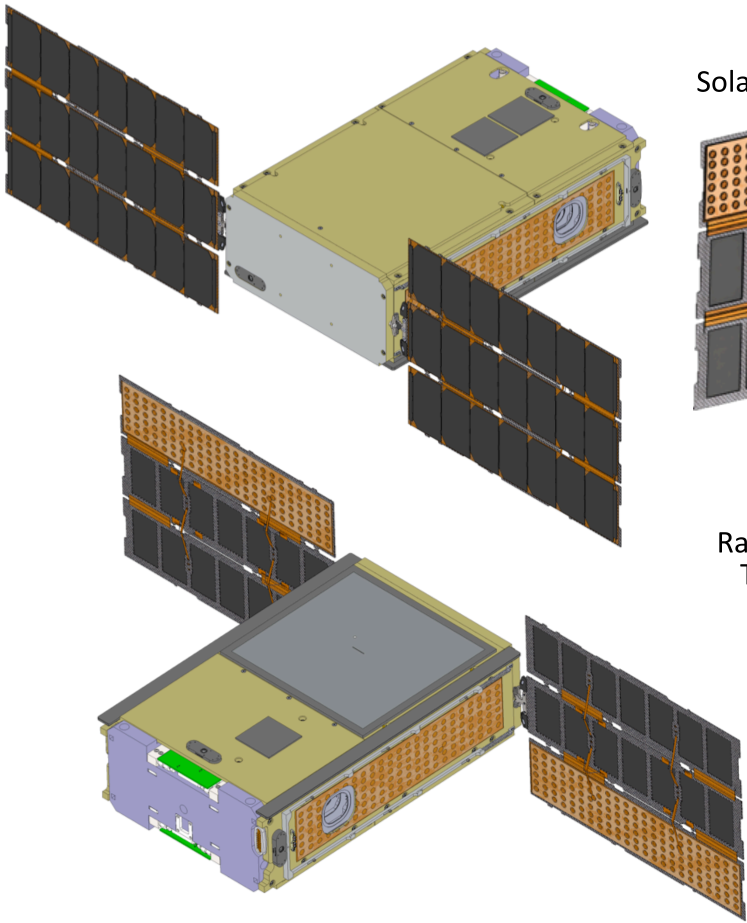
- Up to 13 secondary payloads deployed and powered within the same 2 hour window
- Low relative velocity between secondary payloads
- BioSentinel will not perform a delta-V maneuver, will follow ICPS into disposal orbit

Mission Orbit

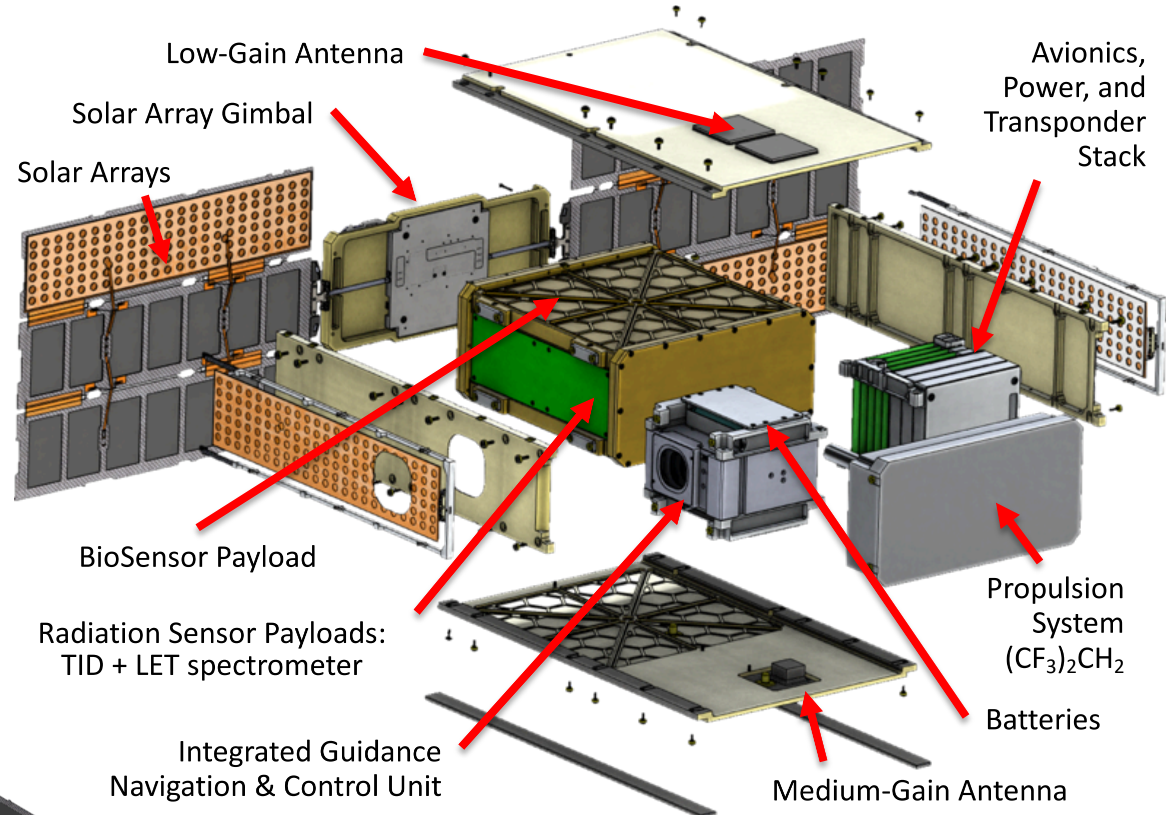


- Final orbit of secondary's to be determined
- Will likely be Earth-interior, heliocentric orbit
- Far outside the LEOs typically occupied by CubeSats
  - Range to Earth of 0.73 AU at 18 months
  - Far outside the protective shield of Earth's magnetosphere

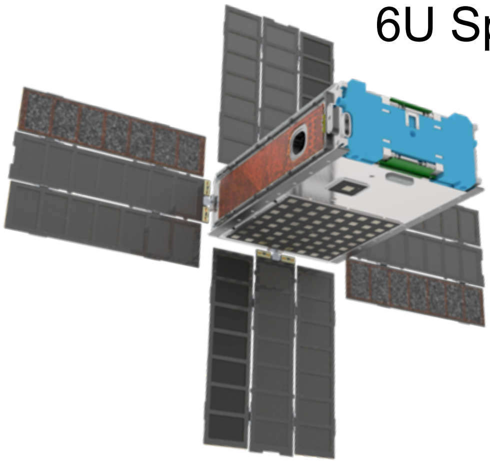
BioSentinel FreeFlyer Spacecraft: Physical Overview



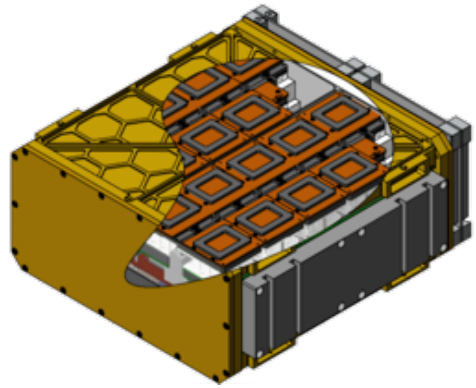
Only showing 2-Panel Gimbaled Solar Array



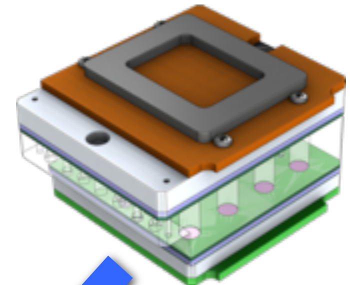
BioSensor – Optical Measurement of Yeast in Fluidic Card Well



6U Spacecraft

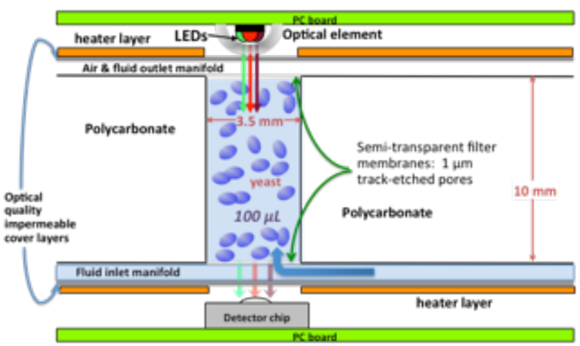


~4U BioSensor Payload

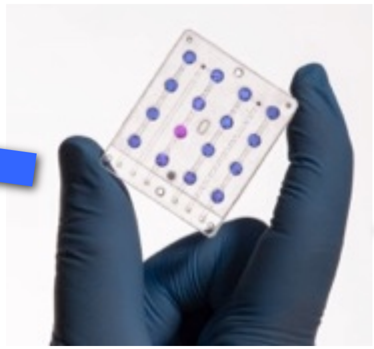


Microfluidic cards (x18)

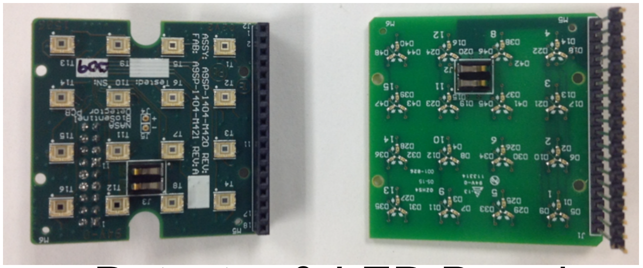
Fluidic Card with Optical Detection System



Fluidic Card cross section of a single well



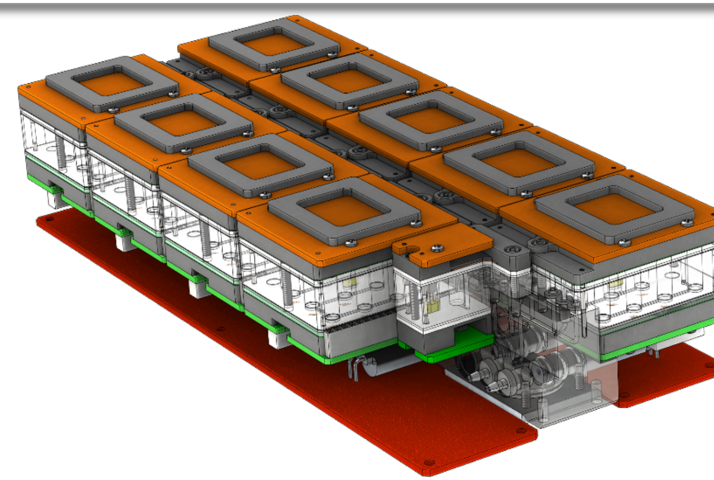
Fluidic Card

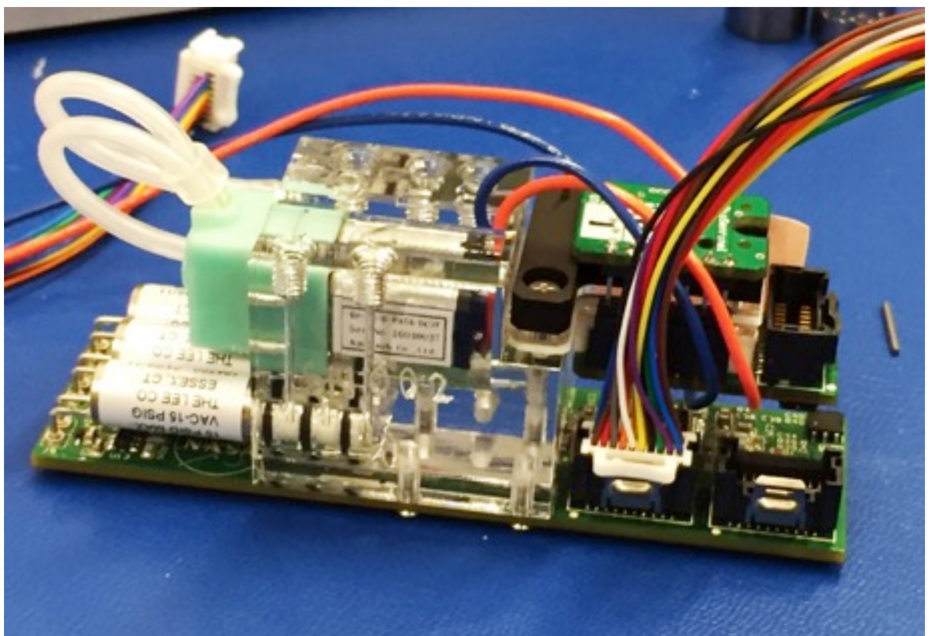


Detector & LED Boards

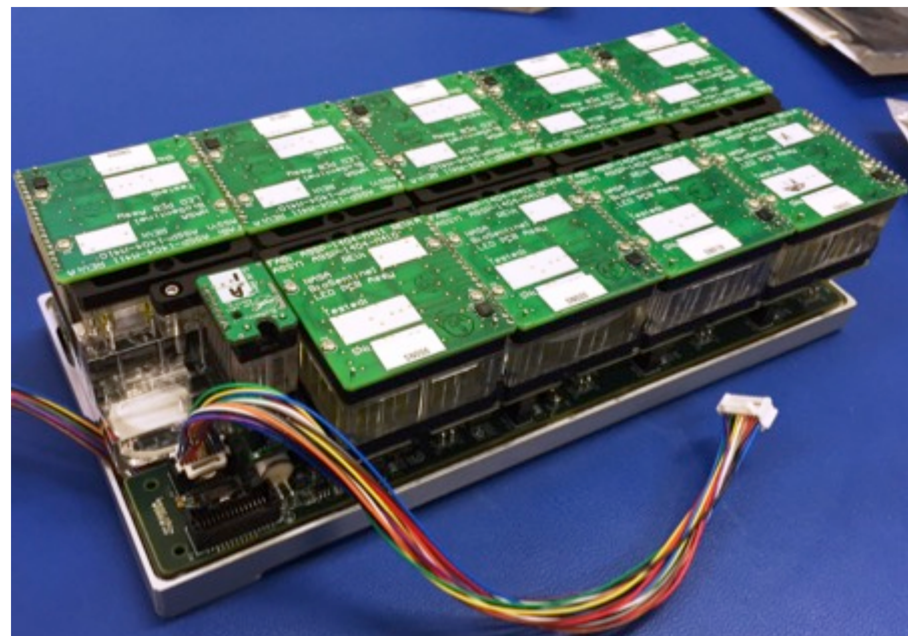
BioSensor Payload Hardware

9-Card Manifold with Bubble Traps & Desiccant





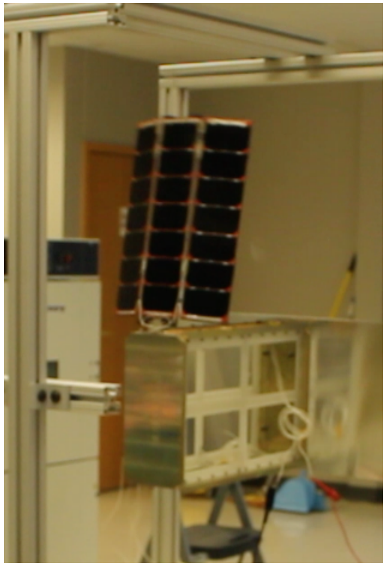
Nutrient Supply Manifold with Electronics

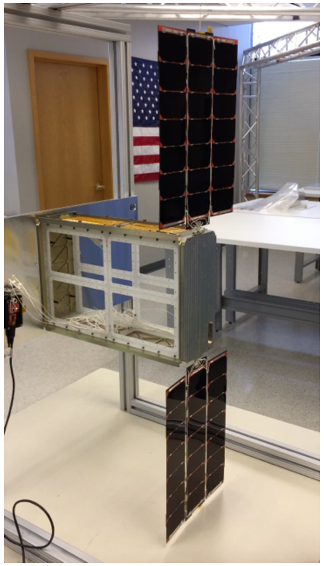


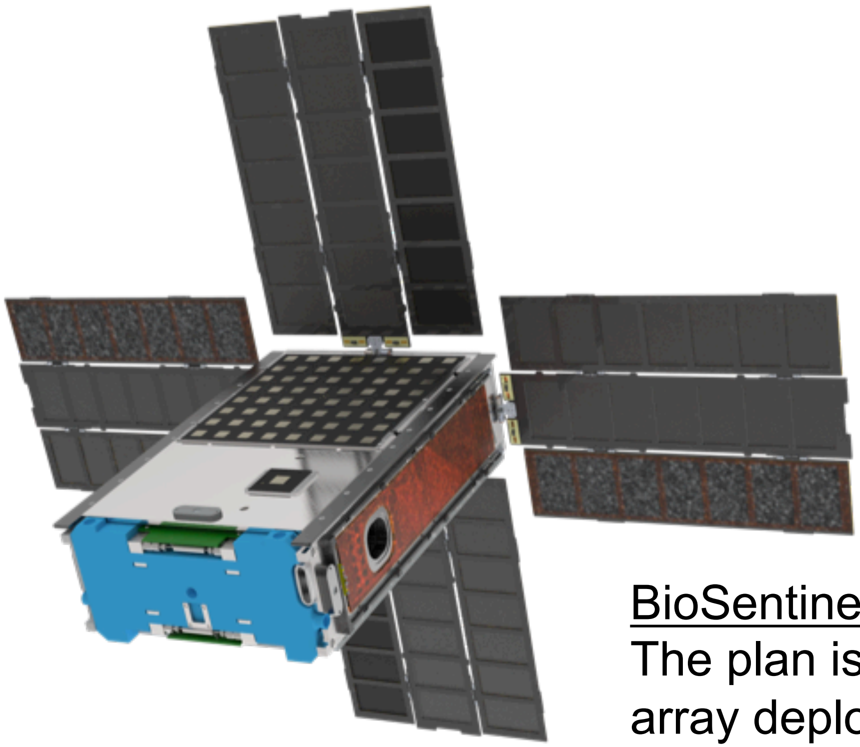
BioSensor 9-Card Manifold Assembly

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

<u>BioSentinel 2-Panel Gimballed Solar Array EDU</u>
1-Panel deployment test
2-Panel gimbal test

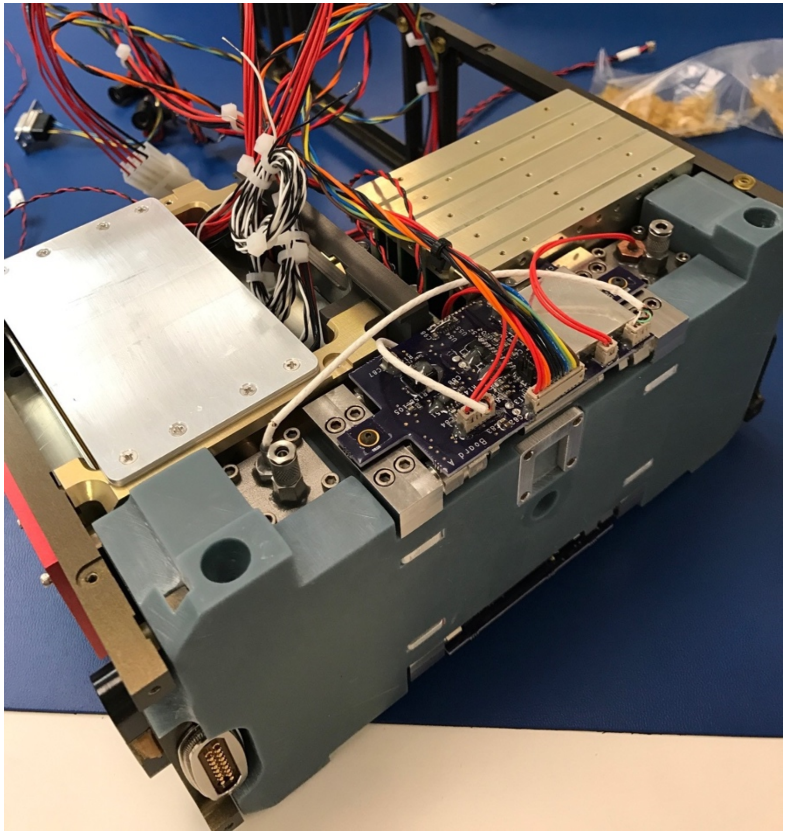




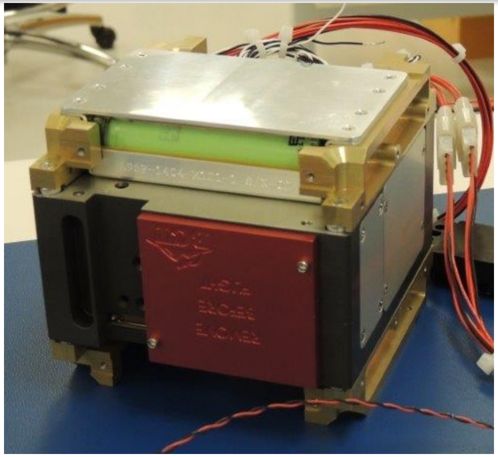


<u>BioSentinel with 4-Panel Solar Array.</u>
The plan is to keep the 2-panel Gimbaled Hawk array deployed from the 1x3 U sides (trifolds) and then add 2 – 2x3U panels that are also hinged to the gimbal housing

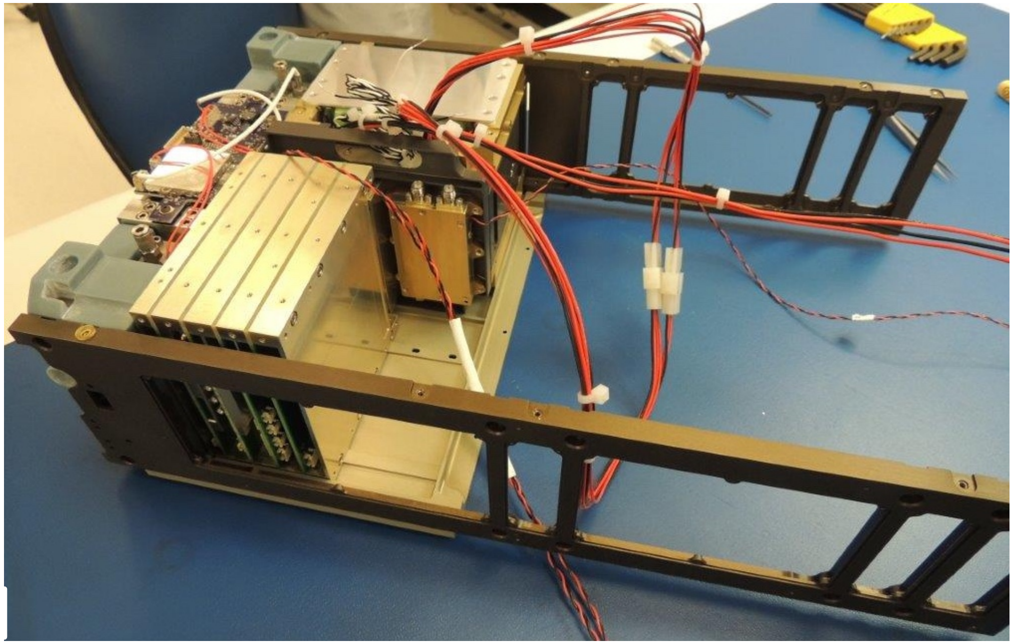
Spacecraft Subsystem Fit Check



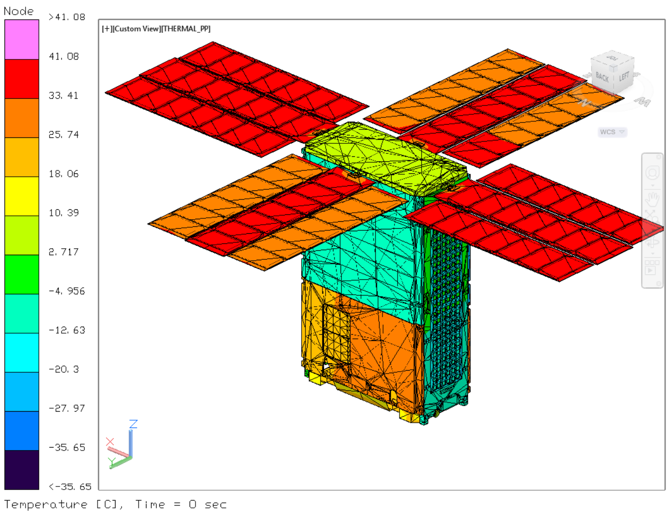
Initial fit check of Structural Panels, Propulsion System, XACT, 2 Battery Packs, Iris Transponder Thermal Simulator, Sun Sensor, Dispenser Separation Connector

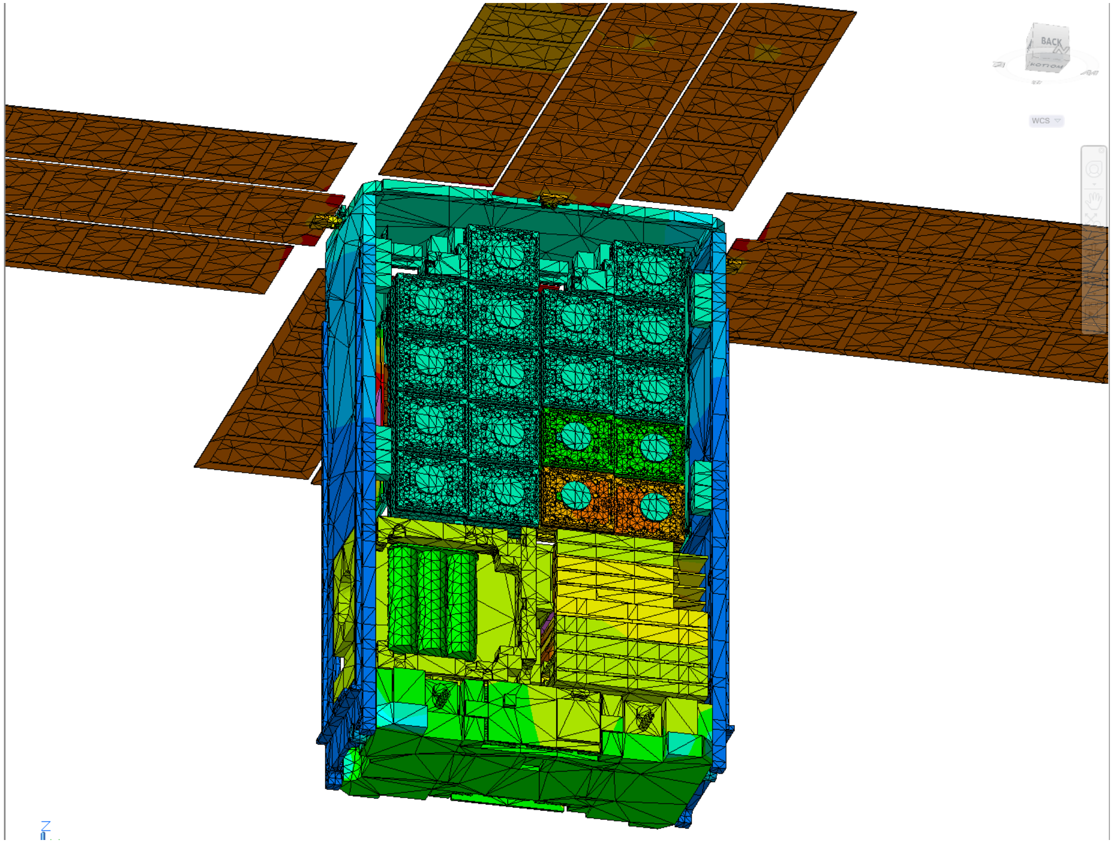


XACT ADCS unit sandwiched between 2 battery packs (top & bottom)



Thermal System Analysis

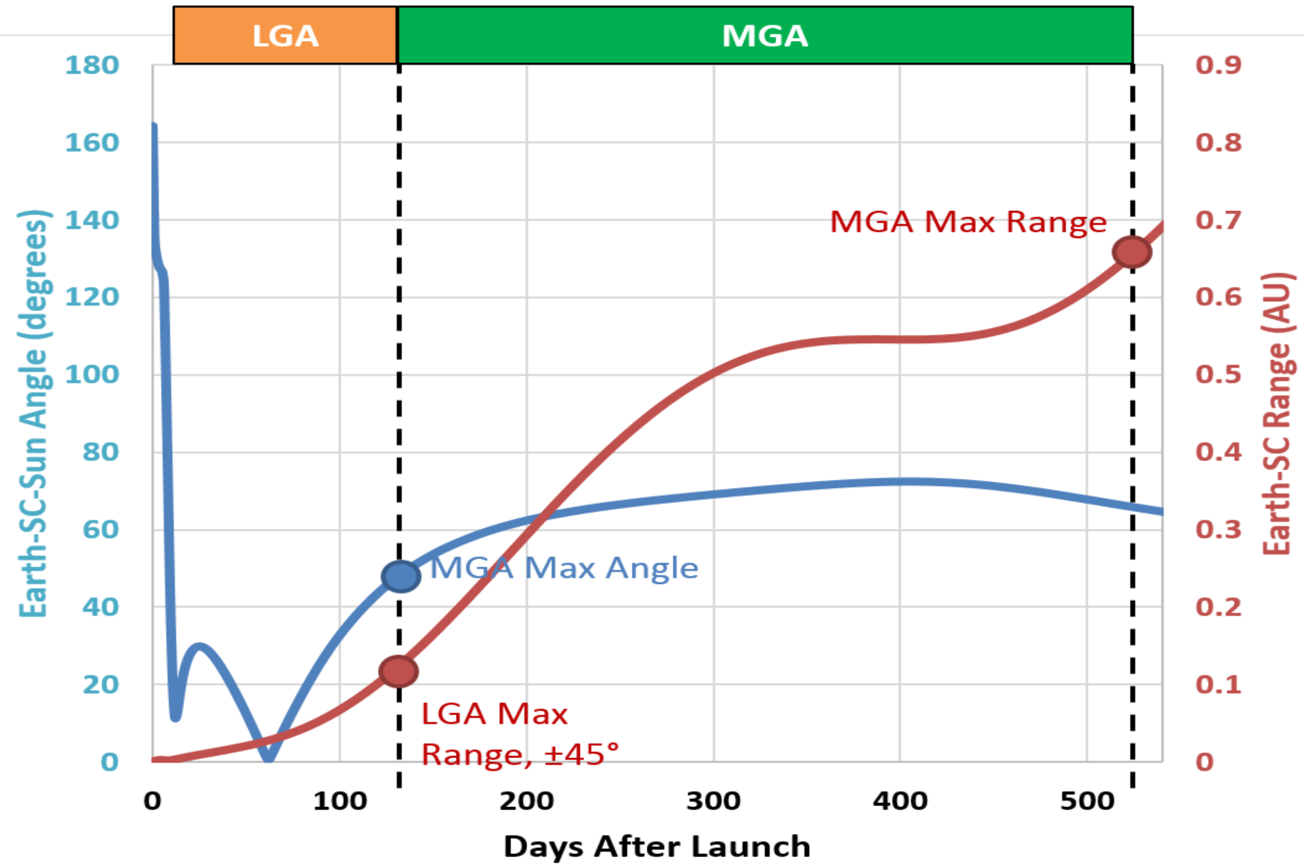




Thermal challenge is to keep warm spacecraft bus subsystems isolated from BioSensor (4-6°C). Cards raised to 23°C during cell growth phase

Comm Mode Timeline

- Nominal Comm Mode operations will use one of two transmit antennas depending on range and Earth-SC-Sun Angle
  - The LGA will be used until data volume requirements require the MGA
  - The MGA cannot be used in conditions where the Earth-SC-Sun Angle is too high due to thermal constraints

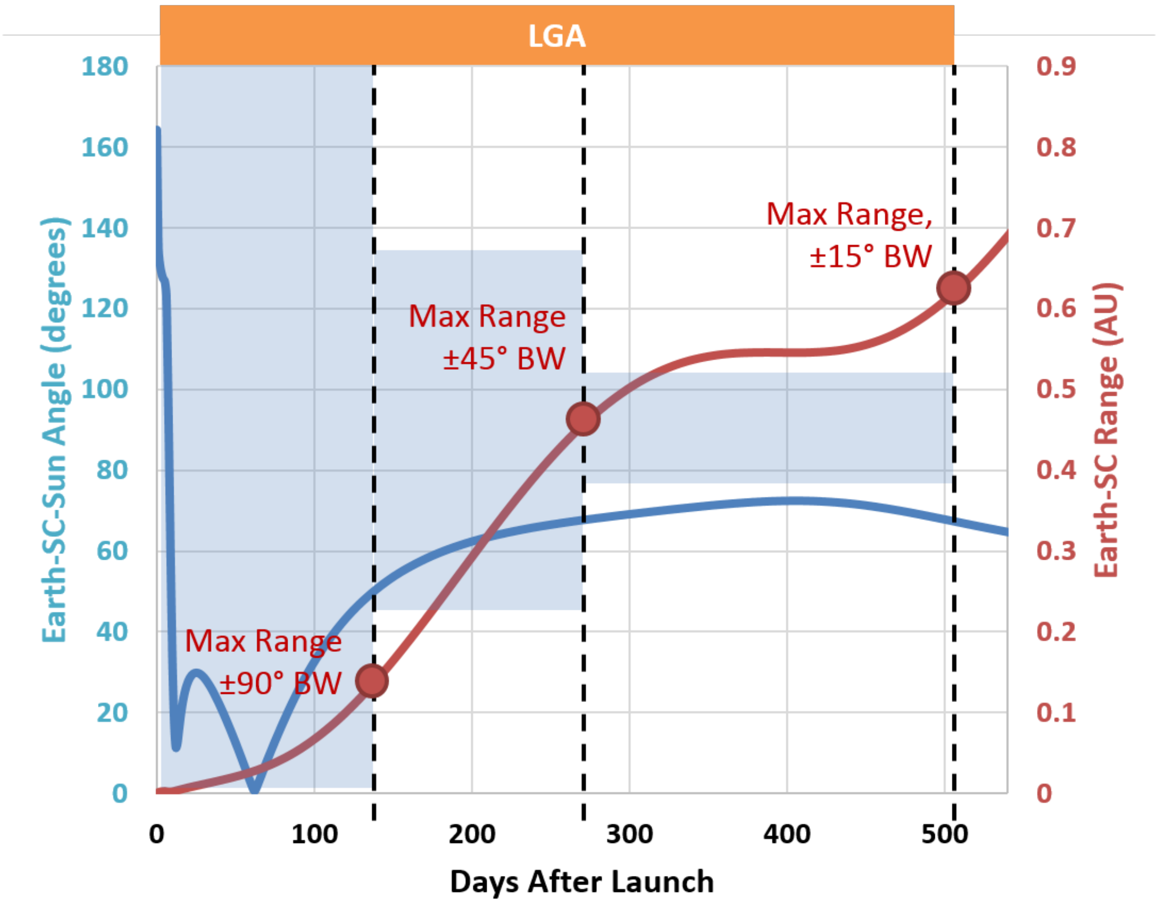


34-meter DSN Antenna

LGA	± 90°	BW	8000 bps	3dB @ 52 days
LGA	**± 45°**	**BW**	**500 bps**	**3dB @ 118 days**
LGA	± 15°	BW	500 bps	3dB @ 130 days
MGA	± 5°	BW	8000 bps	3dB @ 150 days
MGA	± 5°	BW	1000 bps	3dB @ 305 days
MGA	**± 5°**	**BW**	**500 bps**	**3dB @ 515 days**

Safe Mode Timeline

- 70-meter DSN ground antenna is required to close link budget with LGA antenna in later mission
  - MGA cannot be pointed without star tracker and >0° body angle
  - >5° body angle is not thermally sustainable
- Safe Mode recovery becomes harder between 258 and 491 days due to reduced comm window duration



LGA	± 90°	BW	500 bps	3dB @ 87 days
LGA	**± 90°**	**BW**	**62.5 bps**	**3dB @ 137 days**
LGA	± 45°	BW	500 bps	3dB @ 144 days
LGA	**± 45°**	**BW**	**62.5 bps**	**3dB @ 258 days**
LGA	± 15°	BW	500 bps	3dB @ 167 days
LGA	**± 15°**	**BW**	**62.5 bps**	**3dB @ 491 days**

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 Month-in-the-Life ConOps

Monitor Bus Functions

3 — Transmit to DSN (Daily, 30 minute contact, ATS)

1 — Media A: 4 weeks — 1 — Media B: 2 weeks

1 — Wet new cards with Media A (2 fluidic cards every 6 weeks, ATS)

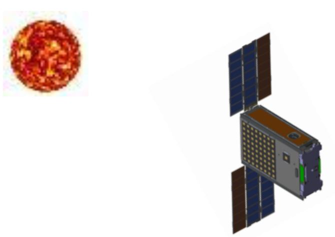
2 — Collect science data (Continuous, RTS)

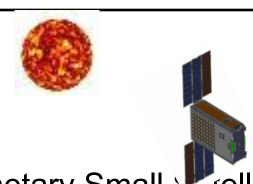
1 — Wet cards with Media B (4 weeks after Media A, RTS)

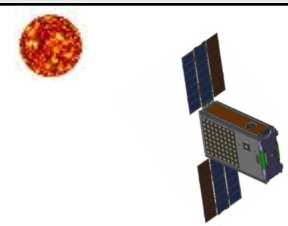
Major Functions	Sub-functions (1)
Select card	• Determine fluidic card • Select μ-controller • Select pump and valve set
Apply Fluids	• Open inlet valve • Open plate valve • Open nutrient valves • Activate Pump
Configure Thermal Control	• Apply cold set points to other cards • Warm set points for Media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





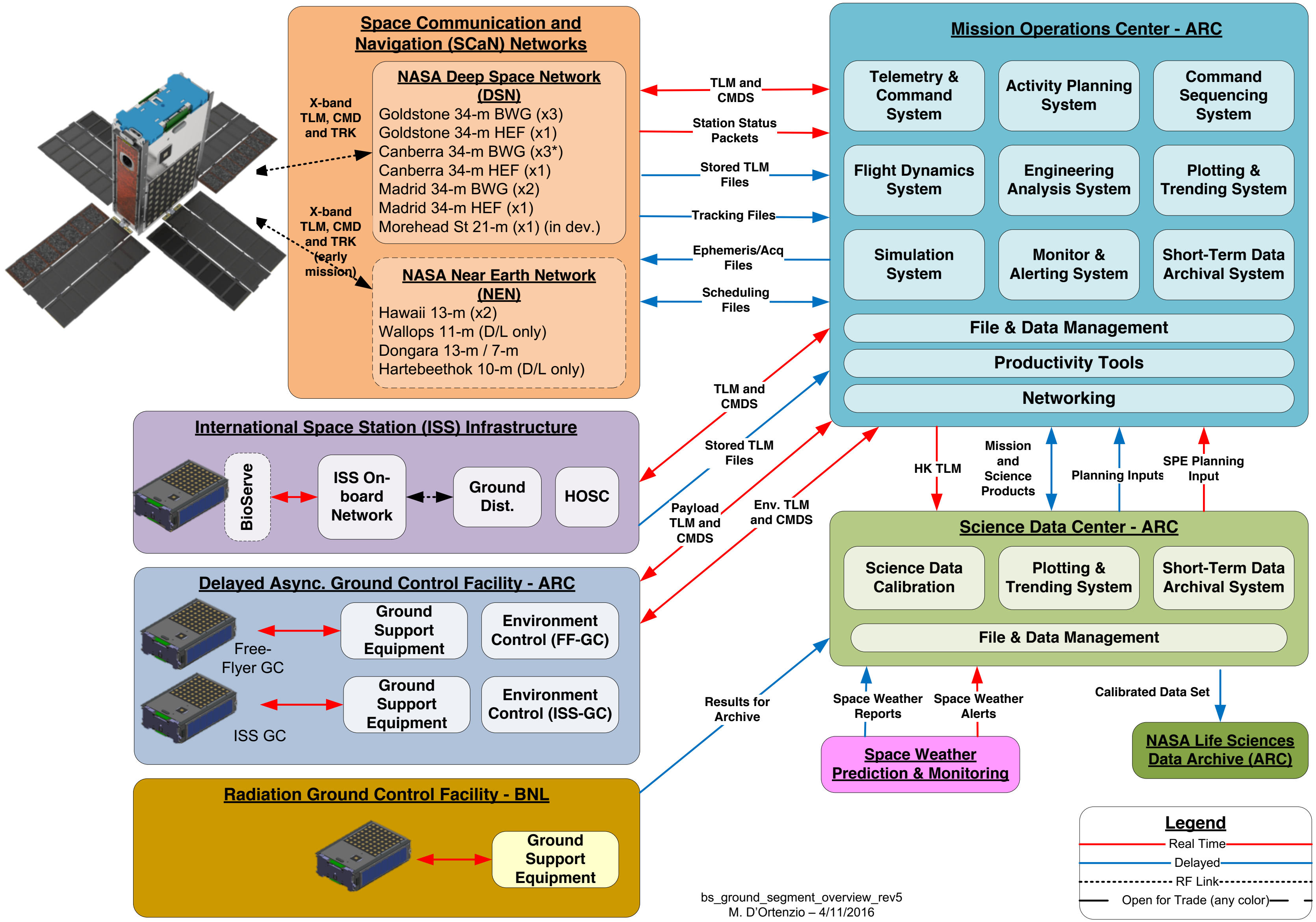


Preliminary Operational Staffing Profile

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	

Questions & Back-Up Charts

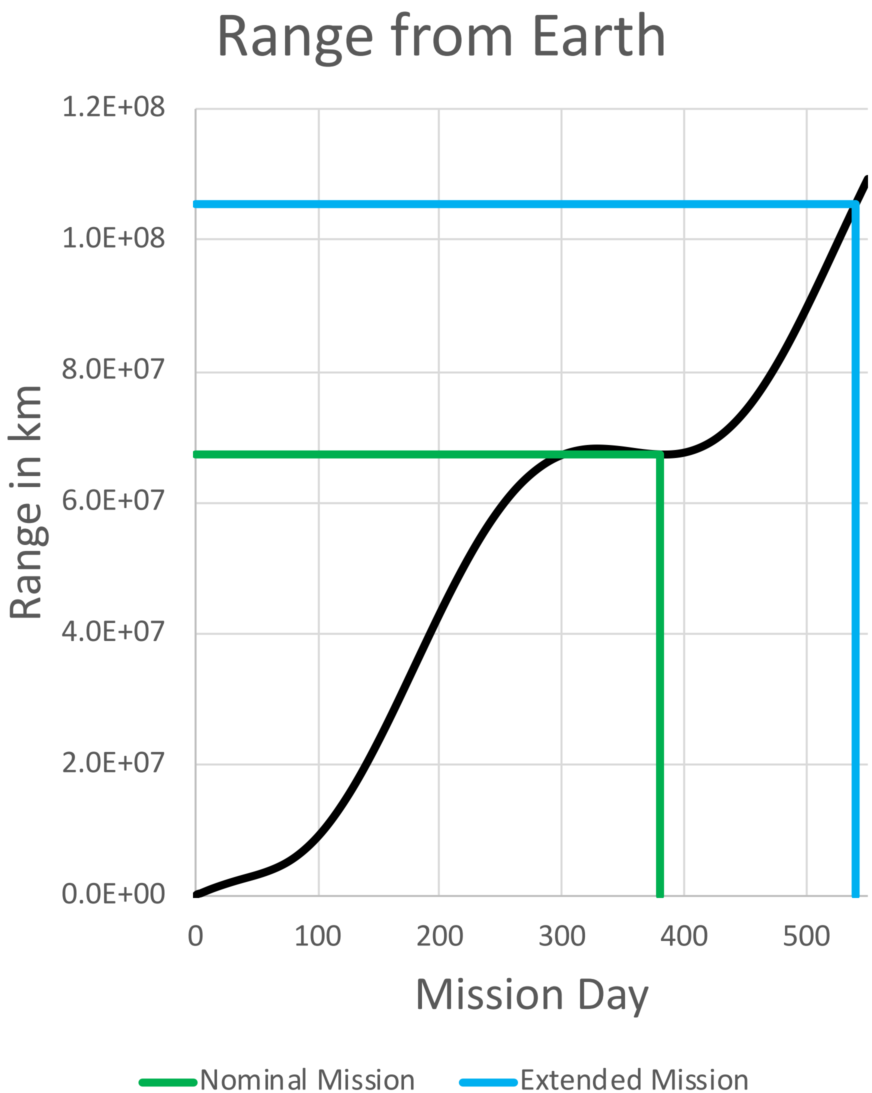
Ground System Architecture

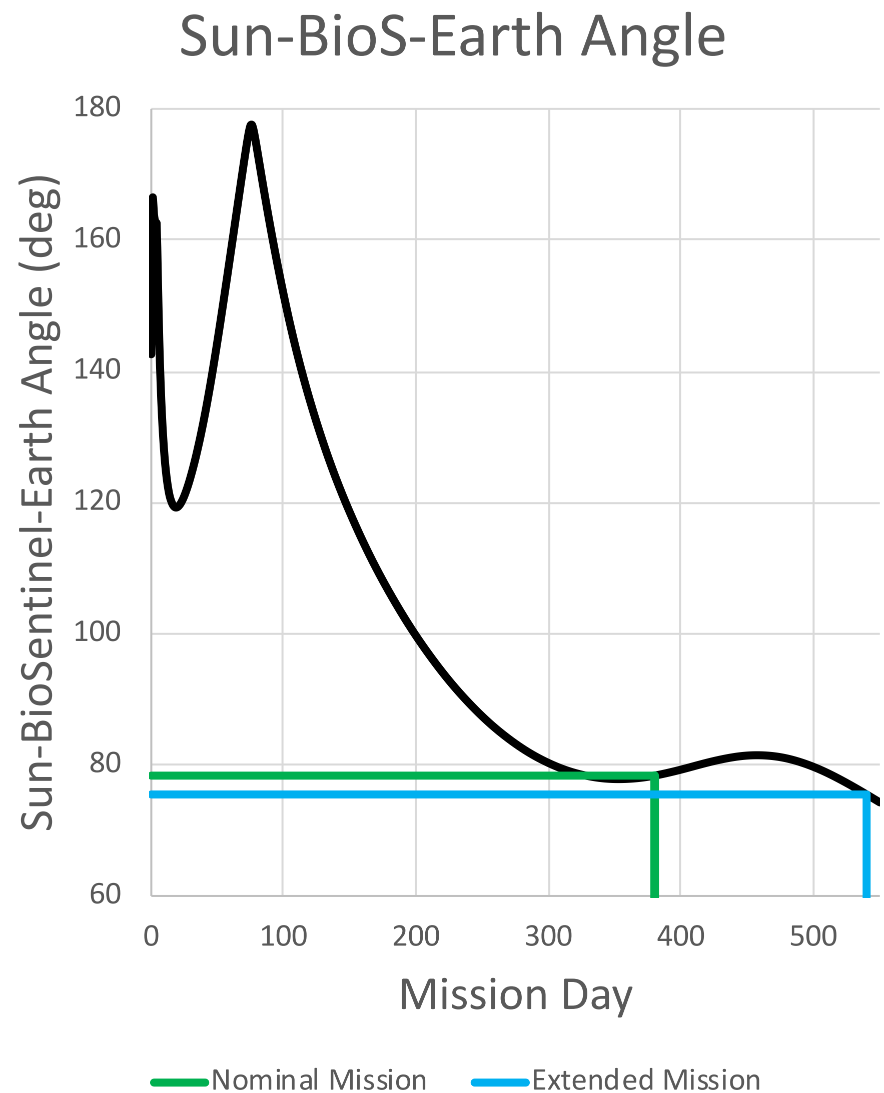


BioSentinel FreeFlyer Spacecraft Bus Summary

- 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

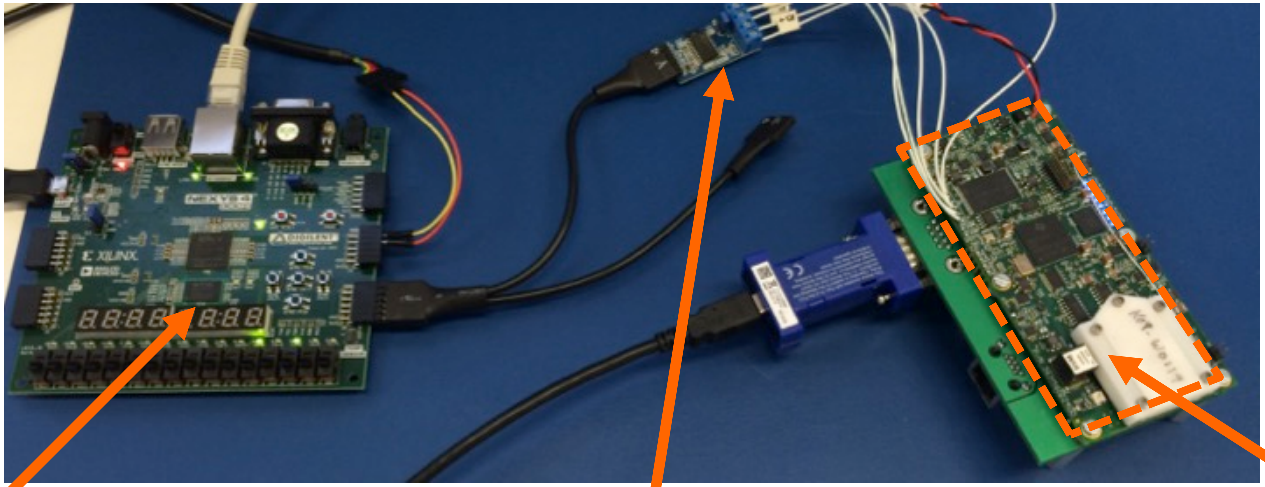
Support

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

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.



C&DH Processor Simulator

RS-422 Interface

LET Spectrometer EDU

Assumptions

- Mission Timeline
  - Initialization (2 weeks) – Launch thru Day 14
  - Science Baseline (12 Months) Day 15 – 380
  - Extended Science (6 Months) Day 381- 563

- Antenna gain depends on angle off boresight
  - LGA – 0° = 7 dB, 15° = 6 dB, 30° =???, 45° = 3 dB, 50° = 2 dB, 90° = -7 dB
  - MGA – 0° = 23 dB, 5° = 21 dB, 9.5° = 20 dB

- Thermally limited Body Angle & Time constraint
  - Body Angle (Theta) -5° ≤ Theta ≤ 45° ;
  - Maximum Communication Time – 30 Minutes
    - For simplicity, a maximum of 30 minute is assumed for any Body Angle > 0°
    - Thermal model shows that ~60 minutes can be achieved at 45° (100% margin)
    - Current best estimate for minimum comm time required for mission operations
      - At 62.5bps = 62.5*60*30 = 112.5 kb
      - At 8kbps = 8000*60*30 = 14.4Mb

- Risks with assumptions
  - Thermal model is inaccurate and 30 minutes at 45° is not achievable
  - Required data volumes (currently TBD) are higher than 30 minutes at 62.5bps (112.5kb)

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BioSentinel Link Margin (dB) vs. Mission Days