National Aeronautics and Space Administration

BioSentinel: DNA Damage-and-Repair Experiment Beyond Low Earth Orbit

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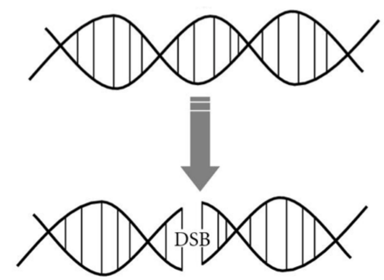
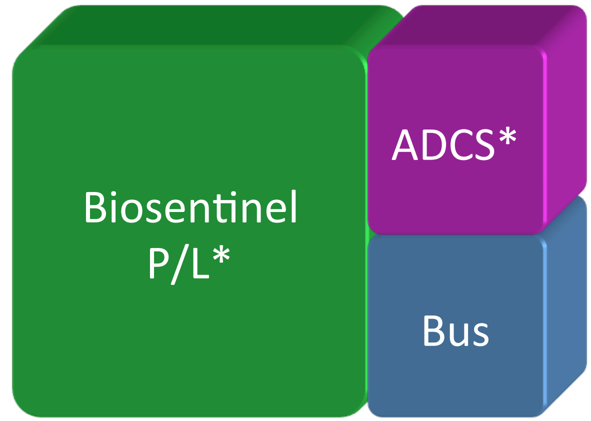
Mission Goals and Objectives

- Demonstrate simple model organisms as “biosentinels”
  - Biologically based sensors for hazards to humans
    - Particularly for radiation, beyond low Earth orbit (LEO)
    - Compare/correlate to physical radiation measurements
  - DNA damage: 1st space demo. of biosentinel concept
  - Validate radiation damage models for biology
  - Develop “transfer standards” from biosentinels to humans
  - Support development of radiation protection
  - Inform mitigation strategies, actions



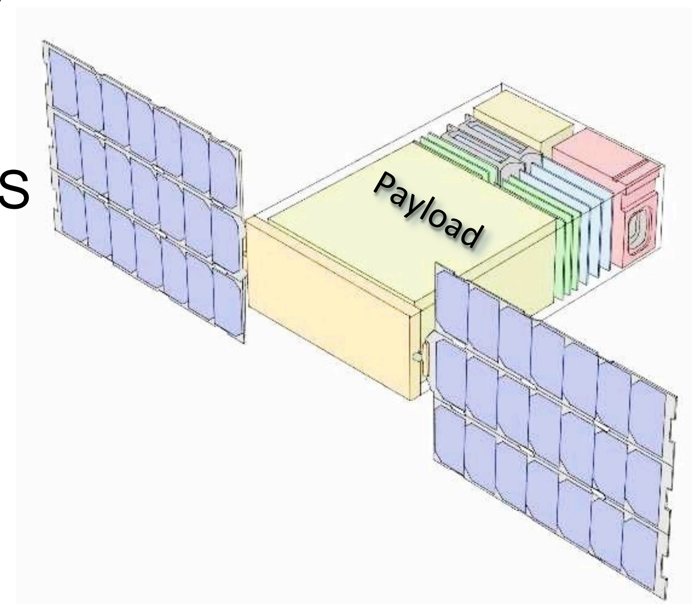
- Conduct life science studies in multiple space environments relevant to human exploration
  - Deconvolute effects on biological systems

Implementation



- 6U autonomous nanosatellite
  - 4U payload, including radiation sensors
  - ≥ 2U for bus + ADCS including μ-propulsion
  - ~ 14 kg total mass
  - ~ 23 W average power (deployable solar panels)
  - Mission duration: 18 months

- Identical BioSentinel payload developed for ISS
  - similar μ-gravity but LEO radiation environment
- Identical P/L for delayed-sync. ground control
  - 1 x***g***; low radiation
- Radiation exposure ground studies (e.g. BNL)
  - 1 x***g***; acute, defined radiation doses



BioSentinel spacecraft design concept

**ADCS = attitude determination-and-control system; P/L = payload*

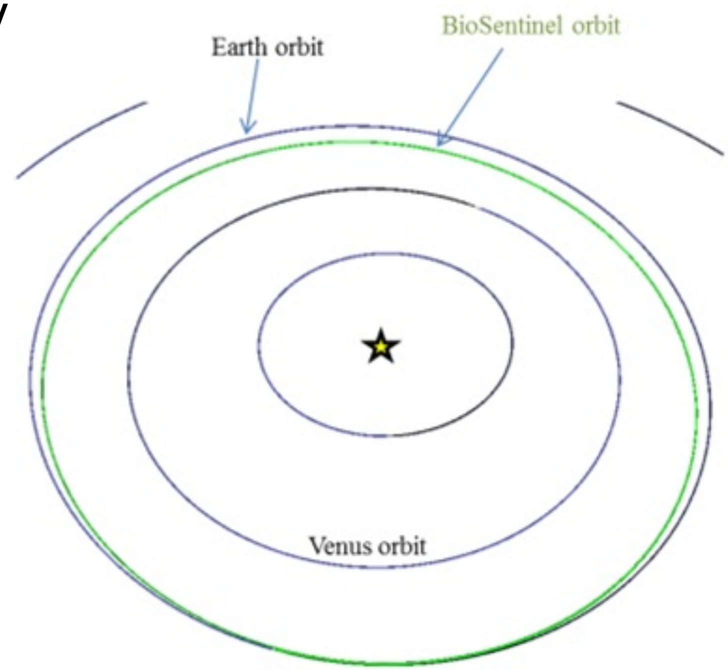
Launch

Artist's rendering of the Space Launch System

- Launched as a secondary payload on **EM**-1
  - ***E****xploration* ***M****ission 1: 1st flight of NASA's Space Launch System*
- Exact deployment orbit of 2° payloads still being determined
- Will likely be Earth-trailing, heliocentric orbit
- Far outside the LEOs typically occupied by CubeSats

… and far outside the protective shield of Earth's magnetosphere

Orbit

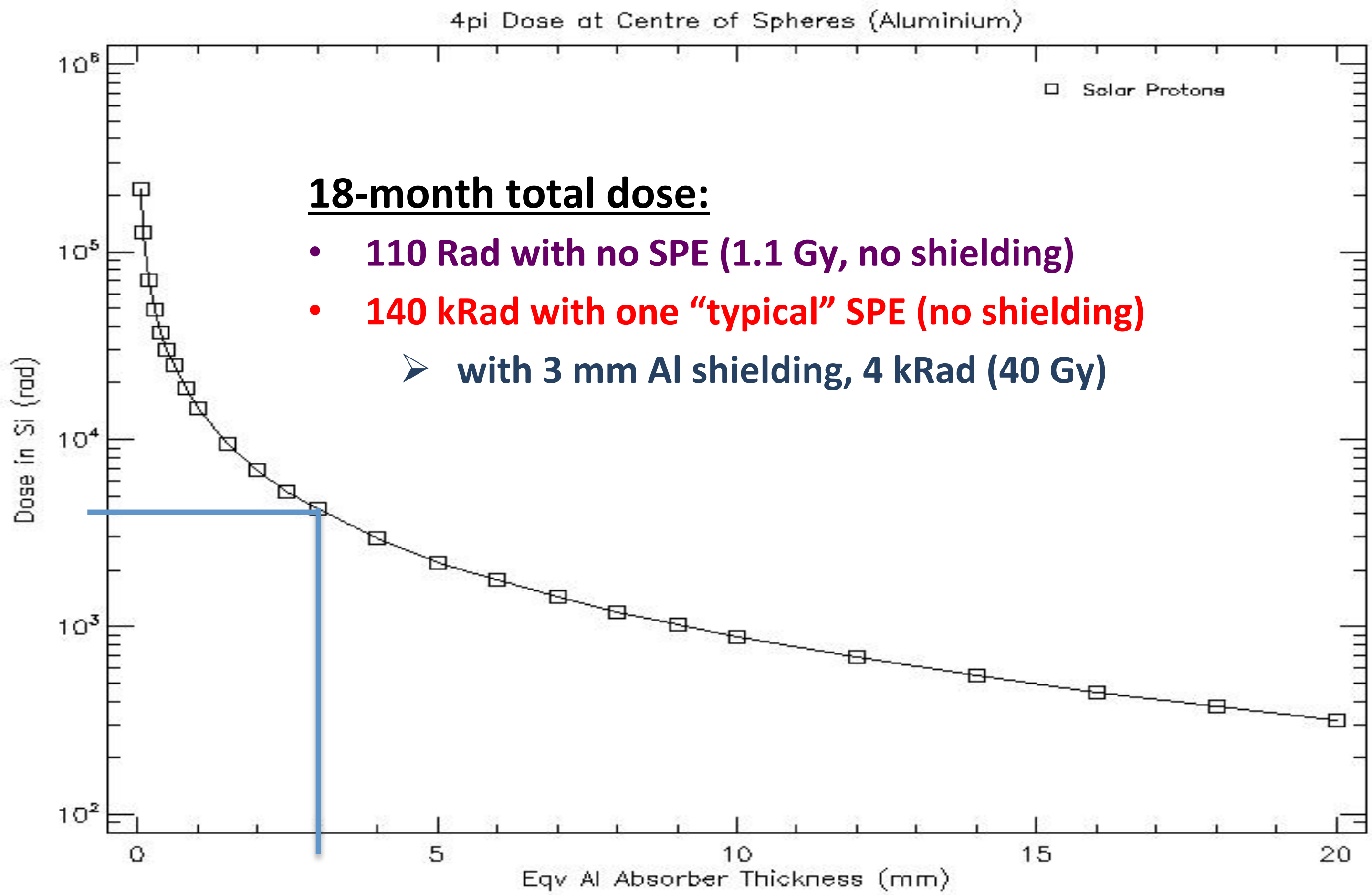


A representative orbit that BioSentinel might occupy

Radiation Environment

Total Ionizing Dose (Si) for 12-month Ambient Flux + single Solar Particle Event

Model:
SHIELDOS
E-2Q



18-month total dose:

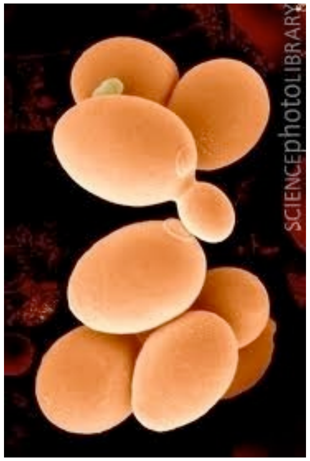
- 110 Rad with no SPE (1.1 Gy, no shielding)
- 140 kRad with one "typical" SPE (no shielding)
  - with 3 mm Al shielding, 4 kRad (40 Gy)

BioSentinel Payload: Science Measurement Concept

- What: Yeast radiation biosensor measures DNA damage caused by space radiation: specifically*, double strand breaks (DSBs)*

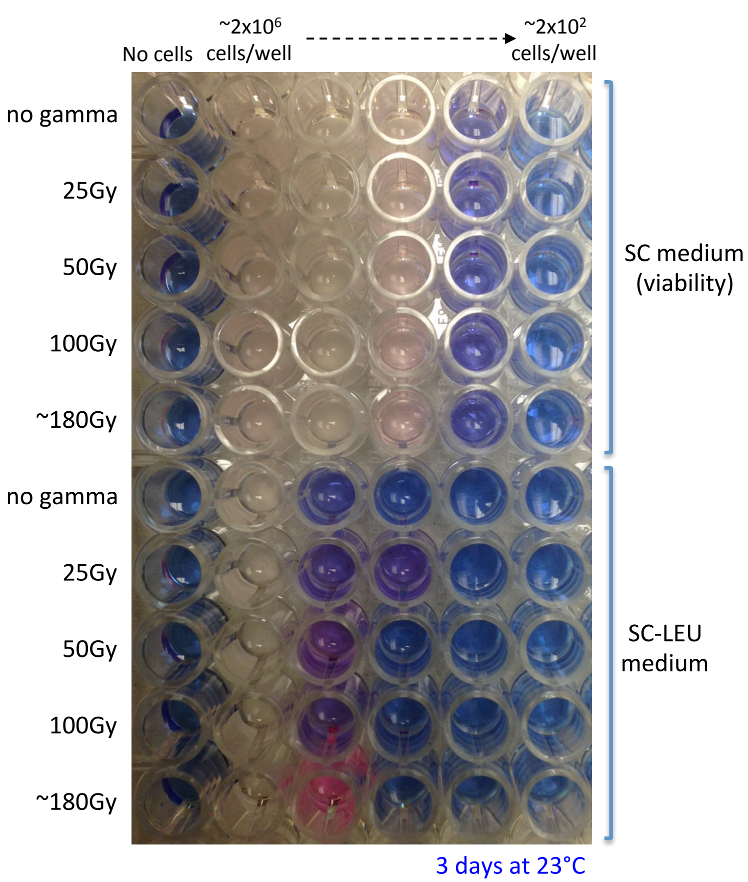
- Why: Space radiation's unique spectrum cannot be reproduced on Earth
  - Various high-energy particles/energy spectra; omnidirectional; continuous; low flux
  - Health risk for humans over long durations beyond LEO
  - Why yeast: repair mechanisms in common with human cells; well studied in space

- How: Before launch, engineered *S. cerevisiae* cells (brewer's yeast) are dried & placed in arrays of microwells
  - In space, a group of wells is rehydrated every few weeks
  - Cells remain dormant until growth is activated by a DSB + gene repair
    - *One repaired DSB can trigger exponential growth in 1 well*
    - *Growth & metabolic activity are monitored optically in all wells*
  - Multiple microwells are always in "active sentinel mode"
  - Extra wells are activated in the event of an SPE

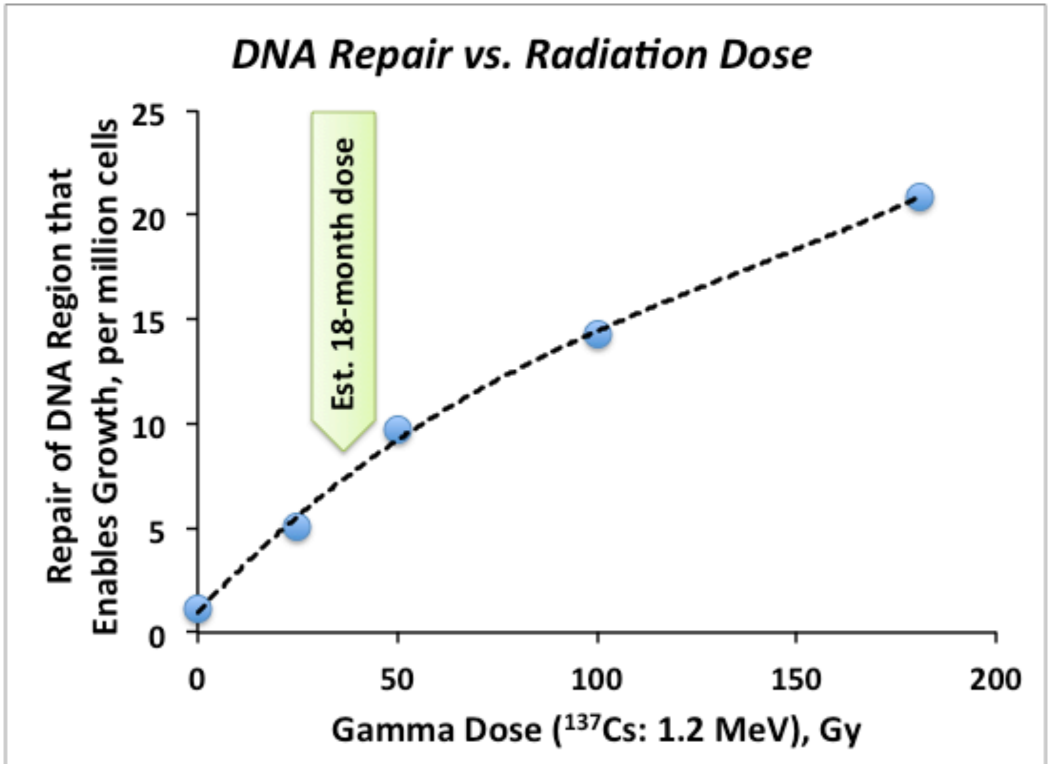


BioSentinel Science: Proof-of-Concept Lab Data

Yeast recombination assay and its response to gamma irradiation



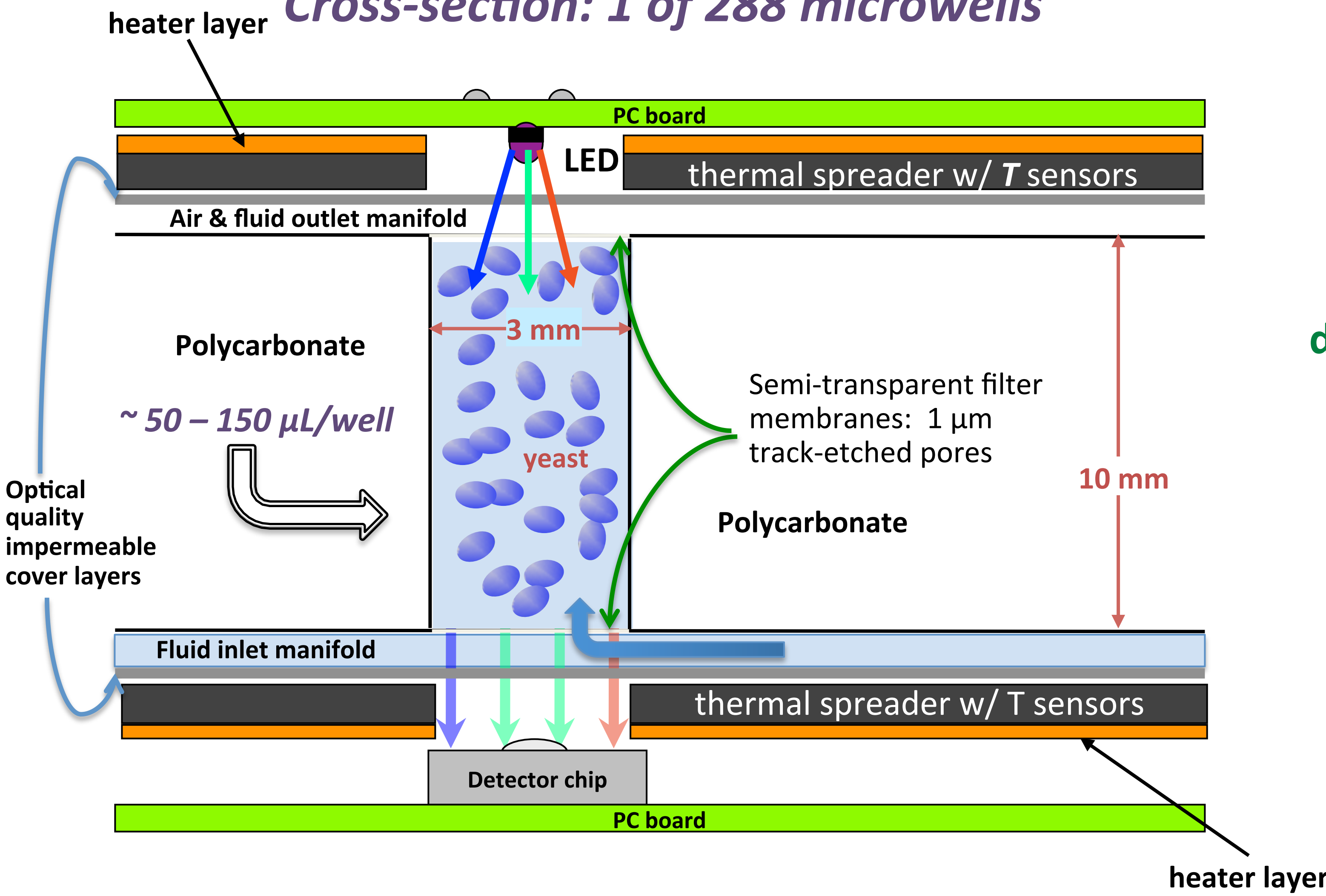
alamarBlue turns pink when cells are metabolically active



Spontaneous recombination rate: ~ 1 event in a million

Payload: Biology/Fluidic/Optical/Thermal Configuration

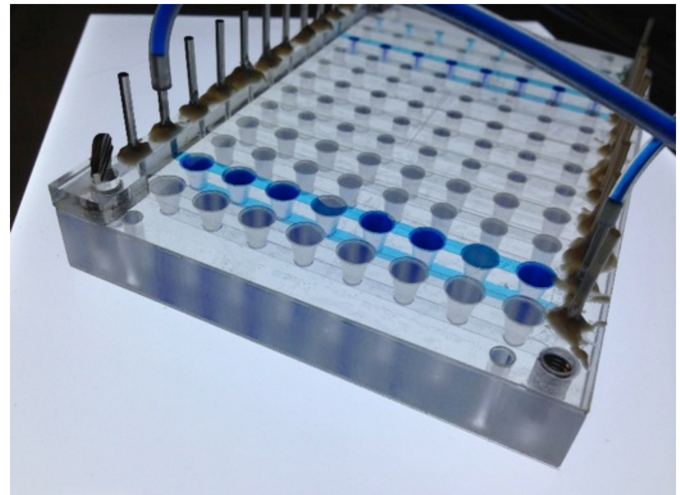
Cross-section: 1 of 288 microwells



3-color LEDs for optical density (OD) and cell metabolic activity: track population during growth, metabolism *via* dye

Detector for OD *and* viability measurement using 3-color absorbance

Payload: Biological Support & Measurement Systems



Requirements

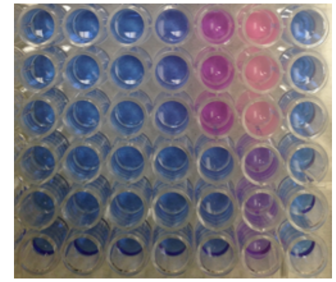
- ➢ support biology in stasis and growth
- ➢ enable & perform measurement

- **Configuration:** 4U containment vessel
  - ➢ 1 atm internal pressure, low RH

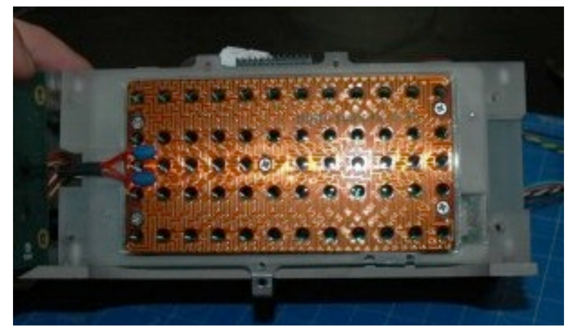
- **3 ea. 96-well fluidics cards**
  - 12 “banks” of 8 wells per card (36 banks total)
    - 2 banks activated per month; 2 – 4 banks on “SPE standby”
  - Organisms fly in dry state in wells, rehydrate to activate
  - Low-permeability “semi-hermetic” fluidic cards & bags

- **Pumps, Valves, Tubing, Media**
  - external to cards; tubes and bags ~hermetic (to keep dried yeast dry)
  - redundancy / isolation as container volume permits

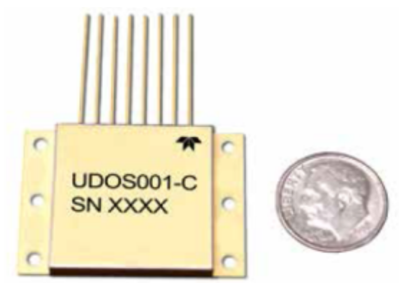
Payload: Sensors & Measurement System



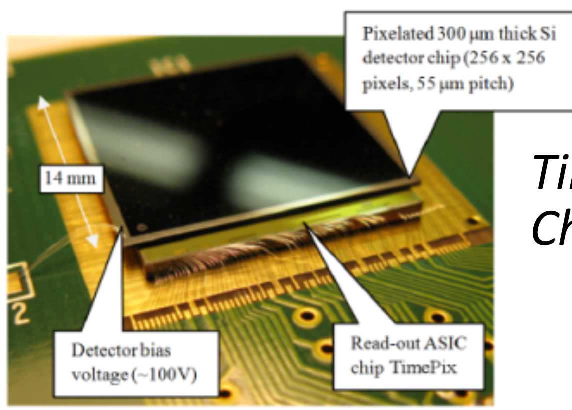
- **Optical absorbance measurement per well**
  - Dedicated 3-color optical system at each well
  - Measure dye absorbance & optical density (cell population)



- **Dedicated thermal control system per card**
  - 0.5 – 1 °C uniformity, accuracy, stability
  - multiple temp. sensors per card & throughout container
- **Pressure & humidity sensors** in payload volume
- **Radiation sensors**
  - 1 – 2 LET "spectrometer" chips & 2 integrating dosimeters
  - Frequent measurement & caching of results; selective downlink

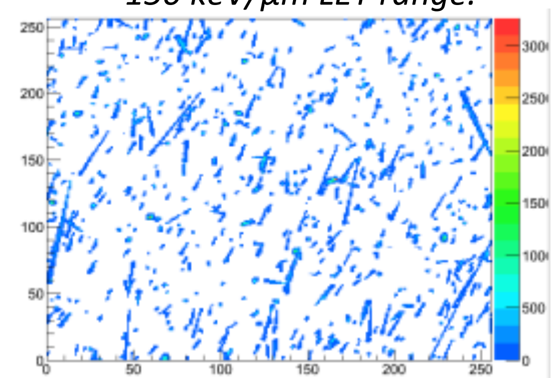


Teledyne dosimeter

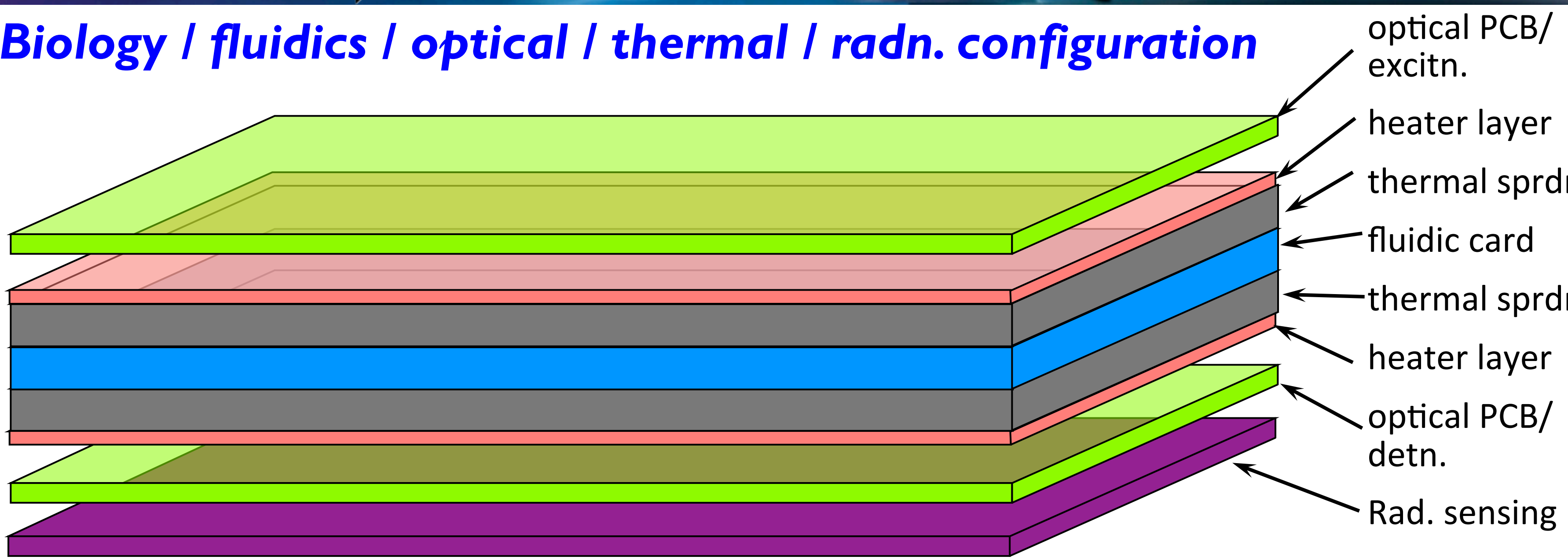


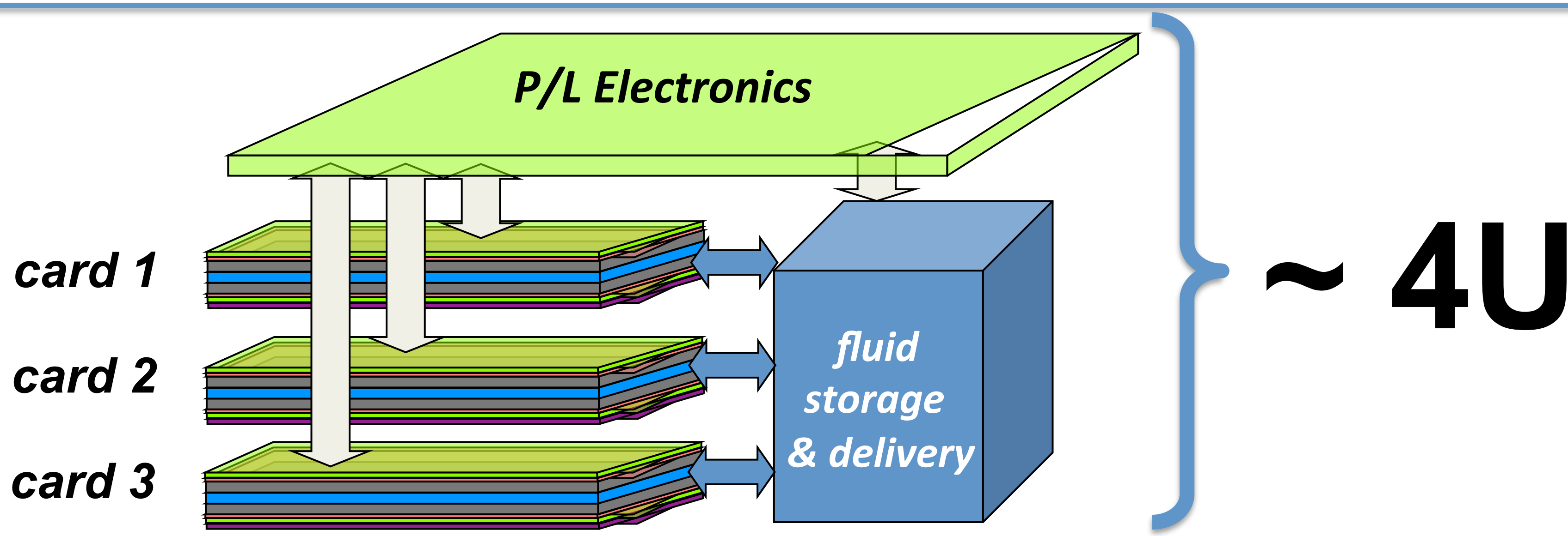
TimePix Chip

Typical TimePix frame: 256x256x14 bits; 0.25 – 150 keV/µm LET range.



Biology / fluidics / optical / thermal / radn. configuration





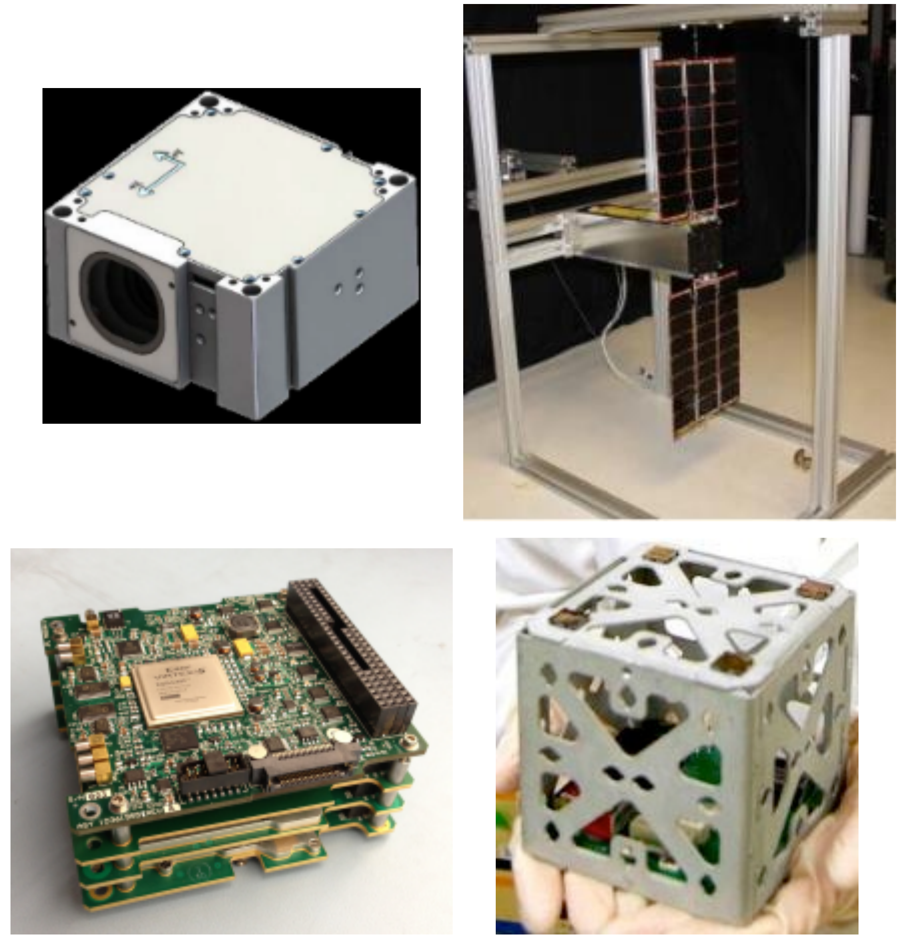
Environmental Considerations & Challenges

- Higher exposure to radiation than previous CubeSats* operating in LEO
  - Approximately 4 kRad total ionizing dose anticipated
  - Non-destructive single events (such as SEUs) motivate > 20 MeV-cm^2 tolerance, destructive single events (SELs, SEBs) require > 37 MeV-cm^2 tolerance
- Distance from Earth eliminates use of GPS for position determination, magnetometers for attitude determination, torquer coils/rods for attitude control
- Solar radiation pressure will be largest disturbance torque

**O/OREOS rec'd. similar 18-month dose but it was trapped electrons & protons; mission duration was 6 months nominal*

Subsystem Challenges & Considerations

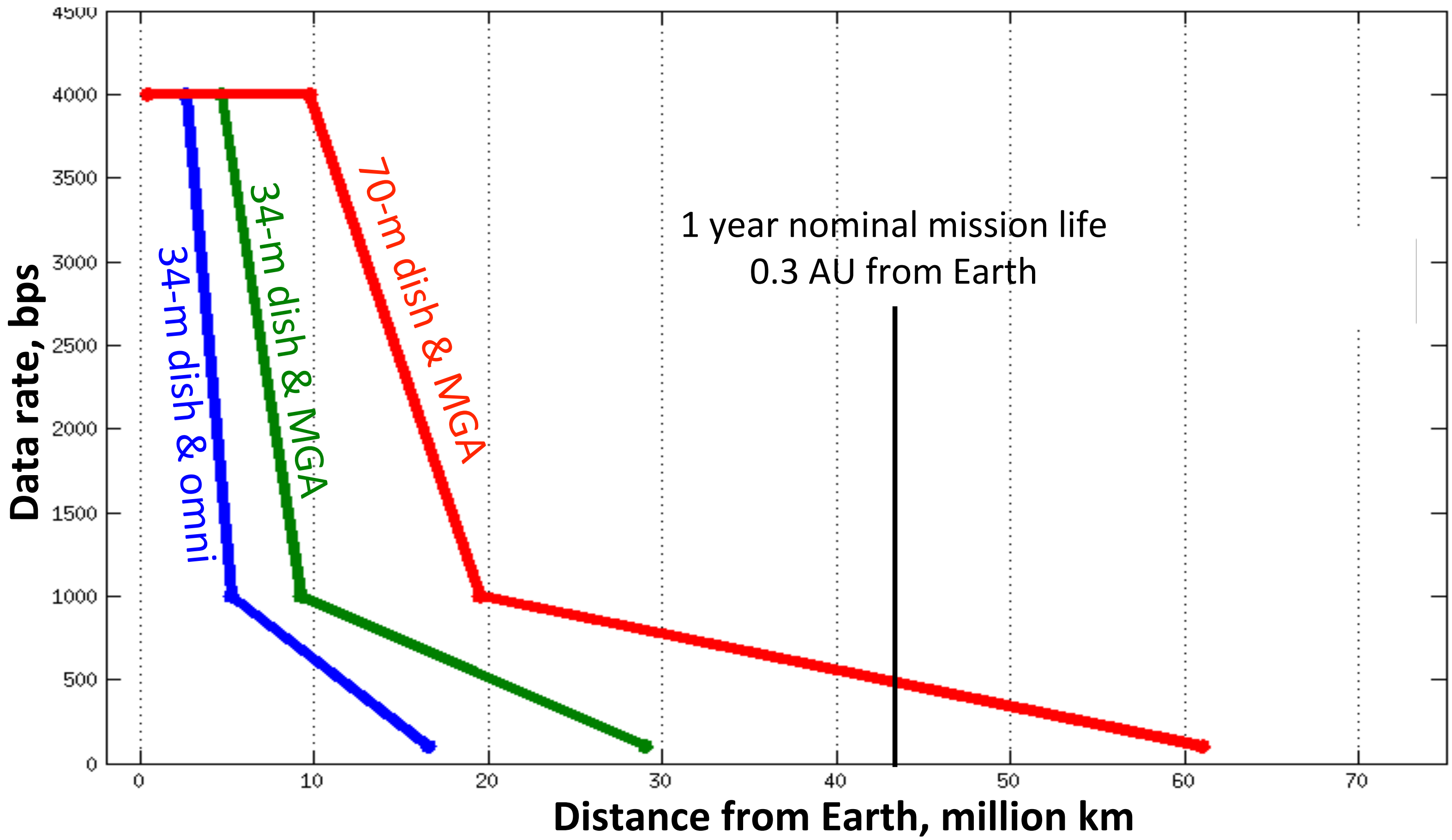
- Deployable solar panels required for sufficient power (> 30 W rating)
- Traditional CubeSat S-band/UHF radios insufficient at mission operating orbit (~ 0.3 – 0.7 AU)
  - X band preferred (up and down) for deep-space missions
- Propulsion required for both detumble and momentum management
- High-capability command & data handling system required relative to previous cubesats
- Radiation tolerance critical: component choice, recovery strategies, selective shielding



Candidate components under consideration for the BioSentinel mission

Estimated Data Rates

Data rate as a function of distance from Earth for X-band communications



BioSentinel (Potential) Firsts and (Real) Challenges

- 1st NASA biology studies beyond LEO in 4 decades
  - Enabling comparison across multiple radiation & gravitation environments
  - ➢ *Maximal science return from 18-month mission duration…*
  - ➢ *… which requires stasis of live organisms for up to 24 months*
  - ➢ Payload includes autonomous measurement response to SPEs
  - ➢ Payload includes physical radiation spectroscopy (LET) and dosimetry

- 1st 6U CubeSat to fly beyond LEO
  - ➢ *Challenges for communications, attitude control, radiation effects for up to 18 months*

- 1st CubeSat to combine both active attitude control and propulsion subsystems

- 1st CubeSat to integrate a third-party deployable solar array

The Team

- Management
  - Bob Hanel, Elwood Agasid, Debra Reiss-Bubenheim, Colleen Smith
- Science
  - Sharmila Bhattacharya, Macarena Parra, Tore Straume, Sergio Santa Maria, Diana Marina, Bob Bowman, Mark Ott, Sarah Castro, Greg Nelson, Troy Harkness
- Payload
  - Tony Ricco, Travis Boone, Ming Tan, Charlie Friedericks, Aaron Schooley, Terry Lusby, Bobbie Gail Swan, Scott Wheeler, Susan Gavalas, Edward Semones
- Spacecraft and Bus
  - Brian Lewis, Matthew Sorgenfrei, Matthew Nehrenz, Marina Gandlin, Vanessa Kuroda, Ben Klamm, Craig Pires, Shang Wu, Abe Rademacher, Josh Benton, John DeWald, Kuok Ling, Stephen Batazzo

Affiliations

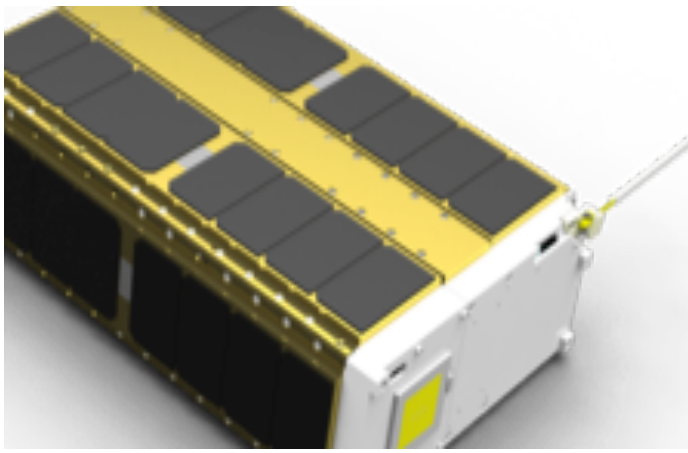
NASA Ames Research Center, NASA Johnson Space Center, Loma Linda Univ. Medical Center, University of Saskatchewan

Support

NASA Human Exploration and Operations Mission Directorate (HEOMD)

Advanced Exploration Systems Division – Jitendra Joshi, Jason Crusan Program Execs.

BACK-UP SLIDES



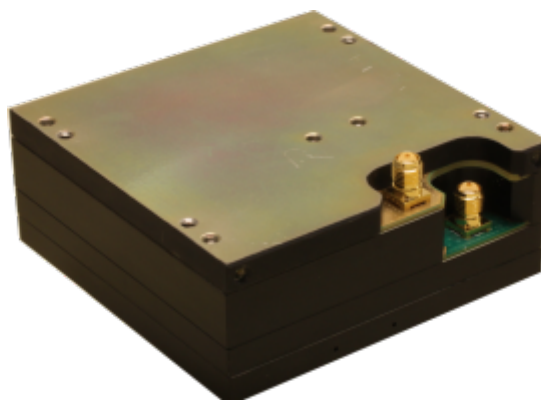
A visualization of one possible formulation of a 6U spacecraft to be used for the BioSentinel mission

3 Distinct Missions

- Marshall Spaceflight Center, Jet Propulsion Laboratory, and Ames Research Center are supplying spacecraft
- MSFC NEOScout will inspect a NEO target, JPL LunarFlashlight will explore permanently shadowed craters on the moon, and Ames BioSentinel will characterize radiation environment

Transponder Options

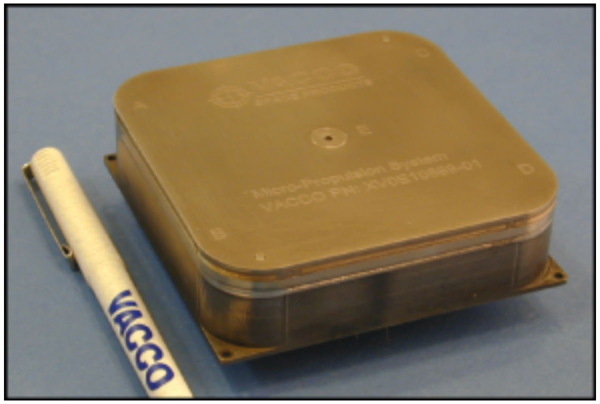
Radio	Mfr.	Band	Tx Power	D/L Modulation and FEC	D/L Rates	U/L Modula-tion	U/L Rate	TRL (Est.)	Heritage
IRIS	JPL	X/X	0.4 W	BPSK, QPSK; RS&CC or Turbo	62.5 bps – 4 kbps	BPSK, FSK	1 kbps	5	INSPIRE (NASA)
DESCREET / SM100	Inno-flight	S/X or X/X	1 W	BPSK, QPSK; RS&CC	- 4.5 Mbps	GMSK, FSK	1 kbps	3-4	SENSE (USAF)
CSR_SDR-SS	Vulcan	S/S						5	SunJammer (NASA)
Micro CDL	L3	S/S or X/X			- 45 Mbps			3-4	Airborne

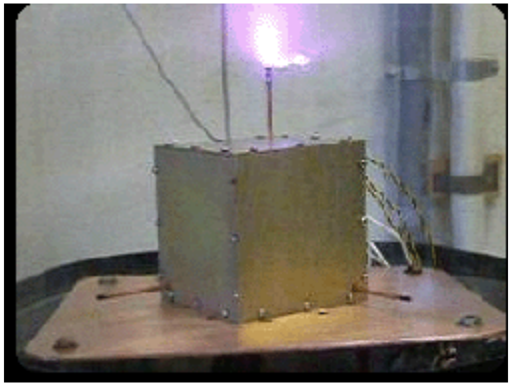




Propulsion

- Momentum Management
  - No torque rod function
- Prop is typical solution
  - Tanks hard to accommodate
  - Hazardous fuels hard to accommodate
  - Need small impulse bits
  - Need low power for valve actuation
- Possible use of solar sailing
  - Alternate pointing direction to counter momentum buildup

Product	Company	Fuel	Perf	Thrust	I_{sp}
PETA	Espace / MIT	Ionic Salt	~200 m/s	25 – 50 µN	3500 s
ChEMS	VACCO	Butane	34 Ns	55 mN	~70 s
BEVO-2	UT Austin	Butane	TBD	TBD	~70 s
MP-110	Aerojet	R-134a	~10 Ns	~30 mN	~70 s
µ-PPT	Busek	Teflon	~250 – 500 m/s	~25 – 40 µN	440 s

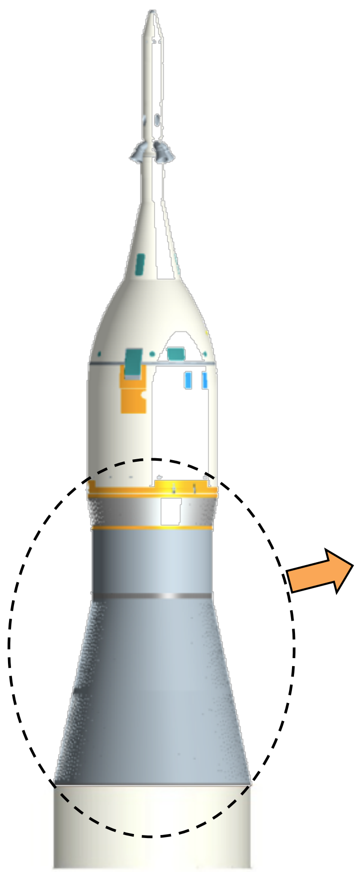




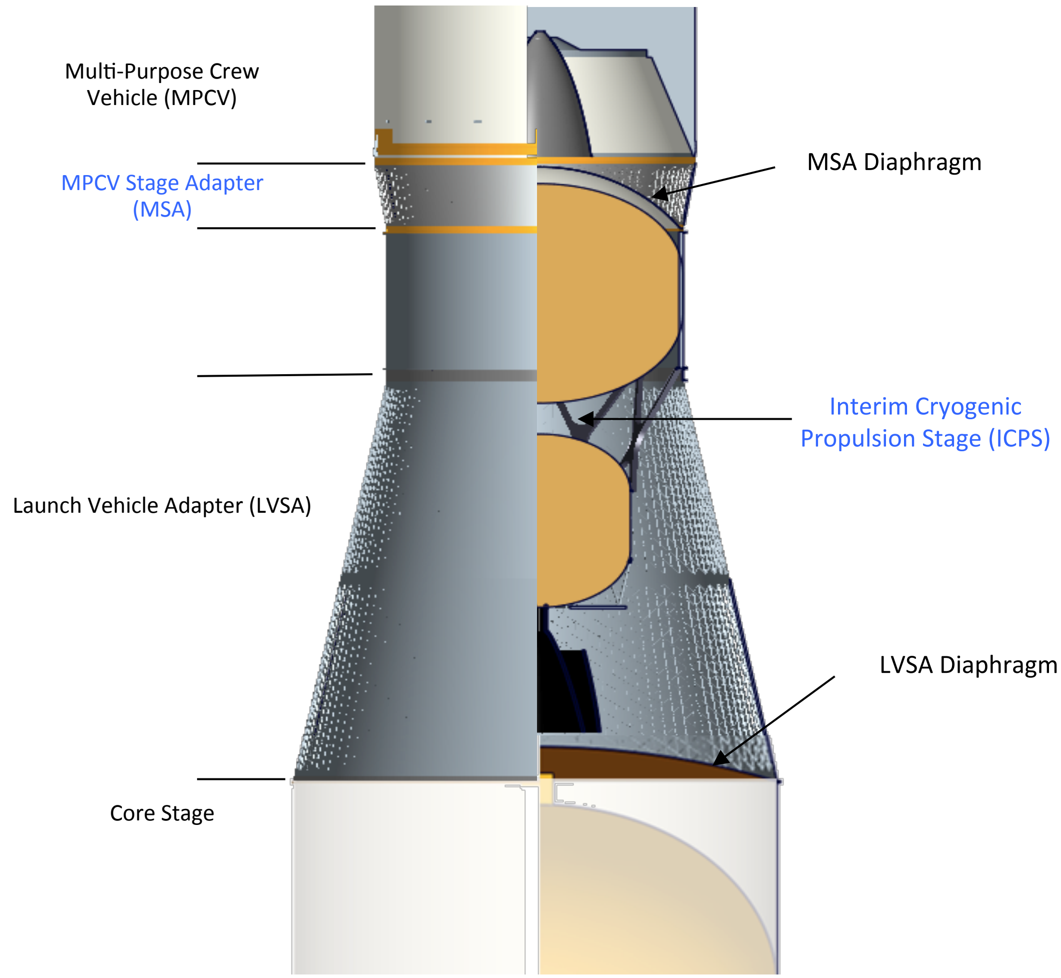
Additional Challenges

- Tip-off conditions from SLS are a major unknown
  - Initial body-fixed rates, potential need for a ΔV maneuver
- Tip-off conditions help to define GNC system needs, which will drive other subsystem budgets
- Detailed power budget assessment: ~30 W orbit-average power should allow for radio to be always on
  - As opposed to traditional CubeSat missions in which subsystem cycling sometimes required
- Need to define ground operations strategy
  - DSN likely the most feasible approach, issues with availability and cost
  - 34m likely acceptable for majority of mission life, larger array required at end of mission

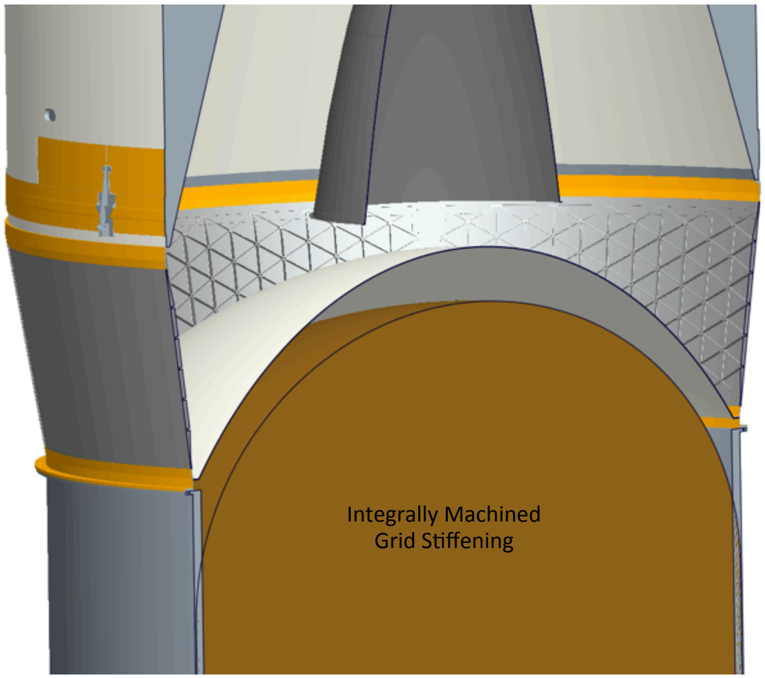
SLS Exploration Mission (EM-1) Overview

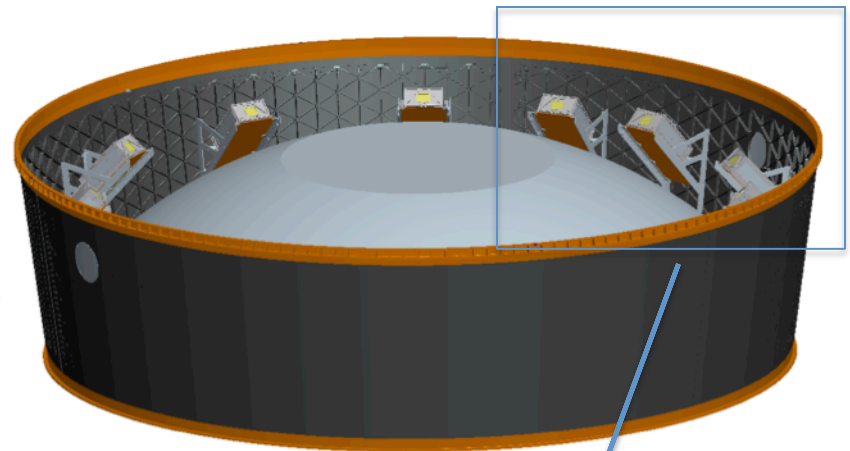


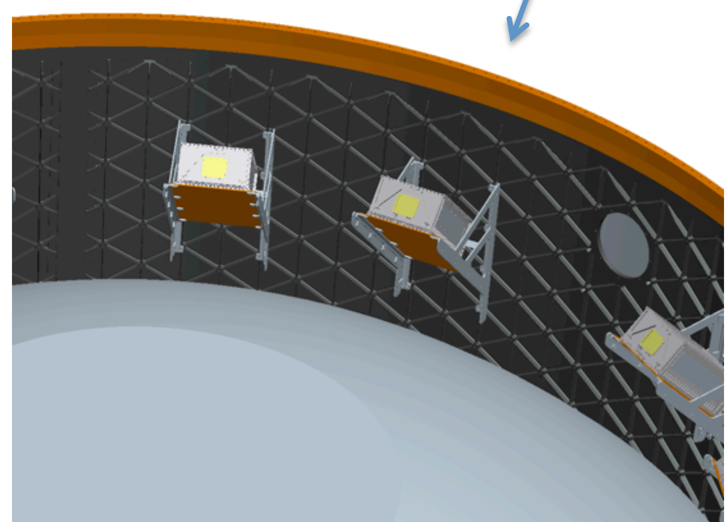
Block 10001



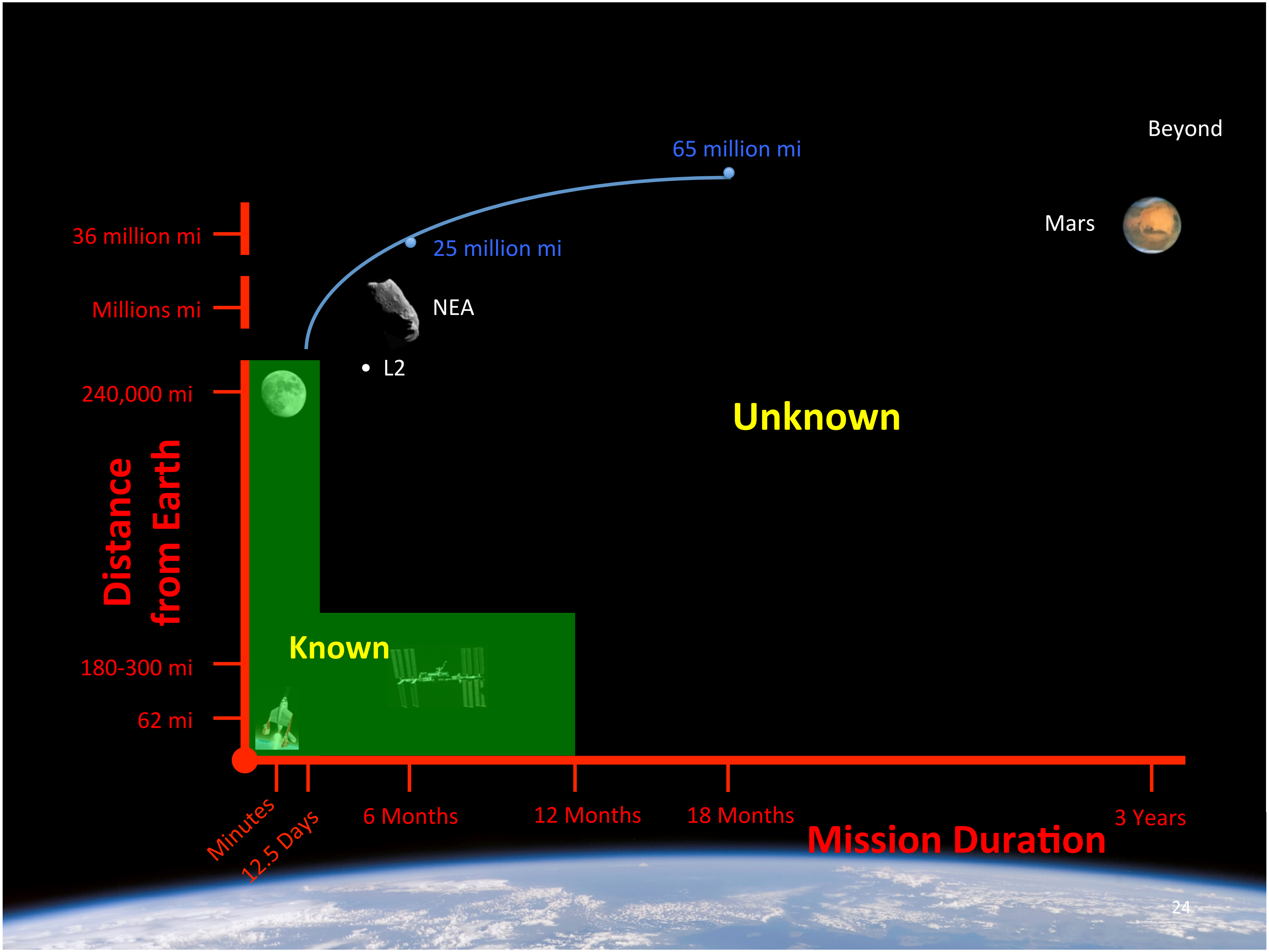
MPCV Stage Adapter (MSA)



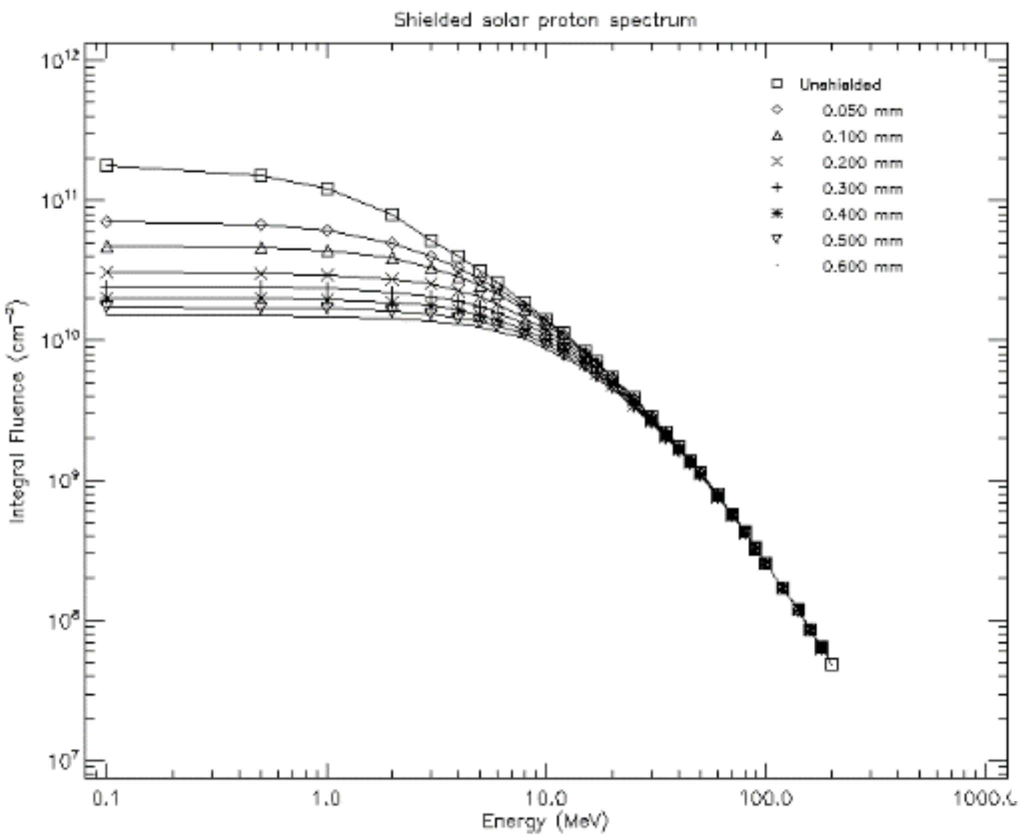




- Concept supports mass & volume for 12 bracket locations
- 11 locations support a dispenser & 6U (14 kg) Secondary Payload
- 1 Bracket location allocated to a sequencer


Beyond
65 million mi
Mars
36 million mi
25 million mi
Millions mi
NEA
L2
240,000 mi
Unknown
Distance from Earth
Known
180-300 mi
62 mi
Minutes
12.5 Days
6 Months
12 Months
18 Months
3 Years
Mission Duration

Radiation Environment



Total Ionizing Dose