BioSentinel

A 6U Nanosatellite for Deep Space Biological Science

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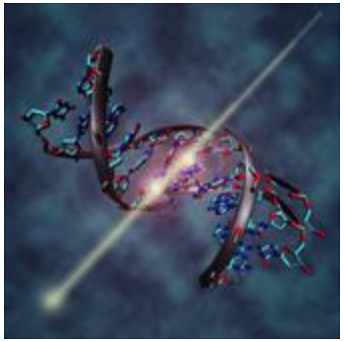
BioSentinel Project Objectives

- 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)

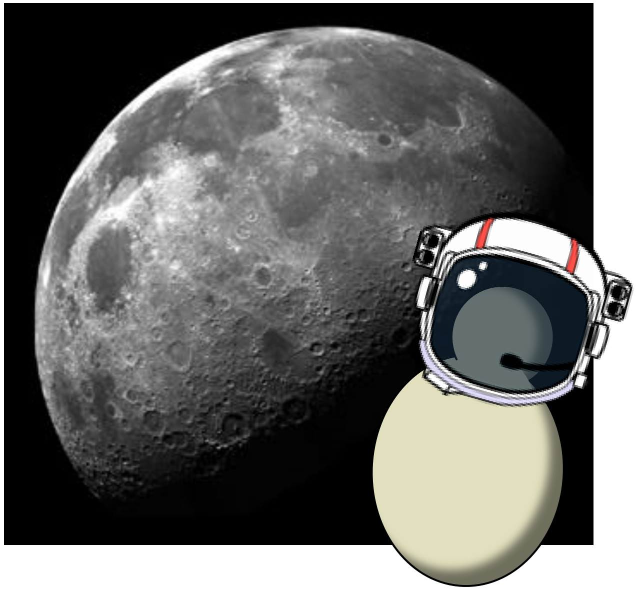
A BioSensor in Space

- **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.

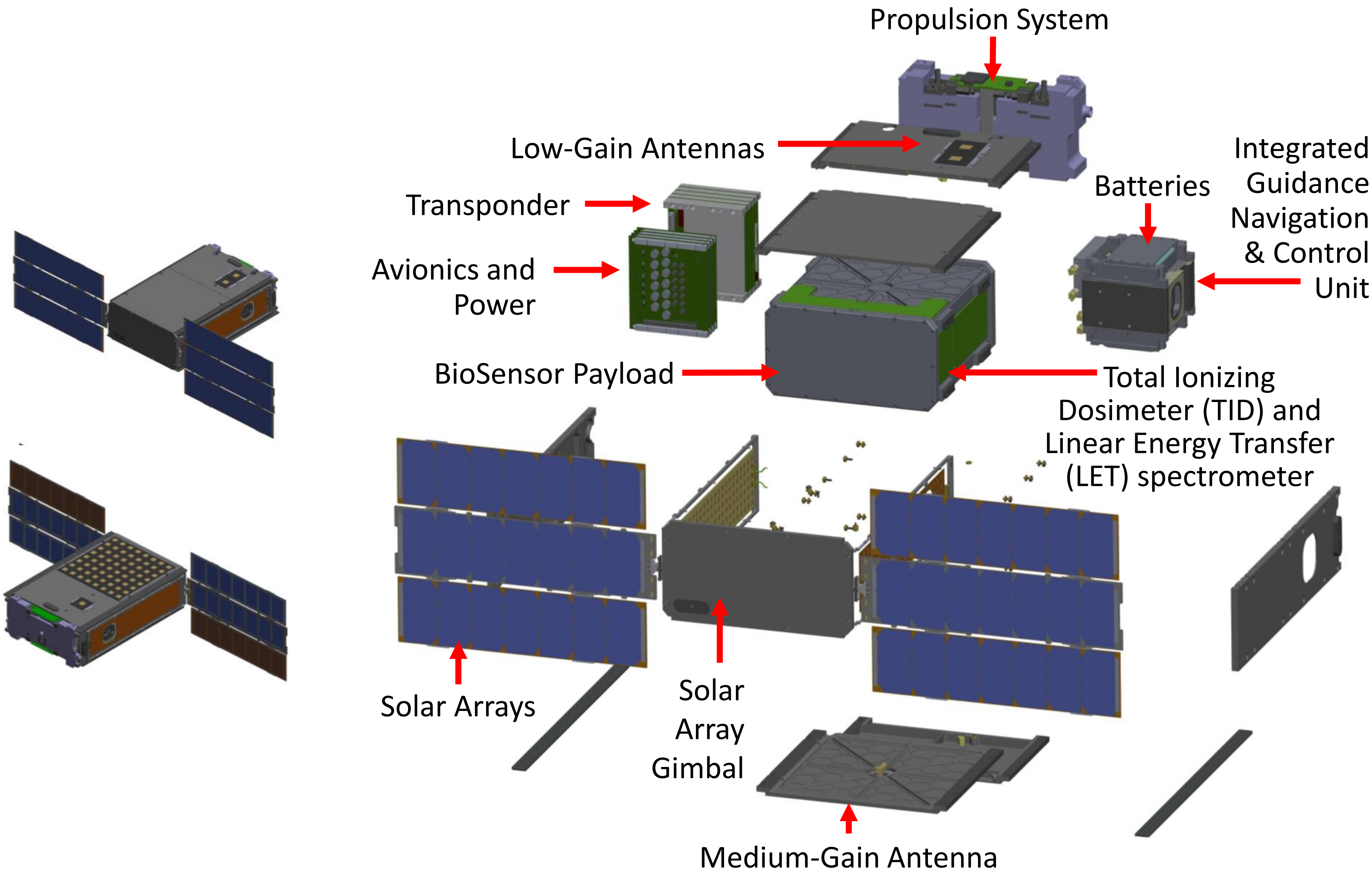
Why budding yeast?

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



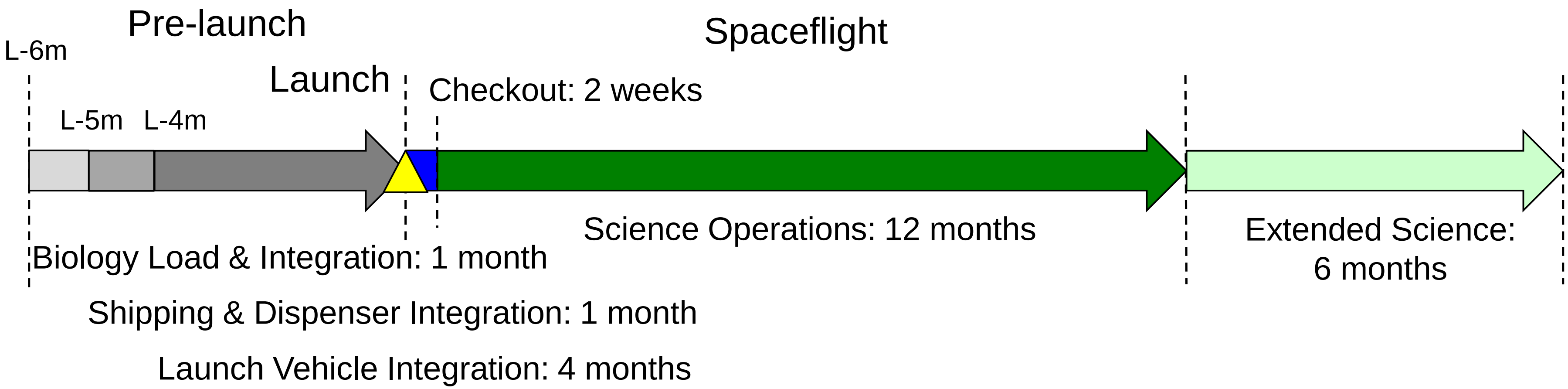
BioSentinel FreeFlyer Spacecraft: Physical Overview

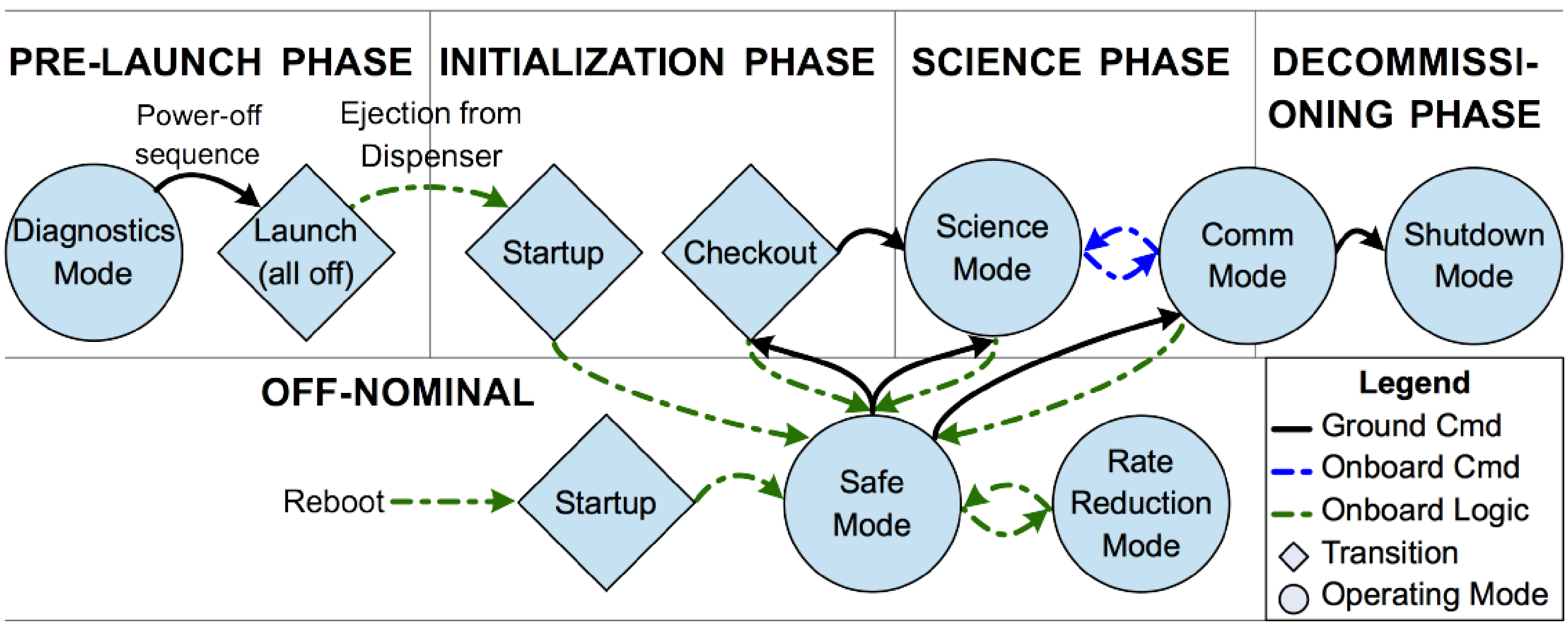


BioSentinel Mission Phases

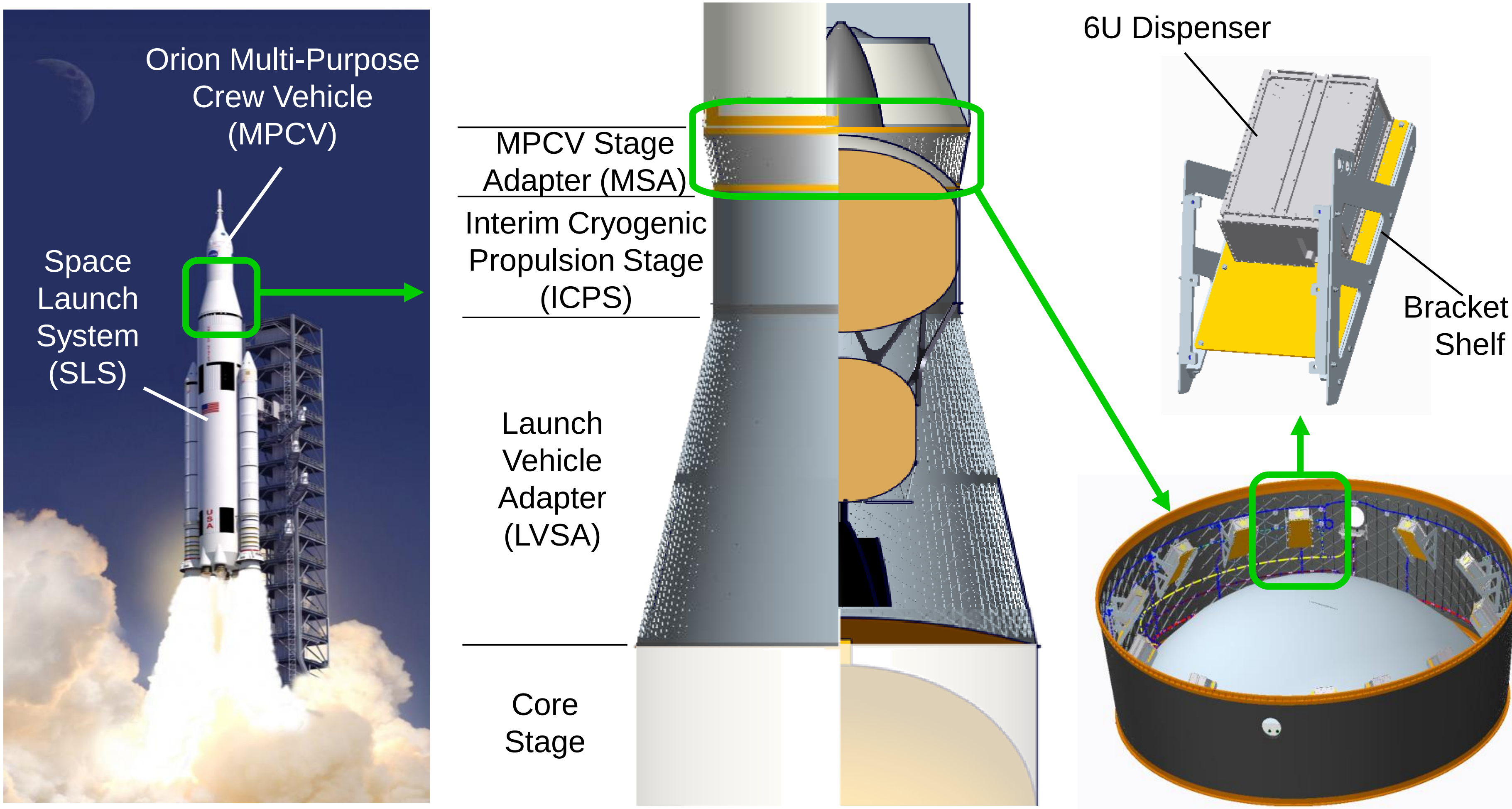
Phase	Entry	Exit	Duration	Summary & Objectives
Pre-Launch	Loading of biology	L/V Lift-off	~180 days	• Load Flight Biology • Charge, checkout, and configure FreeFlyer • Integrate FreeFlyer with Dispenser and SLS
Launch	L/V Lift-off	Deployment of FreeFlyer	<1 day	• FreeFlyer is powered off • Survive launch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





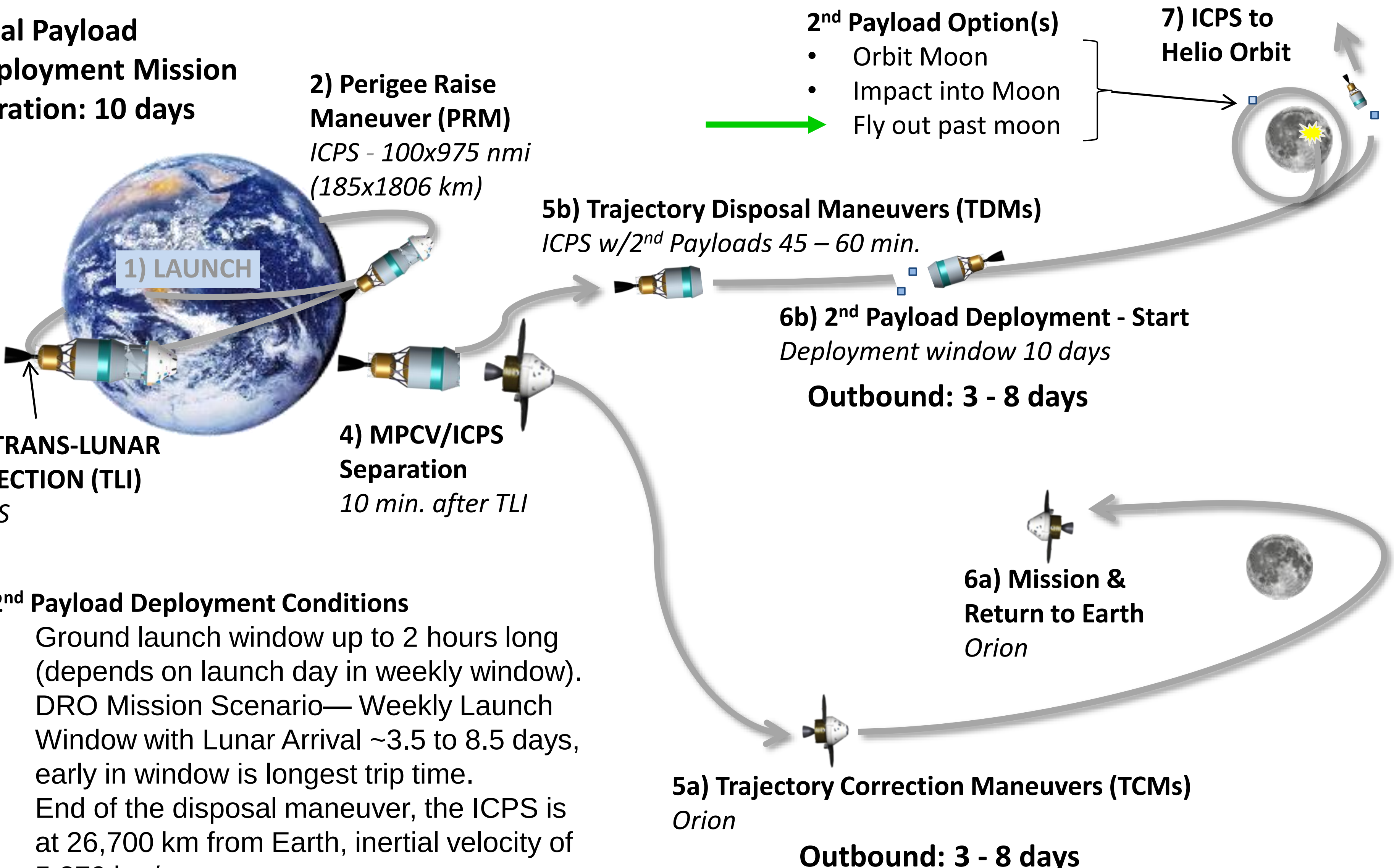
Secondary Payload Location on SLS EM-1



- 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

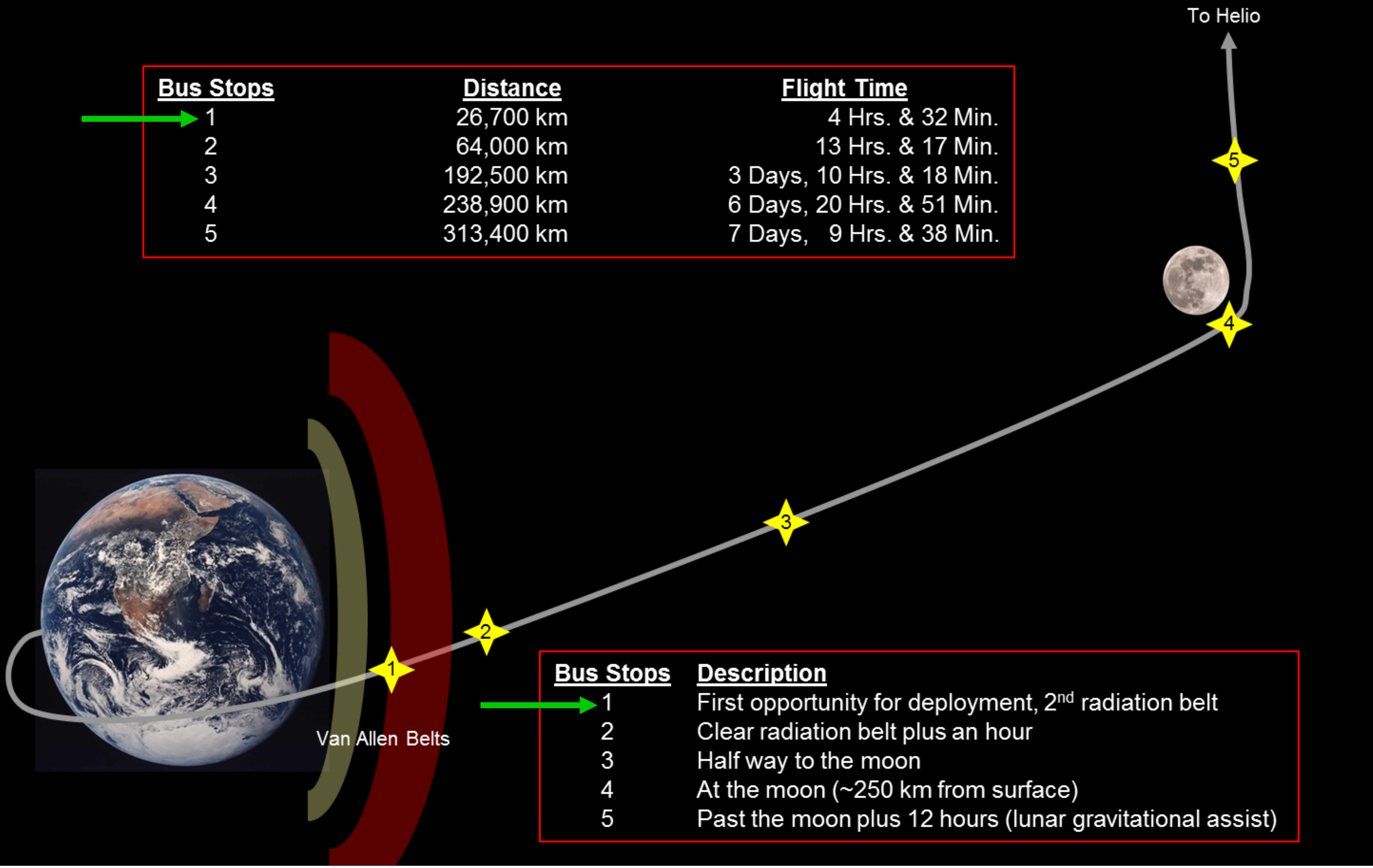
Total Payload Deployment Mission Duration: 10 days



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.

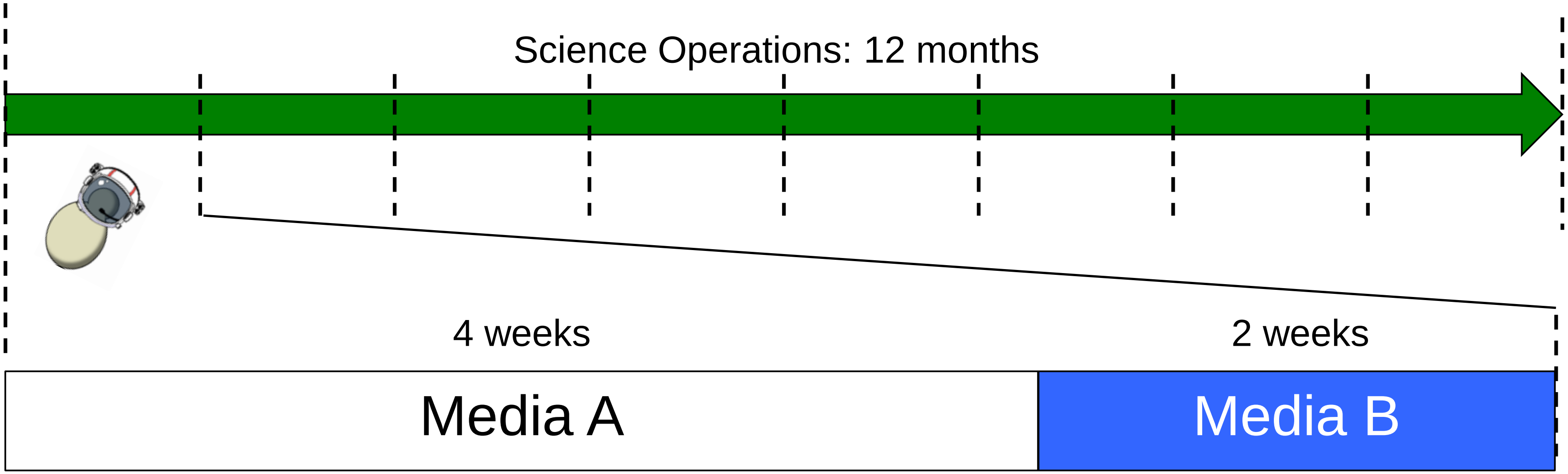
Deployment “Bus Stops”



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.

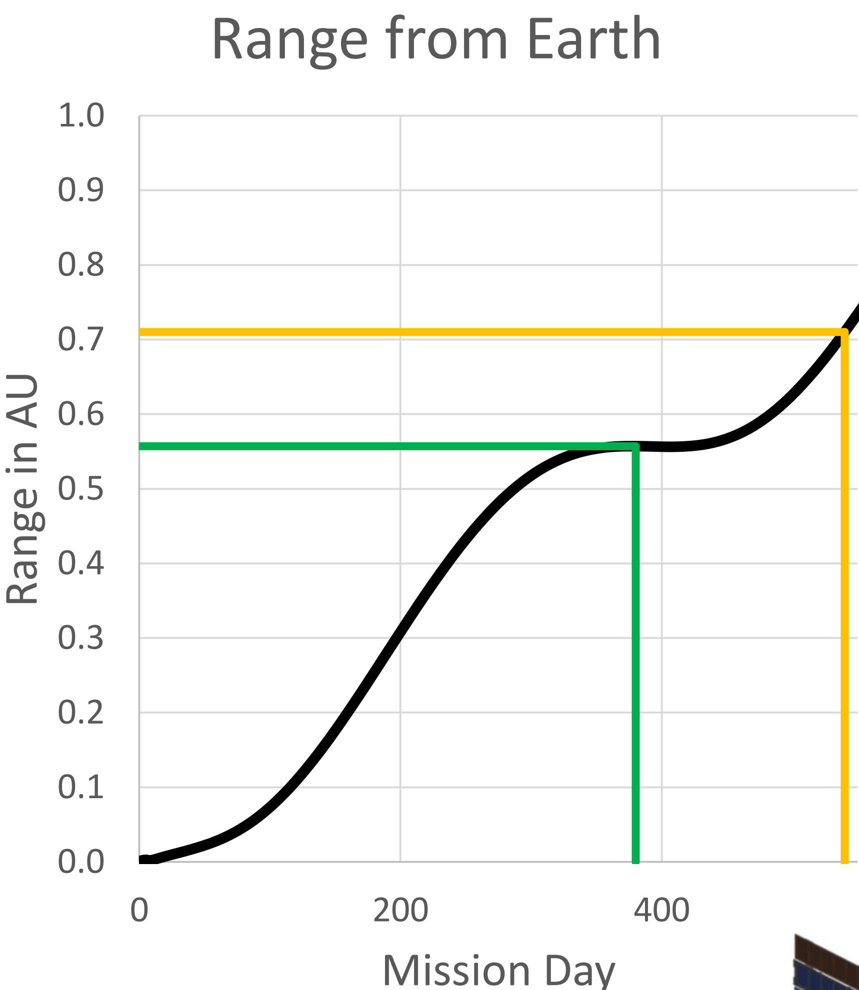
Bus Stops	Description
1	First opportunity for deployment, 2^{nd} radiation belt
2	Clear radiation belt plus an hour
3	Half way to the moon
4	At the moon (~250 km from surface)
5	Past the moon plus 12 hours (lunar gravitational assist)

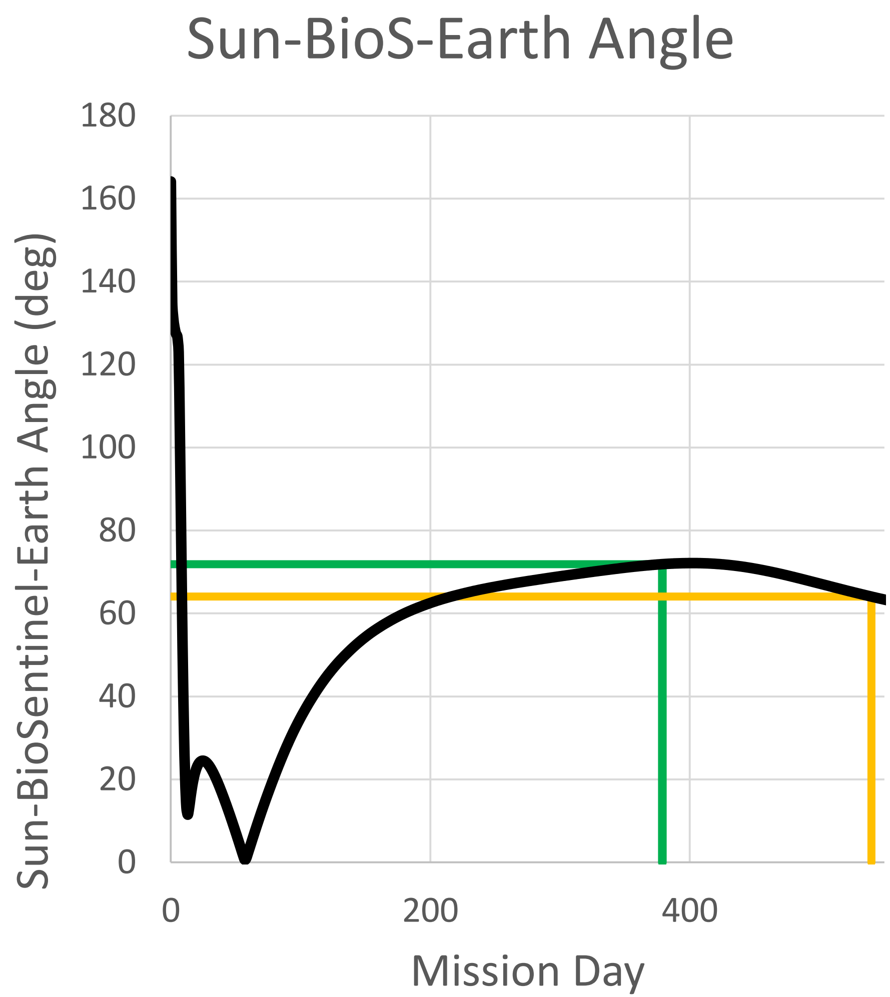
BioSentinel Science Operations

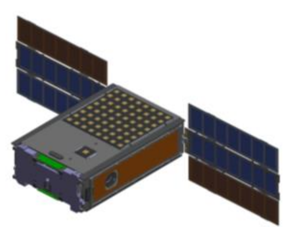


- Science Operations are periodic with 8 time points throughout the 12 months
- 2 cards are kept in reserve for Solar Particle Events (SPEs)
- Activation Time points: T0, T0+45 days, T0+90 days, T0+135 days, T0+180 days, T0+225 days, T0+270 days, T0+315 days
- Schedule is adjustable as part of Science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







Nominal Mission (380d, 0.56AU)

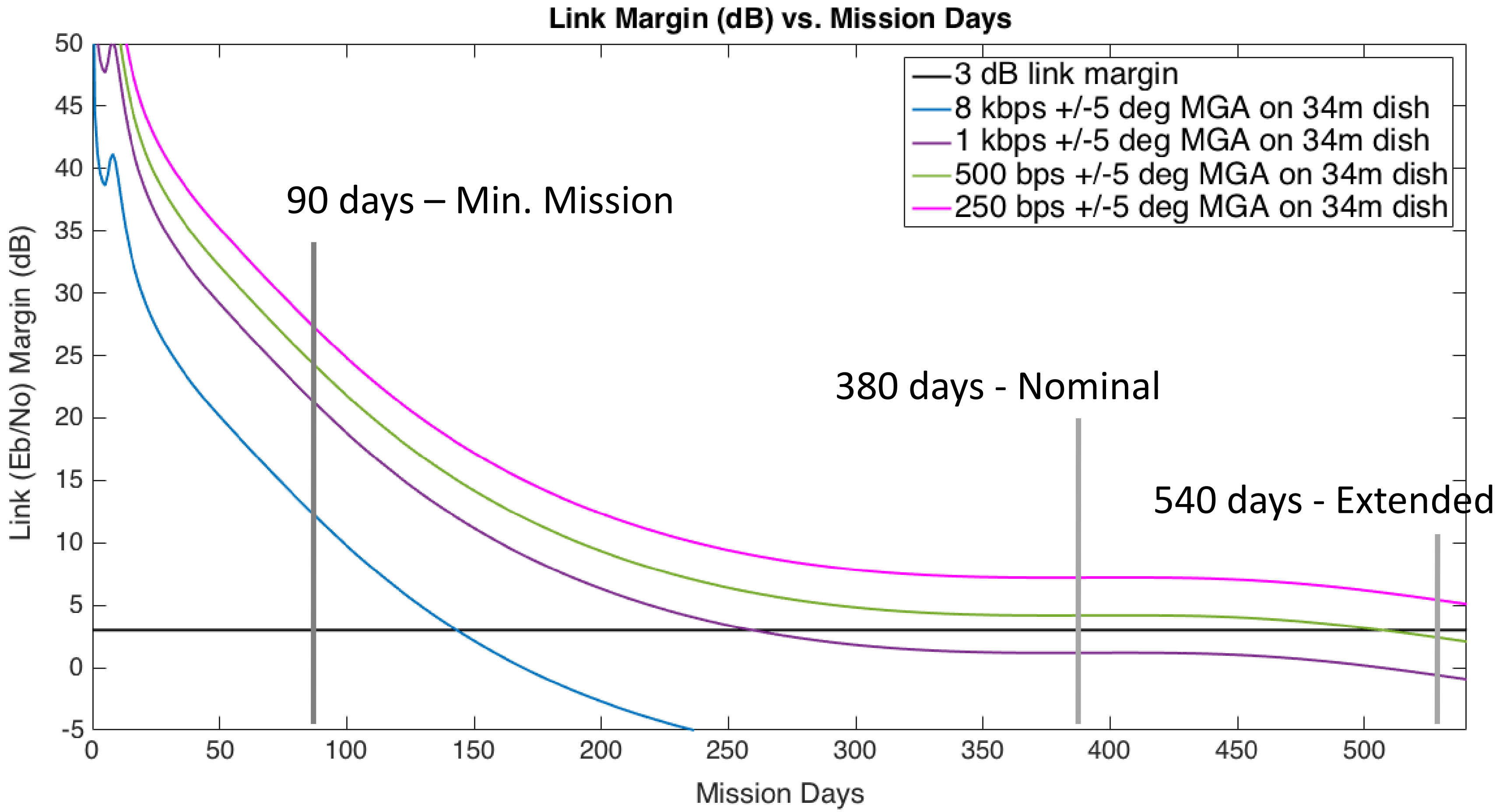
Extended Mission (540d, 0.71AU)

Nominal Mission (379d, 71.9deg)

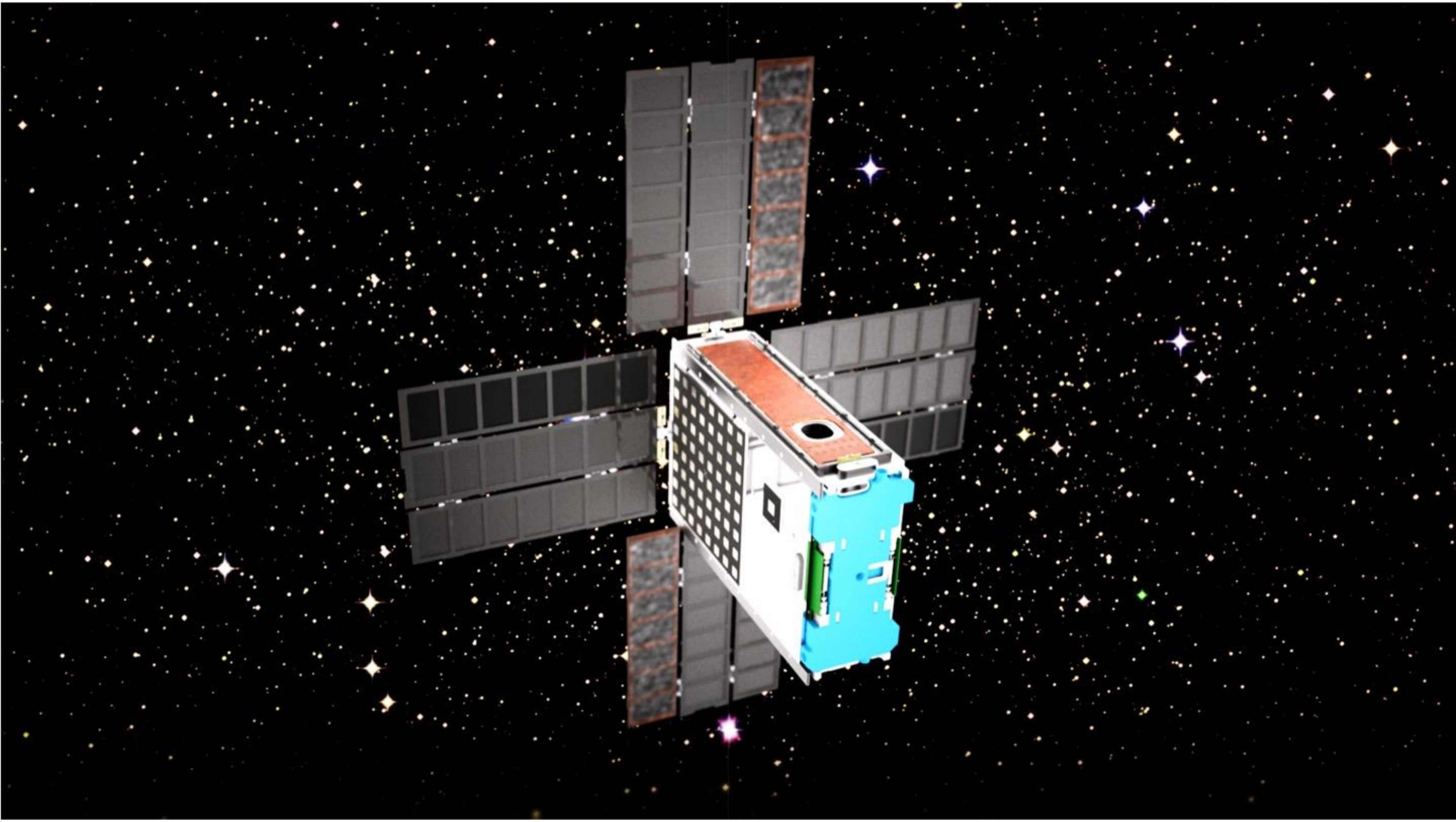
Extended Mission (540d, 64.1deg)

BioSentinel Communication Links

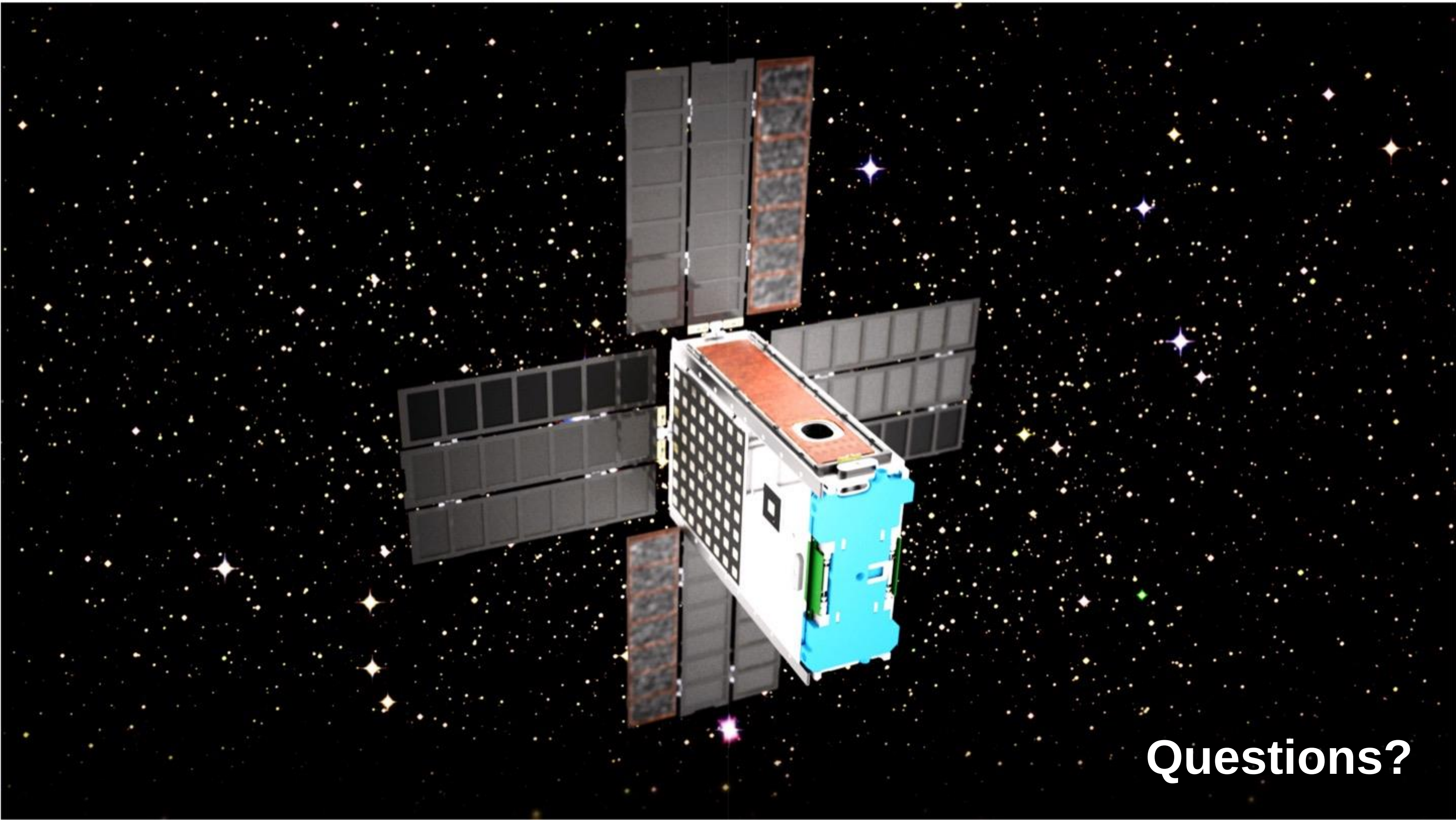
- Based on current trajectory and transponder design assumptions, the system supports:
  - 8 kpbs through the minimum mission duration (3 months)
  - 500 bps through the nominal mission duration (12 months)
  - 250 bps through the extended mission duration (18 months)



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)

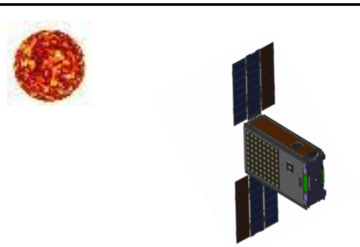
2 Collect science data (Continuous, RTS)

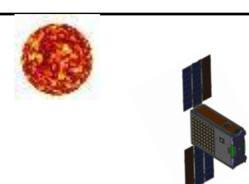
1 Wet cards with Media B (4 weeks after Media A, RTS)

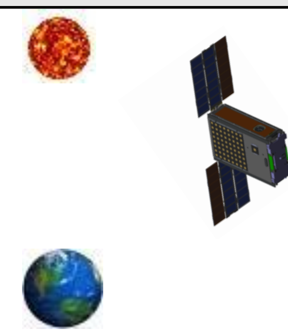
Major Functions	Sub-functions (1)
Select card	• Determine fluidic card • Select μ-controller • Select pump and valve set
Apply Fluids	• Open inlet valve • Open plate valve • Open nutrient valves • Activate Pump
Configure Thermal Control	• Apply cold set points to other cards • Warm set points for Media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



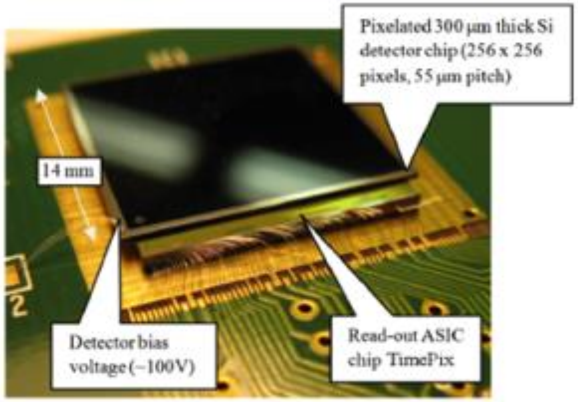




LET Spectrometer & TID Dosimeter Radiation Monitoring

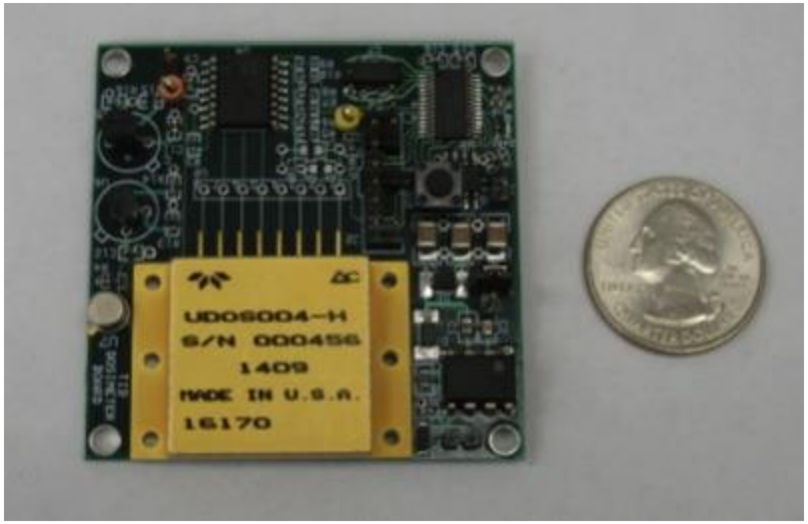
- Linear Energy Transfer (LET) Spectrometer Designed by JSC RadWorks specifically for the BioSentinel Project.

LET Spectrometer Engineering Development Unit (EDU)

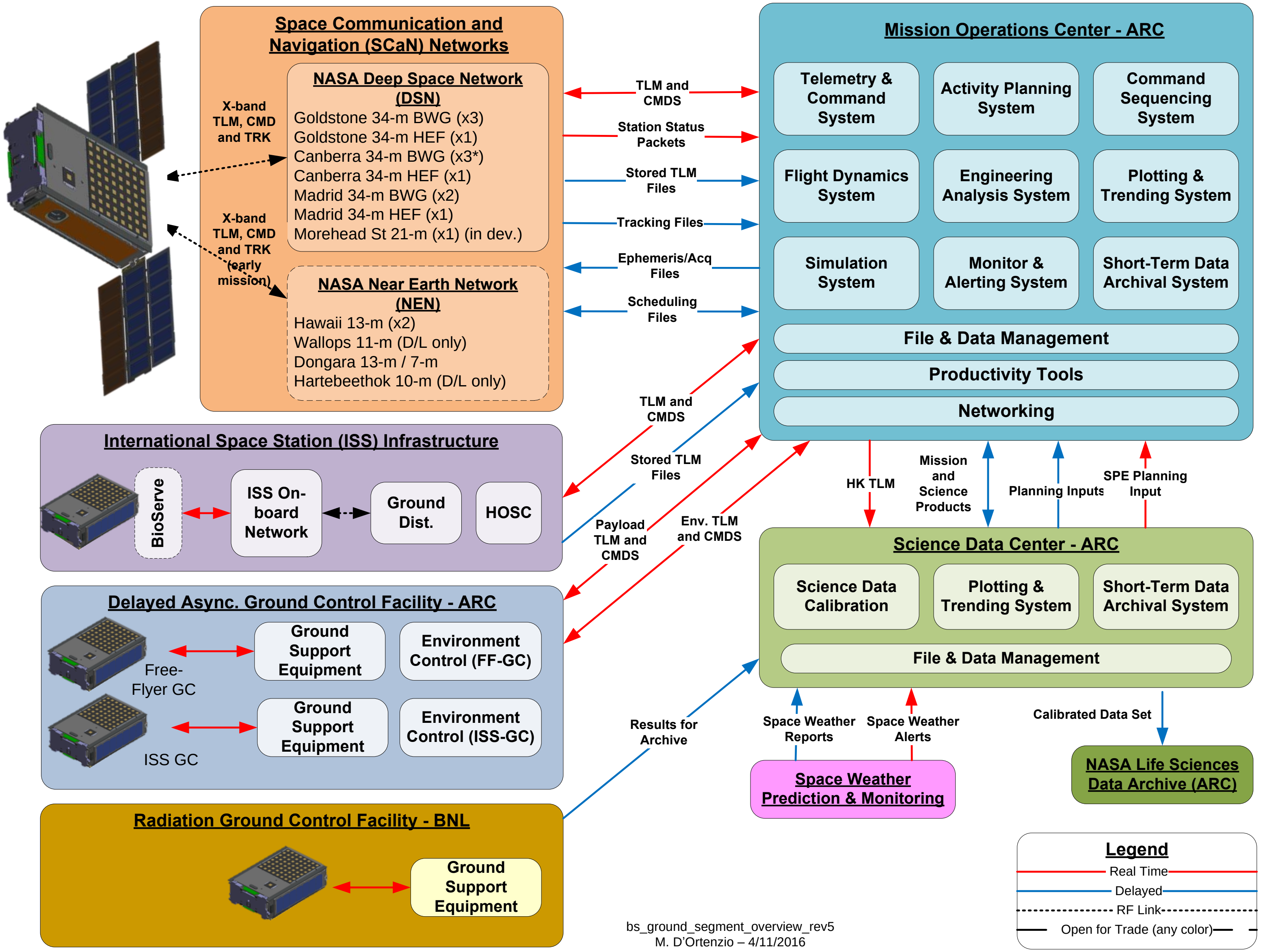


TimePIX Sensor

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



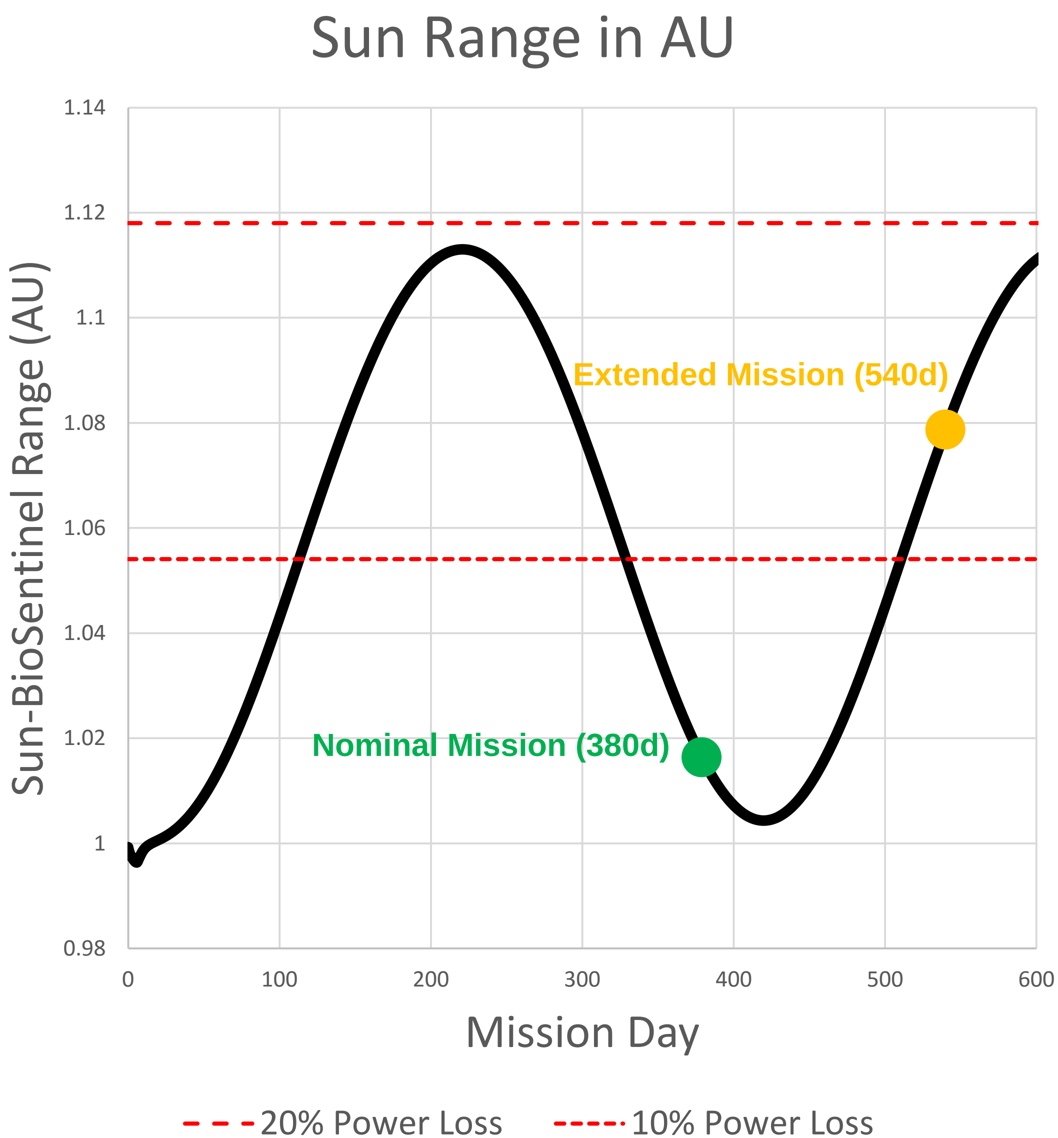
Ground System Architecture

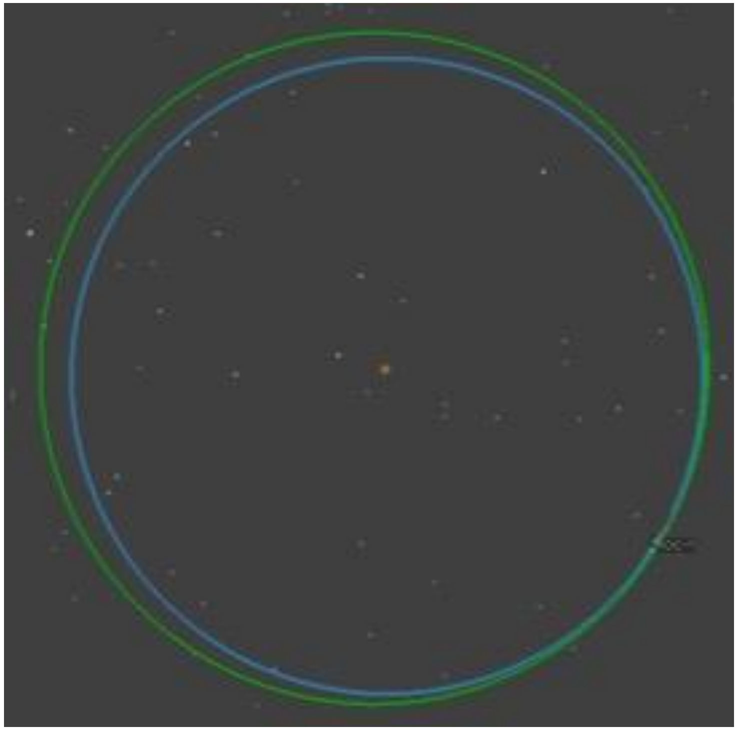


Preliminary Operational Staffing Profile

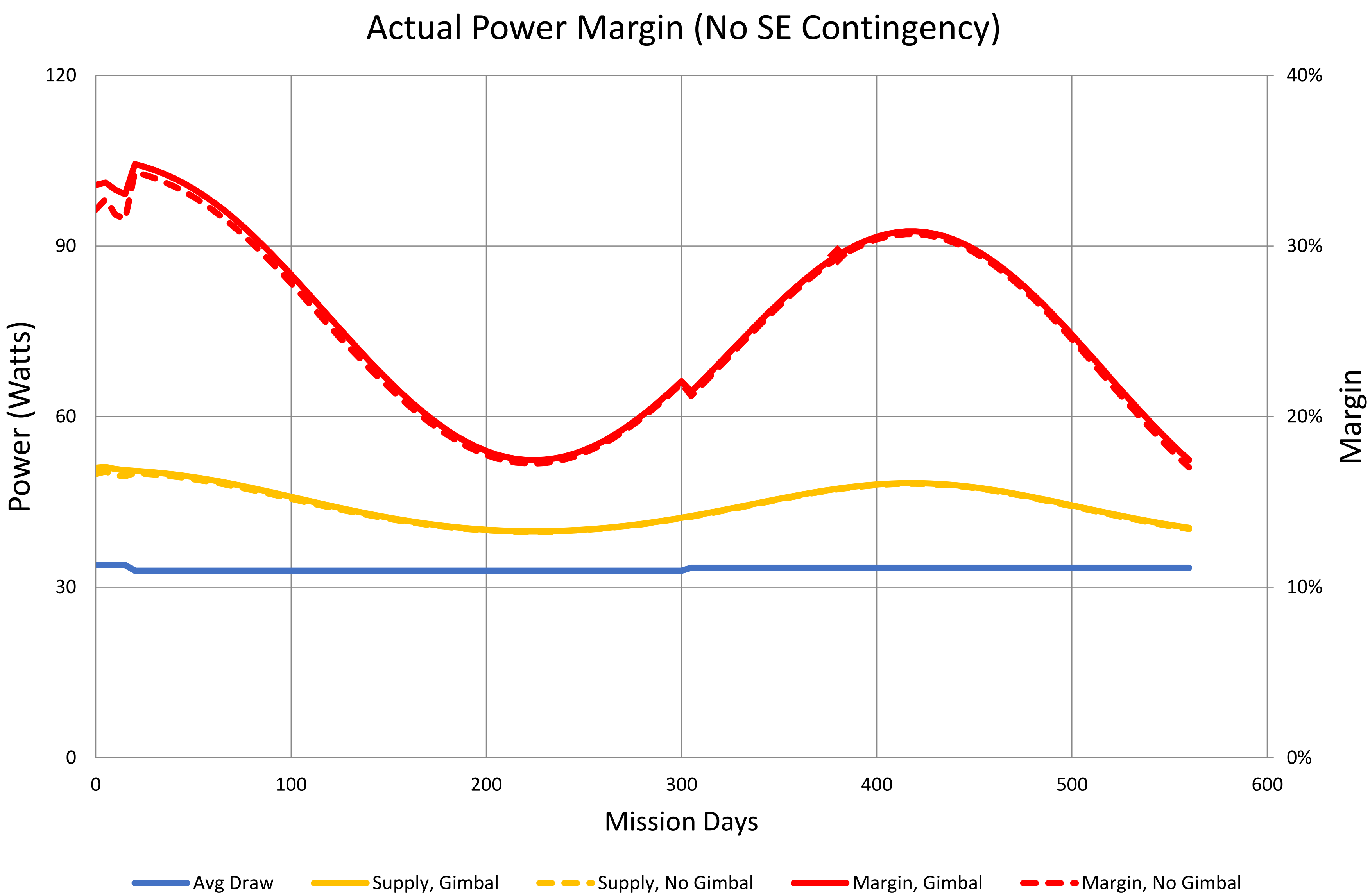
Mission Phase	Length	Mission Operations Staffing Profile	Assumptions/Comments
Pre-Launch	~ 30 day	- 4x5 support for monitoring of BioSentinel DSGC pre-launch profile	- DSGC must start while BioSentinel is at KSC
Launch & Ascent	~ 1 day	- Full team will staff the MOC	- BioSentinel is powered off. No real-time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

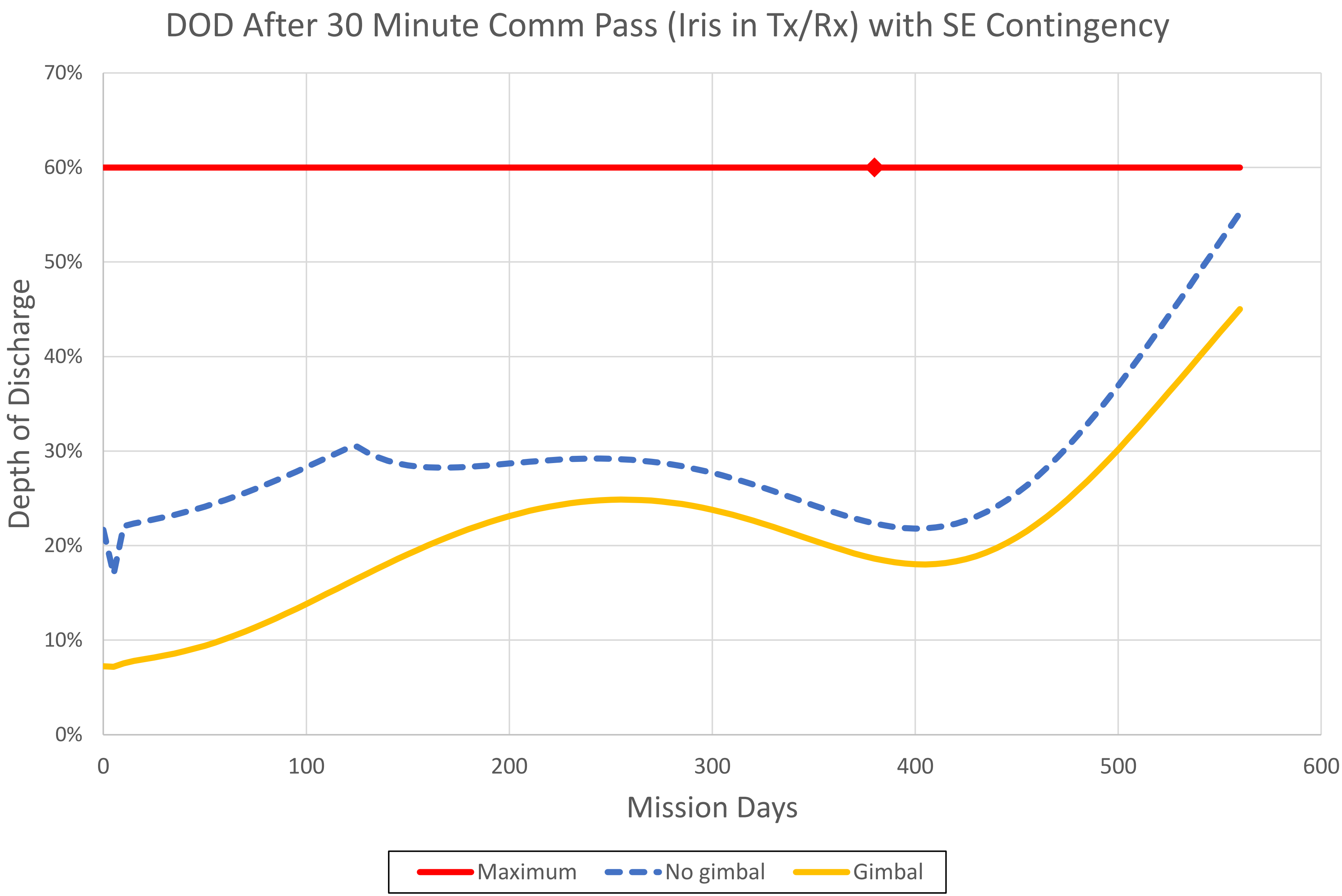




Power Budget



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

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