NASA's BioSentinel mission: lessons learned & what's next

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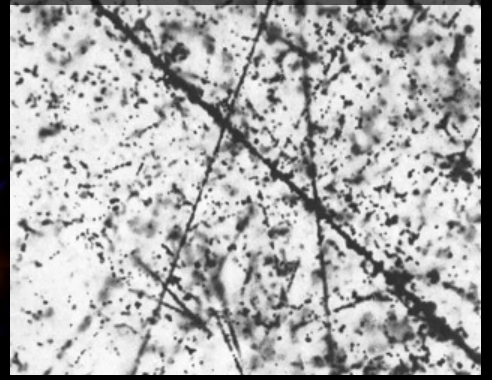
What are we going to encounter beyond LEO?

Reduced gravity

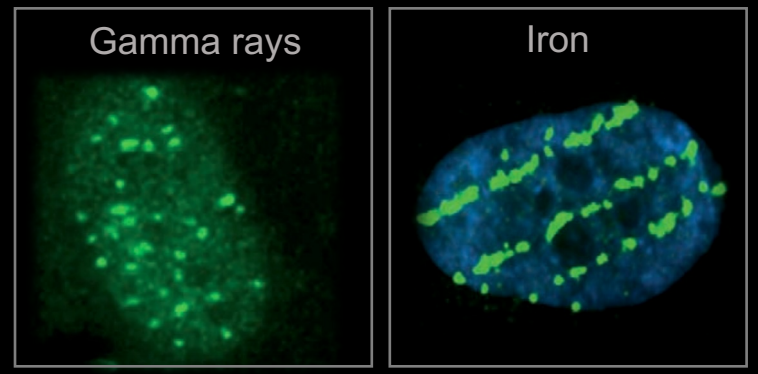
Space radiation (CGRs & SPEs)

Apollo XI particle tracks



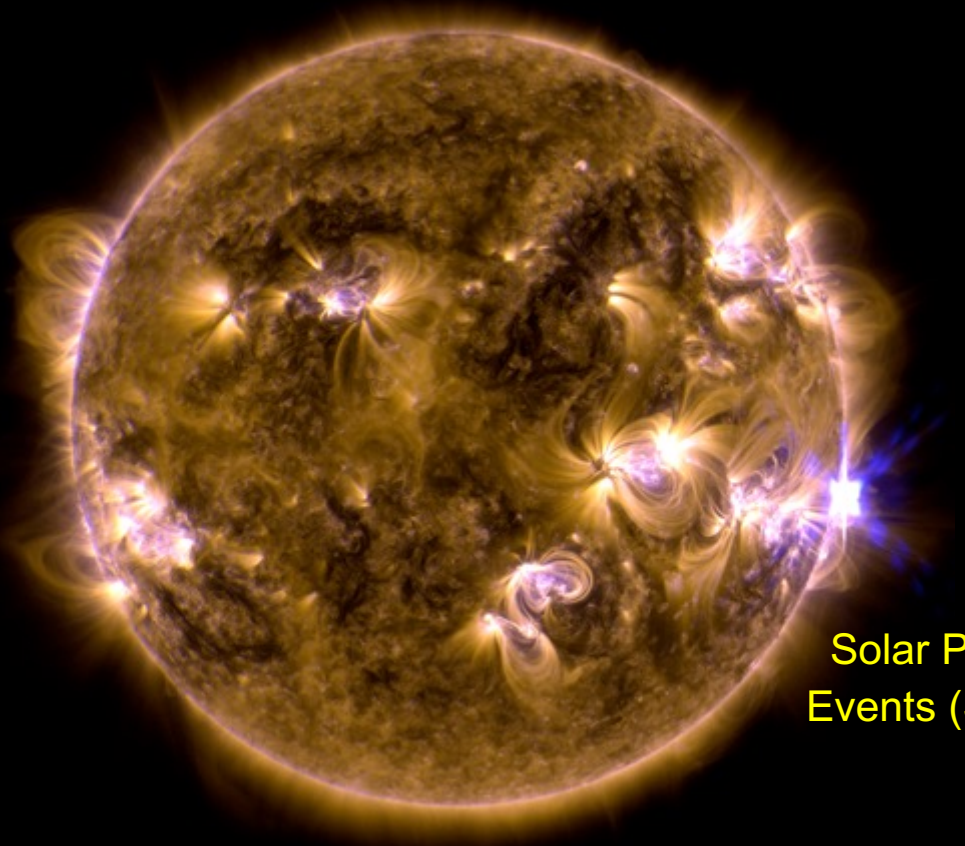
Schaefer *et al*. 1972

Cell nuclei showing DNA damage



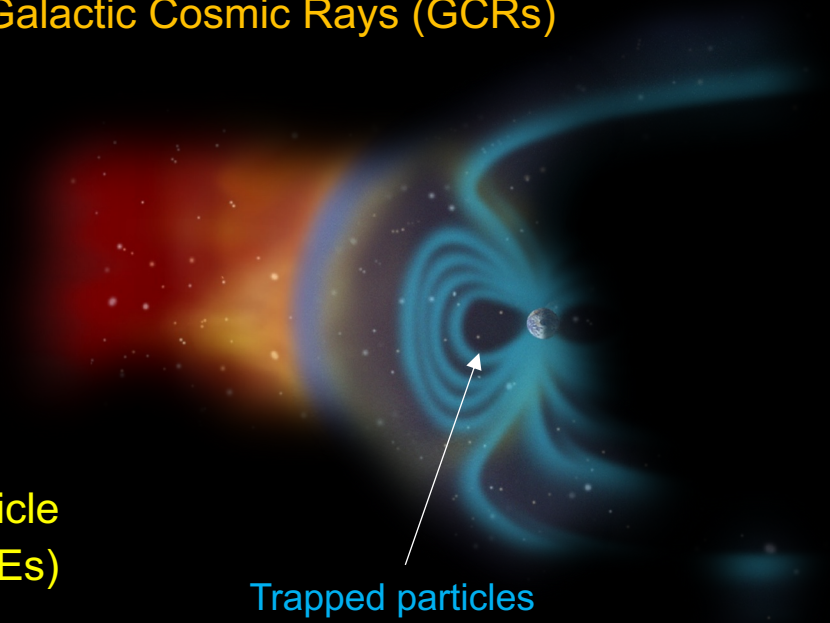
Cucinotta & Durante, 2006

What are we going to encounter beyond LEO?



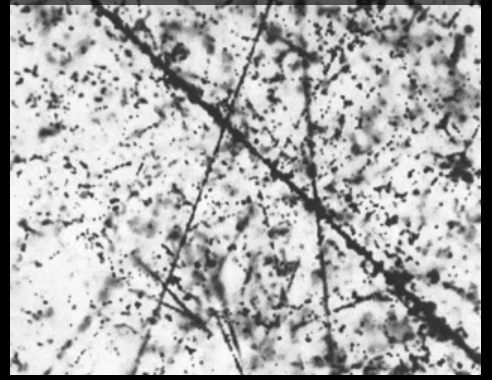
Solar Particle Events (SPEs)

Galactic Cosmic Rays (GCRs)



Trapped particles

Apollo XI particle tracks



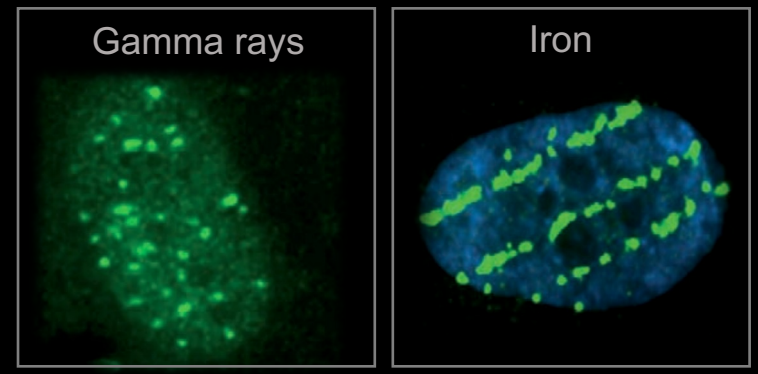
Schaefer *et al*. 1972

- Both interplanetary & modulated by the solar cycle
- GCRs: high-energy protons and highly charged, energetic heavy particles
- GCRs not effectively shielded & can fragment

Challenges: SPEs – unpredictable; large doses in short time

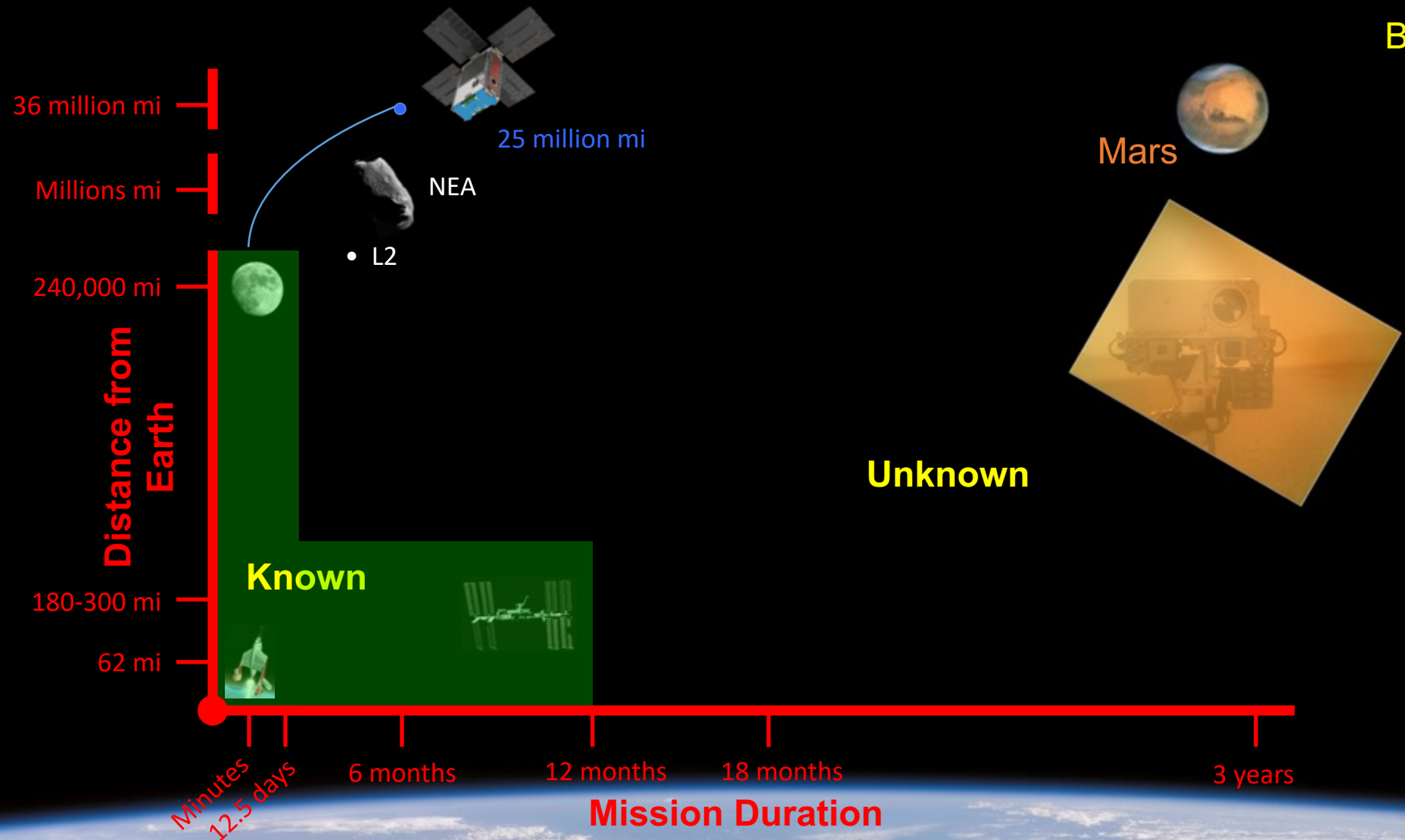
GCRs – biology effects poorly understood (but most hazardous)

Cell nuclei showing DNA damage



Cucinotta & Durante, 2006

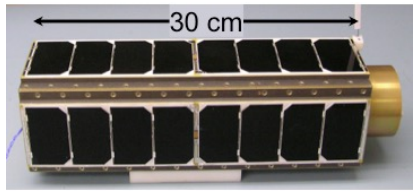
The limits of life in space – as we know it – is 12.5 days on a lunar round trip or 1.2 years in LEO. As we send people further into space, we need to understand the biological risks and how they can be addressed

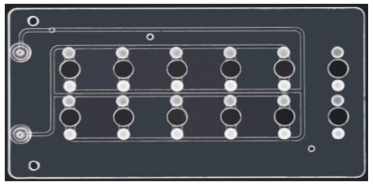


NASA Ames biological CubeSat missions

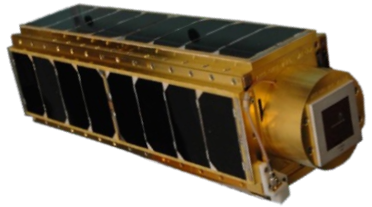
Ames Research Center

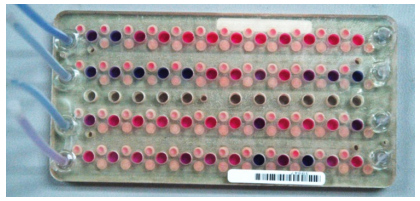
GeneSat-1
3U 2006



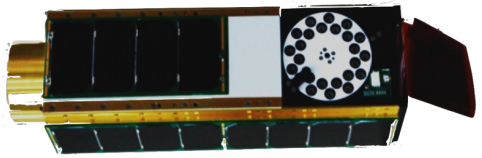


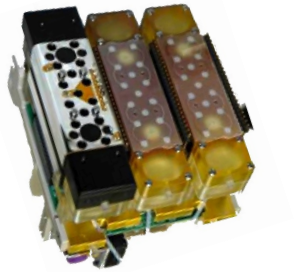
PharmaSat
3U 2009



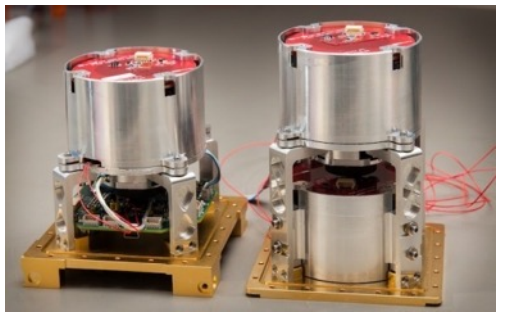


O/OREOS SESLO
3U 2010



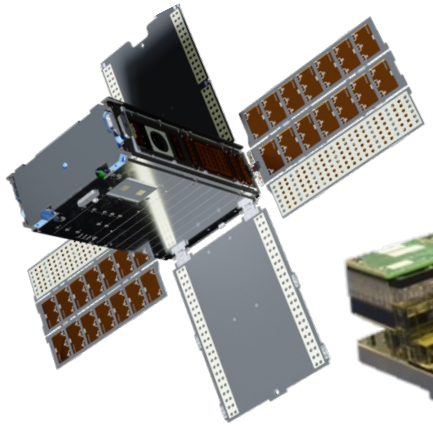


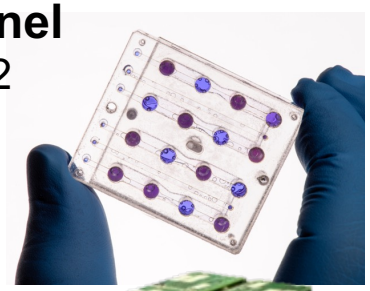
SporeSat
3U 2014

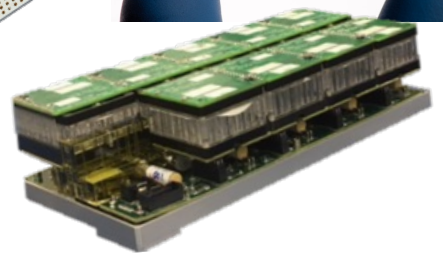


EcAMSat
6U 2017

BioSentinel
6U 2022





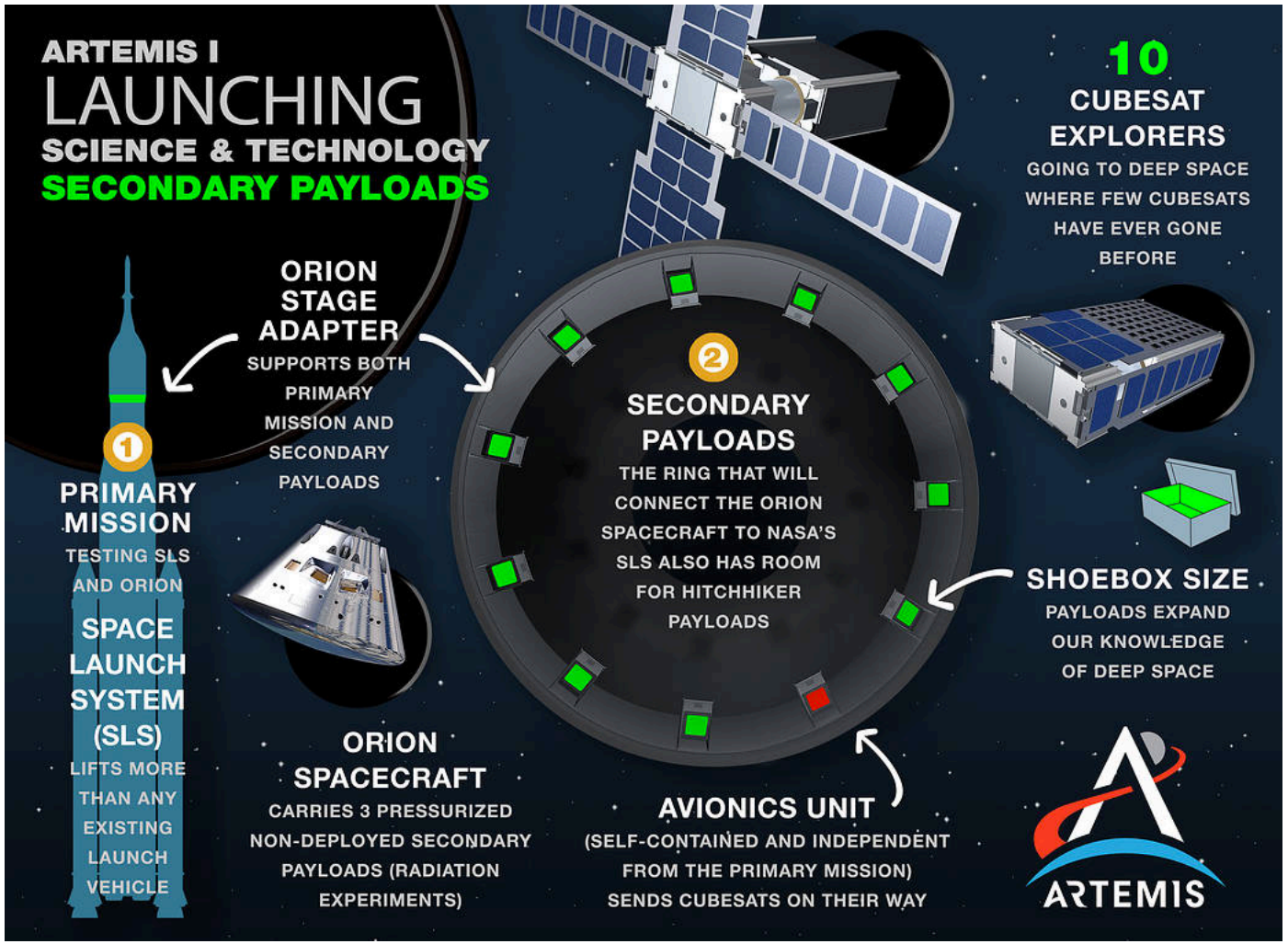


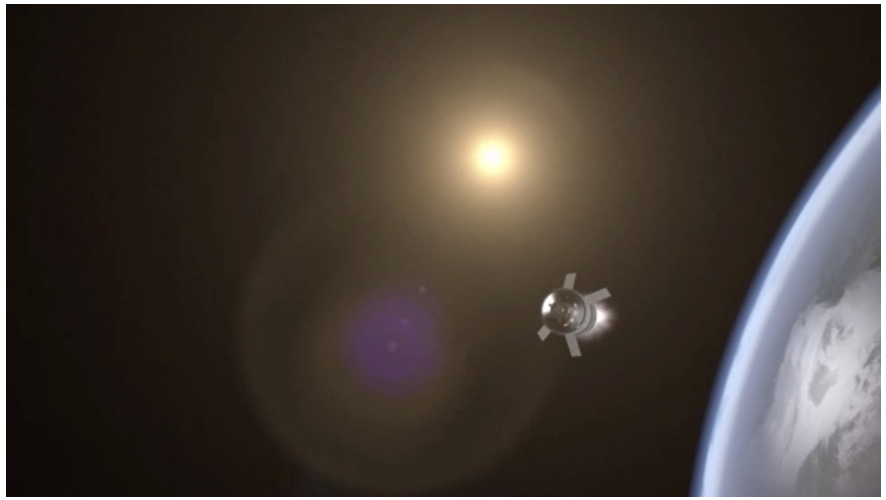
NASA Artemis I mission

BioSentinel missions

SpaceX-24

Artemis 1: secondary payloads (6U CubeSats)





ARTEMIS I

CUBESATS DEPLOY
ICPS deploys 10
CubeSats total

MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days

O DEPARTURE
ave DRO and start
urn to Earth.

TURN POWERED FLYBY (RPF)
F burn prep and return
ast to Earth initiated.

TURN TRANSIT
turn Trajectory Correction
C) burns as necessary to
for Earth's atmosphere.

15 **CREW MODULE SEPARATION FROM SERVICE MODULE**

16 **ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.

17 **SPLASHDOWN**
Pacific Ocean landing within view of the U.S. Navy recovery ship.

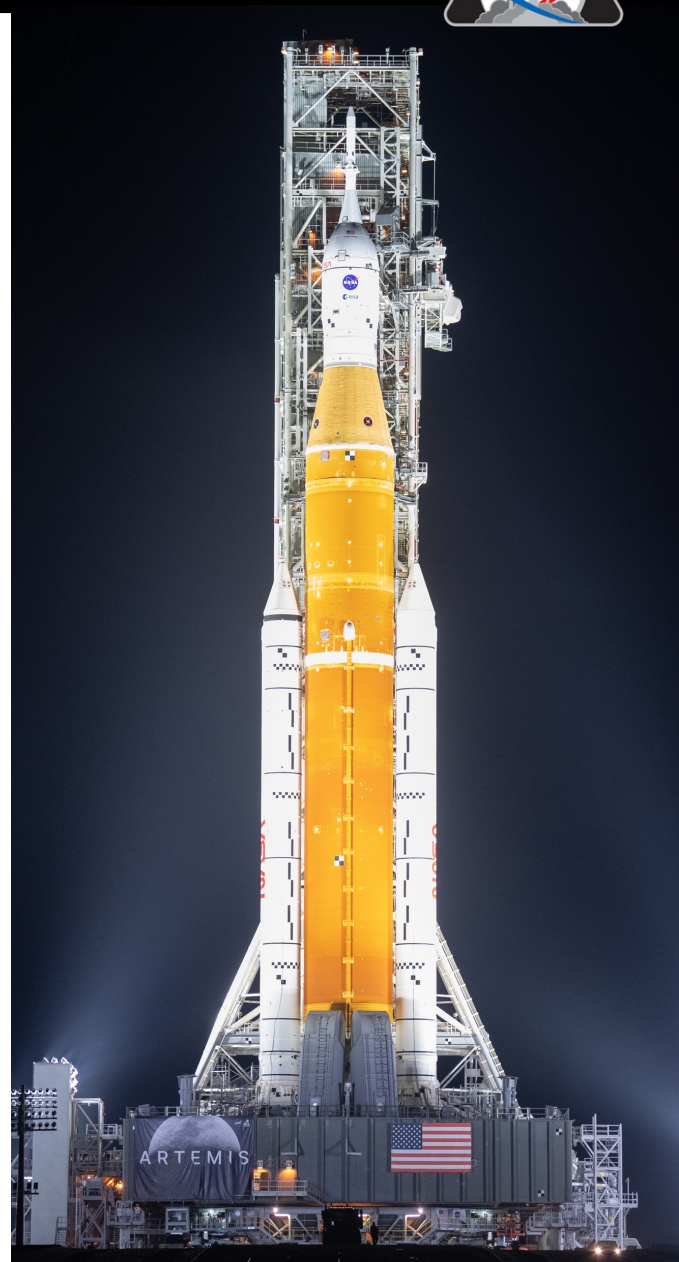
BioSentinel mission

Objectives:

- Develop a deep space tool with autonomous life support technologies
- Study the space radiation environment beyond LEO and its effect on biology

What is it & what's inside?

Key Parameters			
Form Factor	**# Spacecrafts**	**Orbit**	**Launch Date**
6U CubeSat	1	Heliocentric	Nov 16, 2022 (SLS Artemis I)
Mass	**Dispenser or Interface**	**Mission Duration**	**Current Phase/Activity**
~ 14 kg	OSA 6U dispenser	6 months	Science Phase



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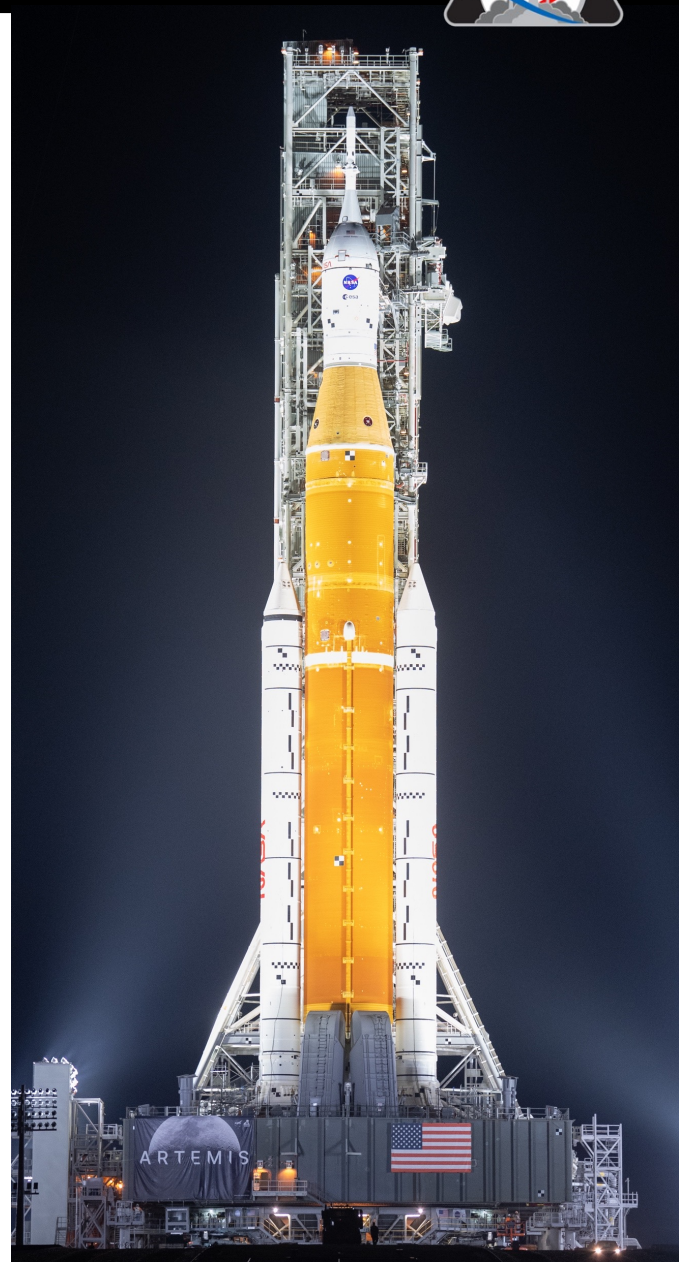
Payload & Bus	Instrument #1	Instrument #2	Spacecraft Bus	Spacecraft Bus
Title/Acronym	4U BioSensor payload	LET spectrometer	Iris v2 radio	Propulsion system
Organization	NASA ARC	NASA JSC	JPL	Georgia Tech

Data Systems	Mission Operations Center	Science Operations Center	Ground Station/Network	Data Repository
Title/Acronym	MMOC	BioSentinel SOC	Deep Space Network	*TBC*
Organization	NASA ARC	NASA ARC	NASA	NASA



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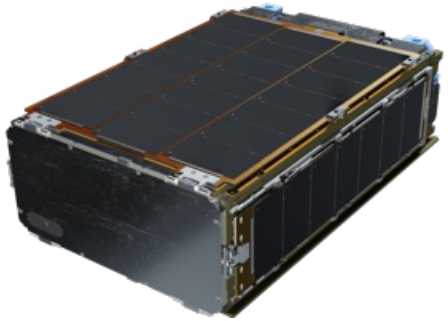
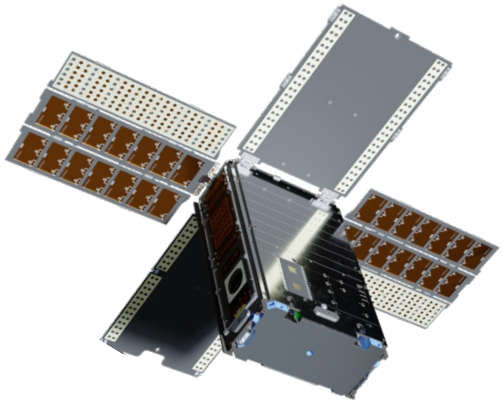
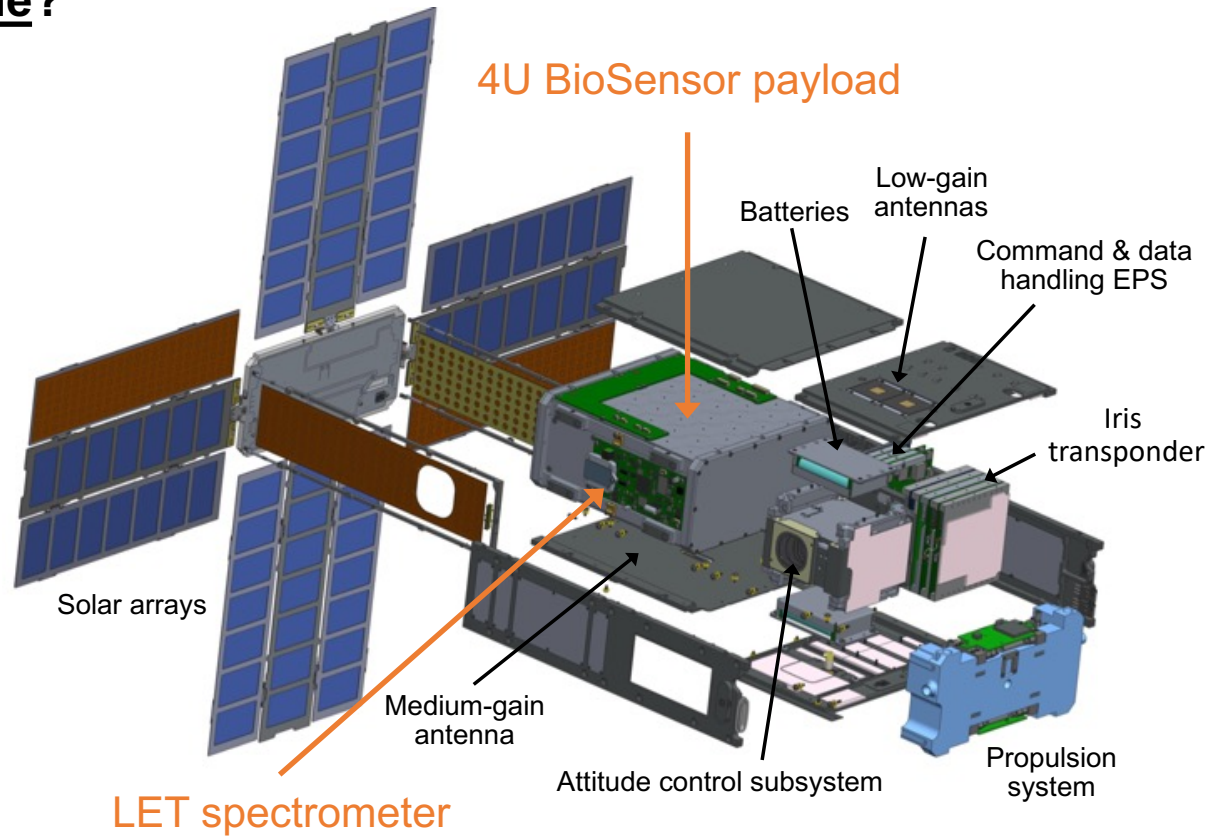
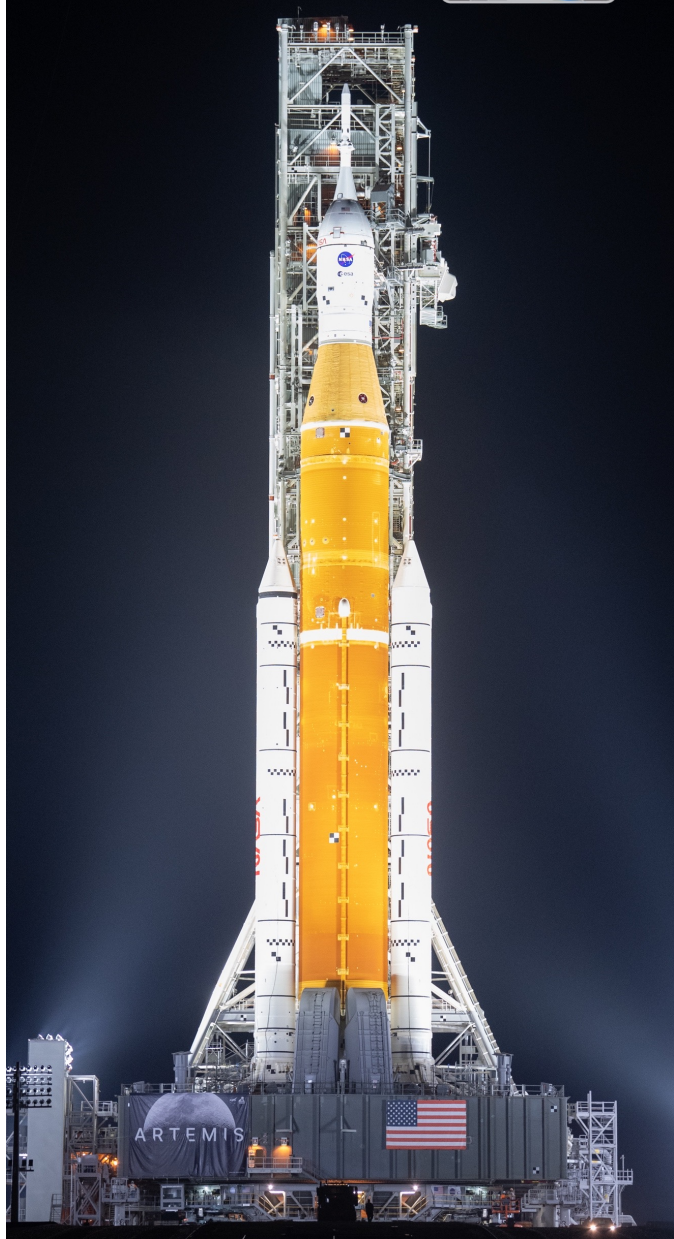






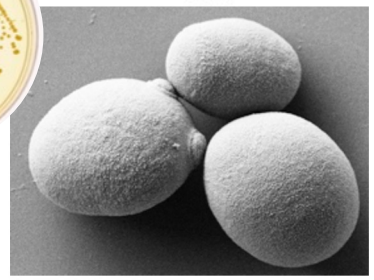


BioSentinel: key components

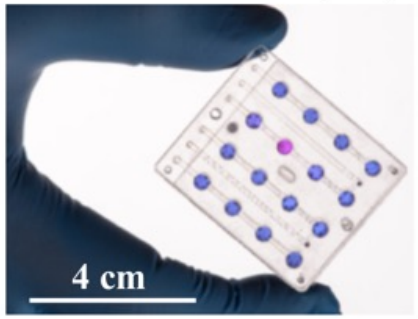
Subsystem	Description	Vendor	Subsystem	Description	Vendor
4U BioSensor			**LET spectrometer**		
Fluidics	18 PC cards & manifolds with integrated valves, pumps, bubble traps & desiccant chambers	NASA ARC	Radiation sensor	Timepix-based sensor (TID and LET particle characterization)	NASA JSC
Optics	3 LED lights & TAOS sensor per fluidic well (16 wells per card)		**Bus ADCS**		
Thermal	Dedicated thermal control per fluidic card		Reaction Wheels / Star Tracker / IMU	XACT 3-axis Attitude-Control System & Star Tracker	Blue Canyon Technologies
Sensors	Temperature, RH, pressure		Sun Sensors	5 sun sensors	SolarMEMS
Bus C&DH			**Bus Power**		
Processor	UT700 LEON 3	Space Dynamics	EPS	TI-MSP430 FRAM	NASA ARC
Data Storage	MRAM & Flash		Batteries	18650B Li-ion	Panasonic
Bus Comm			Solar Array	4 HaWK solar arrays	MMA Design
Radio	Iris v2 transponder	JPL	**Propulsion**		
Antenna	Medium & low gain		Thruster	7-nozzle 3D printed system	Lightsey Space Research

BioSentinel: science payloads

Budding yeast

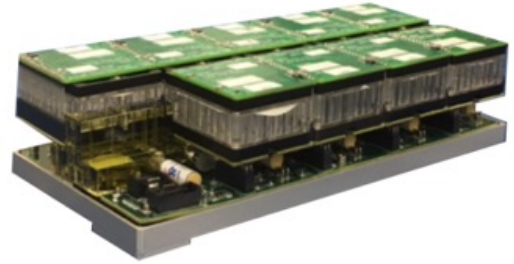


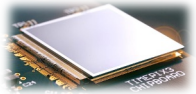
16-well fluidic card (x18)



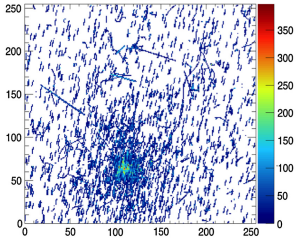
Card stack

9-card fluidic manifold (x2)

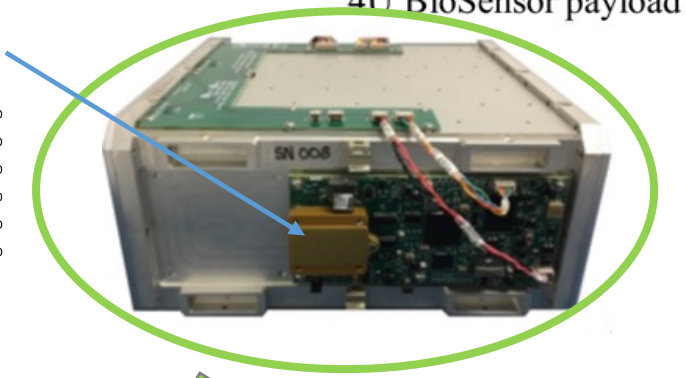




LET spectrometer

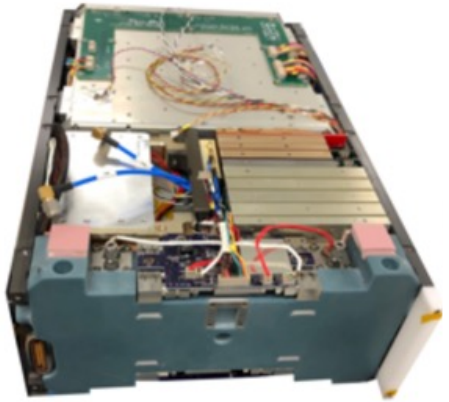


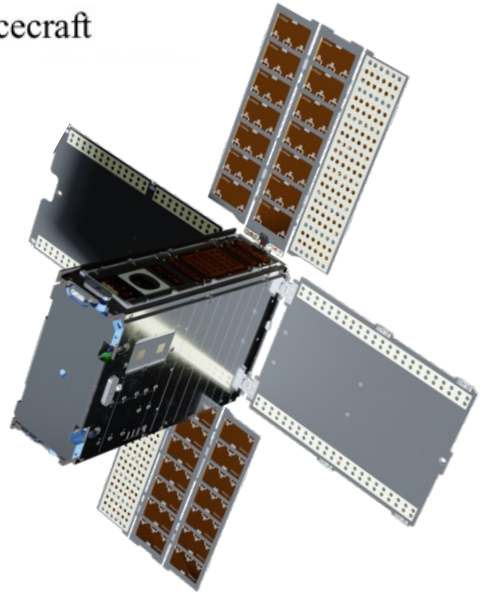
4U BioSensor payload



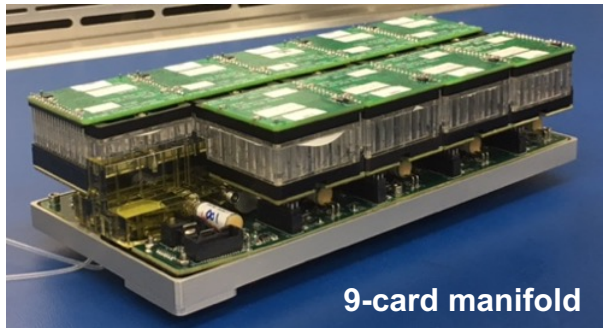
ISS
(& Ground)

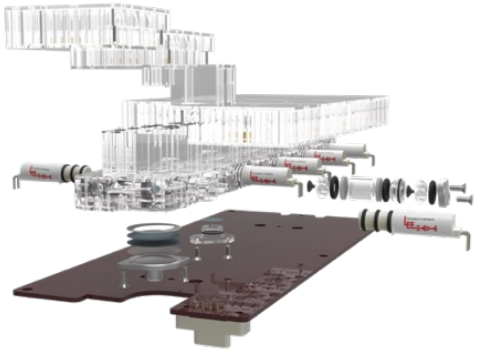
6U BioSentinel spacecraft

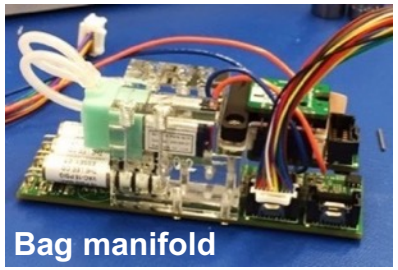


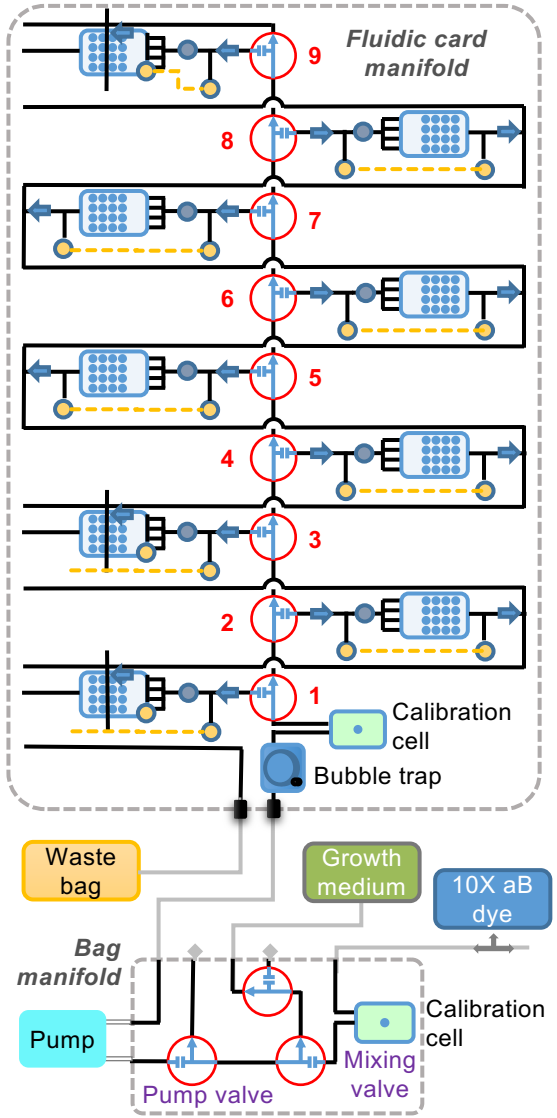


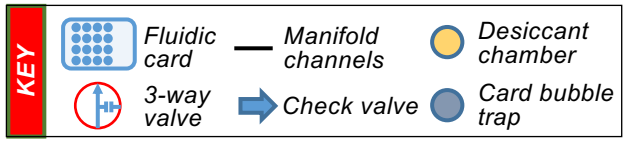
BioSentinel: microfluidic system

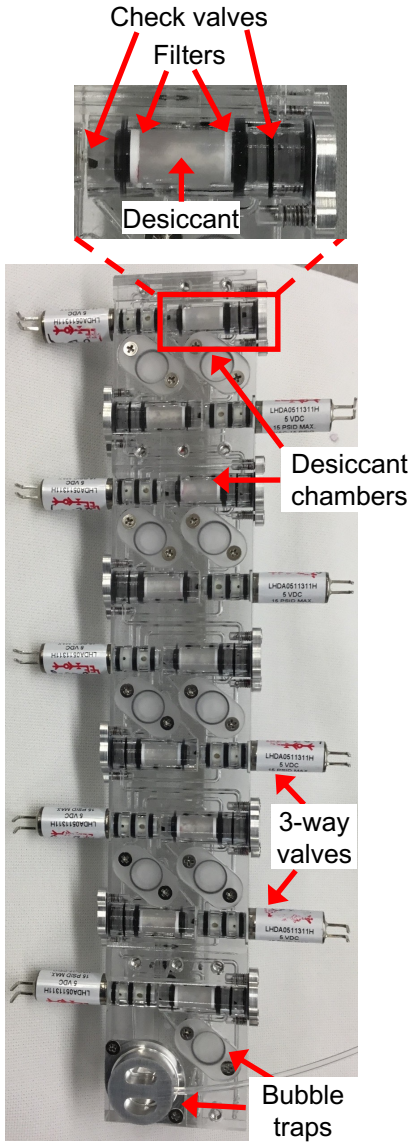


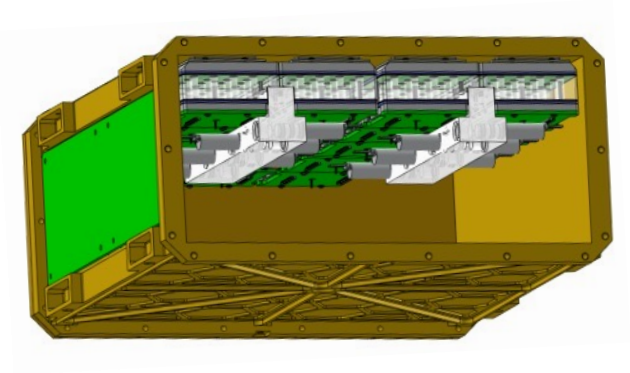


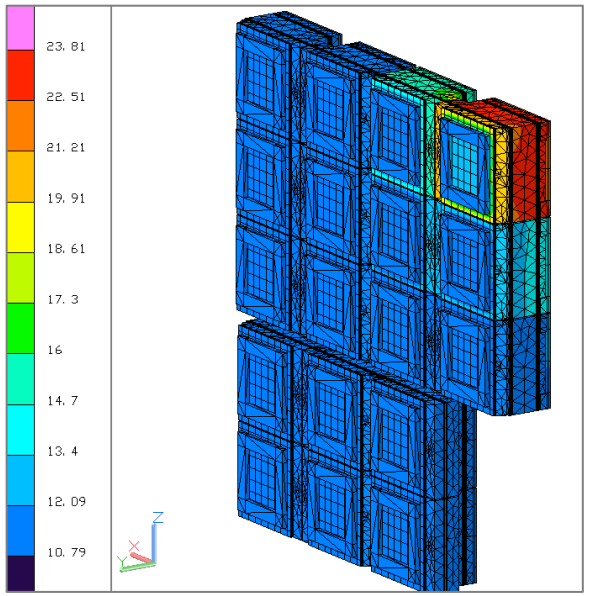






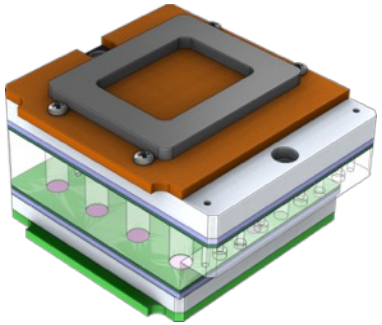


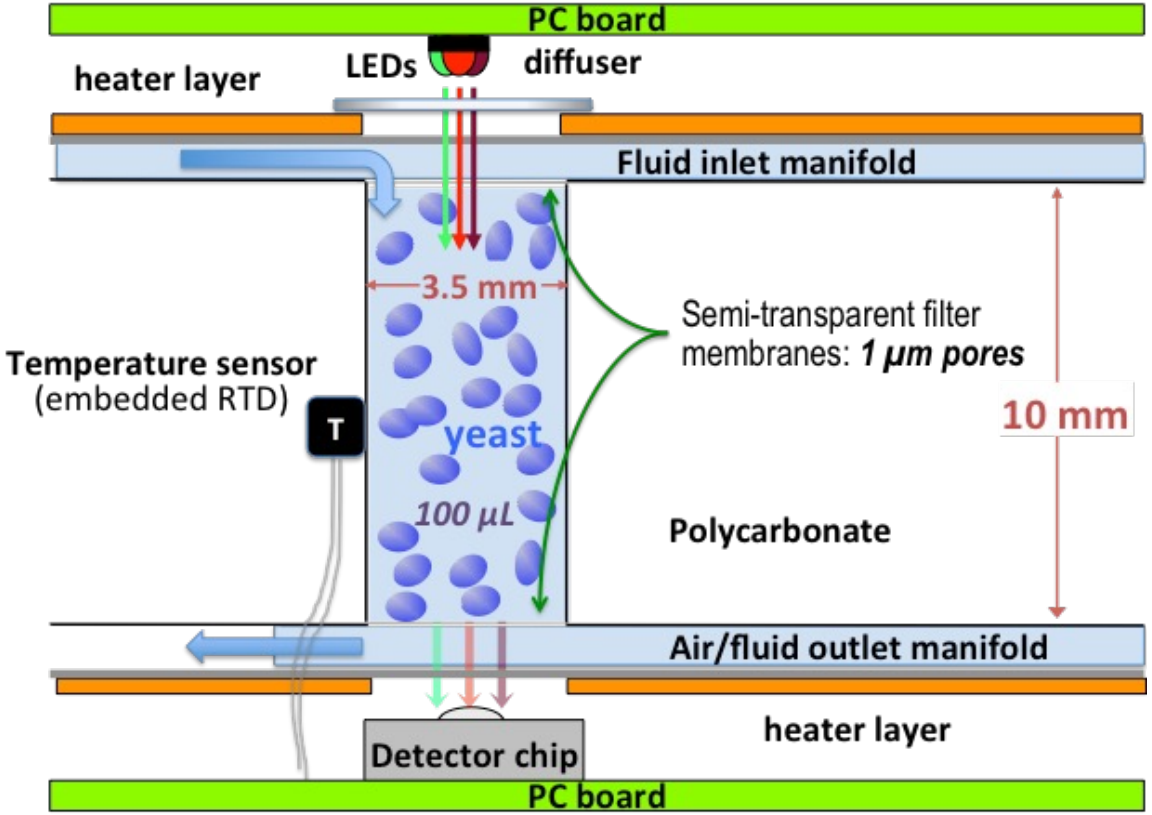




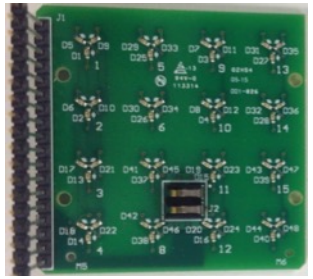
BioSentinel: microfluidic card

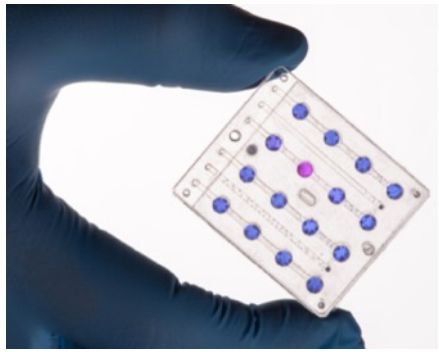
Microfluidic card (x18)



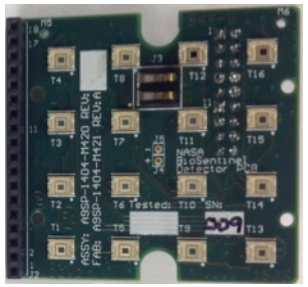


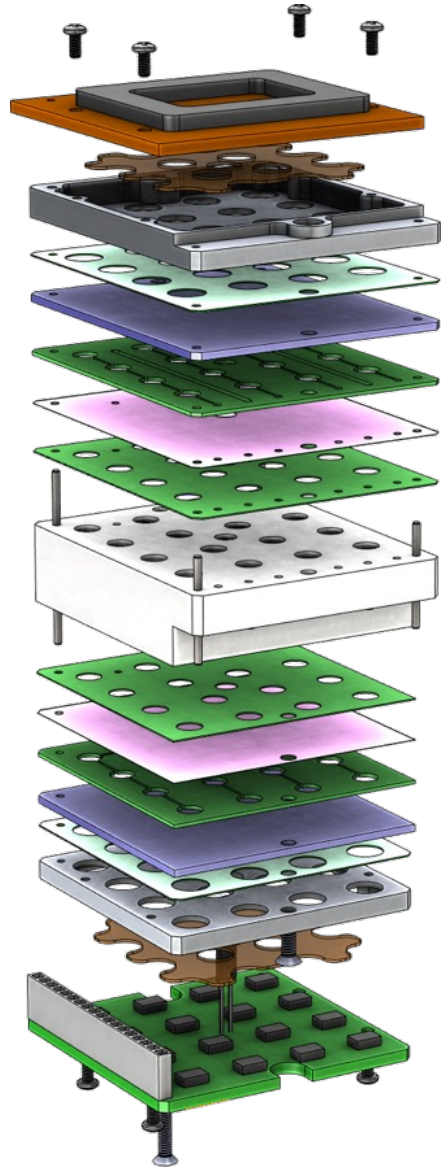
3-LED emitter





Photodiode detector array





BioSentinel: optical detection system

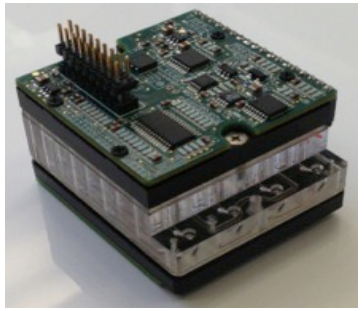
Dedicated 3-color optical system at each well to track growth *via* optical density and cell metabolic activity *via* dye color changes

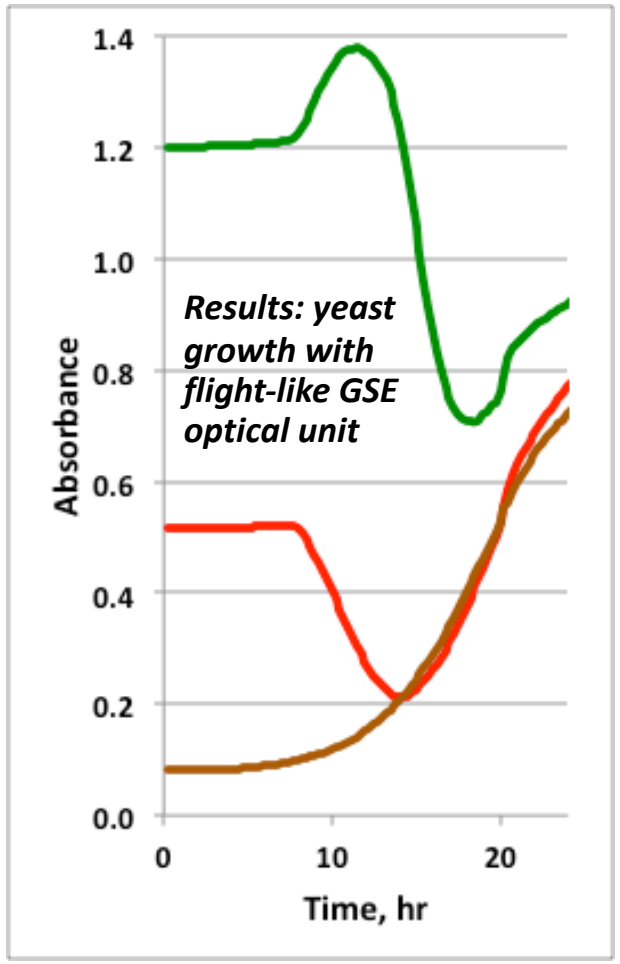
LEDs:

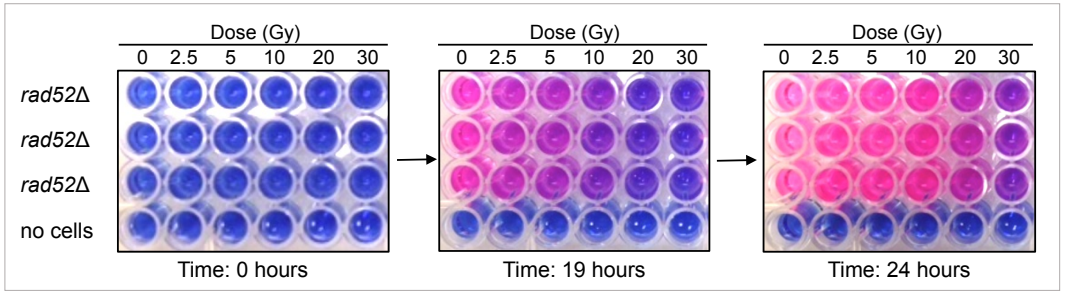
570 nm (green, measures pink)

630 nm (red, measures blue)

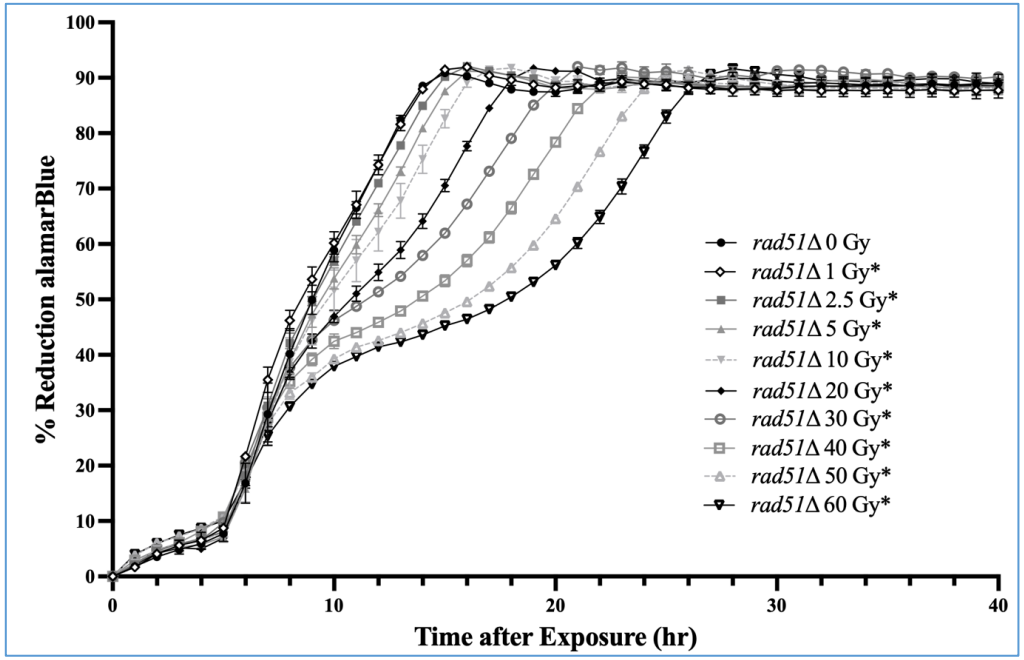
850 nm (infrared, measures growth)







alamarBlue turns pink when cells are metabolically active



HR repair defective cells show sensitivity to ionizing radiation

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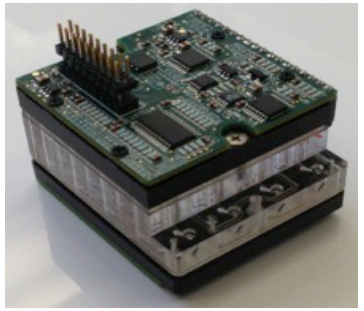

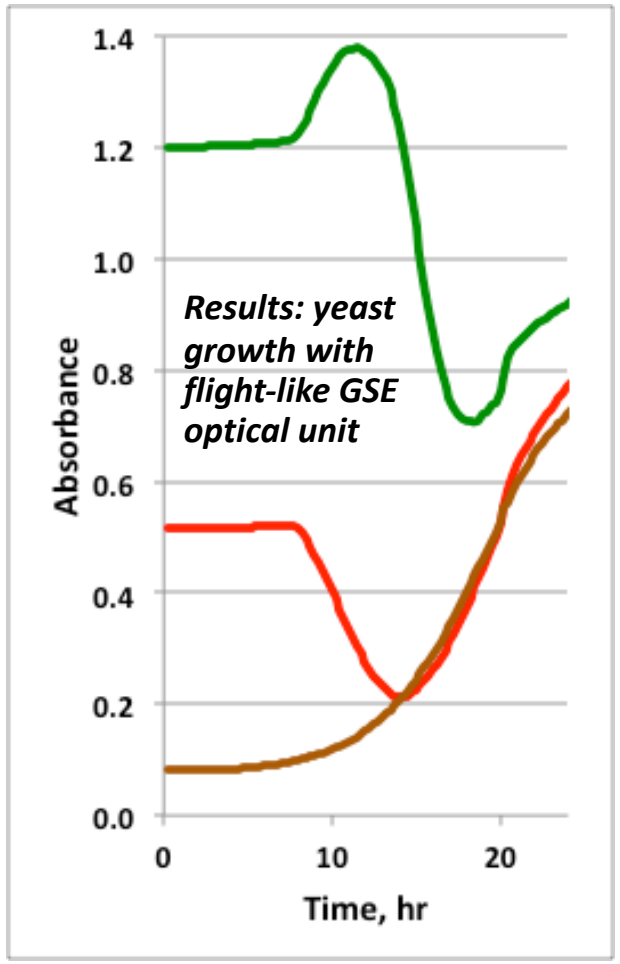

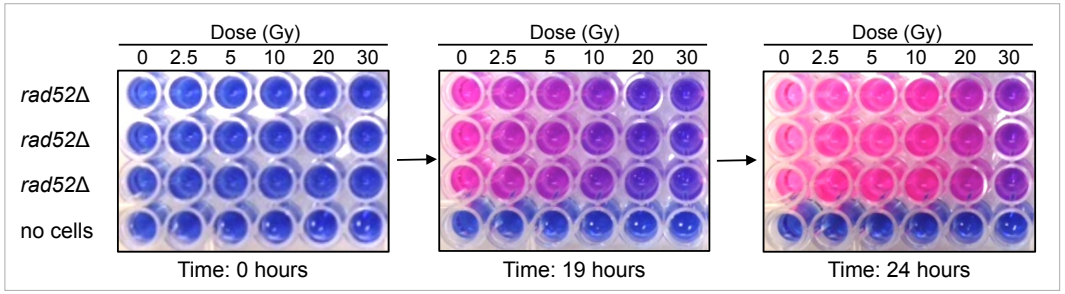

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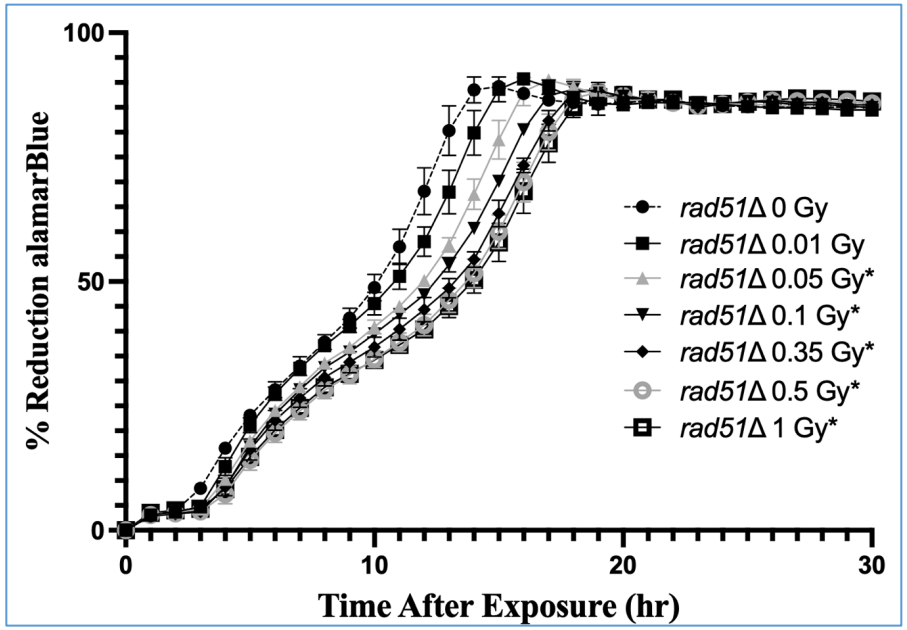
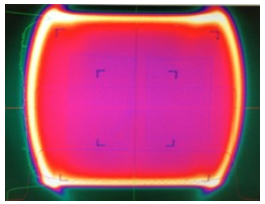


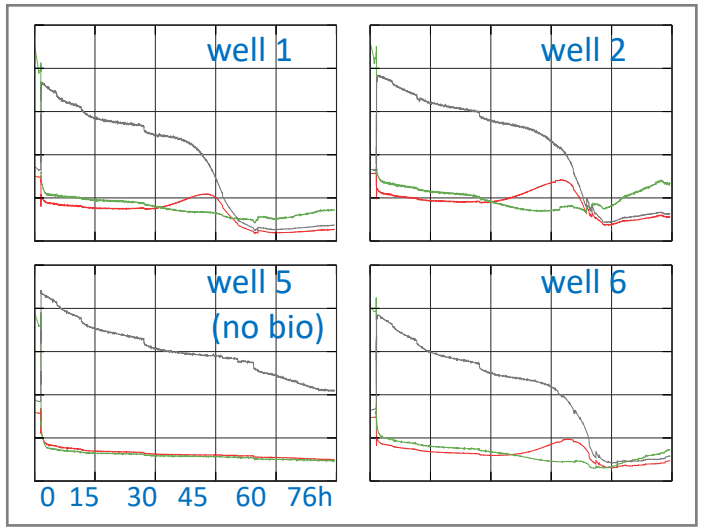


HR repair defective cells show sensitivity to GCRsim ionizing radiation

BioSentinel: ISS experiment

- ISS instrument launched on SpaceX CRS-24 on Dec 21, 2021, and installed into SABL incubator
- First set of fluidic cards (1 out of 9) activated on Jan 31; last one completed in mid-June
- ISS payload returned on SpX-25 in late-August
- Data will be used as LEO microgravity control and compared to deep space mission data

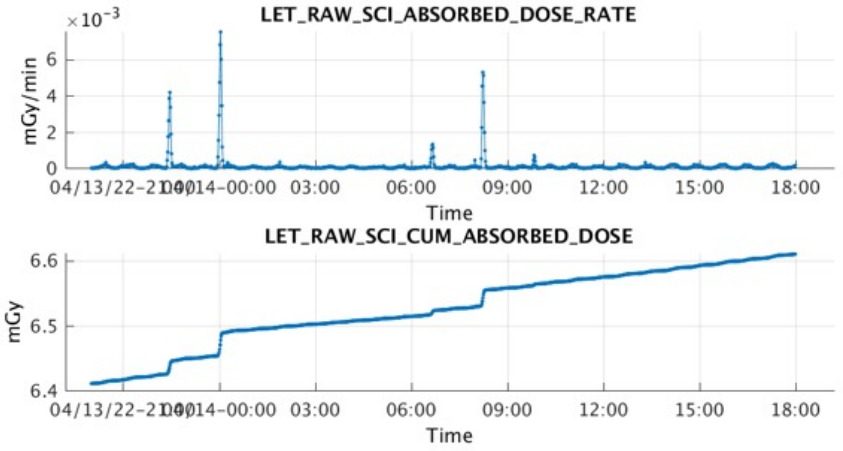
Card 8 optical readings after ~72 hours

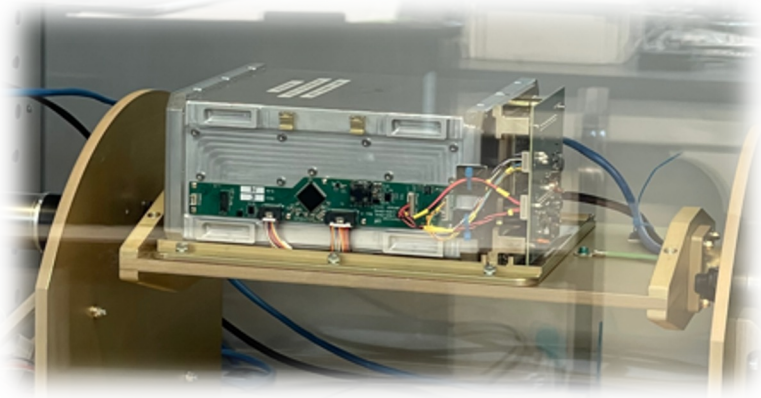


Bio activity ~48 hours after activation (and continued for ~7 days)

Reagents (growth medium and alamarBlue dye) working properly

ISS LET spectrometer data from April 14

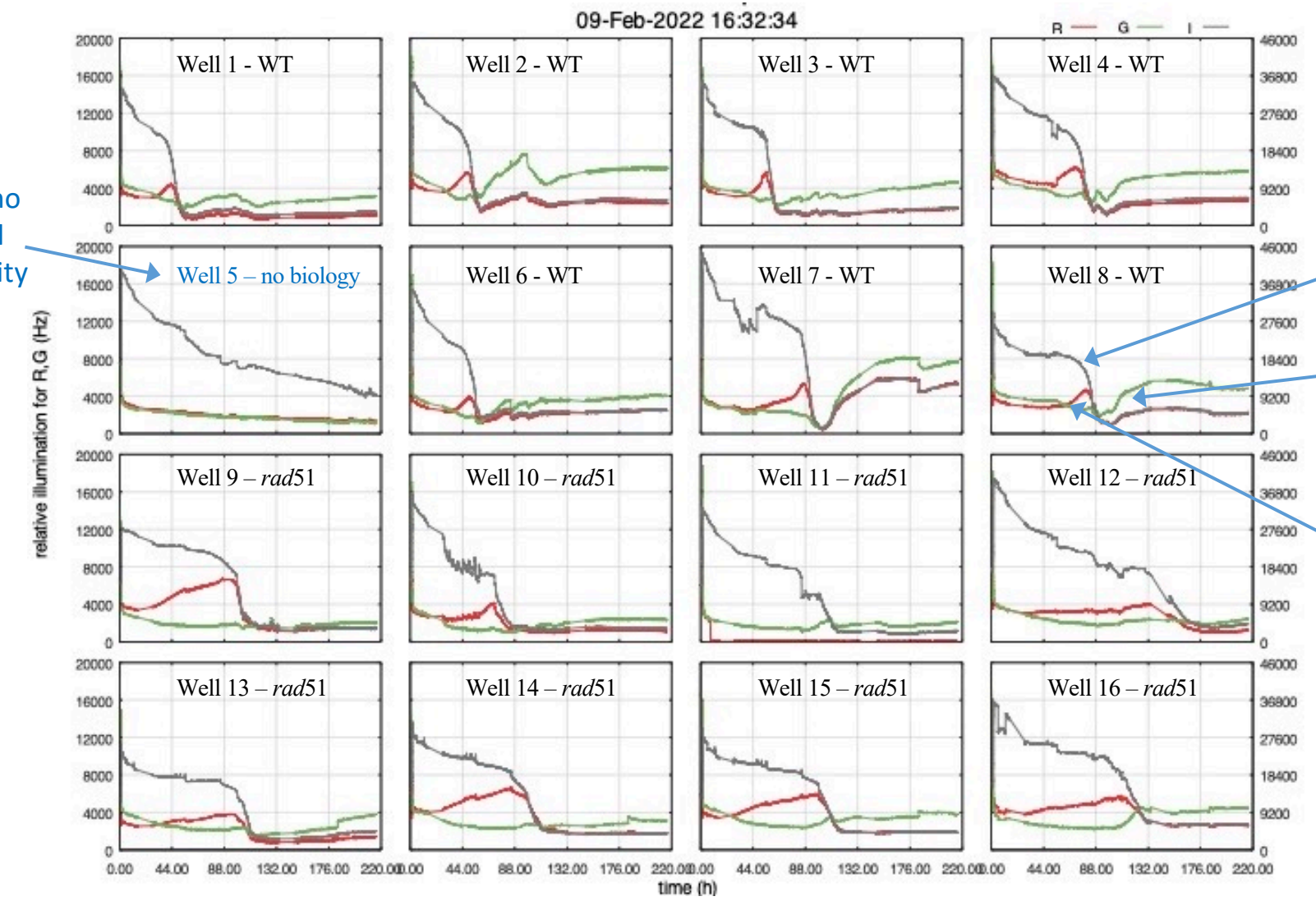




Ground control unit at NASA ARC

BioSentinel: ISS experiment (card 8 example)

Well #5 in all cards has no biology, thus no optical changes due to cell activity are expected

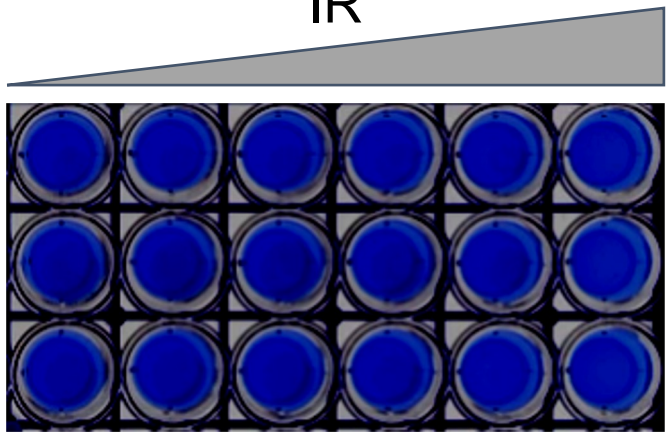


850nm readings show cell growth

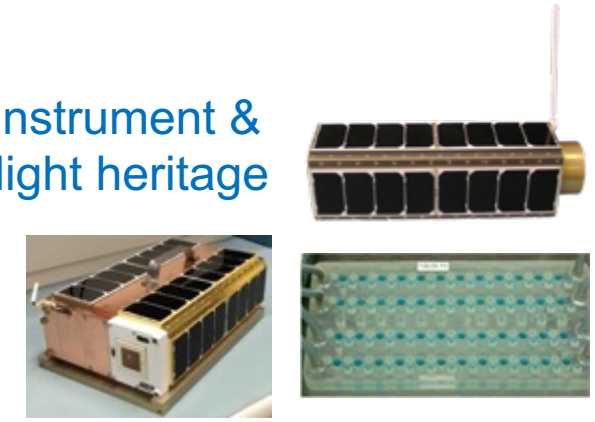
570nm readings (green, going down then up) show transition to pink color, then clear

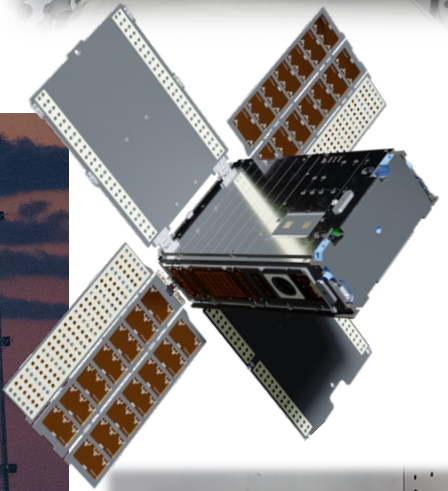
630nm readings (red, going up) show disappearance of the blue color

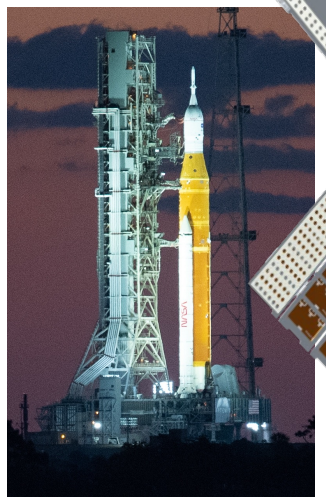
BioSentinel: how did we get here?



Instrument & flight heritage







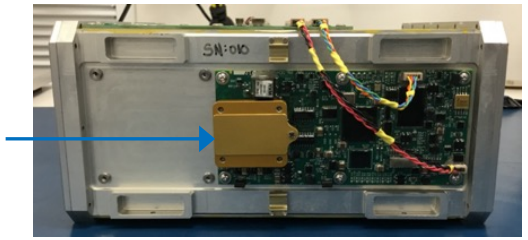
- Model organism & strain selection
- How to fly the biology? Dry/wet?
- Long-term viability & biocompatibility
- Materials, sterilization method, reagents, fluidic components…
- Multiple fluidic cards; 288 wells
- LEO control (and ground)
- Data telemetry & processing

BioSentinel: radiation environment characterization

- LET spectrometer instrument mounted outside the BioSensor enclosure (free-flyer, ISS, ground)
- Reports cumulative ionizing radiation dose & particle distribution based on linear energy transfer (LET)
- Performing nominally; unaffected by BioSensor issues

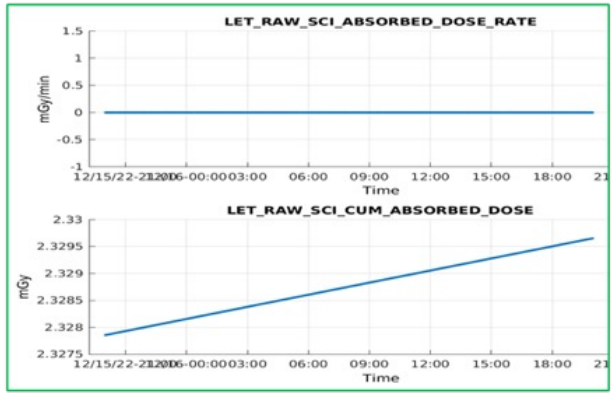
Science objectives:

- Characterize radiation environment
- Compare ISS, deep space, and ground data
- Characterize contribution from solar and GCR particles
- Characterize solar particle event (SPE)

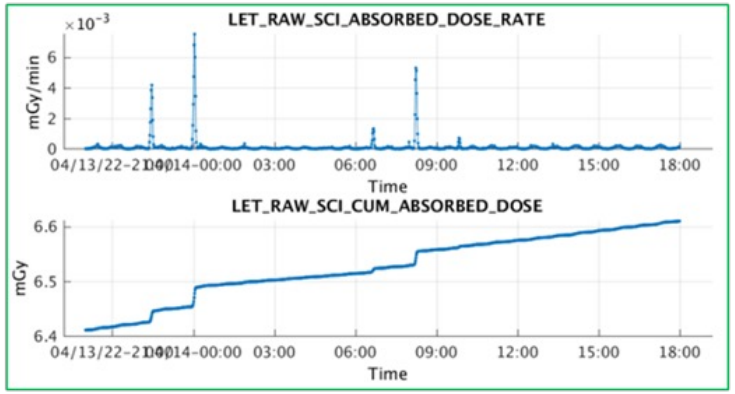


	Absorbed dose rate (mGy/day)	**Total absorbed dose since Artemis I launch (Nov 16)**
Ground	~ 0.002 – 0.003	< 0.5 mGy
ISS (120-day average)	0.218	-
Free-flyer (248-day average)	0.298	73.7 mGy (as of July 21, 2023)
Free-flyer (projected by modeling)	0.25 ± 0.04	-

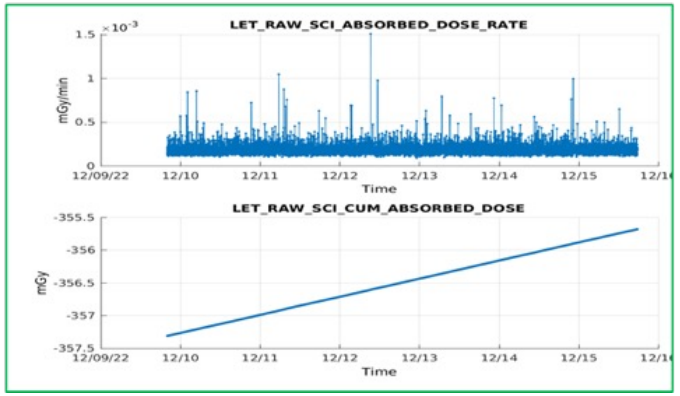
Ground LET spectrometer – Dec 16



ISS LET spectrometer – April 14



Free-flyer LET spectrometer – Dec 16



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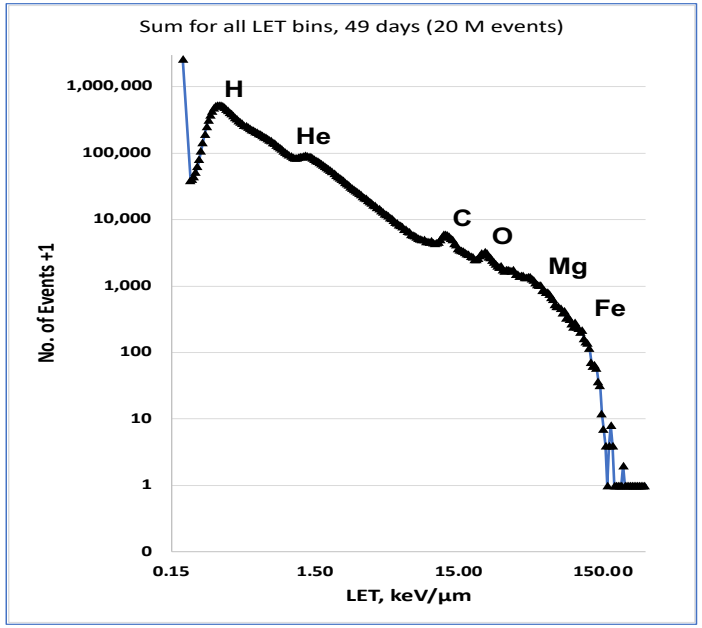
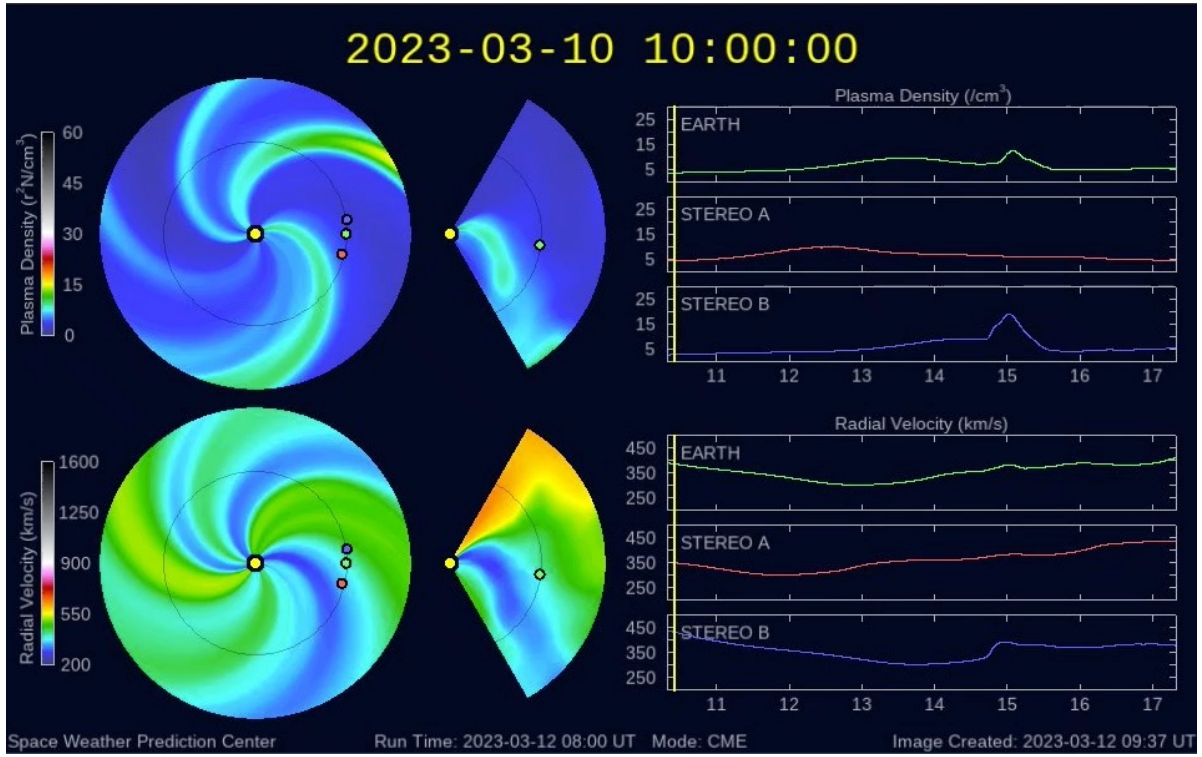
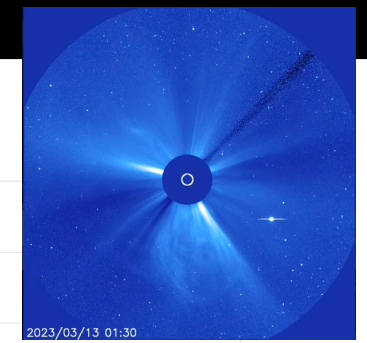
LET spectrum (in Si; 20M events); first 49 days

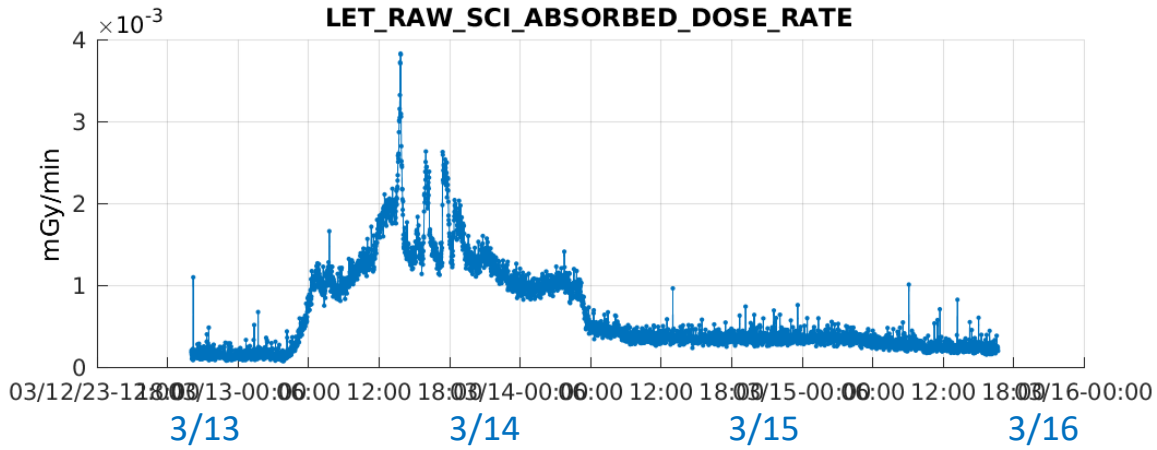


BioSentinel: radiation environment characterization

- CME event on March 13
- >100 MeV proton intensity enhancement
- Steady return to background levels
- BioS LET spectrometer detected event







BioSentinel: top risks & lessons learned

	Risk Description	Mitigation Approach
1	Long-term pre-launch integration time for biology	Turn spacecraft over as late as possible
2	DSN antenna oversubscription	Use non-DSN antennas (e.g., ESA)
3	Flight software update after deployment	SIM tests; revert to previous version if issues arise

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	What Happened?	What did we learn from it?	Proposed Mitigation Strategies	Recommended Actions
1	Lower (than expected) yeast viability on ISS unit	Long duration effects inside sealed enclosure decreases viability of biology	Late integration	Modify design for future missions to include late load and integration options; add more desiccant inside payload enclosure
2	Unknown launch date	Loss of personnel & constant changes in trajectory	Analyze risks associated with unique mission conditions	Document for later project personnel on why specific decisions were made
3	Late payload EVT not ideal	EVT provided many lessons learned that could not be implemented for this mission	Work around issues without design changes	Conduct early EVT (scaled down EVT) to feed potential design changes

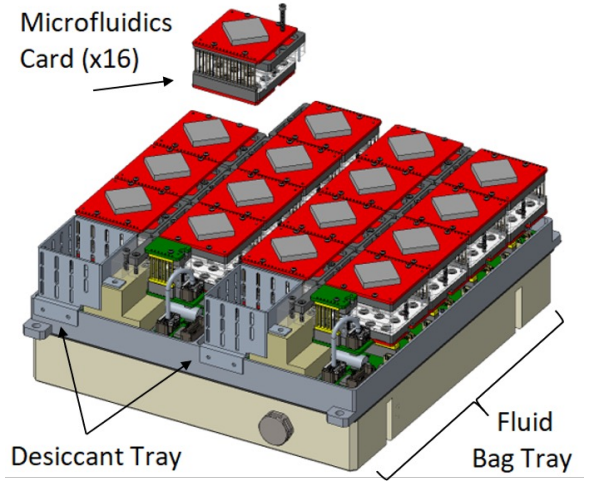
BioSentinel: top issue

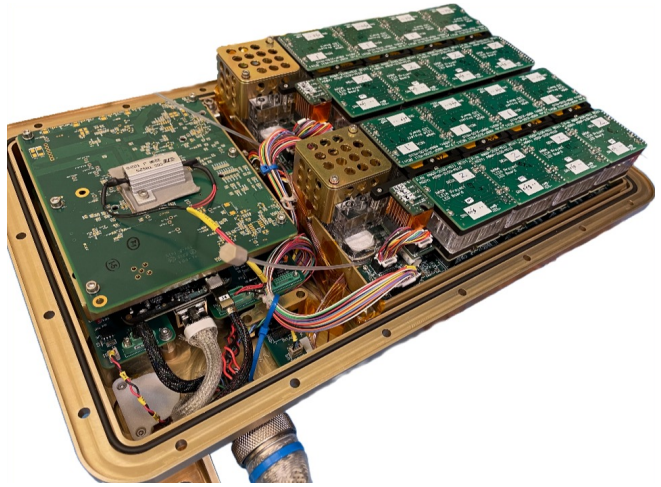
Top Issue: launch delays

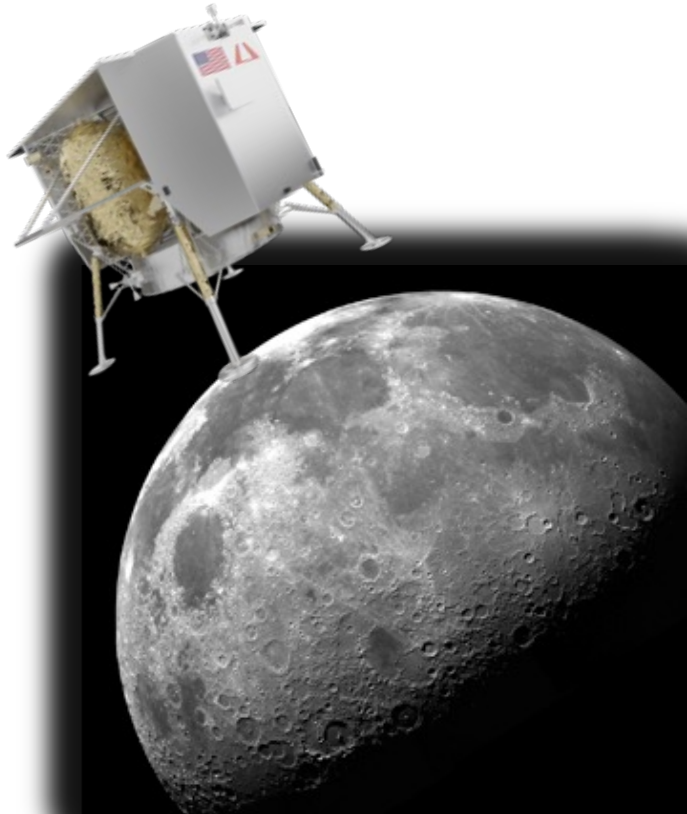
- Issue: Artemis I launch had multiple launch delays independent of secondary payloads
- How the project managed the issue?
  - Long-term testing (reagents, biology, etc.)
  - Environmental monitoring requests once at KSC
  - Constant communication with NASA HQ
- Results:
  - Loss of personnel
  - Constant replanning (*e.g.*, moving trajectories)
  - Additional battery recharging
  - Effects of long-term storage inside BioSensor enclosure
- Recommendations:
  - Constant communication between project, NASA, and SLS
  - Plan for such complex mission (*e.g.*, personnel, battery charging)
  - Improve environmental monitoring if biology involved

BioSentinel: lessons learned & LEIA

LEIA: Lunar Explorer Instrument for space biology Applications

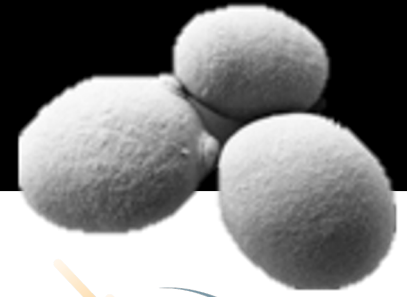






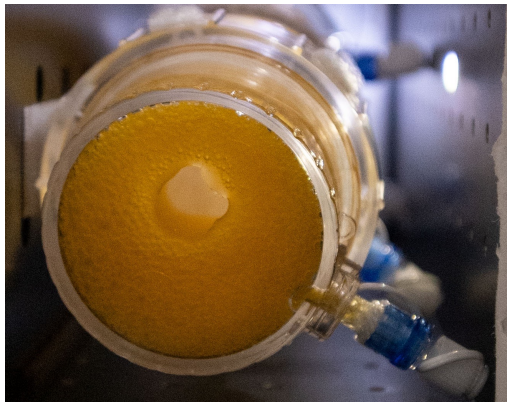
- Three awarded Space Biology ground investigations (two ARC PIs)
- Significant instrument heritage from BioSentinel
- ARC team selected for a PRISM2 award to perform science experiments on the lunar surface (synthetic biology & stress/damage response)
- LEIA will have additional countermeasures to improve long-term viability (*e.g.*, late load of biology and improved desiccant storage)
- LEIA suite also include a LET spectrometer and a fast neutron detector
- Power & data from CLPS lander

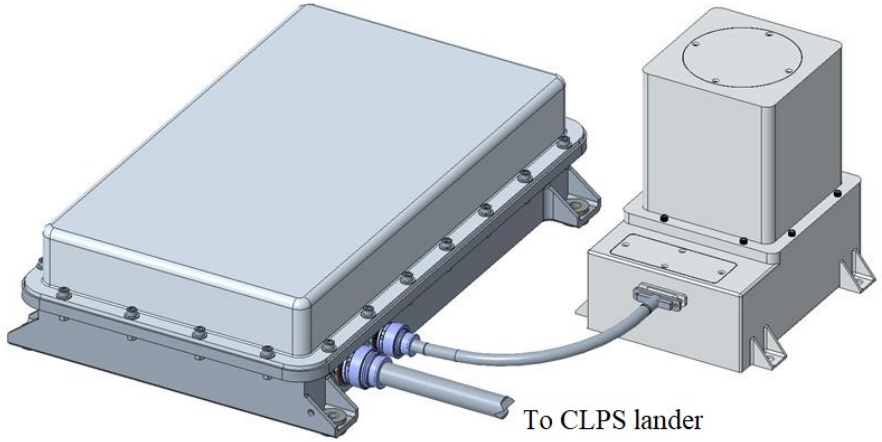
LEIA lunar surface mission

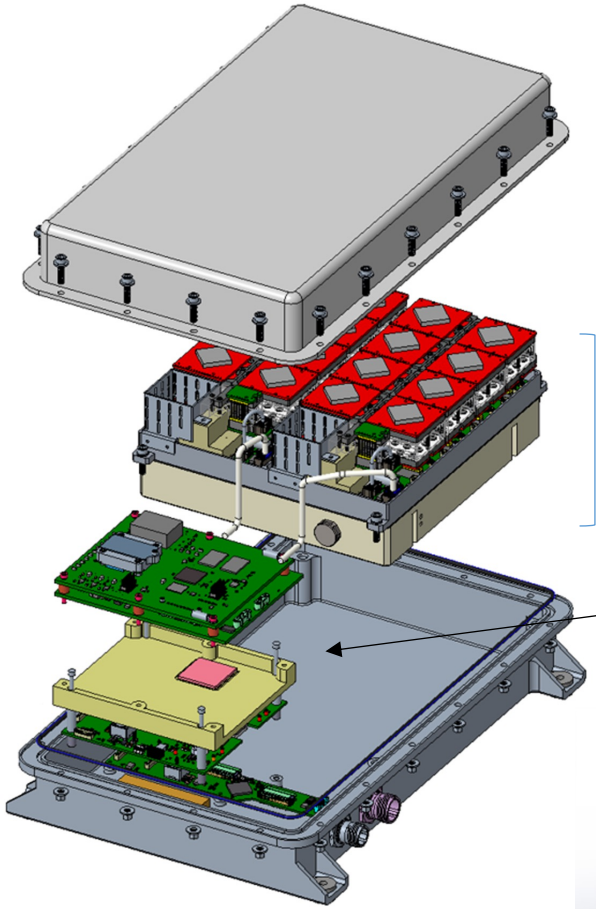


Science Aims:

1. Determine cellular sensitivity to the lunar environment
2. Test production of antioxidant carotenoids for use in crew dietary supplementation.
3. Engineer genes from tardigrades and yeast to test for enhanced tolerance to the lunar surface
4. Measure biologically relevant radiation at the south pole landing site

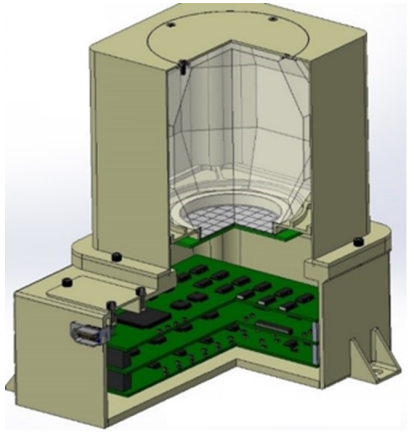






BioSensor

ARES LET Spectrometer

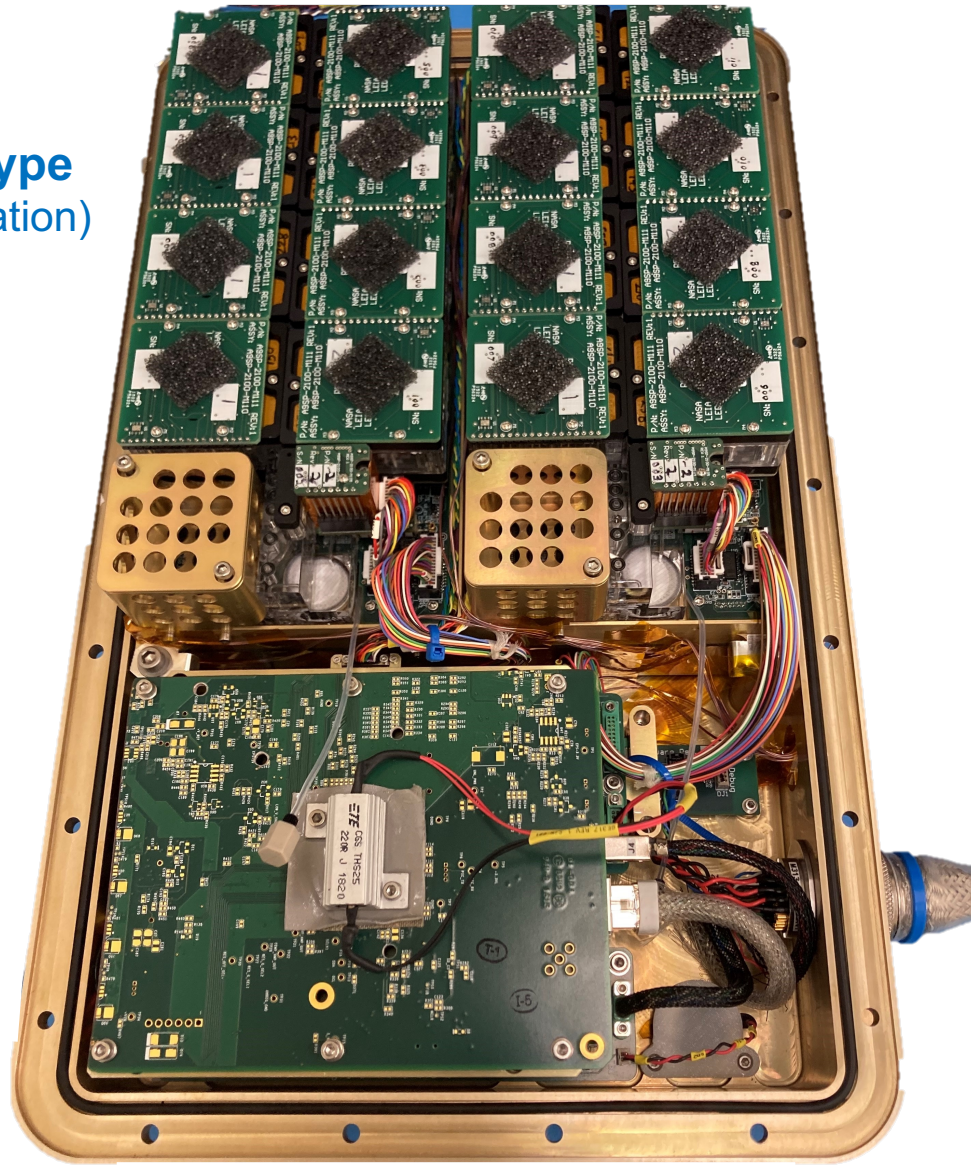


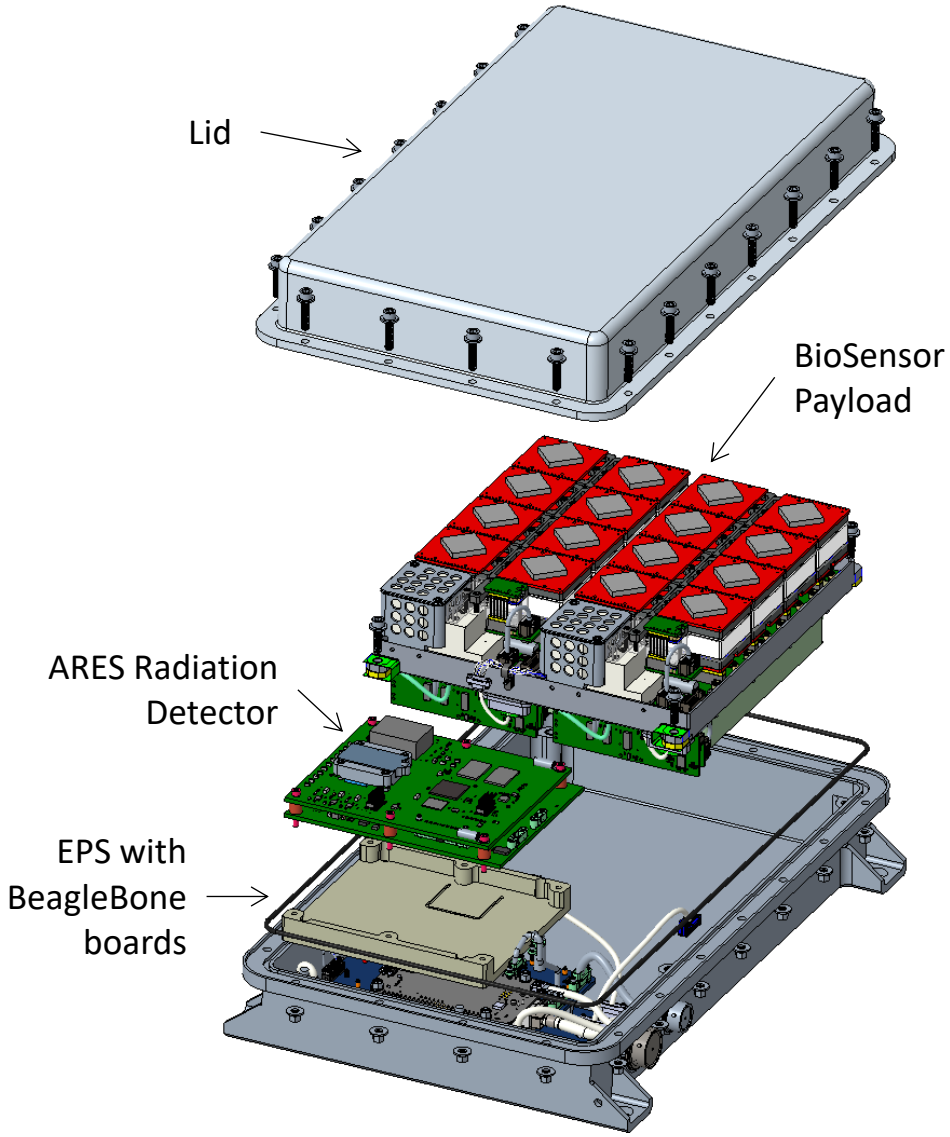
Mini-FND

How are we improving LEIA based on lessons learned from BioSentinel?

LEIA improvements

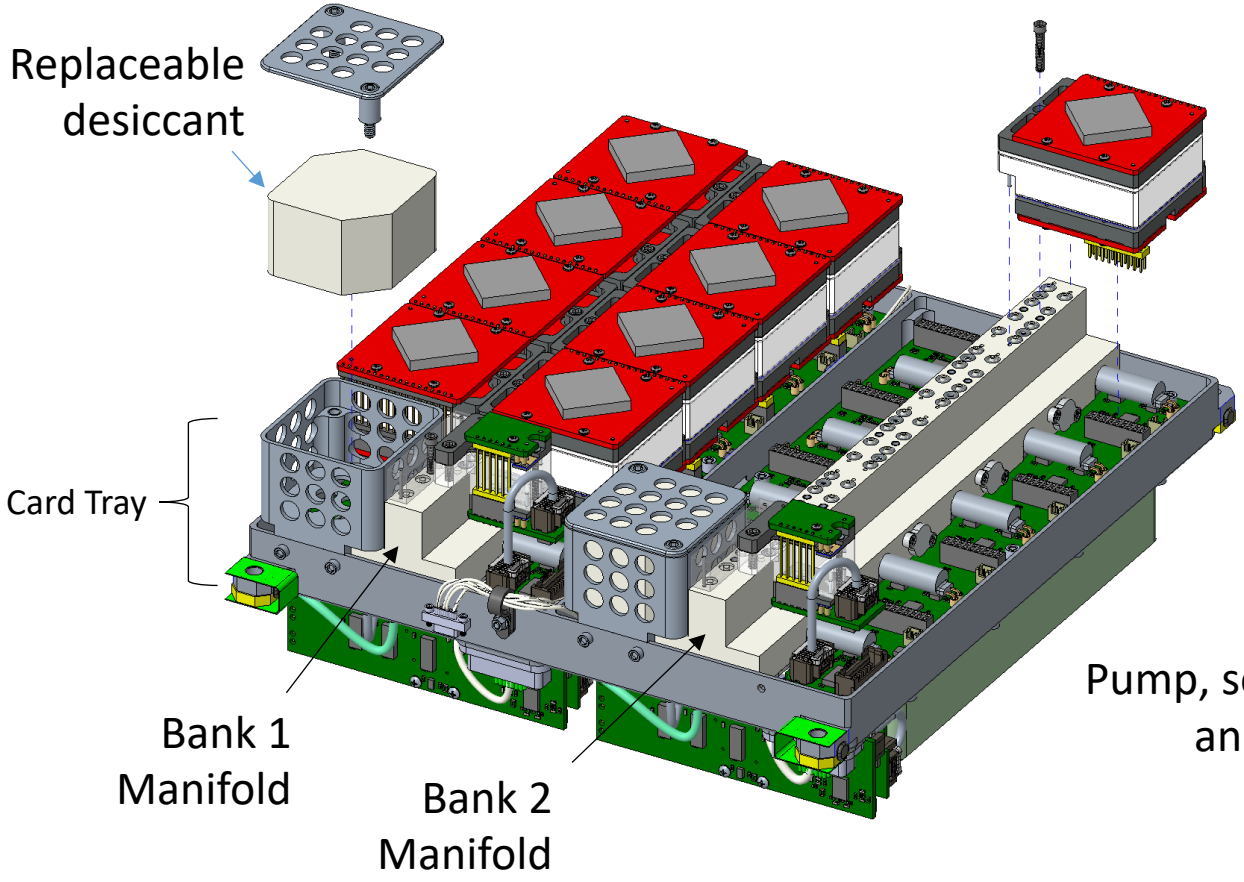
LEIA prototype
(open configuration)



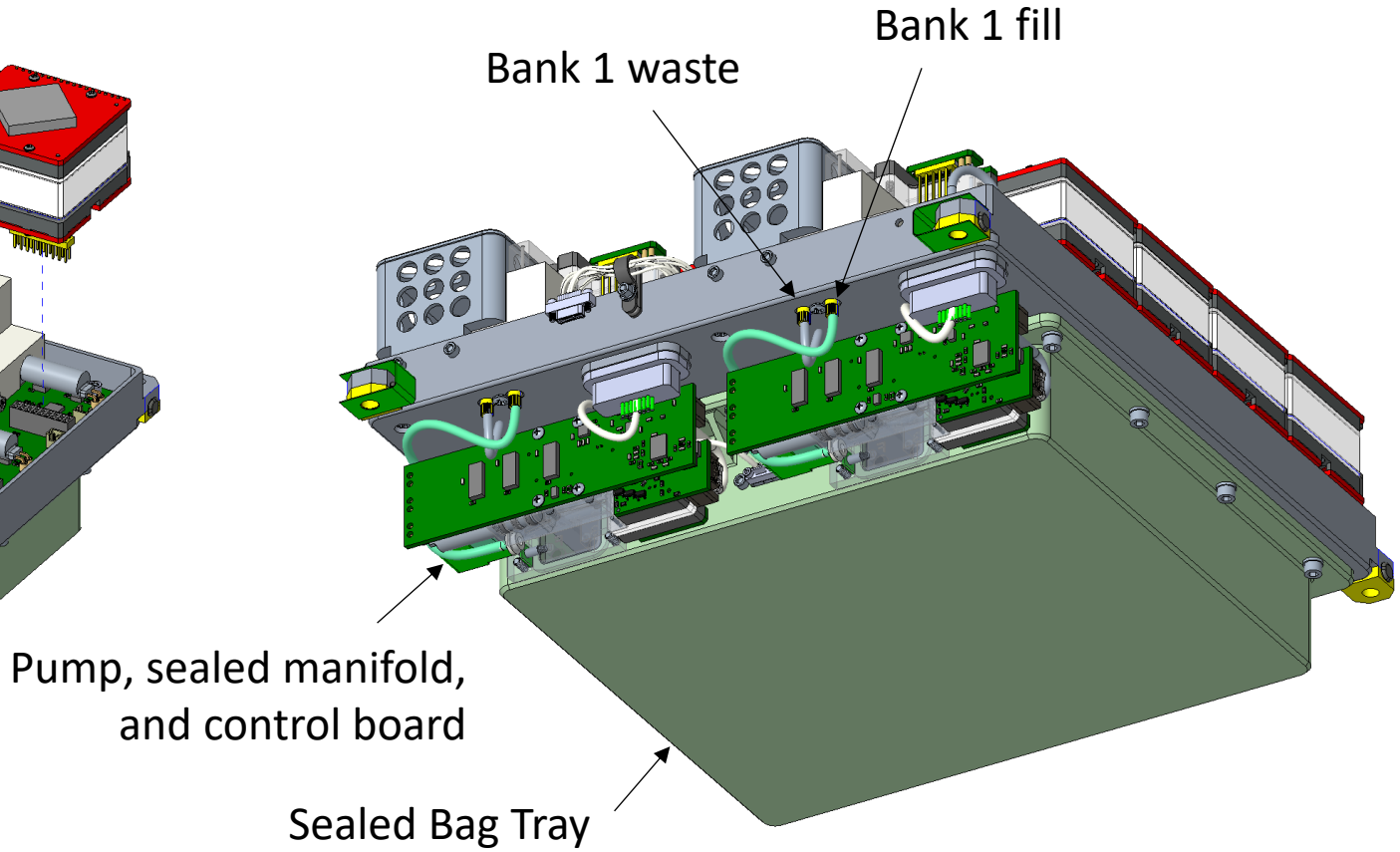


LEIA improvements

How are we preventing high humidity inside the BioSensor enclosure?

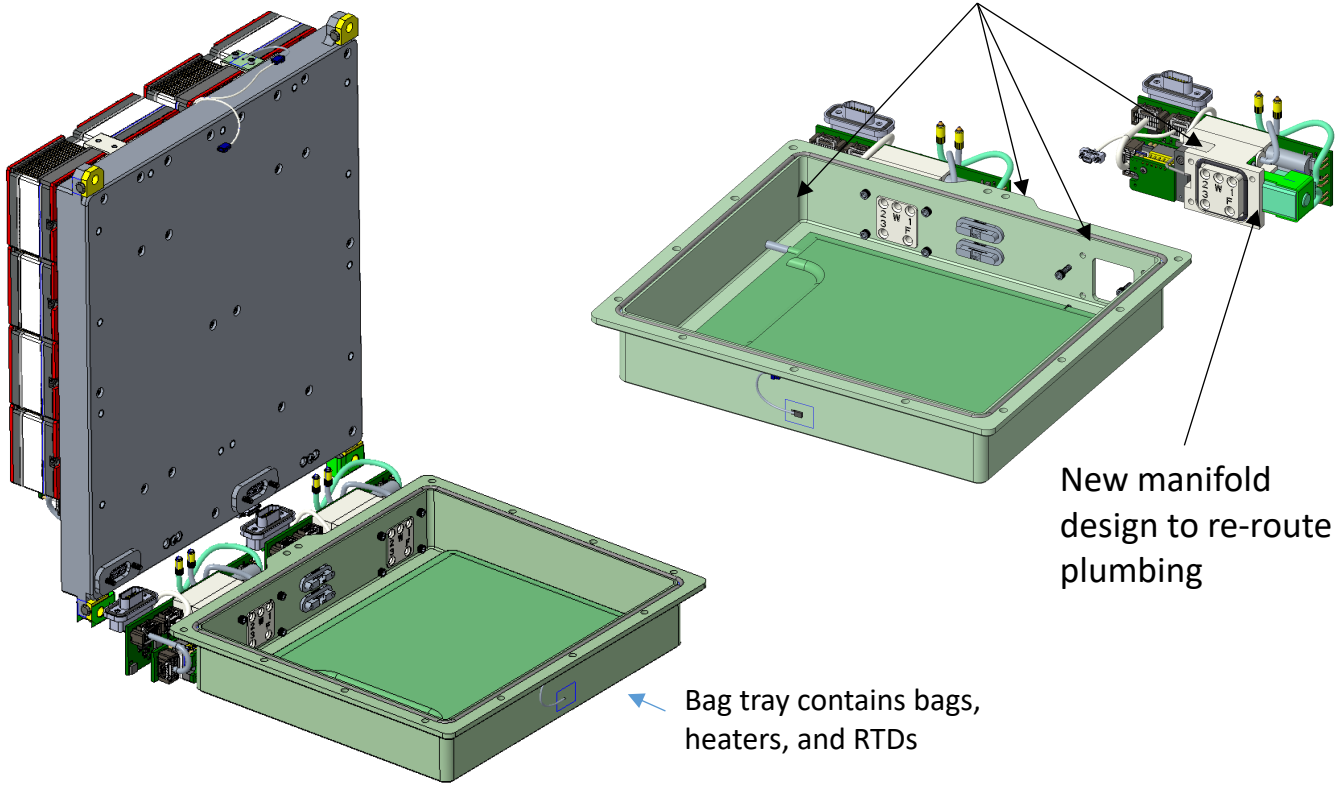


Increased desiccant

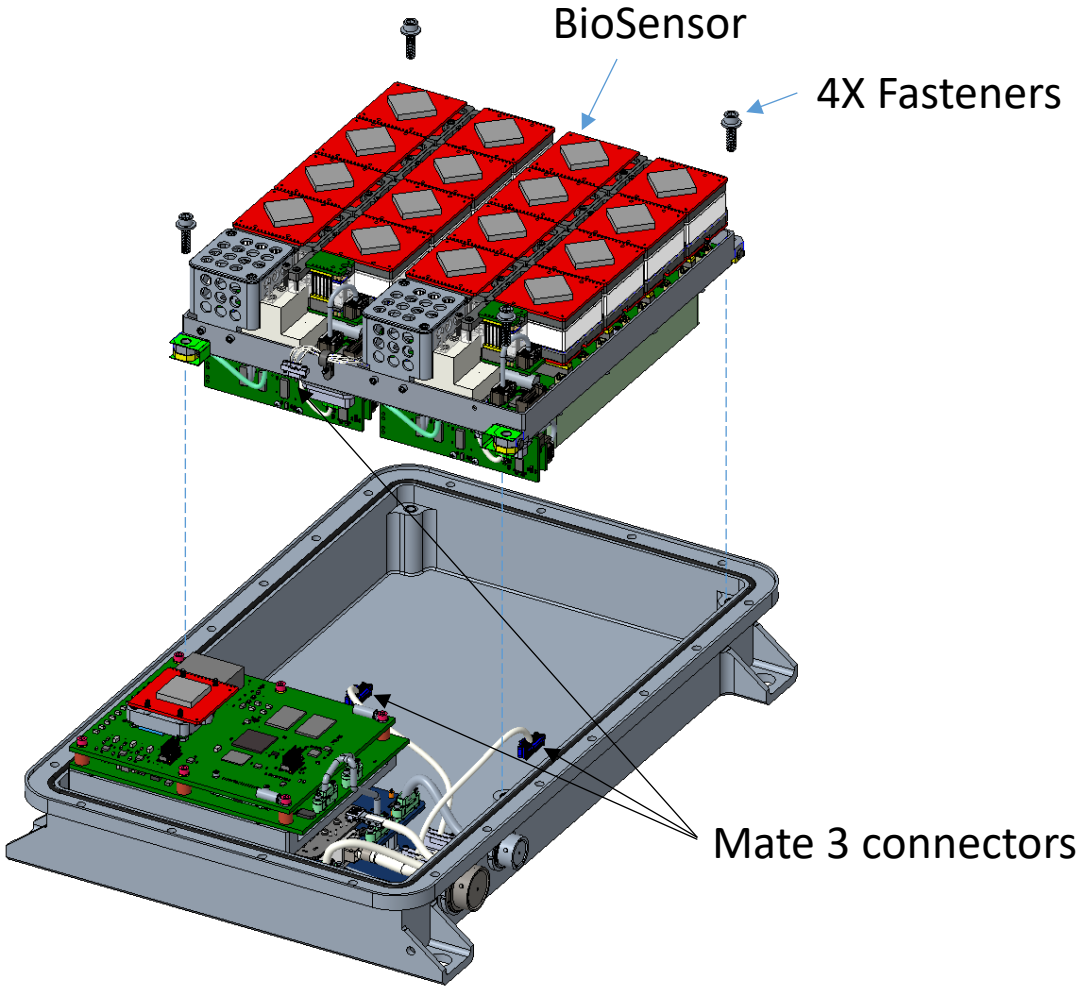


Improved seals & protected connectors

LEIA improvements



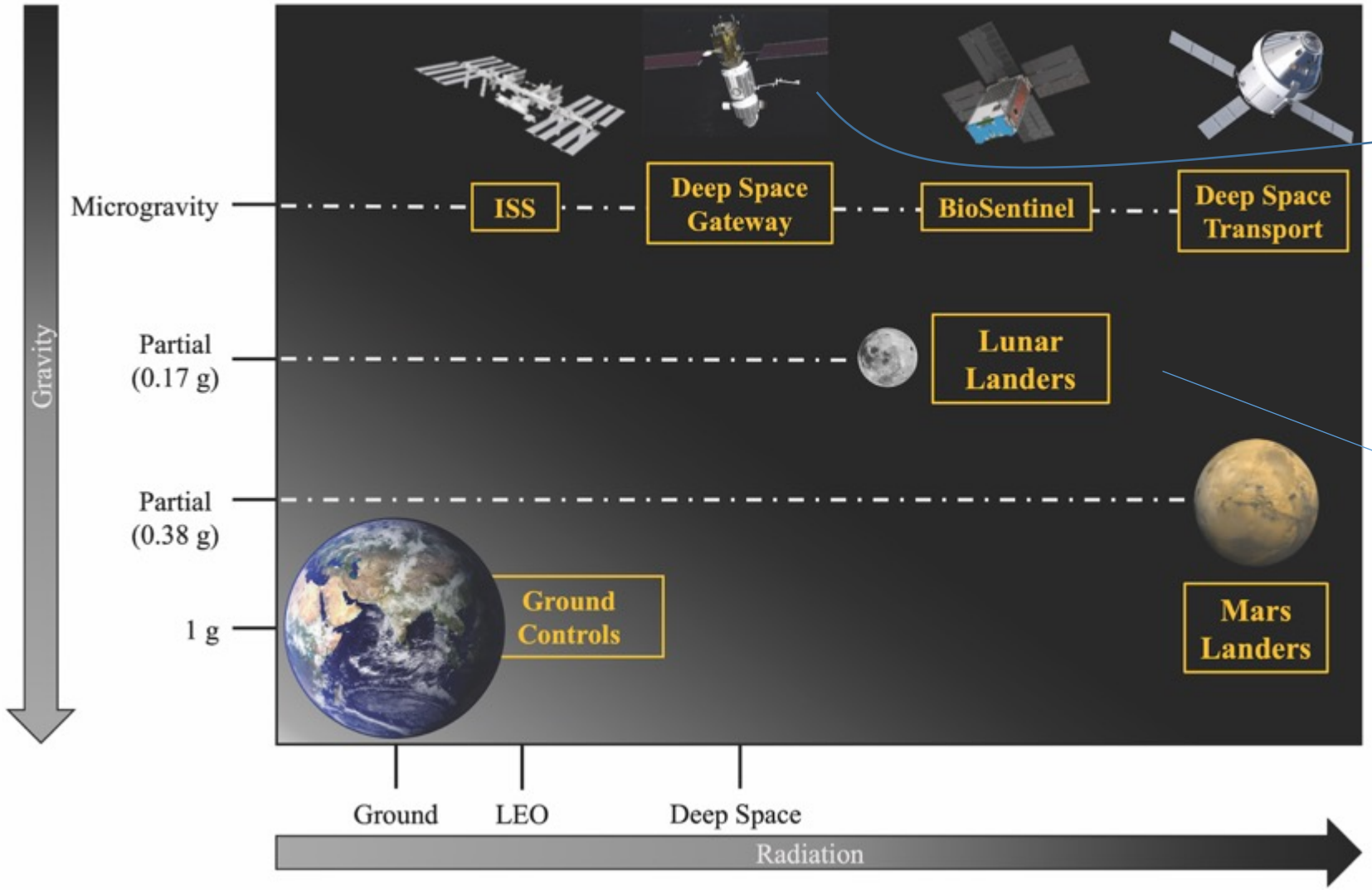
Redesigned bag tray & re-routed plumbing

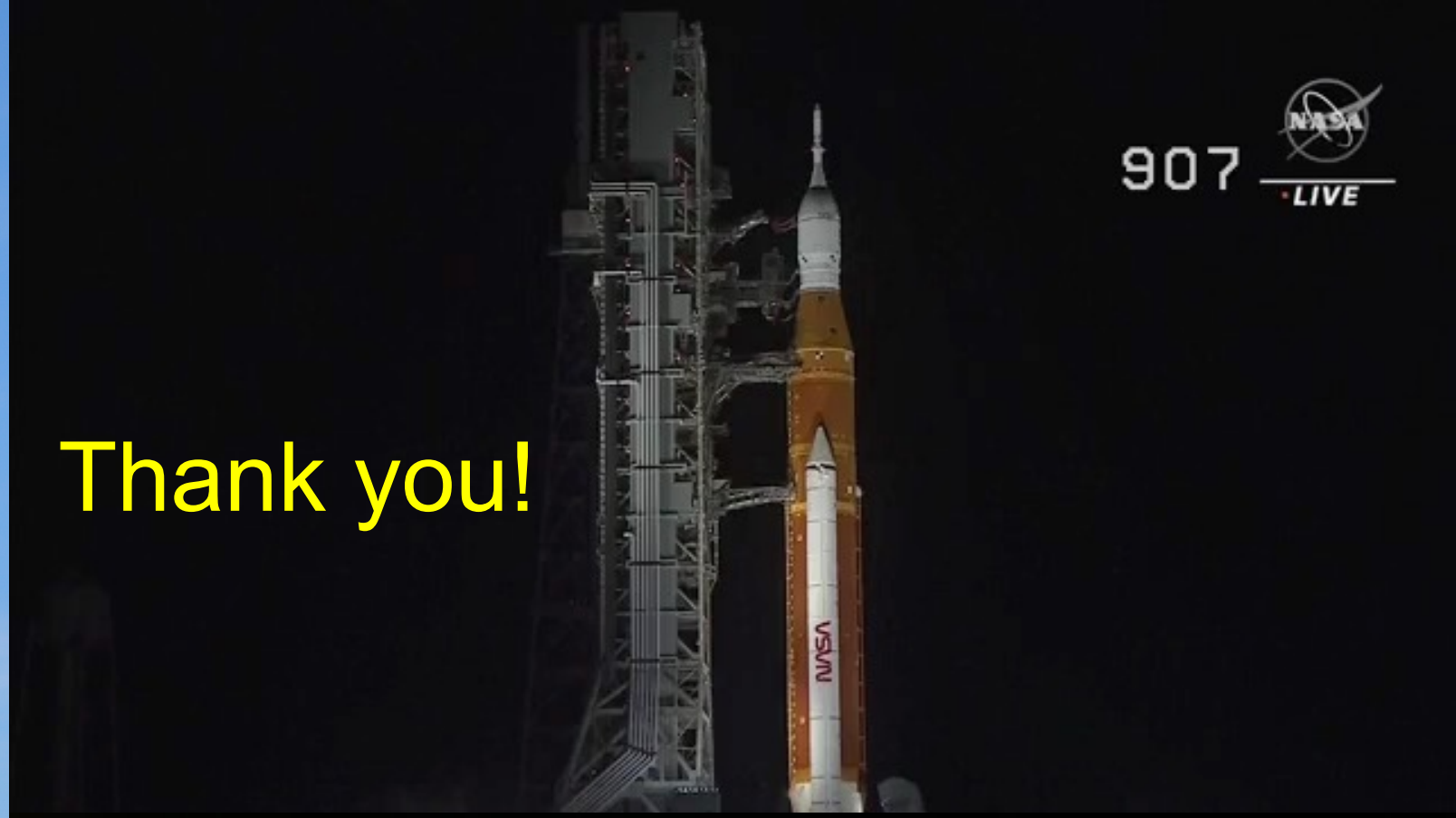


Late load installation

BLEO instrumentation: future & ongoing

A flexible design that will be used in different space environments





Thank you!