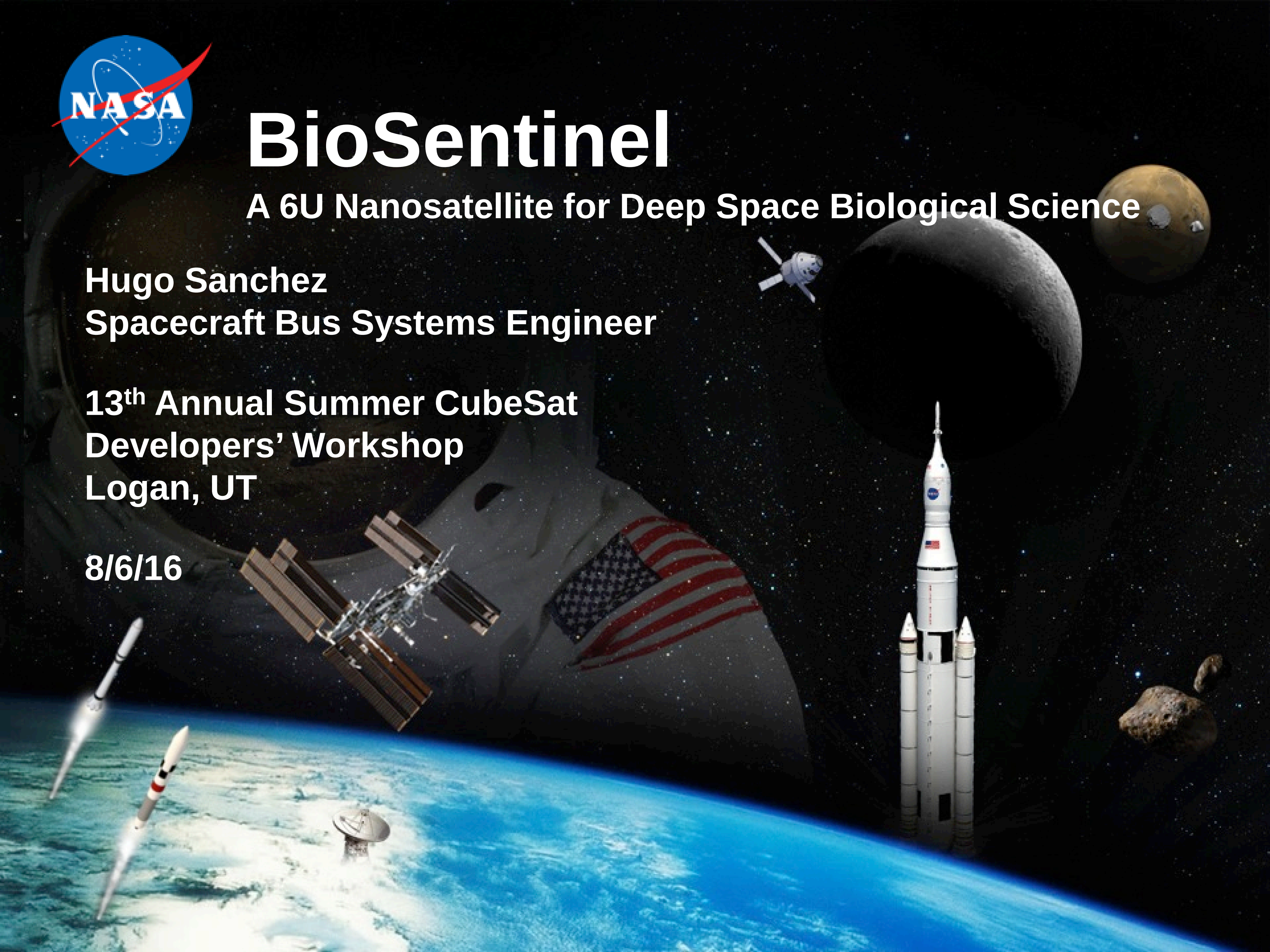
BioSentinel

A 6U Nanosatellite for Deep Space Biological Science



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Spacecraft Bus Systems Engineer

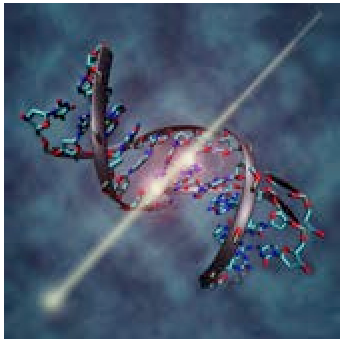
13th Annual Summer CubeSat Developers' Workshop
Logan, UT

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)

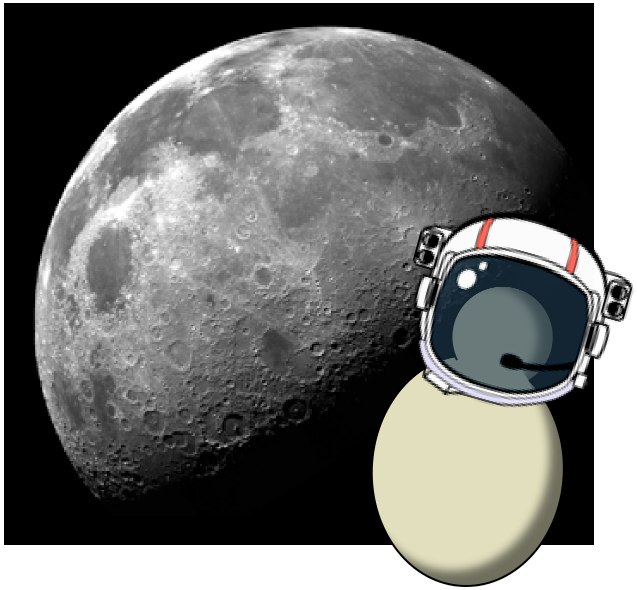
A BioSensor in Space

- **<u>What</u>**: BioSentinel is a yeast radiation biosensor that will measure the response to DNA damage caused by space radiation, primarily double strand breaks (DSBs).
- **<u>Why</u>**: 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.
- **<u>How</u>**: 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.

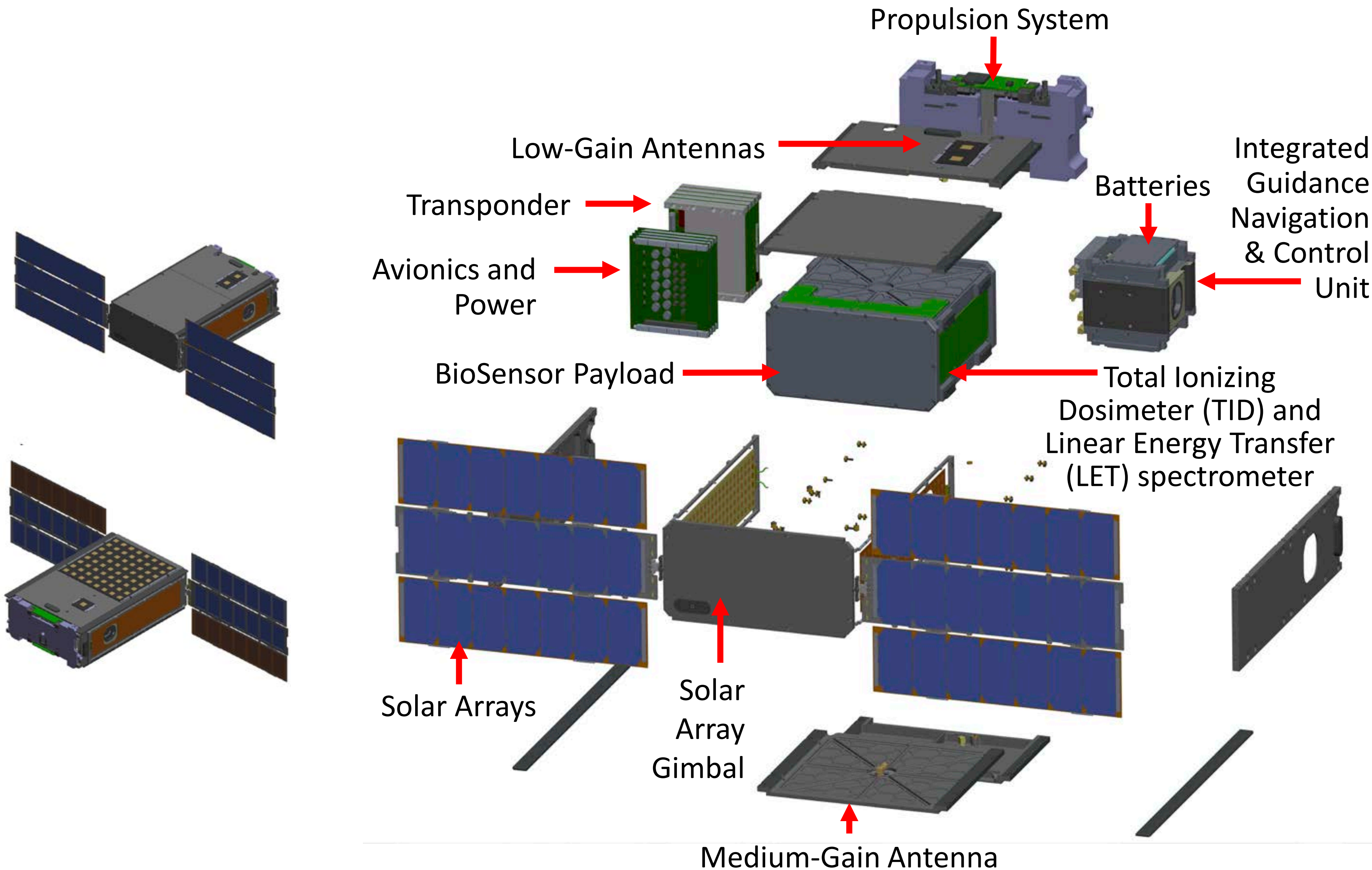
Why budding yeast?

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



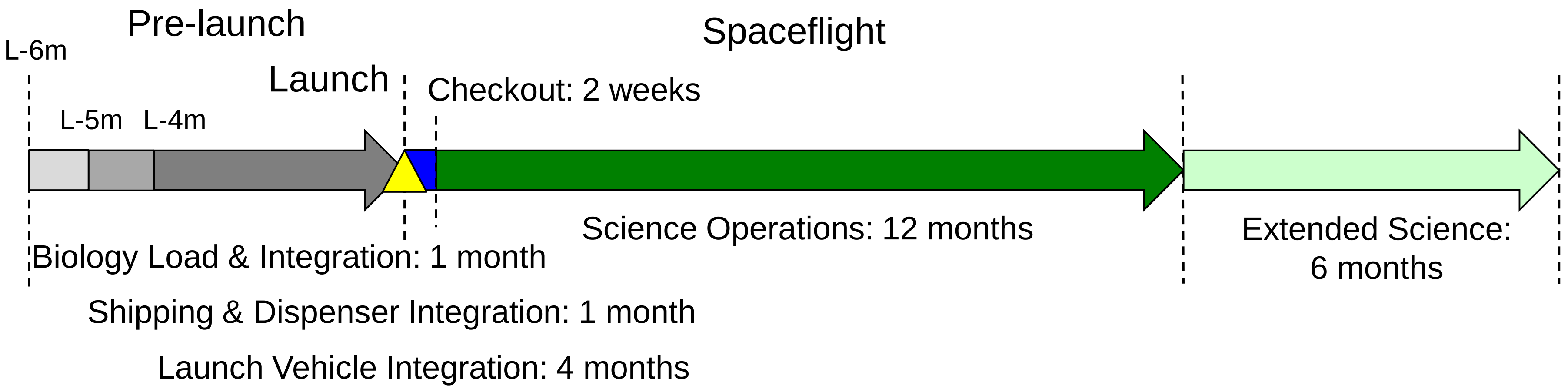
BioSentinel FreeFlyer Spacecraft: Physical Overview

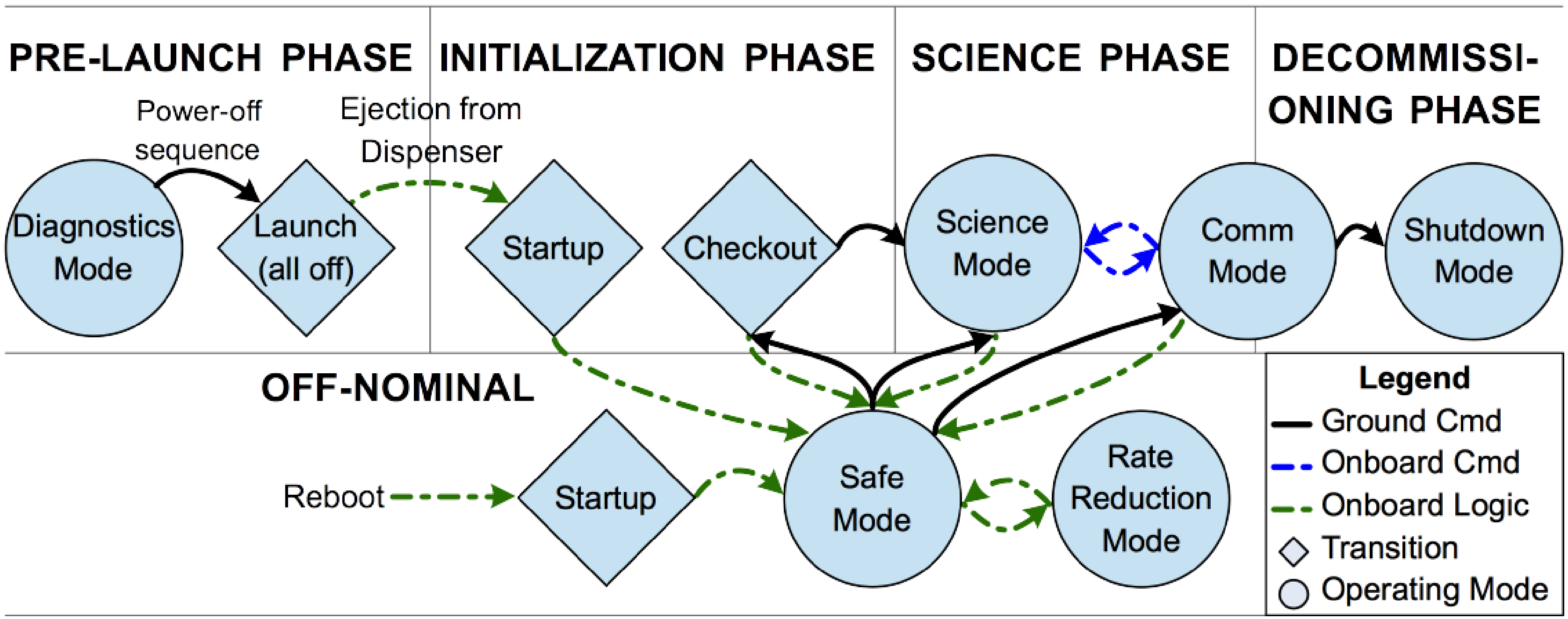


BioSentinel Mission Phases

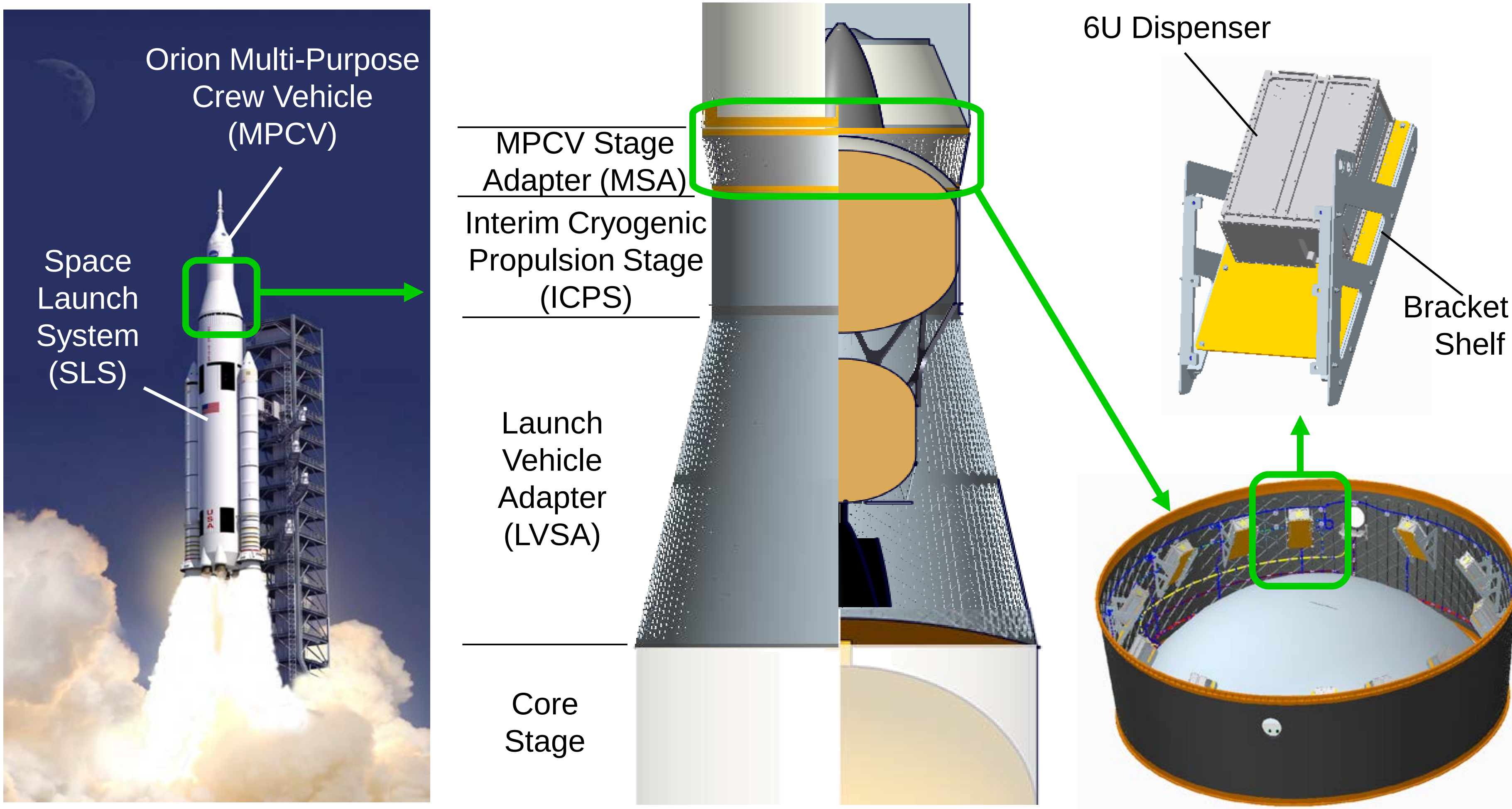
Phase	Entry	Exit	Duration	Summary & Objectives
Pre-Launch	Loading of biology	L/V Lift-off	~180 days	• Load Flight Biology • Charge, checkout, and configure FreeFlyer • Integrate FreeFlyer with Dispenser and SLS
Launch	L/V Lift-off	Deployment of FreeFlyer	<1 day	• FreeFlyer is powered off • Survive launch 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





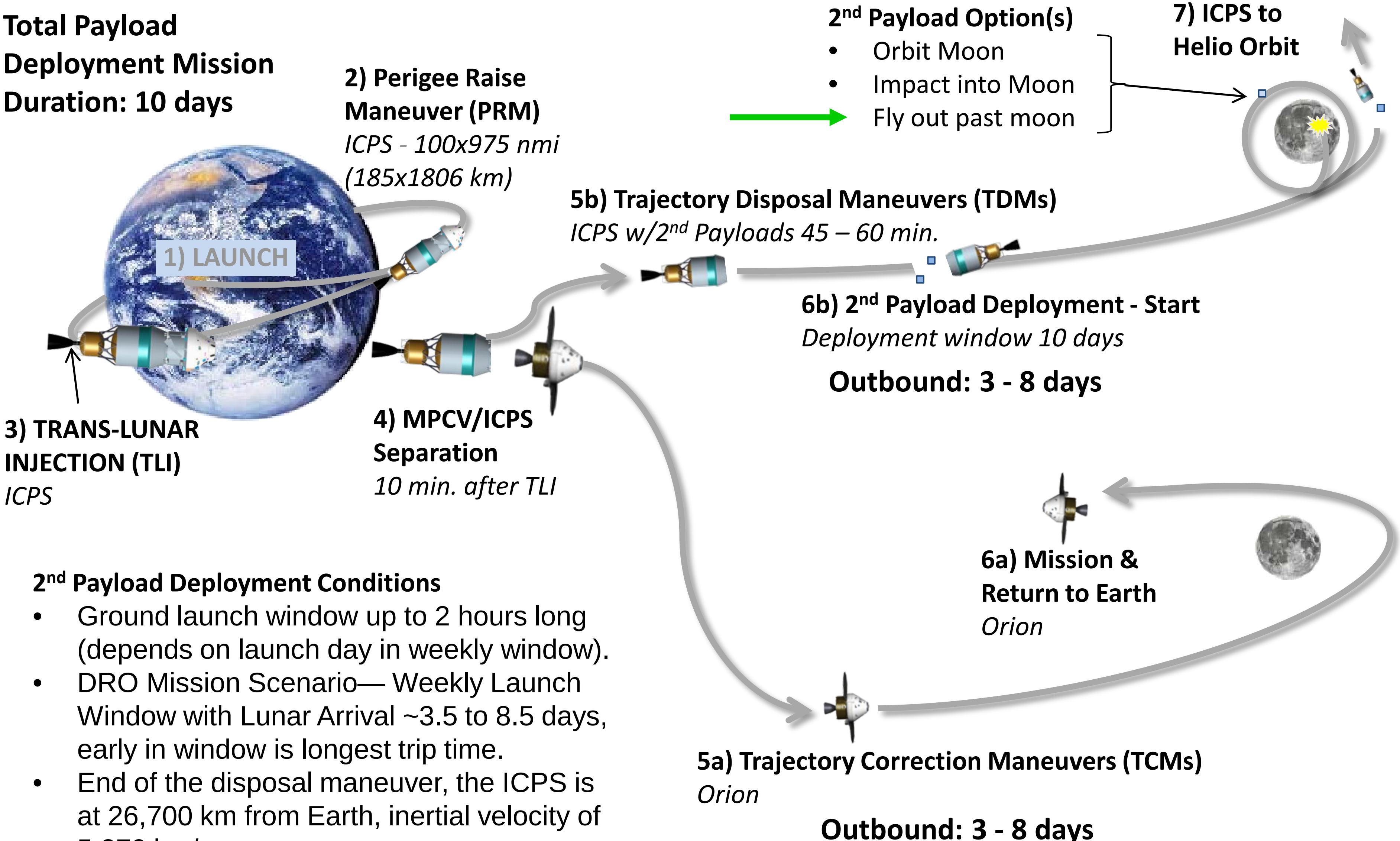
Secondary Payload Location on SLS EM-1



- 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

Launch Phase

Total Payload Deployment Mission Duration: 10 days

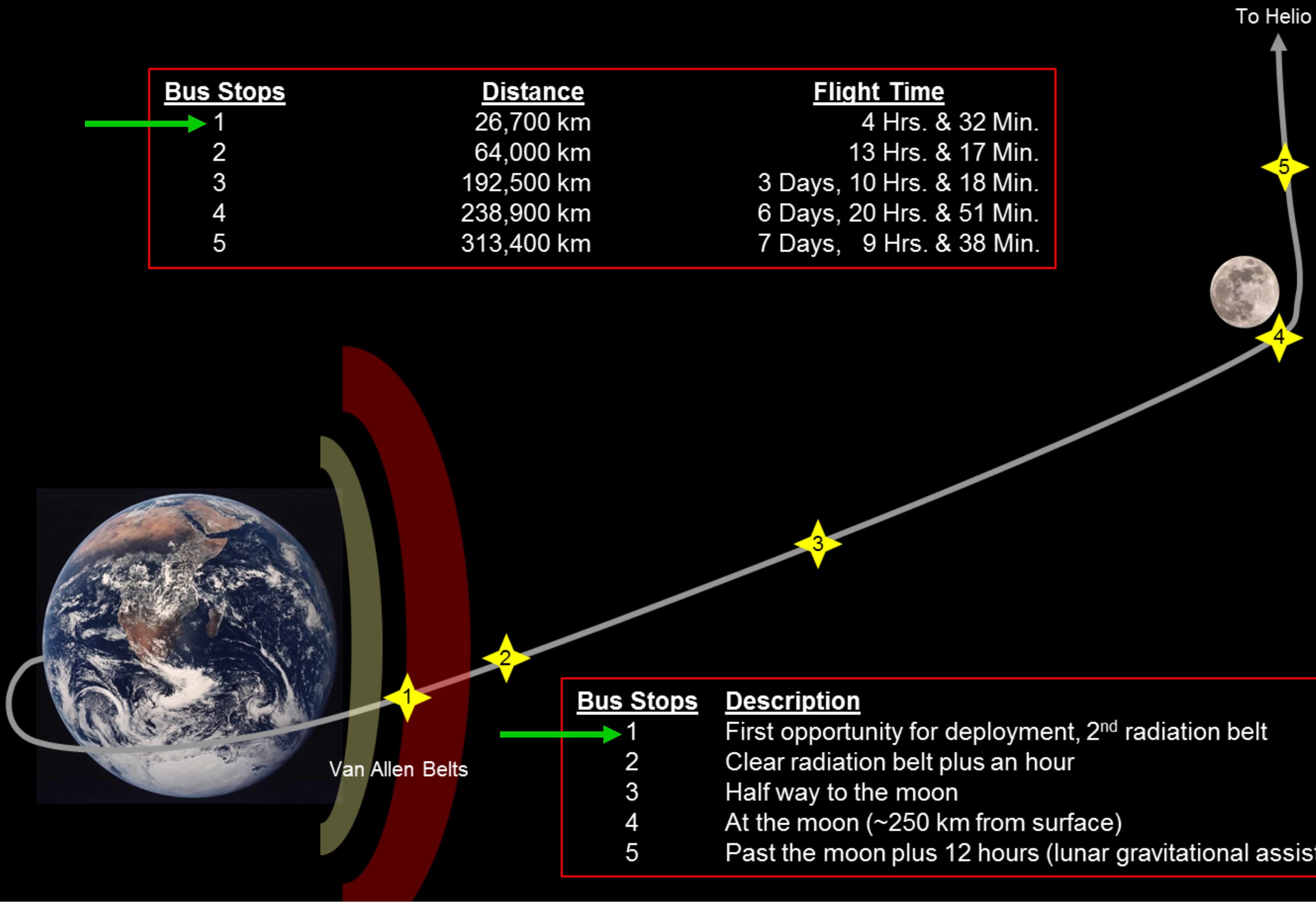


2nd Payload Deployment Conditions

- 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.

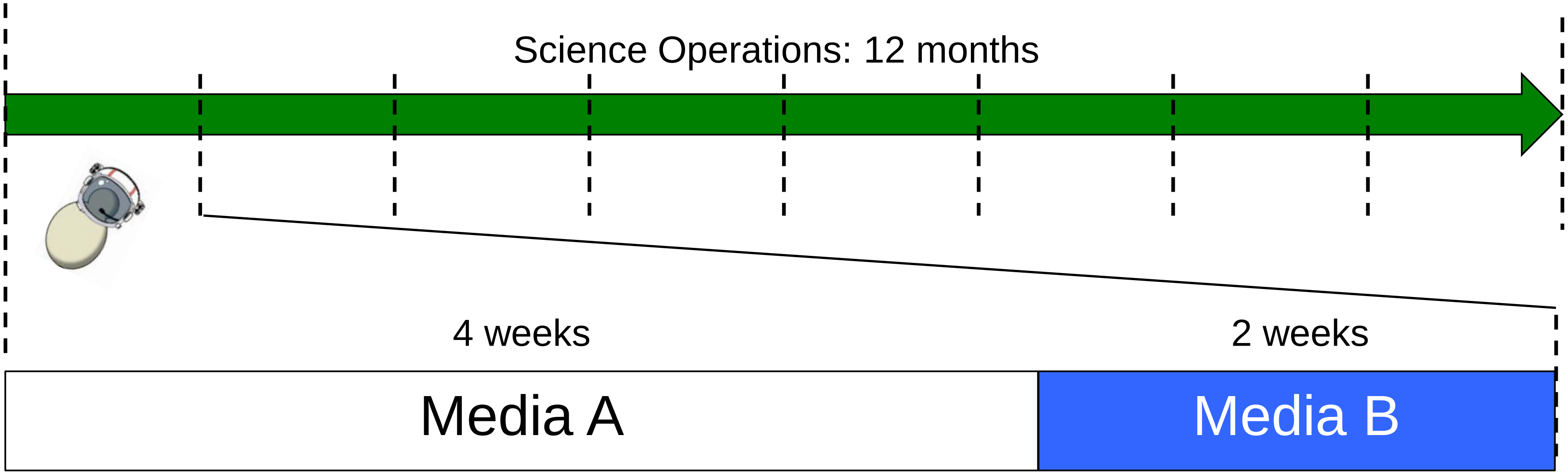
Deployment “Bus Stops”

Bus Stops	Distance	Flight Time
1	26,700 km	4 Hrs. & 32 Min.
2	64,000 km	13 Hrs. & 17 Min.
3	192,500 km	3 Days, 10 Hrs. & 18 Min.
4	238,900 km	6 Days, 20 Hrs. & 51 Min.
5	313,400 km	7 Days, 9 Hrs. & 38 Min.



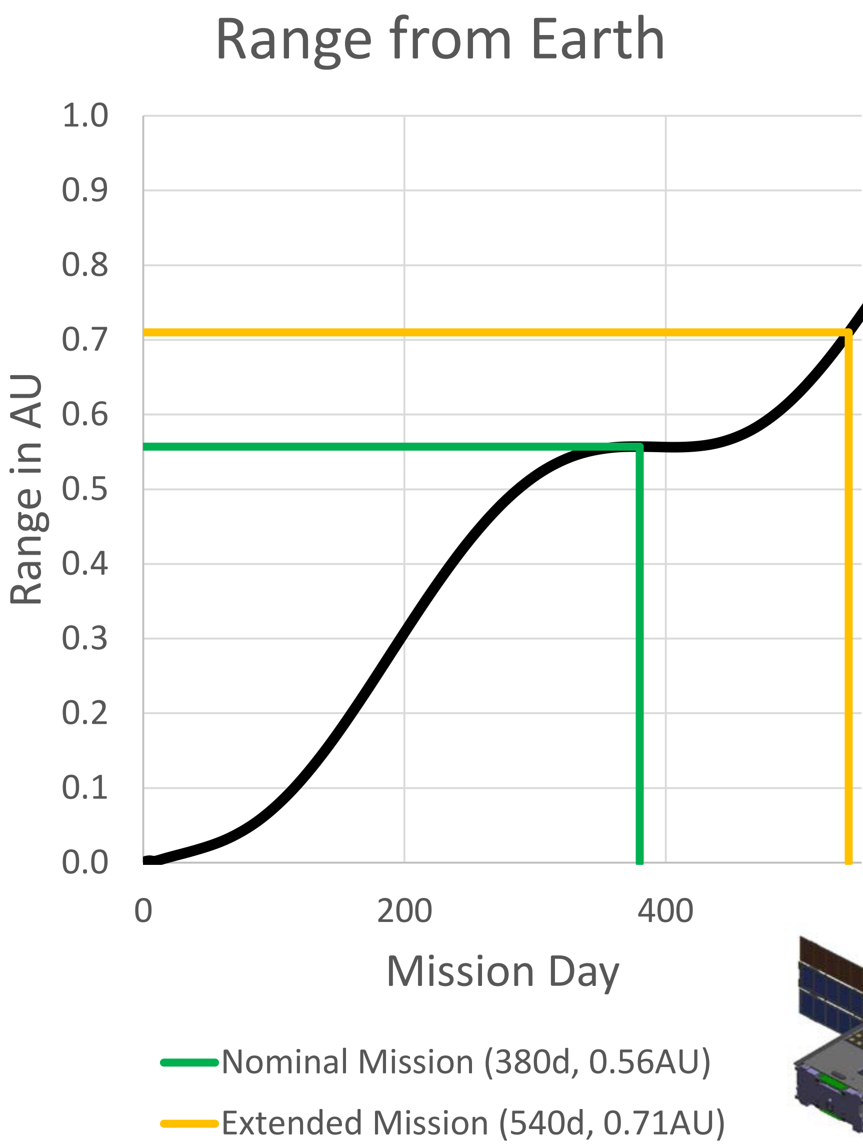
Bus Stops	Description
1	First opportunity for deployment, 2nd radiation belt
2	Clear radiation belt plus an hour
3	Half way to the moon
4	At the moon (~250 km from surface)
5	Past the moon plus 12 hours (lunar gravitational assist)

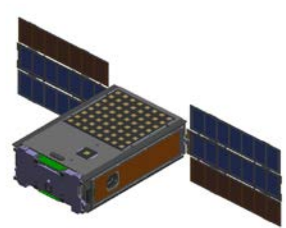
BioSentinel Science Operations

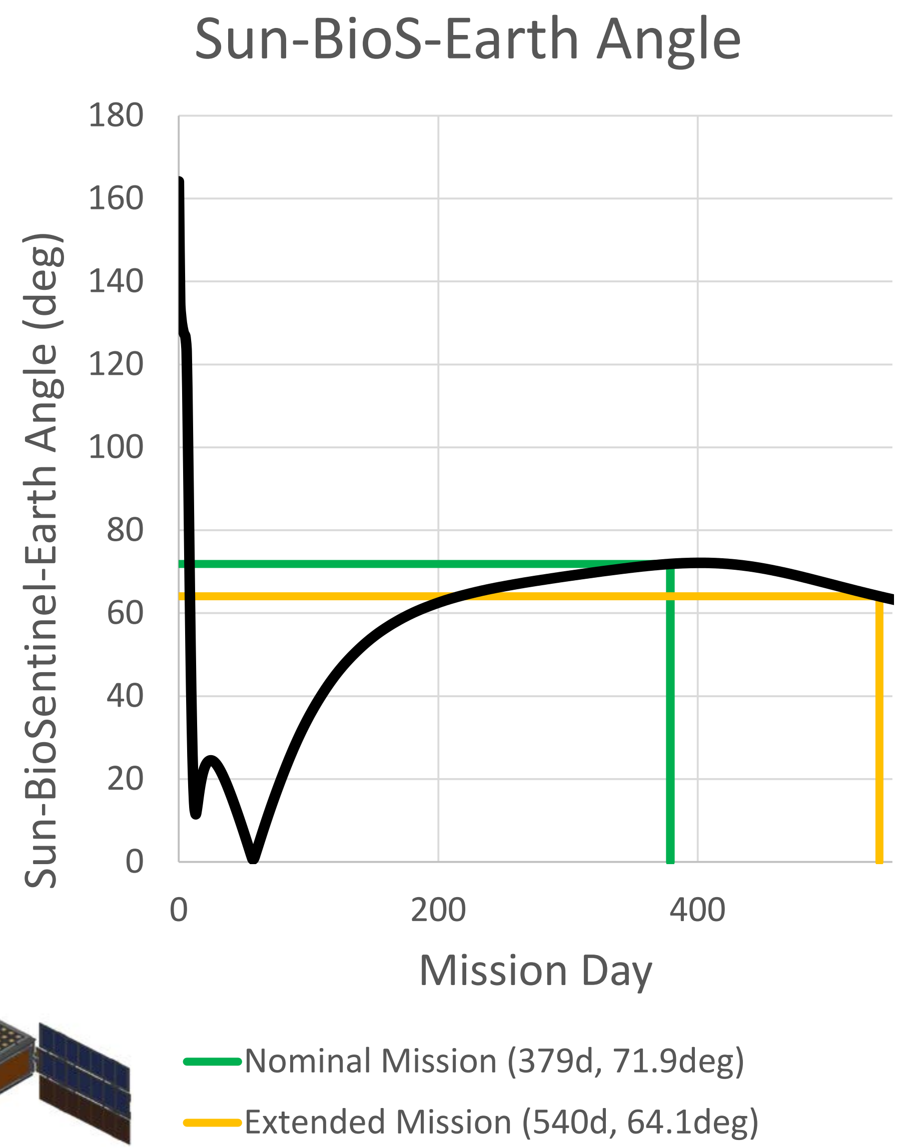


- Science Operations are periodic with 8 time points throughout the 12 months
- 2 cards are kept in reserve for Solar Particle Events (SPEs)
- Activation Time points: T0, T0+45 days, T0+90 days, T0+135 days, T0+180 days, T0+225 days, T0+270 days, T0+315 days
- Schedule is adjustable as part of Science 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

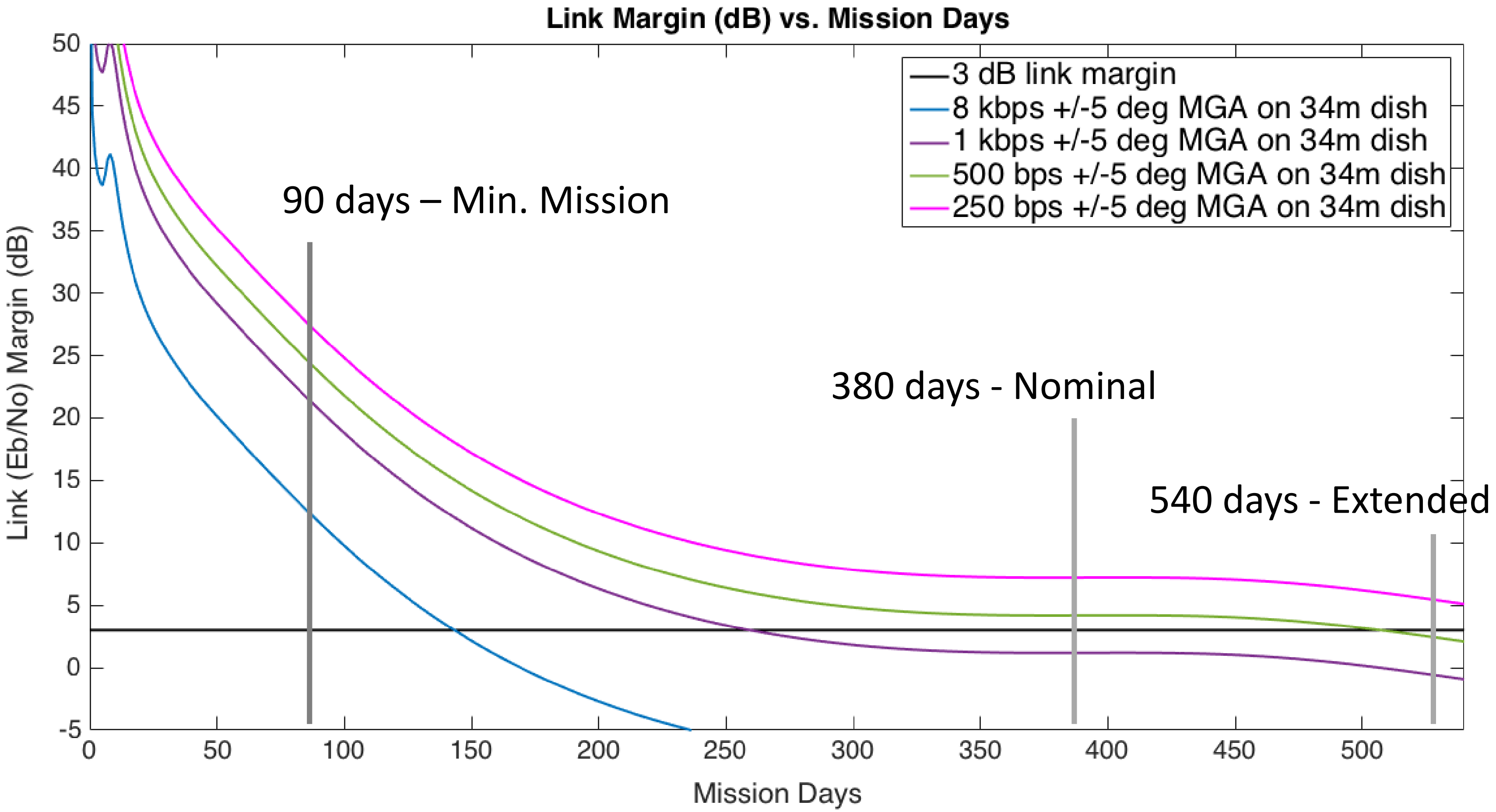




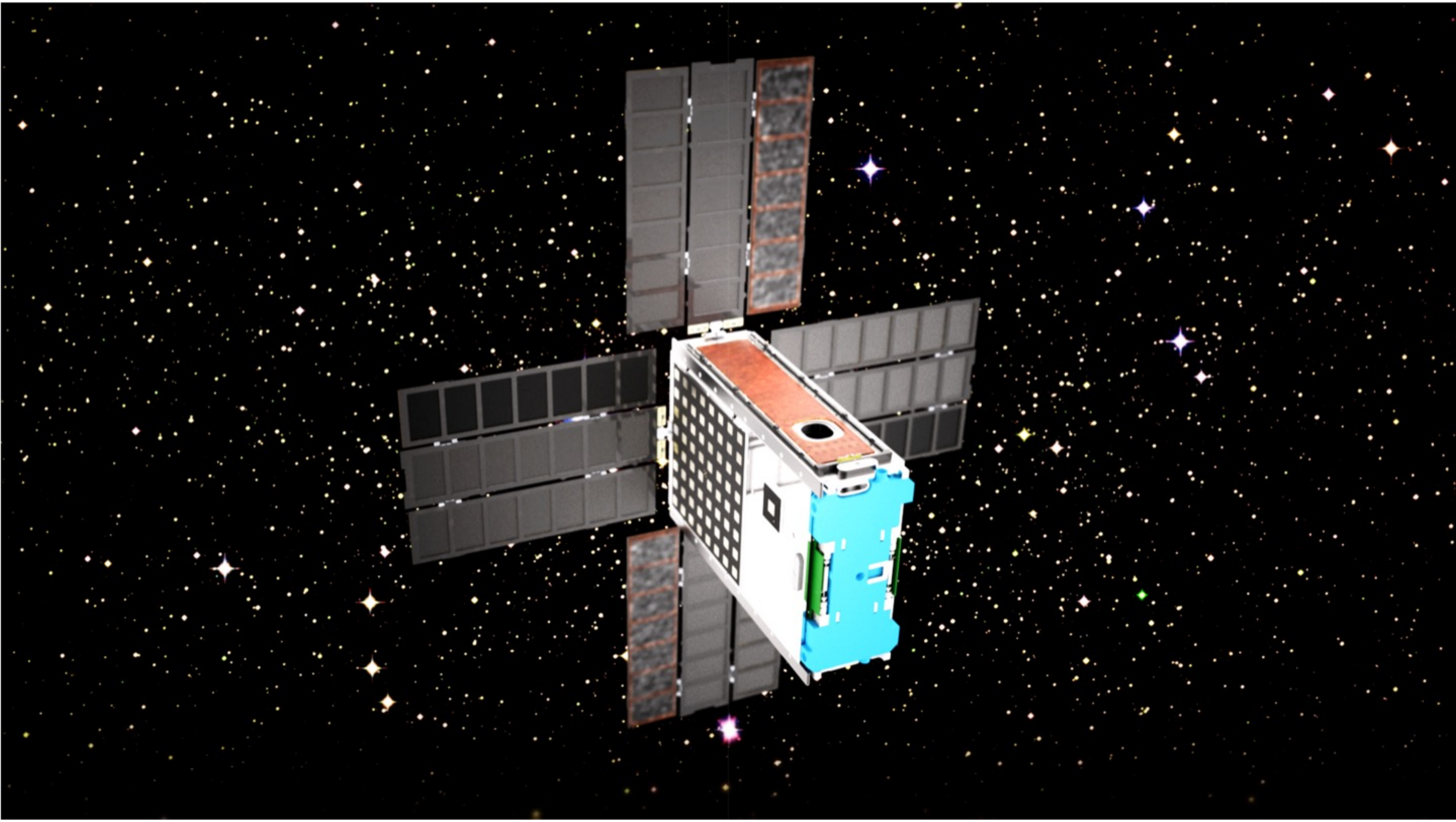


BioSentinel Communication Links

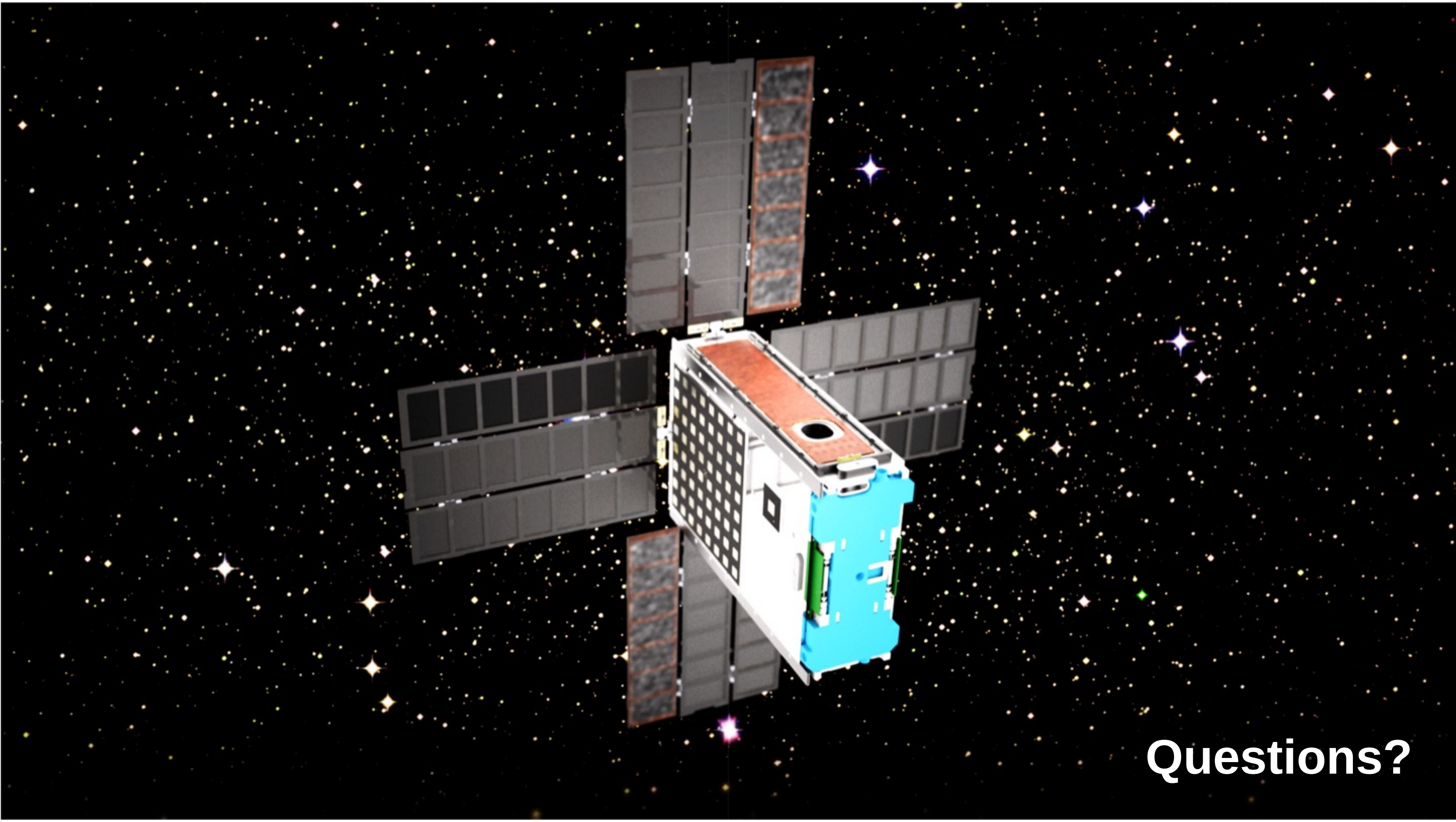
- Based on current trajectory and transponder design assumptions, the system supports:
  - 8 kpbs through the minimum mission duration (3 months)
  - 500 bps through the nominal mission duration (12 months)
  - 250 bps through the extended mission duration (18 months)



More work in progress…



Thank you!



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

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

(1) Media A: 4 weeks (2)

(1) Media B: 2 weeks (2)

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

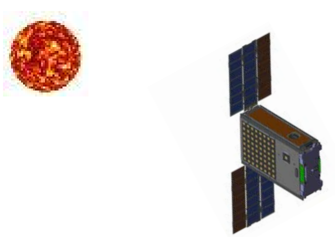
(2) Collect science data
(Continuous, RTS)

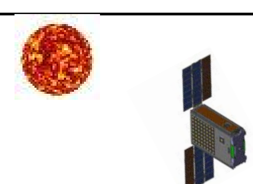
(1) Wet cards with Media B
(4 weeks after Media A, RTS)

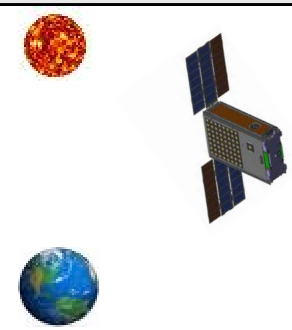
Major Functions	Sub-functions (1)
Select card	• Determine fluidic card • Select μ-controller • Select pump and valve set
Apply Fluids	• Open inlet valve • Open plate valve • Open nutrient valves • Activate Pump
Configure Thermal Control	• Apply cold set points to other cards • Warm set points for Media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



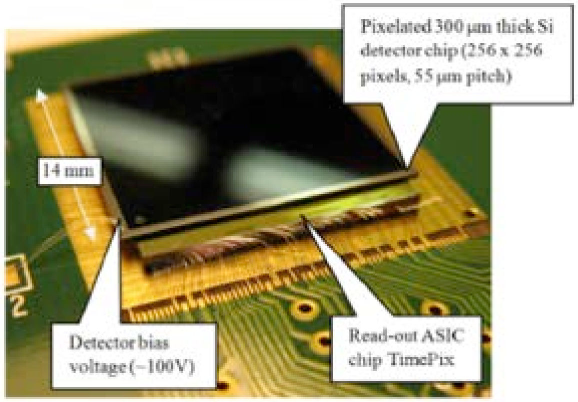




LET Spectrometer & TID Dosimeter Radiation Monitoring

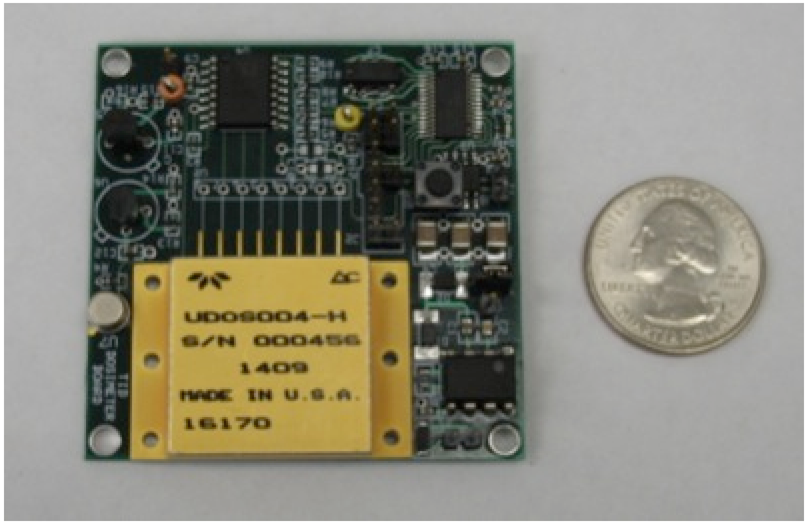
- Linear Energy Transfer (LET) Spectrometer Designed by JSC RadWorks specifically for the BioSentinel Project.

LET Spectrometer Engineering Development Unit (EDU)

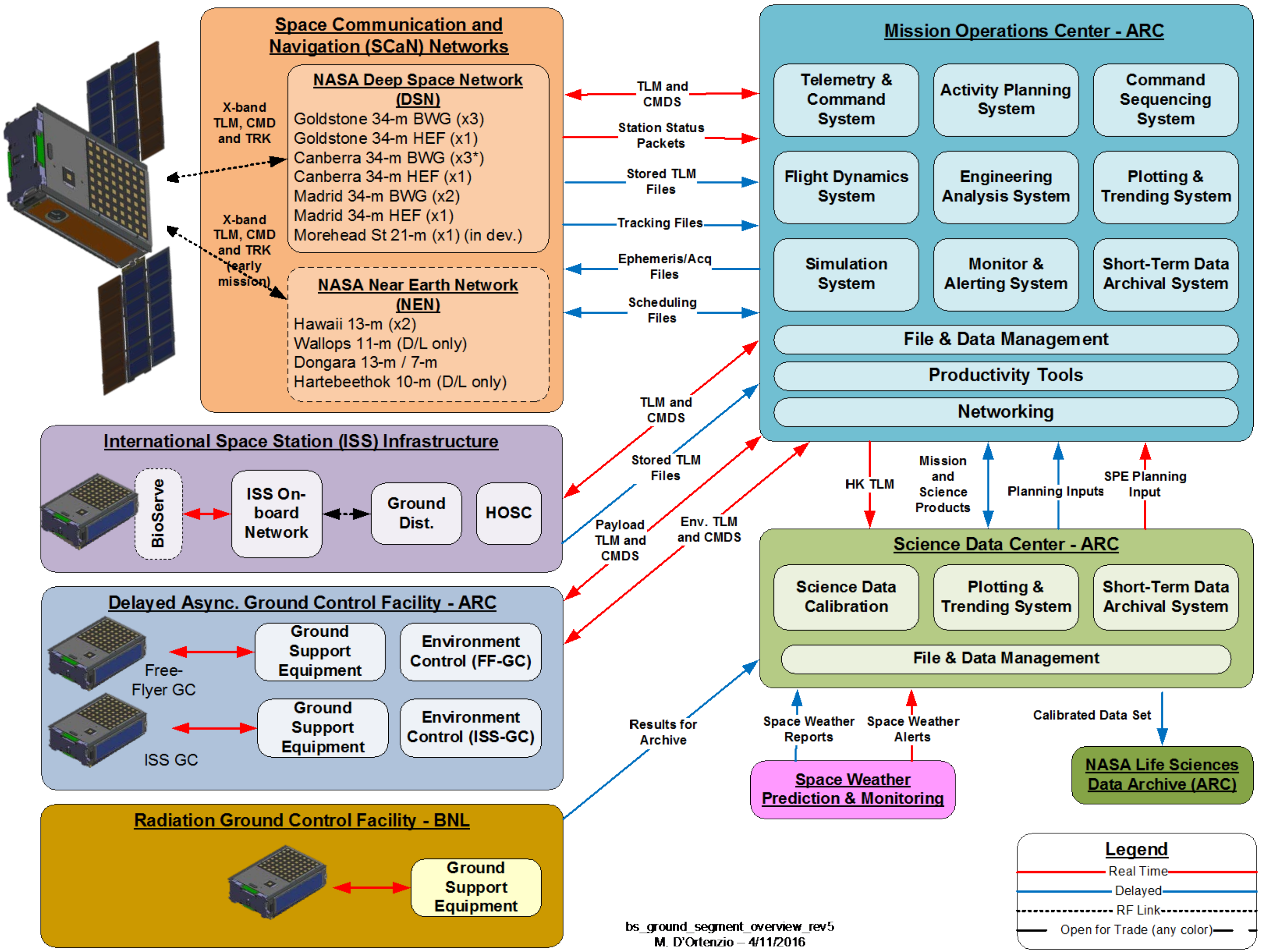


TimePIX Sensor

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



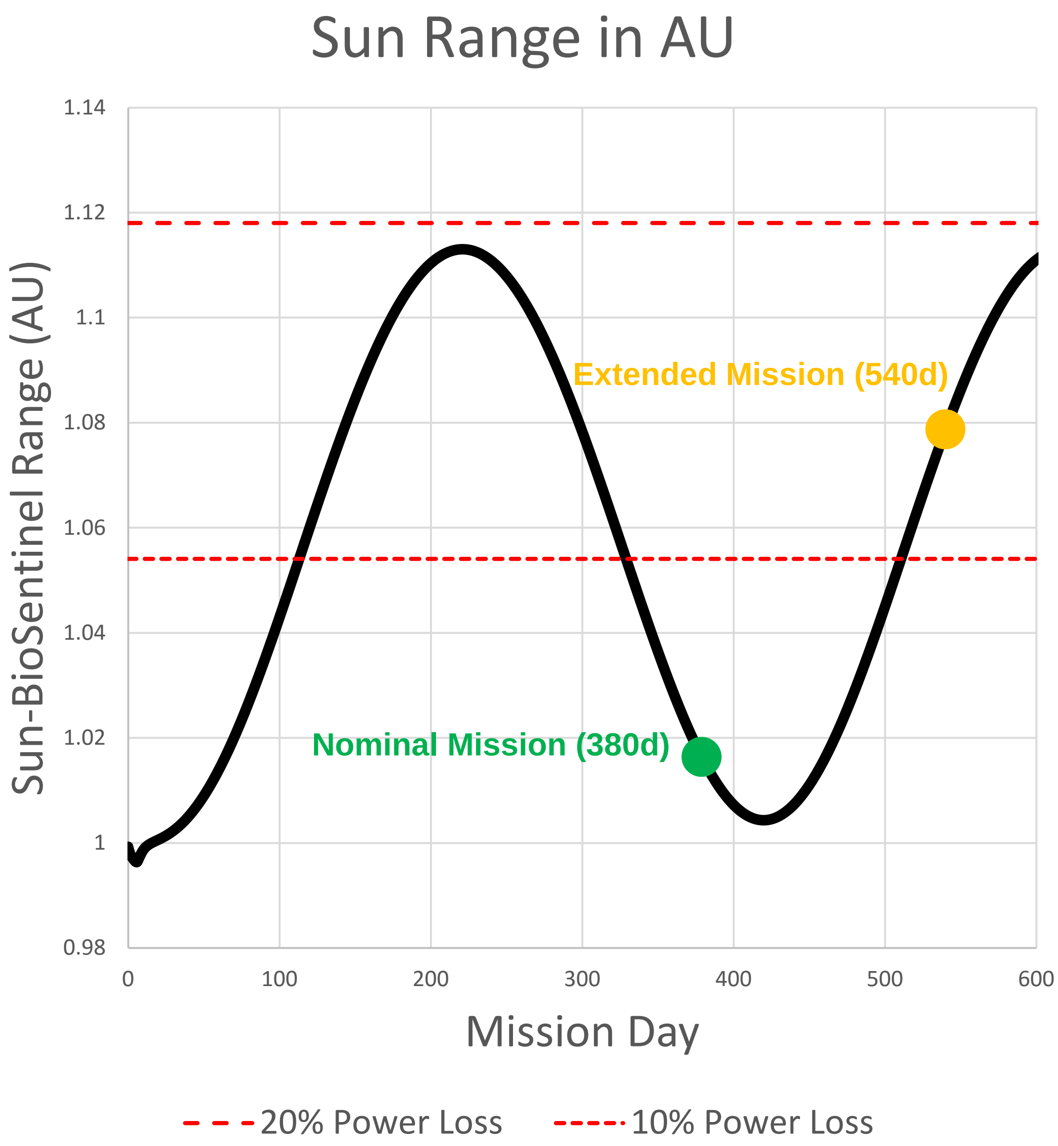
Ground System Architecture

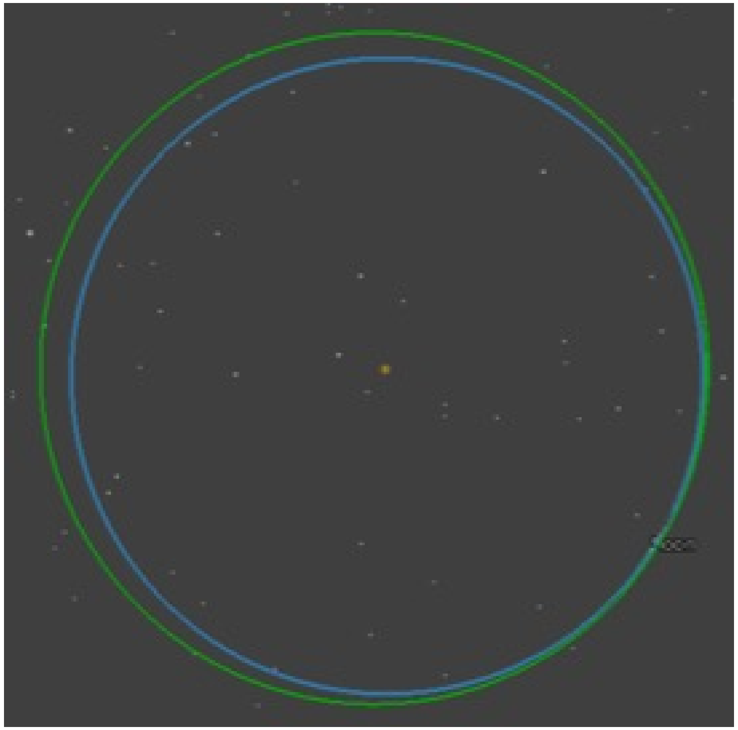


Preliminary Operational Staffing Profile

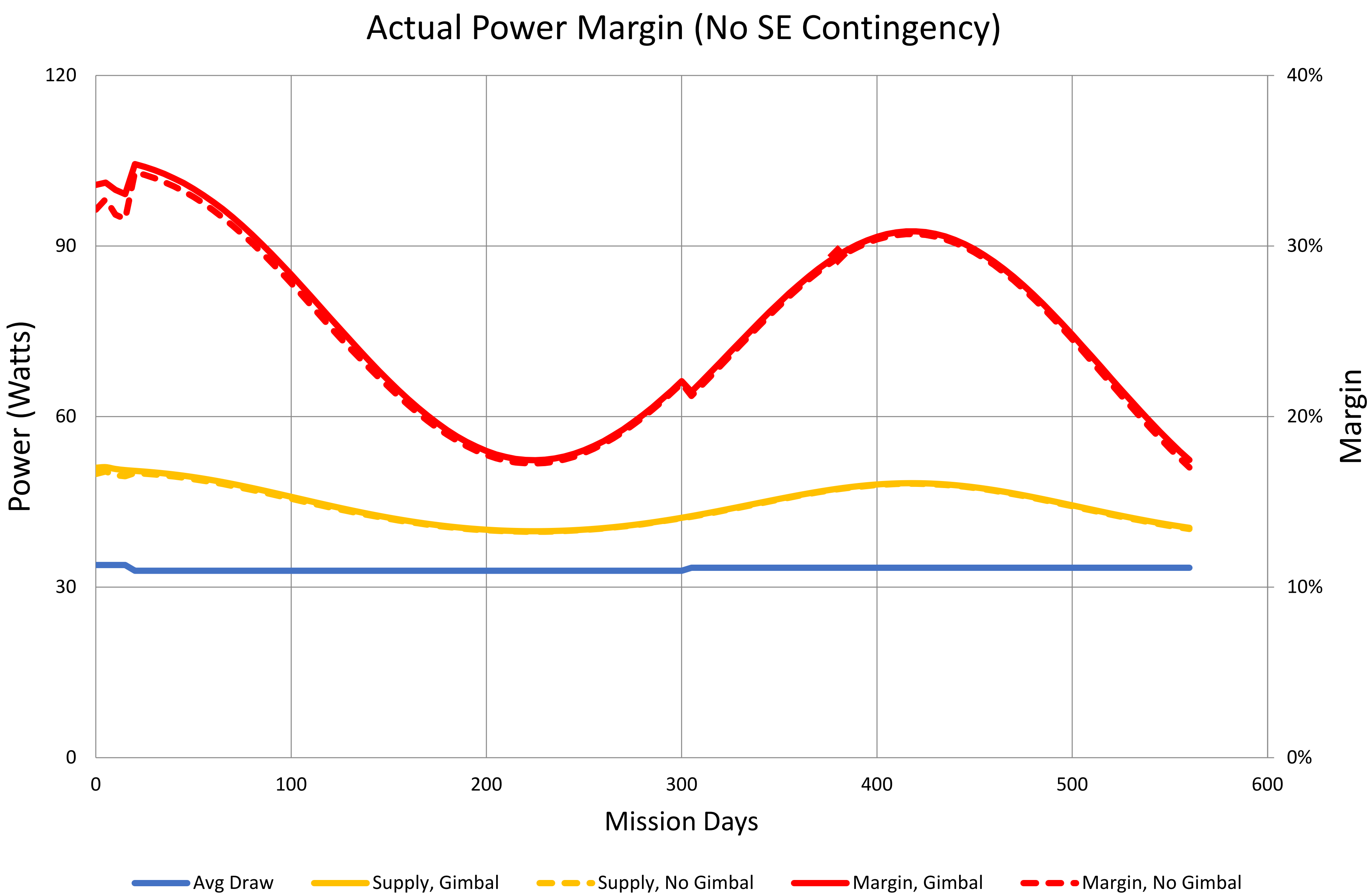
Mission Phase	Length	Mission Operations Staffing Profile	Assumptions/Comments
Pre-Launch	~ 30 day	- 4x5 support for monitoring of BioSentinel DSGC pre-launch profile	- DSGC must start while BioSentinel is at KSC
Launch & Ascent	~ 1 day	- Full team will staff the MOC	- BioSentinel is powered off. No real-time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

Spacecraft to Sun Range

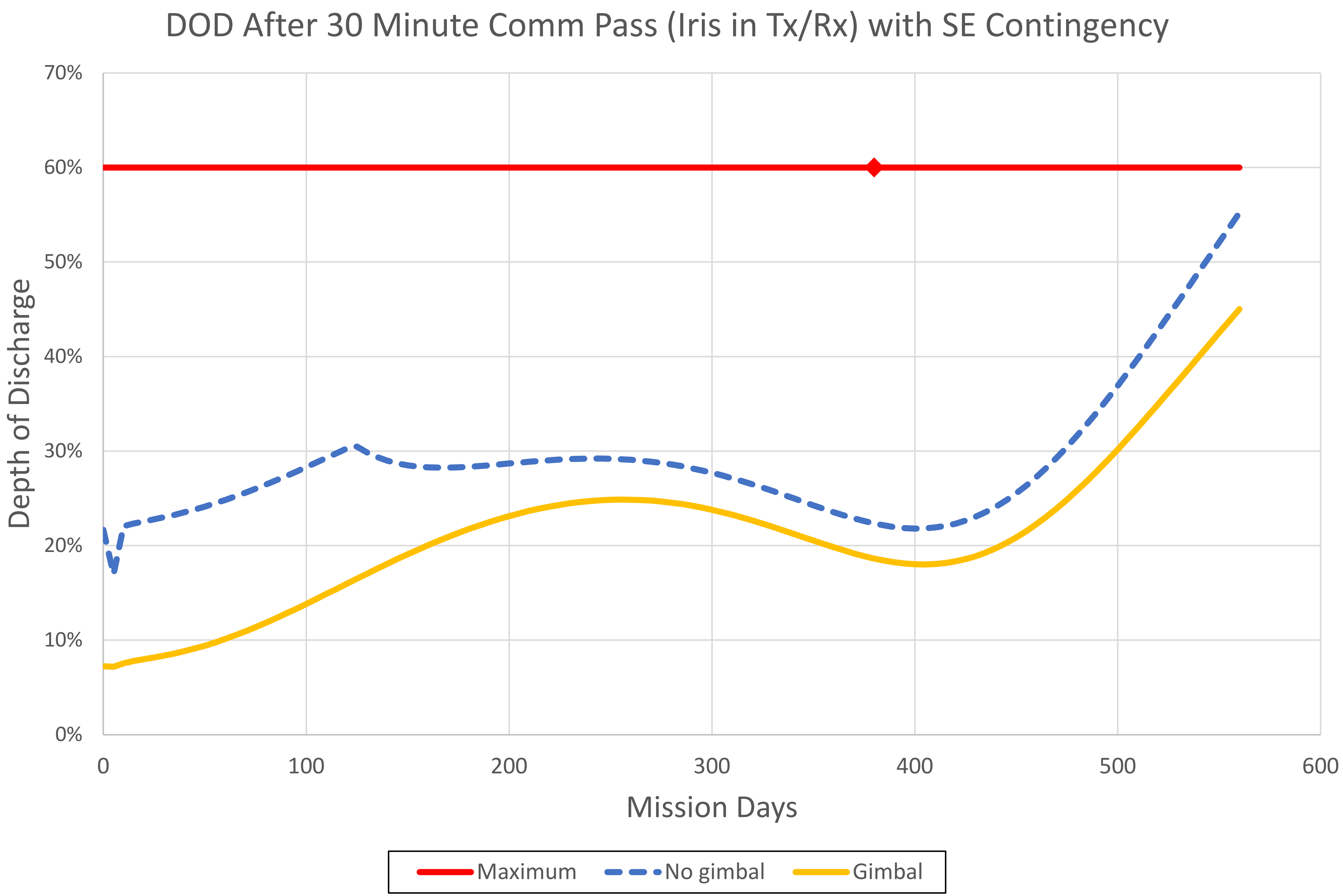




Power Budget



Battery Discharge



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

Support

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